THE CHOICE OF V/STOL TRANSPORTATION FOR THE NORTHEAST CORRIDOR

William M. Swan

June 1972
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The Choice of V/STOL Transportation for the Northeast Corridor

William M. Swan
June 1972
Abstract

Aircraft type, aircraft size, number of terminals, and degree of nonstop routing for a V/STOL transportation system in the Northeast Corridor are chosen by exploring a wide range of combinations. Helicopter and STOL aircraft from 20 to 200 seats are considered. From 15 to 20 total terminals were considered. Nonstop, one stop and two stop routings were used. A market model explores the response of a typical route to variations in these parameters. Demand response to the total trip cost, trip time, and frequency of service is measured by a modal split model. It is found that land costs and manoeuvre times make STOL operations less attractive than VTOL. The system is found to be sensitive to indirect operating costs associated with ticketing and boarding. A small number of terminals is required. A 16 port system serving 10 cities using a 60 seat helicopter can carry 16% of the 1985 intercity traffic while charging the full costs to the user. The results were confirmed by a market by market analysis for the corridor.
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1.0 INTRODUCTION

This report brings together work performed by a number of people at the Flight Transportation Laboratory over the last seven years. The main body of the report can be read for an understanding of the analysis and for the principal results. The appendices contain details which are useful to a complete understanding of the material.

1.1 Introduction to the Northeast Corridor

The Northeast Corridor is the area between Washington, Philadelphia, New York and Boston. Six other cities, Baltimore, Hartford, New Haven, Trenton, Providence, and Wilmington complete the list of major traffic centers. Figure 1.1 is a map of the area. The corridor is interconnected by interstate highways, passenger rail service, and either direct or indirect commercial flights.

At present over 80% of the passenger traffic among these cities travels by car. This is true even though the circuity of the roads and the delay of gas and toll stops reduce the average speed of highway travel to 41.1 mph "as the crow flies". Trains and buses, traveling at similar effective speeds, carry less than a tenth of the traffic. The remainder of the trips are made on aircraft, in spite of delays which stretch the sum of take off and landing times to an average of 35 minutes.

The performance of the current public modes of travel is deteriorating with increasing numbers of travelers. Two solutions have been proposed: (1) improved rail transportation emphasizing the use of existing rights of way along the back bone of the corridor and (2) improved air transportation using aircraft and facilities dedicated to short haul traffic.

This report investigates the second of these two propositions.
Figure 1.1: "Map" of the Northeast Corridor
1.2 A Short Haul Air System

There are great advantages in getting the short haul aircraft out of the current airport traffic. Reduction of congestion at the major airports of the Corridor would reduce expensive delays in both long and short aircraft flights. This would permit expansion of long haul air service. In addition the divorce of both vehicle and terminal from long haul operations can allow a short haul air system to serve what has become a mass transport market.

A new and separate short haul air system would include: (1) new aircraft designed to reduce aircraft take off costs and to use inexpensive terminals, (2) multiple new metroports located for convenience and designed to reduce the cost and delay of boarding the aircraft, (3) an air traffic control environment that permits direct routing, minimal loitering times, and all weather operations without interfering with long haul traffic, and (4) a corporate structure which separates the short haul operations from long haul service.

This report will concern itself with items (1) and (2), aircraft and metroport considerations. Air traffic control is a relatively small part of the system cost, and therefore has not influenced this discussion. A brief discussion of the air traffic control problems is presented in Appendix A. Institutional factors have been left to less technical discussions. This analysis assumes that metroports are financed by tax exempt bond issues and run without loss, and that the aircraft are managed by private enterprise.
1.3 Possible Configurations of a Short Haul System

There are two major candidates for a new short haul air system based on the type of aircraft used. A STOL system offers the relatively low mileage costs of STOL aircraft at the expense of complication of terminal operations. A VTOL system offers more efficient terminals but higher cruise expense. Let us look first at the STOL system.

The set of 15 metroports in table 1.1 is a proposed STOL network. The terminal sites were selected on the basis of both access convenience and total cost. Each site has space for a single 2000' runway and is situated to reduce noise impact. These sites may not all be politically feasible. The expense of elevated city center metroports has forced the selection of existing airport sites for most operations. Initially, a downtown STOL system was studied, but was found prohibitively expensive.

The competition is offered by the corresponding 15 terminal VTOL system in Table 1.2.

In order to choose between these two systems one must consider (1) community acceptance (noise, safety, etc.), (2) ease of implementation, (3) overall system cost, (4) flexibility, (5) compatibility with the current CTOL air system, (6) the changing importance of city center congestion, and (7) technical performance, i.e. the ability to attract sufficient numbers of travelers to operate without financial loss.

This report evaluates and compares technical performance only. The other six considerations are briefly discussed in the last chapter.
Table 1.1 Possible STOL Metroport Locations

New York City

SEC  Secaucus STOLport site
LGF  La Guardia Flushing site
WES  Over an interchange on route 287 in White Plains near Westchester

Boston

BOS  Logan Airport STOL strips (new)
HAN  Hanscom Field STOL strips (new)

Philadelphia

SPC  Over 30th Street Railroad Station (elevated)
SPW  Across Schuykill River from Conshocken, by an expressway

Washington

SUN  Over Union station (elevated)
WAS  Washington National STOL strips (new)

Baltimore

SBL  Over Port Covington Rail Yard

Hartford

HRD  Brainard Airfield STOL strips (new)

Trenton

TTN  Mercer County Airport STOL strips (new)

New Haven

NHV  New Haven Airport STOL strips (new)

Providence

SPV  Providence Airport STOL strips (new)

Wilmington

SWL  New Castle Airport STOL strips (new)
Table 1.2 Possible VTOL Metroport Locations

New York City

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMW</td>
<td>Manhattan on West 30th Street docks</td>
</tr>
<tr>
<td>JME</td>
<td>Manhattan on East River south of U.N. (not included in the STOL comparison)</td>
</tr>
<tr>
<td>LGA</td>
<td>La Guardia Airport</td>
</tr>
<tr>
<td>EWK</td>
<td>Newark Airport</td>
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</table>

Boston

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JNS</td>
<td>Over North Station (downtown)</td>
</tr>
<tr>
<td>J28</td>
<td>Intersection of route 128 and Mass Turnpike</td>
</tr>
</tbody>
</table>

Philadelphia

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC</td>
<td>Over 30th Street station</td>
</tr>
<tr>
<td>SFW</td>
<td>Across Schuykill River from Conshocken</td>
</tr>
</tbody>
</table>

Washington

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUN</td>
<td>Over Union Station</td>
</tr>
<tr>
<td>WAS</td>
<td>Washington National</td>
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Baltimore

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBL</td>
<td>Over Port Covington rail yard</td>
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Hartford

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
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</thead>
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<tr>
<td>HRD</td>
<td>Brainard Airfield</td>
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<tr>
<td>TTN</td>
<td>Mercer County Airport</td>
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New Haven

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
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</thead>
<tbody>
<tr>
<td>SNH</td>
<td>Over Railyard near Connecticut Turnpike</td>
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Providence

<table>
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<th>Code</th>
<th>Location Description</th>
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<tbody>
<tr>
<td>SPV</td>
<td>Over downtown trains</td>
</tr>
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</table>

Wilmington

<table>
<thead>
<tr>
<th>Code</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWL</td>
<td>Over Cherry Island railyard</td>
</tr>
</tbody>
</table>
1.4. Report Structure

This project begins with a set of assumptions about component costs and ends with the selection of a system which is in some sense optimal. The development of time and cost structure for a V/STOL system is given in Chapter 2. Detailed development of individual numbers has been relegated to the appendices. Once the structure for assembling and comparing different systems is established, the system which can attract the greatest traffic without loosing money is found by what is basically a cut and try method. This is done in Chapters 3 and 4. The crude assumptions of the basic structuring are checked in Chapter 5 by exercising the chosen system in a more sophisticated network study. Chapter 6 summarizes the effort and reviews its limitations.

The reader may originally be surprised at the extensive discussion in Chapter 3 and 4 of what has just been described as a "cut and try" approach. In fact, the author has attempted to explore over a broad range the forms a V/STOL transportation system could take. The work in Chapter 3 is independent of demand, and merely defines the range of operating conditions achievable by V/STOL systems. The concept of a three dimensional surface of possible operations is introduced.

It is only in Chapter 4 that a corresponding surface conveying information about the collective desires and values of the users of the system is introduced and by comparison of the surfaces, a "best" system is determined.

The purpose of this somewhat roundabout procedure is to arrive at the destination with some idea of where we have been.
2. METHODOLOGY FOR DEVELOPING THE PERFORMANCE OF V/STOL

2.1 Defining the Performance of an Air Transportation System

For the purposes of this study, the performance of a transportation system is measured by the total cost and total time with which it can serve a given size travel market without a loss. This performance depends not only on the type of system, STOL or VTOL, but also on internal adjustments of the system design. Changes in aircraft capacity, average frequency, number of terminals, and number of direct flights can adjust a single type of system over a wide range of cost and time. This chapter establishes the framework for these design options.

The total cost of a trip is the ticket price plus access (and egress) costs. The ticket price is the shared system cost composed of:

1. a share of the cost of capital investment in terminals.
2. a share of terminal operations and take off costs and
3. a share of the aircraft mileage costs.

To this will be added the access and egress costs. The details of all costs will be explored in the next section.

The total time of a trip includes:

1. the time spent in flight
2. the time spent in boarding, taking off, and making intermediate stops
3. a time associated with waiting for a convenient departure. This time is related to the daily frequency.
4. access and egress times to and from the terminals of the system.
2.2 The Structure of V/STOL Trip Costs

2.2.1. Sharing Method for Capital Costs

A major consideration in the design of a STOL or VTOL system is the cost of the terminals. If the cost is too high, the system very quickly becomes overpriced. Capital investments are assumed to be made at the beginning of a system's life. Land is purchased and buildings are constructed. Financing would normally be through local bond issues. The difficulty lies in allocating the costs in an equitable way. The simplest possibility is to repay interest and debt equally over a 20 year period like a home mortgage. Each boarding passenger pays an equal share of the annuity. This was the method followed.

2.2 Development of Capital Costs

Good metroport design can save considerable expense and reduce transit times. The great advantage of a V/STOL system is the low cost of the airports. Suggested metroports have shown tremendous variations in cost and convenience. In view of the magnitude of cost variations, and the importance of the metroport performance to the system, the design used in this study was chosen with careful consideration.

The gate positions were chosen from design #8 by Allen and Simpson (Reference 1). This design provides a swift boarding procedure at a minimum of capital or operating expense. The cost of a gate position designed to accommodate eighty seat helicopters was estimated at $2.02 million. Two thirds of the cost is proportional to vehicle size.

STOL Runways and taxiways were assumed to cost $0.667 million ($1.21/sq ft) at ground level and nine times that if elevated (See Reference 13).
Figure 2.1: Layout for STOL and VTOL Metroports

2000' STOL STRIP

92 ACRES (INCLUDING NOISE BOUNDARY ZONES)
550,000 SQUARE FEET OF PAVEMENT

VTOL METROPORT

26.4 ACRES
$.5 million was included to represent the cost of half a mile of elevated and half a mile of ground level roadway for access.

The layout for the STOL and VTOL ports is illustrated in figure 2.1. Borderland around each landing site must be purchased because other use is impossible for noise reasons. In cases where the STOL port is located on an existing airport, the land is free. Otherwise the land cost is derived from figure 2.2.

The minimum number of gate positions is two. If the traffic warranted it, more gates were added at cost.

Following these guidelines, the total ground system investment is $252 million for VTOL and $406 million for STOL (see tables 2.1 and 2.2). If financed by 20 year 4.5% bonds these figures become $19.4 and $31.2 million per year respectively. This reduces to $2.66 and $4.28 per boarding if there are 20,000 passengers a day for the total system.

2.2.3. Terminal Maintenance

Maintenance costs for the terminal buildings are estimated a $1.68/ft²/year (reference 13 in 1970 dollars) or $38,400/gate/year. Maintenance is shared just like the capital costs. The annual total is $1.15 million per year for 30 gate positions. This is $0.16 per passenger for 20,000 passengers per day.

2.2.4. Processing Costs

An efficient short haul system will need an automated ticketing system to avoid labor costs. Credit card holders will be able to write their own tickets using machines at the airport. Presumably reservations and perhaps checked baggage will cost extra -- enough to cover additional costs. Under these ground rules it is likely that passenger handling costs will be below $2.00 per boarding. This cost of service falls between current airline and express bus operation, which are roughly $5.00 and $0.50 respectively.
Table 2.1  Cost of VTOL Metroports

<table>
<thead>
<tr>
<th>Metroport Name</th>
<th>Cost/acre</th>
<th>Land Cost</th>
<th>Cost of road and 2 gates</th>
<th>Total Cost</th>
<th>Percent of Metropolitan Market</th>
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<tr>
<td>JMW</td>
<td>$ 1.67</td>
<td>$ 44.0</td>
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<td>JME</td>
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<td>LGA</td>
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<td>4.54</td>
<td>4.54</td>
<td>32</td>
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<td>4.54</td>
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TOTAL: $ 268.44

Notes

1) All costs in millions
2) The cost of unimproved land is used to represent the cost of sharing improved land such as at North Station in Boston
3) The cost of 15 terminals is 15/16 of the cost of 16 terminals
<table>
<thead>
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<th>Metroport Name</th>
<th>Cost/acre</th>
<th>Land Cost</th>
<th>cost of road, runway, and 2 gates</th>
<th>Total Cost</th>
<th>Percent of Metropolitan Market</th>
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<td>SEC</td>
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<td>$ 96.6</td>
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<td>LGF</td>
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**TOTAL:** $ 406.25

**Notes**

1) All costs in millions  
2) The cost of unimproved land is used to represent the cost of sharing improved land such as at 30th street station in Philadelphia
Figure 2.2: Cost of Unimproved Land in the Northeast Corridor

Source: Eastman, reference 3
2.2.5. **Income from Parking**

A significant percentage of air terminal operations is supported by income from nearby parking garages. There is no reason why garages located on floors below the boarding areas cannot contribute to V/STOL overheads.

