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SMALL V/STOL AIRCRAFT ANALYSIS

Volume I

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Prepared by
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for Ames Research Center

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16. Abstract

A study has been made of the economic viability of advanced V/STOL aircraft concepts in performing general aviation missions. A survey of general aviation aircraft users, operators, and manufacturers indicated that personnel transport missions formulated around business executive needs, commuter air service, and offshore oil supply are the leading potential areas of application using VTOL aircraft. Advanced VTOL concepts potentially available in the late 1970 time period were evaluated as alternatives to privately owned contemporary aircraft and commercial airline service in satisfying these personnel transport needs. Economic analysis incorporating the traveler's value of time as the principle figure of merit were used to identify the relative merits of alternative VTOL air transportation concepts.

Four representative advanced VTOL concepts were evaluated-compound helicopter, tilt rotor, tilt wing, and lift fan. Due to its low speed and short range characteristics, the compound helicopter was found to have little advantage over the conventional helicopter. Cost benefit analysis showed, however, that the tilt rotor, tilt wing, and lift fan could all compete favorably with currently used conventional aircraft and, for the higher time value passenger, the airlines. Specific comparison of these three advanced promising concepts showed the tilt wing slightly more advantageous than the tilt rotor due to the former's higher speed and lower cost characteristics. The higher speed lift fan was best suited to the longer range missions. However, since there was little difference between these three advanced concepts, all three appeared promising to pursue.

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Volume I

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I. INTRODUCTION

In recent years the possibility of providing air service into urban or industrial activity centers has received considerable attention. However, vertical and/or short takeoff and landing (V/STOL) aircraft studies and flight test programs instituted to develop and evaluate this service concept have been largely oriented toward large commercial airline applications. To date, there has been no significant examination of the applicability of V/STOL concepts to the needs of general aviation.[1] Historically, general aviation acceptance of new aircraft concepts (e.g., turbojets and helicopters) has, with some exceptions, followed widespread military and commercial applications. The reasons for this delay are primarily economic, but also involved is the need for public familiarity with a concept prior to its broad acceptance. Thus the initial introduction of a new aircraft concept into the usually conservative general aviation field is essentially without precedent.

The objective of the present study was to investigate the applicability of V/STOL advanced technology to significant general aviation transportation needs and to assess the economic viability of V/STOL aircraft in those roles. Identification of technology goals related to small aircraft applications was considered appropriate to provide further direction to V/STOL development activities. The study focused on the late 1970's, a period representing the earliest availability of advanced technology aircraft.

In performing the study, a survey of general aviation users, manufacturers, and trade associations was made first in order to identify the principal applications of the existing general aviation fleet. Based on the survey results, criteria for desired aircraft capabilities were then defined

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[1] General aviation is a broad term applied by the Federal Aviation Administration (FAA) to those operations which are nonmilitary and outside of the Civil Aeronautics Board (CAB) regulated trunk and local service airlines. More than 139,000 aircraft are in use for a wide variety of purposes, ranging from air taxis and corporate personnel transportation to crop dusting and external load carrying.

for the principal mission areas. Preliminary performance and weight characteristics were defined for a number of advanced V/STOL concepts (compound helicopter, tilt rotor, tilt wing and lift fan)[2] and conventional aircraft that satisfied the postulated mission criteria, and these concepts were then compared based on a cost-benefit measure related to the traveler's value of time. The results of this analysis are presented in terms of the traveler's value of time, thereby permitting a wide range of comparisons to be made.

This report consists of two volumes: Volume I contains data and study results related to (1) General Aviation Missions, (2) Aircraft Configurations and Capabilities, and (3) Aircraft Cost-Benefit Analyses. Volume II (Ref. 2) consists of appendices presenting the detailed results of the survey activity, aircraft economics and cost-benefit analysis methodology, and other pertinent reference data.

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[2] The technology and operations of the small advanced V/STOL aircraft utilized in this study are discussed in greater detail in Ref. 1.

II. SUMMARY AND CONCLUSIONS

A study has been made of the potential application of advanced V/STOL aircraft design concepts to general aviation missions. The advanced concepts considered include both small (8 to 10 passenger) and large (15 to 18 passenger) aircraft and reflect a state of the art applicable to the late 1970's. Whereas the evolution of general aviation aircraft has traditionally followed very conservative practices, there are significant advantages apparent for vertical takeoff and landing (VTOL) applications in personnel transport missions formulated around executive needs, commuter air service, and offshore oil supply. The VTOL capability appears most desirable from the standpoint of easy access to locations not served by, or conveniently accessible to, scheduled airlines. Further, since most business activities are schedule oriented, the higher cruise speed advanced configurations appear to be of greater value. In view of these advantages, the economics of the advanced VTOL concepts appears favorable; however, such operational features as complexity and noise may become significant in the final choice.

The following specific conclusions can be drawn from the results of the study:

- Advanced VTOL aircraft concepts have a potential application in executive, commuter, and offshore general aviation operations and can be competitive with current conventional takeoff and landing (CTOL) aircraft and helicopters.
- Based upon survey results and a city center access analysis, there appears to be less interest and advantages in advanced short takeoff and landing (STOL) aircraft in general aviation operations supporting business activities. Rather, advanced VTOL concepts giving maximum access capability appear favored within reasonable economic bounds.

- Cost benefit analysis indicated that:

  a. The compound helicopter has little advantage over the helicopter and cannot compete with the longer range and faster VTOL concepts.

  b. The tilt rotor, tilt wing, and lift fan concepts are roughly similar in their regions of economic operation and can compete favorably with conventional aircraft and for many applications, the airlines.

  c. Detailed comparisons indicate that the tilt rotor concept appears superior to both the helicopter and compound helicopter, but for long range applications lacks the higher speed advantages of the tilt wing and lift fan concepts. The tilt wing concept, because of its speed and cost characteristics, appears to be the most viable of the advanced VTOL aircraft concepts considered. The lift fan, offering high-speed capabilities, appears slightly better than the tilt wing for longer ranges and larger sizes. However, since there was little significant difference among these three advanced concepts for most mission applications, all three concepts would appear promising to pursue.

- While this study has identified preferred VTOL concepts based on mission performance and economic benefits, considerations of technological complexity and environmental impact may greatly affect concept preference.

- The potential market for VTOL aircraft in executive, commuter, and offshore missions could utilize up to approximately 2200 large (16 passenger) aircraft and as many as 5500 small (8 passenger) aircraft by 1982.

- Advanced aircraft concepts combining VTOL capabilities with good high-speed, long-range performance could significantly expand the utilization of aircraft for general aviation purposes, overcoming current access problems to new business locations, providing time savings to business travelers, and giving increased flexibility and improved utilization of the aircraft.

III. GENERAL AVIATION MISSIONS

An initial effort was made to identify the general aviation activities that might be performed by small aircraft incorporating V/STOL technology. The effort concentrated on the late 1970's--a period in which V/STOL concepts now in the design or development stage could be expected to be in service. In addition to identifying the possible applications, the study effort included an attempt to define the critieria by which users of small aircraft select their equipment. The combination of these two study activities was intended to provide a basis for evaluating the merits of alternative V/STOL concepts for satisfying the needs of the general aviation community.

The required data were obtained from the general aviation community itself including aircraft manufacturers, commuter air carriers, and executive and commercial aircraft operators. These sources were supplemented by various aviation associations and governmental organizations that either use or administer the operation of such equipment. Appendix A in Volume II (Ref. 2) identifies the principal sources of the information on which this study effort was based and indicates the cross-section of the general aviation community from which the information was obtained.

In the following material in this section the results of these survey efforts are summarized in terms of (1) current and desired mission and aircraft characteristics, (2) comparison of current and desired mission and aircraft characteristics, and (3) the definition of criteria for identifying promising V/STOL applications and concepts.

The results of these efforts unavoidably include a degree of imprecision. In part this is due to the absence of complete statistics on general aviation activities. More importantly, the operators themselves in many cases tend to be specialized, serving highly constrained markets and consequently choosing their equipment for those applications based upon current aircraft capabilities. In other cases the operators are subjective in their equipment selection--placing emphasis on non-quantifiable factors such as aesthetics, furnishings, and prestige--and are therefore limited in providing precise criteria upon which their response to future aircraft developments could be predicted. The study results are, however, based on a broad sampling of statistics and opinions of general aviation operators and equipment suppliers, and provide a consensus of the needs and requirements of the current general aviation community.

A. MISSION AND AIRCRAFT CHARACTERISTICS

The general aviation community was divided into four mission categories for this study:

1. Air Taxi
   - Commuter Air Carriers[1]
     - Intercity Service
     - Central Business District (CBD) Service
   - Non-Scheduled
2. Business
   - Executive Transportation[2]
     - Short Distance (<100 miles)
     - Medium Distance (100 to 500 miles)
     - Long Distance (>500 miles)
   - Business Transportation[3]
     - Short Distance
     - Medium Distance
     - Long Distance
3. Aerial Application (Crop Dusting)
4. Industrial Special[4]

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(1) Any operator of small aircraft (30 passengers or less or 7500 lb maximum payload) who performs, pursuant to a published schedule, at least five round trips per week between two or more points, or carries mail on contract.

Three of these categories received special emphasis: (1) Air Taxi (Commuter Air Carriers), (2) Business (Executive Transportation), and (3) Industrial Special (those applications dealing with personnel transport). It was judged that these categories would exhibit a high degree of commonality in requirements, would utilize professional flight crews with the skills necessary to adapt to V/STOL operations, and would represent the greatest market potential in terms of numbers of aircraft operated and the capability of the users to meet the investment requirements.

1. CURRENT MISSION AND AIRCRAFT CHARACTERISTICS

Table I shows the type of aircraft currently utilized for the four categories of general aviation missions and summarizes the characteristics of those missions. (The data in this table are predominantly from the survey interviews.)

Table II summarizes the more popular aircraft and helicopter models employed in each mission category as a function of hours flown as determined from Refs. 3, 4, and 5. A more detailed basis for this determination is included in Appendix B of Volume II (Ref. 2). It is noted that in many missions relatively old models are heavily employed. This reflects the apparent desire for minimum investment costs consistent with mission requirements and the relatively prolonged use of an aircraft once purchased. Only the most attractive of the newer models, those showing significant improvement over the older models, will thus appear in the top five aircraft for each mission category.

It appears from Table II that there is no single factor or group of factors that consistently govern the selection of equipment. Cost appears to influence the choice in many cases, but it is also apparent that the most

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(2) Employee transport in company-owned aircraft by professional pilots.

(3) Use of an aircraft by an individual for business transportation purposes (not for compensation or hire).

(4) Use of an aircraft for specialized work allied with industrial activity (e.g., photography, patrol, exploration).

Table I. General Aviation Current Aircraft Types and Mission Characteristics

General Aviation Category	Type Aircraft	Typical Mission Characteristics: Stage Lengths (mi)	Pass/Flt	Aircraft Utilization (hr/yr)	Typical Itineraries
Air Taxi					
Commuter Air Carriers	Twin Turboprop	100	8[1]	2000	General Aviation Airports to Hub Airports
	Twin Piston	100	3[1]	2000	↓ ↓ ↓
	Rotary Wing	25	12[1]	2000	Hub Airports to Central Business District and General Aviation Airports
Nonscheduled	Twin Turbojet	500	4	500	Varied Charter Destinations
	Twin Turboprop	300	4	500	↓ ↓ ↓
	Twin Piston	200	2	600	↓ ↓ ↓
	Rotary Wing	50	4	500	↓ ↓ ↓
Business					
Executive Transportation	Twin Turbojet	500	4	500	Hub Airports to Hub Airports; Some General Aviation Airports
	Twin Turboprop	300	4	500	Hub Airports to General Aviation Airports
	Twin Piston	200	2	400	General Aviation Airports to General Aviation Airports
	Rotary Wing	50	4	400	Plant-to-Plant, Plant-to-Airport; Plant-to-Central Business District
Business Transportation	Twin Turbojet	500	4	500	Same as Executive Transportation
	Twin Turboprop	300	4	500	↓ ↓ ↓
	Twin Piston	200	2	400	↓ ↓ ↓
	Rotary Wing	50	4	400	↓ ↓ ↓
Aerial Application	Fixed Wing	3 (hr)	1	≈700[3]	
	Rotary Wing	1 (hr)	1	≈700[3]	
Industrial Special	Fixed Wing	100	2	800	Patrol Duties
	Rotary Wing[2]	100	4 (small A/C) 10 (large A/C)	800 (small A/C) 1000 (large A/C)	Personnel Transport to Offshore Rigs

(1) 40% load factor (2) Offshore use only shown (3) Utilization varies with season

Table II. Most Commonly Used Aircraft

Mission	Aircraft[1]	Annual Mission Hrs. Flow by Prof. Crews (1969)	No. of Eligible[2,8] Aircraft in Personnel Transport	Passenger Capacity	Speed (mph)	Investment Cost[4] ($000)
Business/Executive Transportation (Aircraft)	Beech King Air	156,000	343	6	253	405
	Gulfstream I	92,000	143	18	348	940
	Beech 18	62,000	192	6-7[5]	212	20
	Lear Jet	57,000	140	6	507	739
	Sabreliner	56,000	122	10	520	1,365
Business/Executive Transportation (Helicopter)	Bell 206	45,000	103	4[6]	131	112
	Bell 47 series	8,000	16	2[6]	82	55
	Fairchild FH 1100	6,000	20	4[6]	133	98
	Sikorsky S55	2,000	9	10	91	380
	Bell 204/205	2,000	2	13	127	425
Air Taxi (Aircraft)	Piper Aztec	175,000	770	4-5[5]	208	70
	Beech 18	153,000	480	6-7[5]	212	20
	DHC-6	125,000	120	18	209	476
	Beech 99	81,000	89	15	254	370
	Cessna 310	65,000	310	4-5[5]	220	70
Air Taxi (Helicopter)	Bell 47 series	151,000	349	2[6]	82	55
	Bell 206	39,000	88	4[6]	131	112
	Bell 204/205	25,000	23	13	127	425
	Hiller H-12E	17,000	55	3[6]	84	N/A[7]
	Sikorsky S55	7,000	30	10	91	380
Industrial Special Personnel Transport only[3] (Helicopter)	Bell 47 series	14,000[3]	15	2[6]	82	55
	Bell 204/205	8,000[3]	15	13	127	425
	Hughes 269 series	6,000[3]	58	2[6]	80	35
	Sikorsky S61	1,700[3]	5	30	140	N/A[7]
	Hughes 500	1,400[3]	4	4[6]	150	110

(1) Five most commonly used
(2) Number of aircraft for noted mission estimated by dividing total annual mission hours by average flight hours per aircraft
(3) Estimated at 50% of "Industrial Special" and "Other" category for mission hours flown in noted helicopters
(4) Basic aircraft
(5) Smaller figure if copilot assumed
(6) Single pilot assumed
(7) Not available
(8) Eligible aircraft are those which meet annual FAA airworthiness standards

popular equipment in each mission category tends to be the smallest consistent with mission requirements, and cost and size are obviously correlated. It should also be noted that in most of the mission categories the bulk of activity is performed by only one or two equipment types and that substantial numbers of such aircraft and helicopters are utilized in these cases. For example, almost 700 Beech 18's are utilized for executive transportation and air taxi operations, and approximately 400 Bell 47 series helicopters are employed in the same mission categories. Consequently there appears to be a substantial market potential for new equipment that is well suited to these applications.

2. DESIRED MISSION AND AIRCRAFT CHARACTERISTICS

Figure 1 illustrates the desired mission and aircraft characteristics identified from the survey of operators, aviation associations, and manufacturers. These characteristics are displayed for Air Taxi, Business and Industrial Special (personnel transport only) operations. Relatively broad ranges are shown for these characteristics reflecting the diversity of opinion expressed by the data sources. The desired characteristics are shown in both "short-term" (through the mid-1970's) and "long-term" (late 1970's through the mid-1980's) categories. Additional detailed data obtained during the course of the survey are presented in Appendix A of Volume II (Ref. 2).

A few significant observations may be drawn from Figure 1. First, it can be seen that the majority of general aviation activities are performed over stage lengths less than 300 miles. Nevertheless, the operators desire equipment having range capabilities on the order of four to six times greater than their "typical" stage lengths for operation. Secondly, with the exception of long-distance Executive Transportation, speeds in the range of from 150 to 350 mph are adequate--it appears that only the highest "time value" passenger requires (or can justify) speeds corresponding to jet equipment.

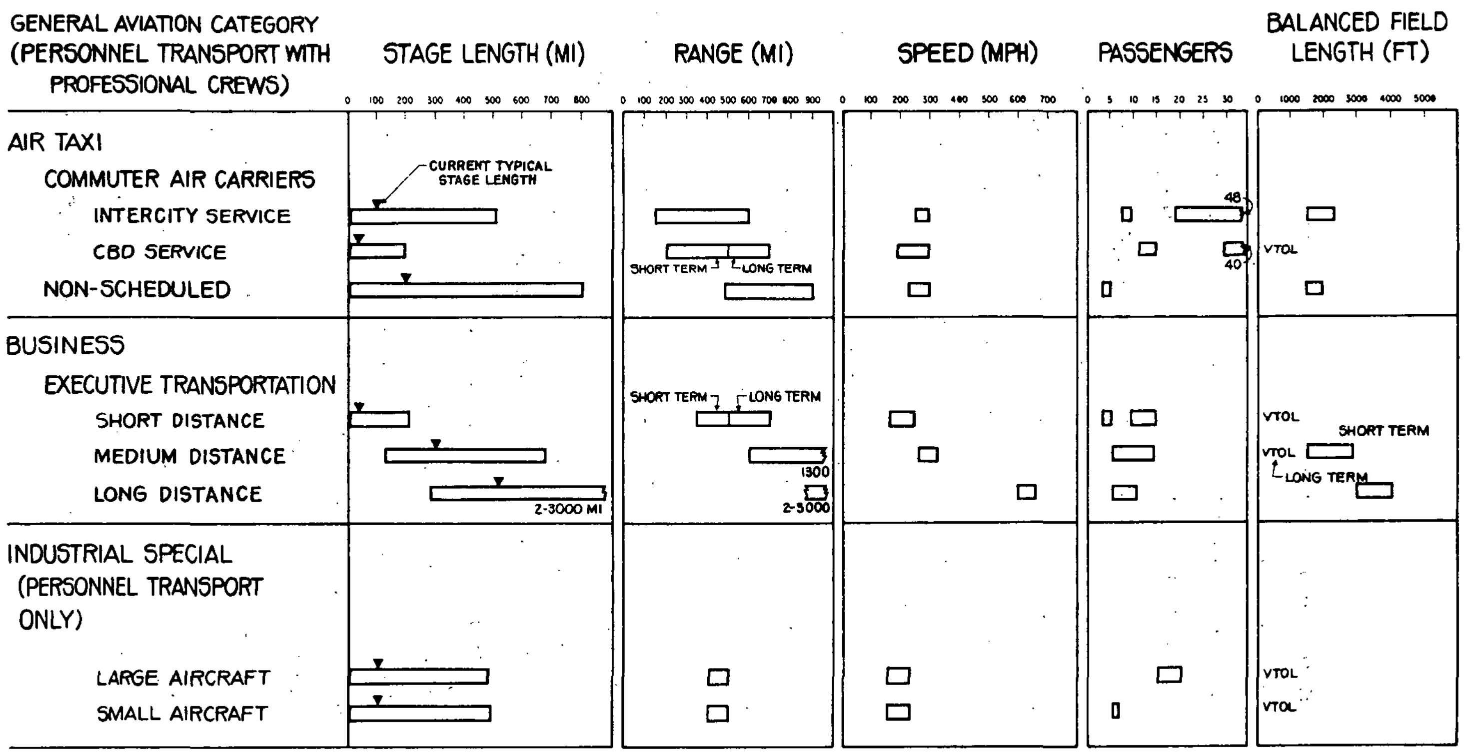

Figure 1. Desired Mission and Aircraft Characteristics

Most interesting, however, are the stated desires related to balanced field lengths (i.e., the runway required for an aircraft accelerated to liftoff speed to brake to a stop or to continue take-off to 35 feet on one engine, whichever is longer). These desires fall into three categories. The first involves long distance Executive Transportation, in which high block speed offers greater time-savings than the ability to use short, "close-in" airports. In these applications, balanced field length capabilities on the order of 3 to 4000 feet are acceptable. In the cases of medium distance operations (i.e., intercity service Commuter Air Carriers, non-scheduled Air Taxis, and medium distance Executive Transportation), block speed loses importance and operational accessibility becomes more important; hence, there is a short-term desire for balanced field length capabilities in the range of from 1500 to 3000 feet with a long-term VTOL desired if cost is not a significant constraint. Finally, there are those operational categories in which direct access is the primary objective. These categories include Commuter Air Carriers providing CBD service, short distance Executive Transportation, and Industrial Special (personnel transport) operations. In these cases, the desire is to have VTOL capability, thereby providing the maximum flexibility for achieving close-in access.

