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Final Report

A STRATEGY FOR ADVANCING TILT-ROTOR TECHNOLOGY

by

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There are two technical reports resulting from this project, this report and the companion report entitled "Cost Characteristics of Tilt-Rotor, Conventional Air, and High Speed Rail Short-Haul Intercity Passenger Service," by David L. Schoendorfer and Edward K. Morlok, dated May 1985.

SUMMARY

Tilt-rotor technology has many features which make it a very exciting and promising development in aviation which might have application to a wide variety of transportation and logistics situations. However, aside from military applications and rather specialized industrial applications, little is known regarding the potential of tilt-rotor for commercial transportation and hence it is difficult to plan a development program which would gain support and be likely to produce a stream of significant benefits.

The purpose of this report is to attempt to provide some of this information in a manner that would be useful for preparing a strategy for development of tilt-rotor aircraft technology. Specifically, the objectives of this research were the following:

1. to identify promising paths of development and deployment of tilt-rotor aircraft technology in the air transportation system considering both benefits and disbenefits, and

2. to identify any particular groups that are likely to benefit significantly and propose plans for gaining their support of research and development of this technology.

Potential advantages of the tilt-rotor technology in the context of air transportation as a door-to-door system were identified, and then promising paths of development of such tilt-rotor systems were analyzed. These then lead to recommendations for specific studies, information dissemination and development of awareness of the tilt-rotor among specific transport-related groups.

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1.0. Introduction

Tilt-rotor technology has many features which make it a very exciting and promising development in aviation which might have application to a wide variety of transportation and logistics situations. However, aside from military applications and rather specialized industrial applications, little is known regarding the potential of tilt-rotor for commercial transportation and hence it is difficult to plan a development program which would gain support and be likely to produce a stream of significant benefits.

1.1. Study Objectives

The purpose of this report is to attempt to provide some of this information in a manner that would be useful for preparing a strategy for development of tilt-rotor aircraft technology. Specifically, the objectives of this research were the following:

1. to identify promising paths of development and deployment of tilt-rotor aircraft technology in the air transportation system considering both benefits and disbenefits, and
2. to identify any particular groups that are likely to benefit significantly and propose plans for gaining their support of research and development of this technology.

Four aspects of the objectives of this study bear particular emphasis. First of all, the identification of likely paths for deployment of new technology is an extremely subjective undertaking, being dependent on creativity and synthesis of diverse and fragmentary pieces of information related to a necessarily uncertain future. Secondly, the focus is on potential use of tilt-rotor technology in commercial aviation, as part of the overall transportation system of the nation. Thirdly, the focus is on person travel, as the carriage of persons appears to have much greater potential for reaping benefits from the unique features of this technology than the movement of freight, at least in the foreseeable future. Fourthly, the likelihood of success of any particular strategy of development is very dependent upon numerous external factors beyond the control of the developers, many of which cannot be predicted with any precision. Therefore, what appears to be the best strategy at any particular moment in time might diminish in attractiveness relative to other strategies with the passage of a few years, and therefore reassessment of development strategies at frequent intervals would be appropriate.

1.2 The Innovation Process

The literature on innovation is replete with many alternative categorizations of motives or reasons for the deployment or implementation of new technology . While any one of these might be applied in the transportation context, a three-part classification as presented below seems to be particularly appropriate, as it emphasizes features that have historically been important in the development of transportation.

One source or reason for deployment of the innovation is simply that the new technology is superior in the sense of being either cheaper, or superior in performance, or both, compared to present technology. In any industry in which new firms are free to enter, or in which there are a number of existing firms which are free to adopt the new technology, competitive pressures generally will lead to the deployment of superior new technology. So long as a firm sees its own position being improved by deployment of the new technology, it presumably will do so.

Historically many transportation industries have been essentially protected monopolies, protected by regulatory agencies, or institutional arrangements have evolved in which austensibly competing firms organized a cartel for mutual cooperation. Such conditions often tend to thwart innovation -- in the form of new technology as well as other forms -- which would improve service quality or reduce prices (fares). However, with the relatively recent regulatory reform of the transportation industries, and the airline industry in particular, such practices have been superceded by outright competition. Thus any superior performance or lower cost of a new technology is much more likely to be an effective reason for adoption of a new technology in the air industry at the present time. However, it should be borne in mind that regulation _per se_ can be a positive force for innovation as well, as when regulations require the adoption of new technology. Examples of this abound in regulations to reduce negative environmental impacts.

The second reason often cited for adopting a new technology is that there exists a manifest problem or set of problems with the existing technology. Most typically these take the form of expectations or demands for performance which exceed that which the existing technology is capable. In the transportation context this often takes the form of a demand for a quality of transportation service which the existing system is simply incapable of. This demand is quite effective when substantial benefits would accrue as a result of providing service of the desired quality, and wherein these benefits can be translated into income and profit for any firm providing that service.

This particular motivation for adopting new technology has been particularly important in the development of the transportation system as we know it today. Indeed, the development of many technologies which we now take for granted, such as the railroad, can be traced to a need on the part of transport system users (in this case, coal mines) for a technology of transportation which overcame many of the problems of then existing technologies.

A final motivation for adoption of the new technology is that the new technology creates new opportunities which, if taken advantage of, would yield benefits to potential implementers of that technology. These are often in the form of what might be considered secondary impacts of improvements or superiority of the new technology in terms of cost or performance, or both, compared to existing technologies. Particularly important in the history of development of transportation has been the reductions in travel time to be translated into opportunities for land development. Often the same firm will be engaged in constructing the improvement in transportation as well developing land which is made more valuable as a result of that transportation improvement. For example, in the early part of this century the firms which constructed streetcar and interurban lines outward from central cities were often the ones which developed land along those lines for residential purposes, profiting typically far more from suburban development than from operation of the rail transit line itself.

While this categorization of motivations for adopting new technology is not "neat and clean," in the sense of the categories being well-defined and mutually exclusive and exhaustive, it is useful in the transportation context. It suggests a framework which we shall use in assessing the potential for tilt-rotor aircraft.

1.3. Relevant Viewpoints

It is essential to identify the ways in which tilt-rotor air service is potentially better than existing or other likely future forms of transportation, for it is only because of such differences that tilt-rotor air service could be the preferred technology in one or more applications. Knowing these features in which tilt-rotor service would be better in some sense is especially helpful in identifying both manifest problems which this system might help to solve and in potential opportunities where the benefits might warrant further development of this technology. In this context it is essential that the characteristics of tilt-rotor technology and systems in which it might be deployed be considered from a very wide range of perspectives rather than simply the narrow ones of aircraft performance, such as speed and cost. It is therefore useful to consider at this juncture the various major perspectives from which transportation systems are normally viewed for purposes of system development, and further to identify the attributes of the system which are of most interest from each major perspective. Tilt-rotor technology can then be examined from these viewpoints in the next section.

It is important to recognize that here we are considering tilt-rotor technology not so much as the technology of the vehicle itself, which has been the primary focus of research and development efforts, but rather considering tilt-rotor technology in the sense of a system for transportation of persons, primarily, and potentially of goods. This system would include in addition to the vehicles the various fixed facilities such as terminals and maintenance facilities, the control system, and the plan for operation of the system. Also included would be factors primarily related to the management and regulation of that system, including not only economic regulation (which of course has diminished considerably in recent years) but also other types of government and involvement. Furthermore, as will be discussed in more detail below, consideration of the potential of tilt-rotor necessarily must include the transportation system as it functions in moving persons (and goods, where these of are interest) from their origin to their destination, not just between intermediate points on the itinerary (such as terminals or airports). Thus when we talk of a tilt-rotor air system we are really talking about a system which extends beyond those points where tilt-rotor aircraft are used to include those other transportation facilities and services which are necessary for passengers and goods to be accommodated from origin to destination.

There are basically five primary perspectives on the transportation system which have been found useful in studies of transportation systems. These five perspectives represent the five groups which are primarily impacted by characteristics of and changes in the transportation system. They are: the user, the system owner/operator, the government, so-called non-users, and suppliers. Each of these will be discussed in turn.

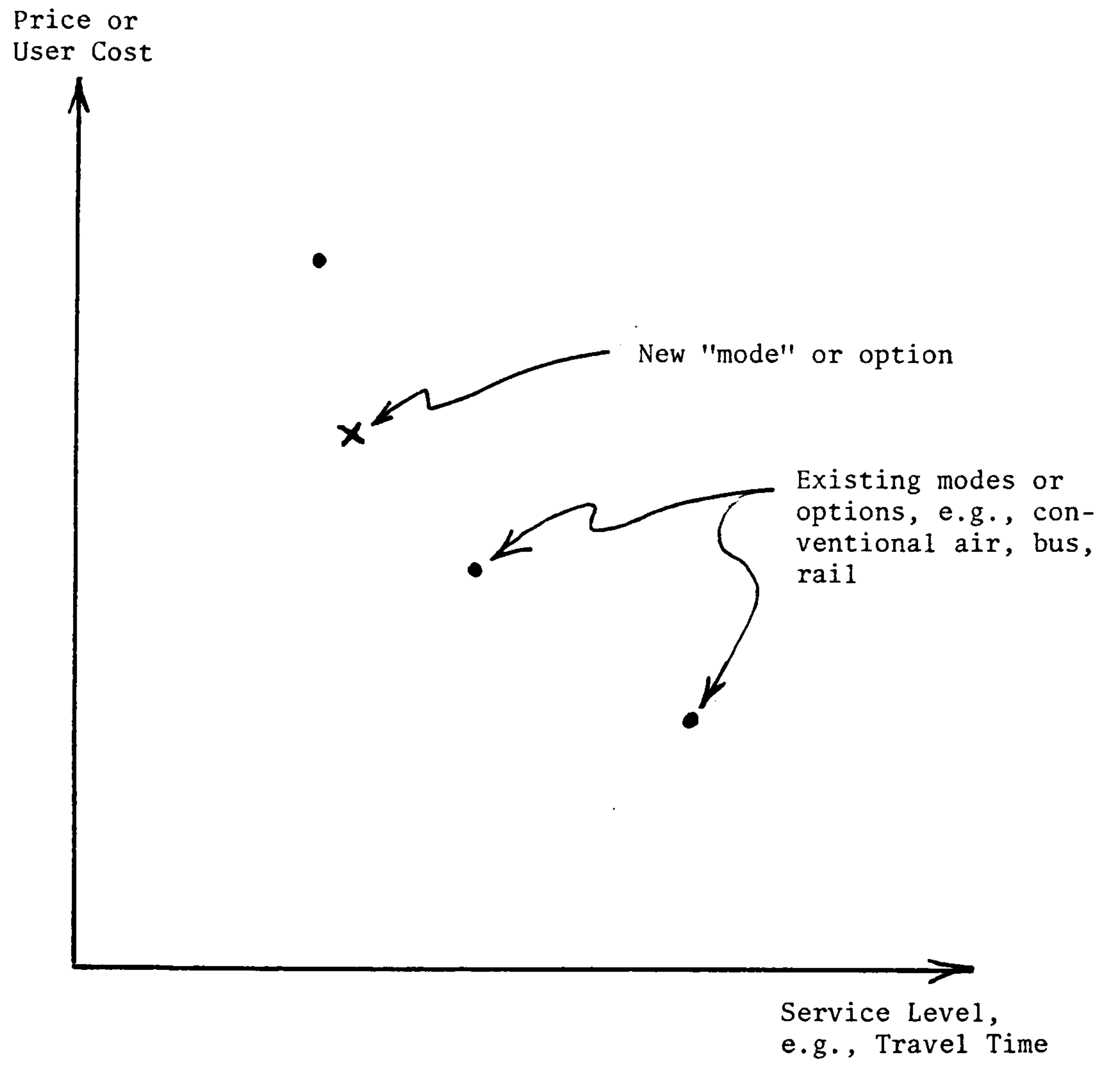
1.3.1. Users

Users of the system are primarily concerned with the ease of travel and the resources which must be given up in order to travel. In a general sense this would be represented by the accessability of the residence of a person, or of their business location, etc., to places which are likely destinations for travel, for the variety of potential trip purposes including work (including long distance business trips), recreation, shopping, etc. More specifically, for any given trip which a person wishes to make from a particular origin to a particular destination (for whatever reason), of importance would be the expenditures necessary in order to take that trip and various quality features of that travel such as the overall travel time, the level of energy necessary to carry luggage, discomfort associated with the traveling, etc. In general the characteristics of travel from one location to another are described in terms of a vector of characteristics which can be partitioned into subsets. One subset represents the out-of-pocket expenditures, which would include direct expenditures for such things as airline tickets, taxi fares, tips to porters, meals, etc., as well as indirect or somewhat hidden expenditures such as those for driving one's automobile. The other attributes are referred to as level of service characteristics, by which is meant all of those quality features of the transportation system which are of importance to the traveler in making travel decisions. In addition to the travel time mentioned above, would be other features such as the waiting time for carriers (taxis, plane departures, etc.) or perhaps more accurately the delay associated with fitting one's travel to the departures of a particular carrier (referred to as schedule delay), discomfort, mental or physical fatigue, etc. Some aspects of service level are relatively easily conceputalized and quantitatively measured, such as those aspects related to travel time, whereas many other aspects are not so readily conceptualized and often surrogates or appoximations are used. For example, in intercity travel aspects of level of service might include availability of air conditioning in various portions of the trip, availability of meals, quality of seating, etc., all intended to reflect the level of comfort associated with this particular trip and route for that trip.