Roughly 44% of the passengers come or go by car. (See appendix C) One quarter of these park for two days at $3.00 per day. A parking place costs $4,800 in capital costs or $1.00 per day. Labor costs are estimated at $0.25 per day per car. Assembling all this, the net income is $1.75 per day or $0.39 per boarding per day. This contributes to the support of the terminal.

2.2.6. **Direct Operating Costs of the Aircraft**

Direct Operating Cost (DOC) is usually half the ticket price. In a STOL or VTOL system, DOC's are expected to be higher since the aircraft is compromised to allow lower indirect operating costs (IOC's) and convenient access. This trend is balanced by the reduced take off and maneuver cost experienced by these aircraft. As a result DOC remains near half of the ticket price for short trips, but is higher at longer ranges.

Operating costs for both the helicopter and the STOL aircraft used in this study were derived from vehicles designed as part of an ongoing effort at the FTL. A 60% load factor was assumed for conversion to ticket costs. The results used in this report are discussed in appendix B. The conclusions are presented here.

It was found that the DOC of STOL and VTOL aircraft could be simply described as a combination of a take off and maneuver cost and a cost per cruise mile. It was further shown that these two costs varied linearly with
the seating capacity. As a result it costs on the order of $1.00 per take off and $.02 per mile for each aircraft seat. These figures go up considerably for smaller aircraft. Using a load factor of 60%, each passenger would be charged roughly $2.00 per take off plus $.04 per mile for his trip. Variations depend on aircraft size and type. Large aircraft are cheaper. VTOL aircraft cost less per take off, but more per mile. In addition, multistop operations cause a greater burden of take off costs.

2.2.7. Stewards

Stewards (male or female) are necessary for safety and boarding, even though no inflight service is necessary. One steward for every forty passengers was assigned to each aircraft. $8.40 per hour was charged against stewards during boarding, takeoff, maneuver, and flight times. These costs, although technically indirect operating costs, were added to the aircraft DOC because they accrue in exactly the same manner.

2.2.8. Aircraft Handling Costs

Short haul aircraft will not be fueled or inspected at every stop. To cover these intermittent servicings, a charge of $6 per landing \(^1\) is added to the aircraft DOC. Ground handling costs, like stewards' salaries, vary directly with aircraft activity.

\(^1\) Reference 8 suggests $10.70 if refueled at every stop.
2.2.9 Operating Overheads

Overhead comes from general and administrative expenses and includes before taxes profits. Since the cost of managing is proportional to the size of operations, overhead was estimated to be a percentage of the total ticket price. Simple operations are assumed to cost 22% of the ticket price.

2.2.10 Total Ticket Price, an example

A short haul ticket cost can be assembled from the several costs listed above. For example

$ 3.00 - contribution to terminal capital costs
  .17 - terminal maintenance
  -.39 - income from parking concession
  2.00 - ticketing costs
  2.41 - aircraft DOC, handling IOC, steward IOC for the take off and maneuver
  4.13 - Cruise costs DOC and steward IOC for 200 miles
  3.18 - 22% G & A and Profits

$14.50 - AIRLINE TOTAL

  1.16 - 8% ticket tax (equaling ATC expenses)

$15.66 - Ticket Price

2.2.11 Access and Egress Costs

Demand models relate the volume attracted by a new mode to the total perceived cost of travel on that mode. This cost of travel is the sum of ticket price and access and egress costs. A new V/STOL system can spend more on its terminals and charge more for its services if it can reduce the average access costs enough.

1 More sophisticated models have weighted the ease of access more highly, but this exercise treats it as a simple part of the total.
Access costs are developed for all modes in appendix C. Figure 2.3 illustrates the results of a study of possible terminal locations in the Northeast corridor. (Appendix D contains discussion of the location methodology.) The average access distance for all potential passengers in the ten metropolitan areas is dependent upon the total number of metroports in the corridor. More metroports offer easier access. Failure to locate STOL sites near the city center puts the STOL system at a slight disadvantage.

The sum of access and egress costs is typically near $4.00 for a V/STOL trip. The cost performance of the V/STOL system would be the ticket price plus the access costs or $15.66 + $4.00 = $19.66 for the 200 mile trip in the preceding example.
Figure 2.3: Average Access Distance to V/STOL Terminal as a Function of the number of Metroports in the Corridor

(points developed from case studies)
2.3 The Structure of V/STOL Trip Times

The trip cost of a V/STOL system is only half of the performance picture. The other predictable index of performance is the total trip time. This involves not only the speed but also the convenience of the scheduled departures.

Viewing a trip through the traveler's eyes the successive steps are: access, boarding, flight time, disembarking, and egress. It is in this order that the times are discussed.

Access times are dependent on access distance. Once again the discussion of appendix C and the data of figure 2.3 apply. Access time is lower for VTOL than STOL operations because of the more convenient metroport locations. As before, increasing the number of terminals can cut access time for either system. An average access time might be 35 minutes.

Boarding through the gate positions should be fast. An average of seven minutes is assumed, although faster processing can easily be imagined with this particularly direct design.

Flight time is composed of takeoff and maneuver time plus time spent in cruise. V/STOL vehicles achieve flight conditions in very little time. The STOL aircraft spend about 10 minutes in takeoff and landing maneuvers. VTOL aircraft do without taxiing and cut this figure in half. On the other hand, cruise speeds are quite low. The STOL aircraft of our design cruise near 300 mph. The helicopters cruise even slower, 240 mph. Thus a 200 mile journey could take from

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1This is the design performance as presented in Appendix B.
40 minutes to an hour. Later designs can achieve higher speeds.

Additional flight time would be experienced by a traveler if he is on a multistop trip. An intermediate landing would add a second increment of maneuver time plus an additional seven or eight minutes of turn around time. The 15 minute penalty is paid only in multi-stop flight operations. Multistop operations are used if the daily frequency would be too low (4 to 7 flights per day) using single load flights.

Upon arrival at his destination the passenger should be able to disembark in three minutes and achieve his final destination with roughly another 35 minutes of egress time.

A tally of the travel times above might look like this for the typical 200 mile trip:

- 35 min. access time (average)
- 10 min. boarding plus disembarking
- 5 min. aircraft maneuver time
- 60 min. flight time (200 miles)
- 12 min. intermediate stop maneuver and turnaround
- 35 min. egress time (average)

Total 2 hours 37 minutes

The last influence on the time is the frequency of service, i.e., the convenience of departure times. An artificial index of this convenience was chosen. Half the average headway was added to the total time to give the time performance of V/STOL service. Thus for 6 flights in a 16 hour day the timeliness delay is $\frac{1}{2} \cdot (16 - 6) = 1.33$ hours. If two demands can be combined into a single route, twice the daily frequency could be maintained and timeliness would improve to
.67 hours. Adding this to the total travel time produces a total trip time of 3 hours 17 minutes.

The data of the preceding sections is repeated in Appendix I, Standard Conditions for 1985 QVTOL studies.
3.0 THE PERFORMANCE OF V/STOL TRANSPORTATION SYSTEM

3.1 The Concept of a Product Possibilities Function

Figure 3.1 illustrates the three dimensional surface which forms the product possibilities\(^1\) function for V/STOL transportation in the Northeast Corridor. It is a surface of "best" system performance measured by total trip time and cost. Notice as passenger volume is increased that average total trip time can be reduced due to increased frequency of service. Average total trip cost is also reduced as the cost of terminals is spread over more passengers.

Each point on the surface is a possible operating condition of some VTOL or STOL system. The surface was defined by cut and try. Each point on the surface is defined by a specific aircraft size and type and a specific set of terminals. Operating the same system at a traffic volume below that indicated by the surface will result in a loss. Operating at volumes above a given point on the surface, but still at the same trip time and cost, will produce a profit if the assumed load factor (60\%) is maintained.\(^2\)

The surface does not portray the performance of any single system. Each part of the surface is defined by the specific system which can perform "best" in that region. Best performance means carrying the minimum traffic volume at the stated cost and time without a loss. Thus the surface is a combination of STOL and VTOL systems both large and small. The aircraft type and size varies over the surface. The number of gates at each terminal

\(^1\) Although functionally similar to the economic concept of production possibilities, this new term refers to a different phenomenon. See Appendix E. There is no reason why the concept could not be extended to more dimensions to include performance characteristics such as noise exposure or ride pleasure.

\(^2\) The load factor could reasonably vary from 40\% to 70\%. The assumption of a constant load factor is only justified by the great simplification of the solution process that results. In essence we have "guessed" that system economics and consumer demand for seat availability always converge on a 60\% load factor as a reasonable compromise of cost and convenience.
Figure 3.1: Product Possibilities Function for a V/STOL Transportation System
and indeed the number of terminals can vary also. A minimum of 2 gates per terminal and 15 terminals was enforced.

The remainder of this section will be devoted to discovering which systems dominate the different areas on the surface. To do this horizontal cuts through the surface are made and the set of cost-time tradeoffs available at the constant passenger volume is graphed. These curves are called "isoquants". In order to fix specific numbers to the cost and time, a representative route was chosen\(^2\) at 200 miles. The volume on the route was such that 274 round-trip passengers a day represented a total of 20,000 trips on all the routes in the V/STOL system for the whole Northeast Corridor.

\(^2\) See Appendix F.
3.2 **Product Possibilities Function for VTOL and STOL**

3.2.1 **VTOL Performance**

Figure 3.2 is a graph of the performance choices for a helicopter based system carrying 20,000 passengers per day. Each point on the graph was developed using the methodology of chapter 2. The set of fifteen terminals was used to evaluate fixed costs. A specific volume of traffic was postulated and a vehicle size was assumed. The resulting unit costs and frequency of service at 60% load factor produced the points on the graph.

The area of the curve closest to the origin is of the greatest interest since this is close to present airline services. In this area one stop service by small to intermediate size aircraft performs best. At extremely low costs (and high times) nonstop service by larger aircraft is better. Also at very low times and high costs one stop service using very small aircraft is competitive.

The two small x's on figure 3.2 illustrate the effect of adding another terminal. The x's mark the system operation if a second Manhattan terminal is built on the east side. Both trip cost and trip time are worse. The unit cost goes up because the additional capital costs must be defrayed. Trip time goes up because the addition of eight new markets (from splitting up old markets) has reduced the market size on each route, thus reducing the daily frequency. The savings in access time and cost are not enough to compensate under stated assumptions.¹ The minimum number of terminals (arbitrarily 15) was best for all V/STOL systems studied.

¹ If access costs are more important, or if they are larger due to congestion, these conclusions can be reversed.
Figure 3.2: Isoquant for VTOL (helicopter) at 20,000 trips per day representative route length of 200 mi. fifteen terminal network represented

- 27 -
3.2.29 **STOL Performance**

Figure 3.3 is the same drawing for the STOL system. Here the nonstop operations are everywhere better than multistop routings. This is because of the higher maneuver costs for STOL. Once again moderate size aircraft dominate the region near the origin.

3.2.3. **STOL and VTOL compared**

Figure 3.4 is an altogether different look at the 3-dimensional supply function. Here a slice has been made at an angle to both cost and time axes. The plane is determined by the point cost = $25, time = 3.5 hours, volume = 20,000 passengers and the line forming the volume axis. This plot shows that for all reasonable volumes VTOL service is better than STOL service. STOL is better only for extremely low time and extremely high cost operations at high volumes. Almost all of the surface is dominated by helicopter based systems.

Four general areas (A, B, C, and D) are suggested on the product possibilities function redrawn in figure 3.5. Except for extreme values of time or cost, the area is dominated by one-stop helicopter service using 40 to 80 seat aircraft.

If passenger volumes are high, and trip time is not as important as cost, a nonstop helicopter service is indicated using large vehicles.

If passenger volumes are high and times is of essence, a high frequency helicopter system using nonstops service is cheapest.

If passenger volume is extremely high and time is extremely important, a STOL system is best. At high volumes STOL port costs are low since they are shared among many people. In addition, large STOL aircraft designs tend to be relatively cheaper and faster than larger helicopters. Nonstop
service is indicated.

If passenger volumes are low or moderate and if there is a balancing of time and cost priorities, a service using a 40 to 80 seat helicopter is best. On longer flights the passengers would experience an intermediate stop.