B. COMPARISON OF CURRENT VS. DESIRED MISSION AND AIRCRAFT CHARACTERISTICS

Figures 2 through 4 present comparisons of the performance characteristics of aircraft and helicopters currently being used to perform general aviation missions with the desired operational characteristics previously shown in Figure 1. Figure 2 displays this comparison for jet aircraft, turboprop aircraft, and helicopters; Figure 3 illustrates the characteristics of large twin piston aircraft; and Figure 4 presents similar information for small twin piston aircraft. These charts show the extent to which present aircraft satisfy the desired mission characteristics and also graphically display the types of operational improvements desired by the general aviation community as discussed below.

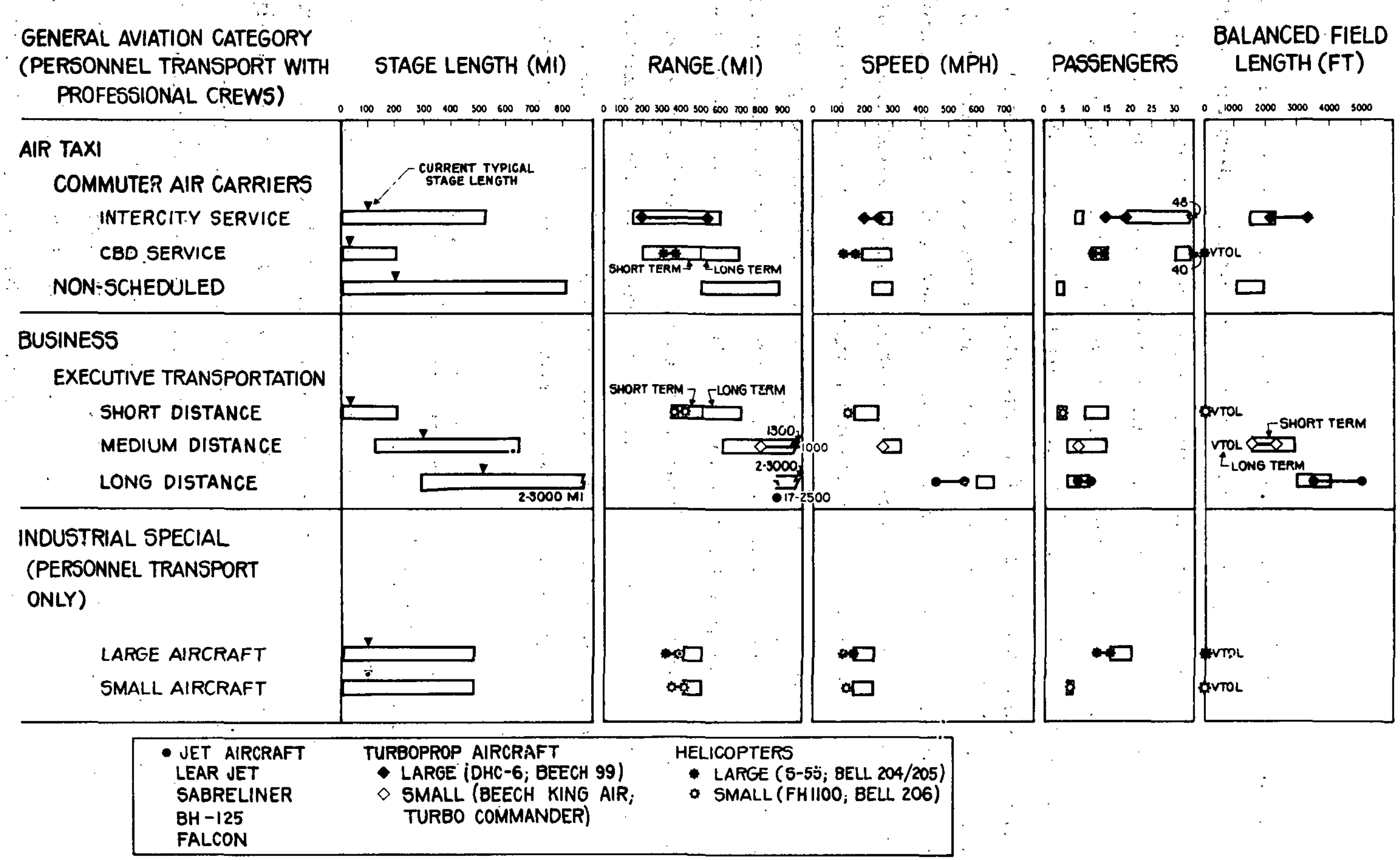

Figure 2. Comparison of Desired Mission and Current Aircraft Characteristics (Turbojet, Turboprop and Helicopter)

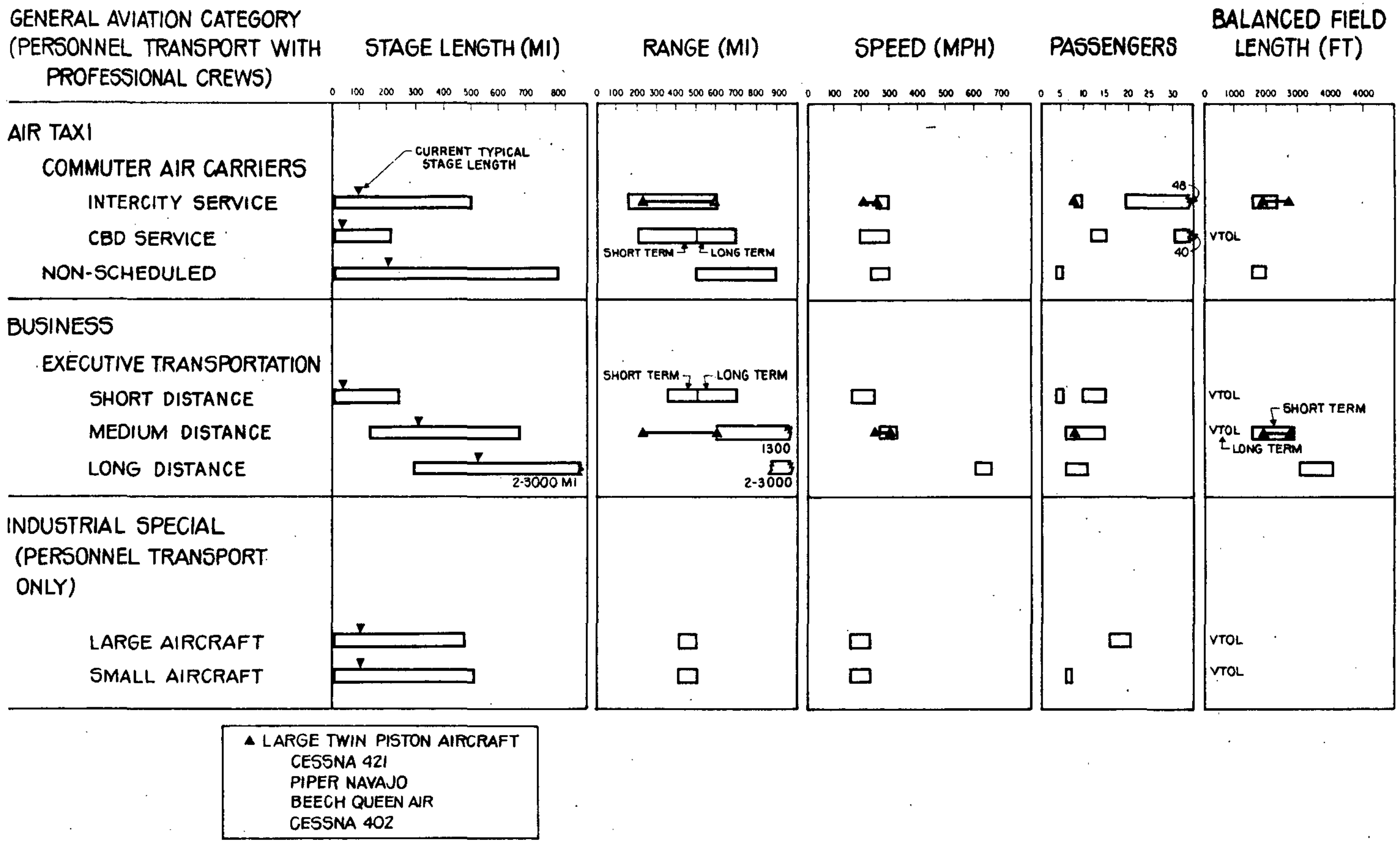

Figure 3. Comparison of Desired Mission and Current Aircraft Characteristics (Large Twin Piston)

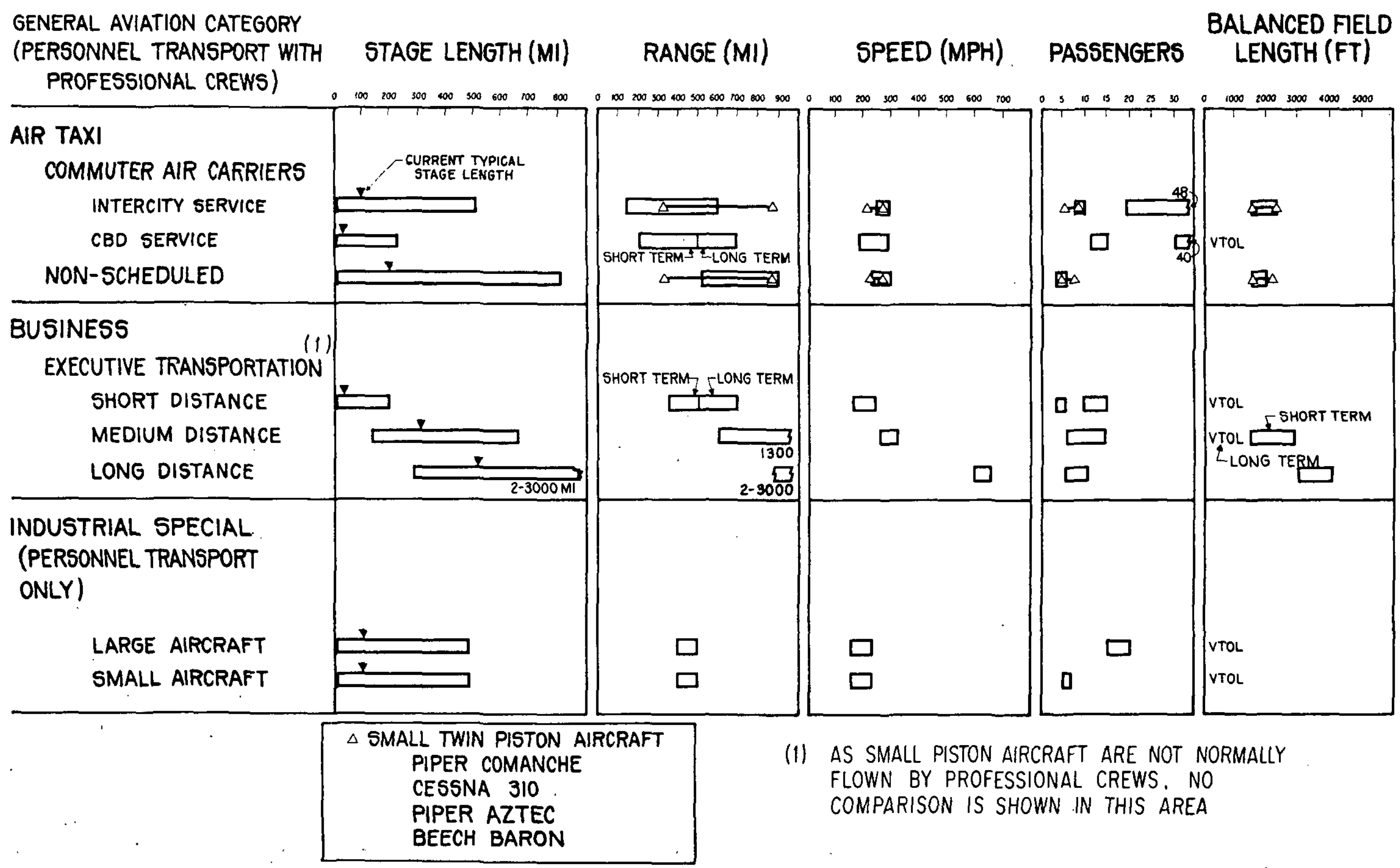

Figure 4. Comparison of Desired Mission and Current Aircraft Characteristics (Small Twin Piston)

1. JET AIRCRAFT

As can be seen from Figure 2, current jet aircraft do not satisfy the desire for high-speed performance. Since this equipment is used to compete with commercial jet service, while offering privacy and departure-on-demand, there is a strong desire for aircraft with comparable speed capabilities. Additionally, current jet aircraft have balanced field length characteristics somewhat longer than desired, but not to the extent that STOL capabilities are required. The operators generally believe that shorter field capability would compromise speed or cost, both of which are more dominant considerations in the selection of such equipment. This again reflects the opinion that block time (i.e., gate-to-gate aircraft-related trip time including taxi, take-off, descent, landing and air traffic delay) rather than access time is more important in those applications utilizing jet equipment, a belief that was confirmed by an example analysis of airport access times for 34 different metropolitan areas in the United States. The analysis [presented in Appendix C of Volume II (Ref. 2)] indicates that short field capabilities, and the corresponding flexibility to operate out of most existing general aviation airports, would only reduce airport access time by fewer than 13 minutes.

2. TURBOPROP AIRCRAFT

Some additional speed is desired for turboprop aircraft utilized in the Commuter Air Carrier category (Figure 2). Additionally, although a 2000-foot field length capability is desired, there was no stated requirement for a true STOL capability of less than 1500 feet. In the Executive Transportation category, the present turboprop aircraft characteristics essentially match the desired characteristics for the medium distance missions with the exception of a desire for some additional speed and the ability to carry more passengers.

3. HELICOPTERS

For helicopters (Figure 2), there is an apparent need for additional speed and range (especially for long-term needs); higher capacity is desired for the larger Commuter Air Carrier missions. The desire for more speed and range is not surprising considering the low speed and limited range of current helicopters. In the offshore petroleum industry, for example, large numbers of helicopters are used exclusively to transport personnel to and from offshore oil and natural gas rigs. These rigs are located up to 200 miles from shore and are expected to be even further out in the future. The commercial operators presently servicing this industry are interested in a vehicle capable of making a maximum payload round trip of 400 to 500 miles (with reserves) without refueling. For the longer distances, additional speed also becomes an important factor.

Executive users of helicopters also appreciate its convenience but they would like to use it over greater stage lengths. Such a capability would have the additional advantage of eliminating intermodel transfers to the company jet or turboprop. Speed and range are thus limiting factors for these missions.

4. TWIN PISTON AIRCRAFT

For large twin piston aircraft (Figure 3), there were no particular performance features of present aircraft that did not match the desired operational characteristics except for a desire for more range and slightly more speed. This was also true for small twin piston aircraft (Figure 4).

C. CRITERIA DEFINITION

The preceding review of general aviation missions and equipment permits a number of conclusions to be drawn relative to operational needs and potential equipment developments. The following paragraphs summarize these conclusions in terms of CTOL modifications, and STOL and VTOL requirements. These conclusions are then generalized into criteria that can be applied to the evaluation of new aircraft concepts.

1. CTOL MODIFICATIONS

The principal needs of executive and commuter operations are related to the reduction of trip time. For long distance operations utilizing jet aircraft, the reduction of trip time is most effectively accomplished through an increase in block speed. Shorter field capabilities do not produce significant reductions in ground access time and are consequently viewed as unnecessary compromises to equipment speed and cost. The executive and commuter operations presently utilizing turboprop and piston aircraft already have a reasonably short field capability (i.e., approximately 3000 feet), and the users of such equipment can presently operate into the majority of United States airports. Since the objective of this study was to identify potential applications for VTOL and STOL technology, rather than techniques for improving block speed, CTOL modifications were not considered further.

2. STOL AIRCRAFT

Based upon the survey results and the city center access analyses, [Appendices A and C of Volume II (Ref. 2)] the market for a new STOL aircraft for general aviation personnel transport missions appears limited. There was some limited interest in STOL aircraft with field length capabilities of about 1000 feet by some corporations with current large parking lots. However, the principal value in short field capabilities (on the order of 1500 to 2000 feet) was related to the potential of operating into general aviation airports close to the CBD or into separate STOL strips at hub airports. Small aircraft currently in use for commuter air carrier and executive transportation already possess satisfactory short field capabilities, and larger aircraft are primarily limited by noise rather than by field length capabilities. Thus, to the extent determinable from the efforts of this study, STOL technology does not appear to have a significant general aviation market potential and subsequent emphasis was applied to VTOL aircraft.

3. VTOL AIRCRAFT

The most promising applications of V/STOL technology in general aviation operations appear in the VTOL category, particularly if such capabilities can be provided in combination with higher speed and longer range than that available with current helicopters. The combination of these features would find application both to the Commuter Air Carrier and to the short and medium distance Executive Transportation categories by offering significant improvements in access and block times. It would also appeal to operators of helicopter equipment performing Industrial Special (personnel transport) missions--particularly those involved in offshore personnel transport wherein large numbers of helicopters are used exclusively for such missions.[1] The combination of these applications represents a significant market potential by 1982 as discussed below in Section D. For these reasons, the remainder of this study concentrates on the evaluation of alternative VTOL concepts and the definition of those VTOL systems most adaptable to these aviation missions.

4. CRITERIA FOR THE EVALUATION OF NEW VTOL CONCEPTS

The following criteria were established for evaluating new VTOL concepts. These criteria are based primarily on a composite of the requirements discussed above for the three general aviation missions: (1) Commuter Air Carrier, (2) Executive Transportation (short and medium distance), and (3) Industrial Special (personnel transport).

a. Range: 400 to 500 miles
b. Speed: 200 to 300 mph
c. Capacity: 8 to 10 passengers and 15 to 18 passengers
d. Operating mode: VTOL

For such equipment, costs must be comparable to those of current helicopters. No special hovering capabilities are needed beyond those required for takeoff and landing.

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[1] Commercial operators that cannot justify exclusive use of a VTOL aircraft for personel transport alone will continue to favor the conventional helicopter with its hover capability and more versatile application.

Similar criteria are appropriate for long distance missions with the exceptions that speed must be equivalent to or better than that of existing jet aircraft, and range capability on the order of 1000 miles is required.

Whereas these criteria do not satisfy each and every interviewee's idea of an ideal aircraft for his needs, it is felt they do represent a good cross-section of desired characteristics as well as actual historical utilization in the noted mission categories.

D. VTOL MARKET POTENTIAL

The market potential for new VTOL aircraft may be estimated from available projections of aircraft inventories in each of the general aviation mission categories. Projections through 1982 for each type of aircraft currently utilized in these missions are shown in Figures 5 and 6. These data are based on FAA projections (Ref. 6) and the assumption of a constant fleet mix.

Table III, also based on FAA statistical data (Ref. 6), summarizes the mission potential for new VTOL aircraft in each of the general aviation mission categories of interest. The table identifies the 1969 fleets of large and small aircraft and the corresponding fleets projected for 1982. During this time period a demand is projected for approximately 1600 large aircraft and 3800 small aircraft for the shorter distance applications, with a grand total of approximately 2200 large and 5500 small aircraft if the long distance applications are included. Some fraction of this market can be satisfied by new VTOL aircraft concepts provided they possess the proper characteristics of speed, range, capacity, cost, and operating mode.

The remainder of this volume is concerned with the evaluation of new VTOL concepts that are potentially capable of satisfying that demand.

