AMES GRANT

IN-05-CR

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COST CHARACTERISTICS OF TILT-ROTOR, CONVENTIONAL AIR AND HIGH SPEED RAIL SHORT-HAUL INTERCITY PASSENGER SERVICE

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May 1985

Research Grant No. NAG 2-305

Final Report to

Powered Lift Flight Investigation Branch, 237-11

National Aeronautics and Space Administration

Ames Research Center

Moffett Field, CA 94035

(NASA-CR-181421) COST CHARACTERISTICS OF TILT-ROTOR, CONVENTIONAL AIR AND HIGH SPEED RAIL SHORT-HAUL INTERCITY PASSENGER SERVICE Final Report (Pennsylvania Univ.) 113 p Avail: NTIS HC A06/MF A01 CSCL 01C G3/05

N87-29501

Unclas
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Acknowledgements

This research was supported by the National Aeronautics and Space Administration through University Research Grant No. NAG 2-305. This support is gratefully acknowledged, but implies no endorsement of the findings.

We wish to thank especially Mr. Thomas L. Galloway, of the Aeronautical Systems Branch of the NASA Ames Research Center, for his support of this research and provision of much of the information used in the study, and Mr. John P. Magee, formerly of NASA Ames, for his leadership in initiating the project.

SUMMARY

This report describes in detail the cost analysis done to support an assessment of the potential for a small (approximately 45-seat) tilt-rotor aircraft to operate in short-haul (300 miles or less) intercity passenger service. Anticipated costs of tilt-rotor air service were compared to the costs of two alternatives -- conventional air (represented by the DC-9) and high speed rail (represented by the Metroliner). Costs were developed for corridor service, varying key market characteristics including distance (between end point cities), passenger volumes (up to 1500 passengers per day in each direction), and minimum frequency standards. The resulting cost vs. output information can then be used to compare modal costs for essentially identical service quality and passenger volumes or for different service levels and volumes for each mode, as appropriate. Extensive sensitivity analyses are performed.

The final section of this report contains a brief comparison of the cost-output features of these technologies. Tilt-rotor is very attractive compared to high speed rail (HSR) in terms of costs over the entire range of volume. It also has costs not dramatically different from conventional air (CTOL) -- but tilt-rotor costs are generally higher. Thus some of its other advantages, such as the VTOL capability, must offset the cost disadvantage for it to be a preferred or competitive mode in any given market. These issues are addressed in the companion report which considers strategies for tilt-rotor development in commercial air service.

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SYMBOL	LIST OF DEFINITIONS
ACTI	The annual cost of fleet investment, $/yr.
AFH	Annual flight hours, aircraft hrs./yr.
AMB	Annual cost of aircraft maintenance burden, $/yr.
APRK	Annual cost for investment for aircraft parking area, $/yr.
APRKM	Annual cost for maintenance for aircraft parking area, $/yr.
AR	Bi-directional number of daily aircraft flights during peak periods, departures/peak periods-day
ASPT	Annual cost of assistant superintendant, $/yr.
ATAAC	Average cost per passenger (total cost), $/pass
ATALC	Average cost per passenger (total cost minus all fixed capital cost), $/pass
ATALCA	Average cost per passenger (total cost minus all capital cost), $/pass
BI	Total number of terminals in the system, terminals
BNSP	Annual number of passengers on system, passengers/yr.
BNTR	Number of aircraft or trains required for service on system, vehicles
BP	Number of base period hours each day, hours/day
BPHP	Bi-directional daily passenger volume during both peak periods, pass/peak periods - day
BPP	Bi-directional daily passenger volume during base period, pass/base period - day
BS	Annual cost of block station, $/yr.
BUTC	Bi-directional total car volume, cars/day
CAP	Bi-directional daily passenger volume, pass/day
CLEN	Annual cleaning expense for terminal , $/yr.
CM	Annual car miles, car miles/yr.
CMISC	Annual miscellaneous cost, $/yr.
CND	Number of cars needed for operation of service , cars
CRF	Capital recovery factor, $/$

DEFINITIONS

CTOL	Conventional take-off and landing aircraft (designation)
DFREQ	Total daily two-way frequency on system, departures/day
DM	Annual cost of direct maintenance, $/yr.
DME	Annual cost of maintenance for vehicles, $/yr.
DMWS	Annual cost of maintenance of way and structures, $/yr.
DO	Annual cost of division operators, $/yr.
DOFR	Daily two-way frequency on system during the base period, departures/ base period-day
DPFR	Daily two-way frequency on system during the total peak period (both morning and evening peak together), departures/peak periods-day
EP	Cost of electric power, $/yr.
FC	Annual cost of flight crews, $/yr.
FDI	Annual cost for flight deck investment, $/yr.
FDM	Annual cost for maintenance of flight deck, $/yr.
FO	Annual cost for fuel and oil, $/yr.
GA	Annual cost for gate area investment, $/yr.
GAM	Annual cost for maintenance of gate area, $/yr.
GFC	Annual general fixed cost, $/yr.
GTM	Annual gross ton miles, ton-miles/yr.
GVC	Annual general variable cost, $/yr.
HI	Hull insurance, $/yr.
HSR	High speed rail (designation)
NCAR	Number of coach cars in train of maximum length, cars
OAR	Bi-directional number of daily aircraft flights during the base period, departures/base-period-day
OCAP	Number of daily usable seats during the base period at the given specified load factor, seats/base period-day
OFR	Unidirectional daily frequency during the base period, departures/ base period-day
OHD	Base period headway, hr./departure
PCAP	Number of usable seats during the daily peak period hours, seats/peak periods-day

DEFINITIONS

PERC	Personnel cost at central office building, \$/yr.
PFR	Directional frequency during the daily peak periods, departures/ peak periods-day
PH	Number of peak hours during the day, hours/day
PHA	Annualized cost of the urban terminal passenger handling area, \$/yr.
PHAM	Annual cost for maintenance of terminal passenger handling area, \$/yr.
PHD	Peak hour headway, hr./departure
PHP	Number of passengers on system during each peak hour, pass/hr.
PPCUU	Cost per passenger mile (total cost considered), \$/pass-mi
PPRK	Annual cost for passenger parking area, \$/yr.
PPUUV	Cost per passenger mile (total direct cost considered), \$/pass-mi
PPWOV	Cost per passenger mile (total direct cost minus fleet investment cost), \$/pass-mi
SCAR	Number of snack cars on train of maximum length, cars
SFC	Annual suburban fixed cost, \$/yr.
SL	One-way stage length of link, miles
SMA	Annual cost of station master, \$/yr.
SMAIN	Annual cost for maintenance of terminal, \$/yr.
TAAC	Total annual cost for operation of aircraft system, \$/yr.
TALC	Total annual cost less all cost from capital expenditures not including vehicles, \$/yr.
TALCAV	Total annual cost less all cost from capital expenditures, \$/yr.
TAM	Total annual flight miles, miles/yr.
TAPRK	Total annual cost for aircraft parking, \$/yr.
TAROPA	Terminal expenditures not due to capital expenditures (all terminals), \$/yr.
TDOC	Total direct operating cost, \$/yr.
TER	Annual cost to upgrade track, \$/yr.
TERCA	Total annual cost for all terminals, \$/yr.
TERCE	Total annual cost for each terminal, \$/yr.

DEFINITIONS

TERCOS	Total terminal cost (passenger and capital expenditures), $/yr.
TEROPE	Terminal expenditures not due to capital expenditures (each terminal), $/yr.
TERPAX	Terminal cost for each passenger in system, $/yr.
TIOC	Total indirect operating cost, $/yr.
TMAX	Total number of seats on train of maximum length, seats/train
TMDO	Number of usable seats on a train of maximum length during the base period, seats/train
TMDP	Number of usable seats on a train of maximum length during both peak periods. seats/train
TRC	Annual cost of train crews, $/yr.
TSTAF	Total annual cost for terminal staff, $/yr.
TT	Total vehicle cycle time (from departure at point A until next departure at point A), hours
TUUC	Total annual cost, $/yr.
UAR	Directional daily aircraft volume during peak periods, departures/day
UBPP	Directional daily passenger volume during the base period, pass/day
UCT	Cars per train during the peak period, cars/train
UFC	Total annual urban fixed cost, $/yr.
UOAR	Directional daily aircraft volume during base periods, departures/day
UOCAP	Directional usable seat volume during the daily base period, seats/day
UOCT	Cars per train during base period, cars/train
UPCAP	Number of usable seats during the daily peak period, seats/day
UPHP	Directional passenger volume during the daily peak periods, pass/day
UTC	Directional car volume, cars/day
UTFREQ	Directional frequency on the link, departures/day

DEFINITIONS

UTIL	Annual cost of utilities for the terminal, $/yr.
UTSO	Annual cost for urban ticket sales operation, $/yr.
UUF	Annual fixed cost, $/yr.
UUV	Annual variable cost, $/yr.
UUVWOV	Annual variable cost excluding vehicle cost, $/yr.
UVC	Annual urban variable cost, $/yr.
VTOL	Vertical take-off-and-landing aircraft (designation)
YAS	Annual yard and switching cost, $/yr.

1.0 INTRODUCTION TO COST MODELS

1.1. OBJECTIVE

One basic criteria for acceptance of tilt-rotor aircraft into the commercial air system hinges on its economic feasibility. The potential opportunities for replacing existing technologies or creating new markets depend in part on how competitive tilt-rotor costs are. Therefore, models estimating costs vs. transportation output (passenger traffic carried and service quality) were developed for tilt-rotor technology and two other short haul intercity passenger transport technologies -- one representing conventional air and the other high speed rail. The following technologies were analyzed:

1. VTOL aircraft (with CTOL capability): 45 passenger tilt-rotor
2. CTOL aircraft: McDonnell Douglas DC-9-30
3. High speed passenger rail: electric Metroliner type trains

While other air and rail designs could have been used, resources limited the analysis to three technologies and these were judged to be good representations of their respective classes.

The costing procedures used conform to the respective modal industry standards. For example, the direct and indirect operating cost component categories of the air modes comply with those normally used by the airline industry. For the rail mode, the cost components are fixed and variable cost categories corresponding to the usual cost categories of that industry. Although the cost components are not directly comparable between the modes, various overall cost comparisons can be made with these models. The main focus of the comparison is on three separate average annual costs per passenger mile, which are based on the following overall costs:

1) Total cost: All costs incurred in providing the service (i.e. both capital cost and cost incurred by performing the service of moving passengers).

2) Total costs minus all fixed facility costs: Cost for maintenance of capital structures and facilities are still included in this cost.

3) Total cost minus all capital costs: This is the same cost as number 2 above except vehicle investment cost are now excluded.

The rationale for the use of total cost is clear; this represents the usual measure of cost that would actually be incurred by the operator of a service with the customary arrangements for cost responsibility in our society. Of course, this cost does not include externalities such as the costs of aircraft noise pollution or train-induced ground vibration. This is the most commonly used cost for comparison purposes, with other relevant factors such as externalities treated separately.

Total cost less fixed facility cost is calculated as well for two reasons. First, some persons argue that since road and air facilities are provided by government, financed partly out of general tax revenues, a useful mechanism by which to make all modal costs comparable is to delete fixed facility costs entirely. While this logic is fallacious for many reasons (e.g., road and air facility users do pay user fees covering at least part of the facility costs), such cost comparisons are often made and it is often useful in modal comparisons to ascertain whether or not the relative performance of modes would vary depending on the cost measure used. A second reason is that air facility charges are often far less than fully allocated costs (partly because of cross-subsidy allowed by surplus auto parking revenues, for example), and it is useful to ascertain what air carrier costs would be with "underpriced" airport costs; excluding all fixed facility costs provides a lower bound on this.

The third cost covers only operating (and maintenance) costs. These are of general interest for a variety of analysis purposes, probably mainly because they are often taken as a measure of short-run marginal costs.

1.2. METHODOLOGY

The specific objectives for each of the cost models include the following:

1. Investigate in depth the full cost elements associated with each of these intercity passenger modes of transportation and develop cost relationships for each of the major elements contributing to total cost.
2. Explore the variation in cost of providing transport service with each of these modes as a function of variations in the characteristics of the market to be served, such as total traffic flow or length of route.
3. Provide information on the sensitivity of cost within each mode to variations in the cost of components, especially those which are uncertain.

The general approach to the development of cost and performance models follows that described in the book E. K. Morlok, *An Analysis of Transport Technology and Network Structure*, 1970. Many of the relationships and parameters employed in this model are from the follow-up 1972 DOT report by Bolusky et al., on short-haul intercity passenger carriers, their costs and service characteristics, which was used extensively for this report. Much of the information directly applicable to tilt-rotor aircraft was taken from the 1975 NASA report, "Conceptual Engineering Design Studies of 1985 - Era Commercial VTOL and STOL Transports that Utilize Rotors." Considerable information applicable to the DC-9-30 was taken from the 1983 report "Aircraft Operating Cost and Performance Report." Additionally, much information was obtained from direct contact with individuals in the aircraft and rail passenger industries.

1.3. ASSUMPTIONS

In computing the levels of output associated with each technology certain assumptions were made. One major assumption was that passenger traffic volumes are equal in both directions on the link. This assumption cannot be altered unless major revisions are made to the model.

Most of the other assumptions can easily be altered by changing a single entry in the data file or program. These include the following, grouped by those pertaining to costs, service quality and capacity, and operations/technology.

Costs

1. All costs of building and maintaining the system are incurred by the operator. For CTOL aircraft, landing fees are charged but no additional costs were assessed for capital investment of runways and terminals. However, maintenance of these facilities are still applicable and were accounted for. For VTOL aircraft operations, it was assumed that a landing area and terminal area had to be constructed. However, it was assumed that no land had to be acquired. For the most part, VTOL aircraft were assumed to operate primarily from existing airports or from major activity centers where land would be made available. For the rail mode, it was assumed that existing urban terminals were being used, which represent a sunk cost.
2. The interest rate used is 15% per annum.

Service

3. Level of service characteristics are similar for each mode. The system consists of two nodes separated by a single link of varying stage length. There are no intermediate stops on the link, as all service is non-stop.
4. The operating day for a passenger system is considered to be 16 hours long. The day starts with the first departure of a carrier in the morning and ends with the last departure in the evening. Intercity passenger

traffic slacks off considerably during the evening hours and does not pick up until about 6 or 7 A.M. each morning. Two two-hour peak periods are assumed. These occur from 7:00 A.M. to 9:00 A.M. and again from 4:00 P.M. to 6:00 P.M.

5. Minimum headways in each direction are as follows unless noted otherwise: peak period: 1 hour; base period: 2 hours.

6. Snack and/or beverage service and lavatory facilities are provided; seat pitch and width are similar and only coach seating is used.

7. The number of peak hour passengers equals 10% of number of daily passengers. The basis of this assumption is found in the demand studies section of the main report of the 1972 DOT report. It appears that an average of 10% of the number of daily passengers travel in both peak periods combined.

8. The maximum average load factors for the cost model computation are assumed to be 50% for base period operations and 80% for peak period operations. These figures were chosen as representative of travel flows in short haul intercity corridors, and represent maximum load factors in this analysis. Load factors vary with the time of the day, but do not vary with the stage length.

9. It is assumed that the service is provided 365 days a year.

Operations

10. The average cruise speed for the VTOL aircraft was assumed to be about 260 mph , for the DC-9-30 aircraft about 325 mph.

11. The capacity for the tilt-rotor aircraft is 45 passengers and for the DC-9-30 aircraft, 115 passengers.

12. Rail train capacity is varied to suit passenger loads, up to a maximum of 10 cars. Train maximum cruise speed is 120 mph, with the average speed being 100 mph. Rail line length is assumed to be 14% longer than the great circle (air) distance, reflecting average U. S. rail circuity.

13. Turn-around times were determined by research performed in the 1972 DOT report. In determining turn-around time, certain specified services were considered to have been performed on the vehicle. Service common to all vehicles during the time they are at the terminal include passenger debarking and embarking, baggage handling (air mode only), passenger compartment cleaning, and vehicle fueling. The minimum turn-around times used for the air modes were 20 minutes at each terminal, and the minimum time for rail was one hour.

1.4. COST AND RELATED DEFINITIONS

Fixed and Variable Cost; In the context of this report fixed costs are considered to be long run fixed costs and include capital expenditures for items such as buildings and runways. Short term contractual commitments such as labor requirements, wages and salaries, and maintenance, are defined as variable costs. Variable costs include all costs other than fixed costs. It is assumed that vehicles can be bought and sold relatively easily, and therefore their costs are included as variable costs.

Direct and Indirect Cost; In the airline industry costs are typically divided among direct and indirect operating expenses. Direct cost are those costs directly related to operating the aircraft. These include the cost of the aircraft, hull insurance, flight crew, fuel and oil, direct maintenance, and maintenance burden. Indirect cost usually include those costs described above as fixed cost. These include items such as terminal investments, runway investments, and the maintenance of these facilities. Basically all cost associated with services performed on the ground are included in this category.

Capital Recovery Factor: The capital recovery factor estimates the annual or periodic equivalent of a monetary investment. The annual percentage of the investment that is to be assigned to each asset determined by its expected life (n), scrap value (s), and the rate of return (r). In this analysis the scrap value for equipment and structures is assumed to be zero so the formula for calculating the capital recovery factor is simplified to the following equation:

$$\text{Capital Recovery Factor (CRF)} = \frac{r(1+r)^n}{(1+r)^n-1}$$

<u>Fleet Requirements</u>: For the purpose of this analysis it is assumed that vehicles may be bought or sold at will, so vehicle costs are considered part of variable costs. The system operator is required to have the correct number of vehicles to satisfy demand. A 10% addition was made to the fleet to represent the maintenance reserve.

Vehicle requirements for each of the technologies considered were computed from formulas derived by Morlok. Morlok described two cases or situations for calculating vehicle requirements: (Morlok, 1967, pp. 79-80).

<u>Case I</u> : $TT / 2 \leq PH$

Number of vehicles required for bi-directional service equals:

$$2\ [(((TT)\cdot(OHD/PHD)) / (2\cdot OHD)) + 1]$$

<u>Case II</u> : $TT / 2 \geq PH$

This describes the more complicated circumstances where vehicle departures are more frequent during the peak period. The number of vehicles required for bi-directional service equals:

$$2[PH((OHD/PHD-1)/OHD)+(TT/2\cdot OHD)+1]$$

where

TT = round trip time of service (including both turn-around times)

PH = peak period of service in hours

OHD = base period headway

PHD = peak period headway

[ ] = the largest integer contained within brackets

2. THE VTOL COST MODEL

The VTOL cost model develops short haul system costs for a 45 passenger tilt-rotor aircraft. Costs are separated into two categories - direct operating cost and indirect operating cost. Direct operating cost encompass the following categories: fleet investment, hull insurance, flight crew, fuel and oil, direct maintenance, and maintenance burden. Indirect operating costs include: terminal construction, flight deck investment, terminal charges, aircraft parking, aircraft maintenance and engine overhaul base, central office building, terminal staff, and miscellaneous costs.

2.1. DIRECT OPERATING COST

Annual Cost of Fleet Investment

The annual cost of fleet investment equals the capital recovery factor times the total airplane investment. The capital recovery factor (CRF) equals .18448, where the capital recovery factor is a function of scrap value, rate of return, and expected life. Scrap value is expected to be zero (Roberts, 1969, p. 9, as referenced in Bolusky et al., 1972) after twelve years of normal airplane life (Hill, et al.,1971, p. 115, as referenced in Bolusky et. al., 1972). Total airplane investment equals the cost of vehicle equipment (air frame, engines, avionics, and spare parts) multiplied by the number of vehicles in the system.

The airplane investment was estimated at $9 million based on the 1974 approximation in Magee et al.(1975) at approximately $5 million for the baseline VTOL tilt-rotor with a $90/lb airframe cost. The 1974 estimate was updated to 1982 dollars by multiplying it by the appropriate consumer price index. The resulting \$9 million price tag was not considered out of line for a new aircraft of this size and technology.[1] Annual cost of fleet investment was calculated as follows:

ACTI = 0.18448 x \$9 million x BNTR

Hull Insurance

The annual cost of hull insurance is computed by multiplying the hull insurance rate by the aircraft flyaway cost less spare parts and by the number of aircraft in the system. The hull insurance rate used was 2% (Roberts, 1969 A, p. 13, as referenced in Bolusky et al, 1972).

Volume II of the 1972 DOT report gave flyaway cost for several aircraft. Based on this data an average value for flyaway cost less spare parts was estimated to be about 86% of the total investment cost for an aircraft. Therefore, the flyaway cost less spare parts was approximated to be about \$7.74 million. The annual hull insurance cost was calculated as follows:

HI = 0.02 x \$7.74 million x BNTR

Flight Crew

Annual crew cost is tabulated as the total number of flight hours times the cost of crew per flight hour. The crew consists of a pilot and co-pilot. An estimate for crew cost was given as \$80 per flight hour for a DHC-7 aircraft (DASH 7) in the 1972 DOT report. Since that aircraft is similar in size to the VTOL aircraft in this analysis, and since both aircraft require specialized pilot skills (i.e. one aircraft has STOL capability and the other one VTOL capability), it was assumed that their crew costs would be similar. The DHC-7 crew cost was updated to 1982 dollars by multiplying it by the appropriate cost recovery index

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[1] This statement is based on a conversation on January 17, 1985 with Ransome Airlines who quoted the price of this aircraft as \$7.5 million (the DASH-7 is similar to tilt-rotor aircraft in size and design).

for labor. The annual crew cost (FC) was estimated as:

$$FC = \$240 \times AFH$$

Fuel

The annual cost of fuel was determined for the tilt-rotor aircraft on a stage length basis. Annual cost of fuel was computed by multiplying the fuel consumption for each flight by the annual number of one way flights. Fuel consumption estimation for each flight was based on the mission profile tabulation for the aircraft, as presented in NASA Report CR-2544. Using the information from the mission segment analysis (Magee et al, 1975, p. 36) regarding cruise distances, a linear approximation for fuel was graphed as shown in Figure 1. An equation was formulated for the fuel consumption in pounds which was converted to fuel consumption in gallons. The fuel cost per flight was calculated by multiplying the number of gallons used by the cost per gallon of fuel. This cost was estimated at $0.95 per gallon (Air Transport World, July 1982). Annual cost for fuel was calculated as follows:

$$FO = \frac{(277 + 8.63 \times SL)}{6.5} \times (\$0.95/\text{gallon}) \times DFREQ \times 365$$

Direct Maintenance

The annual cost of direct maintenance consists of labor and materials. Table XXI in NASA Report CR-2544, estimated direct maintenance in 1974 dollars per seat mile as $0.0051. Labor cost was increased by a factor of 3 and materials by a factor of 1.8 to take into account 1982 price changes. The resulting direct maintenance cost was $0.0158 per seat mile. The annual direct maintenance cost was calculated as follows:

$$DM = \$0.0158 \times 45 \text{ seats/aircraft} \times \text{stage length} \times \# \text{ of flights}$$

Maintenance Burden

Maintenance burden is calculated as a percentage of the total annual cost of direct maintenance for labor and materials. Maintenance burden equals 60% of direct maintenance cost (Roberts, 1971, as referenced in

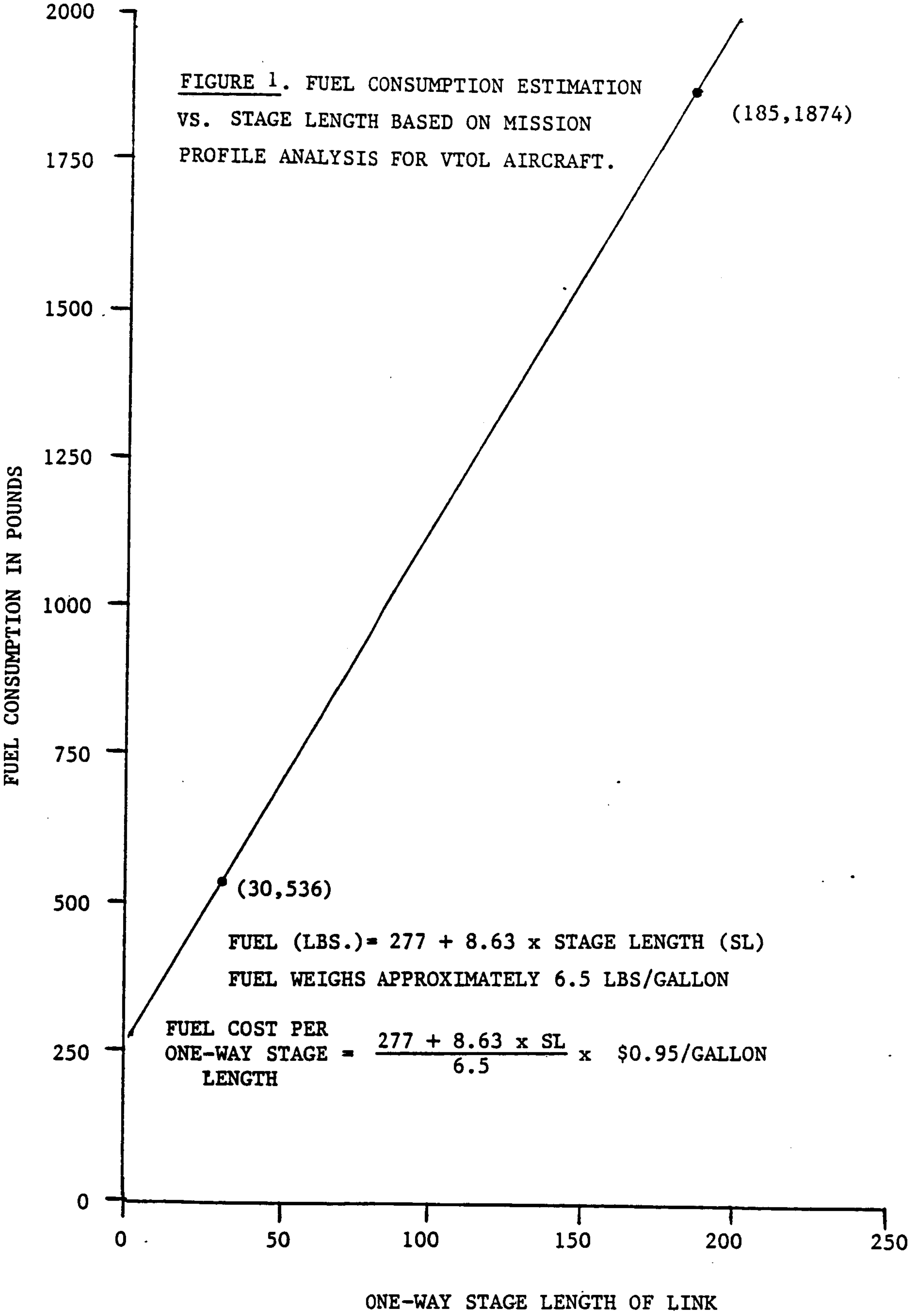

FIGURE 1. FUEL CONSUMPTION ESTIMATION VS. STAGE LENGTH BASED ON MISSION PROFILE ANALYSIS FOR VTOL AIRCRAFT.