Sneaking a look ahead, the demand forces us to look at the area inside line NEM. In this region a viable VTOL system can exist because the demand is available. Another way of looking at is that a less than 60% load factor is economic. We now turn our attention to forecasting the demand for an average market in the Northeast Corridor in order to pick the appropriate VTOL or STOL system.
Figure 3.3: Isoquant for STOL service at 20,000 trips per day representative route length of 200 mi. fifteen terminal network represented
Figure 3.4: Vertical Slice through Product Possibilities Function for V/STOL Service

- **ONE-STOP VTOL**
- **NON-STOP STOL**
- **DEMAND IN 1978**

**Graph Details:**
- **Y-axis:** Daily Traffic Volume (x 10^3)
- **X-axis:** Total Trip Time (Hours)
- **Color Legend:**
  - Black circle for **ONE-STOP VTOL**
  - Black triangle for **NON-STOP STOL**
  - Black circle with an open center for **DEMAND IN 1978**

**Axes Ranges:**
- **Y-axis Range:** 0 to 60
- **X-axis Range:** 2 to 7
- **Total Trip Cost (Dollars):**
  - 20 to 50
Figure 3.5: Intersection of Demand Surface on V/STOL Product Possibilities Function

REGION A: NON-STOP VTOL, LARGE AIRCRAFT
REGION B: NON-STOP STOL
REGION C: NON-STOP VTOL, SMALL AIRCRAFT
REGION D: ONE-STOP VTOL
POINT E: VOLUME = 23,500 TRIPS PER DAY

THE LINE N E M IS THE INTERSECTION OF THE DEMAND SURFACE FOR SOME YEAR ON THE PRODUCT POSSIBILITIES FUNCTION
4.0 THE MARKET FOR V/STOL TRANSPORTATION

4.1 Concept of Demand

The last two figures have included "demand" curves along with the product possibilities function for V/STOL transportation. These demand curves are developed from a demand surface that has much the same shape used in figure 3.1 to illustrate the product possibilities function. The demand surface reflects the maximum number of passengers that would be attracted from the existing air, rail, and highway modes to a new system. At each time and cost a specific volume of travelers prefers the new mode. As time and cost are reduced, these volume increases.

The demand surface is developed using a modal split demand model which compares the performance of a new mode to the existing performances to estimate the percentage of the traffic that will be attracted.

Any individual point on the demand surface marks the largest possible volume that could be attracted by a mode offering the stated performance. All the points below the demand surface represent possible operating conditions for a system offering this performance.

Constant volume "indifference" curves for typical demand in 1978 (as derived from Appendix G) are plotted in figure 4.1. The convexity of the demand surface is slightly less than that of the supply function.

4.2 Intersection of Demand and Product Possibilities

Figure 4.2 is a horizontal (constant volume) cut through both the product possibilities and demand surfaces. The curves are called an isoquant and an indifference curve respectively. The shaded area between
Figure 4.1: Total Demand for V/STOL Transport in the Northeast Corridor in 1978 (indifference curves)

NOTE: CURVES REPRESENT CONDITIONS WHICH WILL ATTRACT THE STATED DAILY TOTAL VOLUME OF TRIPS.
Figure 4.2: Product Possibilities and Demand for V/STOL Travel in 1978
15,000 trips per day
representative route length of 200 mi.
the two curves represents possible operating conditions. The points within the area are feasible from both a profit and a marketing viewpoint.

Figure 4.3 is the same graph, plotted at a higher volume. The isoquant for the STOL system has been included to show that there is no solution at this volume. For VTOL the shaded area is smaller, however another 5,000 travelers find the new service a desirable convenience.

As the volume level is increased points M and N more closer together until they form a single point. The demand and product curves are tangent at 23,500 passengers a day. This is a $24.00 trip with a time of 3.4 hours. A 60 seat helicopter flying multistop services is indicated.

Figure 3.5 illustrates in three dimensions the line formed by the intersection of the demand surface with the product possibilities. This line corresponds to the points M and N. Point E is the maximum possible equilibrium volume. Above this level no V/STOL system can match the existing demand without a loss when operating at 60% load factor.

The intersection point, E, is a characteristic of the market and system interactions. This point has been chosen as the statistic with which systems will be compared. Other intersecting points also could be compared. At higher costs, slower time, and lower volumes there is a point where distance in the direction of the cost axis between the product possibilities function and the demand surface is the greatest. This is the point of maximum profit per passenger. Near it are points of maximum profit as a percent of ticket price and as a percent of capital investments. If the ticket price can be raised enough, it benefits private enterprise to operate at higher frequencies and with smaller aircraft than exist at the maximum volume point.
Figure 4.3: Product Possibilities and Demand for V/STOL in 1978
20,000 trips per day
representative trip length of 200 mi.
The maximum volume point has been selected as a basis for measuring the system both because it is the clearest unique point and because it is the point usually considered in system planning studies. In any case it is a good representative of system operations.

4.3 Redefinition of the Vehicle for a Mature System

The next sections explore the behavior of the system near the maximum volume intersection. Before doing this, however, the ground rules are going to change: 1985 volume levels are going to be examined. In addition a new set of helicopters designed at the Flight Transportation Laboratory will be used. These vehicles were particularly designed to be quiet -- 82.5 pndb at 500 feet in take off and 70 pndb on the ground during cruise. The DOC's are presented in Appendix B. Quiet operating conditions are typical of acceptable new urban operations and would have been used for the STOL/VTOL comparison if appropriate STOL designs had been available. This new system is called a QVTOL system.

Using these ground rules changes the location of the maximum volume intersection point, point E on figure 3.5. The new intersection of product possibilities and demand is at 35,000 passengers per day. A 60 seat helicopter is called for, operating one stop routes.

Figure 4.5 illustrates the intersection of 1985 demand and QVTOL product possibilities at a volume of 35,000 travelers. The 80 seat vehicle is nearly as effective as a 60 seat vehicle.

\[1\] 1985 demands are 35% above 1978 demands. The indifference curves for the demand surface are presented in figure 4.4.
Figure 4.4: 1985 Demand

DEMAND LEVELS IN THOUSANDS/DAY

TOTAL TRIP TIME (HOURS)

TOTAL TRIP COST (DOLLARS)
Figure 4.5: Intersection of 1985 demand surface and QVTOL product possibilities function at volume*35,000 trips
4.4 The Nature of the Maximum Volume Intersection

The intersection of product possibilities and demand is a very shallow one, as can be seen in figure 4.6. Figure 4.6 is a vertical slice through the product possibilities and demand surfaces at the angle cutting through the optimum point. Any small perturbation of the cost of QVTOL service would result in a drastic change in the maximum volume that could be carried. Similarly any change in the demand function creates equally dramatic shifts in volume.

It is interesting to note that while the maximum volume can change quite radically, the operating conditions are nearly the same throughout. The minimum number of terminals, 16 for the QVTOL study, is still desirable, and a 60 seat vehicle can serve the market adequately over a wide range.

Figure 4.7 displays the product possibilities function at several volume levels. Between 5,000 and 20,000 travelers per day the system is barely creeping along. Terminals are severely under-utilized. Multistop service would be used on most routes. Above 50,000 travelers the terminals have costed themselves out and nonstop services have been implemented. Some savings result from the very small advantages of using aircraft over 80 seats capacity. Additional gate positions and eventually additional terminals allow the system to expand to carry quite large volumes before congestion sets in to increase unit costs.
Figure 4.6: Vertical Slice through Product Possibilities Function for QVTOL Service

- **NON-STOP QVTOL**
- **ONE-STOP QVTOL**
- **DEMAND IN 1985**
Figure 4.7: QVTOL Product Possibilities Function at various volumes (isouquants)
4.5 Variation of QVTOL System Parameters

4.5.1 Variation of QVTOL Performance: DOC

In Figure 4.8 the performance of a system employing aircraft with DOC inflated by 25% is compared to the standard QVTOL performance. The effect produces a marked change in the trip costs. The maximum equilibrium volume drops from 35,000 to 26,000. Most of this drop comes from the penalties of cruise costs. A 25% increase in takeoff costs alone has a very small effect since takeoff costs are relatively small originally.

4.5.2 Variation of QVTOL Performance: Processing Costs at Airline Levels

In Figure 4.9 the processing cost and time for each passenger has been altered from what is available through efficient terminal design and operation. Costs at airline levels are even more detrimental to operation than increased DOC. The maximum volume is only 23,000 trips per day. This is a good argument for separating a new short haul system from current airline operations. Spartan processing operations must be insured.

4.5.3 Variation of QVTOL performance: Changes in Capital costs

Once VTOL daily volumes exceed 20,000 trips, the importance of the capital investment costs is reduced dramatically. This is one advantage of VTOL systems, the "fixed" capital costs are the lowest for any high performance system. STOL systems, the next best, have

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1 Both costs and times were made 25% worse.
Figure 4.8: Effect of DOC on QVTOL Isoquant; volume=30,000 trips

DOC INCREASED 25%

BASE CASE
Figure 4.9: Effect of processing costs
QVTOL isoquant at volume=30,000 trips per day

PROCESSING COSTS AT AIRLINE STANDARDS

COST = $5.00 PER BOARDING
TIME = 0.33 HOURS

BASE

COST = $2.00 PER BOARDING
TIME = 0.167 HOURS
nearly twice the capital costs. For the 1980 - 1990 framework, and until
tilt rotor vehicles make both STOL and helicopters obsolete, the traffic
in the Northeast Corridor is best carried by the helicopter system. A
change in the capital costs of $\pm 25\%$ is barely noticeable, changing the
maximum volume point by only $\pm 4\%$.

4.5.4 Variation of QVTOL Performance: 1980, 1990 demands

The demand for travel does not affect the performance function
for V/STOL systems. Only the demand surface changes. This simple
analysis assumed the 1990 demand was 18\% greater than 1985 demand.
This can be done merely by changing the volume scale on the demand
surface. The shape is unaltered.

Table 4.1 lists the demand levels and the performance of a
QVTOL system for the years 1978 - 1990. The table highlights two
very important phenomena. First, a 60 seat vehicle is optimal over
a wide range of volumes. And second, as volumes increase, terminal
activity remains constant because fewer multistop flights are flown.
Thus a system built for 1978 is still optimal in 1990 even though travel
has doubled!

4.5.5 Variation of QVTOL Performance: Comparison with a Tilt Rotor

By 1985 it is entirely possible that a tilt rotor VTOL vehicle
would be manufactured to take the place of the conventional helicopter.
Information from tilt rotor designs performed at the Flight Transpor-
tation Laboratory as a continuation of the work of Ref. 6 was converted
to 1985 quiet tilt rotor design by ratioing the cost of noisy to quiet
tilt rotors by the factors available from the helicopter studies. This
method is crude, especially since the tilt rotor tends to be harder to quiet than the helicopter, but it was the only avenue available. The result was a vehicle with the following parameters:

Cruise speed is 400 mph
Cruise DOC is $0.585 per aircraft plus $0.00498 per seat
Takeoff DOC is $39.50 per aircraft plus $0.521 per seat
Takeoff and manoeuvre time is .054 hrs.

The tilt rotor can use VTOL terminals, but has a cruise speed and cost that approaches the performance of advanced STOL aircraft. A sacrifice in takeoff costs is made compared to helicopters. The performance of the quiet tilt rotor is compared to the quiet helicopter (QVTOL) system in Figure 4.10. Clearly the saving in cruise time and cost increases the capabilities of the system considerably. Indeed the maximum volume point is at 51,000 trips per day. The optimal vehicle size is still 60 seats, in spite of an altered cost structure for the DOC.

Table 4.2 compares the performance of the quiet tilt rotor with the quiet helicopter system. Tilt rotor vehicles offer essentially the same service at reduced cost. A 60 seat tilt rotor is used nonstop to replace a 60 seat helicopter operating multistop routes.
Table 4.1  

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</tbody>
</table>

1 Actually these aircraft could not be in service before 1980.

2 Demand levels are indicative of relative market sizes only. For conversion to actual daily trips expected in the corridor, see discussion in appendix F.
PAGES (S) MISSING FROM ORIGINAL

Page 50 is missing.
Figure 4.10: Comparison of Quieted Tilt Rotor System with Quiet Helicopter isoquant at 35,000 trips per day

- ONE STOP TILT ROTOR
- NON STOP TILT ROTOR
- QUIET HELICOPTER

TOTAL TRIP TIME (HOURS)

TOTAL TRIP COST (DOLLARS)
Table 4.2 System Sizes for QVTOL and Quieted Tilt Rotor at Maximum Volume Optimum

<table>
<thead>
<tr>
<th></th>
<th>1985</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Demand level</td>
<td>216,000</td>
<td>256,000</td>
</tr>
<tr>
<td>(all modes)</td>
<td>QVTOL 35,000</td>
<td>QVTOL 44,000</td>
</tr>
<tr>
<td></td>
<td>TILT-ROTOR 51,000</td>
<td>TILT-ROTOR 66,000</td>
</tr>
<tr>
<td>Performance (at optimal Volume)</td>
<td>35,000 51,000</td>
<td>44,000 66,000</td>
</tr>
<tr>
<td>Number of Vehicles Used (2300 hrs per year)</td>
<td>139 168</td>
<td>176 219-164</td>
</tr>
<tr>
<td>Size (number of seats)</td>
<td>60 60</td>
<td>60 60-80</td>
</tr>
<tr>
<td>Average daily landings per terminal</td>
<td>90 88</td>
<td>76 114-86</td>
</tr>
<tr>
<td>Ticket Cost (1970 dollars)</td>
<td>$18.2 $14.1</td>
<td>$16.8 $13.8-12.3</td>
</tr>
<tr>
<td>Frequency on representative route</td>
<td>8.9 8.7</td>
<td>7.5 11.3-8.5</td>
</tr>
</tbody>
</table>
5.0 CASE STUDY OF 1985 QVTOL

5.1 Introduction to the Case Study

Up to this point a simple market model employing demand and product surfaces has been used to predict the aggregate V/STOL activity that could exist in the Northeast Corridor. The model has suggested that a 16 terminal VTOL system using 60 seat vehicles would work. To test this prediction a market by market study of the corridor was made. This study involved creating and scheduling a network to serve the specific intercity markets in the corridor. The tool that allowed this to be done is called FA-4.