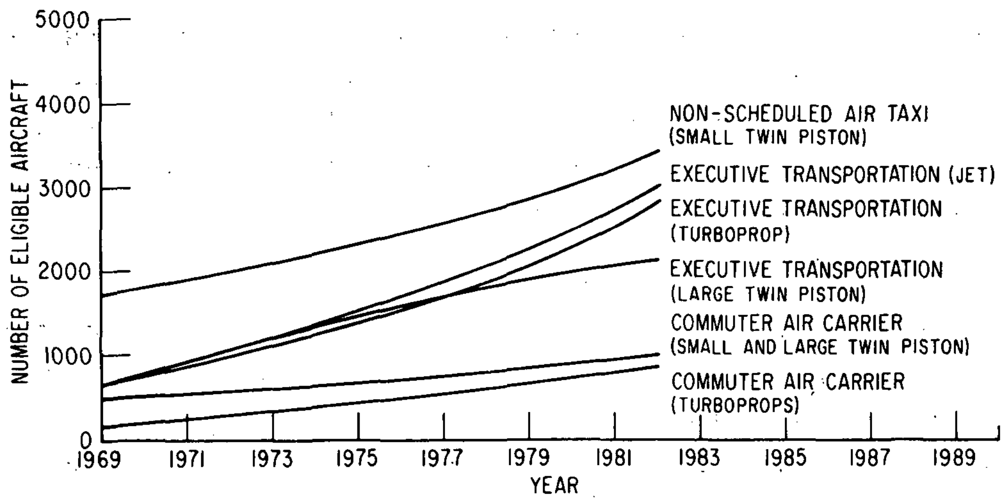


Figure 5. Market Potential--Fixed Wing Aircraft

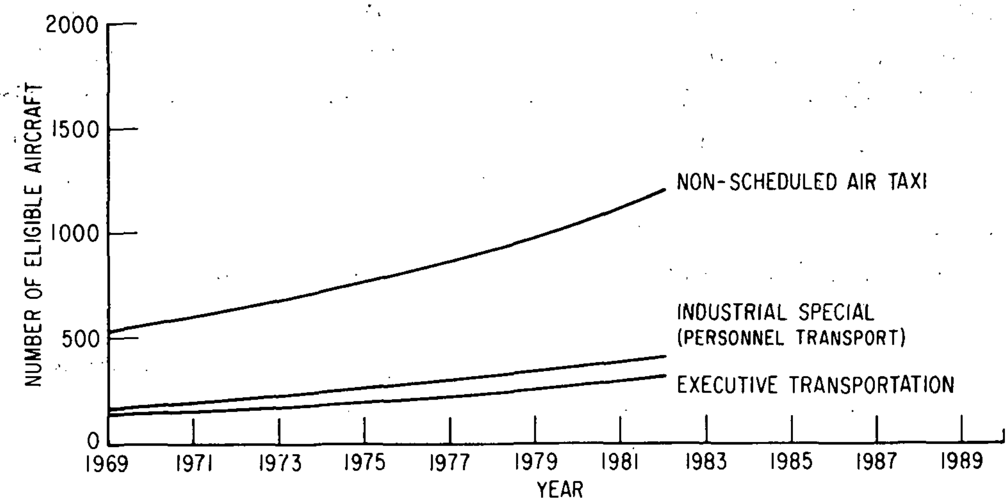


Figure 6. Market Potential--Helicopters

Table III. Potential Market for Improved Technology Aircraft

Applications	Approximate Number of Aircraft					
	1969		1982		Potential Aircraft Market (1982)(5)	
	Size(1)		Size(1)		Size(1)	
	Large	Small	Large	Small	Large	Small
Commuter Air Carriers	193(3)	424(3)	850(3)	1000(3)	660	580
Executive Transportation						
Short Distance	2(2)	103(2)	7(2)	300(2)	5	200
Medium Distance	300(3)	900(3)	1200(3)	3700(3)	900	2800
Long Distance	170(4)	512(4)	750(4)	2250(4)	580	1740
Industrial Special (Offshore Personnel Transport)	15(2)	90(2)	60(2)	320(2)	45	230
Subtotal (Excluding Long Distance)	510	1517	2117	5320	1610	3810
Grand Total	680	2029	2867	7570	2190	5550

(1) Large: 15-18 place
Small: 6-10 place
(2) Helicopters
(3) Turboprops, Twin Pistons
(4) Turbo/Fan Jets
(5) 1982 projections minus current 1969 aircraft (rounded off)

IV. AIRCRAFT CONFIGURATIONS AND CAPABILITIES

This section describes the current and advanced aircraft concepts evaluated in the study and discusses the numerical parameters assigned to each for use in the comparative analyses presented in Section V. The primary parameters needed for the analyses are related to the physical and economic characteristics of the aircraft under study. The physical parameters include size, speed, delay factor, and operational accessibility, which are defined below. The economic factors include development, investment, and operating costs.

Two sizes of aircraft, corresponding to passenger-carrying capabilities of 8 and 16,[1] respectively, were utilized in the comparative analyses. These sizes conform to the desired mission requirements established in Section III.

In the comparative analyses, block time is used as the primary performance characteristic rather than cruise speed. Since block time cannot be stated without regard to a block distance, it is derived from two factors: the design cruise speed and a delay factor. The design cruise speed is the aircraft's cruising speed at a particular optimum altitude and throttle setting. The delay factor refers to the time that the aircraft is operating but is not progressing toward the destination at design speed. This "non-productive" time includes taxi, takeoff, climb, descent, landing, and traffic delays. When combined with cruise speed and distance, the delay factor produces the block time for a given flight distance.

The operational accessibility of an aircraft to a user is generally related to its design concept. VTOL aircraft are considered more accessible than CTOL aircraft since the latter require longer runways which are generally located at greater distances from the origin and destination points of the traveler.

[1] Additionally, two crew seats are available for each aircraft except the small helicopter, which has only one.

A. COMPOSITE CURRENT AIRCRAFT

The concept of a composite aircraft was introduced to permit meaningful comparisons between current and advanced aircraft. The characteristics of the composite aircraft were derived primarily from the features of the more popular aircraft currently performing general aviation missions. The characteristics also reflect the desired mission requirements, such as passenger capacity and range, as developed in Section III. Table IV summarizes the characteristics of aircraft in the current fleet from which the composite aircraft were developed. Performance and cost data shown on this table were derived from Refs. 4 and 5 and the equipment list of Appendix D of Volume II (Ref. 2). A more comprehensive tabulation of current aircraft characteristics is presented in Appendix B of Volume II (Ref. 2).

1. SMALL AIRCRAFT CHARACTERISTICS

Table V presents the primary characteristics for the small composite current aircraft. The three categories of aircraft shown--helicopter, turboprop, and turbojet--possess the characteristics required to perform the short, medium, and long distance Executive Transportation Missions, respectively. Additionally, the small helicopter can satisfy the operational requirements of Offshore Missions in support of the petroleum industry's supervisory personnel transport. The composite CTOL aircraft carries six passengers and the composite helicopter five passengers.

2. LARGE AIRCRAFT CHARACTERISTICS

Table VI provides descriptions of the large composite aircraft. Because of the different mission characteristics, the large turboprop is divided into two classes: the long and medium distance Executive Transportation Missions and the intercity service Commuter Air Carrier Mission. The large helicopter, like its smaller counterpart, performs a short distance Executive Transportation Mission and Offshore Mission (crew change); in addition, it is used for Commuter Air Carrier CBD service. Sizes range from the 12-passenger helicopter to the 18-passenger Executive Transportation turboprop.

Table IV. Representative Current Aircraft

Type	Takeoff Weight (lb)	Empty Weight (lb)	Fuel Weight (lb)	Pass. Seats	No. Engines	Thrust Total(1) (lb)	Cruise Speed (mph)	Fuel Consump. (gph)	Range(2) (s.m.)	Equipped Inv. Cost $(000)
Small Helicopter										
Hughes 500	2,550	1,086	400	4	1	317	150	25	376	126
Bell 206	3,000	1,480	500	4	1	317	131	28	351	128
Vought-Alouette III	4,850	2,467	950	6	1	600	118	62	275	213
Small Turboprop										
Merlin II	10,000	6,150	2,500	6	2	1,330	292	78	770	502
Hawk Commander	9,450	5,519	1,850	6	2	1,210	254	59	851	438
Mooney MU-2	9,920	5,790	2,400	6	2	1,410	325	75	966	429
King Air B 90	9,705	5,684	2,500	6	2	1,100	256	72	1,000	465
Small Turbojet										
Learjet 24	13,500	6,851	5,400	6	2	5,900	507	192	1,670	799
Hansa 9	20,280	11,875	7,100	5	2	6,200	530	340	1,250	1,150
BH 125	23,300	11,875	8,900	7	2	6,720	443	264	2,040	1,130
Saberliner 40	18,340	9,895	6,900	4	2	6,600	520	192	2,000	1,425
Large Helicopter										
Sikorsky 58T	13,000	6,804	1,250	12	2	1,600	106	96	214	441
Sikorsky 55	7,500	5,250	1,200	10	1	800(3)	91	43	400	396
Bell 204/205	9,500	5,197	1,340	13	1	1,400	127	88	311	441
Bell 212	10,000	5,800	1,340	13	2	1,800	127	97	286	591
Large Turboprop (Commuter)										
Beech 99	10,900	6,000	1,650	15	2	1,360	285	90	531	430
DeHavilland DHC-6	12,500	6,750	3,000	20	2	1,240	209	90	191	536
Large Turboprop (Executive)										
Gulfstream I	35,100	21,900	10,462	18	2	4,420	348	250	2,000	1,000
Swearingen Merlin IV	12,500	7,500	4,200	10	2	1,680	305	94	947	705
FH 227D	45,500	28,300	8,900	28	2	4,360	293	198	1,219	1,060
Large Turbojet										
Jetstar-8	42,500	21,199	17,300	10	4	13,200	507	522	2,205	1,810
Grumman G-II	60,000	35,200	22,400	12	2	22,800	590	490	3,717	3,000
Fokker F-28	63,000	36,500	22,400	30	2	19,700	415	672	1,817	3,100
Saberliner 60	20,372	10,900	6,900	10	2	6,600	520	192	2,490	1,425

(1) Shaft hp for turboprops and helicopters (2) Maximum payload (3) Piston engine (hp)

Table V. Small Composite Aircraft Descriptions

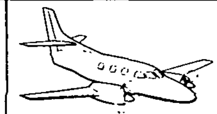
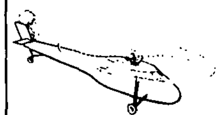
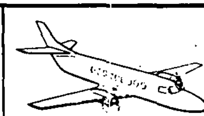
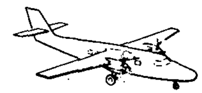
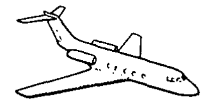
Characteristics	 Small Helicopter	 Small Turboprop	 Small Turbojet
Cruise Speed (mph)	135	280	500
Range (s.m.)	300	900	1,900
Capacity (passengers)	5	6	6
Takeoff Weight (lb)	3,500	9,800	19,000
Empty Weight (lb)	1,700	5,800	10,000
Fuel Weight (lb)	600	2,300	7,100
Number of Engines	2	2	2
Thrust (lb or shp)	400	1,300	6,400
Fuel Consumption (gph)	38	70	247

Table VI. Large Composite Aircraft Descriptions

Characteristics	 Large Helicopter	 Large Turboprop (Executive)	 Large Turboprop (Commuter)	 Large Turbojet
Cruise Speed (mph)	110	315	250	510
Range (s.m.)	300	1,400	400	2,600
Capacity (Passengers)	12	18	18	14
Takeoff Weight (lb)	10,000	31,000	11,700	16,500
Empty Weight (lb)	5,800	19,200	6,400	25,900
Fuel Weight (lb)	1,300	7,850	2,300	17,250
Number of Engines	2	2	2	2
Thrust (lb or shp)	1,400	3,500	1,300	15,600
Fuel Consumption (gph)	80	180	90	470

3. INVESTMENT AND OPERATING COSTS

The economic characteristics of the composite current aircraft discussed above were determined by averaging the investment and operating costs of the aircraft currently performing the various general aviation missions. The investment costs are based on 1971 dollars. Spare parts were not considered in the investment costs but were assumed to be part of the maintenance costs. Operating costs [described in detail in Appendix D of Volume II (Ref. 2)] were divided into two basic portions: variable and fixed. The variable costs are those directly related to cost per flying hour and typically consist of fuel, oil, and maintenance. Fixed costs, because of their independence of flying time, were computed on an annual basis and typically consist of crew, insurance, depreciation, etc. For convenience, the fixed costs were divided by the number of hours flown per year (utilization) and the quotient added to the variable cost to yield a total hourly operating cost.

Table VII summarizes the economic characteristics of the composite aircraft. The utilizations determined as a result of operator survey data for

Table VII. Composite Aircraft Cost Summary

Type	Investment Cost (Equipped) ($000)	Total Cost ($/hr) Annual Utilization (hr) 500(3)	800(4)	1000(5)	2000(6)	Average Number of Passengers Executive(7)	Comm.(8)	Offshore(7)	Cost/Passenger ($/hr) Executive	Comm.	Offshore
Small Helicopter	150	244(9)	152	--	--	4	--	4	61	--	38
Large Helicopter	470	617(9)	--	363	238	8	6	10	103	40	36
Small Turboprop	460	308	--	--	--	4	--	--	77	--	--
Large Turboprop(1)	900	564	--	--	--	8	--	--	71	--	--
Large Turboprop(2)	480	--	--	--	142	--	8	--	--	18	--
Small Turbojet	1,130	620	--	--	--	4	--	--	156	--	--
Large Turbojet	2,230	1050	--	--	--	8	--	--	131	--	--

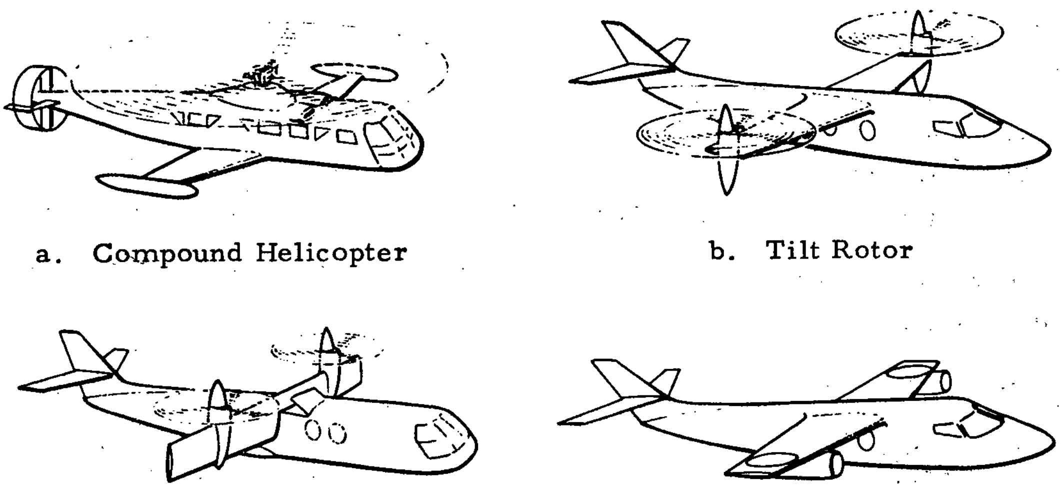
(1) Executive type
(2) Commuter type
(3) Executive Missions
(4) Small A/C Offshore
(5) Large A/C Offshore
(6) Commuter Missions
(7) 1971 average
(8) 40% load factor
(9) @ 400-hr utilization

each mission are noted in the table, and their impact on the total hourly operating cost can be seen in the cases of the helicopters which perform more than one mission. The average number of passengers shown are those carried on a typical flight for the mission specified. The cost per passenger involves a prorated hourly operating cost, assuming that the average number of passengers are carried on each flight. This value is obtained by dividing total cost per hour by average passengers per flight as determined from the user survey data.

B. ADVANCED AIRCRAFT CONCEPTS

Advanced aircraft concepts for the general aviation personnel transport missions defined in Section III were required for comparison with the composite current aircraft. For practical reasons, only a limited number of concepts could be examined. As explained in Section III, these concepts were limited to VTOL aircraft. In addition, only concepts which might be available in the late 1970's were considered, further eliminating some of the VTOL concepts requiring significant development effort. Noise was not a parameter for analysis in this study, but the nature of the missions and current environmental concerns suggested that noise could be used as a parameter to further limit concepts for consideration. The concepts finally selected for evaluation include compound helicopters, tilt rotors, tilt wings, and tip-driven pneumatic lift fans. While noise may be a problem (Refs. 7 through 9), the lift fan was retained as the most promising concept for comparison with the current turbojets in accomplishing the long distance Executive Transportation Missions. (Direct lift concepts using turbojets and low by-pass turbofans were eliminated because of the noise consideration). Although there are additional VTOL concepts that may prove promising for application to general aviation missions, the four selected aircraft design concepts were considered representative to fulfill specific missions of the late 1970's and may be related to the composite current aircraft.

Figure 7 presents sketches of the four concepts selected for evaluation. The compound helicopter shown in Figure 7a is a derivative of the 16H-3J design proposed by Piasecki (Ref. 10). Sikorsky also has investigated



a. Compound Helicopter

b. Tilt Rotor

c. Tilt Wing

d. Lift Fan

Figure 7. Advanced Small Aircraft Concepts

compound helicopter designs and has flown a test version. The tilt rotor of Figure 7b is characteristic of the design work currently in progress at the Bell Helicopter Company (Ref. 11). Some experimental work has been sponsored to date including the flights of the Bell XV-3; however, this design has yet to reach a final prototype stage. The tilt wing in Figure 7c is related to the Canadair CL-84 (Ref. 12) and the LTV XC-142. Both of these experimental aircraft have been extensively flight tested. Figure 7d is representative of current lift fan configurations. This concept has been flown in the Army XV-5A and the NASA XV-5B experimental configurations.

1. SELECTED DESIGN CONFIGURATIONS

As in the case of the composite current aircraft, the salient physical and economic parameters associated with each of the new aircraft concepts were defined to reflect the mission characteristics discussed in Section III. For those mission characteristics expressed as a range of values (e.g., 6 to 10 passengers), the average value was chosen as the design point.

The following design parameters were specified for each advanced VTOL concept:

a. Sizes: 8 and 16 passengers

b. Crew: 2

c. Range: 500 statute miles with maximum payload (10% fuel reserve)

The additional ground rules and assumptions listed below were required to simplify the design effort:

a. Engines were assumed available in any desired power or thrust range (i. e., no development required).

b. Engine thrust (or horsepower) rating could be increased by 10% for no more than 2.5 minutes to cover the contingency of an engine out on takeoff.

c. Takeoff could be continued with the loss of one engine at 2000 feet and 82°F.

d. Thrust to weight ratios:

$T/W \geq 1.05$, with one engine out

$T/W \geq 1.25$, normal operation

e. Ten inches of clearance between the fuselage and the rotors or propellers.

f. Pressurized fuselage.[2]

g. Circular fuselages of 6-foot diameter.

h. Approximate structural load factor of 4 g's.

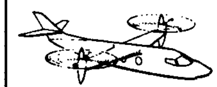
i. Current state-of-the-art for airframe and propulsion technology.

The required physical and economic characteristics of the advanced VTOL concepts were based on extrapolations or interpolations of existing experimental aircraft or conceptual designs proposed by various manufacturers.

The design parameters of the small advanced VTOL concepts are summarized in Table VIII. The small compound helicopter, tilt rotor, and tilt wing were defined for application in the short and medium distance

(2) Except for the small compound helicopter which cruises at low altitudes.

Table VIII. Small Advanced Aircraft Descriptions

Characteristics	 Compound Helicopter	 Tilt Rotor	 Tilt Wing	 Lift Fan Basic	Lift Fan Extended Range
Cruise Speed (mph)	190	380	430	530	530
Range (s.m.)	500	525	430	600	1,420
Capacity (Passengers)	8	8	8	8	8
Takeoff Weight (lb)	9,700	11,600	10,000	12,500	22,000
Empty Weight (lb)	5,900	8,300	6,600	9,100	15,500
Fuel Weight (lb)	1,900	1,300	1,250	1,400	4,400
Number of Engines	2	2	2	3	3
Total Thrust (lb or shp)	1,380	3,480	4,020	7,670	13,410
Fuel Consumption (gph)	100	129	142	171	266

Executive Transportation Missions and the Offshore Missions (personnel transport). The lift fan was designed primarily to fulfill the medium and long distance Executive Transportation Missions as its speed and costs were considered in excess of those desired for the Offshore Mission applications. Some comparative analyses for this mission are shown in Section V. Two lift fan configurations were considered. A basic design was defined in view of the general criteria of Paragraph C.4. To facilitate later comparisons of this basic design with a configuration directly suitable to longer range executive missions, a heavier extended range design incorporating higher thrust engines was also defined. Although the Extended Range Lift Fan has almost twice the takeoff weight of the small lift fan, it is still considered in the "small" category as size is defined in terms of passenger load. The added weight is a result of extra fuel required for the longer range plus the required added thrust and associated airframe weight.