FUEL (LBS.) = 277 + 8.63 x STAGE LENGTH (SL)

FUEL WEIGHS APPROXIMATELY 6.5 LBS/GALLON

$$\text{FUEL COST PER ONE-WAY STAGE LENGTH} = \frac{277 + 8.63 \times SL}{6.5} \times \$0.95/\text{GALLON}$$

1972 DOT report). Annual cost of aircraft maintenance burden is calculated as follows:

$$AMB = 0.60 \times DM$$

2.2. INDIRECT OPERATING COST

It will be assumed that at each node a small terminal must be constructed to handle the new VTOL traffic to this airport. This construction will include a flight deck, gate areas, and passenger handling areas. The land required for this facility will be relatively small and it will be assumed that it is already the property of the airport so no fees will be charged. All of the relationships for indirect operating cost came from the 1972 DOT report, and all of the cost were updated using appropriate indexes to 1982 dollar amounts.

Flight Deck

The annual cost of the flight deck equals the capital recovery factor for structures (35 year expected life and zero salvage value), multiplied by the flight deck investment. An annual maintenance charge is added to this computation.

$$FDI = 0.15113 \times 80{,}000\ ft^2 \times \$30/ft^2 \times 112{,}500\ ft^2 \times \$15/ft^2$$

$$FDI = \$617.764$$

where: runway dimensions = 200 feet by 400 feet = 80,000 ft^2

taxiway area = 750 feet by 150 feet = 112,500 ft^2

runway construction cost = \$30 per square foot

taxiway construction = \$15 per square foot

CRF = 0.15113

$$FDM = 192{,}500\ ft^2 \times \$0.033/ft^2 = \$6{,}334$$

where: maintenance cost = \$0.033 per square foot

pavement area = 80,000 ft^2 + 112,500 ft^2 = 192,500 ft^2

Gate Area

The annual cost of the gate area includes the construction cost plus an annual gate area maintenance cost.

GA = CRF x ft^2/gate x construction cost/gate x number of gates

GA = 0.15113 x 15,105 x \$15 x 2

GA = \$68,484

where: CRF = 0.15113

ft^2/gate = 2.5 + (.6 (AL) + 25) x 1.172(.6 (AL) + 25)

ft^2/gate = 15,105

AL = aircraft length = 78 feet

construction cost per square foot = \$15

number of gates is assumed to be 2

GAM = 2 x 15,105 ft^2/gate x \$0.033/ft^2

where: square feet of gate area = 2 x 15,105

maintenance cost per square foot = \$0.033/ft^2

Passenger Handling Area

The annual cost of the passenger handling area consists of the construction cost multiplied by the capital recovery factor and an annual maintenance cost.

PHA = CRF x sq.ft. of pass. handling area x construction cost/ft^2

where: CRF = 0.15113

construction cost per square foot = \$82

square feet per terminal = 7686 + 80.089 x # peak hour pass.

number of peak hour passengers = daily passenger flow x 0.1

PHAM = maint. cost/ft^2 x ft^2 of passenger handling area.

where: maintenance cost per square foot = \$6.46.

Terminal Staff

The annual cost of terminal staff for the system is computed by multiplying the payroll cost for one terminal and the number of terminals in the system. These costs include administrative personnel, custodians, uniformed guards, clerks, ticket agents, electricians, fire and rescue personnel, and airfield personnel. The annual payroll for terminal staff was estimated to be about $470,800.

Passenger Terminal Charge

A terminal charge was calculated to cover those expenses incurred on the ground before the aircraft becomes airborne. Included in this cost was the additional cost due to a more complex air traffic control costs. The terminal charge for each passenger was estimated to be about $10.

Aircraft Parking

The system operator must provide parking for each and every aircraft in the system. This involves an investment in aircraft parking and an annual charge to maintenance. The size of the parking space for a tilt-rotor 45 passenger aircraft is assumed to be similar to the parking spaces required for a DHC-7 STOL aircraft which is similar in size to the tilt-rotor aircraft.

$$\text{APRK} = 0.15113 \times 10{,}368\ \text{ft}^2/\text{space} \times \$1.26/\text{ft}^2 \times \#\ \text{of aircraft}$$

where: CRF = 0.15113

parking space size = 10,368 ft^2

construction cost per square foot = $1.26

$$\text{APRKM} = 10{,}368\ \text{ft}^2/\text{square} \times \$0.028/\text{ft}^2 \times \text{fleet size}$$

$$\text{APRKM} = \$290 \times \text{number of aircraft in system}$$

where: parking space size = 10,368 ft^2

maintenance cost per square foot = $0.028

Aircraft Maintenance and Engine Overhaul Building

Assuming that the VTOL operation has been an added service by an existing commercial airline, the airline probably has sufficient facilities to handle the additional maintenance of the tilt-rotor aircraft. If no more than 10% of the aircraft are in for maintenance at on time, this will mean that additional space is required for only one or two aircraft, since for our analyses the fleet size is always less than 20. If the VTOL operation was independent, and only a small space was required for maintenance, renting space could be a possibility. No costs were added to the analysis for a maintenance and engine overhaul building.

Central Office Building

The annual cost of the central office building is partitioned into three divisions: 1) annual cost of constructing the building, 2) annual cost of building maintenance, 3) average yearly salary of office building personnel.

As assumed previously, the VTOL service may become part of another existing airline already in operation, so no cost will be added for items 1 and 2 above. However, additional office personnel will be required to handle the additional passengers. This model estimated this number to be 0.01 mutiplied by the number of daily passengers. Salaries for each of these employees was estimated at $25,000/year. It was assumed that no additional space was required for these additional employees.

$$\text{PERC} = \$25{,}000/\text{year} \times 0.01 \times \text{CAP}$$

Miscellaneous Cost

The miscellaneous cost category is made up of food, stewardess cost, advertising and publicity cost, passenger liability insurance, and other cost. Again, it was assumed that these costs would approximate those of the similar sized DHC-7 STOL aircraft.

$$\text{CMISC} = 0.3178 \times \text{total annual aircraft miles}$$

2.3. TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the VTOL total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 1, updated cost parameters used in the model are summarized by identifying the source and value of the original unit cost, and then stating the factor and source used to update this parameter to its present value.

1. Average Annual Total Cost (TAAC):

Direct Operating Cost:

-Fleet Investment (ACTI) = 0.18448 x \$9 million x BNTR

-Hull Investment (HI) = 0.02 x \$7.74 million x BNTR

-Flight Crew (FC) = \$240 x AFH

-Fuel (FO) $= \dfrac{277 + 8.63 \times SL}{6.5} \times \$0.95 \times DFREQ \times 365$

-Direct Maintenance (DM) = \$0.0158 x 45 x SL x annual # flights

-Maintenance Burden (AMB) = 0.60 x DM

Indirect Operating Cost:

-Terminal Cost (for each terminal):

1. Flight Deck Investment (FDI) = \$617,764

   Flight Deck Maintenance (FDM) = \$6,334

2. Gate Area Investment (GA) = \$68,484

   Gate Area Maintenance (GAM) = \$997

3. Passenger Handling Area Investment (PHA):
   0.15113 x (7686 + 80.089 (CAP x 0.1)) x \$89

   Passenger Handling Area Maintenance (PHAM):
   (7686 + 80.089(CAP x 0.1)) x \$6.46

4. Terminal Staff (TSTAF) = \$470,800

-Passenger Terminal Charge (TERPAX) = BNSP x \$10

-Aircraft Parking (APRK) = \$1974 x BNTR

-Aircraft Parking Maintenance (APRKM) = \$290 x BNTR

-Central Office Building (PERC) = \$25,000 x 0.01 x CAP

-Miscellaneous Cost (CMISC) = \$0.3178 x TAM

TAAC = ACTI + HI + FC + FO + DM + AMB + (no. of terminals) x (FDI + FDM + GA + GAM + PHA + PHAM + TSTAF) + TERPAX + APRK + APRKM + PERC + CMISC

The cost per passenger mile based on total cost is calculated by taking the above cost (TAAC) and dividing it by the annual number of passengers on the system multiplied by the one-way stage length.

$$\text{PPCUU} = \frac{\text{TAAC}}{\text{SL} \times \text{BNSP}}$$

2. Average Annual Total Cost Excluding Fixed Facility Capital Cost (TALC):

This cost is equal to the total cost less capital expenditures for flight deck investments, gate area investments, passenger handling area investments, and aircraft parking investment. The cost equation is as follows:

$$\text{TALC} = \text{ACTI} + \text{HI} + \text{FC} + \text{FO} + \text{DM} + \text{AMB} + (\text{no. of terminals}) \text{ X } (\text{FDM} + \text{GAM} + \text{PHAM} + \text{TSTAF}) + \text{TERPAX} + \text{ARPKM} + \text{PERC} + \text{CMISC}$$

The cost per passenger mile based on total cost excluding fixed facility capital cost is calculated by taking the above cost (TALC) and dividing it by the annual number of passengers on the system multiplied by the one-way stage length.

$$\text{PPUUV} = \frac{\text{TALC}}{\text{SL} \times \text{BNSP}}$$

3. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost excluding fixed facility cost calculated above, minus the annual fleet investment.

$$\text{TALCAV} = \text{TALC} - \text{ACTI}$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$\text{PPWOV} = \frac{\text{TALCAV}}{\text{SL} \times \text{BNSP}}$$

TABLE 1. Summary of Updated Cost Parameters:

Cost Component	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Aircraft cost	$5 million (1974)	NASA Report CR-2545	1.8	p. 739 U.S. Statistical Abstract, 1984	$9 million
Flight crew	$80 (1971)	1972 DOT Report	3.0	p. 59 AAR Yearbook	$240
Direct Maintenance	.0051 (1974)	NASA Report CR-2545	3.0 (labor) 1.8 (materials)	p. 59 AAR Yearbook p. 739 U.S. Statistical Abstract, 1984	.0158
Flight deck:					
-runway construction	$12 (1970)	1972 DOT Report	2.5	p. 739 U.S. Statistical Abstract, 1984	$30
-taxiway construction	$6 (1970)		2.5		$15
-maintenance cost	$0.013 (1970)		2.5		$0.033
Gate Area:					
-construction cost	$12 (1970)	"	2.5	"	$15
-maintenance cost	$0.013 (1970)		2.5		$0.033
Passenger Handling Area:					
-construction cost	$30 (1970)	"	2.73	"	$82
-maintenance cost	$2.34 (1971)		2.76		$6.46
Aircraft Parking:					
-construction	$0.50 (1970)	"	2.5	"	$1.26
-maintenance cost	$0.011 (1970)		2.5		$0.028
Miscellaneous cost	.1589 (1972)	1972 DOT Report	2	p. 739, U.S. Statistical Abstract, 1984	0.3178

2.4. COST PER PASSENGER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities for the 45 passenger tilt-rotor aircraft. Three different values were calculated for cost per passenger mile. These were based on the following:

1) Total cost (see Figure 2)
2) Total cost minus fixed facility capital cost (see Figure 3)
3) Total cost minus all capital cost (See Figure 4)

The costs per passenger mile for each of these calculations are summarized in Table 2. Figure 2 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. For all stage lengths, cost per passenger mile decreased substantially ove the 250-500 passenger range. Also, there is a significant reduction in costs as the stage lengths increase. Beyond the 500 passenger per day level, costs per passenger mile remain relatively constant. This is partially due to the higher load factors observed over this range than those experienced at the 0-500 passenger range (in this range the minimum frequency constraint governed the number of operations resulting in lower load factors). Most importantly though, the sunk costs resulting from terminal, runway, and aircraft investments are less per passenger-mile when more passengers are carried and longer stage lengths are traveled (see Table 3).

Figure 3 shows a graph of average cost per passenger mile based on total cost excluding fixed facility capital cost, versus average one-way daily passenger volumes. Perhaps this is the most appropriate cost per passenger mile considered since many of the costs associated with capital investments in terminals and flight decks may be financed by federal, state, and local governments, rather than charged directly to an airline operation. Costs are slightly lower than those observed in Figure 2 and generally follow the pattern that these costs do.

Figure 4 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. Costs are much lower than those observed in both Figures 2 and 3, which reflects the significance of aircraft cost on overall cost. The cost per passenger mile decreases slightly over the 250-500 passenger range, and remains relatively constant for passenger volumes greater than this.

TABLE 2. Tilt-rotor costs per passenger-mile vs. stage length and passenger volume.

Stage Length, mi. Directional Pass. Volume, pass./day	Average Cost, $/pass. mile Total Cost	 Total Cost minus Fixed Facility Cost	 Total Cost minus All Capital Cost
100 miles			
250	.7705	.6791	.4062
500	.6296	.5811	.3537
750	.5163	.4821	.3305
1000	.5142	.4872	.3280
1250	.4693	.4466	.3192
1500	.4725	.4526	.3162
200 miles			
250	.5649	.5191	.2917
500	.3876	.3633	.2496
750	.3617	.3446	.2384
1000	.3530	.3394	.2371
1250	.3244	.3131	.2312
1500	.3220	.3121	.2287
300 miles			
250	.4300	.3995	.2478
500	.3401	.3239	.2178
750	.3102	.2987	.2078
1000	.2992	.2902	.2068
1250	.2961	.2885	.2035
1500	.2884	.2818	.2009

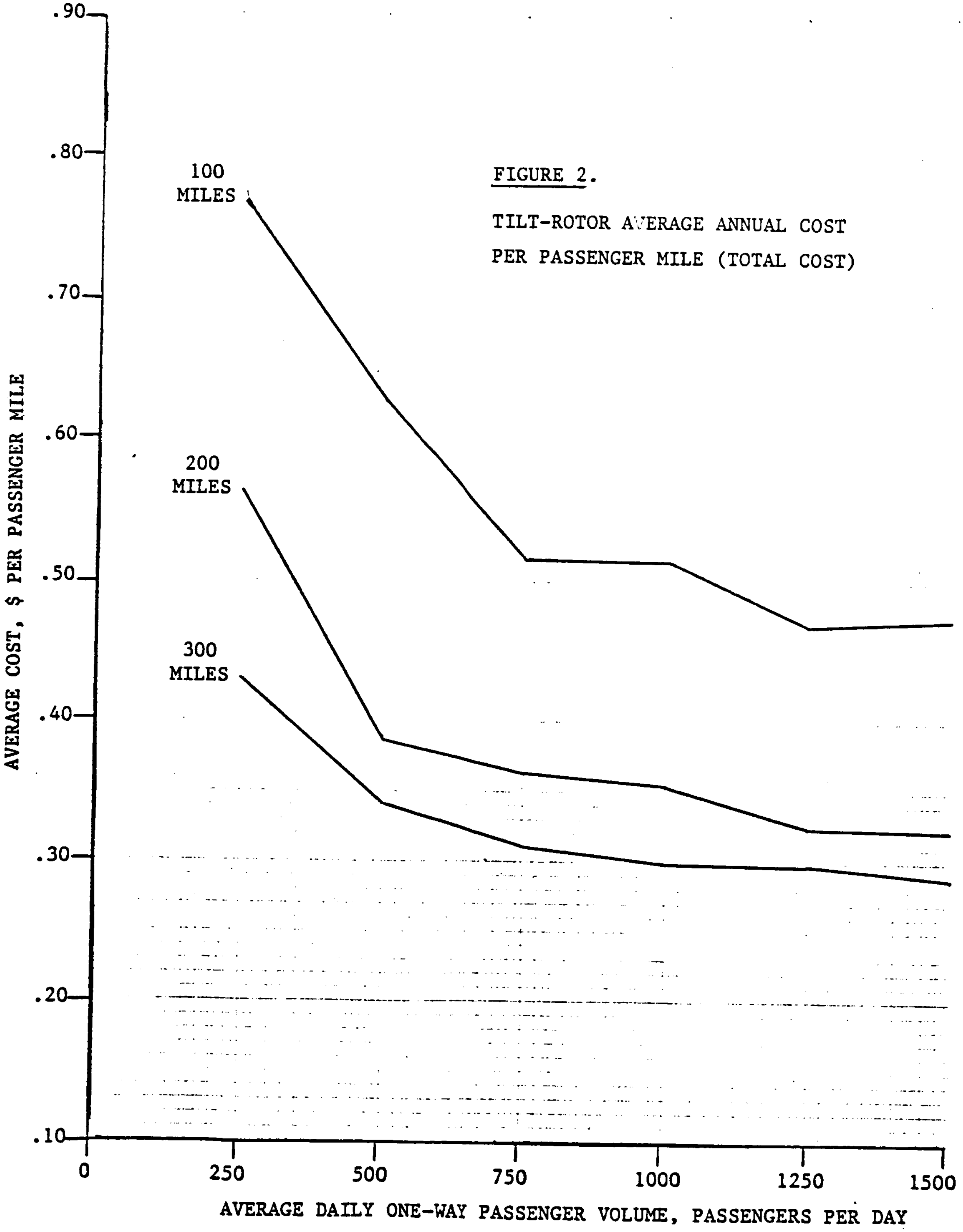

FIGURE 2.

TILT-ROTOR AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST)

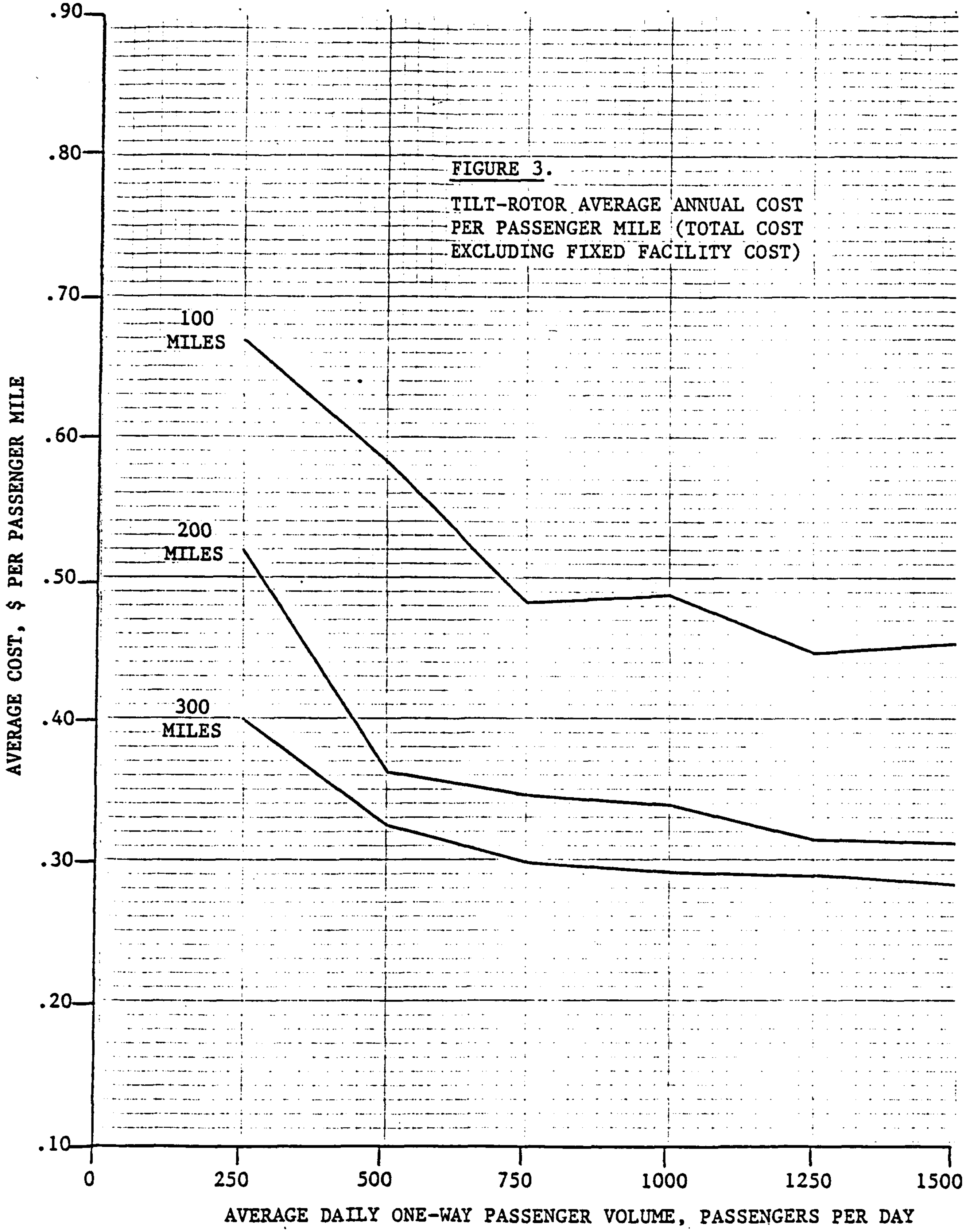

FIGURE 3.