FA-4 is a fleet assignment model created at the Flight Transportation Laboratory (ref. 17). This model assigns aircraft to specific routes in such a way that the daily frequency for each market is built up to attract passengers. FA-4 will continue to schedule flights as long as the income from the additional passengers attracted to the service covers the expense.

The procedure in FA-4 is economically different from the processes used in the product possibilities and demand study above. In the product possibilities function the ticket price was built up from the costs incurred. During this process the capital (i.e. long term) costs of the terminals was shared among the daily passengers. In FA-4 the ticket price (or price structure, for each market has a different ticket price) is fixed. The model attempts to schedule service wherever the costs are below the revenues.

Since most of the costs used in FA-4 are the same as used in the product possibilities function, the result should be nearly identical. The FA-4 solution will differ because: 1) it will seek
to maximize profits -- i.e. operate below the maximum volume at a point where the distance between demand and product possibilities surfaces is large\(^1\), and 2) it will not include the capital costs. This study of the individual markets can only confirm that at the given ticket price, capital costs can be recovered from excess operating profits.

In practice the information available from an FA-4 case study is more than just a check of a possible operating point of the market model. It is possible to consider a mixed fleet of aircraft. FA-4 can decide to use a small and expensive aircraft in order to get the frequency up in a particular market. Alternatively by proper route selection several services can be combined on a single flight and a larger aircraft employed. FA-4 can answer two questions that the market model analyses cannot: 1) what would happen if several different aircraft were simultaneously available to the system? and 2) what route patterns develop?\(^2\)

Thus the purposes of the case study are threefold:

1) to check predictions of the product possibilities function analysis by a study of individual markets,

2) to examine the attractiveness of a mixed fleet,

3) to observe developed route patterns

---

\(^1\)Strictly speaking the FA-4 solution is interested in the cost distance multiplied by the volume. The distance is between the product possibilities surface without capital costs and the demand surface at the established ticket price.

\(^2\)The conclusion in favor of multistop routes in the market model hints at the answer to this already.
5.2 Performance as Defined in the Market Model

In Chapter 4 the product possibilities function was studied in the neighborhood of the maximum volume optimum. This point defined the largest volume of traffic that could be carried by any VTOL system without a loss. In 1985 this point was defined at 34,610 passengers per day carried by 60 seat helicopters. It is this point on the product possibilities function that will be tested in the case study.

A glance at figure 5.1 will reveal that most of the formulations used in this market model are also used in the FA-4 system analysis. The IOC's that were used to build up the ticket cost are used as marginal operating costs in FA-4. The DOC's used to describe the aircraft operations are also considered marginal expenses in the system analysis. Only the capital costs do not enter into the FA-4. If the optimum volume point in the market model is valid, the case study will have a total excess of ticket income over operating costs that will cover the fixed costs.

The work that went into evaluating the product possibilities function must be repeated for each city pair in the corridor for the case study. In the case study the whole network of markets, small and large, long and short, is examined. This means a specific distance, access, competition, and demands are necessary.

5.3 The Demand in each Market

The demand for VTOL service in each market is qualitatively illustrated in Figure G.1 Appendix G. This figure suggests that each additional daily service attracts progressively fewer passengers than the service before. The curve is developed by the same modal split demand model used to generate the demand surface in chapter 4. The competitive
modes' costs are the specific access and ticket costs for that city pair. The time is also the specific trip and access time by city. The line haul costs and times used the distance formulae of figure H.1. The frequency for the competitive modes is fixed. For the VTOL mode, frequency is varied to produce the demand curve.

The total demand for travel between any two cities is established from historical data. Table 5.1 lists the demands in 1978 for each city pair in the corridor. The 1985 demands are 35% higher.

This demand is splintered among the metroports in each city. Thus the New York - Washington market is split into eight separate markets among the six ports. Each port is treated as if it were a separate city.

For example consider the Manhattan west (JMW) and Washington Union Station (SUN) sites. JMW is closest to 25% of the New York trip origins. SUN is best for 75% of Washington traffic. Thus the JMW-SUN demand is 19% (25% of 75%) of the New York-Washington demand.

---

1 The point of inflexion must be eliminated for successful solution. It can be shown that the solution cannot be in the lower region for any single route.
Figure 5.1: Data Flow Between Market Model and FA-4

- Competitive Modes Performance
- Average Network Data
- FTL Helicopter Designs
- Product & Demand Market Model (Maximum Volume Optimum)
- V/STOL Doc

- DOC, times
- Aircraft
- Access costs, distance, market size
- Ticket price
- Number of terminals
- City by City Access

- Intercity Demand Generator
- Route Generator

- Intercity Distances
- DOC

- FA-4 System Synthesis

- Flight schedules
- Passenger traffic
- Aircraft usage
- Route selection
- Airport activities
Table 5.1  Intercity Demands

<table>
<thead>
<tr>
<th>City_pairs</th>
<th>distance (miles)</th>
<th>1978 2 way demand (1000's)</th>
<th>daily frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYC-BOST</td>
<td>187.1</td>
<td>12,001</td>
<td>BUS 27 CTOL 35 RAIL 13</td>
</tr>
<tr>
<td>BALT-BOST</td>
<td>359.4</td>
<td>511</td>
<td>22.5 14 4</td>
</tr>
<tr>
<td>-NYC</td>
<td>172.3</td>
<td>2,850</td>
<td>30.5 13 13</td>
</tr>
<tr>
<td>PHIL-BOST</td>
<td>268.5</td>
<td>1,849</td>
<td>26 24 4</td>
</tr>
<tr>
<td>-NYC</td>
<td>81.5</td>
<td>20,942</td>
<td>73 14 23</td>
</tr>
<tr>
<td>-BALT</td>
<td>91.1</td>
<td>2,584</td>
<td>13.5 15 22.5</td>
</tr>
<tr>
<td>WASH-BOST</td>
<td>395.8</td>
<td>2,466</td>
<td>BUS 27 CTOL 4</td>
</tr>
<tr>
<td>-NYC</td>
<td>208.8</td>
<td>12,114</td>
<td>46 55 13</td>
</tr>
<tr>
<td>-BALT</td>
<td>37.2</td>
<td>0</td>
<td>48 43 24</td>
</tr>
<tr>
<td>-PHIL</td>
<td>127.3</td>
<td>3,623</td>
<td>13.5 38 29</td>
</tr>
<tr>
<td>PROV-BOST</td>
<td>411.1</td>
<td>10,214</td>
<td>18 7 22.5</td>
</tr>
<tr>
<td>-NYC</td>
<td>151.6</td>
<td>2,092</td>
<td>24 9 13</td>
</tr>
<tr>
<td>-BALT</td>
<td>323.7</td>
<td>108</td>
<td>9 6 13</td>
</tr>
<tr>
<td>-PHIL</td>
<td>232.5</td>
<td>309</td>
<td>10.5 6 4</td>
</tr>
<tr>
<td>-WASH</td>
<td>359.7</td>
<td>352</td>
<td>10.5 10 4</td>
</tr>
<tr>
<td>TTN-BOST</td>
<td>242.0</td>
<td>47</td>
<td>2 2 10</td>
</tr>
<tr>
<td>-NYC</td>
<td>54.9</td>
<td>11,469</td>
<td>5 4 15</td>
</tr>
<tr>
<td>-BALT</td>
<td>117.4</td>
<td>106</td>
<td>5 0 5</td>
</tr>
<tr>
<td>-PHIL</td>
<td>26.9</td>
<td>1,884</td>
<td>24 7 24</td>
</tr>
<tr>
<td>-WASH</td>
<td>153.9</td>
<td>251</td>
<td>10 8 8</td>
</tr>
<tr>
<td>-PROV</td>
<td>206.4</td>
<td>5</td>
<td>3 0 3</td>
</tr>
<tr>
<td>HRFD-BOST</td>
<td>92.0</td>
<td>5,646</td>
<td>12 9 0</td>
</tr>
<tr>
<td>-NYC</td>
<td>97.3</td>
<td>2,942</td>
<td>12 9 0</td>
</tr>
<tr>
<td>-BALT</td>
<td>268.6</td>
<td>141</td>
<td>4 6 3</td>
</tr>
<tr>
<td>-PHIL</td>
<td>178.4</td>
<td>805</td>
<td>6 6 3</td>
</tr>
<tr>
<td>-WASH</td>
<td>305.4</td>
<td>628</td>
<td>6 10 3</td>
</tr>
<tr>
<td>-PROV</td>
<td>63.6</td>
<td>1,153</td>
<td>8 18 8</td>
</tr>
<tr>
<td>-TTN</td>
<td>151.6</td>
<td>33</td>
<td>3 0 3</td>
</tr>
<tr>
<td>WILM-BOST</td>
<td>293.8</td>
<td>90</td>
<td>7.5 2 4</td>
</tr>
<tr>
<td>-NYC</td>
<td>106.7</td>
<td>1,710</td>
<td>5 1 5</td>
</tr>
<tr>
<td>-BALT</td>
<td>66.3</td>
<td>1,331</td>
<td>16.5 0 13</td>
</tr>
<tr>
<td>-PHIL</td>
<td>25.3</td>
<td>6,278</td>
<td>24 3 24</td>
</tr>
<tr>
<td>-WASH</td>
<td>102.1</td>
<td>661</td>
<td>16 4 13</td>
</tr>
<tr>
<td>-PROV</td>
<td>257.6</td>
<td>28</td>
<td>3 0 3</td>
</tr>
<tr>
<td>-TTN</td>
<td>52.2</td>
<td>171</td>
<td>5 2 5</td>
</tr>
<tr>
<td>-HRFD</td>
<td>203.8</td>
<td>45</td>
<td>3 0 3</td>
</tr>
<tr>
<td>NEWH-BOST</td>
<td>124.5</td>
<td>850</td>
<td>12.5 0 13</td>
</tr>
<tr>
<td>-NYC</td>
<td>66.7</td>
<td>5,080</td>
<td>10.5 7 13</td>
</tr>
<tr>
<td>-BALT</td>
<td>238.2</td>
<td>525</td>
<td>21.5 1 5</td>
</tr>
<tr>
<td>-PHIL</td>
<td>149.7</td>
<td>411</td>
<td>23 2 5</td>
</tr>
<tr>
<td>-WASH</td>
<td>271.4</td>
<td>130</td>
<td>21.5 4 13.5</td>
</tr>
<tr>
<td>-PROV</td>
<td>87.1</td>
<td>358</td>
<td>3.5 0 13.5</td>
</tr>
<tr>
<td>-TTN</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-HRFD</td>
<td>35.4</td>
<td>2,980</td>
<td>5 4 8</td>
</tr>
<tr>
<td>-WILM</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the JMW-SUN market the competitive modes have the same frequency and speed as in all other New York - Washington markets.\textsuperscript{1}

However, the average access times to the competitive modes depends on which metroport's "subcity" is being considered. The distribution of travelers to subcities is listed in Table 5.2

A ticket price structure of $10.24 per trip plus $0.0482 per mile was established in the market model. Inserting this and the vehicle's speed into the modal split model defined the following demands among the sixteen metroports:

<table>
<thead>
<tr>
<th>Demand Description</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracity markets (zero demand)</td>
<td>9</td>
</tr>
<tr>
<td>Markets with less than five passengers/flight\textsuperscript{2}</td>
<td>31</td>
</tr>
<tr>
<td>Markets with 5 to 10 passengers/flight</td>
<td>11</td>
</tr>
<tr>
<td>Markets with 10 to 50 passengers/flight</td>
<td>54</td>
</tr>
<tr>
<td>Markets with above 50 passengers/flight</td>
<td>15</td>
</tr>
<tr>
<td>Total possible connections for 16 ports</td>
<td>120</td>
</tr>
</tbody>
</table>

\textsuperscript{1}Each metroport pair competes against the same bus, rail, auto, and airline services. The frequencies are included in Table 5.1.