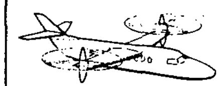
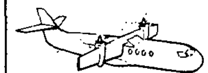
Table IX presents the physical parameters for the large advanced VTOL concepts. The missions envisioned for these aircraft correspond to those for the small concepts (i.e., tilt rotor, tilt wing, and compound helicopter for short and medium distance executive Transportation and Offshore Missions, and the lift fan for medium and long distance Executive Transportation Missions). Additionally, all four large aircraft are considered applicable to the Commuter Air Carrier Intercity Service and CBD Service Missions, with the lift fan restricted from CBD operations due to noise considerations.

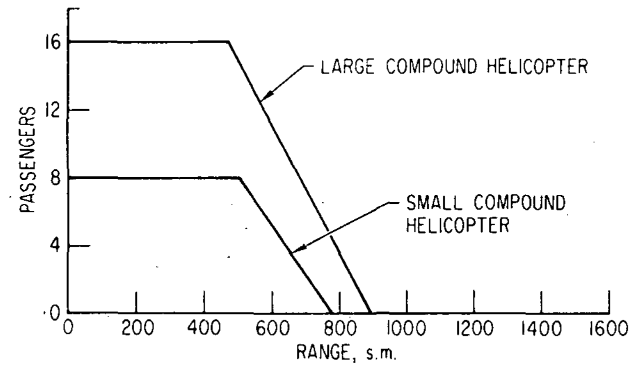
Figure 8 presents passenger load-range curves for the aircraft described above. In all cases, the range is at a constant gross takeoff weight and includes a 10% fuel reserve. To achieve ranges beyond that range associated with a full passenger load, fuel is substituted for passengers.

2. DESIGN CONFIGURATION ANALYSIS

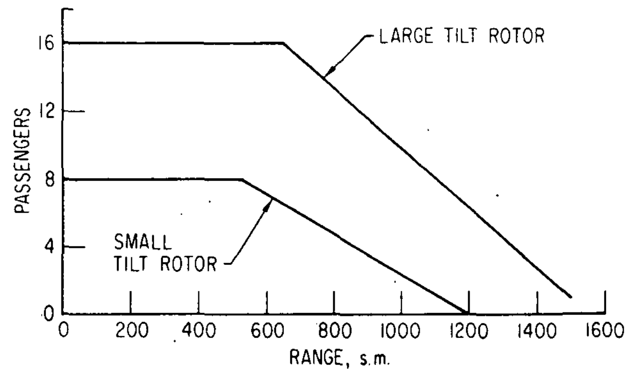
The general arrangements of the small and large advanced aircraft concepts are quite similar except for the compound helicopters. Two principal problems existed in arriving at rotor and propeller design configurations: noise and engine-out capability. Operational experience with heli-

Table IX. Large Advanced Aircraft Descriptions

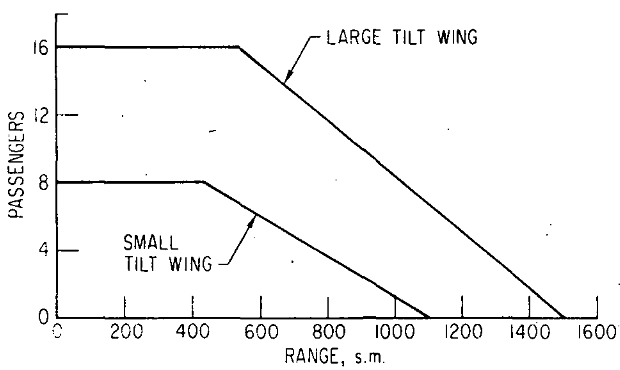
Characteristics	 Compound Helicopter	 Tilt Rotor	 Tilt Wing	 Lift Fan
Cruise Speed (mph)	265	320	370	565
Range (s.m.)	470	650	540	520
Capacity (Passengers)	16	16	16	16
Takeoff Weight (lb)	19,000	20,700	17,500	22,000
Empty Weight (lb)	11,800	14,800	11,500	16,300
Fuel Weight (lb)	3,500	2,300	1,800	2,100
Number of Engines	3	4	4	3
Total Thrust (lb or shp)	4,220	4,360	5,330	13,440
Fuel Consumption (gph)	278	159	176	315



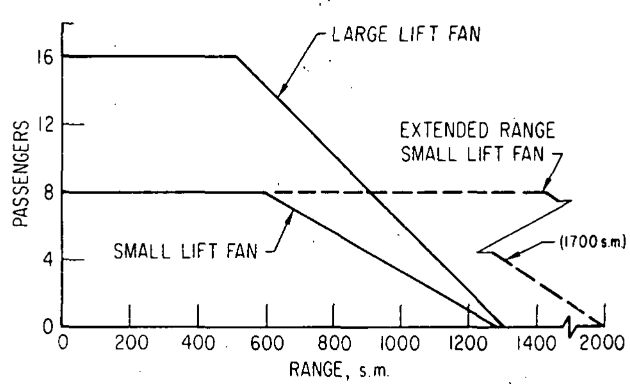
a. Compound Helicopter Aircraft



b. Tilt Rotor Aircraft



c. Tilt Wing Aircraft



d. Lift Fan Aircraft

Figure 8. Passenger/Range Diagram

copters and analytical predictions by manufacturers have indicated that the small rotor type VTOL aircraft considered in this study will be able to satisfy a noise criterion of 95 EPNdB at 500 feet. Therefore the major problem in the conceptual analysis was the selection of an economic propulsion system that would meet an engine-out requirement at 2000 feet and $82^{o}F$. As an example, a typical two-engine tilt rotor would have to exhibit 64% more power per pound of weight to meet the engine-out design criterion (T/W = 1.05) than would be required for T/W = 1.25 at sea level on a standard day. The corresponding increase in power per pound for three- and four-engine aircraft would be 22% and 9%, respectively. Other cost and weight factors tend to reduce the advantage of a large number of small engines, and the optimum power plant arrangement could only be selected by making detailed analyses beyond the scope of this study. Consequently it was assumed that all propeller and rotor aircraft would utilize two and four engines respectively for the 8- and 16-passenger sizes. This assumption for the large tilt rotor and tilt wing aircraft resulted in the incorporation of two engines per nacelle while the small VTOL concepts utilize only one engine per nacelle. Other significant features of each aircraft design are discussed in the following paragraphs.

a. Compound Helicopters

The 8- and 16-passenger compound helicopters differ in their geometry. The small concept is based on the 16 H-3J design that has been proposed by Piasecki. It is powered by one Pratt and Whitney PT6T unit which consists of two PT6B engines driving a single gear box. The cruise thrust is provided by a 5.5-foot diameter shrouded propeller while the anti-torque requirement is derived from vanes mounted in the propeller slipstream. An engine-out capability is provided for takeoff.

The geometry, propulsion, lift, and control systems of the large compound helicopter are similar to those of the S-65-200 helicopter proposed by Sikorsky. One engine is mounted in each of two nacelles while the third engine is contained in the fuselage. All engines are cross-shafted to provide for an engine-out takeoff capability.

b. Tilt Rotor

The geometry of the 8-passenger aircraft is essentially the same as the mockup of the Bell 300. However, the empty weight is 20% greater because of accessories, a pressurized fuselage, and a 50% increase in power.

The 16-passenger aircraft configuration is similar but with slightly greater tail volume coefficients and four turboshaft engines, each pair driving a common gear box (similar to the PT6T engine combination produced by United Aircraft of Canada). The aircraft incorporates cross-shafting between the nacelles.

c. Tilt Wing

Similar geometry is employed for the 8- and 16-passenger tilt wing aircraft. The power plant arrangements in the 8- and 16-passenger versions are similar to the corresponding tilt rotor designs in that two engines are packaged in each nacelle for the large aircraft. The shaft horsepower per pound of the tilt wing aircraft is approximately 50% greater than that of the tilt rotor due to the higher disc loading.

A preliminary analysis was made to determine the propeller diameter, speed, and equivalent shaft horsepower (eshp) required to satisfy the takeoff criterion (T/W = 1.25) with a 4-blade propeller. A propeller diameter of 17 feet and a rotation speed of 1000 rpm were selected. These parameters are also expected to result in acceptable noise levels. The engines, rated at 1420 eshp are also cross-shafted. Individual engine power was determined by the engine-out criterion for an 82°F day at 2000 feet. In cruise flight, the propeller is slowed to 700 rpm.

d. Pneumatic Tip-Driven Lift Fan

The 8- and 16-passenger lift fan aircraft are geometrically similar. One lift fan is mounted horizontally in the aft portion of each nacelle, while one lift/cruise fan is mounted vertically in the forward portion of each nacelle with a thrust deflector. Pitch control is obtained by varying the relative flow rates between the forward and aft fans. The four fans are powered by cross-ducted gas generators, one in each nacelle and a third mounted in the fuselage. During cruise flight, the two horizontally mounted lift fans and the fuselage-mounted gas generator are shut down. The extended range lift fan is similar to the large lift fan except for modifications to provide for additional fuel, and an 8-passenger configuration. Its range is thus significantly improved.

3. INVESTMENT AND OPERATING COSTS

The advanced aircraft costs are presented in Table X. Investment costs were computed principally on the basis of aircraft empty weight, engine thrust (or eshp in the case of turboshaft engines), weight of the dynamic systems, and the anticipated development cost assumed for each airframe concept. Development costs were amortized over an assumed production run of 700 units. Optional communication, navigation, and other electronics for IFR flight were then added to arrive at the equipped investment cost. Details of the cost estimating techniques and typical equipment assumed may be found in Appendix D of Volume II (Ref. 2).

Total hourly cost of operation was computed in the same manner as for the current composite aircraft by determining the variable and fixed costs for each concept and size. Slightly different factors were used to determine the cost elements depending on whether the aircraft was utilized in Executive Transportation or Commuter Air Carrier or Offshore (personnel transport) service. The utilization columns reflect these differences. The average number of passengers assumed per flight for the Executive Mission is equivalent to a 50% load factor. This is slightly lower than for current aircraft, but represents an owner desire (obtained from the surveys) to have the room available to allow flexibility in either the number of passengers or the working room in the cabin. Commuter Missions assume a 40% load factor, while Offshore Missions in the large aircraft assume 10 passengers (equivalent to a typical crew change increment for an oil-drilling rig).

Table X. Advanced Aircraft Cost Summary

Concept	Investment Cost (Equipped) ($000)	Total Cost ($/hr) Annual Utilization (hr) 600(1)	800(2)	1000(3)	2000(4)	Average Number of Passengers Exec.(5)	Commuter(6)	Offshore(5)	Cost/Passenger ($/hr) Exec.	Commuter	Offshore
Small Compound Helicopter	600	421	341	319	276	4	--	4	105	--	85
Large Compound Helicopter	1,090	795	613	574	495	8	7	10	99	71	57
Small Tilt Rotor	950	594	468	434	365	4	--	4	148	--	117
Large Tilt Rotor	1,500	928	714	660	551	8	7	10	116	79	66
Small Tilt Wing	920	562	422	389	322	4	--	4	140	--	105
Large Tilt Wing	1,490	899	664	610	502	8	7	10	112	72	61
Small Lift Fan	1,520	795	559	504	394	4	--	4	198	--	140
Small Lift Fan (ER)(7)	2,160	1176	830	752	596	4	--	--	294	--	--
Large Lift Fan	2,300	1256	866	783	616	8	7	10	157	88	78

(1) Executive Missions
(2) Small A/C - Offshore
(3) Large A/C - Offshore
(4) Commuter Missions
(5) 1971 average
(6) 40% load factor
(7) Extended range

C. SCHEDULED AIRLINE CAPABILITIES

In addition to comparing advanced concepts against composite current aircraft, the analysis of Section V includes scheduled airline service as an alternative mode for satisfying the Executive Transportation Missions. For this reason, a baseline set of time-and-cost characteristics was developed for scheduled airline service.

Figure 9 depicts the gate-to-gate time of typical airline service as a function of block distance. Data to develop this relationship were taken from the Official Airline Guide (Ref. 13). Several data points were obtained for each 100-mile increment and a straight line fitted to the points. At the shorter distances (less than 100 miles), Commuter Air Carrier service is assumed to follow the same relationship. (The slower cruise speeds of the

Commuter Air Carriers compared with those of the larger airlines are hardly discernible owing to the latter's relatively greater traffic delays and higher altitude flight routing.)

Figure 10 is a similar representation of the airline fare vs. distance (Ref. 13). Coach fares were plotted for each 100-mile increment and a straight line fitted to the resulting points. Fares of Commuter Air Carriers tend to be slightly lower due, principally, to the lower boarding cost per passenger. The slope of the segment of the curve from 0 to 100 miles reflects this lower boarding cost.

Formulas are also provided for the relationships displayed in Figures 9 and 10, and were used as airline parameters in the comparative analyses.

The usual limitations of airline services associated with available route structure (cities served), frequencies of schedules, or nonstop vs. segmented vs. connecting flights were not generalized but are included in the comparative analyses in Section V.

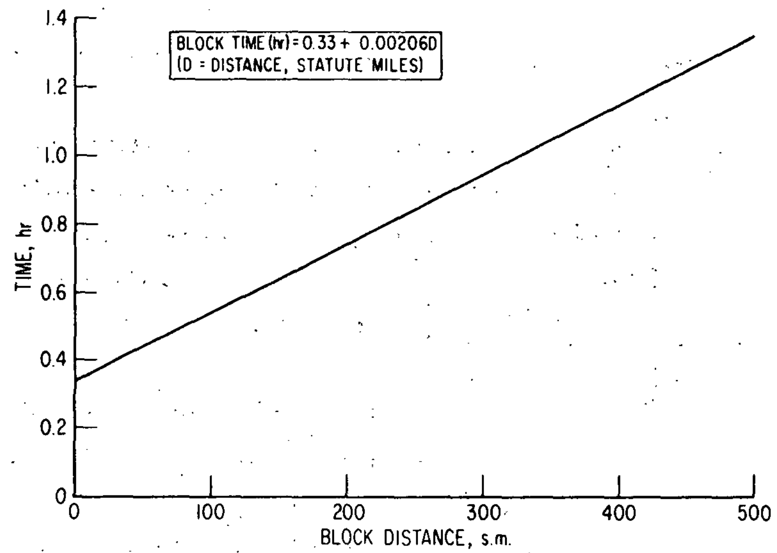


Figure 9. Airline Trip Time (Block)

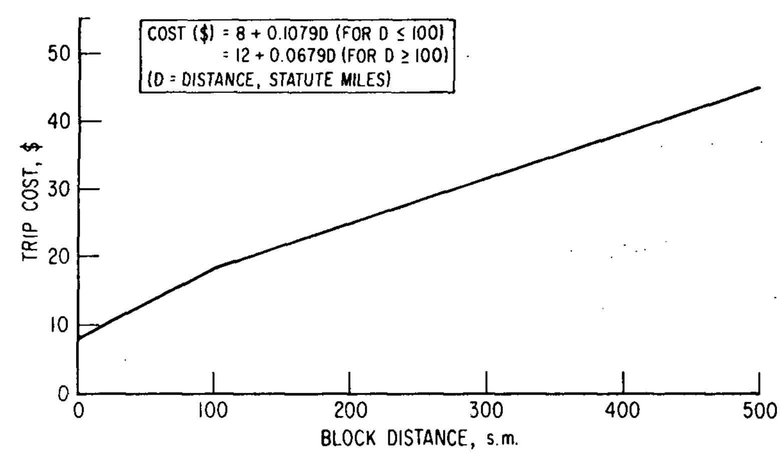


Figure 10. Airline Trip Cost (Coach)

V. AIRCRAFT COST BENEFIT ANALYSES

There are a variety of benefits that can be attributed to the introduction of new aircraft and operating concepts. However, many of these benefits--convenience, accessibility to unusual locations, flexibility of operation--are subjective. These subjective benefits are of varying importance to different users and do not readily permit a quantitative evaluation. There are, however, cost benefits attributable to transportation systems which can form a basis for comparison of alternative air vehicle concepts. The present report is concerned with identifying these potential cost benefits when advanced aircraft concepts are used in selected general aviation missions. The advanced aircraft concepts will be compared only with other air transportation modes such as contemporary CTOL aircraft and scheduled airline service. A broader analysis of intercity short haul business passenger travel, including ground modes, is contained in Refs. 14 and 15.

Three different approaches are presented for assessing the cost benefits of the new aircraft concepts when applied to the Executive Transportation, Commuter Air Carrier, and Offshore Missions. The first is a simplified time line of the traveler's elapsed time from door to door including local travel and processing time (and associated significant costs). This analysis graphically illustrates the dollar cost and relative time savings of a given transportation mode. The second assessment of economic benefit compares the merits of alternative air transportation modes for various trip lengths in terms of the traveler's value of time. Both the performance and economic characteristics of a new mode enter into this analysis as well as the user's economic values. The third measure of cost benefit compares the potential saving resulting from the use of an advanced concept aircraft in place of today's turbojet aircraft. The mission scenarios used as well as each method of analysis is described in the following sections.

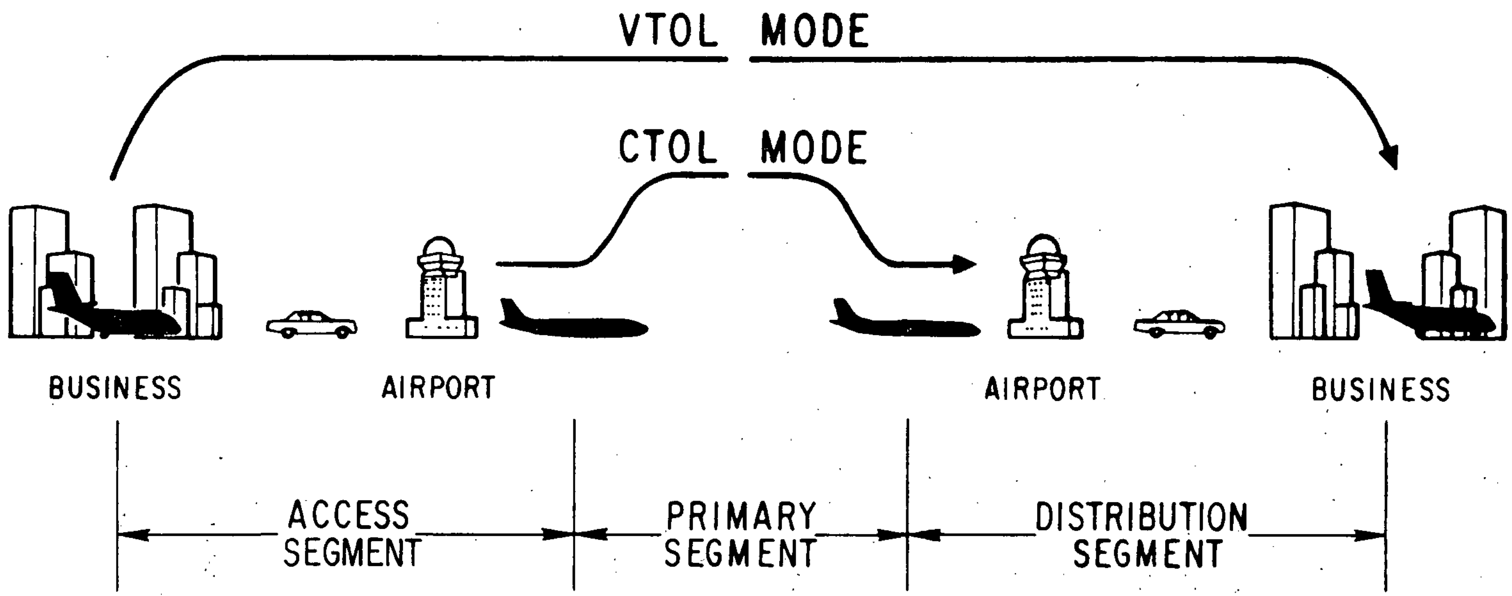


Figure 11. Scenario for Executive Travel

A. EXECUTIVE TRANSPORTATION MISSION COST BENEFIT ANALYSIS

1. MISSION SCENARIOS

The development of a time line and the associated cost of travel is dependent on the use of scenarios which describe all of the steps in a transportation mode which may affect either time or cost. In these analyses each trip is divided into three segments as shown in Figure 11. These segments consist of: the access segment (point of origination to the aircraft), the primary segment of the trip (the flight), and the distribution segment (aircraft to the destination point). Access travel is considered to be by car on surface streets or, in selected instances, by small helicopter. The primary mode of transportation may be by scheduled airline; by company-owned helicopter, turboprop or turbojet CTOL aircraft; or by one of the company-owned advanced VTOL concepts under consideration. The distribution trip from the aircraft to the destination is always assumed to be accomplished by car. Whereas the access and distribution portions of a trip assume a common nominal ground travel distance, the primary mode considers distance as the independent variable.