TILT-ROTOR AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST EXCLUDING FIXED FACILITY COST)

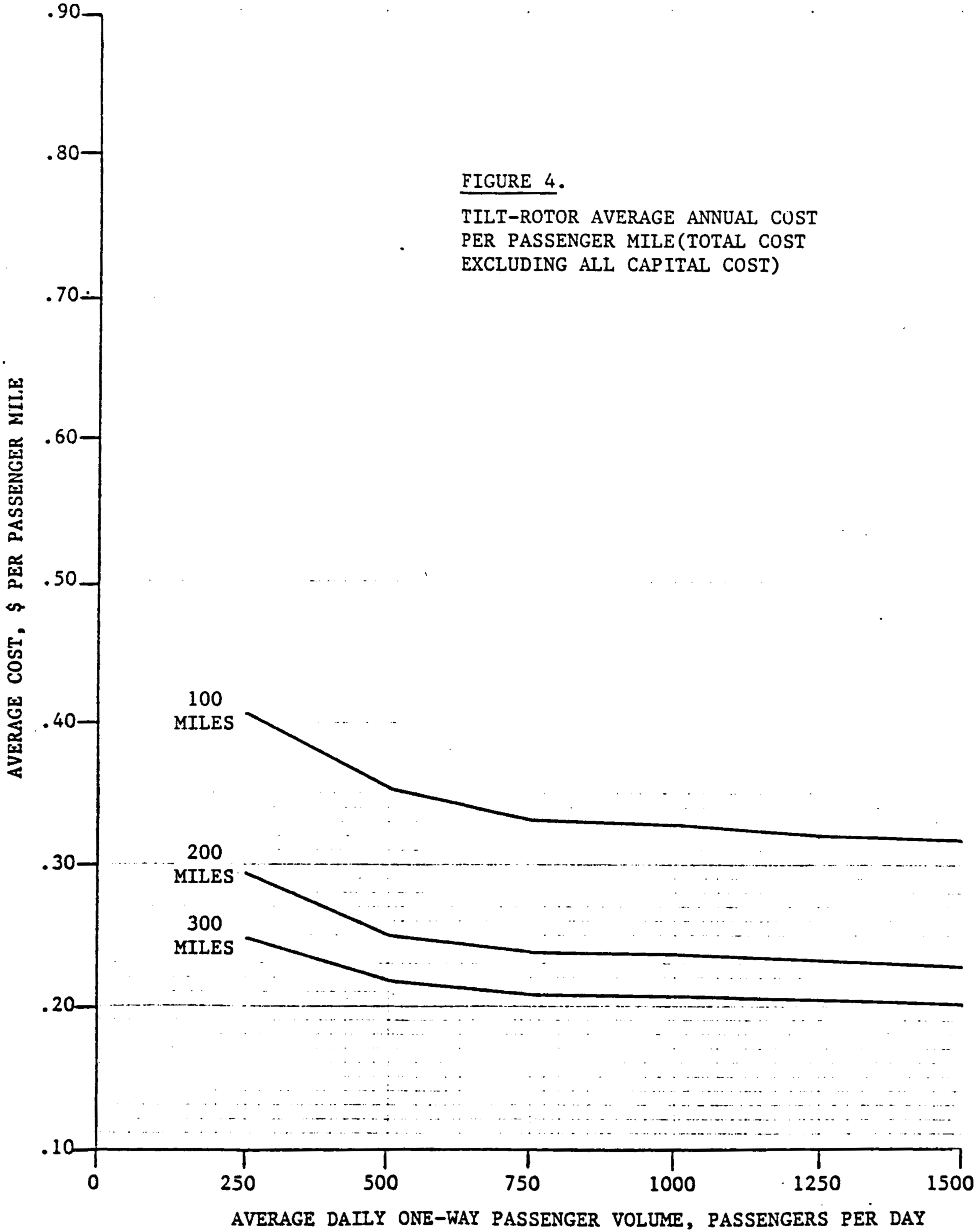

FIGURE 4.

TILT-ROTOR AVERAGE ANNUAL COST PER PASSENGER MILE(TOTAL COST EXCLUDING ALL CAPITAL COST)

TABLE 3. Tilt-rotor system costs and characteristics vs. stage length and passenger volume.

Stage Length, mi Directional Pass. Vol., pass./day	Fleet Size, Veh.	Directional Headways, Hrs./Dep.		Terminal Cost Per Pass., $/Pass.	Total Cost, $1000/yr.
		Peak	Base		
100 miles					
250	3	1.00	1.71	25.18	14,062
500	5	0.67	0.86	18.00	22.981
750	5	0.44	0.60	15.61	28,265
1000	7	0.33	0.44	14.41	37,538
1250	7	0.29	0.35	13.70	42,822
1500	9	0.24	0.30	13.22	51,741
200 miles					
250	5	1.00	1.71	25.18	20,620
500	5	0.67	0.86	18.00	28,295
750	7	0.44	0.60	15.61	39,606
1000	9	0.33	0.44	14.41	51,535
1250	9	0.29	0.35	13.70	59,211
1500	11	0.24	0.30	13.22	70,521
300 miles					
250	5	1.00	1.71	25.18	23,543
500	7	0.67	0.86	18.00	37,244
750	9	0.44	0.60	15.61	50,945
1000	11	0.33	0.44	14.41	65,532
1250	14	0.29	0.35	13.70	81,051
1500	16	0.24	0.30	13.22	94,753

2.5. SENSITIVITY ANALYSIS

Since the VTOL aircraft under consideration is based on a future technological innovation and lacks an established cost background, a sensitivity analysis was performed. Several parameter values were changed in the model developed for the tilt-rotor aircraft investigated to determine if those changes would have a significant effect on passenger mile cost. The sensitivity analysis examined aircraft cost, aircraft speed, crew cost, direct maintenance cost, fuel cost, interest rates, load factors, terminal cost, and aircraft turn-around times. Table 4 presents a summary of these sensitivity analyses. Each column presents the effect of a change in the cost parameter in the direction and amount shown, e.g., column 1 refers to a 20% reduction in vehicle costs. The entries in the column are the percentage changes in a particular overall cost measure for a given passenger volume, e.g., the first row gives the percent change in total cost per passenger mile. Thus a 20% drop in aircraft cost reduces total cost per passenger mile at a 100 passenger per day volume by 7.74%.

Aircraft Cost: Changes in aircraft cost are particularly sensitive for the tilt-rotor technology. As would be expected, the effect on passenger mile cost is more significant at shorter stage lengths and smaller passenger volumes. Even when all capital cost are excluded in calculating passenger mile cost, changes in aircraft cost have a slight influence since hull insurance cost is a function of aircraft cost.

Vehicle Speed: The effect of varying aircraft speed was insignificant at some stage lengths and passenger demands, but very significant at others. The reason for significant changes is that vehicle speed had an effect on fleet size. Aircraft speed also influences the number of annual flight hours which was a factor in calculating certain costs.

Crew Cost: Crew cost changed passenger cost very little and was judged to be a non-sensitive parameter.

Direct Maintenance: The effect of changing direct maintenance cost was also judged to be non-sensitive.

Fuel Cost: Changes in fuel expenditures had little influence on passenger mile cost. The minor effect it had was more apparent at longer stage lengths and higher passenger demand levels.

TABLE 4. SENSITIVITY ANALYSIS FOR VTOL (TILT-ROTOR) % CHANGE IN COST PER PASSENGER MILE

STAGE LENGTH	COST	AVG. DAILY PASSENGERS	VEH. COST (-20%)	VEH. SPEED (-20%)	CREW COST (+10%)	DIR. MAINT. (-20%)	FUEL COST (-20%)	INT. RATE (-20%)	LOAD FACTOR (-10%)	TERM. COST (+100%)	T.A. TIME (+25%)
	1										
100		500	-7.74	+1.32	+0.99	-1.30	-1.89	-6.68	+2.52	+32.68	+1.14
		3000	-6.31	+1.86	+1.40	-1.82	-2.67	-4.40	+4.78	+27.98	+1.61
200		500	-8.80	+1.81	+1.03	-1.77	-2.28	-6.57	+3.01	+22.29	+0.78
		3000	-5.65	+10.47	+1.55	-2.67	-3.45	-3.82	+13.88	+20.53	+8.91
300		500	-7.72	+2.37	+1.21	-2.33	-2.86	-5.77	+3.77	+19.51	+0.67
		3000	-6.10	+5.34	+1.60	-2.98	-3.68	-3.92	+10.40	+15.29	+0.90
	2										
100		500	-8.78	+1.50	+1.12	-1.47	-2.15	-5.02	+2.86	+23.66	+1.30
		3000	-6.58	+1.94	+1.46	-1.90	-2.78	-3.76	+5.02	+24.86	+1.68
200		500	-9.57	+1.96	+1.12	-1.93	-2.49	-5.47	+3.27	+15.49	+0.85
		3000	-5.86	+10.77	+1.60	-2.79	-3.59	-3.36	+14.29	+18.01	+9.16
300		500	-8.31	+2.53	+1.30	-2.53	-3.08	-4.76	+4.03	+13.39	+0.73
		3000	-6.28	+7.03	+1.60	-3.09	-3.76	-3.58	+10.61	+13.31	+0.89
	3										
100		500	-1.26	+2.51	+1.87	-2.46	-3.62	0.00	+4.78	+39.56	+2.17
		3000	-0.82	+2.78	+2.06	-2.75	-4.02	0.00	+7.15	+35.58	+2.40
200		500	-1.47	+3.46	+1.99	-3.43	-4.42	0.00	+5.79	+27.53	+1.51
		3000	-0.70	+4.77	+2.19	-3.80	-4.90	0.00	+9.58	+24.57	+2.58
300		500	-1.13	+4.12	+2.14	-4.04	-4.96	0.00	+6.54	+21.63	+1.21
		3000	-0.75	+4.83	+2.24	-4.28	-5.28	0.00	+9.86	+18.67	+1.24

1. TOTAL COST
2. TOTAL COST EXCLUDING FACILITY CAPITAL COST
3. TOTAL COST EXCLUDING ALL CAPITAL COST

Interest Rates: The interest was a significant factor at lower passenger demand volumes. This is not surprising since the VTOL operation cost were influenced by both expansive fleet investments and high facility capital expenditures.

Load Factors: Reducing the maximum allowable load factors had a significant influence on VTOL passenger mile cost, particularly at higher passenger volumes. This was the result of more frequent aircraft operations and larger fleet sizes.

Terminal Cost: A 100% change in terminal cost had little effect on VTOL passenger mile cost. The small influence that it had was more significant at shorter stage lengths.

Turn-around Time: Turn-around time was not a significant factor for most stage lengths or passenger volumes. This is similar to the effect which was observed for differences in aircraft speed where different turn-around times may influence fleet size requirements.

3. THE CTOL COST MODEL

The CTOL cost model develops short haul system costs for the McDonnell Douglas DC-9-30 aircraft. All seating is coach and the aircraft has a 115 passenger capacity. Costs are separated into two categories - direct operating cost and indirect operating cost. Direct operating cost includes the following categories: fleet investment, hull insurance, flight crew, fuel and oil, direct maintenance and maintenance burden. Indirect operating costs include: air passenger terminal charge, aircraft parking cost, central office building costs, and miscellaneous costs.

3.1. DIRECT OPERATING COST

Annual Cost of Fleet Investment

The annual cost of fleet investment equals the capital recovery factor times the total airplane investment. The airplane investment was estimated at $12,842,000 based on the 1972 estimate of $5,500,000 for a new aircraft. The 1972 cost was updated to 1982 using the appropriate wholesale price index for capital equipment as referenced in the 1984 Statistical Abstract of the United States. Actually, the DC-9-30 aircraft was no longer coming off the assembly line in 1982 and used aircraft were available through the resale market at approximately $7 million per aircraft[2]. The influence of aircraft cost on passenger mile cost is considered in the sensitivity analysis. Annual cost of fleet investment was calculated as follows:

ACTI = 0.18448 x $12,842,000 x BNTR

where BNTR = number of CTOL (DC-9-30) aircraft in system
CRF = 0.18448

Hull Insurance

The annual cost of hull insurance is computed by multiplying the previously used hull insurance rate of 2% by the aircraft flyaway cost less spare parts and by the number of aircraft in the system. Volume II of the 1972 DOT report indicated that the flyaway cost less spare parts was $5 million for the DC-9-30 or approximately 90.909% of the flyaway cost. Therefore, the flyaway cost less spare parts for 1982 was estimated to equal this same percentage multiplied by the aircraft cost. The annual hull insurance cost was calculated as follows:

HI = 0.02 x 0.90909 x $12,842,000 x BNTR

where BNTR = number of CTOL (DC-9-30) aircraft in system

Flight Crew

Annual crew cost is tabulated as the total number of flight hours times the cost of crew per flight hour, where the crew consists of a pilot and a co-pilot. Crew cost for 1982 were taken from the 1983 report "Aircraft Operating Cost and Performance Report". From line 1, the crew cost per block hour was estimated at $290.51. The annual crew cost (FC) was calculated as follows:

FC = $290.51 x AFH

Fuel and Oil

The annual cost of fuel and oil is determined for the DC-9-30 on a

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[2] The source of this statement was from a phone conversation in March 1985 with a marketing representative for the McDonnel Douglas Corporation.

flight hour basis. Fuel and oil cost for 1982 were taken from the 1983 report "Aircraft Operating Cost and Performance Report". From line 2, fuel and oil cost per block hour was estimated at $799.35. Line 36 indicates that this estimate was based on the fuel price of $0.95716 per gallon. Annual cost for fuel and oil was calculated as:

$$FO = \$799.35 \times AFH$$

Direct Maintenance

The annual cost of direct maintenance consists of labor and materials. Direct maintenance cost for 1982 were based on the 1983 report "Aircraft Operating Cost and Performance Report". From line 7, direct maintenance cost per block hour was estimated as $124.21. The annual cost for direct maintenance was calculated as:

$$DM = \$124.21 \times AFH$$

Maintenance Burden

Similar to the VTOL cost model, annual cost of aircraft maintenance burden is equal to 60% of direct maintenance cost.

$$AMB = 0.60 \times DM$$

3.2. INDIRECT OPERATING COST

It will be assumed that all terminal structures have been previously constructed and paid for. Charges that will be applicable will be those resulting from maintaining the facilities and those resulting from greater personnel cost as a result of an increase of passengers using the system. All of the relationships for indirect operating cost came from the 1972 DOT report and all of the cost were updated using appropriate indexes to 1982 dollar amounts.

Passenger Terminal Charge

A terminal charge was calculated to cover those expenses incurred on the ground before the aircraft becomes airborne. These expenses include such things as maintenance and operating costs of runways, taxiways, and gate areas. Volume II of the 1972 DOT report, estimated this terminal cost at \$12 per passenger. Using the appropriate consumer price index this cost was updated to approximately \$27.70 for 1982.

Aircraft Parking

The system operator must provide parking for each and every aircraft in the system. This involves an investment in aircraft parking which is assumed to be completely paid for, and an annual charge for maintenance which is calculated as follows:

$$\text{APRKM} = \$0.028 \times 14{,}715 \text{ ft}^2 \times \text{BNTR}$$

where: maintenance cost per square foot = \$0.028
parking area per aircraft = 14,715 ft^2

Central Office Building

The annual cost of the central office building is partitioned into three divisions: 1) annual cost of constructing the building; 2) annual cost of building maintenance; 3) average yearly salary of office building personnel.

Making the assumption that this service may become an addition to an existing airline operation it was assumed that no cost would be added for items 1 and 2 above. However, additional office personnel will be required to handle the additional passengers. This model estimated this number to be 0.01 multiplied by the number of daily passengers. Salaries for each of these employees was estimated at \$25,000/year. It was assumed that no additional space was required for these additional employees.

$$\text{PERC} = \$25{,}000/\text{year} \times 0.01 \times \text{CAP}$$

Miscellaneous Cost

The miscellaneous cost category is made up of food, stewardess cost, advertising and publicity cost, passenger liability insurance, and other cost. The miscellaneous cost for the DC-9-30 aircraft was calculated as follows:

$$CMISC = 0.7616 \times TAM$$

3.2. TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the CTOL total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 5, updated cost parameters used in the model are summarized by identifying the source and value of the original factor, and then stating the factor and source used to update this parameter to its present value.

1. Average Annual Total Cost (TAAC):

Direct Operating Cost:

-Fleet Investment, ACTI = 0.18448 x \$12,842,000 x BNTR

-Hull Insurance, HI = 0.02 x 0.90909 x \$12,842,000 x BNTR

-Flight Crew, FC = \$290.51 x AFH

-Fuel and Oil, FO = \$799.35 x AFH

-Direct Maintenance, DM = \$124.21 x AFH

-Maintenance Burden, AMB = 0.60 x DM

Indirect Operating Cost:

-Passenger Terminal Charge, TERPAX = BNSP x \$27.70

-Aircraft Parking Maintenance, APRKM = \$0.028 x \$14,715 ft^2 x BNTR

-Central Office Building, PERC = \$25,000 x 0.01 x CAP

-Miscellaneous Cost, CMISC = 0.7616 x TAM

TAAC = ACTI + HI + FC + FO + DM + AMB + TERPAX + APRKM + PERC + CMISC

The cost per passenger mile based on total cost (TAAC) is calculated as follows:

$$PPCUU = \frac{TAAC}{SL \times BNSP}$$

2. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost calculated above, minus the annual fleet investment.

$$TALCAV = TAAC = ACTI$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$PPWOV = \frac{TALCAV}{SL \times BNSP}$$

TABLE 5. Summary of Updated CTOL Cost Parameters.

Cost Component	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Aircraft cost	$5,500,000 (1972)	1972 DOT Report	2.31	p. 487 U.S. Statistical Abstract, 1984	$12,842,000
Passenger Terminal Charge	$12 (1972)	1972 DOT Report	2.31	p. 487 U.S. Statistical Abstract, 1984	$27.70
Aircraft Parking Maintenance Cost	$0.011 (1970)	1972 DOT Report	2.5	p. 739 U.S. Statistical Abstract, 1984	$0.028
Miscellaneous Cost	$.3808 (1972)	1972 DOT Report	2	p. 739 U.S. Statistical Abstract, 1984	$0.7616

3.4. COST PER PASSENGER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities for the 115 passenger DC-9-30 CTOL aircraft. Two different values were calculated for cost per passenger mile. These were based on the following:

1) Total cost (see Figure 5)
2) Total cost minus all capital cost (see Figure 6)

Since for this model, landing fees cover all airport charges, fixed facility costs alone cannot be separated out.

The costs per passenger mile for each of these calculations are summarized in Table 6. Figure 5 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. For all stage lengths, cost per passenger mile decreased substantially ove the 250-500 passenger range. There is a significant reduction in costs as stage lengths increase from 100 miles to 200 miles. This reduction is minimal for the smaller passenger volumes as stage lengths increase from 200 miles to 300 miles, but more noticeable at larger passenger volumes. Beyond the 750 passenger level, costs per passenger mile remain relatively constant. This is due to the excess capacity observed at lower passenger volumes requiring aircraft investment costs to be distributed among fewer passengers. The excess capacity results because a certain number of flights are required to satisfy the minimum frequency constraints regardless of what the passenger demand is. This is evident in Table 7 which shows that the fleet size required at low passenger volumes (i.e. 500 daily passengers) is equivalent to the fleet size required at the 1500 on greater daily volumes.

Figure 6 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. At the lower passenger volumes, costs decrease substantially from those observed in Figure 5, which reflects the significance of aircraft cost at these demands. Cost per passenger mile decreases very little for passenger volumes greater than 500 passengers/day.

Table 6. CTOL costs per passenger mile vs. stage length and passenger volume.

Stage Length Directional Passenger Volume, pass./day	Average Cost, $/pass. mile	
	Total Cost	Total Cost minus all Capital Cost
100 miles		
250	.9008	.5114
500	.5923	.3976
750	.5021	.3723
1000	.4664	.3691
1250	.4451	.3672
1500	.4752	.3670
200 miles		
250	.5449	.3502
500	.3434	.2461
750	.2889	.2240
1000	.3067	.2256
1250	.2889	.2240
1500	.2738	.2197
300 miles		
250	.5214	.3050
500	.3080	.1998
750	.2495	.1774
1000	.2297	.1756
1250	.2178	.1745
1500	.2226	.1721

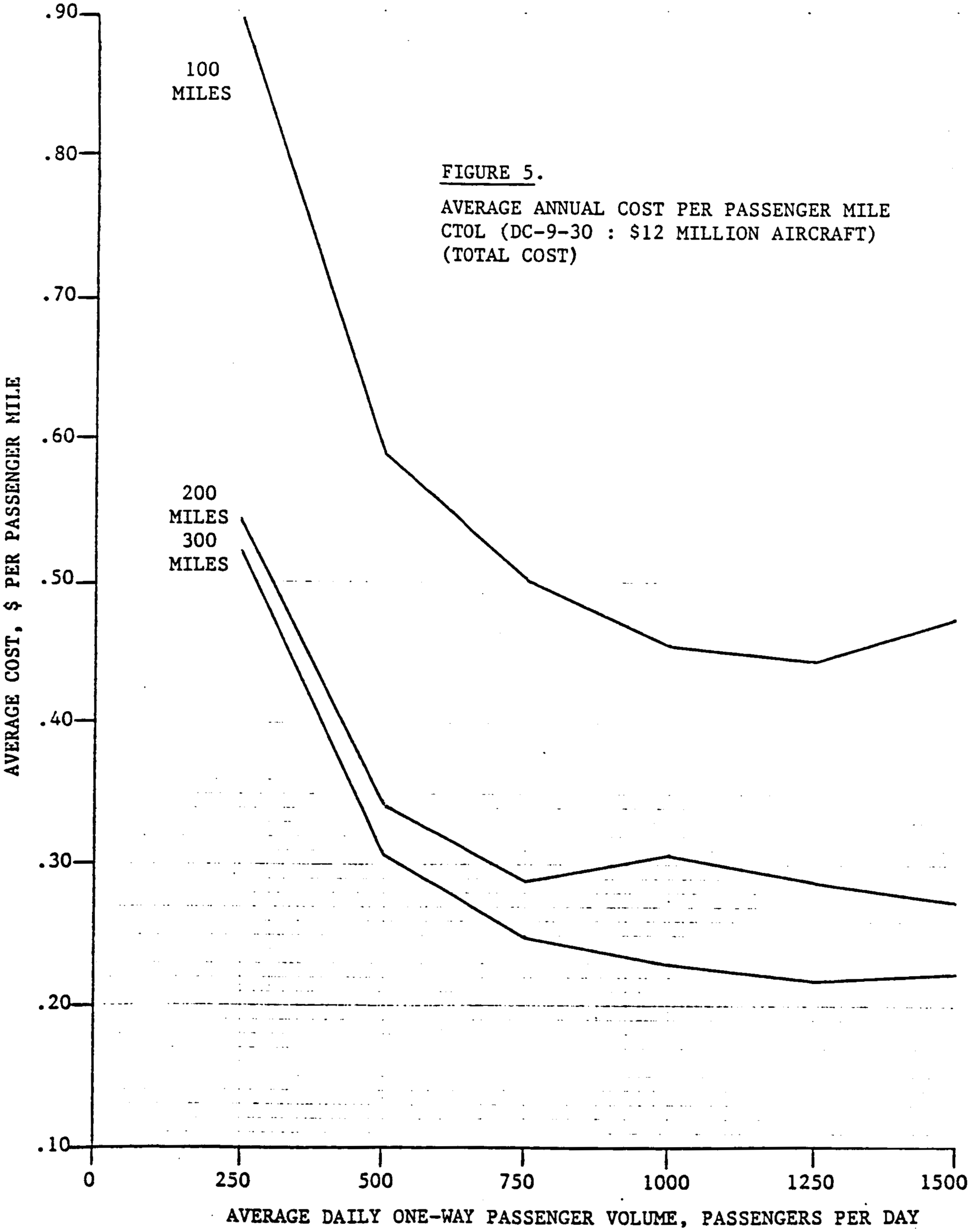

FIGURE 5.