It is very important to emphasize that from the traveler's standpoint the relevant cost and service levels are ultimately from the true origin of the trip to the true destination (and return by whatever route, if applicable). Thus characterizing the price-service characteristics of what would commonly be referred to as an air trip from one's home to a business meeting in another city would be not only the air fare, flight time, etc., but also the cost, time, etc. of access to the airport at the origin end and egress to the destination at the other end, and the same for the return journey. In considering the potential for tilt-rotor aircraft systems, these features of access become quite important. Moreover, it is definitely inadequate and quite misleading to consider these access and egress portions as essentially being characterized by trips between the relevant airport and the downtown heart of the metropolitan areas in question. Relatively few trips out of the total population of trips originate or terminate in central business district areas, and it generally is incorrect to assume that characteristics of access or egress for downtown areas also characterize access and egress to other locations within a metropolitan area. Indeed, any single value of time (or cost, etc.) is an inadequate representation of access or egress characteristics in an entire metropolitan area.

An important feature of actual transportation systems is that they almost always combine to provide a variety of options to a traveler (or shipper) from any given origin to any given destination. The availability of these options is important not because each represents a different physical route, but rather because they are different in cost and level of service. These options are most frequently thought of in terms of different modes of travel, e.g., for an intercity trip, air, auto, bus, and rail. For a family of, say, five persons taking a long trip, these four (modal) options would generally yield an ordering, from least travel time to the longest travel time, of air, rail, bus, and auto; and that ordering would typically also be the ordering from most expensive to least expensive. (Of course, different orderings would be found in specific markets.) But the important point is that the traveler is typically faced with alternatives in terms of price and service level, with a trade-off of better service for higher price (i.e., worse cost). And often there is a trade-off between different service level or quality features at the same price, e.g., rail and air might be the same total cost, but in air one has a short travel time with simple accommodations, a seat, while on the train one has a longer travel time but more elaborate accommodations -- a room, full-service meals at a table, etc. There are even differences within the same mode -- mode in the sense of technology, e.g., the high speed, high comfort, but high price Metroliner rail service in the Northeast Corridor, vs. the regular slower, less comfortable, cheaper train service operated on the same tracks. From the traveler's standpoint, these are really different modes or travel options--because they differ in the price-level of service sense.

These different modes (price-level of service options) can coexist and thrive because travelers differ in their preferences for low cost and various service level features. A mode that is inferior in all respects can not survive, if passengers are rational, but as long as it is better than other modes in at least one respect, it may attract travelers. In general this leads to travelers facing a range of travel options like that shown in Figure 1.3.1, where only two dimensions (price and, say, time) are shown for clarity. A new travel option, a mode in the sense used here, is in



Note: Price and service level are measured from origin to destination.

Figure 1.3.1. Travel Options Represented as Price-Service Level Offerings in a Market, Showing a New "Mode."

essence a new combination of price and service features -- different in one or more respects than the existing array. As will be discussed later, tiltrotor technology offers the opportunity to provide such a new travel option -- or mode -- in many markets.

1.3.2. Owner/Operators

Another very significant viewpoint is that of the system owner/operator. In cases where this is a private for-profit firm, as in the case of most transport carriers in the United States, the profit motive is normally assumed to be of central importance to the firm's decision-making, and therefore profit potential of any innovation would be of paramount importance. Since profit is simply the difference between revenue and cost, factors which influence these assume considerable importance to this viewpoint as well. Revenue naturally relates directly to the out-of-pocket expenditure and service level as seen by potential users, particularly relative to alternative means of transportation available for the same trip. The various costs of investment and operation of the system also loom large from this viewpoint. It is important to recognize that carriers may not provide all parts of the system themselves, but rather some parts of the system may be provided by other entities, and this may include facilities, equipment, or services which the carrier uses. Payments for these may or may not reflect true costs. Indeed, in the United States, government-provided facilities often have a pricing structure not closely related to costs and in some cases there exists a deliberate policy of subsidizing particular carriers. Moreover, revenue may include revenue not only from transportation operations but also from other facilities, some of which may be very closely related to transportation and in which the revenue is dependent upon the transportation services offered. For example, until the suburban train service out of Grand Central Terminal in New York was taken over by a public authority, the railroad not only received revenue from passengers on board those trains but also rents from occupancy of office and residential buildings along its Park Avenue route, and these rentals undoubtedly were higher because of the high accessibility offered by the train service. Of course, in reality factors other than profit influence managerial decision-making, such as risk associated with investments, market share, capital to earnings ratios, and thus, no profit is not the only relevant criterion for this viewpoint.

1.3.3. Government

A third important viewpoint is that of government, including the various levels of government and various types of government agencies. Typically impacts of transportation decisions thought to be especially important to government include the following. Actions influencing the expenditures required of government are important, especially expenditures which would not be directly counterbalanced by revenues from user charges on the facilities or other objects of the expenditures. National defense issues occasionally arise related to transportation investments, although they probably would not be of great importance relative to civilian tilt-rotor aircraft (although this may be an arguable point). Also, indirect impacts on government revenues or expenditures in other areas, such as income from real estate taxes, are important.

1.3.4. Non-Users

A fourth important viewpoint is that of the non-user of the system, as it is referred to commonly, by which is meant impacts of transportation on the environment of the system. These typically take the form of either impacts on the natural environment or impacts on development. The former including noise, air pollution, ground water pollution, land requirements, and the like. The category developmental impacts refers to situations where the availability and quality or price of transportation service influences the development of sites. This development may be industrial in nature, or the exploitation of natural resources, or residential development, etc. These types of impacts are naturally most significant in situations where a dramatic change in the accessibility or ease of transport to and from an area is made. In developed nations where accessibility is fairly uniform everywhere (that there is any development potential) this type of impact tends to be relatively less significant and more difficult to detect.

1.3.5. Suppliers

The final major viewpoint is that of suppliers to the transportation system. This would include the suppliers of all types of resources required - capital, labor, fuel, and others. Many groups of suppliers are very well organized, and any major change in the system is likely to be viewed very carefully by the them in developing any posture relative to government investments. Impacts on suppliers are very significant from the standpoint of overall governmental policy, for basically two reasons. One is their degree of organization, especially labor unions and major manufacturers. The second is the very large fraction of Gross National Product and employment which is related to transportation, and hence impacts on the economy can be substantial. Indeed, the nation's transportation bill has consistently remained approximately 20 percent of the total bill for goods and services in our society, and approximately one in seven persons works for the transportation industry or suppliers.

1.3.6. Application

These five categories have been found to be extremely useful in thinking about the potential impacts--benefits and costs--of changes in the transportation system, ranging from relative modest changes such as investments in a new facility or changing regulatory requirements on a particular transportation service, to major undertakings such as The Interstate and Defense Highway System. It is important to recognize that this categorization is not necessarily mutually exclusive, because a particular individual or organization (firm, government agency, etc.) might in many cases be placed in either one of two or more categories. For example, an individual who lives next to an airport would have a viewpoint as a non-user of the system, being directly impacted in his environment by the presence of that airport and traffic, but that person might also be a regular user of the system and thus be concerned from that standpoint as well. Nevertheless this categorization has been found to be quite comprehensive and extremely useful, and it will be very helpful in discussing important features of tilt-rotor aircraft as well as in assessing the potential opportunities for its deployment to the benefit of various segments of our society.

2.0. Features of the Tilt-Rotor Aircraft

The tilt-rotor aircraft has many features which differentiate it from existing aircraft. These include conventional takeoff and landing aircraft, the type used for virtually all significant intercity passenger carrier routes, and existing helicopters which play an only insignificant role in commercial transportation.

2.1 VTOL and CTOL

The preeminent feature of the tilt-rotor aircraft is that it can take off and land vertically, so that it needs only a small landing area or landing pad similar to that required for a conventional helicopter. This means that the tilt-rotor aircraft can land and take off in regular service from any existing heliport or a new heliport or landing pad of a size sufficient for the craft. Equally important, the tilt-rotor can use a small landing pad at an existing airport that has runways for use by conventional take off and landing aircraft. Also extremely important is the fact that the tilt-rotor aircraft can land as a conventional aircraft, enabling it to use CTOL runways wherever desired. This means that even though special separate landing pads may be provided at some airports for use of the tilt-rotor, it is not necessary to provide these at all airports to be served by this aircraft. This significantly reduces the investment cost in fixed facilities required to initiate tilt-rotor service, for new facilities need to be provided only in areas where the separate landing pad would be necessary in order to avoid the congestion of existing runways. Similarly, the tilt-rotor can taxi to and from existing terminal gates, so that existing terminals can be used. New terminal facilities need be built only where it is desired to either separate tilt-rotor aircraft from CTOL aircraft, such as where capacity is insufficient at the existing terminal facility.

2.2 Avoidance of CTOL Delays

The significant feature here is not simply the ability to take off and land vertically, but the fact that it appears as though the use of the separate landing pad along with separate approach and departure paths (both in the air and on the ground), the tilt-rotor should be able to land and take off at regular airports virtually independently of the movements of CTOL aircraft using the regular runways. As a result it can operate so as to avoid the queues of CTOL aircraft on the ground waiting for departure or for movement to gates and also the CTOL holding patterns in the air. In effect this means that airport capacity can be expanded considerably at minimal cost, through the use of the tilt-rotor craft. Furthermore, since even new landing pads surely could be placed on existing airport land, land expropriation would not be a source of opposition (although other grounds for opposition may be present - to be discussed later). Of course, VTOL movements would have to be controlled, and control capability would have to be expanded.

It is important to realize that there seems to be no thorough studies of the interaction of large volumes of VTOL operations at airports with simultaneous CTOL operations, so the assertion that these could take place independently needs to be investigated in more detail. However, studies have indicated that STOL operations can occur simultaneously with CTOL operations, and indeed the use of short runways to add to capacity (and reduce congestion) under VFR conditions has already occurred at many airports (Dunley, 1985). A current Airport Grant Program is providing funds for planning and implementing short runways for IFR capability at a number of airports. An earlier study of 30 potential candidate airports indicated that 11 had room for and could benefit from separate short IFR runways, and that benefits would be especially large at major congested airports (Amodeo and Koenig, 1979). Since tilt-rotor VTOL landing pads would take far less space, and there is more flexibility for tilt-rotor flight paths - compared to STOL - the potential for simultaneous tilt-rotor and CTOL operations would seem even greater. However, detailed site-specific studies would be necessary to confirm this completely.