In order to identify the significant differences in the characteristics of the primary transportation modes a number of scenario ground rules were developed and are presented in Table XI. A rationale for the use of each rule is also presented. Other ground rules peculiar to the individual missions will be presented along with the analyses.

A series of representative Executive Transportation Mission scenarios are given in Table XII in terms of the time-and-cost increments for the door-to-door trip. The traveler is assumed to depart from his office using either a car or a private helicopter to access to the CTOLport. The primary segment of travel is then accomplished with an aircraft whose block time (gate-to-gate) is a function of cruise speed, distance, and nonproductive flight time. Distribution from the airport to the local destination is assumed to be by car only. Processing times are scaled between modes to

Table XI. Ground Rules for Scenario Development

Rule	Rationale
1. All trips are one-way.	Use of executive aircraft is not typically characterized by flights from A to B and return to A. They more often are multi-legged, A to B to C and return to A. By making trips one way, segments of any multi-legged trip can be analyzed separately and combined to provide total trip costs at will.
2. Aircraft are assigned a fixed time delay for all nonproductive flight time and full operating expense is charged against his time.	CTOL aircraft nonproductive time is 15 minutes, consisting of taxi - 10 minutes, climb - 2 minutes, and landing - 3 minutes. VTOL aircraft are assumed 6 minutes of nonproductive time per flight. This delay combined with economical cruise speeds produces equivalent block speeds.
3. Airline travel times are based on current published airline schedules.	These schedules account for trip distance, aircraft performance, and current air traffic congestion.
4. All CTOL aircraft are assumed to operate from the same airport.	This establishes a common access trip time.
5. Processing times (access mode to primary mode) are assumed less for executive travelers.	Separate terminals and less formality are typical for this type of travel.
6. Average utilization for new VTOL's will be greater than current executive VTOL or CTOL fleet.	New VTOL's will be capable of combined VTOL and CTOL missions, will be more expensive and,therefore, can only be justified by many customers if utilized more effectively.
7. Number of passengers per flight vary with mission.	Load factors are derived from 1971 user surveys and show consistent patterns: a. Executive Aircraft: 50% load factor. b. Commuter Aircraft: 40% load factor. c. Offshore: 4 passengers for aircraft seating 10 or less, 10 passengers in aircraft seating more than 10.
8. Costs are in 1971 dollars.	Provides a standard base and avoids the uncertainties of future economic situations.
9. 1971 airline coach fares are used. Commuter fares are used for distances under 100 miles.	Since airline fares are continously changing it is necessary to select a point in time for reference. The use of 1971 fares is compatible with the use of 1971 dollars. Further, the commuter service has become more mature and its fares are, hopefully, representative of its costs.
10. No cost increment for local travel by car.	Out of pocket car costs are relatively small compared to the primary mode costs. Further, in most scenarios several passengers would use one car making insignificant the car cost per passenger.

Table XII. Executive Mission Time and Cost Parameters

Access Segment				Primary Segment						Distribution Segment		
Mode	Time (hr)	Cost ($)	Process Time (hr)	Mode	Speed (mph)	Delay(1) (hr)	Average No. of Pass.	Range(2) (s.m.)	Cost/Pass(3) ($/hr)	Process Time (hr)	Mode	Trip Time (hr)
Car	0.50	-	0.50	Airline	(Fig. 9)	(Fig. 9)	1		(Fig. 10)	0.25	Car	0.5
Car	0.50	-	0.25	Small Turboprop	280	0.284	4		77	0.10	Car	0.5
Small Helic.	0.25	15	0.15	Small Turboprop	280	0.284	4	(4)	77	0.10	Car	0.5
Car	0.50	-	0.25	Small Turbojet	500	0.250	4		156	0.10	Car	0.5
Small Helic.	0.25	15	0.15	Small Turbojet	500	0.250	4		156	0.10	Car	0.5
Access time, cost and processing time zero for VTOL aircraft				Small Helic.(5)	135	0.1	4	300	61	Distribution processing and trip time zero for VTOL aircraft		
				Large Helic.(5)	110	0.1	8	300	103			
				Small Compound Helic.	190	0.1	4	600	105			
				Large Compound Helic.	265	0.1	8	700	99			
				Small Tilt Rotor	380	0.1	4	850	148			
				Large Tilt Rotor	320	0.1	8	1500	116			
				Small Tilt Wing	430	0.1	4	750	140			
				Large Tilt Wing	370	0.1	8	1000	112			
				Small Lift Fan	530	0.1	4	950	198			
				Small Lift Fan (ER)(6)	530	0.1	4	1700	294			
				Large Lift Fan	565	0.1	8	950	157			

(1) Nonproductive flight time
(2) Range at noted passenger load (see Figure 8)
(3) Based on average passenger load
(4) Range greater than 1000 s.m.
(5) 0.5-hr delay for refueling at range >300 s.m.
(6) Extended range

reflect the interface of large airline terminals or the less formal executive aircraft terminals, as appropriate.

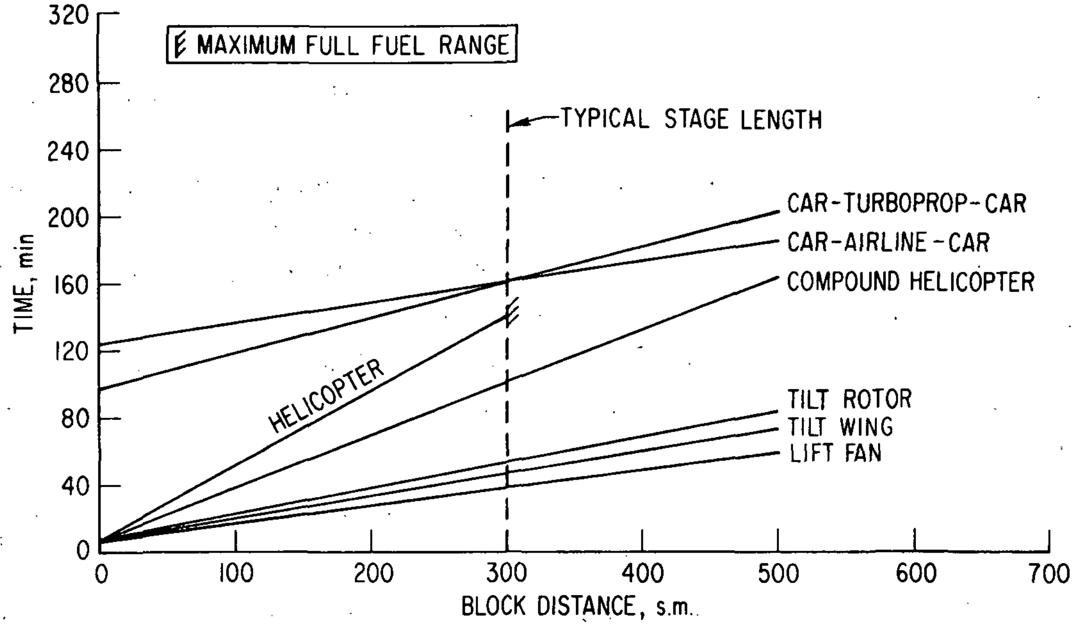
Access and distribution segments of the Executive Transportation Mission are considerably simplified when advanced VTOL aircraft are used as the primary mode of transportation. To take full advantage of their VTOL capabilities they are assumed to operate from the immediate vicinities of both the origin and destination points. The gains thus realized by the elimination of local travel and interface processing times are reflected in reduced overall trip times.

2. TIMELINE ANALYSIS FOR CURRENT AND ADVANCED AIRCRAFT

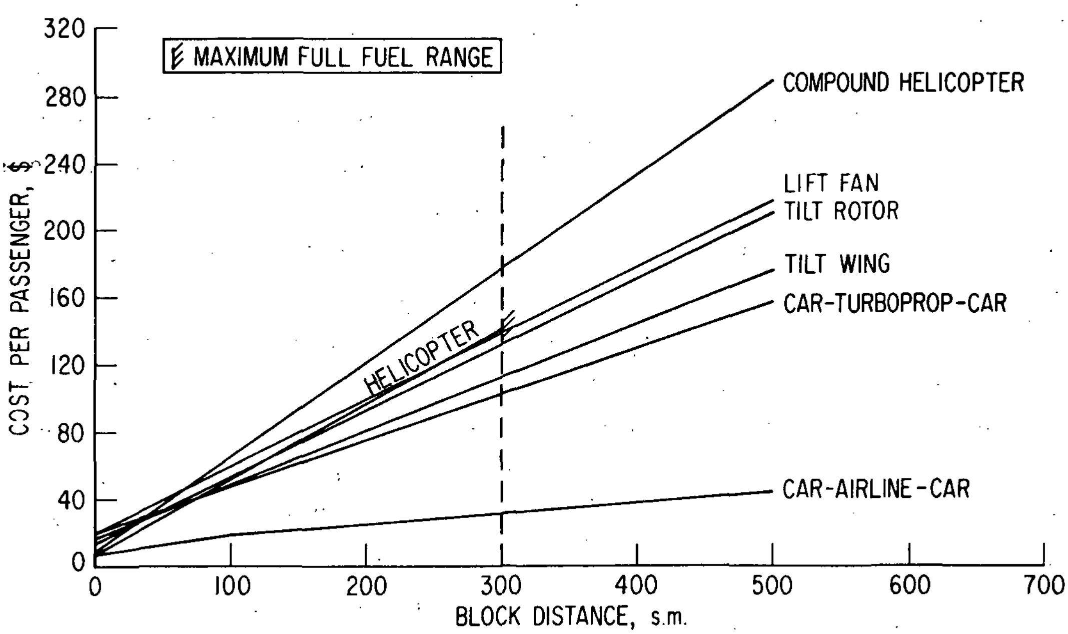
Results of the time line and cost analyses for Executive Transportation Missions are presented in Figures 12 and 13. Figure 12 compares the time lines for the small aircraft scenarios and their attendant costs over short and medium distances. The time advantages of the VTOL concepts which do not require a conventional airport are clearly apparent over both the airline and turboprop aircraft which must use CTOLports. A further advantage accrues to the tilt rotor, tilt wing, and lift fan concepts due to their significant speed capabilities, which provide real time savings out to distances of 500 miles. The helicopter is attractive only at short ranges since it requires refueling for ranges beyond 300 miles, nullifying its VTOL advantage.

Offsetting the time advantages of the VTOL concepts are the somewhat increased costs of operation. These costs, allocated on a per passenger basis in Figure 12b, show only slight increases for the tilt wing and tilt rotor over today's popular turboprop aircraft. Their speed advantage overshadows this small increase in cost as will be seen later in the time value analyses.

The second class of Executive Transportation Missions defined earlier was based on flying greater block distances for which jet-type aircraft may have more applicability. Figure 13 presents time line and equivalent passenger costs for the lift fan VTOL compared with those for contemporary turbojet general aviation aircraft and airline service. The

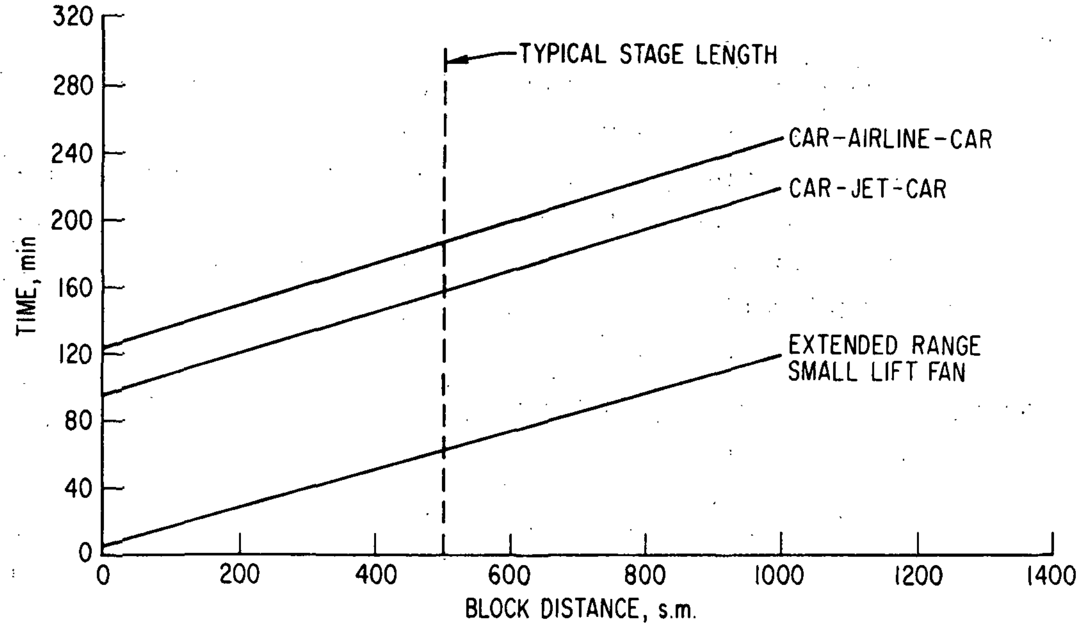


a. Time Line

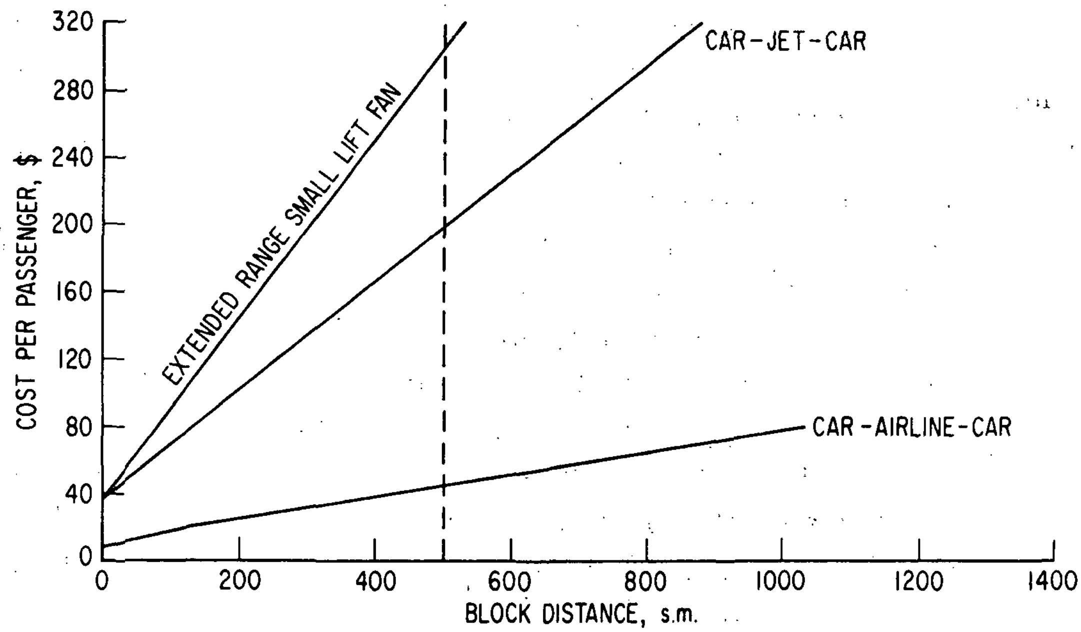


b. Equivalent Passenger Cost

Figure 12. Executive Mission--Short Distance with Small Aircraft



a. Time Line



b. Equivalent Passenger Cost

Figure 13. Executive Mission--Long Distance with Jet Aircraft

combination of jet speed and VTOL capabilities clearly shows up to advantage here, and also over the propeller and rotor concepts of Figure 12a. The equivalent passenger cost increase is, however, just as apparent.

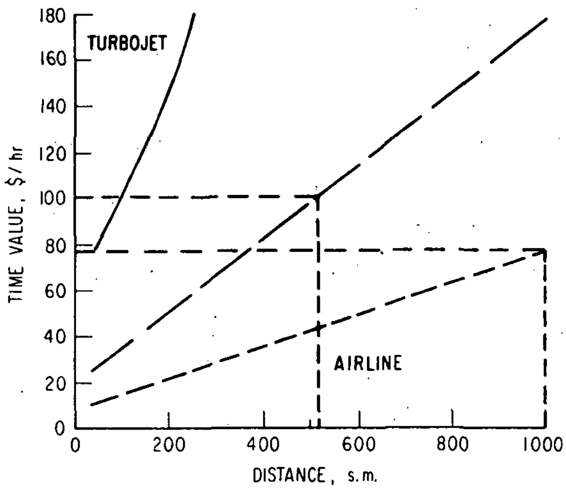
This timeline analysis shows a comparison of trip time and costs per passenger for different Executive Mission scenarios and aircraft concepts but does not include another key factor pertaining to mode benefits, i.e., a traveler's time value. The next section includes a discussion of the integration of time value into the analyses.

3. TIME VALUE ANALYSIS OF COMPOSITE CURRENT AIRCRAFT

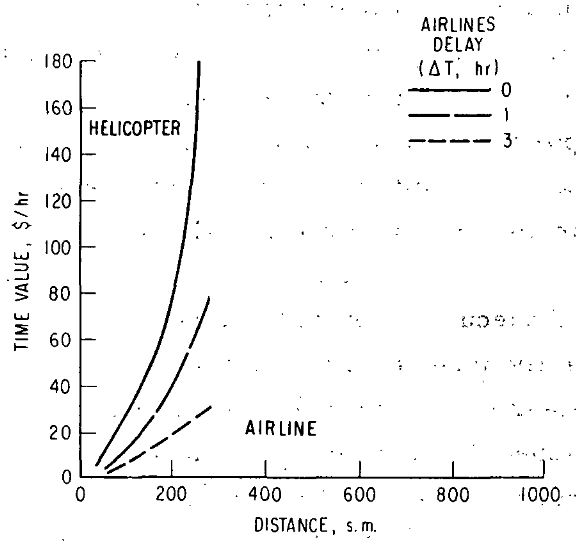
The combined performance and economic characteristics for candidate general aviation aircraft have been analyzed by using "phase" diagrams to examine preferred modal choices for travelers of different time values as a function of distance traveled. By using the scenarios previously described, total trip cost is determined for a given mode as the sum of the transportation costs and the cost associated with the traveler's time for the given mode. Lines of equal travel cost for two modes are created separating the areas of individual mode dominance. These phase diagrams can be made for two or more modes presenting areas of dominance of one mode over the others and have been developed for current and advanced aircraft in both the Executive Transportation and Commuter Air Carrier Mission scenarios described above. A phase diagram analysis is less meaningful for the Offshore Mission due to (1) a lack of reasonable transportation alternatives for the longer distances under certain weather conditions and (2) less significant monetary values of time for the individual travelers. This mission was not addressed in the time value analysis.

a. Turbine-Powered Company-Owned CTOL Aircraft

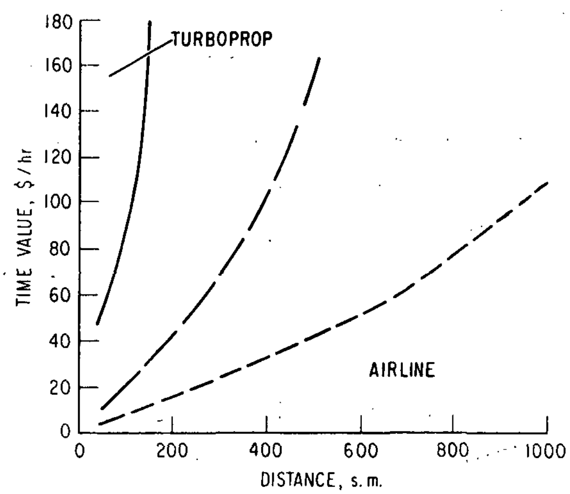
Phase diagrams displaying the preferred transportation modes from among current aircraft serving the Executive Transportation Mission are shown in Figure 14. The mission illustrated is the short distance Executive Mission for which both company-owned turboprop and turbojet aircraft may be used as well as scheduled airline service. The dashed lines in the figure