\textsuperscript{2}Passengers are the maximum attracted to any additional daily service. This is the initial slope of the curve presented in Figure G.1.
Table 5.2  Division of City Demands Among the Metroports

<table>
<thead>
<tr>
<th>City</th>
<th>Metroport</th>
<th>Port</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>JNS</td>
<td>North Station</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>J28</td>
<td>Route 128</td>
<td>26%</td>
</tr>
<tr>
<td>New York</td>
<td>JMW</td>
<td>Manhattan west</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>JME</td>
<td>Manhattan east</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>LGA</td>
<td>La Guardia</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>EWR</td>
<td>Newark</td>
<td>16%</td>
</tr>
<tr>
<td>Washington</td>
<td>SUN</td>
<td>Union Station</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>WAS</td>
<td>National Airport</td>
<td>25%</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>SPC</td>
<td>30th Street Station</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>PNW</td>
<td>Suburban NW</td>
<td>26%</td>
</tr>
</tbody>
</table>

Notes:

1. Demands from Wilmington, Trenton, New Haven, and Providence are concentrated from J28, EWR, PNW, and WAS to city center ports since the markets are too small to receive service alone.

2. Any tendency of people to travel to a more distant metroport in order to take a more convenient flight will improve levels of service.
5.4 The Importance of Routes

Routes in short haul operations are not just flights from A to B. Multistop services are essential to efficient operation. Nonstop connections are mandatory only in heavily traveled markets. In light markets it is better to add fifteen minutes to the flight time for an intermediate stop if the services can thereby be offered at a healthy daily frequency.

The analysis of FA-4 chooses from a list of possible multistop routes those routes which best amalgamate demands. In this way the maximum frequency can be maintained and the largest number of passengers satisfied. Unfortunately, there are quite a few geometrically reasonable routes that can be created for the 80 markets considered. In some cases the markets are so large that nonstop service is the only possibility. For the other flights the possibility of having enough demand on each segment and of exchanging passengers at each stop must be considered. In the final analysis each market must be satisfied with a reasonable choice of routes rather than all possible connections.

Using these considerations the case study was made with a total of 40 possible nonstop routes, 108 possible one stop flights, and 12 two stop services. From this set the final solution was chosen.

In the market model the product possibilities function includes the cost and time penalties associated with these intermediate stops. In the case study the operating cost is increased, but the ticket price remains the same. Still, the passenger is assumed to find the multistop service less convenient; the time delay of a one-stop service causes only 90% of the nonstop demand to be attracted to a flight. For a two stop the figure is 80%.
5.5 Summary of Inputs to FA-4 Case Study

Demand curves stating traffic generated as a function of frequency were input for markets among all the metroports.

Routes that were attractive were input with the aircraft DOC's and travel times\(^1\) for each aircraft considered.

Indirect operating costs proportional to passenger boardings, passenger miles, aircraft departures, and aircraft miles were included to allow calculation of costs.

Using this information, (details in Appendix J), FA-4 put aircraft on specific routes in order to earn demands by frequency of service. The objective was to create the largest possible contribution to the support of fixed (capital) costs.

---

\(^1\)The times were used to limit daily utilization.
<table>
<thead>
<tr>
<th>Total Daily Activities</th>
<th>Market Model</th>
<th>Network Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$ 635,000</td>
<td>$ 495,000</td>
</tr>
<tr>
<td>% DOC</td>
<td>75%</td>
<td>63%</td>
</tr>
<tr>
<td>% IOC</td>
<td>12%</td>
<td>15%</td>
</tr>
<tr>
<td>% Capital Costs for terminals and excess profits</td>
<td>13%</td>
<td>22%</td>
</tr>
<tr>
<td>Capital Costs</td>
<td>$ 83,000</td>
<td>$ 83,000</td>
</tr>
<tr>
<td>Excess Profits</td>
<td>$ 0</td>
<td>$ 28,000</td>
</tr>
<tr>
<td>Aircraft needed</td>
<td>165</td>
<td>107</td>
</tr>
<tr>
<td>Passengers per day</td>
<td>34,600</td>
<td>27,200</td>
</tr>
<tr>
<td>Average trip length</td>
<td>200</td>
<td>197</td>
</tr>
<tr>
<td>Average stage length</td>
<td>100</td>
<td>170</td>
</tr>
<tr>
<td>Average landings per terminal</td>
<td>120</td>
<td>55</td>
</tr>
<tr>
<td>Number of markets served</td>
<td>81</td>
<td>82</td>
</tr>
</tbody>
</table>

"Market Model" is the optimum volume point for 1985 QVTOL system.

"Network Model" is the FA-4 case study using identical ticket pricing and aircraft as the optimum volume point, but seeking to maximize profits.
5.6 Results of Case Study of 1985 QVTOL

5.6.1 Covering costs from Revenues

The above sections have outlined the ground rules for converting the analyses of the demand and product possibilities surfaces to the specific case study performed by FA-4 modeling. The optimum volume point and the results of the FA-4 study are compared in Table 5.4.

The case study revealed that a system operating at the ticket price suggested and using the aircraft suggested could cover all costs from revenues. The FA-4 solution resulted in a smaller number of passengers because it was not constrained to remain on the minimum profit surface of the product possibilities function. Nonetheless, the agreement is satisfactory. The excess profits would be consumed in offering service up to the maximum volume level.

Independent confirmation of the product possibilities' predictions reinforces the validity of the work presented in the first four chapters of this report. The simple market model analysis can be trusted to predict the performance of more detailed studies.

5.6.2 The Value of a Fleet of Mixed Aircraft Sizes

Case studies were run with a choice of vehicle seating capacities. A 120 seat vehicle was added to the 60-seat craft already available. A second run introduced the option of a 20-seat craft as well.

A glance at Table 5.4 reveals that nothing dramatic occurred. The addition of aircraft options allowed a more economic carriage of passengers, as expected. Excess profits increased slightly. At the
### Table 5.4  Daily Activities for Combinations of Aircraft Sizes

<table>
<thead>
<tr>
<th></th>
<th>60 seat QVTOL</th>
<th>60 and 120 seat QVTOL</th>
<th>20, 60, and 120 seat QVTOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>$496,000</td>
<td>$444,000</td>
<td>$453,000</td>
</tr>
<tr>
<td>Excess Profit(^1)</td>
<td>$28,000</td>
<td>$32,500</td>
<td>$47,500</td>
</tr>
<tr>
<td>Passengers</td>
<td>27,200</td>
<td>24,500</td>
<td>25,100</td>
</tr>
<tr>
<td>Aircraft needed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 seat</td>
<td>-</td>
<td>-</td>
<td>23</td>
</tr>
<tr>
<td>60 seat</td>
<td>107</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>120 seat</td>
<td>-</td>
<td>31</td>
<td>45</td>
</tr>
<tr>
<td>Maximum Landings at any single airport</td>
<td>130</td>
<td>81</td>
<td>86</td>
</tr>
<tr>
<td>Number of Markets served</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 times per day</td>
<td>13</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>3-7 times per day</td>
<td>42</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>7-15 times per day</td>
<td>20</td>
<td>16</td>
<td>26</td>
</tr>
<tr>
<td>15+ times per day</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>82</td>
<td>76</td>
<td>79</td>
</tr>
</tbody>
</table>

\(^1\)The cost of gate positions for 120 seat aircraft is greater than that for 60 seat aircraft.
same time, the maximum profit point dropped to a lower volume level. The conclusion must be that additional aircraft sizes are not extremely valuable contributions to system economics.

A deeper examination of Table 5.4 reveals a singular phenomenon. In the case study using 20, 60, and 120 seat vehicles, no 60-seat aircraft were employed at all. This suggests that a combination of two vehicle sizes approaches the performance of an infinite selection of sizes. This is in part due to a weakness in the modeling; in real life there is difficulty maintaining both utilization and load factor when several aircraft are used on the same route.

5.1.3 Prediction of Average Stage Length

The product possibilities study suggested that most passengers would travel on one-stop flights. It was predicted that the average stage length would be closer to 100 miles than 200 miles. In the case study, this prediction was overthrown. The average stage length was 170 miles.

Nonstop services were offered between most points. The vast majority of multistop services connected through New York City. In this way, service to thin markets was established at healthy frequencies.

This network pattern occurred because of the particular structure of the Northeast Corridor markets. The thin markets lie in between the dominant Washington to New York and New York to Boston traffic flows. Travelers between these major cities support such high flight frequencies that nonstop service is mandatory. Such routings as Washington-Trenton-New York are unacceptable because the Washington-New York traffic does not need the Trenton traffic to make the frequency of service high.
5.4 Development of a Minimum Daily Frequency

Early studies of the intersection of demand and product possibilities surfaces revealed that no service could be feasible from both profit and market considerations unless the frequency was above four flights a day. The case studies of multiple aircraft fleets revealed the same phenomenon. If the frequency using a 60 seat vehicle was above five flights a day, 120 seat vehicles were substituted to gain economic efficiency. Few services were offered below three flights a day. See Table 5.5.

Figure 5.2 illustrates that near five flights per day, the time savings from adding further flights diminish. For short-haul markets, the minimum viable number of flights per day is near four or five. Otherwise, the service is basically not convenient.
Table 5.5  Daily Frequency in 1985 Case Study

<table>
<thead>
<tr>
<th>JNS</th>
<th>J28</th>
<th>JME</th>
<th>JMW</th>
<th>LGA</th>
<th>EWR</th>
<th>SBL</th>
<th>SPC</th>
<th>PNW</th>
<th>SUN</th>
<th>WAS</th>
<th>SPV</th>
<th>TTN</th>
<th>HRD</th>
<th>SWL</th>
<th>NHV</th>
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<tbody>
<tr>
<td>JNS</td>
<td>xx</td>
<td>A</td>
<td>30</td>
<td>19</td>
<td>20</td>
<td>9</td>
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<td>9</td>
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<td>4</td>
<td>B</td>
</tr>
<tr>
<td>JME</td>
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<td>xx</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>7</td>
<td>14</td>
<td>4</td>
<td>30</td>
<td>9</td>
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<td>xx</td>
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<td>9</td>
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<td>6</td>
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<td>B</td>
<td>9</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>xx</td>
</tr>
</tbody>
</table>

Case study with 20, 60, and 120 seat vehicles available

Codes:

A  Intracity route, no demand. No services used intracity links
B  Service prohibited between these points. The demand transfers to other city terminals
C  No demand exists between these points. No services were offered
D  Demand existed, but it was uneconomical to serve it
Figure 5.2: The Importance of 5 flights per day in service attractiveness

**TOTAL TRIP TIME (HRS) INCL WAIT**

- **CRITICAL REGION**
- **AVERAGE WAIT TIME**

**FLIGHT AND ACCESS**

**DAILY FREQUENCY**

- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14

**MARKET PENETRATION CURVE**

- **CRITICAL REGION**

**PASSENGERS**

- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14

- 69 -
6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

The preceding chapters have traced the following steps:

1) A methodology for developing V/STOL system's performance in total trip time and cost was presented.

2) The performance of various systems was graphed. Advanced helicopters were found to be more attractive than STOL aircraft. A relatively small number of terminals (15) was found to be best.

3) The characteristics of the demand function were brought into the analysis. In 1978 as many as 23,500 passengers per day could be served over the whole corridor.

4) The demand and performance in 1985 were examined. Although the maximum volume that could be carried was quite sensitive to variations in performance and demand, a 60 seat helicopter was best over a wide range of operating conditions. Passenger processing costs were found to be very important.

5) The performance of the 60 seat 1985 helicopter at the maximum volume level was translated into conditions for a complete case study of the Corridor's markets.

6) The case study confirmed the feasibility of a viable 1985 QVTOL service.

At the beginning of this report the analysis was limited to considerations of technical performance. From this viewpoint a quiet 60 seat helicopter serving 16 metroports in the Northeast Corridor is the best choice. The choice was made considering only the ability of different designs to provide an attractive service to the passenger at cost. If non-technical considerations create any great objections to the chosen
system, it would be appropriate to evaluate the penalties for alternative choices. We now mention some of the other factors which must be considered in selecting a new transportation system.
6.2 **Community Acceptance**

Community acceptance of a transportation system is loosely associated with the amount of *noise* impact, the perceived fear of crashes, and the perceived business impacts.

The noise impact of helicopter operations is as small as any other form of operations. Helicopters can reach the lowest levels of absolute noise output. They also have small noise footprints. Since noise levels tend to rise with vehicle size, the choice of a moderate size vehicle is fortunate. A complete study of the impact of noise distributed in frequency and location is necessary to delineate the full implications of different systems, but the recommended system has no critical drawbacks.

The picture is not so clear with respect to safety. It is true that helicopters tend to pass higher overhead than STOL vehicles, causing less fear. But the public safety record to date is not enviable. Just the same, helicopters with engine-out hover capability may well be safer than STOL aircraft in city center operations. There will be a community acceptance problem in safety, and it may or may not reflect the actual safety performance.

The businessmen in a given community probably prefer small airports. Business is easier if good transportation is at hand; yet a large airport will cause undue local ground congestion. More than sixteen metroports would be urged from a purely business oriented community acceptance viewpoint.

In general, the chosen system comes out well in the most important consideration of community acceptance -- noise impact.
6.3 Ease of Implementation

The proposed short-haul air system is almost totally new. Very little is shared with current air systems. This allows for the system to escape the institutional inefficiencies that make conventional short-haul air uneconomic. However, this "newness" causes a problem in implementation. The system is not a gradual adaptation of current air travel.

On the other hand, a VTOL system can start with limited facilities and very small ground investments. It is relatively easy to initiate service from non-airport sites using VTOL.