2.3. Low Noise

A third critical feature of the tilt-rotor aircraft is the relatively low noise footprint which it has in comparison to both helicopters and existing CTOL aircraft. With respect to CTOL, this of course arises primarily from the fact that it takes off and lands vertically rather than along the conventional sloped path intersecting runways, and as a result the tilt-rotor is sufficiently close to the ground to present a noise problem only in a very limited space. Thus the tilt-rotor is more compatible with environmental factors compared to other types of aircraft. This means that the potential for the tilt-rotor to have a landing pad or terminal close to various human activities is increased substantially. In principal it would be possible to have a terminal very close to or in the midst of a major activity center, such as an office park, or even near a residential area. Furthermore, one would expect somewhat less opposition to tilt-rotor use of an existing small general aviation airport, in the VTOL operating mode, near other human activities than would be generated by introducing additional CTOL flights into that airport.

2.4 High Cost Per Seat Mile

Another feature of the tilt-rotor which is extremely important from the standpoint of commercial airline use is the fact that the presently contemplated aircraft are very small compared to the typical CTOL aircraft used by both major and regional carriers. The tilt-rotor aircraft which can be developed from the currently planned military version would have accommodations for approximately 44 passengers, and studies of larger tilt-rotor craft have contemplated sizes up to approximately 100 passengers only. This is a marked contrast to conventional CTOL aircraft which typically seat from approximately 150 passengers to about 400. Of course, many regional and commuter airline services are now operated with aircraft of the size represented by the military conversion (44 seats). And some carriers use 19-seat aircraft for some services where the fare levels are not significantly different from those of the basic fares of major trunk lines. The development of a 100 passenger tilt-rotor aircraft was treated with some uncertainty in the technical documentation and evaluation of its feasibility, but such an aircraft would require some technical barriers to be overcome and consequently a longer time frame is required for development compared to a 45 or 50 seat version. Also, the development of the currently planned military version corresponding to 44 seat civilian craft may face some unforeseen problems, in which case the development and actual availability of even the smaller aircraft would be delayed somewhat. For these reasons it was felt prudent to emphasize 44 passenger aircraft in our analyses. Since this aircraft will have features which are somewhat less attractive for commercial application than the larger aircraft, this was a conservative assumption, with respect to the benefits and likelihood of actual deployment of this aircraft in commercial service.

The smaller size - 44 seats - of the contemplated tilt-rotor has two very significant implications for commercial service. The first is that the cost per seat mile offered is going to be higher than that of a larger CTOL aircraft in any given market operated by any given airline. The primary but not exclusive reason for this is simply that the fixed portion of the flight crew is spread over fewer seats, as are other fixed or partially fixed costs such as landing fees and terminal costs.

The magnitude of the cost difference is illustrated by Figure 2.4.1, taken from the companion cost report (Schoendorfer and Morlok, 1975). This presents the total annual average cost per passenger mile of a tilt rotor aircraft (assuming here 45 seats) service and a service operated by DC-9 aircraft. The costs are in 1982 dollars, and are for a service in which the minimum frequency was one departure per hour in the peak period, one every two hours in the remainder of the 16-hour operating day, and maximum annual average load factors could be 80% in the peak and 50% otherwise. Tilt rotor is more costly at all but the lowest passenger volumes by 5% to 10% at 100 mile stage lengths, 20% to 30% at 200 mile lengths, and up to 50% at 300 mile lengths. Clearly the cost disadvantage of the tilt-rotor increases with increasing stage length, so shorter markets are the most likely applications. The same pattern of cost difference applies for other market conditions, and persists even with changes in basic cost parameters for the tilt-rotor, which of necessity are not known with precision.

While the tilt-rotor has a decided cost disadvantage at longer stage lengths, it is important to recognize that the operating costs of major trunk airlines seem to be considerably above those of the most efficient carrier which could be operating in any given market. This is partly but not entirely due to higher than market level wages being paid to employees of these larger carriers, undoubtedly reflecting a market control by unions on labor and by carriers on service and fares. This market control permitted passing on higher costs to passengers in the form of higher fares. Nevertheless, faced with particular markets where low operating cost were extremely important for profitability, many carriers have found that they could substantially reduce their operating cost for any given aircraft by contracting a specific service with small carriers on a competitive basis, thereby reducing or eliminating the market power of labor, lower level management, suppliers, etc. Many major carriers have done this, primarily in markets where traffic levels are only sufficient to support very small aircraft, usually feeder services to minor airports. However, the same strategy could be used by a major carrier to lower the costs of tilt-rotor service, regardless of where operated.

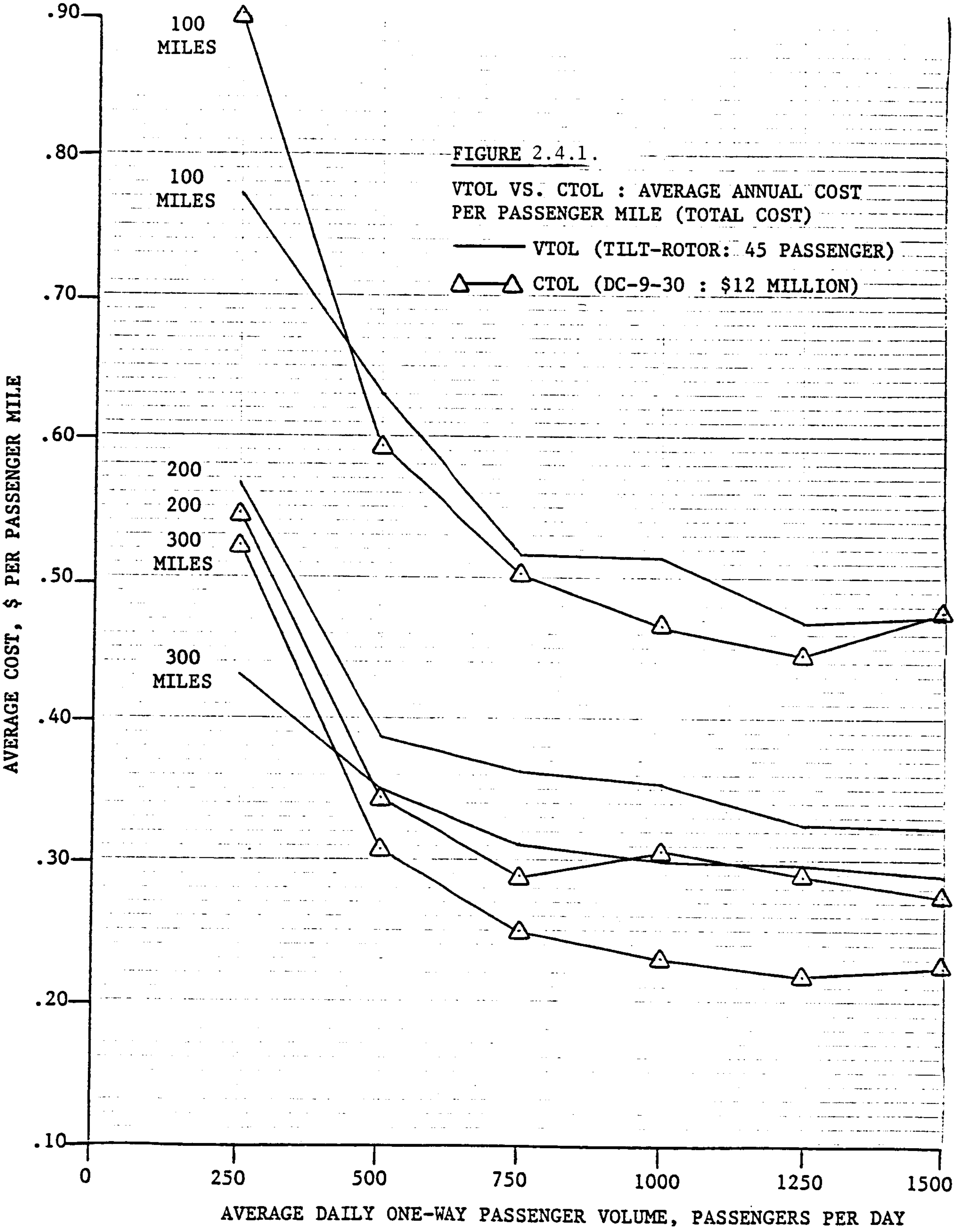


FIGURE 2.4.1.

VTOL VS. CTOL : AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST)

2.5 Low Cost Per Departure

A related feature of the tilt-rotor aircraft is that the cost per departure is generally lower than that of the most typically used CTOL aircraft. This is extremely important because in any market the frequency of departures is an important level of service feature, and all other things being equal, higher frequencies will attract more passengers and hence increase revenue. To be discussed in more detail below, this basically means that a service with tilt-rotor aircraft could use a higher frequency of departures to offset, or partially offset, higher fares which might have to be charged for that service as a result of the higher seat mile costs. This feature will also be important in terms of other types of changes in the air transportation system which might take advantage of these cost features of the tilt-rotor. In particular network restructuring to eliminate concentration of aircraft operations and passenger transfers at a few airports may use this feature.

2.6 Higher Frequency Supply Function

A related feature of the tilt-rotor is that because of its small size if the volume of passengers in a market determines the frequency of departures per day, then the tilt-rotor will have a higher frequency than if that service were operated with larger CTOL aircraft. In the terminology of transportation systems, the frequency minimum supply function for tilt-rotor aircraft is higher than that for the CTOL aircraft. Alternatively stated, the tilt-rotor aircraft has a higher capacity-limited frequency to passenger volume ratio than CTOL aircraft. In the end this is important in the context of the overall reaction of air travelers to the service, in the sense that the tilt-rotor service is likely to have the frequency feature of quality of service better than that of a CTOL service, all other things being equal.

2.7 Low Start-Up Costs at Risk

A final important feature is the relatively low start-up costs of tilt-rotor service and in particular the very low cost which would be at risk in the sense of not being portable or transferable to another market should any one particular market be found not suitable for the service. Most of the investment in a new tilt-rotor service would be in the aircraft, because either no new runway or landing or terminal facilities would be required or at worse a new landing pad and appropriately sized terminal would be required. It is highly unlikely that these would be required at both ends of the route, or at all terminals in a network of service to be offered. Rather, a new landing pad and new terminal are likely to be required at only one or perhaps a small number of airports which are now already congested. Thus the fixed facility investment is small. And this means that should any one route or a collection of routes fail financially, most of the investment can be transferred to other routes and possibly other carriers.

3.0. Major Problems

Before describing likely ways in which the tilt-rotor aircraft technology might be used in the air transportation system in the foreseeable future, it is important to discuss major problems which are manifest in the air transportation system at the present time. As was discussed in the introduction, one of the primary motivating factors for actually adopting a new technology is the existence of a problem which the new technology promises to solve, or at least diminish. This reason for adopting new technology has been especially important in connection with major changes in the transportation system, probably because of the substantial risk associated with the large initial investments often required to implement new technology, and the high degree of interconnectedness among parts of the system which often make for difficulties in integrating new technology into the system. Major problems with the air transport system of relevance to tilt-rotor technology appear to be the following: capacity expansion, ground access delays, airside delays, long distance to new airports, high cost of substitute high speed ground transport, and air safety. These will be discussed in turn.

3.1. Capacity Expansion

One of the most striking features of the development of the air transportation system has been its sustained level of very substantial growth, which has characterized its life with the exception of a few brief periods. Movements of persons, goods, and aircraft have reached the point where many airports are severely taxed during peak periods of aircraft operations, including of course periods when IFR operations must replace VFR operations.

And indeed, air traffic is expected to continue to grow. Forecasts of future air travel are naturally inherently very uncertain, and the uncertainty has been exacerbated by recent changes such as the regulatory reform which has led to carriers offering new types of service -- in the sense (described earlier in section 1.3) of new price-level of service combinations -- which have attracted increased numbers of travellers. While the sustainability of some of these new services (in terms of profitability in the long term) or their implications for the travel market are not well understood, nevertheless, the National Transportation Policy Study Commission forecasts of intercity travel by air through the year 2,000 are indicative of possible levels of growth. Table 3.1. presents these forecasts, which indicate that a doubling of air traffic measured by passenger miles is possible by the end of this century.

The traditional approach to accommodating this growth at airports has been primarily to add capacity to terminals and construct new runways, first on existing sites, and then, when no more land was available at the existing terminal, to construct an entirely new terminal. Of necessity these new terminals have had to be located on the outskirts of the developed area,

Table 3.1. National Transportation Policy Study Commission Forecasts of Future Air Travel.