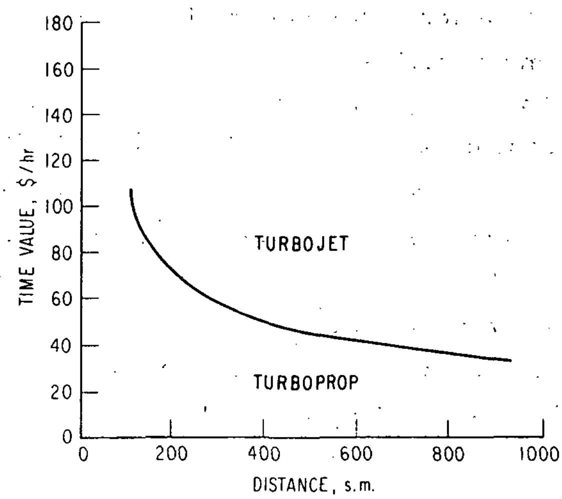
a. Turbojet, Airline



b. Helicopter, Airline



c. Turboprop, Airline



d. Turbojet, Turboprop

Figure 14. Two-Phase Time Value Diagrams for Small Contemporary Aircraft

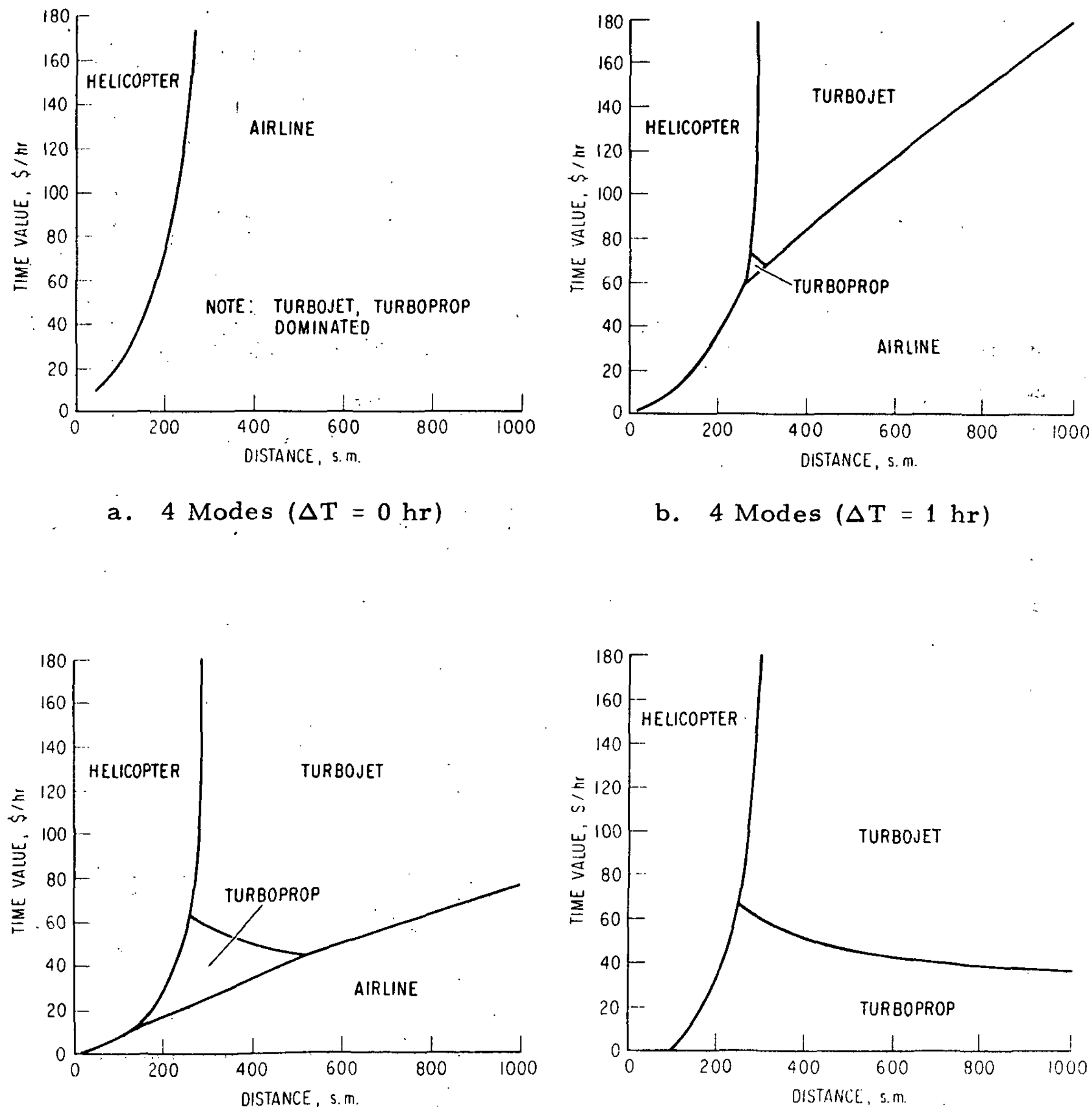
represent airline delay times (ΔT) attributable to the fact that a scheduled airline flight may not be precisely scheduled at the desired time of departure by the executive. Lines showing a zero delay, a one-hour delay, and a three-hour delay are illustrated in the figure and compared with each composite current aircraft concept. It should be noted the airline delay referred to is in addition to the aircraft delay times and access and distribution segment times identified in the mission scenarios.

Such delay times are considered appropriate as the survey of users of executive aircraft indicated in general that their aircraft are not customarily used in direct competition with the airlines. Companies that operate their own aircraft normally utilize them for trips to points where airline schedules are incompatible with the purpose of the trip, or into points not served by airlines. Examples of incompatibility include: (1) business concluded early, (2) time between planned conclusion of business and next airline flight departure exceeds the time required to access and board the airline, and (3) a nonstop flight is not available or additional access time is required for the airline since the executive may be able to fly in his own aircraft to an airport closer to his destination. These incompatibilities are felt to be realistic of most airline schedules with the possible exceptions of the services offered between Los Angeles-San Francisco and New York-Washington, where very frequent service is offered. As can be seen in Figure 14, the relatively low cost and high speed of the airline is such that airline travel dominates all but the very high time value range at short distances, if no airline delay time is considered ($\Delta T = 0$). As airline delay times are considered, however, both the turbojet and the turboprop become more favorable at lower time values. The helicopter, due to its limited range, is able only to favorably compete with a scheduled airline up to a trip distance of approximately 300 miles.

In general, the "break-even" value-of-time increases as the distance increases for any ΔT since the airlines are the more efficient mode at long distances. Also, the business turbojet becomes increasingly more competitive as the airline penalty time becomes greater. For example, if we assume an airline penalty time of one hour, Figure 14a shows that at $100/hr time value and 500-mile trip distance, both modes would have equal costs. This distance is about the median value for executive trips with company-owned jets. For an airline penalty time of three hours and a 1000-mile trip distance, the turbojet is more economical at time values greater than $77/hr. These results seem in the neighborhood of consistency with existing usage of business jets.

One of the primary uses for executive aircraft is to provide service to airports where there is no airline service available. In this application the choices of current turbine CTOL aircraft are between small turbojet or turboprop aircraft as illustrated in Figure 14d. The economy of the turboprop aircraft dominates the lower time values even to distances as great as 1000 miles. The higher time value passenger, however, clearly benefits from the turbojet speed capabilities.

As a further comparison, multiphase time value diagrams have been constructed. Figure 15a, b, and c compares current executive aircraft with each other as well as to the airline at airline delay times (ΔT) of zero, one, and three hours. As can be seen in Figure 15a, b, and c, the helicopter dominates the very short distance missions through almost the entire range of time values. The turboprop becomes more attractive for the 250- to 500-mile range missions, with the turbojet dominating for the higher time values and the longer missions once airline delays are considered. Again, however, even with delay times of three hours, the airline will dominate for longer range missions up to time values of approximately $60/hr. A further comparison for the case where airline service is not available is shown in Figure 15d. As can be seen again, the helicopter dominates for shorter distance trips, the turboprop dominates for the lower time value traveler for longer distance trips, and the turbojet dominates for long distances and time values in excess of $60/hr.



a. 4 Modes (ΔT = 0 hr)

b. 4 Modes (ΔT = 1 hr)

c. 4 Modes (ΔT = 3 hr)

d. 3 Modes

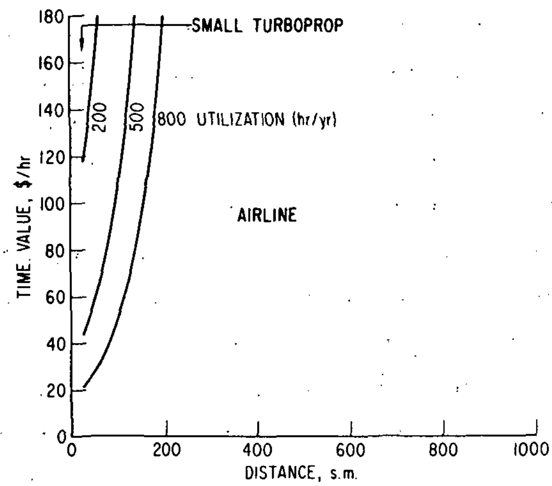
Figure 15. Multiple-Phase Time Value Diagrams for Small Contemporary Aircraft

b. <u>Effect of Varying Aircraft Utilization</u>

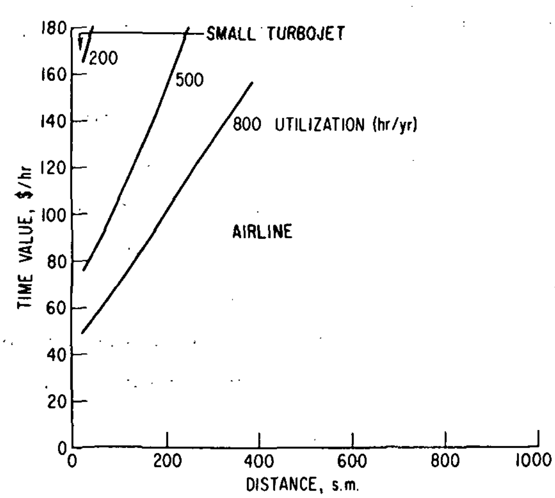
The previous examples assumed a fixed utilization for the executive aircraft at 500 hours per year. Although the survey and other available data show this to be a reasonable average there are applications in which lesser or greater annual utilizations occur. The effect of varying utilization of the turboprop and turbojet aircraft on their break-even economics with the airline is shown in Figures 16a and 16b, using the optimum (zero delay) airline schedule. (The executive aircraft are always to the left of the utilization line selected.) Increasing utilization to 800 hours per year causes the break-even passenger time value to decrease and, thereby, almost doubles the area of the phase diagram in which the turboprop and turbojet are favored over airline service. However, the ranges over which they are preferred are still limited to 200 to 300 miles.

c. <u>Productive Work En Route</u>

A further cost benefit associated with the use of executive aircraft is that productive work can be accomplished en route by the passengers. For simplicity the scenarios and phase diagrams shown here have assumed transit time as nonproductive time. Figure 17 illustrates the change in break-even distances for executive travelers conducting productive work en route (assumed to occur during one-half of the block time) in an executive aircraft as opposed to nonproductive transit time in an airline with optimum schedule. Although the passenger time values for which a turbojet is attractive do not significantly decrease, the range is greatly extended over which the executive turbojet can be effective. This capability to accomplish productive work en route decreases the effective cost of executive travel in corporate aircraft and can be a valuable consideration in the decision to operate an executive airplane.



a. Turboprop and Airline with Optimum Schedule (ΔT = 0 hr)



b. Turbojet and Airline with Optimum Schedule (ΔT = 0 hr)

Figure 16. Effect of Varying Aircraft Utilization

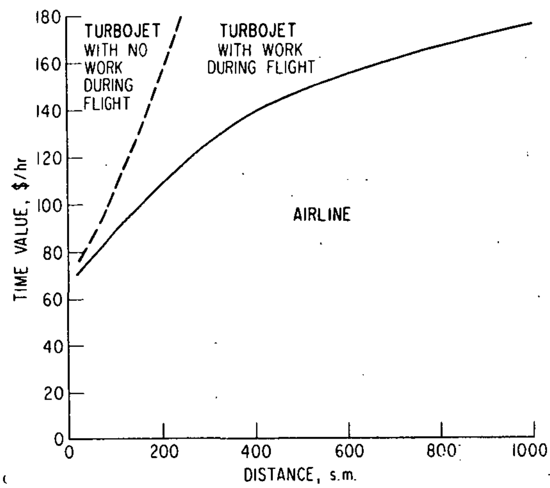


Figure 17. Effect of Productive Work-Enroute Airline with Optimum Schedule (ΔT = 0 hr)

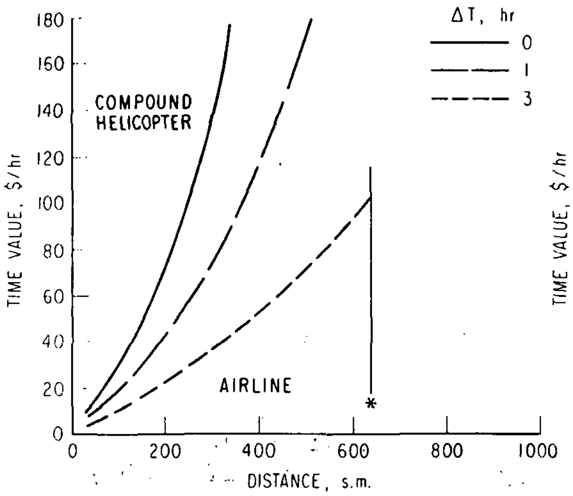
4. TIME VALUE ANALYSIS OF ADVANCED AIRCRAFT

A selection of the principal time value phase diagrams is presented here, illustrating potential areas of economic application for advanced aircraft concepts competing against each other as well as against current air modes.

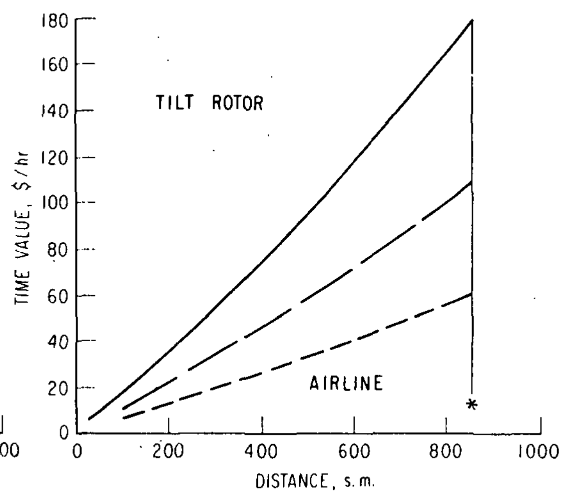
a. Small Aircraft

The potential areas of application for advanced small aircraft concepts serving the Executive Transportation Mission are illustrated in Figure 18. This figure identifies each advanced concept and compares it against an airline, again with optimum scheduling and one- and three-hour delay times. The compound helicopter appears most efficient at shorter distances over almost all time value ranges. The tilt rotor and tilt wing dominate even further due to their higher speed and longer range capabilities. The lift fan, the fastest of all concepts, dominates throughout distances approaching 1000 miles; however, it does this at slightly higher time values due to increased costs compared to the tilt wing and tilt rotor.

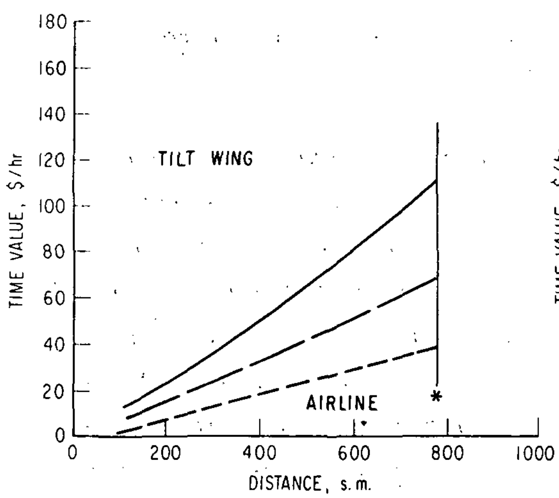
A further comparison of each of these advanced concepts with current aircraft as well as the airline can be seen in Figure 19, with an airline delay time of one hour assumed. As can be seen in Figure 19a, the helicopter and

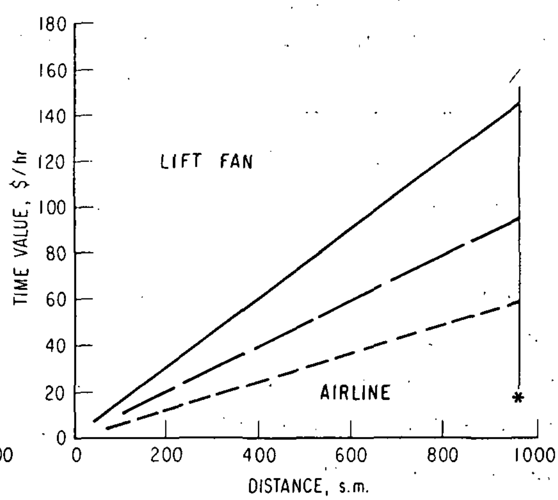


a. Compound Helicopter, Airline



b. Tilt Rotor, Airline





* MAXIMUM RANGE AT 50% LOAD FACTOR

c. Tilt Wing, Airline

d. Lift Fan, Airline

Figure 18. Two-Phase Time Value Diagrams for Small VTOL Aircraft and Airlines

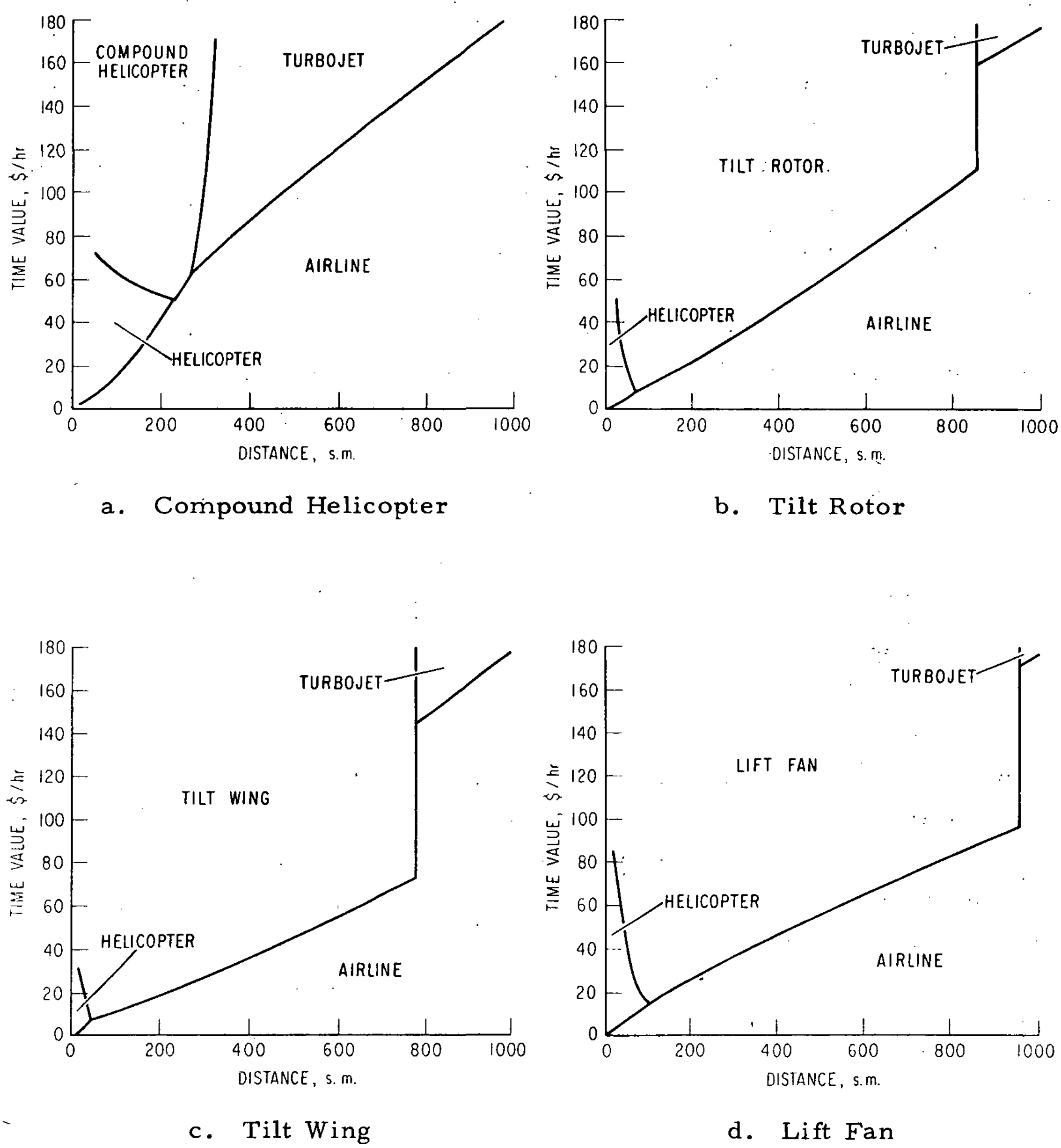


Figure 19. Multiple-Phase Time Value Diagrams for Small VTOL and Contemporary Aircraft (ΔT = 1 hr)

compound helicopter predominate in the shorter ranges for higher time values with the higher cost compound helicopter requiring time values in excess of approximately $60/hr. Thus the compound helicopter does not appear to have any significant time value advantages over the conventional helicopter. From Figure 19b, c, and d the tilt rotor, tilt wing, and lift fan all appear to have significant advantages over conventional company-owned aircraft (see Figure 15b). They also compete favorably with the airline at passenger time values above $15/hr at the shorter distances and increasing almost linearly with the longer distances out to approximately 800 miles. If the three advanced concepts are compared in more detail, the tilt wing aircraft appears slightly better for the shorter range executive missions. This is due to slightly lower cost and higher speed of the tilt wing when compared to the tilt rotor. For the longer range missions, the lift fan appears preferable for the higher time value passenger. However, there is litte significant difference between these three concepts and all three appear promising to pursue further.