The problem of inherent separateness of VTOL operation is compensated for by its basic flexibility.

6.4 Flexibility of Operation

All air services are intrinsically flexible because they need no right-of-way on the ground. VTOL is the most flexible because it has the smallest ground commitments. The small VTOL ports can be most easily located within existing activity patterns. The technologically optimal system can not be faulted in this respect.¹

¹When designing in the face of uncertainty, adaptibility may be more important than design performance.
However, the concept of flexibility has other dimensions. A VTOL system is economic only where land costs are high. A STOL system would have wider applicability to travel markets that exist outside of the crowded corridors. VTOL vehicles are essentially dedicated to city-center operations.

Thus, the proposed system is flexible in its ability to serve metropolitan environments, but not so widely suited as STOL operations to a spread of population densities.

6.5 Over-all Capital Investment

The time staging of capital investment is a consideration in choosing a new transportation system. A VTOL system would involve investment in vehicle technology before it could become economic. This investment falls heavily on the manufacturers, who are little able to absorb it. This hurts a VTOL system more than a STOL system, because VTOL vehicle costs are higher. This fact, coupled with the limited market types, may prevent the development of the system.

The investment in terminals can be slow and is by nature small for a VTOL system. It is less likely that the chosen system would be infeasible for a lack of metroport construction money.

Fortunately, one size vehicle is suited to quite a range of market sizes.
6.6 Connections to Existing Transportation Systems

The proposed VTOL system does not rely heavily on existing airport sites. Because of this, the short-haul system does not serve to connect long-haul passengers with their flights as well as it might. If the demand for this connecting service were significant services could be initiated at airports. Without these additional flights, the proposed VTOL system lacks connectivity with long-haul air service.

On the other hand, the metroports are quite accessible from rail, transit and superhighway transportation links.

6.7 City Center Congestion, Changes in Importance of Access

Performance and cost considerations urged a small number of metroports. The cost of adding more metroports to the system is not negligible. Still, if city center congestion places an increasingly high value on ease of access, a VTOL system based on a small vehicle should be able to respond more easily than any other system. In the present design, the major contribution in reducing access inconvenience is the use of well located metroport sites rather than in the number of sites served.

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1 Connecting traffic was not included in demand predictions for the Northeast Corridor.
6.8 Summary of Results

A study of the V/STOL systems performance over a wide range of operating volumes and cost and time performance showed that a helicopter based system was superior to a STOL based system. This is true because of the increased terminal investment costs for STOL, because of STOL's greater maneuver times, and because of the reduced convenience of STOL metroport sites. Table 6.1 compares the operations of two comparable systems, STOL and VTOL, at the greatest level of traffic the systems can attract. A typical cost breakdown is illustrated in figure 6.1. VTOL provides better service to more people at this maximum equilibrium volume.

A study of a quiet helicopter system revealed that in 1985 36,000 people a day can be served by a sixteen terminal system. A route map developed from a case study is presented in figure 6.2.

6.9 Conclusions

1) Future air transport systems can serve short-haul transportation needs.

2) A system based on a 60 seat helicopter can produce the best service at the least total cost.

3) Such a system has no unusual problems adopting to non-technical considerations.
Table 6.1 Comparison of VTOL and STOL

<table>
<thead>
<tr>
<th></th>
<th>VTOL Helicopters</th>
<th>2000' STOL</th>
</tr>
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<tbody>
<tr>
<td><strong>1978 Demands</strong></td>
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<td></td>
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<tr>
<td>Maximum Passengers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attracted per day</td>
<td>23,486</td>
<td>12,494</td>
</tr>
<tr>
<td>Representative Trip</td>
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<td></td>
</tr>
<tr>
<td>Cost</td>
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<td>$34.66</td>
</tr>
<tr>
<td>Time</td>
<td>3.41 hrs</td>
<td>4.10 hrs</td>
</tr>
<tr>
<td>Total Land Based</td>
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<td></td>
</tr>
<tr>
<td>Investment (million)</td>
<td>$268</td>
<td>$406</td>
</tr>
<tr>
<td>Aircraft DOC</td>
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<td></td>
</tr>
<tr>
<td>($ per Passenger Trip)</td>
<td>$10.59</td>
<td>$13.59</td>
</tr>
<tr>
<td>Average Access Distance</td>
<td>8.2 miles</td>
<td>9.31 miles</td>
</tr>
</tbody>
</table>
Figure 6.1: Relative Costs for STOL and VTOL over the same 200 mile Market (typical)

**TICKET PRICE**

**OVERHEAD AND TAXES**

**AIRCRAFT COSTS**

**TERMINAL COSTS**

**ACCESS AND EGRESS**

**TRAVEL TIME**

**FLIGHT TIME**

**AVERAGE WAIT TIME**

**ACCESS, EGRESS, AND PROCESSING**

*COSTS FOR 60 PASSENGER AIRCRAFT (THE OPTIMUM SIZE IN EACH CASE)*
Figure 6.2: Route Segments Flown in 1985 case study with 60 seat helicopter
REFERENCES


5. Passenger Demand and Modal Split Models, DOT, NECTP-217 (1969)


10. A Location Study for a System of V/STOL Airports in the Boston Metropolitan Area, O'Doherty, J.D., MIT Civil Engineering thesis (1968)


16. Hearings before the House Ways and Means Committee, Administration's Proposal on Aviation User Charges, October 1969


APPENDIX A

Air Traffic Control for Short Haul Systems
Appendix A:  Air Traffic Control for Short-Haul Systems

Short-haul air systems will be different from current long-haul operations in three basic ways: cruise will be at lower altitudes, cruise will be in straight lines, and landings will involve curvilinear high angle approach paths.

Cruise Flight

V/STOL operations will probably occur at low altitudes (10,000 feet for STOL; 5,000 feet for VTOL) in order to avoid existing traffic and to achieve economic flight profiles. Current STOL aircraft need an automatic gust alleviation system to improve ride quality, since low wing loadings aggravate the normal problems of turbulence at these altitudes. VTOL vehicles are less sensitive to gusts, but have some vibration problems. These vibrations can be reduced by design of rotor and fuselage and by bifilar energy absorbers.

Flight paths will probably be direct, or in any case will not follow the high altitude airways. This means that the aircraft must have area navigation abilities.

Terminal Areas

Both STOL and VTOL landing patterns can fit within the structure of current terminal area traffic patterns. Curved high angle approach paths will be followed. Although there will be less congestion on current approaches if short-haul traffic has its own system, the metropolitan area traffic monitoring load will not decrease.

The curved approach paths will be used in city center operations to reduce noise impact. STOL aircraft must be able to make cross-wind landings on elevated runways in all weather conditions. This requires considerable performance from both the aircraft and the landing system.
For VTOL, the landing system requirements are much less demanding. The aircraft is flown using a "velocity control system" -- a black box which automatically corrects for acceleration due to gusts while allowing the pilot to control velocity. In poor weather the aircraft will be guided to a hover at a point above the landing pad. The final touchdown will be made relying on ground lights.

Cost

The cost of the ground based part of both enroute and terminal area air traffic control is borne by the FAA. Currently a 4.8% ticket tax supports these operations. The average cost is very roughly $33 per flight hour plus $21 per departure for current commercial operations. A 60-passenger V/STOL would contribute some 80% of these costs from ticket taxes. There are arguments for these costs going either up or down. In either case the relief of CTOL congestion probably makes any small cross subsidy of V/STOL worthwhile.

FTL aircraft design studies made in reference 6 revealed that the cost of electronic gear in the aircraft was not an unusually expensive part of DOC. As a consequence, no special treatment of the electronics costs was made in this study.

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1 The other 3.2% of the ticket tax supports the airport development trust fund services. The split is for 1970 operations as presented in Reference 18.
APPENDIX B

Aircraft Performance
Appendix B: Aircraft Performance

Theoretical aircraft were used to represent vehicle performance in this study. Minimum cost for a 100 mile trip was sought in the design process. The use of "paper" aircraft designs allowed for consistent evaluations to be made across the full range of aircraft sizes. Because of variations in design mission and costing, industry data showed no clear patterns.

Three distinct aircraft were examined. Unpublished designs similar to those of reference 6 were used for STOL aircraft. These designs represented 10 year advances over 1965 abilities. A set of helicopters were designed using identical assumptions. In chapter 5, an advanced (prototype in 1975) quiet helicopter was used for parametric studies. The Lockheed-New York Airways formula (reference 12) employing 12 year depreciation, 2300 hours annual utilization, and labor rates 25% above the 1967 figures was used for DOC's.

The traditional DOC curve could be converted to linear form employing a cost per seat take off and a cost per seat mile (figure B.1). This was true for all the aircraft that were examined.

Within the accuracy of the designs, the cost per aircraft take off and the cost per aircraft mile could be represented as linearly dependent on aircraft size (figure B.2). This is the case for three reasons: First, certain vehicle parts and weights have minimum sizes. Second, crew costs are expressed as a fixed salary plus an increase proportional to vehicle gross weight. And third, maintenance costs are expressed in terms of dollars per operation plus dollars per aircraft pound.
Block times were calculated from vehicle design performance. The maneuver time was derived from the zero distance intercept of block time vs. distance plots. Take off and landing for all helicopter designs included 500' of vertical path. This reduces the noise footprint. Both STOL and VTOL vehicles had very low maneuver times. Some variation with size was found, see Figure B.3.

Minimum turnaround times were assumed as in Figure B.3 also.

STOL vehicles were designed for 200 mile range. No noise considerations were taken into account.

Competitive VTOL vehicles were designed for the same range. Once again noise was not a factor.

Additional characteristics of the designs included low weight furnishings suitable for short trips, wide aisles, and at least two boarding doors for each forty seats in order to speed passenger movements. The helicopters could hover with one engine out. The basic design is that of reference 6.

Details of an 80 seat STOL design
Configuration: 4 engine straight wing turboprop STOL
Cruise Speed: 350 mph at 20,000 feet
Field Length: 1800 feet
Range: 200 miles
Capacity: 80 passengers
Crew: 2 pilots, 2 stewardesses
Cost: $2,400,000
Weights: gross weight 51,000 lbs., weight empty 30,000 lbs.
Wing loading: 50 lbs/sq ft
Engine specifications: 2,233 shp; SFC: .55 lbs/shp-hr; horsepower weight: 5.31 hp/
Fuel burned in 100 mile trip: 1475 lbs.; block speed: 196 mph
Configuration: tandem rotor helicopter, four truboshats cross coupled
Cruise speed: 237 mph at 5,000 ft.
Field length: 0
Range: 200 miles
Capacity: 80 passengers
Crew: 2 pilots, 2 stewardesses
Cost: $2,900,000
Weights: gross weight 50,000 lbs. Empty weight: 30,000 lbs.
Rotor: 6 blades; 90 ft diameter; solidity: .058; disc loading: 4 lbs/sq ft
Engine specifications: 5,438 shp; SFC: .55 lbs/shp-hr; horsepower weight: 6.0 hp/lb
Fuel burned in 100 mile trip: 1140 lbs; block speed: 211 mph

Details of Advanced 80 seat QVTOL design
Configuration: 4 engine tandem rotor helicopter
Cruise speed: 223 mph
Field length: 0
Range: 300 miles
Capacity: 80 passengers
Crew: 2 pilots, 2 stewardesses
Cost: $5,600,000
Weights: gross weight 74,000 lbs, Weight Empty 51,500 lbs
Rotor: 6 blades; 90 ft diameter; solidity: .208; disc loading: 6 lbs/sq ft
Engine specifications: 10,289 shp; SFC: .40 lbs/shp-hr; horsepower weight: 9 hp/lb
Fuel burned in 100 mile trip: 1650 lbs; block speed: 183 mph

The quiet helicopter was designed for a 300-mile range.\(^1\) Costs are presented in Figure B.4. Noise on the ground during cruise was 70 pndb. Take-off noise at 500 feet is roughly 82.5 pndb. The noise source considered was the vortex noise. While vortex noise is the dominant noise in present helicopters, quiet operations may well make other noises critical.

\(^1\) A 2% increase in DOC would be expected for 400 mile range capability. 400 mile range was allowed in the FA-4 case study.
An aircraft making 95 pndb of noise at 500' is audible over a vast land area. A vehicle making 82.5 pndb at 500', which sounds about half as loud, is heard over a much smaller area. Figure B.6 compares the land areas where operations could be heard at each of these levels. A contour for a quiet STOL vehicle has been included for comparison.