	Domestic Travel		International Travel
Year	Air Person Miles, 10^6	Average Air Trip Length, Miles	Person Trips, 10^6
1975 - Base Year	148,000	525	25.8
2000 - Low Growth Scenario	257,000	540	51.1
% Increase over 1975	74%	2.8%	98%
2000 - Medium Growth Scenario	472,000	545	93.1
% Increase over 1975	219%	3.8%	261%
2000 - High Growth Scenario	651,000	538	132.0
% Increase over 1975	340%	2.6%	412%

Source: National Transportation Policy Study Commission (1979), 159 and 167 usually quite far from the central city and much of the suburban development which they are intended to serve.

In recent years this trend has abated, partly because of environmental concerns and partly for financial reasons. Other measures have been developed to deal at least partially with increased traffic, such as voluntary restrictions on flight operations during peak periods, some peak load period pricing to discourage use during peak periods, and, in the case of the Northeast Corridor (primarily New York to Washington), the improvement of high speed rail service (HSR) as an alternative mode (although its impact on aviation is certainly arguable). None of these approaches seems to be viewed as an adequate solution, although certainly in principle peak period pricing would have the possibility of eliminating the congestion. However, there seems to be a reluctance to use peak load pricing, undoubtedly partly because its negative effects are felt to be sufficiently great as to outweigh its advantages in many situations. These include inducing travelers to shift travel to other periods, to other modes, or to forego making the trip. With widespread use of such pricing being elusive, the problem of capacity is likely to remain and become worse.

3.2. Ground Access Delays and Costs

In the context of door-to-door transportation involving travel by air as the major mode, ground access times at each end of the trip have become extremely lengthy in many situations and are often considered a major problem in the air system. This includes not only situations where the average access time is large but also ones where it may be reasonable but there is a reasonable probability that the average will be exceeded significantly due to unexpected delays. Such delays can substantially increase access time, possibly resulting in missing one's flight or a business appointment, etc. Air carriers often indicate that typical ground access times will be of the order of three quarters of an hour to one and a half hours, and that passengers should plan for more time. Certainly for relatively short distance trips, say under 300 miles, where air is used as the major mode, ground access time can easily consume more than half of the total trip time. While recent comprehensive data on the magnitude of ground access problems throughout the U. S. do not exist, to our knowledge, there can be very little doubt that this is in fact perceived as a significant problem in many areas. Indeed, the proposals to build rapid transit lines to airports, and the actual construction of such lines in Atlanta, Cleveland, Philadelphia, and Washington, all point to significant attention to this problem area.

Nor is the problem simply one of access time. The cost associated with access to and from airports can be substantial, especially if one must use either a taxicab or rental car. Although the rental car is useful for more than just access, if the car is required only for access, the entire charge must be considered an access cost. Taxi fares typically are in the vicinity of $10 or more for a one-way trip to an airport, and of course can be much larger if the metropolitan area is large and the distances are great.

3.3. Airside Congestion and Delays

Another major problem which is reasonably well documented and widely acknowledged as serious is that of airside congestion at airports. This naturally results from the growth air traffic alluded to earlier, absent corresponding increase in the capacity of airport facilities. A recent study estimated that airlines pay in increased aircraft operating costs (labor, fuel, etc.) due to delays caused by airfield congestion, approximately one billion dollars per year (Gosling et al., 1981).

The tendency of many airlines to operate with hub and spoke networks is increasing the negative consequences of congestion and delays, because they have a cascade or rippling effect throughout the carrier's network. The use of hub networks has increased markedly in recent years. Airlines apparently have found the resulting concentration of traffic has two desirable features. One is an increase in frequency in any one market (since each flight now serves more than one market via hub connections) being very attractive to travelers. The other is the ability to fill larger planes to capacity, reducing their cost per passenger mile, and enabling lower fares. Recent investigations of this phenomena have indicated no reason to expect that this trend toward increased use of hub type networks will diminish, given currently available aircraft technology and costs, on the one hand, and current passenger preferences for price-service combinations on the other (Kanafani and Ghobrial, 1985). It is not clear exactly what effect increased passenger traffic will have on hubbing, but it probably will increase at least in the near term. Thus the problem of airside congestion is not only substantial now but certainly could increase in the future at many airports.

3.4. Distance to New Airports

As mentioned in preceding sections, one of the major means for overcoming capacity problems at existing airports is to construct a new, larger airport. Of necessity these are quite far from both central cities and major concentrations of suburban activity, and as a result the distance to the airport can be quite lengthy. Even with good uncongested highways -- a relatively unknown phenomena in major metropolitan areas -- access time and cost would be substantial. With actual road conditions, this exacerbates the access and egress costs for an air trip.

3.5. High Cost of HSGT

Often suggested as a desirable form of intercity transportation for travel up to perhaps 500 miles is some form of high speed ground transportation (HSGT). With successful implementation of 160 mile per hour passenger trains in Japan almost two decades ago, interest in high speed ground transport and high speed rail (HSR) in particular was rekindled in the U. S. Various other forms of high speed ground transportation are often proposed, the main other contender being magnetically levitated (MAG LEV) vehicle systems. Although research and development work on these technologies in the U. S. ceased about a decade ago, in Japan and Germany consortia of government and private industry are working on such systems, and in both nations test track operation of modest-sized vehicles (about 30 passengers) has been achieved.

A common feature of Maglev and HSR is a very high cost associated with construction of the guideway. For conventional high speed rail technology, a minimum cost for upgrading a two-track electrified line has been estimated at approximately 4.5 to 6.0 million dollars per mile, not including the cost of obtaining the right of way. A new line, in rugged or urban areas, could cost 20 to 40 million per mile, based on Japanese experience (Office of Technology Assessment, 1983, 39-40). While the latter estimate is certainly subject to error, because there is little experience with constructing such high speed lines in the U. S. (our one high speed line is upgraded track on an existing right of way in the New York to Washington corridor), costs almost surely would be very high for any new system. In addition, there is a substantial cost of purchasing the trains, constructing stations (if none exist which are useable), etc. All this means that current high speed ground transportation technologies have a very high initial cost which must be incurred regardless of the number of passengers to be carried.

In addition, this high initial cost which is independent of the number of passengers carried leads to very high average cost per passenger mile transported for all but extremely high passenger volumes. Figure 3.5.1 illustrates this for a high speed rail system, with conservative costs based on utilizing equipment of the type now purchased in large quantity by Amtrak for speeds up to 120 miles per hour, and using a cost of only six million dollars per route mile (Schoendorfer and Morlok, 1985). As can be seen, the total cost per passenger mile is far above the approximate range of 15 to 35 cents per mile [a] normally charged for regular coach air tickets by commercial carriers in the U. S. Discount fares, on which the vast majority of passengers travel, are even less, of course. Since passenger travel in the very heavily populated Northeast Corridor region of the U. S. is only in the vicinity of a few thousand riders per day, it is questionable indeed whether or not high speed ground transport could achieve substantial economies through attracting higher passenger volumes. This is especially true considering the development of the metropolitan areas in the northeast -- around rail lines which feed directly into this intercity system. Access and egress to stations would be less convenient without such extensive rail transit systems, increasing overall trip time and cost.

[a] This is based on an informal sampling of fares and the statement in Aviation Week and Space Technology (Anon., 1985, 27) that American Airlines' regular fares are in the range of 16 to 34 cents per passenger mile.

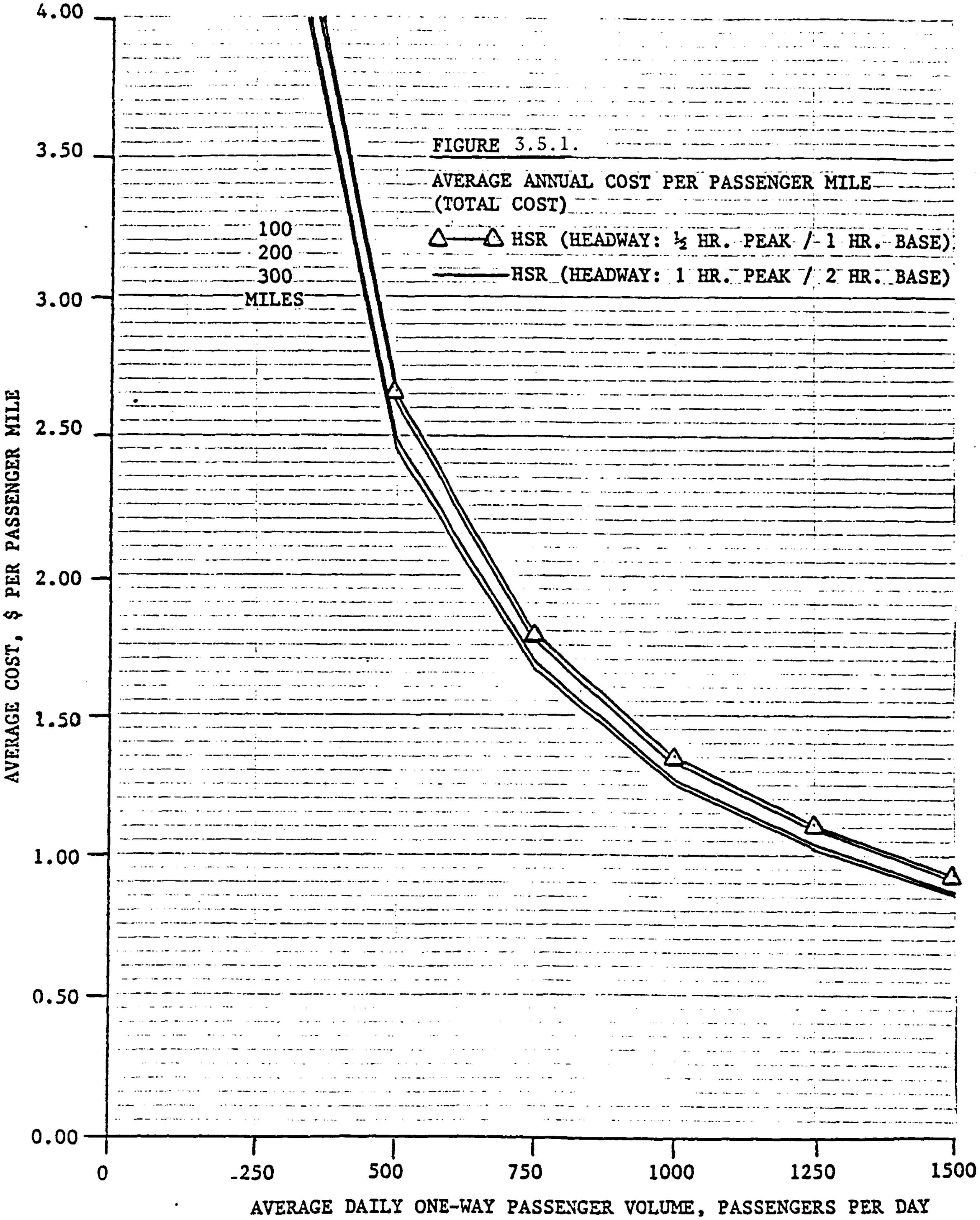


FIGURE 3.5.1.

AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST)

3.6. Air Safety

This problem which has surfaced recently and appears to be growing in at least the public perception of its importance. The recent rash of reported near miss incidents, as well as numerous statements by observers of the air transport system that control towers at many airports are extraordinarily overloaded, all creates a feeling of uneasiness with regard to air safety. And now there are accusations that FAA data has been falsified to cover up a worsening air safety problem. While the veracity of a present and growing safety problem can not be settled, the issue is important. Furthermore, given the high regard for human life and avoidance of suffering endemic to our society and culture, it is clear that should safety emerge as a significant problem with air transport, actions would be taken very swiftly to improve that safety. Recent programs dealing with highway safety, from redesigning and rebuilding highways with safety objectives to anti-drunk driving and related campaigns, all attest to the power which can be brought to bear on safety problems. While current data do not suggest a serious problem with air safety, expected increases in traffic could result in a safety problem, and if so this would provide a substantial impetus to the implementation of technology which would improve safety.