AVERAGE ANNUAL COST PER PASSENGER MILE
CTOL (DC-9-30 : $12 MILLION AIRCRAFT)
(TOTAL COST)

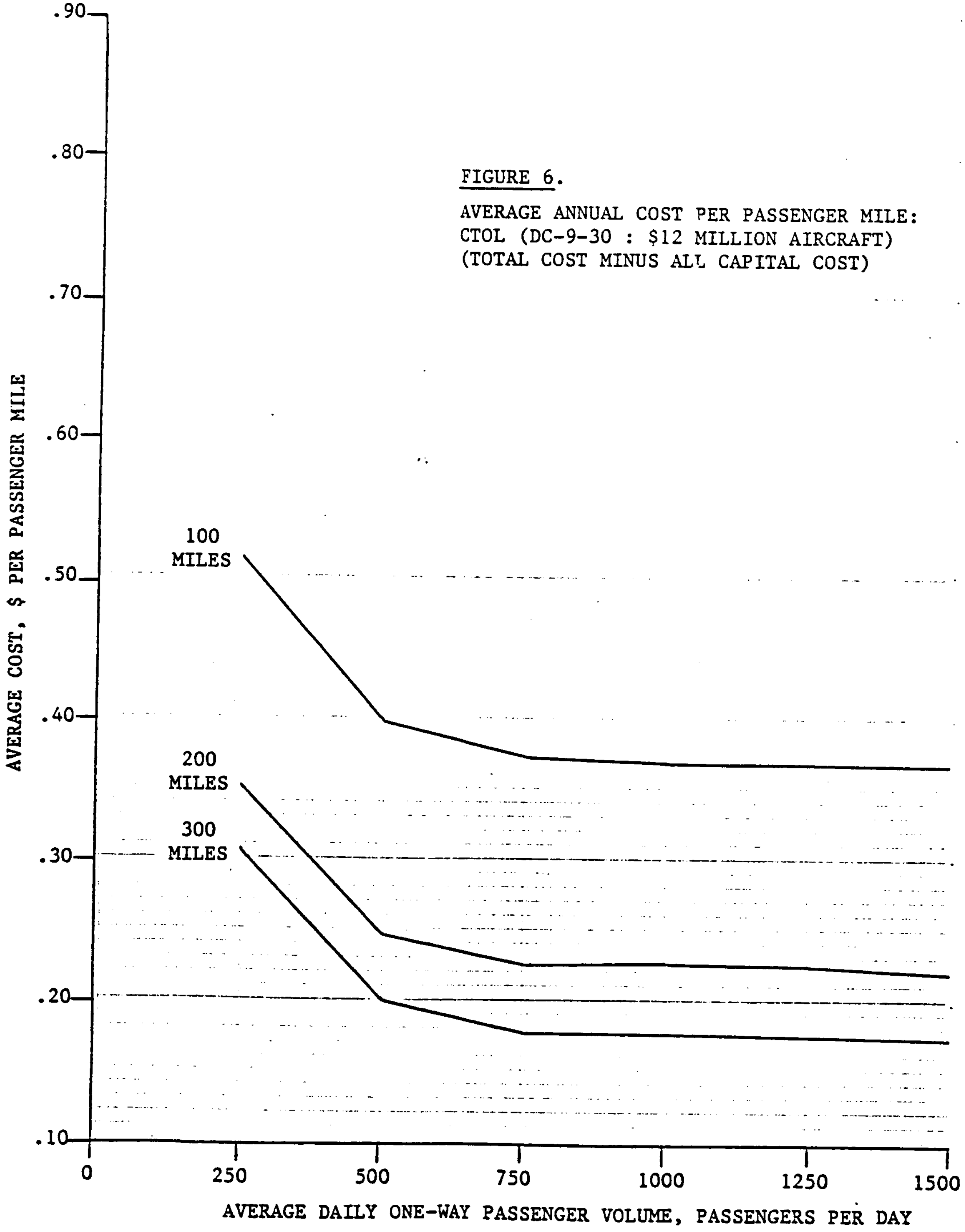

FIGURE 6.

AVERAGE ANNUAL COST PER PASSENGER MILE:
CTOL (DC-9-30 : $12 MILLION AIRCRAFT)
(TOTAL COST MINUS ALL CAPITAL COST)

TABLE 7. CTOL system costs and characteristics vs. stage length and passenger volume.

Stage Length, mi Directional Passenger Volume, Pass./day	Fleet Size, Vehicles	Directional Headways Hrs./Dep. Peak	Base	Terminal Cost Per Passenger, $/pass.	Total Cost $1000/yr.
100 miles					
500	3	1	2	27.70	16,440
1000	3	1	2	27.70	21,620
1500	3	1	1.5	27.70	27,490
2000	3	0.8	1.09	27.70	34,051
2500	3	0.67	0.86	27.70	40,611
3000	5	0.57	0.75	27.70	52,032
200 miles					
500	3	1	2	27.70	19,890
1000	3	1	2	27.70	25,070
1500	3	1	1.5	27.70	31,631
2000	5	0.8	1.09	27.70	44,770
2500	5	0.67	0.86	27.70	52,718
3000	5	0.57	0.75	27.70	59,968
300 miles					
500	5	1	2	27.70	28,546
1000	5	1	2	27.70	33,727
1500	5	1	1.5	27.70	40,977
2000	5	0.8	1.09	27.70	50,298
2500	5	0.67	0.86	27.70	59,618
3000	7	0.57	0.75	27.70	73,110

3.5. SENSITIVITY ANALYSIS

While the model for CTOL aircraft was based on the established technical background of several years of operation of the DC-9-30 aircraft, and the parameter values used were thought to be relatively accurate, a sensitivity analysis was conducted to investigate what changes in the model would have a significant effect on passenger mile cost. Similar to the sensitivity analysis which was performed on the VTOL model, the parameters investigated were aircraft cost, aircraft speed, crew cost, direct maintenance cost, fuel cost, interest rates, load factors, terminal cost, and aircraft turn-around times. Table 8 presents a summary of the sensitivity analysis performed for the DC-9-30 aircraft representing CTOL technology.

Aircraft Cost: Changes in aircraft cost are moderately sensitive for the CTOL technology. The effect on passenger mile cost is relatively significant at lower passenger demands, but not too significant at the higher passenger volumes.

Vehicle Speed: The effect of varying aircraft speed was insignificant at some stage lengths and passenger demands, but very significant at others. The reason for significant changes is that vehicle speed had an effect on fleet size at these stage lengths and demands. Aircraft speed also influences the number of annual flight hours which was a factor in calculating several of the cost components in the CTOL model.

Crew Cost: Crew cost changed passenger cost very little and was judged to be a non-sensitive parameter.

Direct Maintenance: The effect of changing direct maintenance cost was also judged to be non-sensitive.

Fuel Cost: Changes in fuel expenditures had little influence on passenger mile cost. The minor effect which it did have, was more apparent at longer stage lengths.

Interest Rate: Changes in the interest rate effected passenger mile cost more significantly at low passenger demand volumes. Since the only capital expenditure in this model was the fleet investment the overall minor effect of this parameter is not surprising.

Load Factors: Reducing the maximum allowable load factors had no effect at low passenger volumes since there was excess capacity at these demands. However, the effect was significant at the longer stage lengths and higher passenger volumes. This was the result of more frequent aircraft operations and the cost associated with increasing fleet size.

Terminal Cost: Terminal passenger cost for the CTOL aircraft model appears to be an extremely sensitive parameter. It appears to be most significant at high passenger volumes and shorter stage lengths.

Turn-around Time: Turn-around time was not a significant factor for most stage lengths or passenger volumes. This is similar to the effect which was observed for differences in aircraft speed where different turn-around times may influence fleet size requirements.

TABLE 8. SENSITIVITY ANALYSIS FOR CTOL (DC-9-30)
% CHANGE IN COST PER PASSENGER MILE

COST STAGE LENGTH	AVG. DAILY PASSENGERS	VEH. COST (-45.5%)	VEH. SPEED (-20%)	CREW COST (-20%)	DIR. MAINT. (-20%)	FUEL COST (-20%)	INT. RATE (-20%)	LOAD FACTOR (-10%)	TERM. COST (-20%)	T.A. TIME (+25%)
	1									
100	500	-21.60	+4.41	-0.79	-0.54	-2.19	-5.40	0.00	-6.15	0.00
	3000	-11.38	+3.20	-0.59	-0.40	-1.60	-2.84	+1.98	-11.66	0.00
200	500	-17.86	+33.46	-1.30	-0.90	-3.60	-4.46	0.00	-5.08	+26.19
	3000	-9.86	+5.55	-.99	-0.66	-2.74	-2.45	+3.47	-10.12	0.00
300	500	-20.73	+7.59	-1.38	-0.94	-3.78	-5.18	0.00	-3.55	0.00
	3000	-11.37	+6.83	-1.26	-0.85	-3.41	-2.83	+4.22	-8.31	0.00
	2									
100	500	-3.42	+7.74	-1.41	-0.96	-3.85	0.00	0.00	-10.83	0.00
	3000	-1.31	+4.14	-0.74	-0.52	-2.04	0.00	+2.59	-15.10	0.00
200	500	-2.48	+14.99	-2.03	-1.40	-5.63	0.00	0.00	-7.91	+3.66
	3000	-1.09	+6.92	-1.23	-0.82	-3.41	0.00	+4.32	-12.61	0.00
300	500	-3.18	+13.02	-2.33	-1.61	-6.43	0.00	0.00	-6.03	0.00
	3000	-1.34	+8.83	-1.63	-1.10	-4.42	0.00	+5.46	-10.75	0.00

1. TOTAL COST
2. TOTAL COST EXCLUDING ALL CAPITAL COST

4. THE HSR COST MODEL

The rail cost model develops a cost relatioship for the construction and operation of a short-haul intercity rail passenger service utilizing a fleet of high speed rail (HSR) trains. The cost are separated into two categories; those costs which are associated with major capital expenditures, and those costs which accrue as a direct result of train operation and service.

4.1. MAJOR CAPITAL EXPENDITURES

These are expenses associated with the long-term investment of capital into track, and new terminal facilities. For purpose of this study, vehicle equipment is considered a variable cost rather than a major capital expenditure since vehicles can be resold. The annual cost for capital investments is calculated by multiplying their initial cost by an appropriate capital recovery factor (CRF).

Track and Roadbed Upgrading

It is necessary to upgrade existing track and roadbed to accommodate high speed service(i.e. install new rail, surfacing and lining of track, replacement of cross ties, reballasting and upgrading the roadbed, changes in alignment). These costs, of course, are very dependent on the amount of upgrading to be undertaken. In a 1983 publication printed by the Office of Technology Assessment titled, "U.S. Passenger Rail Technologies", it was stated that using existing right-of-way with major upgrading, could cost $4.5 million to $6 million per route mile with two tracks per route. These costs are assumed to include all costs for new electrification of an existing facility such as those associated with catenary with supports, substations and switching stations, supply lines, signaling and block station systems, and communication systems. The annual cost to upgrade track is calculated as follows:

TER = 0.15230 x $4.5 million x stage length

where CRF = 0.15230

cost per route mile = $4.5 million

stage length = one-way air distance stage length multiplied by 14% curcuity factor.

New Terminal Facilities

In recent years, there has been very little new rail terminal construction, especially of major terminals in urban areas. This model assumes that an existing terminal will be used since most major cities have an AMTRAK terminal. Many of these have been renovated as part of AMTRAK's capital improvement program, and a few new terminals have been built. These have been paid for as part of federal (and sometimes state and local) appropriations for rail passenger service, and represent sunk costs. Therefore, no annual cost for such capital expenditure will be charged to HSR service. Variable costs associated with the operation of terminals will be included in the analysis, however, as additional trains and passengers will generally increase terminal maintenance and operating costs.

4.2. VARIABLE COST

These are the costs which are directly associated with the actual operation of the trains and accompanying service. All costs are assumed to be linear in the explaining output variables; and with the exception of way and structure costs, all operating costs are assumed to be zero when output is zero.

Vehicles

The type of cars used are the ones most frequently used for passenger service in the United States. Only snack and coach cars are considered in this study for comparison with the type of service offered by the air modes. A standard coach has a seating capacity of 80 passengers, and a snack coach has a seating capacity of 64 passengers. Trains can be run with a minimum of one locomotive and one coach up to a maximum of one locomotive and ten coaches. Coach costs were estimated at $650,000 per car (Ernst, Robert, The Budd Co., as referenced in Marchetti, 1984), while locomotives such as the AEM-7, a new high speed, light weight, electric passenger locomotive (Ephraim, 1981), were estimated to cost not less than $1 million each. The annual fleet investment cost is based on a 15% interest rate and a maximum expected life of 30 years.

ACTI = CRF x ($1,000,000 (L) + $650,000 (C))

where: CRF = 0.15230

L is the number of locomotives necessary to operate service

C is the number of coach cars necessary to operate service

Transportation Operating Costs

These are costs incurred as a direct result of operating the train service. These costs include crew, fuel, and switching operations and are computed on the basis of train miles and car miles. The relationships for this part of the analysis were developed entirely by updating similar relationships from the 1972 DOT Report. The coefficients in these equations were updated to 1982 dollars by multiplying them by the appropriate railroad cost recovery index (Association of American Railroads Yearbook, 1983). The updated cost relationships are:

(1) Electric Power (Fuel): EP = $0.4286 x CM

(2) Block Station: BS = $0.5247 x TM

(3) Division Operator: DO = $0.2501 x TM

(4) Yard and Switching: YAS = $0.2064 x TM

(5) Asst. Superintendant of Passenger Transportation: ASPT = $0.1817 x TM

Crew costs, which are a part of transportation operating cost, were based on three crewmen for a one car train and one crewman for each additional two cars added. The updated equation for crew cost is:

$$TRC = \$2.2945 \times TM + \$0.3047 \times CM$$

Maintenance of Equipment Cost

These are all the cost associated with the maintenance of the locomotives and coaches including labor, material, insurance, and building rental. The costs are functions of train miles and car miles. Cost relationships were updated resulting in the following equation:

$$DME = \$1.1469 \times TM + \$0.3105 \times CM$$

Maintenance of Way and Structure

These costs include all maintenance of track, structures, and communications signals. The costs are explained on the basis of a fixed component per route mile and a variable component per gross ton mile of the system. The updated relationship from the 1972 DOT report is as follows:

$$DMWS = \$31{,}873 \times SL + \$0.00608 \times GTM$$

where: GTM = annual gross ton miles

The gross weight of a locomotive is based on the AEM-7 locomotive which equals 100 tons (Ephraim, 1981), and a standard coach which has a fully loaded weight of 60 tons. Therefore, annual gross ton miles are calculated as follows:

$$GTM = 100 \times TM + 60 \times CM$$

Terminal Operating Costs:

These are the costs incurred as a direct result of operating a terminal facility. All costs for an existing urban terminal, with the exception of stationmaster expense, are explained on the basis of number of passengers utilizing the system. Station maintenance is included here rather than under maintenance of way and structures in order to keep all terminal expenses together. The following cost relationships have been updated for an existing urban terminal:

Ticket Sales: $UTSO = \$0.6750 \times BNSP$

Station Utilities: $UTIL = \$0.2321 \times BNSP$

Station Cleaning: $CLEN = \$0.1428 \times BNSP$

Station Maintenance: $SMAIN = \$0.1652 \times BNSP$

Station Master: $SMA = \$0.4969 \times TM$

4.3 TOTAL COST EQUATIONS

The purpose of this section is to present the components which comprise each of the HSR total cost equations and the cost per passenger mile equation corresponding to each one. Additionally, in Table 9, updated cost parameters used in the model are summarized by identifying the source and value of the original factor, and then stating the factor and source used to update this parameter to its present value.

1. Average Annual Total Cost (TAAC):

Major Capital Expenditures:

-Track and Roadbed Upgrading (TER) = 0.15230 x $4.5 million x SL

Variable Cost:

-Fleet Investment (ACTI) = CRF x ($1,000,000 (L) + $650,000 (C))

-Transportation Operating Cost:

1. Electric Power (EP) = $0.4286 x CM
2. Block Station (BS) = $0.5247 x TM
3. Division Operator (DO) = $0.2501 x TM
4. Yard and Switching (YAS) = $0.2064 x TM
5. Asst. Superintendant of Passenger Transportation (ASPT) = $0.1817 x TM
6. Crew Costs (TRC) = $2.2945 x TM + $0.3047 x CM

-Maintenance of Equipment (DME) = $1.1469 x TM + $0.3105 x CM

-Maintenance of Way and Structure (DMWS) = $31,873 x SL + $0.00608 x GTM

-Terminal Operating Cost:

1. Ticket Sales (UTSO) = $0.6750 x BNSP
2. Station Utilities (UTIL) = $0.2321 x BNSP
3. Station Cleaning (CLEN) = $0.1428 x BNSP
4. Station Maintenance (SMAIN) = $0.1652 x BNSP
5. Station Master (SMA) = $0.4969 x TM

$$\begin{aligned} \text{TAAC} = {} & \text{TER} + \text{ACTI} + \text{EP} + \text{BS} + \text{DO} + \text{YAS} + \text{ASPT} + \text{TRC} + \text{DME} + \text{DMWS} + \\ & \text{UTSO} + \text{UTIL} + \text{CLEN} + \text{SMAIN} + \text{SMA} \end{aligned}$$

The cost per passenger mile based on total cost is calculated as follows:

$$\text{PPCUU} = \frac{\text{TAAC}}{\text{SL x BNSP}}$$

2. Average Annual Total Cost Excluding Fixed Facility Capital Cost (TALC):

This cost is equal to the total cost excluding the major capital expenditure of track and roadbed upgrading.

$$TALC = TAAC - TER$$

The cost per passenger mile based on total cost excluding fixed facility capital cost is calculated as follows:

$$PPUUV = \frac{TALC}{SL \times BNSP}$$

3. Average Annual Total Cost Excluding All Capital Cost (TALCAV):

This cost is equal to the total cost excluding fixed facility cost calculated above, minus the annual fleet investment.

$$TALCAV = TALC - ACTI$$

The cost per passenger mile based on total cost excluding all capital cost is calculated as follows:

$$PPWOV = \frac{TALCAV}{SL \times BNSP}$$

TABLE 9. Summary of Updated Cost Parameters:

Unit Cost Parameter	Parameter Value (Year)	Source of Original Parameter	Updating Factor	Source of Updating Factor	Parameter Value (1982)
Transportation Operating Costs:		1972 DOT Report			
(1) Electric Power	$0.1522 (1972)	"	2.82	p. 493 U.S. Statistical Abstract, 1984	$0.4286
(2) Block Station	$0.2171 (1972)	"	2.42	p. 59 Association of American Railroads Year Book (1983)	$0.5247
(3) Division Operator	$0.1035 (1972)	"	2.42	"	$0.2501
(4) Yard & Switching	$0.0854 (1972)	"	2.42	"	$0.2064
(5) Asst.Superintendent of Pass. Transp.	$0.0752 (1972)	"	2.42	"	$0.1817
(6) Crew Costs	$0.8381 (1972)	"	2.74	"	$2.2945
	$0.1113 (1972)	"	2.74	"	$0.3047
Maintenance of Equipment Costs	$0.4096 (1971)	"	2.80	"	$1.1469
	$0.1109 (1971)	"	2.80	"	$0.3105
Maintenance of Way and Structure	$10980 (1970)	"	2.90	"	$31,873
	$.002094 (1970)	"	2.90	"	$0.00608
Terminal Operating Costs:					
(1) Ticket Sales	$.2793 (1972)	"	2.42	"	$0.6750
(2) Station Utilities	$.0898 (1972)	"	2.42	"	$0.2321
(3) Station Cleaning	$.0591 (1972)	"	2.42	"	$0.1428
(4) Station Maintenance	$.0639 (1972)	"	2.42	"	$0.1652
(5) Station Master	$.2056 (1972)	"	2.42	"	$0.4969

4.4. COST PER PASSENGTER MILE

The purpose of this section is to present the cost per passenger mile and output capabilities from the high speed rail cost model. These different values were calculated for the cost per passenger mile. These were based on the following:

1) Total cost (see Figure 7)
2) Total cost minus fixed facility capital cost (see Figure 8)
3) Total cost minus all capital cost (see Figure 9)

The costs per passenger mile for each of these calculations are summarized in Tables 10 and 11. Figure 7 shows a graph of average cost per passenger mile based on total cost, versus average one-way daily passenger volumes. The cost is influenced almost entirely by the cost component of track and roadbed upgrading, and the cost per passenger mile is tremendously high. When all costs are considered frequency of train operation has very little significance as observed by the small difference in passenger mile cost between the two frequencies considered (the service which is slightly more expensive operates twice as many trains). Changes in stage length resulted in insignificant changes in cost which is not surprising since the major cost component is assessed by the mile. Obviously, the more passengers there are on the system, the less costly it is per passenger.

Figure 8 shows a graph of average cost per passenger mile based on total cost excluding fixed facility capital cost, versus average one-way daily passenger volumes. Eliminating the cost component for track upgrading reduces costs by as much as 400%. Again, costs per passenger decreases as daily passenger volume increases. Also, the difference in costs for different stage lengths is not significant, but frequency of train operation does become significant.

Figure 9 shows a graph of average cost per passenger mile based on total cost excluding all capital cost, versus average one-way daily passenger volumes. Costs are slightly lower than those observed in Figure 8, since car and locomotive costs have been eliminated. Additionally, stage lengths do not effect cost per passenger mile, but frequency and passengers volumes do.

TABLE 10. High speed rail costs per passenger mile vs. stage length and passenger volume, with directional headways of 1.0 hour/departure in peak and 2.0 hours/departure in base period.

Stage Length		Average Cost, $/Pass. Mile	
Directional Passenger Volume, Pass./Day	Total Cost	Total Cost Minus Fixed Facility Costs	Total Cost Minus All Capital Cost
100 miles			
250	4.9136	.6322	.5358
500	2.4821	.3414	.2933
750	1.6929	.2658	.2210
1000	1.2727	.2024	.1688
1250	1.0399	.1837	.1503
1500	.8751	.1615	.1337
200 miles			
250	4.8593	.5779	.5297
500	2.4520	.3113	.2872
750	1.6644	.2373	.2149
1000	1.2498	.1795	.1627
1250	1.0172	.1609	.1442
1500	.8551	.1415	.1276
300 miles			
250	4.8504	.5690	.5277
500	2.4465	.3058	.2852
750	1.6592	.2321	.2129
1000	1.2454	.1751	.1607
1250	1.0132	.1570	.1422
1500	.8515	.1379	.1256

TABLE 11. High speed rail costs per passenger mile vs. stage length and passenger volume, with directional headways of 0.5 hours/departure in peak and 1.0 hour/departure in base period.

Stage Length, mi.	Average Cost, $/Pass. Mile		
Directional Passenger Volume, Pass./Day	Total Cost	Total Cost Minus Fixed Facility Cost	Total Cost Minus All Capital Cost
100 miles			
250	5.2933	1.0119	.8604
500	2.6527	.5120	.4363
750	1.7946	.3675	.3206
1000	1.3490	.2786	.2435
1250	1.1060	.2497	.2075
1500	.9347	.2212	.1878
200 miles			
250	5.2321	.9507	.8543
500	2.6191	.4784	.4302
750	1.7738	.3466	.3145
1000	1.3319	.2615	.2374
1250	1.0840	.2277	.2014
1500	.9172	.2036	.1817
300 miles			
250	5.2071	.9257	.8523
500	2.6056	.4649	.4282
750	1.7641	.3370	.3125
1000	1.3241	.2537	.2354
1250	1.0758	.2195	.1994
1500	.9100	.1964	.1797

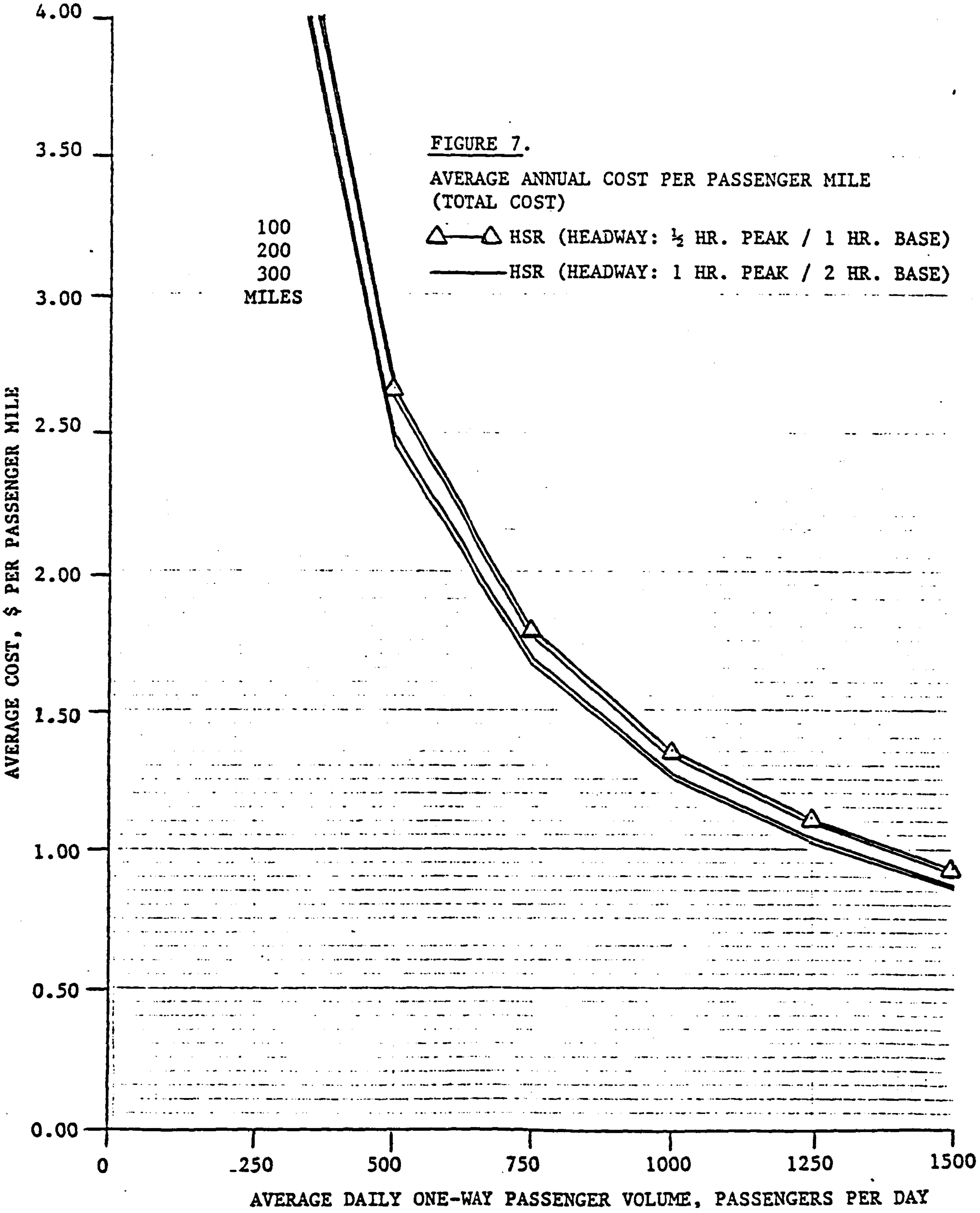

FIGURE 7.

AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST)

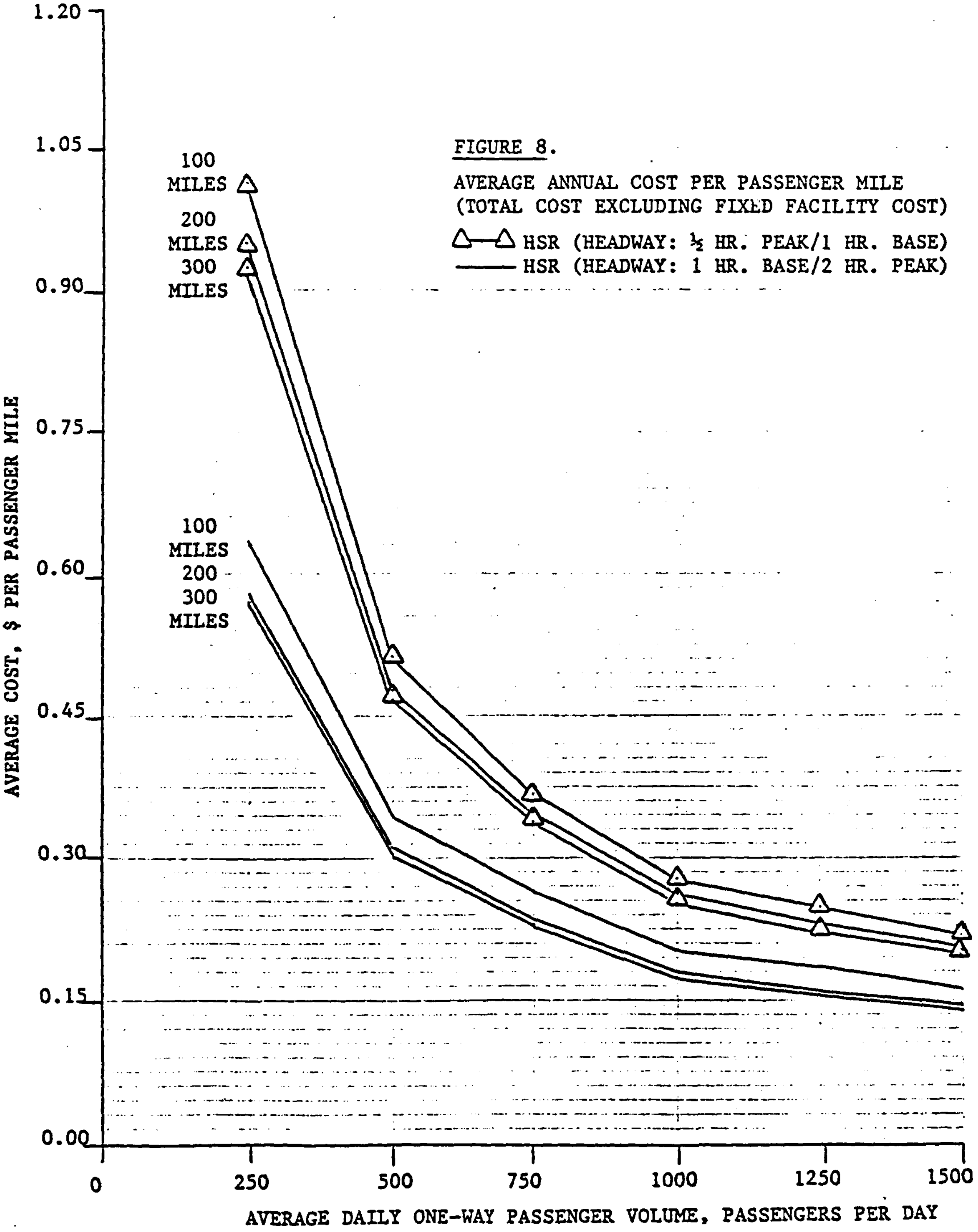

FIGURE 8.

AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST EXCLUDING FIXED FACILITY COST)

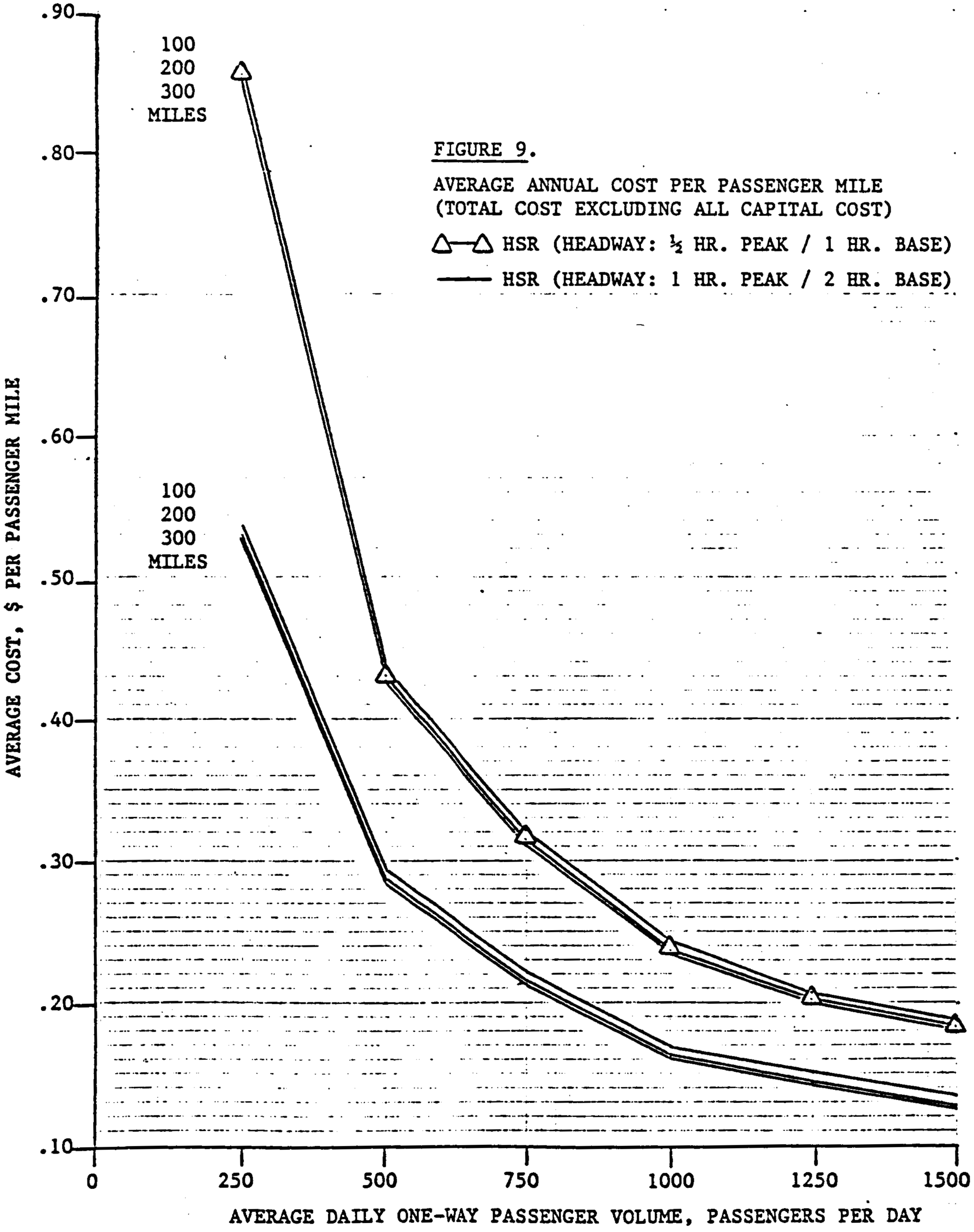

FIGURE 9.

AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST EXCLUDING ALL CAPITAL COST)

4.5. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to investigate if changes in certain model parameters would have a significant effect on passenger mile cost. The analysis examined frequency of operation, fuel cost, interest rates, load factors, track upgrading cost, and vehicle cost. Table 12 presents a summary of the sensitivity analysis performed for the tilt-rotor technology. The format is identical to that used in Table 4.

Frequency: When total cost is considered frequency of train operations become insignificant as all costs are dominated by the track upgrading cost component. For the other costs measures considered, frequency is a significant factor. Running trains more often at lower passenger volumes has a greater effect on these costs than running trains more often at higher passenger volumes, and the same effects are observed regardless of stage length.

Fuel Cost: Fuel cost (electricity) changed passenger cost very little and was judged to be a non-sensitive parameter.

Interest Rate: Since the majority of total cost is due to the major expenditure for track upgrading, interest rates are extremely sensitive. When the track upgrading component was eliminated from the cost per passenger mile calculations, interest rates were basically insignificant.

Load Factors: Reducing the maximum allowable load factors had absolutely no effect for the high frequency (headway 1/2 hr. peak/1 hr. base) since there was excess capacity under this operating scheme. For the lower frequency (headways: 1 hr. peak/2 hr. base) there was excess capacity at the 500 passenger volume and costs were not effected. For demands greater than this costs were affected since more train operations and larger fleet sizes were required to satisfy demand. Of course, for total cost the effect was minimal as previously explained. For the other costs considered, reducing maximum allowable load factors was relatively significant.

Track and Roadbed Upgrading: Since this cost component represents such a large proportion of total cost, it is not surprising that this parameter is extremely sensitive to change. This component was excluded for the other two cost categories considered, so it did not effect them.

Vehicle Cost: Changes in vehicle cost had caused little change in passenger mile cost and was generally judged to be a non-sensitive parameter. The minor effect that it did have was more apparent at shorter stage lengths.

TABLE 12. SENSITIVITY ANALYSIS FOR HIGH SPEED RAIL
% CHANGE IN COST PER PASSENGER MILE

COST								
STAGE LENGTH	AVG. DAILY PASSENGERS	FREQ. (-100%)	FUEL COST (+10.64%)	INT. RATE (-20%)	L.F. 8-12 FREQ (-10%)	L.F. 16-24 FREQ (-10%)	TRACK UPGRADE (+10%)	VEH. COST (+100%)
	1							
100	500	-7.17	+0.08	-15.49	0.00	0.00	+8.08	+2.86
	3000	-6.38	+0.19	-14.77	+1.21	0.00	+7.63	+3.57
200	500	-7.13	+0.08	-15.47	0.00	0.00	+8.18	+1.84
	3000	-6.77	+0.20	-14.83	+0.87	0.00	+7.77	+2.40
300	500	-6.85	+0.08	-15.47	0.00	0.00	+8.22	+1.41
	3000	-6.43	+0.20	-14.85	+0.82	0.00	+7.84	+1.85
	2							
100	500	-37.52	+0.41	-2.77	0.00	0.00	0.00	+14.96
	3000	-26.99	+0.80	-2.80	+4.24	0.00	0.00	+15.05
200	500	-39.21	+0.44	-1.87	0.00	0.00	0.00	+10.14
	3000	-30.50	+0.88	-1.96	+5.30	0.00	0.00	+10.81
300	500	-38.53	+0.45	-1.46	0.00	0.00	0.00	+7.94
	3000	-29.79	+0.92	-1.58	+5.08	0.00	0.00	+8.55
	3							
100	500	-37.73	+0.49	0.00	0.00	0.00	0.00	0.00
	3000	-28.81	+0.96	0.00	+3.22	0.00	0.00	0.00
200	500	-38.00	+0.49	0.00	0.00	0.00	0.00	0.00
	3000	-29.77	+0.99	0.00	+3.37	0.00	0.00	0.00
300	500	-38.09	+0.48	0.00	0.00	0.00	0.00	0.00
	3000	-30.11	+1.00	0.00	+3.42	0.00	0.00	0.00

1. TOTAL COST
2. TOTAL COST EXCLUDING FACILITY CAPITAL COST
3. TOTAL COST EXCLUDING ALL CAPITAL COST

5. COMPARISON OF TECHNOLOGIES

5.1. TILT-ROTOR AND CTOL

The purpose of this section is to present the results of the comparison of the two aircraft modes in terms of their cost and transport output capabilities. The individual cost per passenger mile for the 45 passenger tilt-rotor aircraft was presented in section II, and those for the CTOL technology were presented in section III.

Figure 10 shows a graph comparing average cost per passenger mile based on total cost versus average one-way daily passenger volumes. At the 100 mile stage length VTOL technology has a lower cost per passenger mile until approximately the 500 one-way passenger volume. At volumes greater than this, the cost are very similiar. At the 200 mile stage length the CTOL cost is less than VTOL cost for all passenger volumes. For the 300 mile stage length, VTOL technology once again has a lower cost per passenger mile up until about the 500 passenger volume, but is more expensive for all passenger volumes exceeding this.

As previously stated, another appropriate cost per passenger mile to consider is the one based on total cost minus fixed facility capital cost, since many of these costs are typically financed by federal, state, and local governments, or other airport revenues, rather than charged directly to an airline. The VTOL cost per passenger mile minus fixed facility cost will be compared to the CTOL cost per passenger mile based on total cost. This is because the total cost calculations for CTOL assumed that no further construction of terminals and runways was required.

Figure 11 shows the comparison of these costs for tilt-rotor aircraft and a $\$12^{+}$ million CTOL aircraft. Figure 12 shows this comparison considering a $7 million CTOL aircraft since it was stated in section III that DC-9-30 aircraft were available at this price on the resale market, and since the sensitivity analysis showed that aircraft cost was a moderately sensitive parameter, particularly at lower passenger volumes.

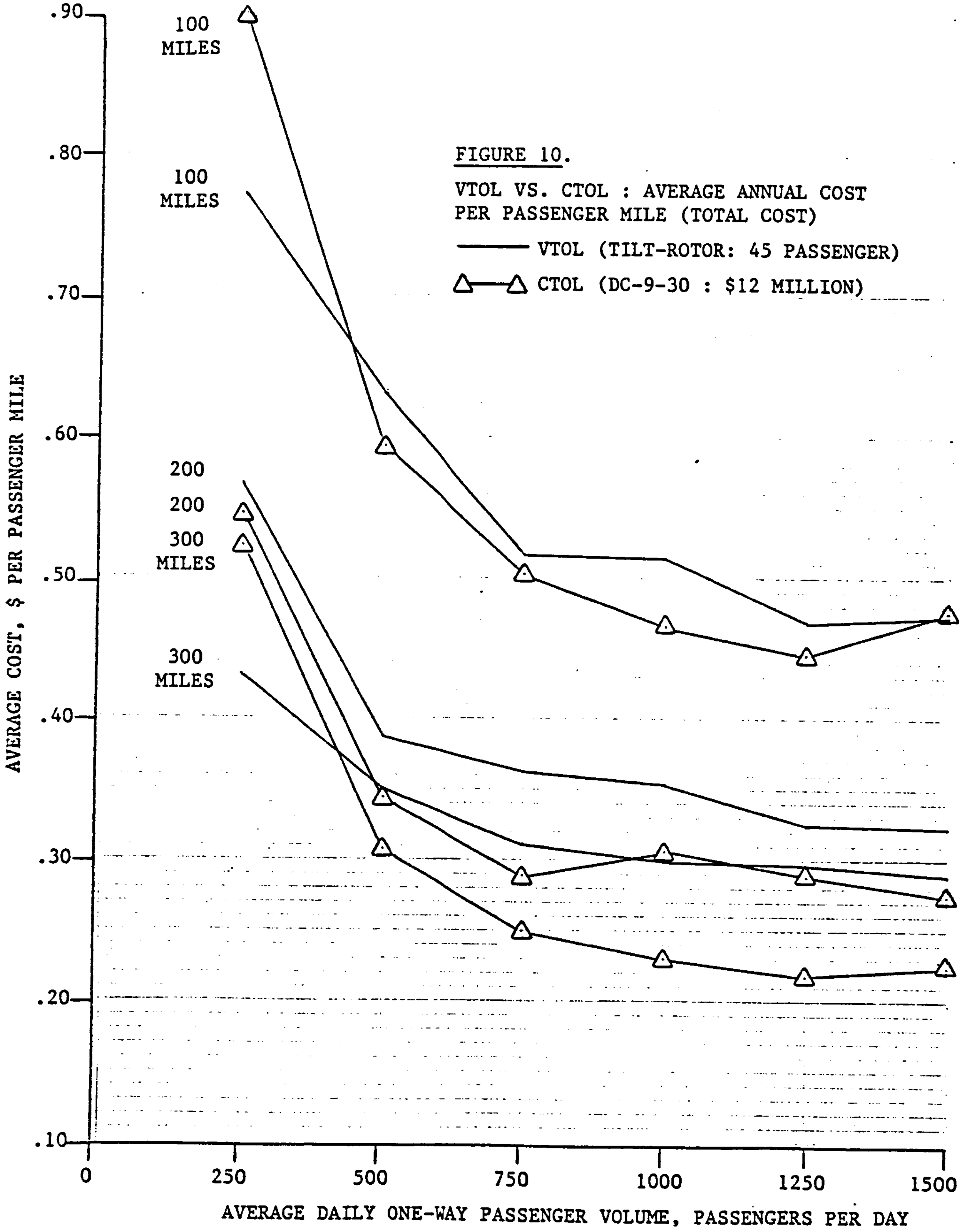

FIGURE 10.

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

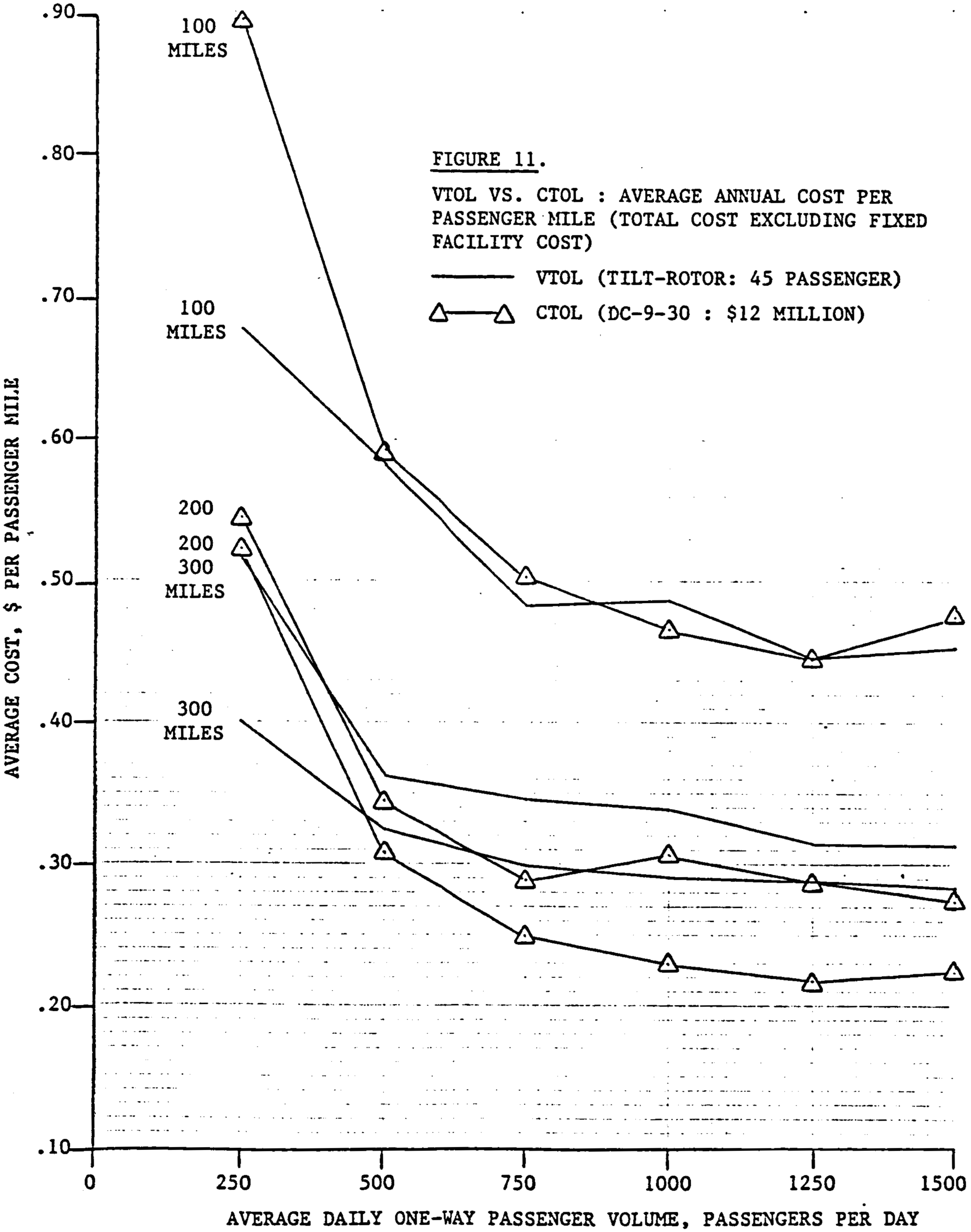

FIGURE 11.

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

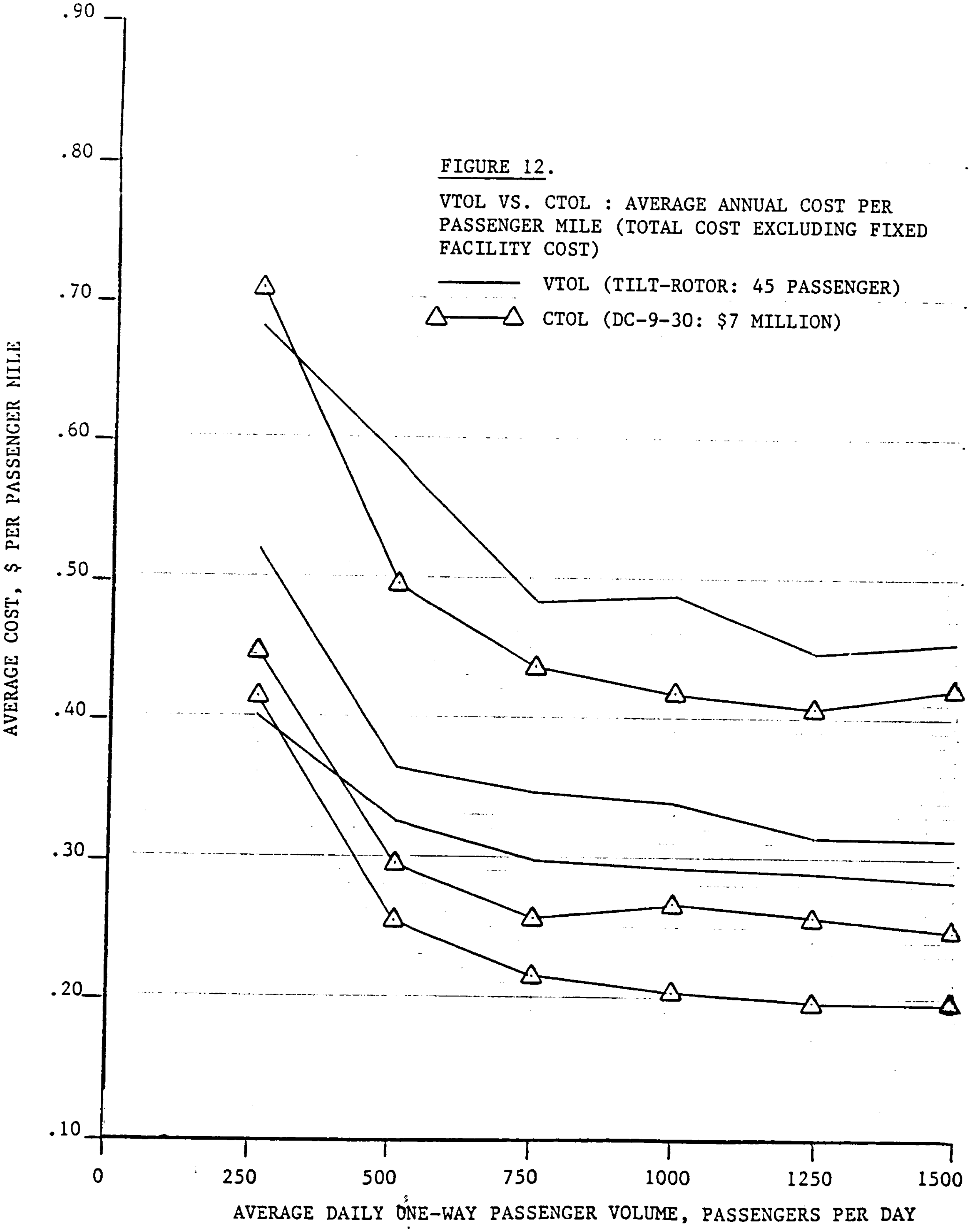

FIGURE 12.