Figure B.6 shows how important it is to reach low noise levels. The quietest helicopter could be as low as 75 pndb at 500'. A complete later study of helicopter design for minimum noise is presented in reference 18.
Figure B.1: Conversion of DOC to Linear Format

**DOC FOR FORTY PASSENGER VTOL, TYPICAL**

- **CONVENTIONAL DOC FORMAT**

**DOC CONVERTED TO LINEAR FORM, SAME DATA**
Figure B.2: DOC Comparison for Similarly Designed 1978 STOL and VTOL Aircraft

STOL:
- $64 + $0.57/seat
- $6.40 + $0.05/seat

VTOL:
- $21.60 + $0.375/seat
- $2.16 + $0.035/seat
Figure B.3: Takeoff, Maneuver, and Turnaround Times

- STOL 0.179 HOURS
- ALL VTOL 0.03 HOURS + 0.000167 HOURS/SEAT
- STOL & VTOL 0.12 HOURS + 0.0002 HOURS/SEAT
Figure B.4: DOC Comparison for Quiet Helicopter and Tilt Rotor for Similar 1985 Designs

**Tilt Rotor**
- TILTR: $39.50 + $0.521/seat

**Helicopter**
- QVTOL: $22.00 + $0.49/seat
- TILTR: $39.50 + $0.521/seat

**Dollars per Aircraft Takeoff**

**Dollars per Aircraft Per Cruise Mile**

QVTOL: $.63 + $.0108/seat
TILTR: $.585 + $.00498/seat
MAP OF BOSTON BEDROOM COMMUNITIES WITH NOISE CONTOURS FOR VTOL TAKEOFF FROM ROUTE 128 AND MASS TURNPIKE INTERSECTION

LEXINGTON

ARLINGTON

BELMONT

WALTHAM

WESTON

WATERTOWN

MAS S PIKE

NEWTON

BROOKLINE

WELLESLEY

NEEDHAM

STOL CONTOUR

CONTOUR FOR 82.5 PNDB AT 500 FEET

CONTOUR OF AUDIBILITY FOR 95 PNDB AT 500 FEET

AUDIBILITY IS 60 PNDB (BACKGROUND NOISE LEVEL)

SCALE OF MILAGE

1 2 3

0
APPENDIX C

City Access Costs & Times for all Modes
Appendix C: *City Access Costs & Times for all Modes*

The cost in time and money to access line haul transportation is a major part of trips within the Northeast Corridor. This section details the methodology followed in assessing access costs for V/STOL as well as train, bus, and air modes.

The proper inputs for the modal split model employed in this study are the average trip time and cost for all the passengers who might use a particular V/STOL terminal.\(^1\) Thus it is necessary to allot a fixed catchment area to each terminal. This is not practically correct; a person might go to either of two nearby V/STOL terminals depending on which has the most convenient flight or whether he is headed north or south. Nevertheless the use of a fixed catchment area is a great simplification and is acceptable in an average sense. The task is to calculate the access costs to each of the modes: rail, air, bus, and V/STOL, averaged over all the travelers in a V/STOL terminal catchment area.

In order to do this the access distance to the closest terminals is calculated for roughly a score of geographic divisions within a city. A 15\% penalty is charged to non-suburban travel. The demand from each division is then assigned to the catchment area of the closest V/STOL terminal. At the end the access distance to each mode is averaged over all

---

\(^1\) Appendix D outlines the methodology of terminal site choice.

\(^2\) As provided in the DeHavilland report (reference 14) or estimated from map information where data is unavailable.
the divisions in a catchment area. Per mile times and costs are applied to this distance to determine access costs.

Per mile costs are difficult to estimate. Travelers use varying mixtures of access means (i.e., car, taxi, transit, limousine) at varying access distances. It would seem from both actual data and professional estimation that travel costs can be approximated by a linear formula (cost = a + b\cdot distance). While this is not very accurate for specific trips in known conditions, it is not inappropriate for average trips in a future city transportation environment. By combining linear costs for each access means with estimates of which means are used at varying distances, a generalized access cost and time can be plotted. The procedure is outlined below:

Automotive Costs: In the city a car can be presumed to cost $.06/mi. to drive. To this must be added a parking charge that varies with the length of the trip as well as the location. Furthermore only a fraction of the people park. For a two day trip with parking at $3.00 a day and only a quarter of the people parking\(^1\), parking charges are $.75 per access. The other 75% of the people must be "dropped off" at the terminal, doubling the mileage of the access trip. FTL data suggests that cars are shared in such a way that only 71% of the costs should be born by a single traveler. Combining these characteristics car access costs are $.53 + $.0745/mi.

\(^1\)The standard percentage from reference 4.
**Taxi Costs:** Taxi fares are around $.55 + $.60/mi. To this must be added a tip (15%/passenger). Then the tab must be shared among the passengers according to the likelihood of occupancy for taxicabs. Following these rules, which result in an individual paying 89% of the fare, cab costs are $.40 + $.55/mi.

**Transit:** Transit costs (except for express transit, which is similar to limousines) are subsidized by individual cities. A fare of $.20 + $.04/mi was considered representative.

Needless to say, taxis are favored only for short distances and automobiles and limousines are used for longer trips. FTL report R68-7 (ref. 9) deals with this access mode split for airports. From figure 4 of reference 9 we get the following table:

<table>
<thead>
<tr>
<th>Access Mode</th>
<th>Distance in miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>5 10 15 20 28</td>
</tr>
<tr>
<td>Taxi</td>
<td>44 35 26 17 8</td>
</tr>
<tr>
<td>Limousine</td>
<td>12 17.5 23 28.5 34</td>
</tr>
</tbody>
</table>

Data corrected to 100%

Using this information and the characteristics of travel by car, taxi, and limousine above, trip cost vs. distance was plotted in figure C.1. The value for CTOL is $1.50 + $.105/mi.
Figure C.1: Access Costs to CTOL Airports
For access to bus and rail, public transit plays a major role. No comparable data on modal split versus distance is available. However some meager facts do exist. Reference 4 provides the access to selected bus terminals and to Union train station in Washington:

Access Mode

<table>
<thead>
<tr>
<th>Access to:</th>
<th>TAXI</th>
<th>CAR</th>
<th>TRANSIT</th>
<th>WALKING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington (train)</td>
<td>45%</td>
<td>22</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Corrected to 100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selected (bus)</td>
<td>25</td>
<td>12</td>
<td>59</td>
<td>1/4</td>
</tr>
</tbody>
</table>

Access characteristics for taxi and car travelers were assumed to be represented by the access for CTOL and a weighted average with transit costs is made. The results are:

\[
\begin{align*}
\text{Bus} &= 0.67 + 0.062 \times \text{Distance} \\
\text{Rail} &= 1.05 + 0.079 \times \text{Distance}
\end{align*}
\]

These were considered acceptable.

In the case of V/STOL access no data exists. A reasonable average between rail and near distance CTOL was taken. This produced costs of $1.00 + $12\cdot\text{Distance}.

Travel time is a simpler matter. Car, cab, and limousine speeds are roughly the same (25 mph). Transit is usually about half:
<table>
<thead>
<tr>
<th></th>
<th>Boarding Delay (Minutes)</th>
<th>Driving Delay (Minutes)</th>
<th>Speed</th>
<th>Approximate % use by:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>Car</td>
<td>0</td>
<td>10</td>
<td>25 mph</td>
<td>50</td>
</tr>
<tr>
<td>Cab</td>
<td>5</td>
<td>10</td>
<td>25 mph</td>
<td>25</td>
</tr>
<tr>
<td>Limousine</td>
<td>15</td>
<td>10</td>
<td>25 mph</td>
<td>25</td>
</tr>
<tr>
<td>Transit</td>
<td>15</td>
<td>10</td>
<td>12.5 mph</td>
<td>0</td>
</tr>
</tbody>
</table>

To the driving delay must be added the terminal impedance:

Terminal impedance (average of access + egress)

<table>
<thead>
<tr>
<th></th>
<th>CTOL</th>
<th>V/STOL</th>
<th>Bus</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 (min.) (reference 4)</td>
<td>(Estimated from the FTL design work in reference 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTOL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V/STOL</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>12 (reference 4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>12 (reference 4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Taking a weighted average of driving times and adding terminal impedances, the access or egress times are:

access to | CTOL          | V/STOL                 | Bus       | Rail       |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 min. + 25 mph</td>
<td>17.2 min. + 23.5 mph</td>
<td>33 min. + 17.5 mph</td>
<td>29.5 min. + 21.8 mph</td>
</tr>
</tbody>
</table>

1 The terminal impedance is included in the trip time calculations for V/STOL, so it has been subtracted out here. See section 2.3.

- 1 0 2 -
APPENDIX D

Discussion of Metroport Location Methodology
Appendix D: Discussion of Metroport Location Methodology

The problem of V/STOL access time is both intriguing and disappointing. On the one hand, fixed costs of additional terminals and increased aircraft operating costs can be balanced against savings in access cost. On the other hand, time savings from increased numbers of metroports are not dramatic.

Several sets of metroports were considered for Washington, New York, Philadelphia, and Boston. In addition, a choice of locations in the smaller cities of Wilmington, Trenton, Baltimore, New Haven, Hartford, and Providence were investigated. From these studies the variation of access time in the corridor with number of metroports presented in figure 2.3 was developed. Variations of access time with metroport cost were not represented in the final performance function, since cost considerations forced STOL terminals to airport sites, and VTOL costs were not heavily dependent on land prices.

The study that led to the final selection of terminals can best be illustrated by discussion of the case history of the typical city pictured in figure D.1. We shall call the city Oz. Oz has a train and a bus station in the CBD (central business district) and Oz International Airport to the south.

Potential V/STOL travelers include all the trips originating within the dotted boundary to the greater Oz metropolitan area. This excludes fringe area travelers and those using V/STOL as the tail end of a long-haul trip at Oz International Airport.
Figure D.1: Typical City in the Corridor: Oz
The location of the first metroport anywhere within the metropolitan area produces very much the same average access time (reference 7). The choice of VTOL south would be good, since its location at a node in the highway system is advantageous.

This advantage, however, would not appear in our access methodology.

If the River Flumen presents a real impediment to travel, the addition of VTOL north will knock the equivalent of two miles off the average access distance for the area. In New York, for instance, the Hudson River costs as much to cross as five miles of open road. For most cases, the additional site will only reduce the average access distance by a mile or so.

For a smaller city only a single site can be justified. Although STOL might be able to operate out of the CBD VTOL site, costs drive it to the nearby airport. VTOL could either use the city center location if there is a good site, or move out to VTOL south.

For a large city, a terminal would be located at the VTOL CBD site to provide the large city center market very small access costs. Reduction to small inconveniences may have a disproportionately high influence on perceived ease of travel. Unfortunately this factor did not enter the costing methodology. One or two secondary metroports would be located outside of the city center. The cost of land for STOL drives these locations to existing airports. VTOL tends to be closer in, providing some small savings in access time.

Using these methods, feasible locations were chosen in each city on the basis of city by city information some of which did not influence the mathematical performance. A list of possible locations is presented in Tables 1.1 and 1.2.
APPENDIX E

The Market for Transportation Services
Appendix E: The Market for Transportation Services

The product possibilities function is a surface of constant profit for the operator of a V/STOL system. All the cost minimization tradeoffs have already been made\(^1\), and the operator is willing to function at any point on the surface using one or another of the combination of aircraft, terminals, and routings available to him.

The surface used in this study is an approximation of the level of profit a government regulation agency would approve. Points above this surface represent higher profits. Since the market for transportation is multidimensional, and since dollar cost is only part of one of these dimensions, it is possible to enjoy excess profits even in a seemingly "competitive" situation.

It takes all three dimensions -- volume, time, and costs -- to characterize the output of transportation activities. A simple enumeration of the number of seats is not sufficient. What is demanded by the market is a level of service, which is characterized by seats, time, and cost. (Other dimensions such as reliability, availability, comfort, etc., have been ignored in this simple formulation.\(^2\)) Thus the output of the system is characterized by a three-dimensional surface.

There are two reasons why the dimension of time had to be added to the study. First of all, the conversion of time to cost in the traveler's evaluation of a service was variable depending on the existing levels of both. And, secondly, the conversion has a different position dependence

---

\(^1\)By varying the combinations of aircraft type, number of terminals, routings, etc. This is a study of production possibilities.

\(^2\)The effects are lumped into the mode specific appeal factors of the modal split model.
for the system operator. Since time could not be "costed", consistently
over different times and since the value of time conversion was not the
same for aircraft and passenger, a new dimension had to be added to the
problem.

The adding of this time dimension drastically alters the nature
of the intersection of profit and market forces. The condition that the
volume of production at least equal the volume of sales is no longer
sufficient to determine the operating point. As was seen in section 4.2,
the intersection of demand forces and product possibilities is a set of
points. Operation above the product possibilities surface means excess
profits. Operation below the demand surface means that there are people
who would benefit from the system who have not been served.

Any point in this intersection set is a possible operating
condition. Profit motives urge serving lower volumes with smaller
aircraft and higher frequencies. This is where the income most exceeds
the cost. Social benefit motives suggest serving the maximum possible
volume of travelers. The final resting place for the solution process
depends on the relative strength of corporate and governmental influences.
APPENDIX F

The Choice of a Representative Route
Appendix F: The Choice of a Representative Route

The studies comparing STOL and VTOL performance in 1978 and examining the performance of quiet helicopters in 1985 were made using the concept of a representative route. The demand volume and the length for this route were carefully chosen so that performance on this route reflected ability to perform in all the markets in the corridor. This section describes the choice of size for the route.

Initially, a route length of 125 miles was chosen. This was the distance that resulted from dividing the total intercity miles traveled between the ten cities involved by the number of trips on all modes. The market size (demand) was then determined from Figure F.1. This is a plot of the number of significant markets developed among a varying number of terminals.

This number of markets was divided into the total demand for travel to predict the representative demand. For the original 15 terminal cases, 321,000 people were shared among 73 markets to produce 2,200 one-way travelers per day. The addition of a 16th terminal creates 8 new markets (by splitting up the old ones) and reduces the representative market size to 1,980 people.