3.7. Closing

This concludes the discussion of major problems associated with the air transport system. Clearly all problems which have surfaced in various public forums have not been included here. Rather, only those problems which were felt to be extremely significant and likely to relate to the tilt-rotor aircraft were included.

4.0. Opportunities for Tilt-Rotor

4.1. Introduction

Based on the previously identified problems with the aviation system, characteristics of the tilt-rotor aircraft, and interests of various groups affected by the commercial aviation system, opportunities for deployment of the tilt-rotor were identified. Four distinct opportunities were identified and are described below, in terms of the opportunity itself, likely patterns of deployment, impacts on various affected groups, an assessment of likelihood of support from these, and finally recommendations for development.

4. 2. Selected Replacement of Existing CTOL Flights

4.2.1. Opportunity

Clearly an opportunity exists to deal with congestion and aircraft delays at selected airports by replacement of some CTOL flights by tilt-rotor flights. The VTOL capabilities of the tilt-rotor would be used to avoid the congestion of the CTOL runways, terminal areas, etc. This scenario represents the most limited and orthodox use of the tilt-rotor, for it involves opening up no new markets for air service.

4.2.2. Deployment

Seizing the opportunity created by the tilt-rotor aircraft for avoiding congestion at those airports where congestion is a serious problem would probably be done by the existing carriers in that market. The reason for this is essentially that at any given volume of passengers and assuming identical (minimum) load factors, in general tilt-rotor has somewhat higher costs per passenger mile than conventional aircraft as described earlier. As a result of this any new small carrier entering the market is likely to be at an immediate competitive disadvantage, for an existing carrier with sufficient cash reserves could wage a price war which might cripple a new carrier and drive it out of business. A large carrier is most likely to favor experimentation with a new service in markets it already serves, partly because of its knowledge of that market and experience with its competitors there. However, a large carrier entering a new market (for it) is a possibility.

Motivating a carrier to introduce tilt-rotor service would be potential gains from general service quality improvements compared to its prior service (if any) and service of its competitors. The substitution of tilt-rotor for CTOL flights would presumably be done on those flights where delays are frequently encountered and where the passengers are likely to value elimination of the delay sufficiently to pay a premium fare should that be necessary. This would most likely be flights catering to businessmen, with a relatively short distance hop (probably under 300 miles). Ideally, but not necessarily, the market would be such that flights would experience congestion at both endpoint airports. The improvement in quality of service of this carrier relative to others would then lead to some travelers switching to this carrier, increasing revenue and market share. In addition, presumably a higher fare could be charged for the improved quality of service (in the sense of reduced delay), further increasing revenue. This increase in revenue would of course have to be sufficient to cover additional costs.

Since the tilt-rotor aircraft is likely to seat approximately 44 passengers, in contrast to the 100 plus seating typical of CTOL aircraft, each CTOL flight eliminated would require replacement by at least two and probably more tilt-rotor flights. The increased frequency would also be an improved service quality feature, in itself attracting more travellers. And again in the right market it further enhances the ability to extract a higher average fare from travellers.

Our studies indicate that VTOL aircraft costs would be typically of the order of 10 or 20 per cent greater per seat mile (or per passenger mile, assuming the same load factor) than conventional aircraft. Many factors which can not be predicted at this point will influence the actual difference in average cost. Naturally the cost of tilt-rotor could be greater than anticipated, in both construction and/or operation, increasing the difference. Also, the CTOL cost included the full costs of an aircraft, while some carriers have been able to substantially reduce their costs by purchasing primarily second-hand aircraft. This option is of course not available for operators of tilt-rotor aircraft, so this again would increase the relative costs of tilt-rotor.

Under these circumstances, it would seem prudent for any carrier introducing tilt-rotor service to attempt to keep costs as low as possible. This suggests not operating the tilt-rotor service itself, but rather contracting the operation of the aircraft and perhaps other related activities on a competitive bid basis to small carriers which generally experience lower costs than the major carriers. This has been a very effective way of controlling costs on very thin margin (i.e., low profitability) feeder and other light volume routes, and there is no reason in principle why it could not be applied to new services as well.

4.2.3. Benefits and Disbenefits

The benefits in this would seem to be substantial for services operating into and out of airports with substantial congestion, of which there are at least 30 in the United States today. Naturally the airline which introduces the service would benefit only to the degree that this service finds an appropriate profitable market niche for itself. However, congestion is widely regarded as a major problem at many airports, and passengers who value time highly and need predictable or reliable service should be willing to switch airlines to use the service and indeed to pay more for this service. The benefit to the airline would naturally be in the form of higher profit for that service, and various intangible benefits might also accrue such as a reputation for being an innovator in air transportation.

In addition to the benefits to travellers and the introducing airline, there would be benefits to other airlines and their travellers who use that congested airport. By virtue of removing some flights from CTOL runways (and perhaps other parts of the terminal) delays to remaining CTOL aircraft and travellers would be reduced as well.

In addition, this should diminish pressure on the airport agency itself to expand facilities or to construct a new airport, and thus from that standpoint it would be positive as well. Finally, in this era of reduced government spending and a general tendency to try to avoid massive investments in public works, finding ways of alleviating airport conditions which do not demand enormous expenditures would be seen as contributing to the national good. Thus in principle tilt-rotor development could have broad political appeal.

4.2.4. Likely Support

Support for this is most probable from airlines serving heavily congested airports and the corresponding airport authorities. These are the groups which seem to be in a position to experience the greatest gains and are in a position to realize those gains even if they are only localized to a few airports and markets. There should, however, be no opposition from air travellers and indeed there probably would be at least a chance of support from airlines which cannot use tilt-rotor aircraft (e.g., because the stage lengths are too long) but who would stand to gain to some extent from reduced congestion at selected airports.

4.2.5. Development Recommendations

The support of at least a few airlines and a few airport authorities would seem to depend on detailed studies of particular situations which demonstrate that the benefits would indeed be realizable and substantial. Therefore it is recommended that as a first step a study be undertaken to make certain that tilt-rotor aircraft could use existing airports in the VTOL operating mode in a manner that avoids interference with CTOL operations. If this is the case, then the technical feasibility of operating tilt-rotor services avoiding the congestion and delays of normal CTOL operations would be assured.

The second study is one which would look at one or more heavily congested airports and identify likely candidate markets for the introduction of tilt rotor aircraft, using the civilian version of the military aircraft now being planned. This study would examine the feasibility of replacing selective flights of particular carriers with tilt-rotor flights, estimating the attractiveness to travellers, likely overall change (CTOL and tilt-rotor) in revenues and costs therefrom, and hence the profitability of the replacement. Also of critical importance is the impact on overall congestion in the airport, noise, etc. In addition, it would be important to determine whether new landing pads would have to be built for the tilt-rotor, and whether or not new terminal facilities would be required. This study should explicitly consider the competition among carriers in the selected markets and the likely competitive response of other carriers to the introduction of such aircraft. This study would naturally have to make use of recent developments in competitive transportation market equilibrium modeling techniques.

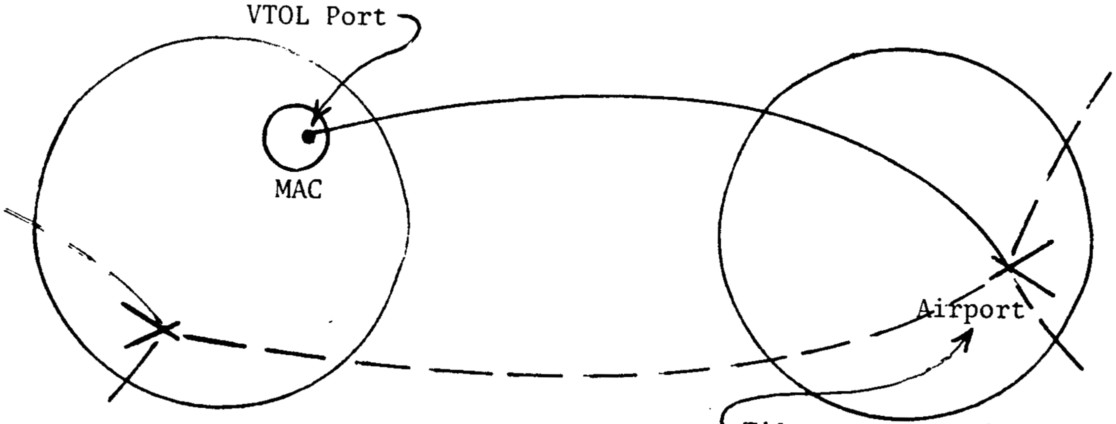
If the outcome of these studies were positive -- and there is every reason to believe that they would be -- then a very persuasive case is made for the use of the tilt-rotor technology in those markets. Probably the next step would then be trying to convince one or more carriers to actually undertake this, and secure the cooperation of the involved airport authorities. They could cooperate in the planning for the introduction to the service, offer incentives for carriers to use tilt-rotor rather than CTOL aircraft (such as low landing fees, access to preferred terminal positions, etc.) and also make sure that there are no restrictions upon tilt-rotor operations. Peak period or congestion pricing of CTOL operations would also be a powerful inducement for the introduction of tilt-rotor technology at these airports.

4.3. Major Activity Center Service

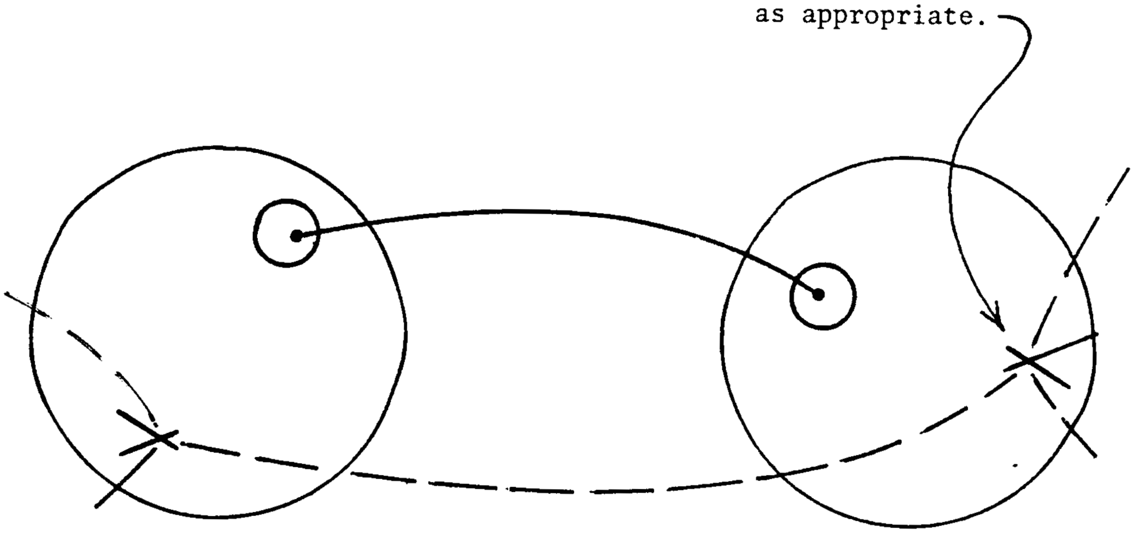
4.3.1. Opportunity

Major Activity Center Service (MAC Service) is envisioned as a service which takes full advantage of the tilt-rotor aircraft's ability to take off and land vertically, and its relatively small noise footprint and otherwise environmentally benign features. This service would operate to and from a major activity center -- an office center, industrial area, possibly residential area, etc. -- with the other end of the flights typically being at a conventional airport. By virtue of the landing pad being in the midst of this activity center or very close to it, access and egress time and cost would be reduced dramatically compared to that for a conventional CTOL airport. This then gives an immediate benefit from introducing this type of service, namely, a reduction in door-to-door travel time for those travelling to or from this activity center and nearby areas. This service is envisioned to be for only selected MAC's markets -- those where demand is expected to be sufficiently high to support a reasonably frequent service -- of the order of a flight every two hours at a minimum except in peak periods where it would be at least every hour. These would be essentially new links in the air system even though much of the passenger traffic might be diverted from other routes.