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

In Figure 11, VTOL costs are substantially less than CTOL costs for the 100 mile stage length up to the 500 passenger volume and very similiar for all other passenger volumes. For the 200 mile stage length VTOL and CTOL costs are very similiar up to the 500 passenger volume. At volumes greater than this, CTOL is always less expensive. For the 300 mile stage length, VTOL is less expensive than the CTOL up to the 500 passenger volume, and more expensive at passenger volumes greater than this.

When the $7 million aircraft is considered as in Figure 12, CTOL technology appears much less expensive than VTOL technology for almost all stage lengths and passenger volumes. The costs are similiar at very low passenger volumes for both the 100 and 300 mile stage lengths.

Figure 13 shows a comparison of average costs per passenger mile based on total cost excluding all capital cost. At the 100 mile stage length VTOL has the advantage over the entire range of passenger volumes. At the 200 mile stage length VTOL has a slight advantage up to the 500 passenger level. Beyond this point, costs per passenger mile are almost identical. At the 300 mile stage length VTOL is less expensive up until the 400 passenger level. At volumes greater than this, CTOL has a slight advantage over VTOL.

In summary, VTOL seems favorable, or at least competitive, up until about a one-way volume of 500 passengers, particularly at shorter stage lengths. This is attributable to the excess capacity of the DC-9-30 at low passenger volumes which result from the frequency of flights required to meet a specified minimum level of service.

Actually, output above the 1000 one-way passenger level may prove infeasible for the small tilt-rotor aircraft analyzed here. This level of demand would require departures at each terminal approximately every 20 minutes during peak periods and about every 26 minutes in base periods (see Table 3). While one of the primary reasons for introducing the tilt-rotor service may be to help alleviate the problem of air congestion, the impact of this number of aircraft movements would hardly do that.

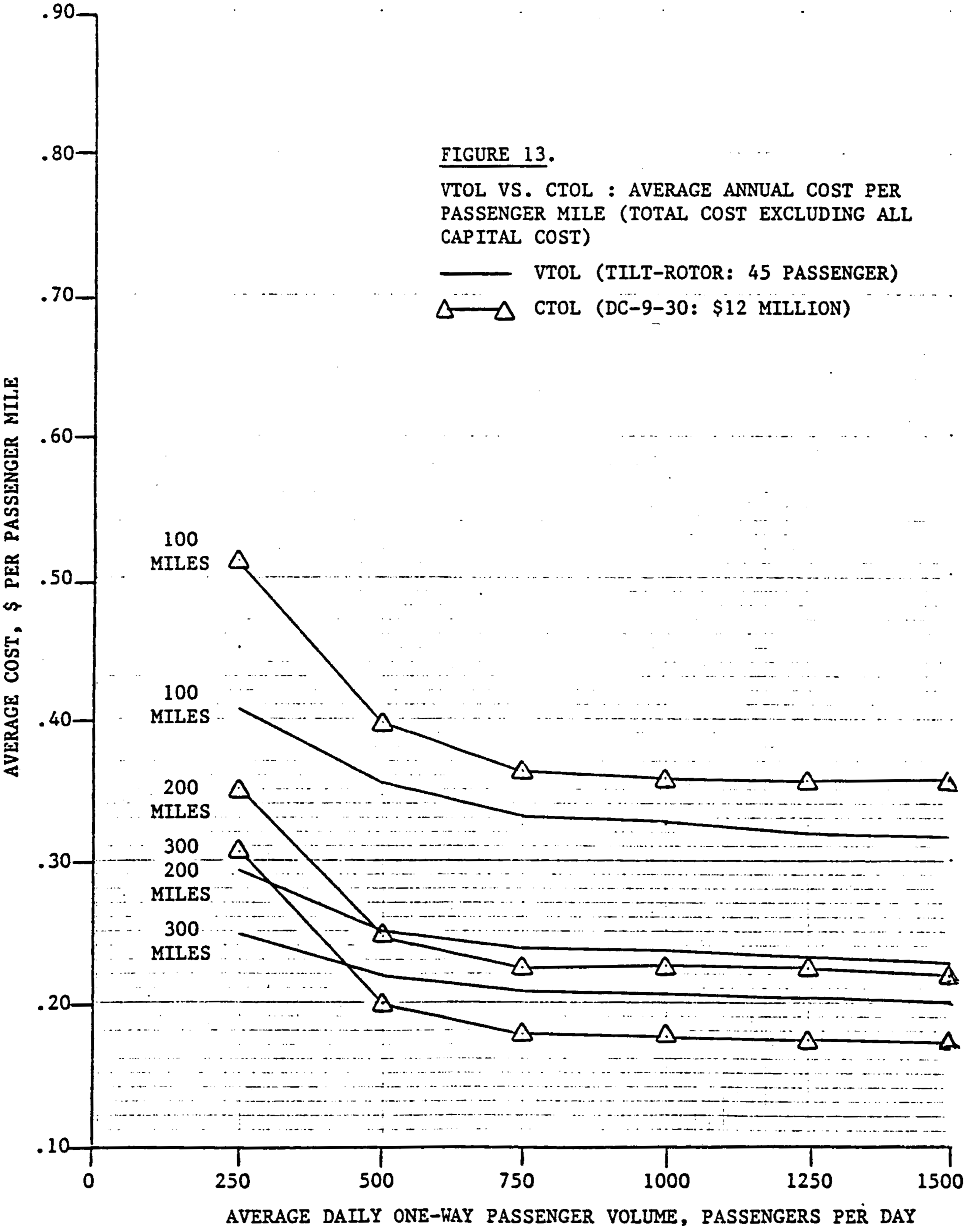

FIGURE 13.

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

5.2. TILT-ROTOR AND HSR

The purpose of this section is to present the results of the comparison of tilt-rotor and HSR technologies in terms of their cost and transport output capabilities. The individual cost per passenger mile for the 45 passenger tilt-rotor aircraft was presented in section II, and those for the HSR technology were presented in section IV.

When average costs per passenger mile based on total cost are compared as in Figure 14, tilt-rotor technology appears much superior to the exorbitant cost of rail.

Figure 15 shows a graph comparing average cost per passenger mile based on total cost excluding fixed facility cost. This cost eliminates the major capital expenditure of track and roadbed upgrading and allows HSR to become much more competitive with tilt-rotor technology, particularly as passenger volumes increase.

Figure 16 shows a comparison of average cost per passenger mile based on total cost excluding all capital cost. As in the previous figure VTOL is less expensive than HSR at low passenger volumes. HSR becomes more competitive as passenger volumes increase.

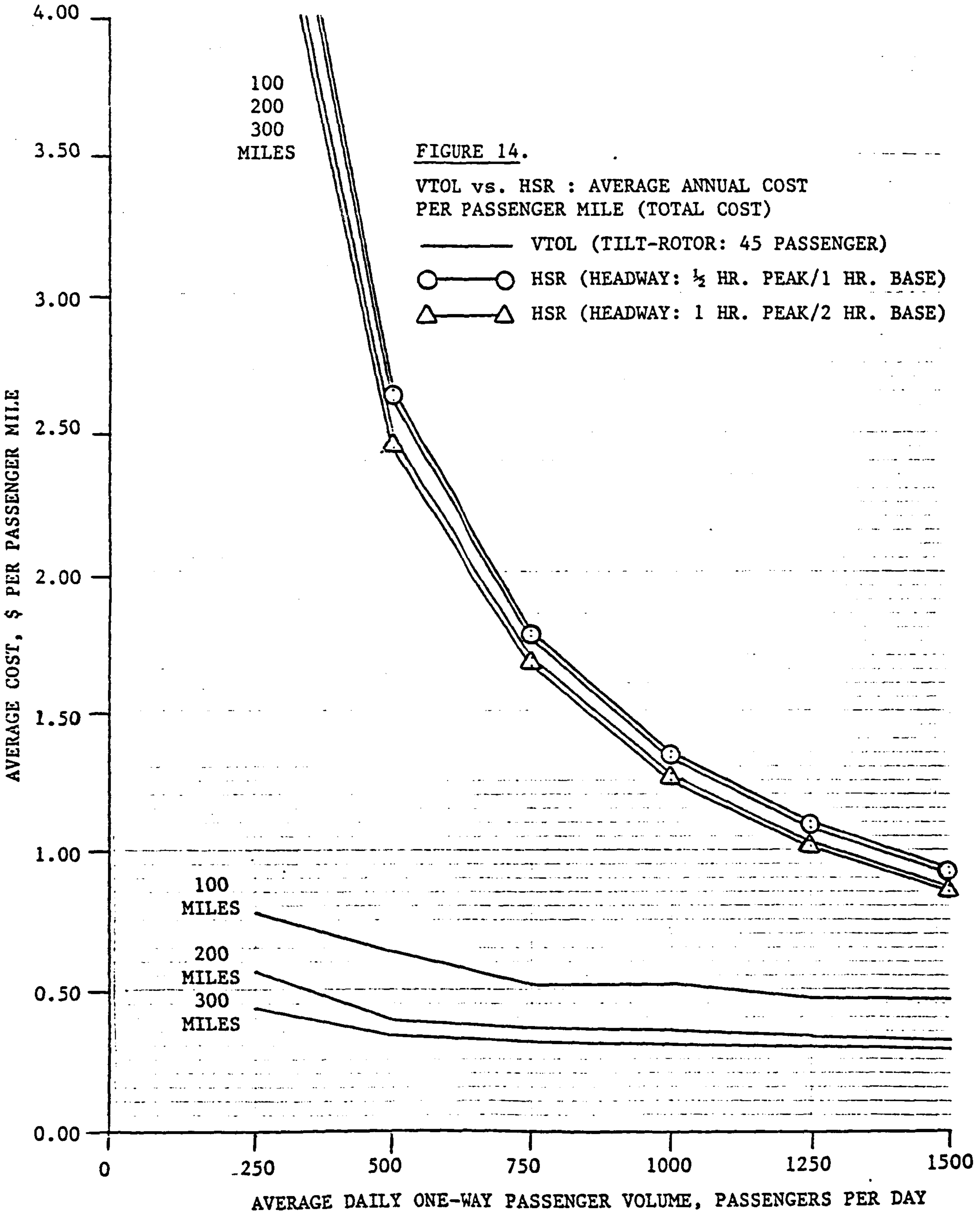

FIGURE 14.

VTOL vs. HSR : AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST)

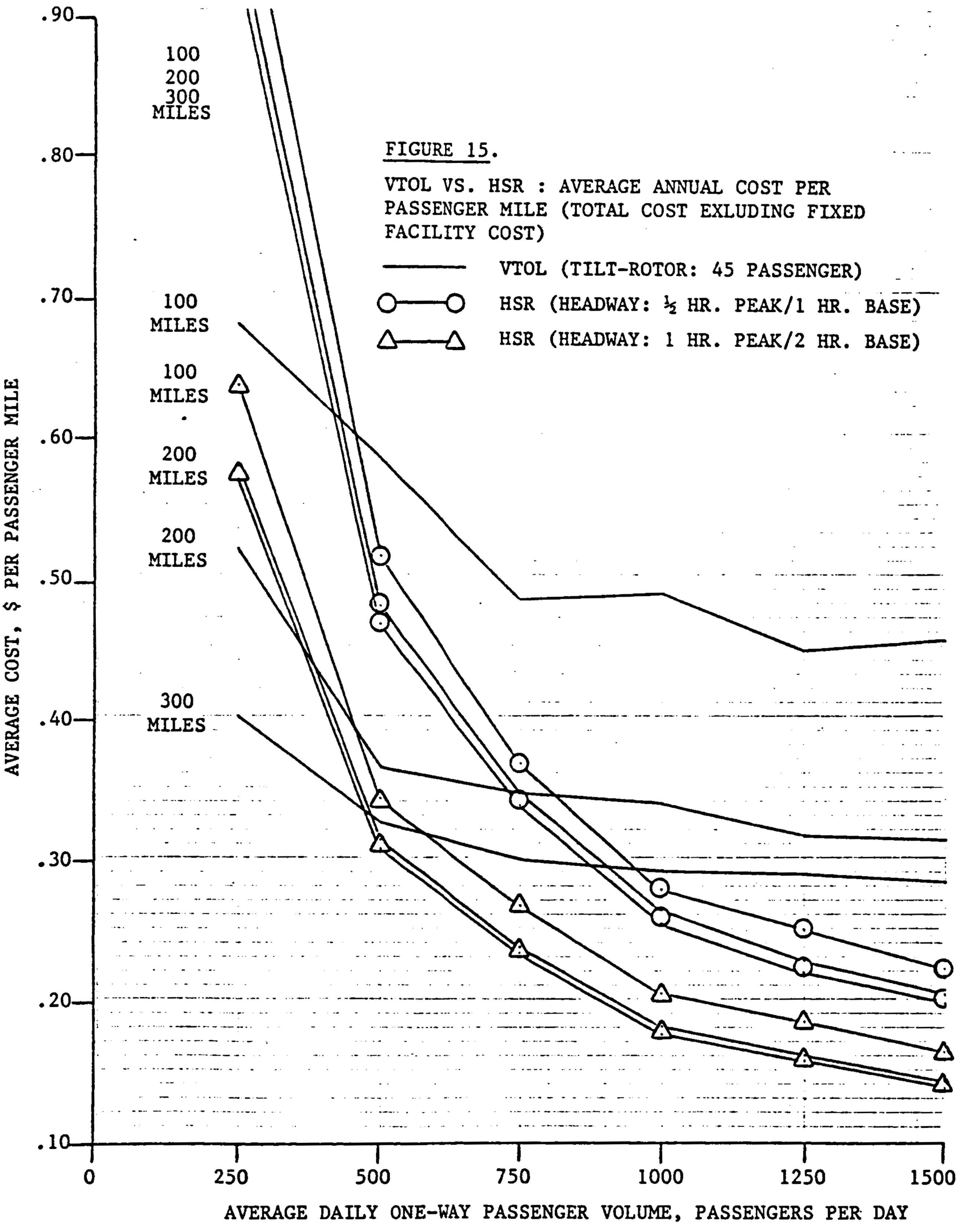

FIGURE 15.

VTOL VS. HSR : AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST EXLUDING FIXED FACILITY COST)

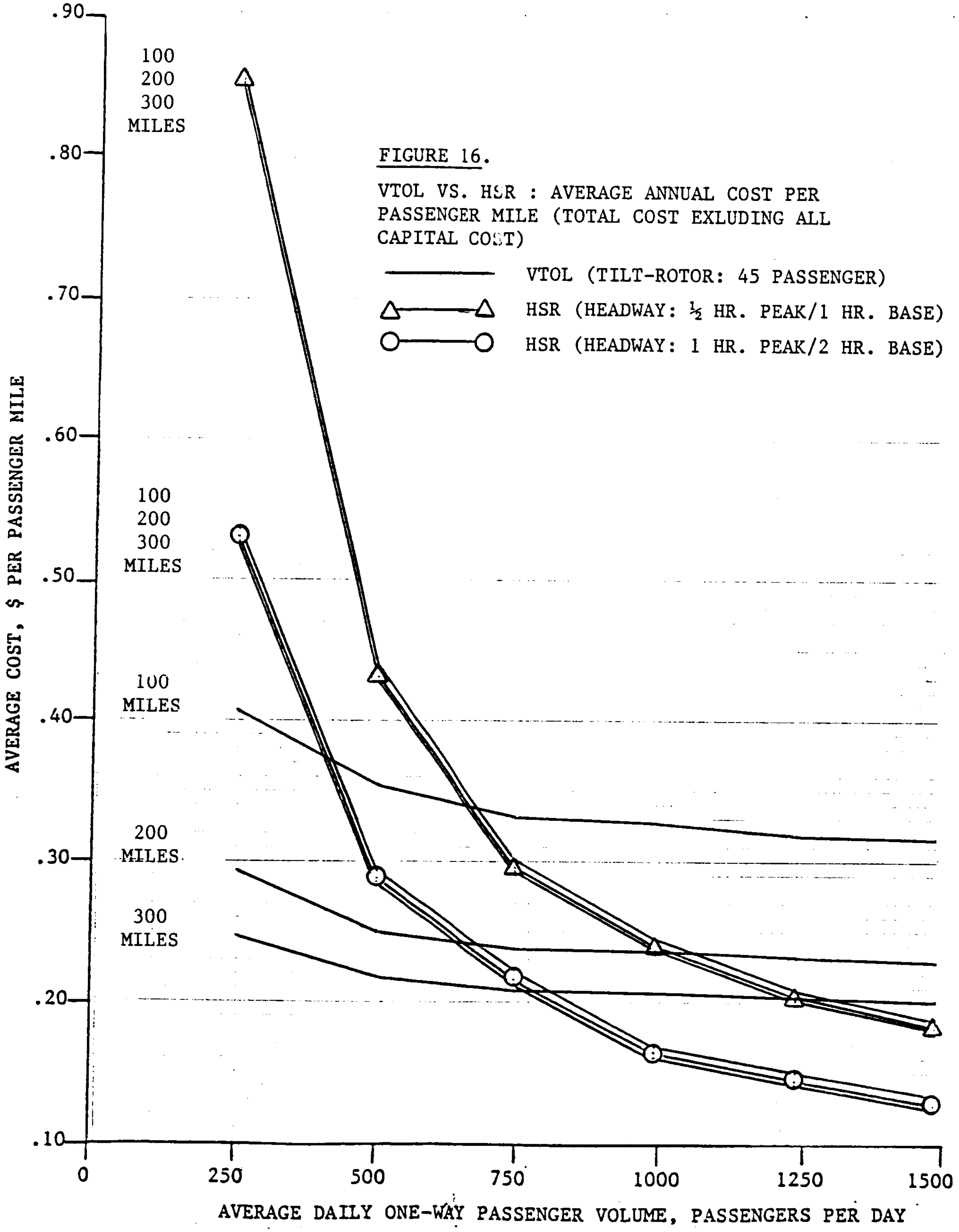

FIGURE 16.

VTOL VS. HSR : AVERAGE ANNUAL COST PER PASSENGER MILE (TOTAL COST EXLUDING ALL CAPITAL COST)

6. CONCLUSIONS

It appears from this cost analysis that at low passenger volumes and particularly at shorter stage lengths tilt-rotor aircraft could compete with conventional aircraft. Unless HSR transportation is greatly subsidized, VTOL and CTOL technologies both seem much superior based on cost per passenger mile.

More accurate cost information will be available once the military tilt-rotor aircraft is produced and cost data gathered from its flight experience. This will allow for better estimates of the tilt-rotor potential to enter a market. The sensitivity analysis showed that the aircraft cost was particularly sensitive, therefore if tilt-rotor aircraft can be acquired at cost substantially lower than those estimated in the VTOL mode, total cost may be reduced and the aircraft may become more feasible.

While this analysis has compared VTOL, CTOL, and HSR technologies for a variety of passenger demands and stage lengths, the true feasibility of a tilt-rotor aircraft operation can only be determined by identifying and analyzing specific markets where this technology might be applicable.

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APPENDICES

APPENDIX A

VTOL Cost Computer Program

This program, named "LINKTR", is the computerized version of the VTOL cost model. For every stage length, passenger flow, minimum allowable frequency and load factor specified in the data entries, the following calculations are performed and printed in the computer output:

- useable seats for both peaks and base periods
- actual aircraft frequency per period (number of daily departures in each period)
- annual direct cost (dollars)
- annual indirect cost (dollars)
- annual total cost (dollars)
- cost per passenger mile based on total cost
- cost per passenger mile based on total cost minus fixed facility capital cost
- cost per passenger mile based on total cost minus all capital cost
- fleet size
- terminal cost (dollars)

Note: Distances refer to airline distances.

The basic logic of the LINKTR program is outlined in the following steps:

1. Read data
2. Calculate passenger flows during peak and base periods
3. Calculate usable seats for specified minimum allowable frequency
4. Test whether usable seats generated from running at minimum allowable frequency satisfies peak demand
    - If demand is satisfied, go to step 5
    - If demand is not satisfied, increase frequency in order to satisfy demand; go to step 5

5. Repeat steps 3 and 4 for base period
6. Determine fleet size which enables operator to provide frequencies required to satisfy demand and level of service requirements
7. Calculate direct, indirect, and total costs
8. Calculate costs per passenger miles
9. Print output

* DO LOOPS repeat above process for all stage lengths and capacities.