b. Lift Fan Cost Sensitivity

During the course of establishing the economic base for the advanced VTOL aircraft some cost areas were difficult to estimate with any reasonable degree of certainty. Authorities on the subject differed to a marked degree, and confidence in some cost numbers was limited. One such area concerned the cost of the lift fan mechanisms for the lift fan aircraft. Estimates varied as much as +100% and -50% from nominal. In order to assess the sensitivity of the results to these cost variations, the aircraft unit costs were adjusted to reflect fan cost uncertainty and a time value diagram made up as shown in Figure 20. The small lift fan is compared to the airline with optimum schedule and the break-even curve represents nominal lift fan costs. Doubling the cost of the lift fan mechanism results in a 6% increase in the

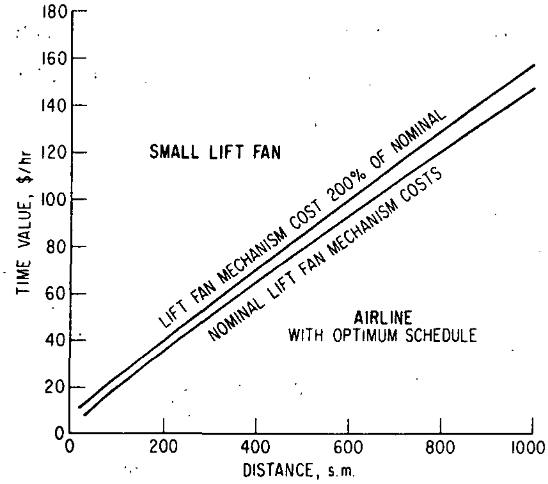


Figure 20. Lift Fan Cost Sensitivity

aircraft hourly cost and raises the break-even curve to time values approximately $5 to $10 per hour higher than for the nominal case, which is felt to be within the accuracy of this type of analysis.

c. Extended Range Missions for Small Aircraft

The design criteria previously developed were weighted toward the average 1970 missions as reported by current users of executive and commuter aircraft. This raised some concern about the potential for long range missions using advanced VTOL concepts. A small lift fan (Extended Range Lift Fan) was designed for longer ranges to determine if a design incorporating extended range capability significantly affected its time value application. The Extended Range Lift Fan design had a full load (8 passenger) range of 1420 miles as compared to the 600-mile range of the basic lift fan design with the same passenger load. The resulting impact on time values is compared in Figure 21 using the Executive Mission scenario parameters shown in Table XII. This figure compares the basic lift fan and the Extended

Range Lift Fan to the small turbojet, all at a 50% load factor. As can be seen, there is a definite advantage in using the basic lift fan configuration and offloading passengers and adding fuel for range extension in comparison to using the Extended Range Lift Fan.

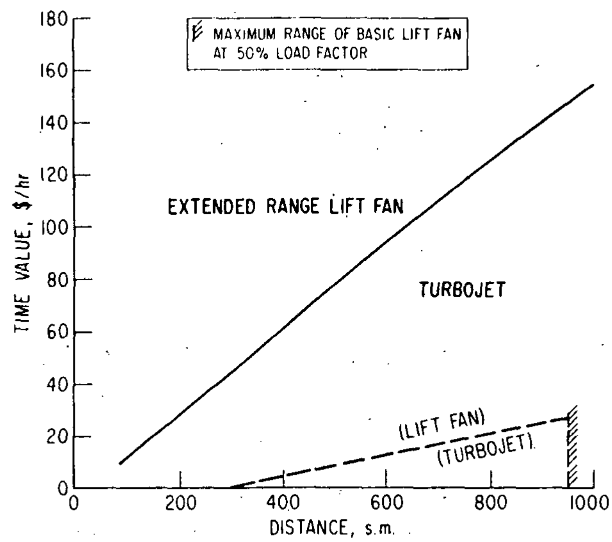


Figure 21. Small Lift Fan Extended Range Capabilities

At a range of 950 miles the Extended Range Lift Fan configuration requires passenger time values of approximately $160 per hour for economic utilization while the basic lift fan competes with the turbojet at $30 per hour time value. If $100-per-hour time value passengers are assumed, the basic lift fan could lose one hour refueling at 950 miles and still be more economical than the Extended Range Lift Fan configuration. The apparent large penalty incurred in range extension through design rather than offloading appears prohibitive when weighed against a stated requirement for average mission ranges of about 500 miles and average load factors of 50%.

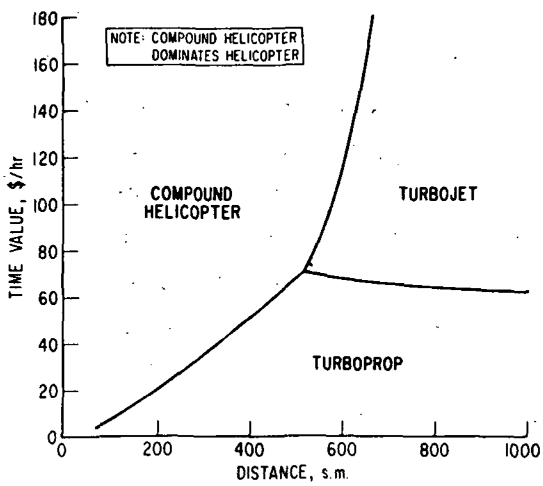
d. Large Aircraft

Regions of potential economic viability for the large advanced aircraft concepts in the Executive Transportation Mission are shown in Figures 22a through d. In general large VTOL aircraft follow the same pattern as the previously discussed small aircraft with only minor exceptions. The helicopter has been eliminated in the larger sizes due to its increased cost per passenger. Also, the tilt rotor is "dominated" in turn by the tilt wing (Figure 22b) and the lift fan (Figure 22c). The large tilt wing is effective to approximately 1000 miles, which exceeds the range of the large lift fan (Figure 22c). The airline has been added in Figure 22b and "dominates" the low time value segment of the diagram, displacing the turboprop.

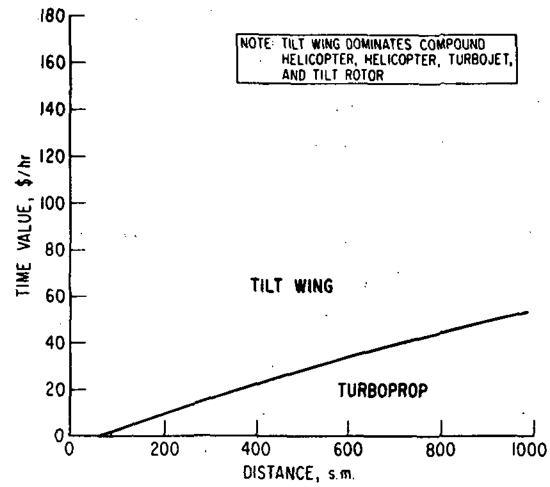
Generally the lift fan seems most advantageous in serving the Executive Transportation Mission requiring large aircraft. The lift fan is followed closely by the tilt wing concept. The tilt rotor is less advantageous in this economic performance analysis because of its lower speed. However, there is little significant difference when comparing these three concepts; other measures of acceptability such as technical risk and noise may have a significant impact.

e. Combined Company-Owned Helicopters and CTOL Aircraft Missions

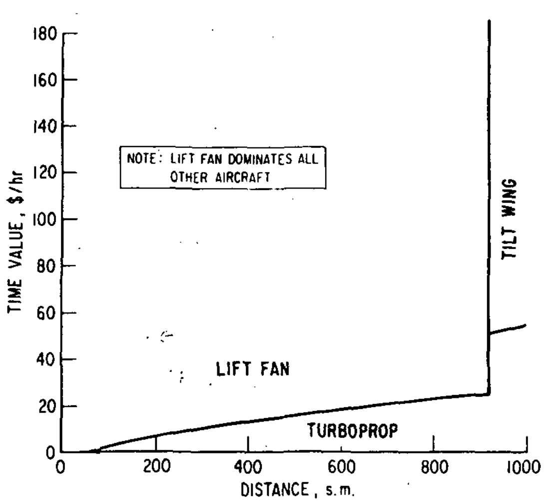
The previous sections examined the attractiveness of advanced design concepts combining VTOL capabilities and significant speed in competition with current turbine aircraft. To circumvent the need for an advanced VTOL concept an operator could use a helicopter for access to a CTOLport from which a turboprop or turbojet aircraft could be utilized. Two scenarios were developed to analyze this case (see summary in Table XII). By using these scenarios the time value diagrams of Figure 23 were created. Figure 23a shows that, when compared to the compound helicopter, the combination turboprop-helicopter is more economical than the turboprop-car only at the shorter ranges. Hence, in general, the added expense of the helicopter is not made up by time savings and the small



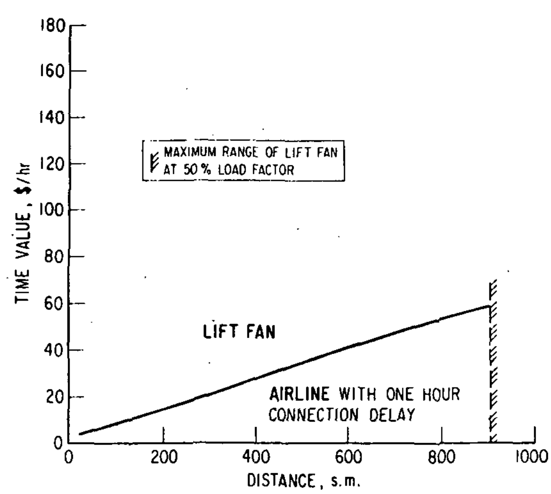
a. Compound Helicopter Dominant



b. Tilt Wing Dominant

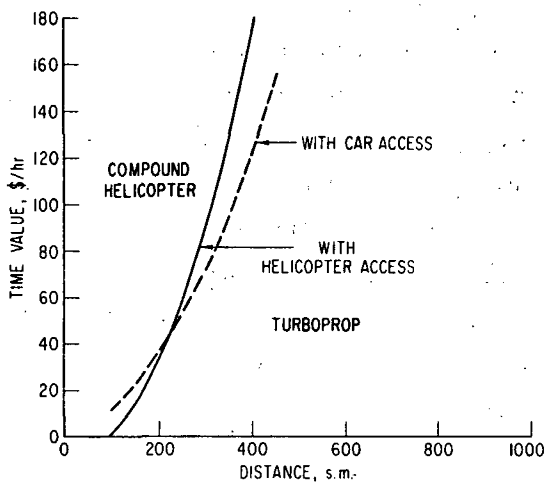


c. Lift Fan Dominant

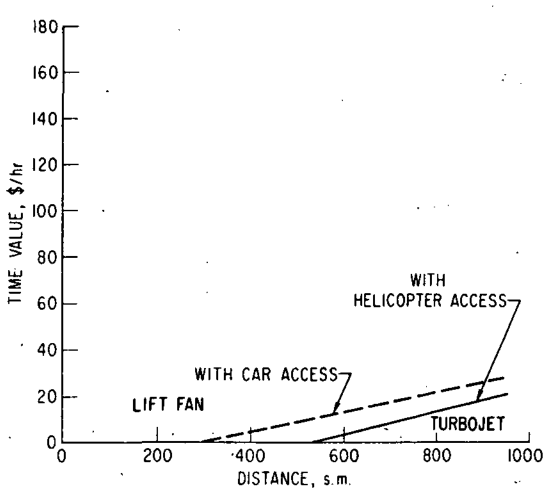


d. Lift Fan with Airlines Available

Figure 22. Advanced Large Aircraft Serving Executive Mission



a. Small Compound Helicopter



b. Small Lift Fan

Figure 23. Small Helicopter--CTOL Aircraft in Combination

compound helicopter continues to be more desirable. The situation is slightly improved for the small lift fan when compared with the combination turbojet-helicopter, as shown in Figure 23b. Since the lift fan dominates the turbojet at such low time values, the use of helicopter access results in a further advantage for the lift fan. The analyses generally indicate that a helicopter-CTOL combination has only limited advantage as compared to advanced aircraft concepts having both VTOL and reasonable speed capabilities.

A further advantage accrues through using a VTOL concept such as a lift fan that is capable of performing a long range mission competitively with a turbojet in that a single vehicle can replace both the helicopter and the turbojet. Such would be the case, however, only for a company that uses its helicopter predominantly to access the turbojet.

5. COST SAVINGS ANALYSIS CONSIDERING AIRCRAFT ALTERNATIVES

The trip scenarios for the Executive Transportation Mission given in Table XII assumed a fixed annual utilization for all aircraft concepts under consideration. By using this assumption the number of miles flown per year is a function of the block speed and the mission distance. Where aircraft of widely varying speed capabilities are being compared it is also of interest to examine their capabilities for conducting a fixed number of annual missions, which results in a variable utilization for the different concepts. This fixed mission approach is more applicable to the case where a company operates a particular aircraft and is considering a replacement. In this case the company has (initially) fixed mission requirements and the present aircraft flies a specified number of hours annually to satisfy these missions, while a faster and/or less delay-prone aircraft (VTOL) may fly fewer hours while accomplishing the same annual mission requirements. While operating costs per hour of the faster aircraft may be greater, since the fixed portion of the cost is spread over fewer hours, they also fly fewer hours to satisfy the mission requirement. Hence, their aggregate variable costs are generally less for the year. The net result is a potential decrease in the total annual operating costs for the more advanced concepts and a possible cost saving.

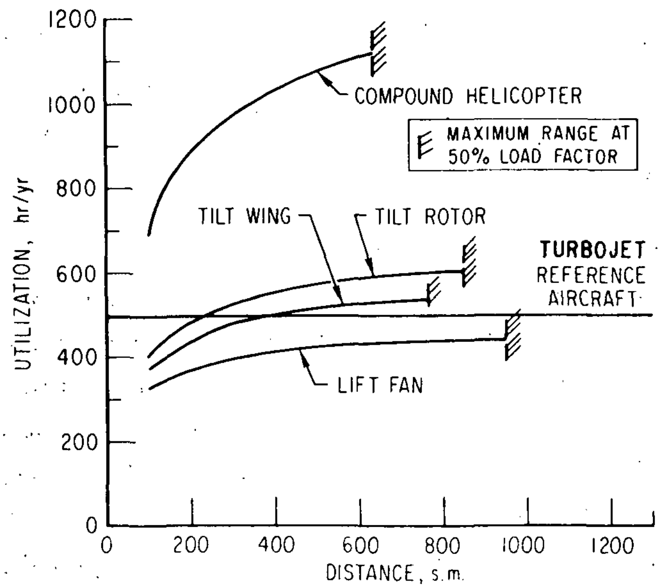
The following cost savings analyses are made on the basis of satisfying a fixed number of annual Executive Transportation Missions, and cost savings of the advanced aircraft concepts are developed relative to the composite turbojet aircraft.

a. <u>Comparison of Cost Savings for Small Aircraft</u>

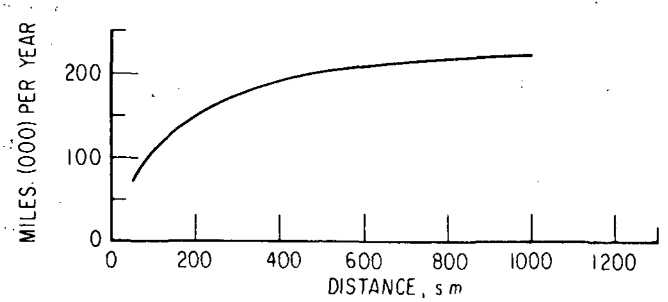
The scenarios used in the cost savings analyses are those defined as the primary segment of travel in Table XII. As a reference case it is assumed that a corporation now uses a turbojet to accomplish its nominal annual mission. This mission is defined in Figure 24. The utilization is 500 hours per year as indicated in Figure 24a, and the yearly miles flown and the number of flights per year are indicated in Figures 24b and 24c as a function of trip distance (all the trips made in accomplishing the yearly mission are assumed to be a constant distance).

Since the VTOL aircraft have different speeds, their required utilization to accomplish the same nominal annual mission as the turbojet will vary as shown in Figure 24a. The utilization of the tilt rotor and tilt wing aircraft is either greater or less than 500 hours per year depending on trip distance. The lift fan utilization never exceeds 450 hours per year, while the slower compound helicopter varies from 700 hours per year to over 1000 hours per year depending on trip distance.

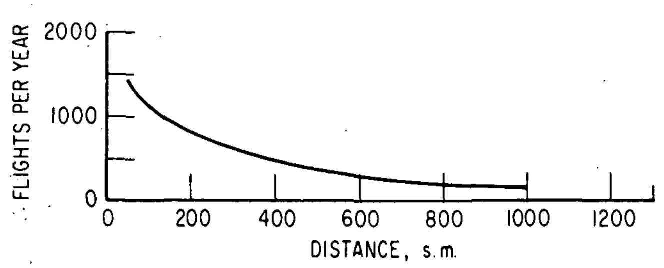
Figure 25 is a result of savings computations for the four concepts under study using the utilization data of Figure 24a. The effect of varying utilization on operating costs has been included in the analysis. The savings shown in Figure 25 represent the total difference in yearly costs (including time value as well as aircraft operating costs) between the turbojet and the VTOL aircraft while making the same number of trips and carrying the same number of passengers. Three different time values, \$50, \$100, and \$150/hr are shown parametrically. The greatest savings for all four concepts are in the short ranges. Here many business jet flights are required to accumulate 500 hours and each is inefficient with respect to the traveler's time. Consequently the CTOL concept is penalized accordingly. As mission range increases, the savings for all the VTOL aircraft decrease. At approximately 400 miles, it is seen in Figure 25a that the slow speed and high cost



a. Utilization



b. Total Miles (All Aircraft)



c. Number of Flights (All Aircraft)

Figure 24. Definition of Fixed Distance Mission (Small Aircraft)