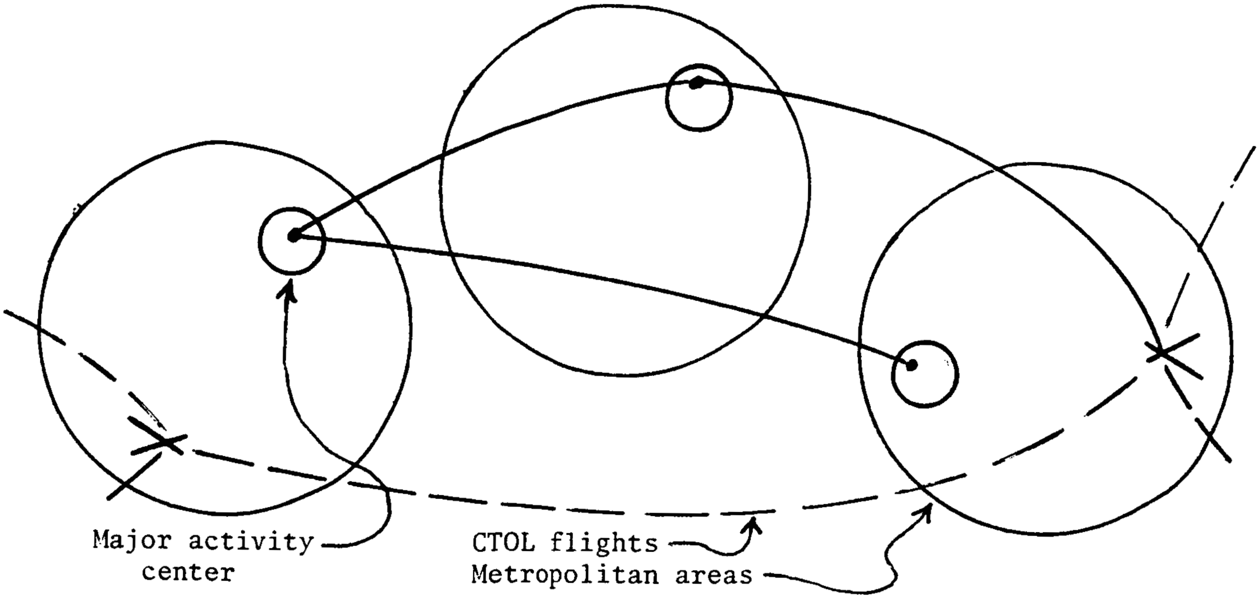
Variations on this concept would be for service to be provided from a MAC to another airport with the VTOL operation being used at both terminals. The advantage of VTOL operation at the CTOL airport would be to avoid congestion which exists for CTOL operations, as was discussed in the preceding section. A further variation would be for the new service to connect one MAC area with another MAC area, and thus the service would exist entirely independently of, and be unconnected to, the regular air system. These various options are shown in Figure 4.3.1.



a. MAC -- airport connection



b. Independent (unconnected) MAC service



c. Indirect and direct connections to CTOL systems

Figure 4.3.1. Major activity center (MAC) service network options.

4.3.2. Deployment

Because of the cost disadvantage of tilt-rotor compared to CTOL aircraft, which was discussed at length in preceding sections, this service would undoubtedly be developed to serve a rather specialized market, at least initially. It would tend to focus on travellers who value their overall trip time highly, and trip time would be reduced because of either VTOL operation to avoid congestion in a larger airport or the proximity of the MAC airport to the ultimate origin or destination. Because of the small or specialized nature of the market and the risk involved in using a new technology, it would seem most likely that the first airlines to offer this type of service would be ones which already have a significant knowledge of the market and also have the cash to maintain the service through a period of development in which it might not be profitable even though the long run profitability seems to be reasonably certain. Thus it is likely that the first service would be first introduced by airlines who are already in a particular market or service between a particular pair of cities.

For an existing carrier to introduce such a new service poses some additional requirements. First of all, the carrier is most unlikely to want to give up entirely the existing service between the two CTOL airports in the endpoint cities of this market. But much of the tilt-rotor traffic will be diverted from CTOL service, and as a result the carrier would want to introduce this service only in markets where the traffic expected to remain on CTOL flights would be sufficient to maintain a reasonable minimum quality of service with adequate load factors. Thus there must be sufficient traffic for the sustaining of both a reasonable minimum service frequency with tilt-rotor aircraft and also a reasonable minimum with a conventional aircraft. Our cost studies, detailed in the companion report, indicate that tilt-rotor costs with a reasonable minimum frequency for business and other travel (one flight every hour in the peak period and every two hours in the base period) are reached at a level of passenger volume of approximately 1,000 passengers per day in each direction. In the case of CTOL, average costs for the same minimum service frequency are essentially constant at approximately 1,300 passengers per day (each way). Thus the minimum total market one would expect for this service to be initiated would be of the vicinity of 2,300 passengers per day. Of course, there undoubtedly are markets where it might be advantageous for the carrier to introduce this type of service where passenger volumes are less, but where correspondingly less frequent service would be deemed acceptable. Determining these would of course require a detailed investigation.

A key feature of the MAC service is that the MAC terminal will be in the midst of a major activity center. Thus this terminal will have to be accepted by those in the immediate vicinity who would be impacted by the noise, road traffic, danger of air crash (however small), etc. of the tilt-rotor flights. For this to be the case, air service will almost surely have to be an important factor in the vitality of the MAC area. This would be the case for many of the office and high technology centers being developed. Also, such air service might fit very well into the redevelopment plans of an older area which is attempting to increase its attractiveness to newer growing industries and types of office activities.

4.3.3. Benefits and Disbenefits

Another important consideration is the likely impacts and perception of benefits and disbenefits on the part of the community as a whole that surrounds the MAC terminal facility. This is important because this is the group which will experience the immediate negative environmental impacts associated with both aircraft operations and ground access to and from the terminal. As emphasized above, the MAC terminal would basically serve trips originating or terminating in its immediate vicinity. As a result, to a very large extent, the same group of people will, on the one hand, be experiencing the disbenefits associated with these air operations and terminal activity, while on the other hand they will be experiencing the benefits of the high accessibility afforded by the MAC terminal. In contrast, the more typical CTOL airport accommodates a large number of passenger movements -- changing aircraft, on board aircraft, and going to and from the terminal -- which neither originate nor terminate in the immediate area of the airport. In these circumstances, the neighbors of the airport are asked to bear the brunt of the disbenefits while they do not experience the corresponding benefits. This situation is quite different in the case of the MAC terminal. Thus there is a greater likelihood that the benefits will be seen as offsetting the disbenefits, essentially being a price one has to pay to capture these net benefits. For these reasons, opposition to the MAC terminal should be significantly less than that which would occur relative to a more conventional air terminal.

Another important consideration is the risk associated with introducing a service of this type to a new terminal facility within a metropolitan area. While the long term profit prospects for such a service may be substantial, carriers may be reluctant to enter that market unless they foresee an opportunity to reap substantial benefits commensurate with the effort and financial outlay necessary to initiate service and to develop the market initially. Very often in transportation and other contexts, an exclusive right to serve an area is offered to a firm in order to offset the risk associated with developing a new market. This exclusive right would insure that the carrier is rewarded if the carrier develops the service into a profitable one. This can easily be done with this concept of MAC service, by limiting the service at a particular terminal to one carrier. This carrier then has every incentive to develop the overall market but has protection from other competitors coming in once the market is developed. This exclusive right should not be granted in perpetuity, of course, but could be granted for a period of perhaps five to ten years, as would seem appropriate considering the likely growth and profitability of the market.

4.3.4. Likely Support

Likely initial support for this sort of service is likely to come from three sources. First will be airports and metropolitan areas which could envision specialized service to MAC areas as a way of alleviating congestion in existing airports, or possibly fostering a greater economic development in particular locations. This support is likely in only a few areas, as only a few areas would have either the condition of extreme congestion of existing airports or envision development of major activity centers with direct air transportation as a very desirable feature. Another potential source of support is air carriers which already serve densely developed metropolitan areas where MAC terminals and service to them would alleviate problems from congestion and high costs. For carrier support to be forthcoming, the carrier would have to have a very positive attitude toward innovation and toward taking risks.

4.3.5. Development Recommendations

The potential for this type of service would seem to be very substantial, but the initial focus should be on areas where the problems with the existing air system in terms of quality of service to travellers are especially acute and where the market is clearly large enough to support the dual type of service envisioned in this scheme. The primary requirement would seem to be, therefore, for a market study to pinpoint particular metropolitan areas where one or more MAC terminals would be advantageous, and to identify the particular market or markets (i.e., other end of the route) which should be served as well. Also to be considered would be the suitability of sites for a MAC type facility, especially attractive ones being large concentrations of employment where there is a substantial need for rapid travel and where these sites are far removed from existing major airports. Such a study would include an explicit consideration of the ability for the market or markets to sustain a dual service to both the existing airport as well as the MAC port and the likely levels or split of traffic among these services and their relative profitability. Also important in some markets would be the ability of tilt-rotor aircraft to land and take off at CTOL airports in the VTOL operating mode without interference with other operations, so as to avoid congestion, etc., but this feature would not be necessary in all markets.

Such a study would identify one or more metropolitan areas which are likely candidates for MAC terminals and this type of service. Once that were done, it would seem prudent to try to involve the local airport authority directly in attempting to plan this type of service. The airport authority would play a crucial role in developing support for this type of activity, as a representative of the local area rather than an outsider, and could also offer the types of incentives to the carrier to enter this market which may be necessary for their support. The Port Authority of New York and New Jersey, in the New York City Metropolitan area, appears to be ready to embark on a program of this sort, related to the use of (essentially) abandoned pier on Manhattan as the MAC terminal. This effort should naturally be pursued vigorously. However, because of the uniqueness of New York City and of the pier sites, other alternatives should be explored as well, particularly in metropolitan areas which are experiencing more rapid growth.

4.4. Substitute for High Speed Ground Transportation

4.4.1. Opportunity

A major opportunity seems to exist to substitute tilt-rotor aircraft systems for proposed or contemplated high speed ground transportation systems with considerable benefits. Such systems have been contemplated in a number of corridors in the U. S. including:

Los Angeles - San Francisco
Los Angeles - San Diego
Las Vegas - Los Angeles
San Francisco - Sacramento
Dallas - San Antonio
Dallas - Houston
Milwaukee - Chicago - St. Louis
Chicago - Detroit
Chicago - Cleveland
Pittsburgh - Philadelphia
Pittsburgh - Cleveland
Philadelphia - Atlantic City
Miami - Orlando (Disney World) - Tampa
New York - Washington (as replacement for current improved rail system)
New York - Boston
New York - Montreal
Washington - Norfolk/Newport News

These corridors, and perhaps others, are in various degrees of study, ranging from apparently serious (Miami - Orlando - Tampa) to corridors where there seems to be only limited interest and support (e.g., Los Angeles - San Diego). In some corridors there is some private funding, primarily from potential suppliers of equipment or construction firms, to others where it is solely government (primarily state) money.

All of these have a number of common characteristics. First of all, they tend to be corridors where the access time for air travel leads to a relatively long total journey time for many types of trips, yet the distances are beyond the normal range of comfortable driving for a one day return trip. Supporters of HSGT argue that the existing transportation system really does not serve many trips well, and as a result a new mode (in the sense of quality of service and price) is needed. All of these studies are seriously considering high speed rail, although in some studies more advanced technology such as a magnetically levitated train is being considered as well. These technologies are seen as partially filling a "gap" in the existing array of transportation options in these corridors. This is primarily the result of the combination of relatively high line haul average speed (usually 120 to 160 miles per hour for HSR, up to 250 mph for MAGLEV) plus convenient CBD access resulting from central city terminals.