The application of the program was particularly useful in performing a sensitivity analysis of various parameters used in the model. For example, the following parameters were changed and their effect on annual cost and cost per passenger mile were observed: aircraft cost, aircraft speed, crew cost, direct maintenance, fuel cost, interest rate, load factors, terminal cost and turn-around times.

```
LINKTR

C       INTERCITY PASSENGER MODES COST COMPARISON
C       COST OF TILTROTOR OPERATING FROM EXISTING TERMINALS FOR
C       A SINGLE LINK
C
        DIMENSION D(14,8)
C
C       THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
        DO 100 I=1,14
        READ(13,50) (D(I,J) ,J=1,8)
   100  CONTINUE
C
C       THIS SECTION SETS THE DO LCOPS AND ADVANCES THE LOAD FACTOR,MINIMUM
C       FREQUENCY,PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
C       SPECIFICATIONS IN THE DATA DECK
        I1=D(1,1)
        DO 402 J=1,I1
        JO=J
        JO=JO+1.
        I2=D(5,1)
        DO 403 K=1,I2
        KO=K
        KO=KO+1
        CAP=D(3,2)
        I3=D(3,1)
        DO 404 I=1,I3
        SL=D(4,2)
        I4=D(4,1)
        DO 405 M=1,I4
        I13=D(13,1)
        DO 407 N=1,I13
        NO=N
        NO=NO+1
C
C
C
C       CALCULATE RCUND TRIP TRAVEL TIME
        TT=2*(SL/D(10,1))+0.667
C
C       CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
        BPHP=CAP*D(7,1)*D(12,1)*2
C
C       CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
        UPHP=BPHP/2.0
C
C       CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
        BPP=CAP-BPHP
C
C       CALCULATE UNIDIRECTIONAL PASSENGER FLOW DURING BASE PERIOD
        UBPP=BPP/2.0
C
C       CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY
C       FOR THE PEAK PERIOD
        PFR=D(5,KO)/2.0
C
C
C       THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR A TILT-
C       ROTOR AIRCRAFT OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
C       FREQUENCY
        PCAP=D(9,1)*D(5,KO)*D(1,JO)
        IF (BPHP-PCAP)190,190,192
C
C       IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
C       IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
   192  PFR=UPHP/(D(9,1)*D(1,JO))
        PFR=PFR+0.99
        IPFR=IFIX(PFR)
        PFR=IPFR
C
C       THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT
C       MOVEMENTS AND NUMBER OF USABLE SEATS DURING THE PEAK PERIOD
   190  UPCAP=PFR*D(9,1)*D(1,JO)
        UAR=PFR
        AR=UAR*2.0
        PCAP=UPCAP*2.0
C
C       CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
C       THE BASE PERIOD
        GFR=D(6,KO)/2.0
C
```

```
LINKTR

C       THIS SECTION CALCULATES TOTAL BASE PERIOD USABLE SEATS FOR A TILT-
C       ROTOR AIRCRAFT  OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
C       FREQUENCY
        OCAP=D(9,1)*D(6,KO)*D(2,JO)
        IF (BPP-OCAP) 390,390,392
C
C       IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
C       MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
  392   OFR=UBPP/(D(9,1)*D(2,JO))
        OFR=OFR+0.99
        IOFR=IFIX(OFR)
        OFR=IOFR
C
C       THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT MOVEMENTS
C       AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
  390   UOCAP=OFR*D(9,1)*D(2,JO)
        UOAR=OFR
        OAR=UOAR*2.0
        OCAP=UOCAP*2.
C
C
C       CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
        UTFREQ=OFR+PFR
C
C       CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
        DPFR=PFR*2.0
C
C       CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
        DOFR=OFR*2.0
C
C       CALCULATE DAILY TWO WAY TOTAL FREQUENCY
        DFREQ=DPFR+DOFR
C
C       CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
        PHP=CAP*D(7,1)
C
C       CALCULATE NUMBER OF ANNUAL PASSENGERS
        BNSP=CAF*365
C
C       CALCULATE TOTAL ANNUAL MILES
        TAM=SL*DFREQ*365
C
C       CALCULATE ANNUAL FLIGHT HOURS
        AFH=(TT/2.)*DFREQ*365.
C
C       CALCULATE PEAK PERIOD HEADWAY
        PHD=(2*D(12,1))/PFR
C
C       CALCULATE BASE PERIOD HEADWAY
        OHD=(D(11,1)-(2*D(12,1)))/OFR
C
C       THIS SECTION CALCULATES THE NUMBER OF VTOL AIRCRAFT
C       NEEDED TO OPERATE SERVICE
        IF(D(12,1)-(TT/2)) 151,150,150
  150   BNTR=(TT/(2*PHD))+1.
        GO TO 152
  151   BNTR=(D(12,1)*((OHD/PHD-1)/OHD)+(TT/(2*OHD))+1)
  152   NTR=IFIX(BNTR)
        BNTR=NTR*2.
        BNTR=BNTR+0.99
        BNTR=IFIX(BNTR)
C
C       THIS SECTION CALCULATES DIRECT OPERATING COSTS
        ACTI=0.12448*9000000.*BNTR
        HI=0.02*0.80*9000000.*BNTR
        FC=240.*AFH
        FO=((277.+(8.63*SL))/6.5)*0.95*DFREQ*365.
        DM=259.515*SL*DFREQ
        AMB=0.60*DM
        TDOC=ACTI+HI+FC+FO+DM+AMB
C
C       THIS SECTION CALCULATES TOTAL INDIRECT OPERATING COST
C
C
C       THIS SECTION CALCULATES ANNUAL TERMINAL COST FOR EACH TERMINAL
        FDI=0.15113*4027500.
        FDM=6334.
        GA=0.15113*453150.
        GAM=997.
```

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OF POOR QUALITY

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LINKTR

1865         PHA=0.15113*82.*(7686+(60.089*D(7,1)*CAP))
1870         PHAM=0.46*(7686+(60.089*D(7,1)*CAP))
1875         PPRK=0.0
1880         CLAND=0.0
1885         TSTAF=470800.
1887         TERPAX=10.*365.*CAP
1890         TERCE=FDI+FDM+GA+GAM+PHA+PHAM+PPRK+CLAND+TSTAF
1893         TERCA=D(13,JO)*TERCE
1894         TERCOS=TERCA+TERFAX
1896  C
1897  C      THIS SECTION CALCULATES ANNUAL TERMINAL EXPENDITURES NOT DUE
1898  C      TO CAPITAL EXPENDITURES
1899         TEROPE=FDM+GAM+PHAM+TSTAF
1900         TAROPA=D(13,JO)*TEROPE
1901  C
1902  C      THIS SECTION CALCULATES AIRCRAFT PARKING COST
1904         APRK=0.15113*10368.*1.26*ENTR
1906         APRKM=10368.*0.028*ENTR
1908         TAPRK=APRK+APRKM
1910  C
1912  C      THIS SECTION CALCULATES COST OF CENTRAL OFFICE BUILDING
1914         PERC=25000.*0.01*CAP
1916  C
1918  C      THIS SECTION CALCULATES MISCELLANEOUS COSTS
1920         CMISC=19.92*(0.3178*TAM)
1921  C
1922  C      THIS SECTION CALCULATES TOTAL INDIRECT OPERATING COSTS
1923         TIOC=TERCA+TAPRK+PERC+CMISC*TERPAX
1955  C
1960  C      THIS SECTION COMPUTES THE INFORMATION TO BE PRINTED AS OUTPUT
1965  C
1970  C      THIS SECTION CALCULATES TOTAL COST
1990         TAAC=TDOC+TIOC
1991  C
1992  C      THIS SECTION CALCULATES TOTAL OPERATING COST LESS ALL COST
1993  C      FROM CAPITAL EXPENDITURES NOT INCLUDING VEHICLES
1994         TALC=TDOC+TAROPA+APRKM+PERC+CMISC+TERPAX
1995  C
1996  C      THIS SECTION CALCULATES TOTAL OPERATING COST LESS ALL COST
1997         TALCAV=TALC-ACTI
1998  C
2000         UUVWOV=TDOC-ACTI
2010         ZZ=CAP*SL*365
2020         PPCUU=TAAC/ZZ
2030         PPUUV=TALC/ZZ
2040         PPWOV=TALCAV/ZZ
2050         PH=D(12,1)*2
2060         BP=D(11,1)-PH
2065  C
2070  C      THIS SECTION PRINTS THE OUTPUT
2080         WRITE(20,8)
2085         WRITE(20,8)
2090         WRITE(20,1)
2095         WRITE(20,8)
2100         WRITE(20,10) SL
2110         WRITE(20,11) CAP
2130         WRITE(20,9)
2132         WRITE(20,9)
2134         WRITE(20,8)
2140         WRITE(20,12)
2145         WRITE(20,8)
2150         WRITE(20,31) PH,BP
2160         WRITE(20,32) D(1,JO),D(2,JO)
2170         WRITE(20,33) PCAP,OCAP
2180         WRITE(20,34) BPHP,BPP
2190         WRITE(20,35) D(5,KO),  D(6,KO)
2210         WRITE(20,37) DPFR,DOFR
2215         WRITE(20,8)
2220         WRITE(20,15)
2222         WRITE(20,16)
2228         WRITE(20,8)
2230         WRITE(20,13)
2240         WRITE(20,14)
2250         WRITE(20,6)
2270         WRITE(20,9)
2300         WRITE(20,8)
2320         WRITE(20,25) TDOC
2330         WRITE(20,8)
2350         WRITE(20,26) TIOC
```

```
LINKTR

2360        WRITE(20,3)
2380        WRITE(20,27)  TAAC
2390        WRITE(20,8)
2410        WRITE(20,29)  PPCUU
2415        WRITE(20,17)
2420        WRITE(20,8)
2440        WRITE(20,38)  PPUUV
2445        WRITE(20,18)
2447        WRITE(20,20)
2450        WRITE(20,8)
2470        WRITE(20,39)  PPWCV
2475        WRITE(20,19)
2476        WRITE(20,8)
2477        WRITE(20,61)  BNTR
2478        WRITE(20,8)
2479        WRITE(20,62)  TERCOS
2480 C      PLACE OPTION OUTPUT PRINT AND FORMAT STATEMENTS HERE
2490        NO=NO-1
2500 407    CONTINUE
2510        SL=SL+D(4,3)
2520 405    CONTINUE
2530        CAP=CAP+D(3,3)
2540 404    CONTINUE
2550        KO=KO-1
2560 403    CONTINUE
2570        JO=JO-1
2580 402    CONTINUE
2590        STOP
2600 8      FORMAT(1H0)
2620 10     FORMAT(1H0,15X,'ONE WAY STAGE LENGTH',15X,F7.1,2X,'MILES')
2630 11     FORMAT(1H0,15X,'DAILY PASSENGER FLOW ON LINK',7X,F7.1)
2650 12     FORMAT(1H0,51X,'PEAK',11X,'BASE')
2660 13     FORMAT(1H0,5X,'ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED')
2665 14     FORMAT(1H0,5X,'TOTAL OF THE MORNING AND EVENING PEAKS')
2680 15     FORMAT(1H0,5X,'ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW')
2685 16     FORMAT(1H0,5X,'ON THE LINK')
2690 31     FORMAT(1H0,5X,'DURATION OF PERIOD, HOURS',19X,F7.1,8X,F7.1)
2700 32     FORMAT(1H0,5X,'LOAD FACTOR',33X,F7.1,8X,F7.1)
2710 33     FORMAT(1H0,5X,'USABLE SEATS PER TOTAL PERIOD',15X,F7.1,8X,F7.1)
2720 34     FORMAT(1H0,5X,'PASSENGER FLOW DURING PERIOD',16X,F7.1,8X,F7.1)
2730 35     FORMAT(1H0,5X,'MINIMUM ALLOWABLE FREQUENCY',17X,F7.1,8X,F7.1)
2750 37     FORMAT(1H0,5X,'ACTUAL FREQUENCY PER PERIOD'17X,F7.1,8X,F7.1)
2800 25     FORMAT(1H0,5X,'ANNUAL DIRECT COST',13X,F15.2)
2810 26     FORMAT(1H0,5X,'ANNUAL INDIRECT COST',11X,F15.2)
2820 27     FORMAT(1H0,5X,'ANNUAL TOTAL COST',14X,F15.2)
2840 29     FORMAT(1H0,5X,'COST PER PASSENGER MILE',9X,F13.4)
2841 17     FORMAT(1H0,5X,'TOTAL COST')
2842 38     FORMAT(1H0,5X,'COST PER PASSENGER MILE',9X,F13.4)
2843 18     FORMAT(1H0,5X,'TOTAL COST MINUS CAPITAL COST')
2844 20     FORMAT(1H0,5X,'NOT INCLUDING VEHICLES')
2845 39     FORMAT(1H0,5X,'COST PER PASSENGER MILE',9X,F13.4)
2846 19     FORMAT(1H0,5X,'TOTAL COST MINUS CAPITAL COST')
2850 41     FORMAT(1H0,31X,'TILTROTOR')
2860 50     FORMAT(8F10.2)
2861 61     FORMAT(1H0,5X,'FLEET SIZE',14X,F5.2)
2862 62     FORMAT(1H0,5X,'TERMINAL COST',1X,F15.2)
2870        END
```

Computer Program Input

The data file used with the LINKTR program is called VTOL and consists of an array of 14 rows and 8 columns (8 F 10.2 format), which is referred to as array D (I,J). The following entries are made from each row.

Row 1 and 2: These lines specify the base period and peak period load factors to be used in the analysis. At least one pair of load factors must be specified, but the program can analyze up to 7 pairs of load factors.

Note: Any columns not being used to specify load factors may be left blank.

Row 3: This row specifies the daily two-way passenger flow on the link. It is assumed that passenger flows are equal in both directions on the link.

Row 4: This row specifies the one-way, air statute mile stage length on the link. This data card corresponds in format to Row 3.

Row 5 and 6: These rows specify the frequency, called here minimum allowable frequency, on which vehicles will operate in the peak and base periods. Like Rows 1 and 2, these rows operate as a pair. Row 5 specifies the peak period minimum allowable frequency, Row 6 specifies the base period minimum allowable frequency. Minimum allowable frequency is defined as that number of departures, in both directions on the link, which must be performed, to conform to some standard or level of service. At least one pair of frequencies must be given, but up to seven pairs of frequencies can be read by the program.

Row 7: Row 7 specifies the fraction of daily passengers on the link in each peak hour. For example, if there are 2000 daily passengers, and in each peak hour there are 200 passengers on the link, then the fraction of daily passengers on the link in each peak hour is 1/10, or .10.

Row 8: Does not apply to air programs. Enter a 1.0 in the first 10 columns.

Row 9: Row 9 specifies the aircraft capacity; the number of seats in one vehicle.

Row 10: This row specifies the average cruising speed of the aircraft. The speed is given in miles per hour.

Row 11: Row 11 specifies the number of hours in a 24 hour day the system is in operation. Time starts when the first vehicle departs and ends when the last vehicle departs.

Row 12: Row 12 specifies the number of hours in each peak period. The morning and evening peaks are assumed to have the same duration. This row shows the number of hours out of the total hours of operation that are in each peak period.

Row 13 and 14: Rows 13 and 14 specify the number of intermediate plus endpoint stops on the link. At least one pair of terminal combinations must be specified, but the program will analyze up to seven combinations; at least the two endpoints must be specified.

Computer Program Output

The computer output calculated by the LINKTR program, is listed under the heading "STANDARD", which gives annual cost and cost per passenger mile for capacities 500-3000 daily passengers (in 500 passenger increments) and for stage lengths 100-300 miles (in 100 mile increments).

```
VTOL

100  1.0             0.5
110                  0.5
120  6.0             500.0       500.00
130  3.0             100.0       100.0
140  1.0             8.0
150                  12.00
160  0.1
170  1.0
180  45.0
190  260.0
200  16.0
210  2.0
220  1.0             2.0
230                  0.0
```

```
STANDARD

 1 0
 2 0
 3 0                              TILTROTOR
 4 0
 5 0                   ONE WAY STAGE LENGTH               100.0  MILES
 6 0                   DAILY PASSENGER FLOW ON LINK       500.0
 7 0
 8 0
 9 0
10 0                                                       PEAK          BASE
11 0
12 0           DURATION OF PERIOD, HOURS                    4.0          12.0
13 0           LOAD FACTOR                                   .8            .5
14 0           USABLE SEATS PER TOTAL PERIOD              288.0         315.0
15 0           PASSENGER FLOW DURING PERIOD               200.0         300.0
16 0           MINIMUM ALLOWABLE FREQUENCY                  8.0          12.0
17 0           ACTUAL FREQUENCY PER PERIOD                  8.0          14.0
18 0
19 0           ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW
20 0           ON THE LINK
21 0
22 0           ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED
23 0           TOTAL OF THE MORNING AND EVENING PEAKS
24 0
25 0
26 0
27 0           ANNUAL DIRECT COST                7265606.13
28 0
29 0           ANNUAL INDIRECT COST              4979253.50
30 0
31 0           ANNUAL TOTAL COST                12244859.63
32 0
33 0           COST PER PASSENGER MILE                .6710
34 0           TOTAL COST
35 0
36 0           COST PER PASSENGER MILE                .5797
37 0           TOTAL COST MINUS CAPITAL COST
38 0           NOT INCLUDING VEHICLES
39 0
40 0           COST PER PASSENGER MILE                .3977
41 0           TOTAL COST MINUS CAPITAL COST
42 0
43 0           FLEET SIZE              2.00
44 0
45 0           TERMINAL COST     4594511.00
46 0
```

APPENDIX B

CTOL Cost Computer Program

This program, named "LINKDC9," is the computerized version of the CTOL cost model. This program computes the same output that was calculated by the VTOL cost model and follows the same basic logic as outlined in Appendix A for the LINKTR program. A sample of the computer output for the program is listed under the heading "STANDARD." The data file is called CTOL and has the same format and entries that the VTOL file has.

```
LINKDC9

100 C          INTERCITY PASSENGER MODES COST COMPARISON
110 C          COST OF MCDONNEL DOUGLAS DC-9-30 OPERATING FROM EXISTING TERMINALS FOR
120 C          A SINGLE LINK
130 C
150            DIMENSION D(14,8)
160 C
170 C          THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
190            DO 100 I=1,14
200            READ(13,50) (D(I,J) ,J=1,8)
210 100        CONTINUE
215 C
220 C          THIS SECTION SETS THE DO LOOPS AND ADVANCES THE LOAD FACTOR,MINIMUM
230 C          FREQUENCY,PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
240 C          SPECIFICATIONS IN THE DATA DECK
250            I1=D(1,1)
260            DO 402 J=1,I1
265            JO=J
270            JO=JO+1.
280            I2=D(5,1)
290            DO 403 K=1,I2
295            KO=K
300            KO=KO+1
310            CAP=D(3,2)
320            I3=D(3,1)
330            DO 404 I=1,I3
340            SL=D(4,2)
350            I4=D(4,1)
360            DO 405 M=1,I4
370            I13=D(13,1)
380            DO 407 N=1,I13
385            NO=N
390            NO=NO+1
391 C
392 C
445 C
450 C          CALCULATE ROUND TRIP TRAVEL TIME
460            TT=2*(SL/D(10,1))+0.667
470 C
500 C          CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
510            BPHP=CAP*D(7,1)*D(12,1)*2
515 C
520 C          CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
530            UPHP=BPHP/2.0
535 C
540 C          CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
550            BPP=CAP-BPHP
555 C
560 C          CALCULATE UNIDIRECTIONAL PASSENGER FLOW DURING BASE PERIOD
570            UBPP=BPP/2.0
575 C
580 C          CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY
590 C          FOR THE PEAK PERIOD
600            PFR=D(5,KO)/2.0
605 C
695 C
700 C          THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR A CTOL
710 C           AIRCRAFT OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
715 C          FREQUENCY
720            PCAP=D(9,1)*D(5,KO)*D(1,JO)
760            IF (BPHP-PCAP)190,190,192
765 C
770 C          IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
780 C          IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
785 192        PFR=UPHP/(D(9,1)*D(1,JO))
790            PFR=PFR+0.99
800            IPFR=IFIX(PFR)
810            PFR=IPFR
815 C
820 C          THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT
830 C          MOVEMENTS AND NUMBER OF USABLE SEATS DURING THE PEAK PERIOD
840 190        UPCAP=PFR*D(9,1)*D(1,JO)
850            UAR=PFR
950            AR=UAR*2.0
960            PCAP=UPCAP*2.0
965 C
970 C          CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
980 C          THE BASE PERIOD
990            OFR=D(6,KO)/2.0
995 C
```

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```
LINKDC9

1000 C      THIS SECTION CALCULATES TCTAL BASE PERICD USABLE SEATS FOR A CTOL
1010 C       AIRCRAFT  OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
1015 C      FREQUENCY
1030        OCAP=D(9,1)*D(6,KO)*D(2,JC)
1050        IF (BPP-OCAP) 39C,390,392
1055 C
1060 C      IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
1070 C      MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
1080 392    OFR=UUPP/(D(9,1)*D(2,JO))
1090        OFR=OFR+0.99
1095        IOFR=IFIX(OFR)
1100        OFR=IOFR
1105 C
1110 C      THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL AIRCRAFT MOVEMENTS
1120 C      AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
1130 390    UOCAP=OFR*D(9,1)*D(2,JO)
1140        UOAR=OFR
1200        OAR=UOAR*2.0
1210        OCAP=UOCAP*2.
1215 C
1235 C
1240 C      CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
1250        UTFREQ=OFR+PFR
1255 C
1260 C      CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
1270        DPFR=PFR*2.0
1275 C
1280 C      CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
1290        DOFR=OFR*2.0
1295 C
1300 C      CALCULATE DAILY TWO WAY TCTAL FREQUENCY
1310        DFREQ=DPFR+DOFR
1315 C
1320 C      CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
1330        PHP=CAP*D(7,1)
1335 C
1340 C      CALCULATE NUMBER OF ANNUAL PASSENGERS
1350        BNSP=CAP*365
1355 C
1360 C      CALCULATE TOTAL ANNUAL MILES
1370        TAM=SL*DFREQ*365
1375 C
1380 C      CALCULATE ANNUAL FLIGHT HOURS
1390        AFH=(SL/D(10,1))*DFREQ*365.
1415 C
1420 C      CALCULATE PEAK PERIOD HEADWAY
1430        PHD=(2*D(12,1))/PFR
1435 C
1440 C      CALCULATE BASE PERIOD HEADWAY
1450        OHD=(D(11,1)-(2*D(12,1)))/OFR
1455 C
1460 C      THIS SECTION CALCULATES THE NUMBER OF CTCL AIRCRAFT
1470 C      NEEDED TO OPERATE SERVICE
1480        IF(D(12,1)-(TT/2)) 151,15C,15C
1490 150    BNTR=(TT/(2*PHD))+1.
1500        GO TO 152
1510 151    BNTR=(D(12,1)*((OHD/PHD-1)/OHD)+(TT/(2*OHD))+1)
1530 152    NTR=IFIX(BNTR)
1540        BNTR=NTR*2.
1560        BNTR=BNTR+0.99
1570        BNTR=IFIX(BNTR)
1735 C
1740 C      THIS SECTION CALCULATES DIRECT OPERATING CCSTS
1750        ACTI=0.18448*12842000.*BNTR
1760        HI=0.02*0.90909*12842000.*BNTR
1770        FC=290.51*AFH
1780        FO=799.35*AFH
1790        DM=124.21*AFH
1800        AMB=0.60*DM
1805        TDOC=ACTI+HI+FC+FO+DM+AMB
1810 C
1820 C      THIS SECTION CALCULATES TOTAL INDIRECT OPERATING COST
1825 C
1830 C
1835 C      THIS SECTION CALCULATES ANNUAL CONVENTIONAL AIR TERMINAL COST
1896        TERCA=27.70*365.*CAP
1901 C
1902 C      THIS SECTION CALCULATES AIRCRAFT PARKING CCST
1906        APRKM=14715.*0.026*BNTR
```