Using the original combination, 321,000 people and 125 miles, studies were made for the maximim equilibrium volume for quieted helicopter operations in 1978. Then the performance at these volumes was used in an analysis by FA-4 of the complete system. This analysis followed the lines of the later one described in Chapter 5. The result in terms total system performance was compared to the prediction of the market model using the representative route:
The degree of agreement, particularly in revenues, was better than expected. However, it was clear that the average route length should be increased to 200 miles and the market correspondingly reduced to 200,000 people. It was quickly found that so many smaller markets had been eliminated from service that a further 20% reduction in total trip demand was appropriate. After this first iteration, the representative market was 200 miles with a total of 160,000 people to be shared among 73 markets.\(^1\) This was the basic representative route used in the discussion presented throughout the study of 1978 systems.

By the same analysis, in 1985, 216,000 people are shared among 81 routes.

---

\(^1\) at this rate, 274 people on the representative route would represent a total volume of 20,000 passengers per day on V/STOL. The competitive modes could carry the rest of the 1,100 daily trips each way in each market.
MARKETS = (PORTS - 6) \times 8.17

Number of Valid Markets vs Number of V/STOL Ports in the Northeast Corridor

Range of Interest

Number of Markets with at Least Five Passengers Per Flight

Number of Ports in the Corridor
APPENDIX G

The Modal Split Demand Model
Appendix G. The Modal Split Demand Model

A modified version of the model developed by NeuveEglise (ref. 11) was used to predict V/STOL market share. It is essentially the same as the DOT models for the Northeast Corridor of reference 5.

The problem of measuring service to a whole market is a difficult one. Each traveler has a different local origin and destination, a different accessibility to each mode, a different value for his time and money, and a different opinion of the amenities of each mode. Furthermore there is significant amount of correlation between the several factors. In short, the market does not lend itself to statistical reconstruction.

The best compromise so far has been to employ a relatively simple trip impedance model using average values for trip cost, time, and appeal. The volumes of travelers are viewed as responding to the relative merits of the several modes. All variations such as proximity to access arteries, individual convenience of departure times, personal preferences for types of travel, and specific nearness to terminals are smoothed into an averaged curve.

To predict the V/STOL share of the travel between two cities, the V/STOL convenience (I) for all travelers in the cities is compared to the mean convenience of all the available travel modes:
V/STOL Market Share = \frac{I_{\text{VSTOL}}}{I_{\text{VSTOL}} + I_{\text{CTOL}} + I_{\text{BUS}} + I_{\text{CAR}} + I_{\text{TRAIN}}}

I = KT^\alpha C^\beta = \text{convenience}
K = \text{mode specific appeal factor}
T = \text{total trip time by mode}^1
C = \text{total trip cost by mode}

This formula predicts the market share of a new transportation service between two cities given the performance of the existing modes. The values of alpha, beta and the "appeal" factors K are constant. They were obtained from a regression analysis of 24 markets in the Northeast Corridor. The data from reference 4 for 1965 was used to obtain the following values:

\begin{align*}
\alpha &= -1.354 \\
\beta &= -1.298 \\
K_{\text{Car}} &= 3.91 \\
K_{\text{Bus}} &= 0.5355 \\
K_{\text{CTOL}} &= 1.589 \\
K_{\text{Train}} &= 1.
\end{align*}

The appeal factor for V/STOL was estimated to be $K_{\text{V/STOL}} = 1.3$, reflecting a level of service below that of the airlines but above that of the trains. This appeal could easily be as high as current aircraft service, and most certainly will be even higher during the years when V/STOL is a novelty.

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^1\text{Time is the sum of line haul, access, and a "waiting" time associated with daily frequency.}
The effect of sharing travel costs for automotive travel was arbitrarily lumped into the automotive appeal factor. However, the large appeal of automotive transportation is chiefly derived from such conveniences as having a personal car at the destination.

It is distressing to note that with this and all similar market share models, market penetration is handled poorly. V/STOL service does not cut deeply into the regular air service, as one would expect, but steals an equal percentage of each mode's passengers. This is not quite as upsetting as it seems at first. What the model really does is predict penetration of alternative modes into a basically automotive travel market. The process is essentially a curve fit.

This model will not be accurate over a specific route. For instance, a business-oriented city pair will have a market which values time above cost; while a pleasure market works the other way. All models calibrated on corridor-wide data share this weakness. However, the weakness becomes a strength in our use of the model to predict the generalized level of V/STOL activity over the whole corridor.

The final reservation about the market share model involves the use of "wait" time. The only way frequency is reflected in the system performance is in terms of the average waiting time for a flight. Studies show (reference 15) that if the passengers arrive when they desire to depart, without concern for schedules, and if the aircraft are scheduled to respond to demand peaks, the average waiting time is half the average headway. With frequent departures, waiting time and wasted time are the same. But at frequencies near four or five flights a day, travelers can
plan to make constructive use of the time between desired departure and the next scheduled flight. Thus, at low frequencies, the methodology may underestimate the market share.

**The Underlying Demand**

Only a limited number of cities were considered in this study. Most of the traffic in the corridor is between the four major cities: New York, Washington, Philadelphia and Boston. Traffic from people outside of the metropolitan area was considered negligible. In addition, traffic from towns in the corridor down to the size of New Haven was included. V/STOL traffic to smaller markets was not investigated. This does not imply that such travel should not be offered in the final system, but only that it is economically justifiable only on the basis of short-run marginal costs. Small markets do not contribute to the overhead of a V/STOL system.

The total trip demand between the ten major cities was used in the DOT studies of the Northeast Corridor, and was obtained from reference 5. The numbers used are listed in Table 5.1. For any individual market the demand for V/STOL travel was developed by applying the modal split model to these total demand figures. For the FA-4 case study the frequency of V/STOL service was allowed to vary, so that the demand was dependent on the frequency of service. Figure G.1 illustrates the resulting demand curve. The performance of the competitive modes is given in appendix H. Access times are explained in appendix C.

The demand surface used in chapter 4 was developed using the same modal split model. To generate the surface the performance stated by the
Figure G.1: Typical Market Share vs. Frequency for V/STOL
time and cost coordinates was compared to the performance of the competitive modes over the same representative route. The market penetration that could be expected by a V/STOL mode having the stated performance is applied to the total trip demand in the corridor to establish the number of passengers for the volume axis.
APPENDIX H

The Performance of Existing Competitive Modes
Appendix H: The Performance of Existing Competitive Modes

The performance of bus, rail, CTOL and automotive transportation was calculated for the modal split model. Trip time, trip cost, frequency of service, and access time and cost were needed.

Bus, car and rail travel times and costs were plotted against CBD (central business district) to CBD distances for the cities in the Northeast Corridor. The data used came from reference 4. In addition, aircraft travel times were similarly plotted from data in the 1970 OAG for noon flights. The resulting curves are presented in figures H.1.

Costs for 1965 travel were inflated by 21% to create 1970 costs. For CTOL, the fare structure used was $6.40/take off and $.057/mile plus an 8% ticket tax. Costs for auto include gas, oil, and tolls and are not shared by riders.

Average frequency1 for bus was determined by assuming a 3.3% market share and a 60-passenger bus at 70% load factor. For CTOL and train the values are chosen by comparing frequencies with bus frequencies in similar markets. Thus, bus frequency was 9 trips a day, CTOL 8 and rail was 7 trips a day. Cars, of course, have no waiting time (infinite frequency).

Average access distances2 are the average for the whole market considered, i.e., for all people in the ten cities' metropolitan areas.

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1 The average frequency was used in market study only. The actual frequencies listed in table 5.1 were used in conjunction with FA-4.

2 The average was used in market study only. See note above.
Table H.1  Performance of Competitive Modes in Northeast Corridor

<table>
<thead>
<tr>
<th></th>
<th>CAR</th>
<th>BUS</th>
<th>CTOL</th>
<th>TRAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Circle Speed</td>
<td>41.1</td>
<td>35.3</td>
<td>323.</td>
<td>43.7</td>
</tr>
<tr>
<td>Starting time</td>
<td>0</td>
<td>0</td>
<td>.31</td>
<td>0</td>
</tr>
<tr>
<td>Cost per mile</td>
<td>.0623</td>
<td>.051</td>
<td>.0615</td>
<td>.0741</td>
</tr>
<tr>
<td>Starting Cost</td>
<td>0</td>
<td>0</td>
<td>6.92</td>
<td>0</td>
</tr>
<tr>
<td>Access Cost&lt;sup&gt;1,2&lt;/sup&gt;</td>
<td>0</td>
<td>1.48</td>
<td>2.65</td>
<td>1.84&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Access time&lt;sup&gt;1,2&lt;/sup&gt;</td>
<td>.1</td>
<td>1.29</td>
<td>1.1</td>
<td>.95</td>
</tr>
<tr>
<td>Frequency&lt;sup&gt;2&lt;/sup&gt;</td>
<td>∞</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Mode Specific appeal&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3.91</td>
<td>.5355</td>
<td>1.589</td>
<td>1.</td>
</tr>
</tbody>
</table>

<sup>1</sup>To account for egress, double the figure

<sup>2</sup>Corridor average

<sup>3</sup>See Modal split model, appendix D, for explanation

<sup>4</sup>Erroneously run as $1.57 for the 1978 demand
Figure H.1: Line Haul Travel Times and Costs for the Competitive Modes in the Northeast Corridor
APPENDIX I

Standard Conditions for 1985 Quiet Helicopter (QVTOL) Studies
Appendix I: Standard Data for the 1985 Quiet Helicopter (QVTOL) Studies

All these figures are presented in detail elsewhere in this report. This appendix merely serves as a summary.

Network Data

16 terminals in 10 cities
Rent per terminal for land and access roads is $980,000/year
Rent for a pad and gate position for an 80-seat vehicle including upkeep is $193,400.
Rent for a pad and gate position for a vehicle having S seats is $64,400 + (S/80) · $128,000.
A minimum of 2 pads per metroport is required.
Network size is 8.17 · (16-6) = 81.7 markets
Total network flow is 216,000 people or 2,640 trips per market
Representative route length is 200 miles. Cruise distance is 206 miles.
Average access distance is 10 miles minus .12 mile per terminal = 8.08 miles

DOC Data

Assumed load factor is 60%
Aircraft speed is 237 mph
Cost per cruise mile is $.63 per aircraft plus $.0108 per seat.
Cost per take off, landing, and associated maneuvering is $22. plus $.49 per seat.
Time for above activities is 3.0 hrs. plus .000167 hrs. per seat.
Minimum turnaround time is .12 hrs. plus .0002 hrs. per seat
Turnaround cost is $6 per aircraft landing.
IOC Data

Stewards cost $8.40 per hour for the line haul trip time including boarding and intermediate stops. One steward for each 40 passengers.

Processing costs are $2.00 per passenger.
Ticketing, boarding and disembarking together form a total terminal occupancy time of .167 hours
Overhead is 22% of the total ticket price.
Tax is 8% added to the ticket price.
Parking income is $.39 per passenger.

Other Data

Average access cost is $1. + $.12 per mile = $1.97
Average access time is .292 hrs. + 23.5 mph = .636 hrs. 1

The performance of the competing modes, bus, CTOL, train and air is listed in appendix H. The demand model parameters are presented in appendix G.

For the 1978 STOL vs. VTOL comparison, the following changes were made:

VTOL
Cost per cruise mile is $.72 per aircraft plus $.00925 per seat
Cost per takeoff is $21.60 per aircraft plus $.375 per seat
Cruise speed is 240 mph
15 terminals were used
1978 demand was 160,000 trips per day for all modes

STOL
Cost per cruise mile is $.60 per aircraft plus $.0066 per seat
Cost per takeoff is $64 per aircraft plus $.57 per seat
Cruise speed was 310 mph

1double to account for egress.
Takeoff and maneuver time was .179 hrs.
15 terminals were used.
Average access distance was 9.31 miles
Cost per terminal for land, access road, runway, and taxiway was $1,770,000 per year (average).
APPENDIX J

Inputs to FA-4
Appendix J: Inputs to FA-4

FA-4 is a linear programming solution to the airline scheduling problem. The objective is to produce the greatest income from the excess of revenues over operating costs. The demand in each market is dependent on the frequency of service. For a description of the formulation of FA-4, the reader is referred to reference 17.

Ticket prices were established for each metroport pair (each market) from the formula:

\[ \text{ticket} = \$10.24 + \$0.0485/\text{great circle mile} \]

Operating costs for the aircraft were established from the data presented in appendix B for the QVTOL machines.

Indirect operating costs were developed from the data in the standard case in appendix I:

Cruise speed and stewards' hourly cost produced an IOC of \$.00161 per passenger mile.
An IOC of \$2.12 per passenger boarding was derived from the excess of processing costs over parking income. Included in this figure is stewards' hourly cost during boarding.
\$9.09 per aircraft departure covered ground handling and the cost of one steward during maneuver times.
No IOC costs were dependent on aircraft miles.
In all cases of both IOC and DOC, 28\% has been added to cover overhead.
Multistop routes were less attractive than nonstop services. A one-stop drew 90\% of the passengers a non-stop drew; a two-stop 80\%.