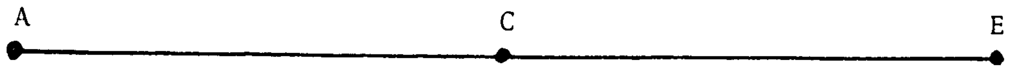
Another common feature of these, resulting from the technology being considered, is the extremely high initial cost of constructing a corridor system, independent of the traffic volume. This makes for a very high total cost per passenger mile actually carried regardless of any of the realistically expected travel volumes which might emerge in these corridors. In order for the systems to be deemed successful in any sense, they must attract a reasonably large number of travelers and be available for use by a large number of travelers, and as a result fares would undoubtedly have to be far below the average total cost, and perhaps even below the average operating cost. As a result, not only is government finance of construction contemplated, but also like most rail passenger services an operating subsidy is likely to be required.

It is precisely here that the opportunity for a substituting tilt-rotor technology emerges, for the tilt-rotor cost analyses indicate that its cost should be substantially below those of high speed rail transport for any traffic volume that might be realistically expected in these corridors. This was discussed in detail in section 3.5.

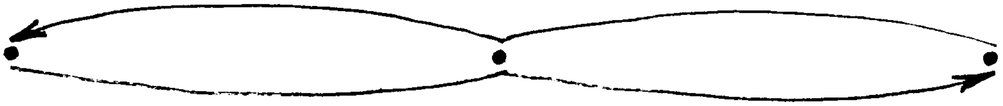
4.4.2. Deployment

Corridors differ in terms of the characteristics of the network and also of the operation contemplated for a high speed rail. Some are simply connections between two major metropolitan areas, and only non-stop service is contemplated. In these situations, the normal airline practice of non-stop service would be a direct substitute for the rail service.

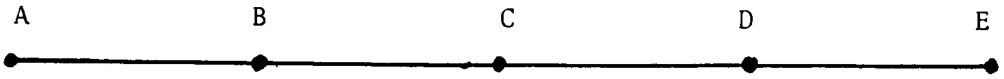
In other corridors, one or more intermediate stops are contemplated, with the rail line appearing as in Figure 4.4.1. On a route with a number of intermediate stations, trains are normally planned to stop at the various intermediate points, unless they are so close together that the overall travel time is substantially increased, in which case some expresses would also be operated. In either case, for the tilt-rotor system to be an affective substitute it is essential that it serve the intermediate points also. Given the rather substantial time penalty resulting from aircraft stops, in comparison to that for railroad train stops (at least 10 minutes vs. about 3-4 minutes), an aircraft stopping at all cities en route is an undesirable itinerary. Therefore it seems prudent to consider alternative operating plans, in which aircraft would fly with no or few intermediate stops. The small capacity of the tilt-rotor aircraft lends itself well to such an operating plan. In such a plan, each train departure (perhaps one per hour in each direction) would be replaced by a number of aircraft departures. Referring to Figure 4.4.2., one aircraft might fly directly from city A to



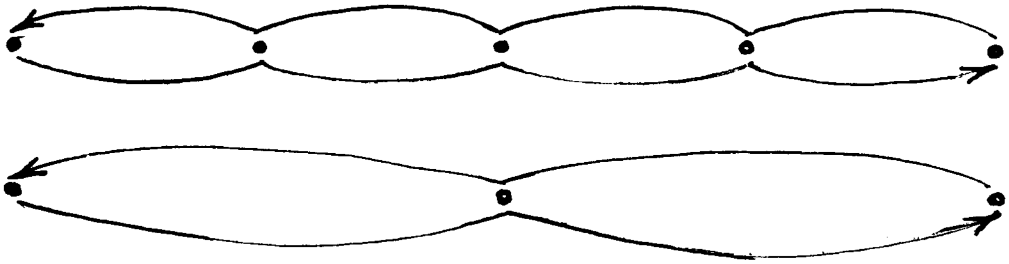
Line: Long distances between stations



a. Operating plan: All trains stop at all stations.



Line: Short distances between stations.



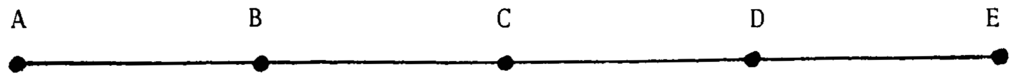
b. Operating plan: Local and express trains.

Figure 4.4.1. Alternative operating plans for different station spacings.

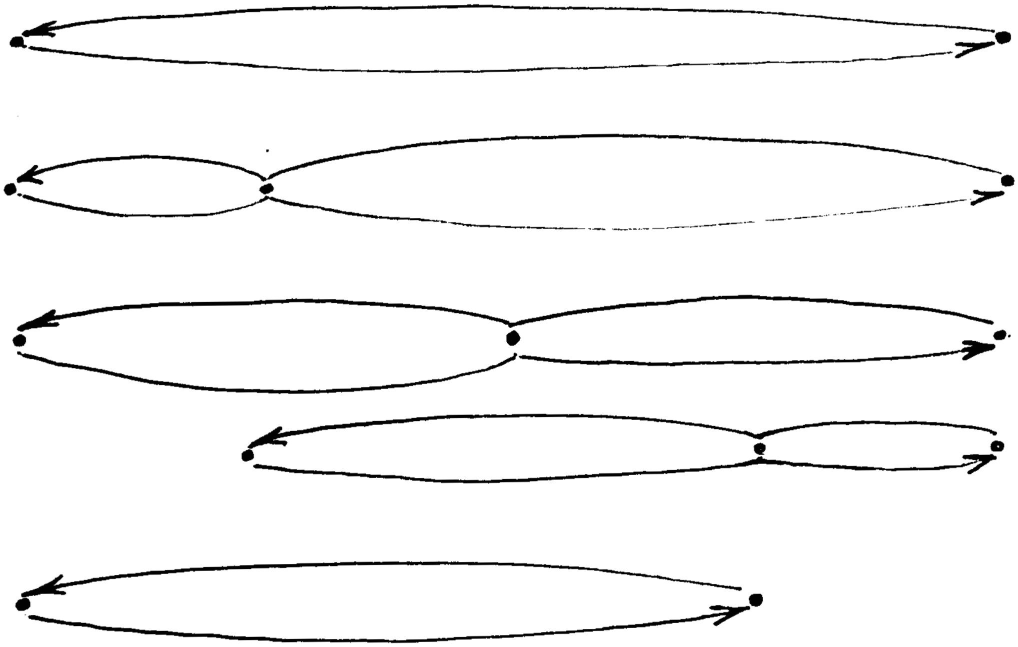
city E each hour, thus substituting very well for the train. Another aircraft might fly from city A to city B and then fly on to city E, providing service between those two pairs of cities. Presumably travelers from A to B would choose the non-stop flight. Another flight might leave city A and go to city C, and then go on to E, etc. Obviously if there were more intermediate stops, then additional flights would be required, and each flight might make more than one intermediate stop. Nevertheless the basic effect would be to replace the train service with flights between all pairs of cities such that one could travel between all pairs of cities on a flight of perhaps no more than one or two intermediate stops. Since a train typically will seat 500 to 1000 passengers, and typically carry half that, multiple flights replacing one train will still yield high load factors.

Another issue is the location of terminals, for it has a significant bearing on access and egress times and cost, and hence on the degree to which tilt-rotor might realistically be thought of as a substitute for high speed rail directly serving downtown areas. Rail stations typically require large tracts of land, and the terminal buildings themselves are generally quite large (a typical HSR train is six to eight coaches long, sometimes more). Under these circumstances it would seem reasonable to assume that a suitable landing pad for VTOL operation could be provided in the same land area as for a rail station, and thus air service could be provided to precisely the same location. In fact, the land area required for the air terminal may be smaller. Of course if air service could be provided to an alternate location even more desirable, then that presumably would be done.

Naturally one might expect environmental opposition to introducing air service into central cities, but it may very well be true that tilt-rotor aircraft present no more of a noise or other environmental threat than high



Corridor: Short distances between terminals.



Operations plans: Many non-stop and on-stop runs.

Figure 4.4.2. Illustrative operation plan for tilt-rotor system serving many city pairs in a corridor.

speed trains. Trains are certainly not noiseless nor pollution free. In Europe opposition has been expressed to upgrading rail lines because of the problems with noise and vibration. In Japan, the maximum speed of the HSR service has been limited to 131 mph (rather than the planned 160 mph) because of environmental opposition. Environmental impacts and opposition are the prime reasons why the German Federal Railways have opted for constructing new high speed passenger lines rather than trying to upgrade tracks on existing lines through many built-up areas -- at a substantial increase in cost.

Another important feature that is particularly relevant to the U. S. situation is that in many larger metropolitan areas the old, still-used railroad stations have very large land areas devoted to storage and maintenance yards. These could prove to be very suitable sites for tilt-rotor aircraft landing facilities, and the terminal building itself might be used as the air terminal. Many such terminals continue to have good rail service, and many serve also as intercity bus terminals, so the addition of flights provides for excellent connections to the air system. This might be particularly important in the case of current (and possible future) rail corridor cities, where rail service is quite frequent.

A major question with respect to deployment is who would actually take responsibility for developing such a system. If direct substitution of tilt-rotor for HSGT were made, then the same entity, almost certainly a state or multi-state government entity, would presumably take the lead in attempting to develop such a service. However, because of the tilt-rotor's lower cost, profitability is much more likely and hence the government entity's role could be to simply sponsor or facilitate introduction of the service by a private firm. The private firm would actually operate the service, own most of the assets, etc. In the current climate in favor of privatization of government service enterprises, and the concomitant desire for such services to be more efficient and more nearly self-supporting, tilt-rotor substitution for HSGT would seem to be particularly attractive.

4.4.3. Benefits and Disbenefits

One significant group of beneficiaries of the substitution of tilt-rotor for high speed rail would of course be the various governments which would be expected to subsidize the high speed rail system. In the past HSR proposals have emphasized federal money for subsidies (and indeed the Northeast Corridor project was financed virtually entirely with federal money), but a vastly diminished role is now seen for the federal government, financing responsibility shifting to the states.

To the extent that lower costs would lead to lower prices for travelers, travelers would be expected to benefit as well. However, the experience with intercity rail passenger service in the U. S. is that fares generally are kept quite low (typically that of alternative modes, bus and lower cost air service), and (massive) subsidies are expected and gotten from various levels of government. Other possible user benefits of tilt-rotor, such as typical greater frequency of service, would be offset at least in the minds of many by less desirable service features such as higher noise levels, the inability to walk through the vehicle, a lack of variety in accommodations (e.g., parlor cars versus coach versus club cars), etc. Thus it is unclear that users would really be any better off with the tilt-rotor than HSGT.

There might be some environmental support for tilt-rotor, stemming from opposition to new rail line construction or reconstruction of existing rights-of-way, but this is not likely to be very significant. Opposition to major transportation construction projects such as highways, airports, and rapid transit lines seems to be quite successful in situations where citizens feel strongly about that opposition, without an alternative meeting the transportation "need" being proposed. Thus it is unlikely that opponents to rail service would feel the need to support an alternative service, especially one that has some negative environmental impacts itself. Also, the general public image of air is that it is less environmentally beneficial than rail, and under these circumstances it may be difficult to transfer support to tilt-rotor regardless of the facts of the case.

In terms of disbenefits, there are basically two groups which would probably oppose any such substitution. One is of course the suppliers of high speed ground transport, including vehicle builders, suppliers of electrical equipment, and firms that would be engaged in the design and construction of the guideway and terminal facilities. It is important to recognize that these groups are very significant players in the current studies of high speed ground transportation and seem to have been the major source of political support for these studies in most -- but not all -- cases.

A second proponent group for HSGT -- and in particular high speed rail -- consists of people who are simply very supportive of advanced rail passenger technology, feel that society needs it and would benefit from its deployment. It is difficult to judge the size and political power of this group. It is tempting to assert that this group must be quite small, for few people use intercity trains, but it is certainly not insignificant, for otherwise one would imagine one of the last two national administrations would have been successful in its attempts to cut back or eliminate Amtrak subsidies. Naturally any group which is wedded to a particular technology would not favor the substitution of an alternative technology.