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```
LINKDC9

C
C       THIS SECTION CALCULATES COST OF CENTRAL OFFICE BUILDING
        PERC=25000.*0.01*CAP
C
C       THIS SECTION CALCULATES MISCELLANEOUS COSTS
        CMISC=47.74+0.7010*TAM
        TIOC=TERCA+APRKM+PERC+CMISC
C
C       THIS SECTION COMPUTES THE INFORMATION TO BE PRINTED AS OUTPUT
C
C       THIS SECTION CALCULATES TOTAL COST
        TAAC=TDOC+TIOC
C
C
C       THIS SECTION CALCULATES TOTAL OPERATING COST LESS ALL COST
        TALCAV=TAAC-ACTI
C
        UUVWOV=TDOC-ACTI
        ZZ=CAP*SL*365
        PPCUU=TAAC/ZZ
        PPWOV=TALCAV/ZZ
        PH=D(12,1)*2
        BP=D(11,1)-PH
C
C       THIS SECTION PRINTS THE OUTPUT
        WRITE(20,8)
        WRITE(20,8)
        WRITE(20,41)
        WRITE(20,8)
        WRITE(20,10) SL
        WRITE(20,11) CAP
        WRITE(20,8)
        WRITE(20,8)
        WRITE(20,8)
        WRITE(20,12)
        WRITE(20,8)
        WRITE(20,31) PH,BP
        WRITE(20,32) D(1,JO),D(2,JO)
        WRITE(20,33) PCAP,OCAP
        WRITE(20,34) BPHP,BPP
        WRITE(20,35) D(5,KO), D(6,KC)
        WRITE(20,37) DPFR,DOFR
        WRITE(20,8)
        WRITE(20,15)
        WRITE(20,16)
        WRITE(20,8)
        WRITE(20,13)
        WRITE(20,14)
        WRITE(20,8)
        WRITE(20,8)
        WRITE(20,8)
        WRITE(20,25) TDOC
        WRITE(20,8)
        WRITE(20,26) TIOC
        WRITE(20,8)
        WRITE(20,27) TAAC
        WRITE(20,8)
        WRITE(20,29) PPCUU
        WRITE(20,17)
        WRITE(20,8)
        WRITE(20,39) PPWCV
        WRITE(20,19)
        WRITE(20,8)
        WRITE(20,60) BNTR
        WRITE(20,8)
        WRITE(20,61) TERCA
C       PLACE OPTION OUTPUT PRINT AND FORMAT STATEMENTS HERE
        MO=MO-1
 407    CONTINUE
        SL=SL+D(4,3)
 405    CONTINUE
        CAP=CAP+D(3,3)
 404    CONTINUE
        KO=KO-1
 403    CONTINUE
        JO=JO-1
 402    CONTINUE
        STOP
 8      FORMAT(1H0)
```

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```
LINKDC9

10      FORMAT(1H0,15X,'ONE WAY STAGE LENGTH',15X,F7.1,2X,'MILES')
11      FORMAT(1H0,15X,'DAILY PASSENGER FLOW ON LINK',7X,F7.1)
12      FORMAT(1H0,51X,'PEAK',11X,'BASE')
13      FORMAT(1H0,5X,'ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED')
14      FORMAT(1H0,5X,'TOTAL OF THE MORNING AND EVENING PEAKS')
15      FORMAT(1H0,5X,'ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW')
16      FORMAT(1H0,5X,'ON THE LINK')
31      FORMAT(1H0,5X,'DURATION OF PERIOD, HOURS',19X,F7.1,8X,F7.1)
32      FORMAT(1H0,5X,'LOAD FACTOR',33X,F7.1,8X,F7.1)
33      FORMAT(1H0,5X,'USABLE SEATS PER TOTAL PERIOD',15X,F7.1,8X,F7.1)
34      FORMAT(1H0,5X,'PASSENGER FLOW DURING PERIOD',16X,F7.1,8X,F7.1)
35      FORMAT(1H0,5X,'MINIMUM ALLOWABLE FREQUENCY',17X,F7.1,8X,F7.1)
37      FORMAT(1H0,5X,'ACTUAL FREQUENCY PER PERIOD'17X,F7.1,8X,F7.1)
25      FORMAT(1H0,5X,'ANNUAL DIRECT COST',13X,F15.2)
26      FORMAT(1H0,5X,'ANNUAL INDIRECT COST',11X,F15.2)
27      FORMAT(1H0,5X,'ANNUAL TOTAL COST',14X,F15.2)
29      FORMAT(1H0,5X,'COST PER PASSENGER MILE',9X,F13.4)
17      FORMAT(1H0,5X,'TOTAL COST')
39      FORMAT(1H0,5X,'COST PER PASSENGER MILE',9X,F13.4)
19      FORMAT(1H0,5X,'TOTAL COST MINUS VEHICLE COST')
41      FORMAT(1H0,31X,'CTOL DC-9-30')
50      FORMAT(8F10.2)
60      FORMAT(1H0,5X,'FLEET SIZE',14X,F4.1)
61      FORMAT(1H0,5X,'TERMINAL COST',1X,F15.2)
        END
```

```
CTOL

100 1.0        0.8
110            0.5
120 6.0        500.0      500.00
130 3.0        100.0      100.00
140 1.0        8.0
150            12.00
160 0.1
170 1.0
180 115.0
190 325.0
200 16.0
210 2.0
220 1.0        2.0
230            0.0
```

```
STANDARD

 1 0
 2 0
 3 0
 4 0                       CTOL DC-9-30
 5 0              ONE WAY STAGE LENGTH                      100.0  MILES
 6 0              DAILY PASSENGER FLOW ON LINK              500.0
 7 0
 8 0
 9 0
10 0
11 0                                                          PEAK         BASE
12 0       DURATION OF PERIOD, HOURS                          4.0         12.0
13 0       LOAD FACTOR                                         .8           .5
14 0       USABLE SEATS PER TOTAL PERIOD                     736.0        690.0
15 0       PASSENGER FLOW DURING PERIOD                      200.0        300.0
16 0       MINIMUM ALLOWABLE FREQUENCY                         8.0         12.0
17 0       ACTUAL FREQUENCY PER PERIOD                         8.0         12.0
18 0
19 0       ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW
20 0       ON THE LINK
21 0
22 0       ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED
23 0       TOTAL OF THE MORNING AND EVENING PEAKS
24 0
25 0
26 0
27 0       ANNUAL DIRECT COST                     8099550.31
28 0
29 0       ANNUAL INDIRECT COST                   5737089.69
30 0
31 0       ANNUAL TOTAL COST                     13836640.00
32 0
33 0       COST PER PASSENGER MILE                    .7582
34 0       TOTAL COST
35 0
36 0       COST PER PASSENGER MILE                    .4985
37 0       TOTAL COST MINUS VEHICLE COST
38 0
39 0       FLEET SIZE              2.0
40 0
41 0       TERMINAL COST     5055250.00
42 0
43 0
```

APPENDIX C

High Speed Rail Cost Computer Program

This program is the computerized version of the HSR cost model and was given the name "LINKML." For every stage length, passenger flow, minimum allowable frequency and maximum load factor specified in the data entries, the following calculations are performed and printed in the computer output:

- usable seats for both peak and base periods
- actual train frequency per period (number of daily departures in each period)
- annual fixed cost (dollars)
- annual variable cost (dollars)
- annual total cost (dollars)
- cost per passenger mile based on total cost
- cost per passenger mile based on variable cost
- cost per passenger mile based on variable cost minus vehicle cost

* Note: Distances refer to airline distances

The basic logic of the LINKML program is outlined in the following steps:

1. Read data
2. Calculate passenger flows during the peak and base periods
3. Calculate train consists for a train of maximum length
4. Calculate usable seats for a train of maximum length operating at the peak period - minimum allowable frequency
5. Test whether usable seats generated from running at minimum allowable frequency satisfies peak demand
    - If demand is satisfied, go to step 6
    - If demand is not satisfied, increase frequency in order to satisfy demand; go to step 6

6. Calculate the number of individual car movements and number of usable seats during the peak period
7. Repeat steps 2 and 4 through 6 for base period
8. Determine the number of locomotives and cars required to provide the service specified above
9. Calculate fixed, variable, and total costs.
10. Calculate costs per passenger miles
11. Print output

* DO LOOPS repeat above process for all stage lengths and capacities.

In addition to performing the calculations for the base case as described in the development of the HSR cost model, the application of the program was particularly useful in performing a sensitivity analysis of various parameters used in the model. The following parameters were changed and their effect on annual cost and cost per passenger mile were observed: train frequency, fuel cost, interest rates, load factors, track upgrading cost, and vehicle cost.

```
LINKML

100 C        INTERCITY PASSENGER MODES COST COMPARISON
110 C        COST OF METROLINER OPERATING FROM EXISTING TERMINALS FOR
120 C        A SINGLE LINK
130 C
150          DIMENSION D(14,2)
160 C
170 C        THIS SECTION READS THE DATA MATRIX INTO THE PROGRAM
190          DO 201 I=1,14
200          READ(14,50) (D(I,J), J=1,2)
210 201      CONTINUE
215 C
220 C        THIS SECTION SETS THE DO LOOPS AND ADVANCES THE LOAD FACTOR,MINIMUM
230 C        FREQUENCY,PASSENGER FLOW AND STAGE LENGTH PARAMETERS ACCORDING TO
240 C        SPECIFICATIONS IN THE DATA DECK
250          I1=D(1,1)
260          DO 402 J=1,I1
265          JO=J
270          JO=JO+1.
280          I2=D(5,1)
290          DO 403 K=1,I2
295          KO=K
300          KO=KO+1
310          CAP=D(3,2)
320          I3=D(3,1)
330          DO 404 I=1,I3
340          SL=D(4,2)
350          I4=D(4,1)
360          DO 405 M=1,I4
370          I13=D(13,1)
380          DO 407 N=1,I13
385          NO=N
390          NO=NO+1
391 C
392 C
400          ZSL=SL
410          SL=SL*1.14
420          BI=D(13,NO)+D(14,NO)
430          BBI=BI-2.
440          TIS=BBI*.0833
445 C
450 C        CALCULATE ROUND TRIP TRAVEL TIME
460          TT=2*((SL/100.)+TIS) +2.
470 C
500 C        CALCULATE TWO WAY PASSENGER FLOW DURING THE PEAK PERIOD
510          BPHP=CAP*D(7,1)*D(12,1)*2
515 C
520 C        CALCULATE UNIDIRECTIONAL FLOW DURING PEAK PERIOD
530          UPHP=BPHP/2.0
535 C
540 C        CALCULATE TWO WAY PASSENGER FLOW DURING THE BASE PERIOD
550          BPP=CAP-BPHP
555 C
560 C        CALCULATE UNIDIRECTIONAL PASSENBER FLOW DURING BASE PERIOD
570          UBPP=BPP/2.0
575 C
580 C        CALCULATE UNIDIRECTIONAL MINIMUB ALLOWABLE FREQUENCY
590 C        FOR THE PEAK PERIOD
600          PFR=D(5,KO)/2.0
605 C
610 C        THIS SECTION CALCULATES TRAIN CONSIST FOR A TRAIN OF
620 C        MAXIMUM LENGTH
630          CAR=D(8,1)/2.0
640          NCAR=IFIX(CAR)
660          KCAR=CAR+0.5
670          SCAR=IFIX(KCAR)
675 C
680 C        CALCULATE THE CAPACITY OF A TRAIN OF MAXIMUM LENGTH
690          TMAX=(D(9,1)*NCAR) + (D(9,2)*SCAR)
695 C
700 C        THIS SECTION CALCULATES TOTAL PEAK PERIOD USABLE SEATS FOR TRAIN OF
710 C        MAXIMUM LENGTH OPERATING AT THE PEAK PERIOD MINIMUM ALLOWABLE
720 C        FREQUENCY
730          TMDP=TMAX*D(5,KO)*D(1,JO)
740          ITMDP=IFIX(TMDP)
750          TMDP=ITMDP
760          IF (BPHP-TMDP)190,190,192
765 C
770 C        IN THIS SECTION THE PROGRAM SETS ITS OWN PEAK PERIOD FREQUENCY
780 C        IF THE MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
```

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```
LINKML

 192  PFR=UPHP/(TMAX*D(1,JO))
      PFR=PFR+0.99
      IPFR=IFIX(PFR)
      PFR=IPFR
C
C     THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL CAR MOVEMENTS
C     AND NUMBER OF USEABLE SEATS DURING THE PEAK PERIOD
 190  UPCAP=PFR*D(9,2)*D(1,JO)
      UCT=1.0
 195  IF(UPHP-UPCAP) 181,181,196
 196  UCT=UCT+1.0
      UPCAP=UPCAP+(PFR*D(9,1)*D(1,JO))
      IF(UPHP-UPCAP) 181,181,198
 198  UCT=UCT+1.0
      UPCAP=UPCAP+(PFR*D(9,2)*D(1,JO))
      GO TO 195
 181  PCAP=UPCAP*2
C
C     CALCULATE UNIDIRECTIONAL MINIMUM ALLOWABLE FREQUENCY FOR
C     THE BASE PERIOD
      OFR=D(6,KO)/2.0
C
C     THIS SECTION CALCULATES TOTAL BASE PERIOD USABLE SEATS FOR TRAIN
C     OF MAXIMUM LENGTH OPERATING AT THE BASE PERIOD MINIMUM ALLOWABLE
C     FREQUENCY
      TMDO=TMAX*D(6,KO)*D(2,JO)
      ITMDO=IFIX(TMDO)
      TMDO=ITMDO
      IF(BPP-TMDO) 390,390,392
C
C     IN THIS SECTION THE PROGRAM SETS ITS OWN BASE PERIOD FREQUENCY IF
C     MINIMUM FREQUENCY DOES NOT SATISFY THE DEMAND
 392  OFR=UBPP/(TMAX*D(2,JO))
      OFR=OFR+0.99
      IOFR=IFIX(OFR)
      OFR=IOFR
C
C     THIS SECTION CALCULATES THE NUMBER OF INDIVIDUAL CAR MOVEMENTS
C     AND NUMBER OF USABLE SEATS DURING THE BASE PERIOD
 390  UOCAP=OFR*D(9,2)*D(2,JO)
      UOCT=1.0
 295  IF(UBPP-UOCAP) 281,281,296
 296  UOCT=UOCT+1.0
      UOCAP=UOCAP+(OFR*(D(9,1)*D(2,JO)))
      IF(UBPP-UOCAP) 281,281,298
 298  UOCT=UOCT+1.0
      UOCAP=UOCAP+(OFR*(D(9,2)*D(2,JO)))
      GO TO 295
 281  OCAP=UOCAP*2.0
C
C     CALCULATE DAILY UNIDIRECTIONAL TOTAL CAR MOVEMENTS
      UTC=(UCT*PFR)+(UOCT*OFR)
C
C     CALCULATE DAILY TWO WAY TOTAL CAR MOVEMENTS
      BUTC=2.*UTC
C
C     CALCULATE TOTAL DAILY UNIDIRECTIONAL FREQUENCY
      UTFREQ=OFR+PFR
C
C     CALCULATE DAILY TWO WAY PEAK PERIOD FREQUENCY
      DPFR=PFR*2.0
C
C     CALCULATE DAILY TWO WAY BASE PERIOD FREQUENCY
      DOFR=OFR*2.0
C
C     CALCULATE DAILY TWO WAY TOTAL FREQUENCY
      DFREQ=DPFR+DOFR
C
C     CALCULATE THE NUMBER OF PASSENGERS IN EACH PEAK HOUR
      PHP=CAP*D(7,1)
C
C     CALCULATE NUMBER OF ANNUAL PASSENGERS
      BNSP=CAP*365.
C
C     CALCULATE TOTAL ANNUAL MILES
      TAM=SL*DFREQ*365.
C
C     CALCULATE ANNUAL GROSS TON MILES
      GTM=((60.*SL*BUTC*365.)+(100.*SL*DFREQ*365.))
```

```
LINKML

C
C      CALCULATE ANNUAL CAR MILES
       CM=SL*BUTC*365.
C
C      CALCULATE PEAK PERIOD HEADWAY
       PHD=(2*D(12,1))/PFR
C
C      CALCULATE BASE PERIOD HEADWAY
       OHD=(D(11,1)-(2*D(12,1)))/OFR
C
C      THIS SECTION CALCULATES THE NUMBER OF TRAINS NEEDED TO OPERATE
C      SERVICE AND THE AVERAGE NUMBER OF CARS PER TRAIN
       IF(D(12,1)-(TT/2)) 151,150,150
  150  BNTR=(TT/(2*PHD))+1.
       NTR=IFIX(BNTR)
       BNTR=NTR*2.
       BNTR=BNTR*0.1+BNTR
       BNTR=BNTR+0.99
       BNTR=IFIX(BNTR)
       CND=NTR*2.*UCT
       CND=CND*0.1+CND
       CND=CND+0.99
       CND=IFIX(CND)
       GO TO 152
  151  BNTR=(D(12,1)*((OHD/PHD-1)/OHD)+(TT/(2*OHD))+1)
       NTR=IFIX(BNTR)
       BNTR=NTR*2.
       BNTR=BNTR*0.1+BNTR
       BNTR=BNTR+0.99
       BNTR=IFIX(BNTR)
       MBNTR=TT/(2*OHD)-PH/OHD
       MBNTR=IFIX(MBNTR)
       NPTR=NTR-MBNTR
       CND=2.*((NPTR*UCT)+(MBNTR*UOCT))
       CND=CND+(CND*0.1)
       CND=CND+0.99
       CND=IFIX(CND)
       GO TO 152
C
C      THIS SECTION CALCULATES GENERAL VARIABLE COSTS
  152  ACTI=.1523*((1000000.*BNTR)+(650000.*CND))
       EP=.4286*CM
       BS=.5247*TAM
       DO=.2501*TAM
       YAS=.2064*TAM
       ASPT=.1817*TAM
       TRC=(2.2945*TAM)+(.3047*CM)
       DME=(1.1469*TAM)+(.3105*CM)
       DMWS=(31873*SL)+(.00608*GTM)
       GVC=ACTI+EP+BS+DG+YAS+ASPT+TRC+DME+DMWS
C
C      THIS SECTION CALCULATES URBAN VARIABLE COSTS
       UTSO=.6750*BNSP
       UTIL=.2321*BNSP
       CLEN=.1428*BNSP
       SMAIN=.1652*BNSP
       SMA=.4969*TAM
       UVC=UTSO+UTIL+CLEN+SMAIN+SMA
C
C      THIS SECTION CALCULATES ALL FIXED COSTS
       TER=685400*SL
       GFC=TER
       SVC=100000.
       SFC=0.
       UFC=0.0
C
C      THIS SECTION COMPUTES THE INFORMATION TO BE PRINTED AS OUTPUT
       UUV=GVC+UVC+SVC*D(14,NO)
       UUF=GFC+D(13,NO)*UFC+D(14,NO)*SFC
       TUUC=UUF+UUV
       UUVWOV=UUV-ACTI
       ZZ=CAP*ZSL*365.
       PPCUU=TUUC/ZZ
       PPUUV=UUV/ZZ
       PPWOV=UUVWOV/ZZ
       PH=D(12,1)*2
       BP=D(11,1)-PH
C
C      THIS SECTION PRINTS THE OUTPUT
.
.
```

```
LINKML

              WRITE(21,8)
              WRITE(21,8)
              WRITE(21,41)
              WRITE(21,8)
              WRITE(21,10) ZSL
              WRITE(21,11) CAP
              WRITE(21,8)
              WRITE(21,8)
              WRITE(21,8)
              WRITE(21,12)
              WRITE(21,8)
              WRITE(21,31) PH,BP
              WRITE(21,32) D(1,JO),D(2,JO)
              WRITE(21,33) PCAP,OCAP
              WRITE(21,34) EPHP,BPP
              WRITE(21,35) D(5,KO), D(6,KO)
              WRITE(21,37) DPFR,DOFR
              WRITE(21,8)
              WRITE(21,15)
              WRITE(21,16)
              WRITE(21,8)
              WRITE(21,13)
              WRITE(21,14)
              WRITE(21,8)
              WRITE(21,8)
              WRITE(21,8)
              WRITE(21,25) UUF
              WRITE(21,8)
              WRITE(21,26) UUV
              WRITE(21,8)
              WRITE(21,27) TUUC
              WRITE(21,8)
              WRITE(21,29) PPCUU
              WRITE(21,17)
              WRITE(21,8)
              WRITE(21,38) PPUUV
              WRITE(21,18)
              WRITE(21,8)
              WRITE(21,39) PPWCV
              WRITE(21,19)
C
C             PLACE OPTION OUTPUT PRINT AND FORMAT STATEMENTS HERE
              NO=NO-1
      407     CONTINUE
              SL=2SL+D(4,3)
      405     CONTINUE
              CAP=CAP+D(3,3)
      404     CONTINUE
              KO=KO-1
      403     CONTINUE
              JO=JO-1
      402     CONTINUE
              STOP
      8       FORMAT(1H0)
      10      FORMAT(1H0,15X,'ONE WAY STAGE LENGTH',15X,F7.1,2X,'MILES')
      11      FORMAT(1H0,15X,'DAILY PASSENGER FLOW ON LINK',7X,F7.1)
      12      FORMAT(1H0,51X,'FEAK',11X,'EASE')
      13      FORMAT(1H0,5X,'ALL VALUES FOP THE PEAK PERIOD ARE THE COMBINED')
      14      FORMAT(1H0,5X,'TCTAL OF THE MORNING AND EVENING PEAKS')
      15      FORMAT(1H0,5X,'ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW')
      16      FORMAT(1H0,5X,'ON THE LINK')
      31      FORMAT(1H0,5X,'DURATION OF PERIOD, HOURS',19X,F7.1,8X,F7.1)
      32      FORMAT(1H0,5X,'LOAD FACTOR',33X,F7.1,8X,F7.1)
      33      FORMAT(1H0,5X,'USABLE SEATS PER TOTAL PERIOD',15X,F7.1,8X,F7.1)
      34      FORMAT(1H0,5X,'PASSENGER FLOW DURING PERIOD',16X,F7.1,8X,F7.1)
      35      FORMAT(1H0,5X,'PINIMUM ALLOWABLE FREQUENCY',17X,F7.1,8X,F7.1)
      37      FORMAT(1H0,5X,'ACTUAL FREQUENCY PER PERIOD',17X,F7.1,8X,F7.1)
      25      FORMAT(1H0,5X,'ANNUAL FIXED COST',14X,F15.2)
      26      FORMAT(1H0,5X,'ANNUAL VARIAELE COST',11X,F15.2)
      27      FORMAT(1H0,5X,'ANNUAL TOTAL COST',14X,F15.2)
      29      FORMAT(1H0,5X,'CCST PER PASSENGER MILE',9X,F13.4)
      17      FORMAT(1H0,5X,'TOTAL COST')
      38      FORMAT(1H0,5X,'CCST PER PASSENGER MILE',9X,F13.4)
      18      FORMAT(1H0,5X,'VARIABLE COST')
      39      FORMAT(1H0,5X,'CCST PER PASSENGER MILE',9X,F13.4)
      19      FORMAT(1H0,5X,'VARIABLE COST MINUS VEHICLES')
      41      FORMAT(1H0,5X,28X,'HIGH SPEED RAIL')
      50      FORMAT(8F10.2)
              END
```

Computer Program Input

The data file used with the LINKML program is called VTOL and consists of an array of 14 rows and 8 columns (8 F 10.2 format), which is referred to as array D (I,J). The following entries are made from each row.

Row 1 and 2: These lines specify the base period and peak period maximum load factors to be used in the analysis. At least one pair of load factors must be specified, but the program can analyze up to 7 pairs of load factors.

Note: Any columns not being used to specify load factors may be left blank.

Row 3: This row specified the daily two-way passenger flow on the link. It is assumed that passenger flows are equal in both directions on the link.

Row 4: This row specifies the one-way, air statute mile stage length on the link. For rail, a circuity factor computed by the program calculates rail distances from the given air distance. If actual stage lengths are used, the circuity factors should be set at zero.

Row 5 and 6: These rows specify the frequency, called here minimum allowable frequency, on which vehicles will operate in the peak and base periods. Like Rows 1 and 2, these rows operate as a pair. Row 5 specifies the peak period minimum allowable frequency, Row 6 specifies the base period minimum allowable frequency. Minimum allowable frequency is defined as that number of departures, in both directions on the link, which must be performed, to conform to some standard or level of service. At least one pair of frequencies must be given, but up to seven pairs of frequencies can be read by the program.

Row 7: Row 7 specifies the fraction of daily passengers on the link in each peak hour. For example, if there are 2000 daily passengers, and in each peak hour there are 200 passengers on the link, then the fraction of daily passengers on the link in each peak hour is 1/10, or .10.

Row 8: This row specifies the maximum number of cars per train. If the number of passengers increases and equals this number, a new train is started.

Row 9: Row 9 is used to show seating capacities of alternative types of railroad cars. This row accommodates two different seating capacities. For instance, if level of service requirements dictate a coach car and snack coach car to be added alternately to the train consist, then the capacity of the coach car would be entered in the first field, the capacity of the snack-coach in the second field. The program develops the train consist by selecting each seating arrangement alternately, for example, snack-coach, coach, snack-coach, etc. Obviously, alternative seating pairs could be used; coach and parlor, parlor and snack-coach, etc.

Row 10: Row 10 does not apply to the rail mode. For the rail mode enter 1.0 in columns 1-3 of this row.

Row 11: Row 11 specifies the number of hours in a 24 hour day the system is in operation. Time starts when the first vehicle departs and ends when the last vehicle departs.

Row 12: Row 12 specifies the number of hours in each peak period. The morning and evening peaks are assumed to have the same duration. This row shows the number of hours out of the total hours of operation that are in each peak period.

Row 13 and 14: Rows 13 and 14 specify the number of intermediate plus endpoint stops on the link. At least one pair of terminal combinations must be specified, but the program will analyze up to seven combinations; at least the two endpoints must be specified.

Computer Program Output

The computer output calculated by the LINKML program, is listed under the heading "RAILCOST," which gives annual cost and costs per passenger mile for capacities 500-3000 daily passengers (in 500 passenger increments) and for stage lengths 100-300 miles (in 100 mile increments).

```
RAILDATA
100 1.0       0.8
110           0.5
120 6.0       500.0     500.00
130 3.0       100.0     100.00
140 2.0       16.0       8.0
150           24.00     12.00
160 0.1
170 10.0
180 80.0      64.0
190 1.0
200 16.0
210 2.0
220 1.0       2.0
230           0.0
```

```
COSTRAIL

                              HIGH SPEED RAIL

                    ONE WAY STAGE LENGTH                 100.0  MILES
                    DAILY PASSENGER FLOW ON LINK         500.0


                                                         PEAK           BASE
               DURATION OF PERIOD, HOURS                  4.0           12.0
               LOAD FACTOR                                 .8             .5
               USABLE SEATS PER TOTAL PERIOD            409.6          384.0
               PASSENGER FLOW DURING PERIOD             200.0          300.0
               MINIMUM ALLOWABLE FREQUENCY                8.0           12.0
               ACTUAL FREQUENCY PER PERIOD                8.0           12.0

               ALL OF THE ABOVE VALUES REPRESENT A TWO WAY FLOW
               ON THE LINK

               ALL VALUES FOR THE PEAK PERIOD ARE THE COMBINED
               TOTAL OF THE MORNING AND EVENING PEAKS


               ANNUAL FIXED COST                    78135600.00

               ANNUAL VARIABLE COST                 11537775.63

               ANNUAL TOTAL COST                    89673375.00

               COST PER PASSENGER MILE                   4.9136
               TOTAL COST

               COST PER PASSENGER MILE                    .6322
               VARIABLE COST

               COST PER PASSENGER MILE                    .5756
               VARIABLE COST MINUS VEHICLES
```