4.4.4. Likely Support

The substitution of tilt-rotor for high speed ground transport is an idea which would gain support only if the need for improved intercity travel would be perceived by a broad group of people, most of whom have no vested interest in high speed rail. At the present time it does not appear as though there is national support for high speed rail or other forms of high speed ground transportation. Few political leaders seem to pay much attention to the studies of HSGT in various corridors, except (at the time this is written) for the Florida corridor and the Los Angeles - Las Vegas corridor. In these corridors, an opportunity presents itself, and similar opportunities will probably emerge elsewhere.

4.4.5. Development Recommendations

Given the apparently serious interest in HSGT in at least two U. S. corridors, and the fragmentary concern for higher performance short-distance intercity transport, it is only prudent to try to seize this opportunity for tilt-rotor technology. Two efforts are envisioned.

Since the main advantage of tilt-rotor over high speed rail is lower costs at almost any expected traffic volume, one effort would be to update cost comparisons of the type made in the companion report to reflect better tilt-rotor cost data as experience makes it available. Similarly better cost data for high speed ground transport should become available, and this should be included also.

These comparisons should be in a form which is readily made available to interested parties and is easily understood, so that they can be readily used. Both a summary document for use by steering committees, boards, etc., and separate complete technical documentation (similar to the companion cost report to this study) for use by technical analyses groups, should be available. An organization with no current or prospective financial interest in the tilt-rotor should undertake this effort, on a continuing basis.

Once reasonably definitive cost information is available on tilt-rotor, specific studies should be made in each corridor where HSGT is being considered seriously. These should consider - for tilt-rotor - costs, likely traffic volumes and revenue, and other factors of interest, with a direct comparison with the then-current projections for HSGT. This might be sponsored by NASA alone, or in cooperation with the U. S. Department of Transportation, and possibly with potential tilt-rotor suppliers or operators. Again, however, the performing organization should have no interest in tilt-rotor development or deployment, and should work independently so that charges of bias will not negate the conclusions of the comparison.

4.5. National Tilt-Rotor System

4.5.1. Opportunity

The preceding opportunities for development of a tilt-rotor air service all emphasized particular markets where the tilt-rotor's unique advantages create an opportunity for potentially effective deployment in competition with other forms of transportation. Taken as a whole, however, the types of advantages cited above could conceivably provide the basis for providing a tilt-rotor service throughout most of the United States. The essence of this concept is that the tilt-rotor has some service quality features which are generally advantageous compared to conventional air or high speed rail service, and that therefore a tilt-rotor-based air system could provide a higher quality of service in general than a conventional system. Because of this higher service quality, the service would be different, and indeed a somewhat higher fare could presumably be charged. Thus one has the basis for creating another air system, higher in quality and higher in fare than the conventional system, serving markets of perhaps up to 300 miles. This would represent a different travel alternative, in the sense of a different mode, just as high speed rail is differentiated from conventional rail in those nations where such service is offered (including the Northeast Corridor of the U. S.). In those cases the high speed rail service has been deliberately conveived and marketed as a service distinct from conventional rail, with its own somewhat higher standards of service with respect to train speeds, frequencies, and passenger accommodations, and of course it typically commands a higher fare than conventional trains.

It is conceivable that tilt-rotor air service could be developed in the same way. However, such service would not be initiated at one time throughout the nation, but rather individual services would be introduced in those markets where the potential for the tilt-rotor is greatest. If those initial applications proved successful, then service would be expanded and gradually a large comprehensive regional system, or perhaps a national system, would emerge. The basic manner of deployment and pattern of impacts (benefits and disbenefits) would be essentially identical to those discussed previously, so there is no need to repeat them here. While such a comprehensive system may appear unlikely, it is difficult to support the proposition that there is little or no potential for such a tilt-rotor system to emerge.

However, it is only appropriate to focus initially on a more incremental deployment of this aircraft, and thus this particular extension of the more limited paths of development described earlier is not pursued in detail here.

5.0. Recommended Actions

The preceding discussion of possible paths of development of tilt-rotor aircraft as a significant component of the commercial aviation system of the United States included the identification of a number of specific studies which would be necessary to support what are now only partially-supported contentions that the benefits to various groups would be substantial. In this chapter three specific studies and related actions are identified. These are designed to help engender support for development of tilt-rotor aircraft and tilt-rotor systems, and they would do so provided the attractive features of the tilt-rotor concept described earlier continue to emerge from more detailed analysis.

5.1. VTOL-CTOL Airport Operations

The first action area would be to examine in considerable detail the potential for tilt-rotor aircraft to take off and land at existing airports, in the vertical take off and landing mode of operation, essentially independently of the operations of conventional take off and landing aircraft. This study is extremely important because one of the significant hypothesized advantages of the tilt-rotor would be its ability to serve existing major airports without experiencing the congestion of conventional aircraft. Furthermore, in addition to the avoidance of delays by tilt-rotor aircraft, the reduction in CTOL operations, resulting from substitution of VTOL (tilt-rotor) flights, would diminish the demand for CTOL runways, taxiways, etc., and thereby reduce the congestion experienced by CTOL aircraft. As has been pointed out numerous times, at the high levels of congestion experienced for some periods at many airports, even a small reduction in the number of flights could significantly reduce expected delays.

This study should include at a minimum a few case studies of reasonably typical existing congested airports. It is extremely important in demonstrating the ability of the tilt-rotor to reduce CTOL delays and thus offer relief from the pressure to construct new runways or entirely new airports. Congestion relief is the critical factor for gaining airport support of the tilt-rotor concept. Furthermore, benefits from diversion and substitution of tilt-rotor aircraft would accrue to airlines that would not expect to use such aircraft, and thus this study would be instrumental in gaining their support, at least minimally, of tilt-rotor development.

Another aspect of this study would be an examination of the ability of tilt-rotor aircraft to be accommodated at existing airports without the need to construct additional terminals. If this could be done, then one of the larger capital expenditures in fixed facilities, and thus one of the expenditures which is at the highest risk in case of failure of tilt-rotor service, is avoided. Since an important consideration is the ability to use an existing terminal would be the mingling of tilt-rotor and other aircraft, this would seem to be an appropriate part of the congestion study.

Finally there is the related question of the degree to which tilt-rotor aircraft operations would potentially interfere with conventional air traffic in the vicinity of facilities to be used only by the tilt-rotor aircraft, presumably in the vertical take off and landing mode. This would then shed light on the degree to which existing air traffic might constrain the location of new tilt-rotor air facilities, such as in major activity centers, and the degree to which accommodation either in moving those facilities or in altering the flight paths of conventional aircraft would be necessary.

The purpose of this study is of course to document the benefits that would accrue to congested airports and airlines using them from the substitution of tilt-rotor flights for some CTOL flights. The results would be most credible to such organizations if they had some direct involvement in the study. Various ways exist to achieve this. One is to have the study jointly sponsored by NASA and the FAA. Another is to have an oversight panel for the study consisting of representatives from airports and airlines. They would be actively involved in the study design and review of intermediate as well as final products. Such active involvement also facilitates dissemination and assimilation of study results, and should lead to willing support of tilt-rotor deployment, provided of course the results are positive.

5.2. Tilt-Rotor Cost Refinement and Comparison

The second important major study area relates to the cost of tilt-rotor service. Obviously the cost of building tilt-rotor aircraft as well as the cost of operating such aircraft are essentially unknown at the present time, and must be extrapolated from experience with other types of aircraft, resulting in a considerable degree of uncertainty. As tilt-rotor aircraft are constructed for the military, these costs should be monitored carefully and used as a basis for refining estimates of the cost of constructing civilian tilt-rotor aircraft.

Also, as the military begins use of these aircraft, their experience should be used to develop better estimates of tilt-rotor operating costs. Because the factor prices in the military are so radically different from those in the civilian sector, it is only appropriate here to obtain information on the amount of physical resources required (man hours by type, spare parts, etc.), and then to make appropriate modification to these and apply civilian factor prices to develop overall cost levels as they would be expected by a civilian carrier. An important consideration here would be the learning effect, i.e., costs declining as experience is gained with these aircraft. Similarly, any operational problems, unreliability, or other factors that might influence the suitability of the aircraft for civilian application should be monitored.

This cost and related information on tilt-rotor should be continuously updated, and be kept in a form useful to any technical groups -- in airlines-government transportation agencies, and elsewhere -- who are likely to wish to evaluate tilt-rotor service in any market. A similar regularly updated cost and performance information source has been provided by the Urban Mass Transportation Administration -- for bus, rail, and auto transport in urban areas--and it has proven very useful in facilitating analyses of alternative urban transportation plans, local policy , and management actions.

Similarly, costs and performance characteristics of alternate technologies, especially high speed ground transport but possibly also including CTOL, should also be maintained and updated. This would serve the same basic purpose as the tilt-rotor information, but allow cross-mode comparisons.

This information must be made available to prospective users, and they must be aware of its availability. Publication of an annual or bi-annual cost update by N.T.I.S. or U.S.G.P.O. would satisfy the availability goal. Copies should be sent automatically to state DOT planning offices, and to state DOT intercity public carrier offices where they exist. Publication of the methodology used in preparing and updating the cost and performance information (or models) should appear in a few journals for practicing transport engineers, e.g., Transportation Quarterly, Transportation Research Record, and certainly in a corresponding journal directed toward the air transport industry.

Finally, NASA should take an active role in making potential users of tilt-rotor technology aware of its features. Keeping abreast of intercity passenger transport studies, especially corridor studies, and providing limited technical assistance would seem appropriate.

5.3. Tilt-Rotor Profitability Analysis

A final study area is that of examining the extent to which tilt-rotor could actually operate as a profitable component of the air transport system in selected markets of the types described earlier. In all of these markets the tilt-rotor would have to compete with conventional air service, and to a lesser extent with other forms of intercity transportation. This study should therefore examine the degree to which tilt-rotor could find an appropriate market niche in terms of service quality, price, and air facilities to be served.

The only appropriate type of modelling in this context is that of an equilibrium of traffic flows over a network, in which each of the various competing carriers attempts to maximize its own objectives. The analysis is of course further complicated by the effect of each airline's and other carrier's choice of fare and service quality to offer on the split of traffic among modes and particular carriers. Models of traveler choice behavior have been reasonably well developed and seem to predict competitive outcomes reasonably well. In the past five years models of carrier behavior have been developed and successfully applied to modeling the changed competitive conditions among intercity freight carriers. Results tested against historical data indicate quite good predictive abilities. Thus this type of model should be applicable to the air system. Simpler more traditional network models, which assume a single actor or carrier attempting to maximize its own objectives would of course not apply to a situation in which many carriers operate and where a new carrier or new service are to be introduced. Making a multi-carrier model more feasible in the air case than in the freight case is the fact that the network structure would be much simpler, often just a single link or number of spokes eminating from a single hub, as well as the diminished interdependence among competing carriers in the air case in contrast to, say, the case of intercity freight railroads.

An important issue to be studied in this context is that of whether or not a tilt-rotor aircraft should be developed which has a larger capacity than the approximately 44-seat capacity envisioned for the civilian version of the military aircraft. While cost per seat mile would undoubtedly decline with the larger aircraft, it is unclear whether the benefits from this would be worth the additional development cost. The market niche of tilt-rotor may not require an extraordinarily low seat mile costs, because of the distinct and higher quality of service that is offered by the tilt-rotor compared to conventional aircraft.

This particular effort should be undertaken in two phases. The first would be developing the basic model, adapting and modifying the freight model for the passenger case. The simpler network structure and the larger number of service quality features in the air case would suggest a different solution algorithm. The structure of costs would also change.

Once the basic model is developed, the application would follow. Like the airport operations study described earlier, this study would benefit considerably from the direct involvement of potential users of the results. In this case these would be primarily airlines, and to a less extent airports, so these groups should be involved. An overview panel would be very appropriate, especially helpful in identifying good application markets and in assessing empirical inputs to the model.

5.4. Conclusion

Three groups of actions are thus recommended for purposes of developing support for R&D and actual deployment of tilt-rotor aircraft in the commercial aviation system. These three efforts could move in parallel, and probably should, given the differing groups which each study has as its target. In terms of priority, the VTOL-CTOL airport operations study and the cost study are of highest immediate priority, but the third study probably would be necessary to interest a potential private air carrier in the near future.

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