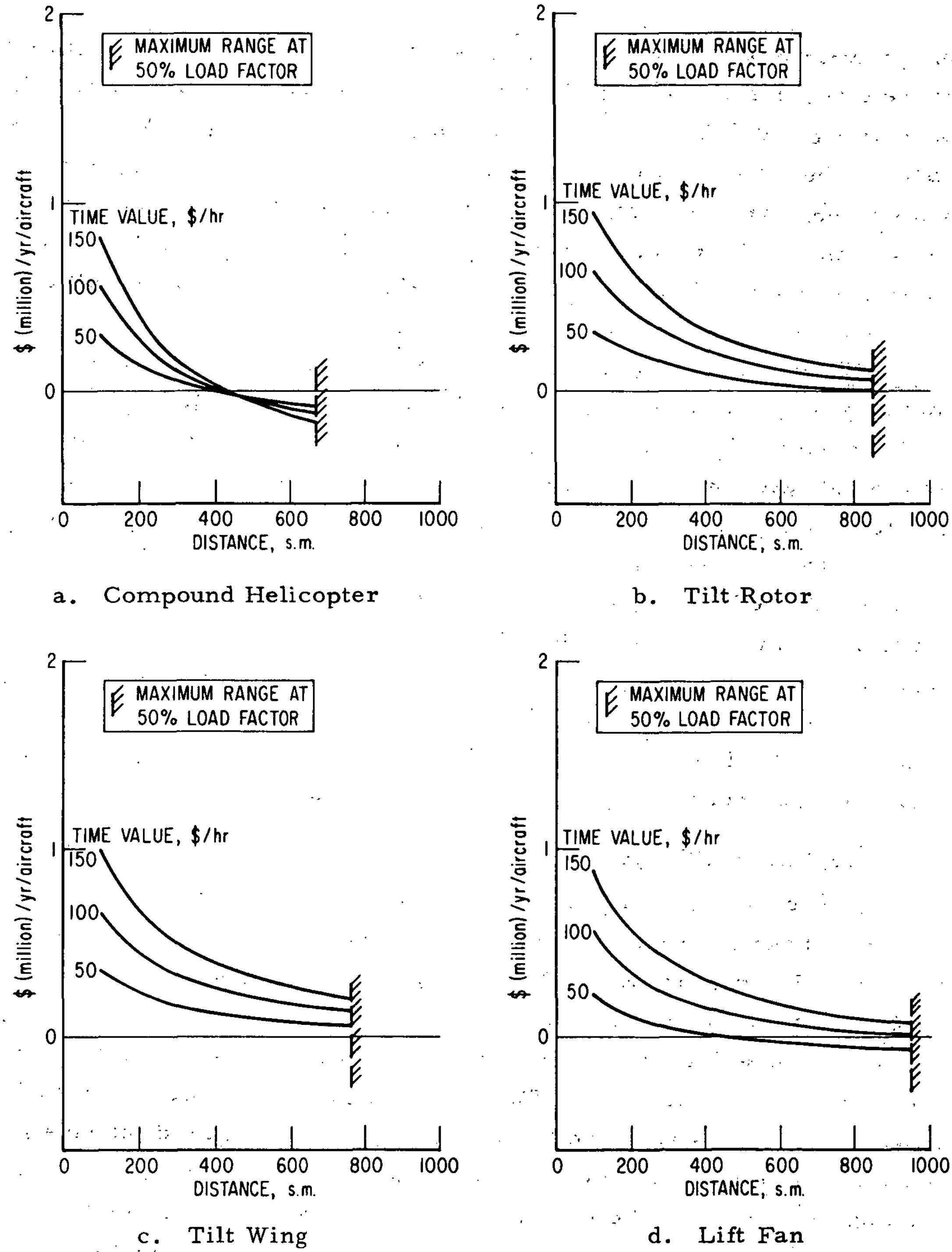


Figure 25. Cost Savings of Small VTOL Relative to Small Turbojet

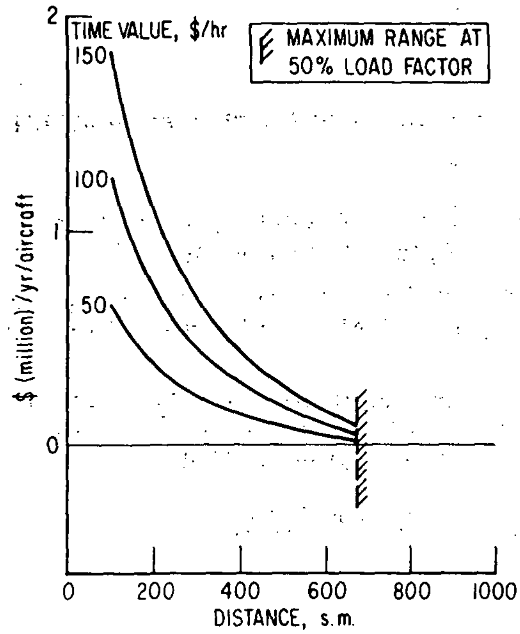
of operation of the compound helicopter puts it at a disadvantage with respect to the turbojet and, instead of saving money, it begins to cost more. It is seen in Figures 25b and 25c that despite higher operating costs and lower speeds, the tilt rotor and tilt wing exhibit savings to their respective maximum ranges for almost all values of traveler's time. However, the higher costs associated with the lift fan (Figure 25d) result in savings only for travelers whose time value exceeds $100/hr. These savings result at any trip distance within the maximum range shown.

For the nominal Executive Transportation Mission distance of 500 miles, yearly cost savings of $200,000 to $300,000 per aircraft may be realized using tilt rotor, tilt wing or lift fan concepts. The results of Figure 25 indicate that the tilt rotor and tilt wing concepts could produce the greatest savings as a replacement to the small turbojet Executive Aircraft.

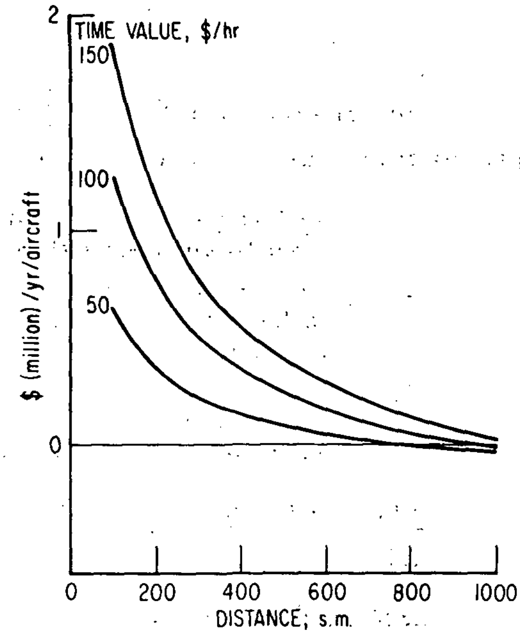
The curves in Figure 25 also answer the question of how much more economical one VTOL concept might be than another in a given region of the phase diagrams. For example, although the tilt wing indicates an economic superiority over the tilt rotor in the phase diagrams of Figures 18 and 19, it can be seen by comparing Figures 25b and 25c that the economic difference is small. For this reason a choice between these two concepts may be based on other considerations such as noise, ride quality or aesthetics.

b. Comparison of Cost Savings for Large Aircraft

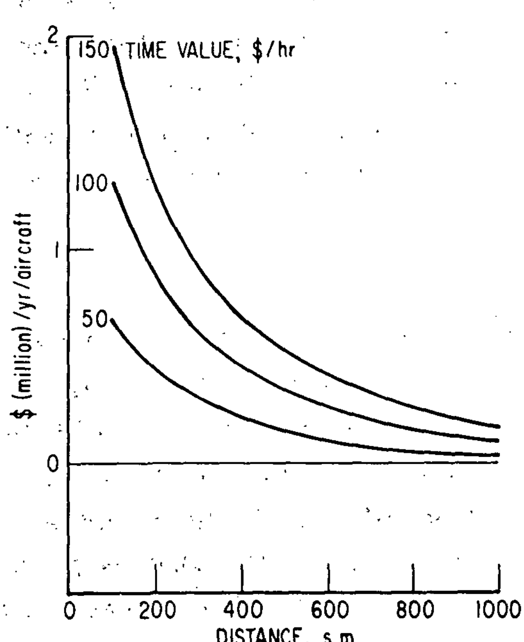
A similar cost savings analysis was conducted for the large (16 passenger) advanced VTOL concepts in comparison with the large turbojet aircraft. The results obtained, by using similar procedures given previously for the small aircraft, are illustrated in Figure 26. It can be seen that all of the advanced aircraft have a significant potential for cost savings over the composite turbojet. The large compound helicopter (Figure 26a) produces cost savings to greater mission distances than did the small compound helicopter. Since the costs associated with large aircraft operations are higher than those of small aircraft operations, the corresponding savings available through the use of large VTOL concepts are also significantly greater.



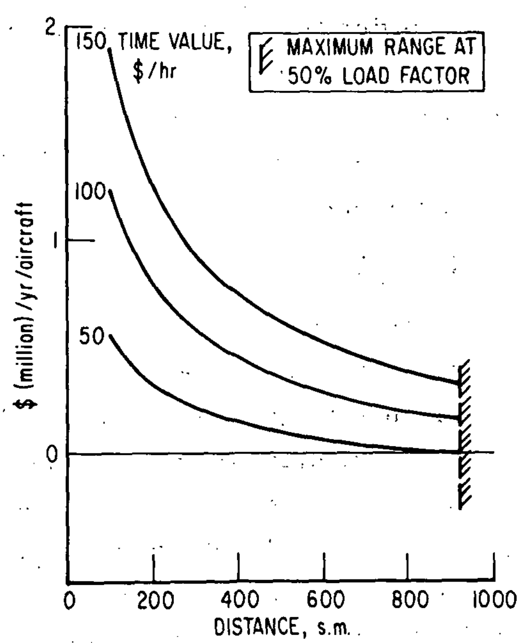
a. Compound Helicopter



b. Tilt Rotor



c. Tilt Wing



d. Lift Fan

Figure 26. Cost Savings of Large VTOL Relative to Large Turbojet

In general the following conclusions on potential cost savings for equal missions using large aircraft are:

1. For trips below 500 miles all four concepts can produce a significant cost saving as a replacement for the turbojet.
2. For trips beyond 500 miles the tilt wing and lift fan appear to have the best cost saving potential compared to the other concepts.
3. The large tilt wing concept appears to provide the best cost saving potential for low time value passengers; for high time value passengers the large lift fan appears best.

B. COMMUTER AIR CARRIER MISSION COST BENEFIT ANALYSIS

1. MISSION SCENARIOS

Selected scenarios for Commuter Air Carrier Missions are developed in Table XIII. These missions assume that a traveler starting from home or office travels to the nearest commuter port by car, boarding the primary mode with minimum processing time. Large, advanced VTOL aircraft are assumed to operate from VTOLports which are more conveniently located to the traveler, resulting in shorter access and distribution times than for airline service.

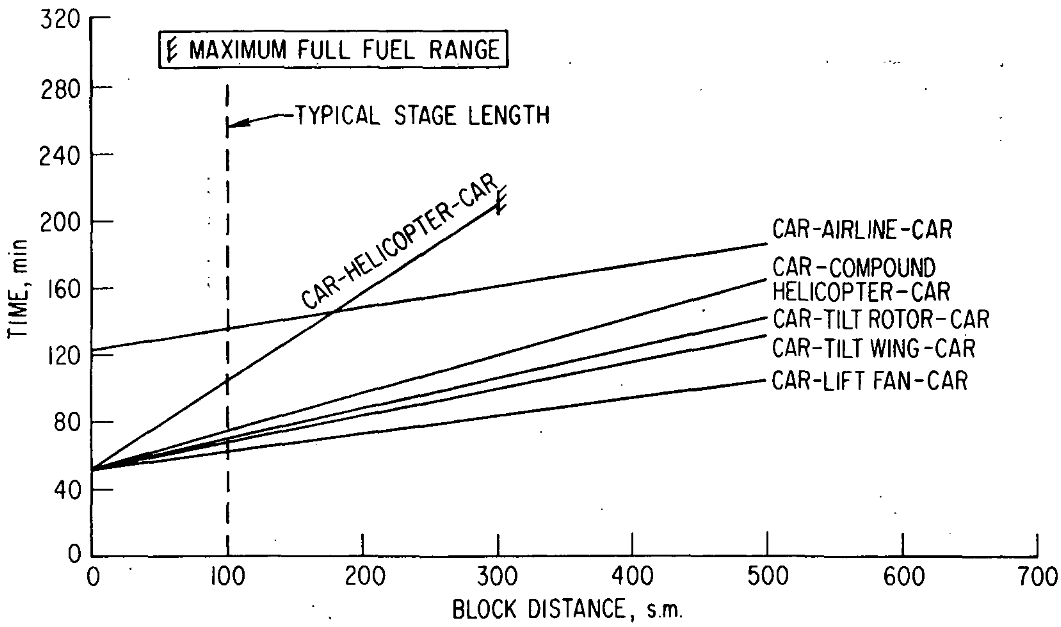
2. TIME LINE ANALYSIS

Results of the time line and cost analyses for Commuter Air Carrier Missions as described in the foregoing scenarios are given in Figure 27. Again the advantage of VTOL aircraft operating from a multiplicity of neighborhood VTOLports becomes evident in minimizing access and distribution segment time. The Commuter Mission is generally short (typical stage length approximately 100 miles); hence, all VTOL aircraft--whether rotor, propeller or fan--have significant time advantages over CTOL aircraft operating from today's few air carrier ports. The operating cost per passenger of the lift fan concept (Figure 27b) is only slightly in excess of that of the airline, even though the scenario indicates the cost per hour per passenger

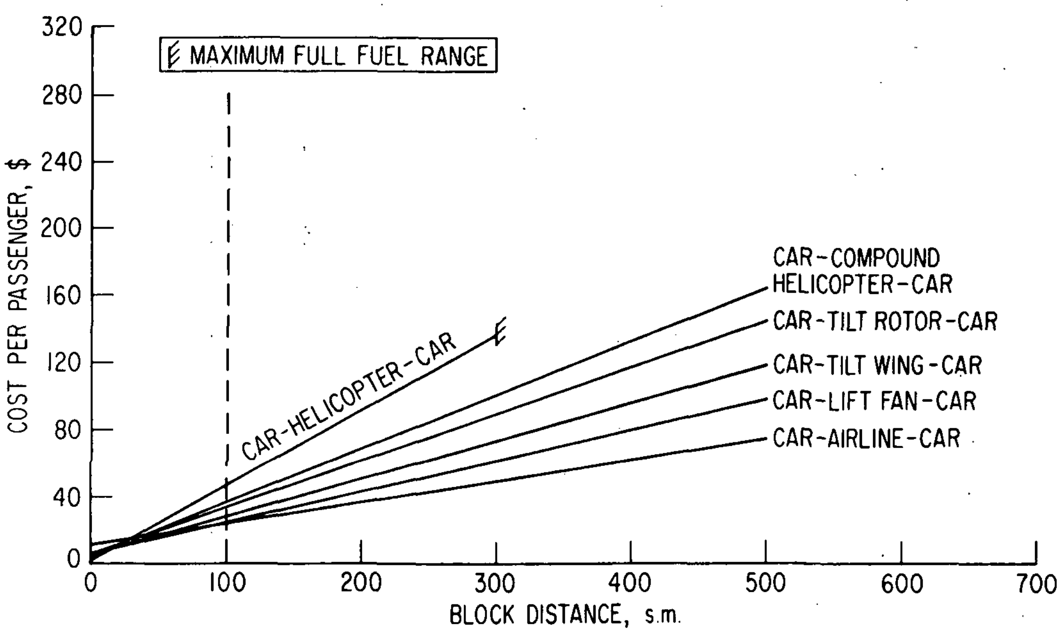
Table XIII. Commuter and Offshore Mission Time and Cost Parameters

	Access Segment(1)				Primary Segment					Distribution Segment		
	Mode	Time (hr)	Cost ($)	Process Time (hr)	Mode	Speed (mph)	Delay(2) (hr)	Average No. of Pass(3)	Cost/ Pass. ($/hr)	Process Time (hr)	Mode	Trip Time (hr)
a. Commuter	Car	0.5	--	0.25	Commuter Airline	250	0.1	1	35	0.15	Car	0.2
	Car	0.2	--	0.20	Large Helicopter	110	0.1	6	40	0.15	Car	0.2
	Car	0.2	--	0.20	Large Comp. Helic.	265	0.1	7	71	0.15	Car	0.2
	Car	0.2	--	0.20	Large Tilt Rotor	322	0.1	7	79	0.15	Car	0.2
	Car	0.2	--	0.20	Large Tilt Wing	368	0.1	7	72	0.15	Car	0.2
	Car	0.2	--	0.20	Large Lift Fan	564	0.1	7	88	0.15	Car	0.2
b. Offshore					Small Helicopter(4)	135	0.1	4	38			
					Large Helicopter(4)	110	0.1	10	36			
					Small Comp. Helic.	190	0.1	4	85			
					Large Comp. Helic.	265	0.1	10	57			
					Small Tilt Rotor	380	0.1	4	117			
					Large Tilt Rotor	320	0.1	10	66			
					Small Tilt Wing	430	0.1	4	105			
					Large Tilt Wing	370	0.1	10	61			
					Small Lift Fan	530	0.1	4	140			
					Large Lift Fan	565	0.1	10	78			

(1) VTOLports assumed (2) Nonproductive flight time (3) 40% load factor (4) 300-mile range



a. Time Line



b. Equivalent Passenger Cost

Figure 27. Commuter Mission--Intercity Service with Large Aircraft

is much greater, reflecting its increased speed over slower commuter airline aircraft.[1] The rotor craft show up as least desirable in this analysis because of their lower speeds which are not offset by lower cost per passenger.

It should be noted that all of the new, large VTOL concepts are over 12,000 pounds in gross takeoff weight. They are, however, all under 30 passengers and 7500 pounds in maximum payload. Thus they could be operated by commuters in accordance with changes to the CAB's ruling pertaining to Part 298 operations. The FAA, however, has yet to relieve the requirement that all aircraft over 12,500 pounds in gross takeoff weight be operated under Federal Aviation Regulation (FAR) Part 121 rather than the less stringent FAR Part 135 under which most commuters presently operate. Thus direct comparison of the new VTOL concept operating costs with present commuter Part 135 costs (as reflected by their fares) can only be valid if the FAA adopts criteria similar to the CAB and thus permits operation of the larger aircraft under Part 135.

3. TIME VALUE ANALYSES OF ADVANCED AIRCRAFT

A complete analysis of the role of advanced VTOL aircraft in the Commuter Air Carrier Missions was beyond the scope of the present study. However, the previous section showed favorable time savings at relatively small increases in cost for some of the concepts. Since the Commuter Air Carrier Mission is generally short (under 200 miles) full advantage cannot be taken of the speed of the lift fan concept. Therefore, the next most attractive candidate is the tilt wing which also showed up favorably in the executive mission analyses. Consequently a time value analysis has been made for the Executive Transportation Mission (considering airline, small helicopter, and small tilt wing alternatives) and the large tilt wing in the Commuter Air Carrier Mission.

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[1] Here the cost of operation includes both direct operating costs and indirect operating costs, but not a return on investment, and can be thought of as the commuter "break-even" fares.

Figure 28a compares a company-owned small tilt wing aircraft, an executive small helicopter, and current CTOL commuter fares. Figure 28b then adds a large tilt wing commuter application to the scenario. As can be seen, Figure 28b shows that a tilt wing aircraft utilized in the Commuter Air Carrier Mission would be attractive for executive travelers with time values up to approximately $10 per hour for the nominal commuter distance of 100 miles. For greater distances conventional commuter airline service becomes more attractive, and for greater traveler time values a company-owned small tilt wing concept in the Executive Transportation Mission would be more cost effective to the traveler. Fares for the CTOL and VTOL commuter aircraft are also shown in Figure 28. Although the tilt wing may be competitive with the CTOL commuter for the executive traveler, the required fare for a commuter tilt wing may be too high to attract lower time value classes of commuters.

C. OFFSHORE MISSION COST BENEFIT ANALYSIS

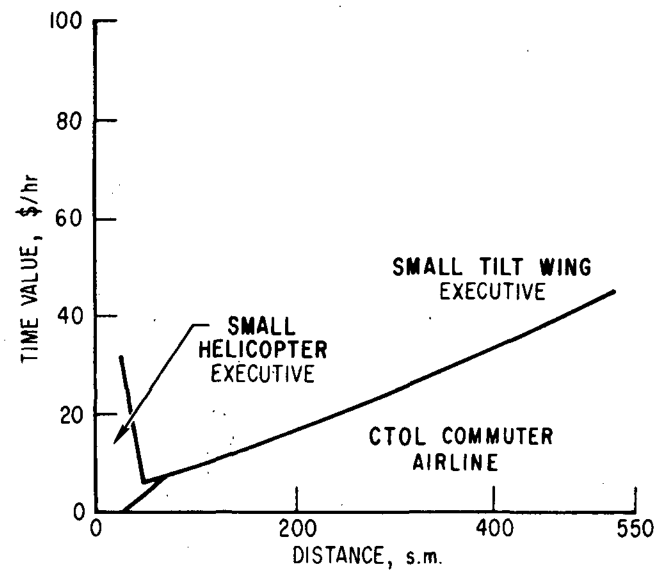
One of the more significant Industrial Special applications of the helicopter is the delivery of personnel on routine schedules to offshore oil drilling sites (platforms). The helicopter typically operates between a land base and drilling sites approximately 100 miles offshore. VTOL capabilities are required and hence the scenarios shown in Table XIIIb incorporate only the primary segment of travel. The four advanced aircraft concepts are shown along with conventional helicopters as now used. Both small and large configurations are shown in the scenario and these are not generally interchangeable in the Offshore Mission since the large helicopters are used for scheduled crew changes while the small vehicles are used for movement of supervisory personnel.

Results of the time line and cost analyses for the two Offshore Missions are shown in Figures 29 and 30. It appears from Figure 29 that the efficiency of crew change could be enhanced through the use of advanced VTOL aircraft, with the lift fan concept leading the candidates both in improved delivery time and cost per passenger. All of the advanced

COMMUTER FARES

DISTANCE (s.m.)	TILT WING COMMUTER FARE ($)[1]
50	18.60
100	28.60
200	48.60

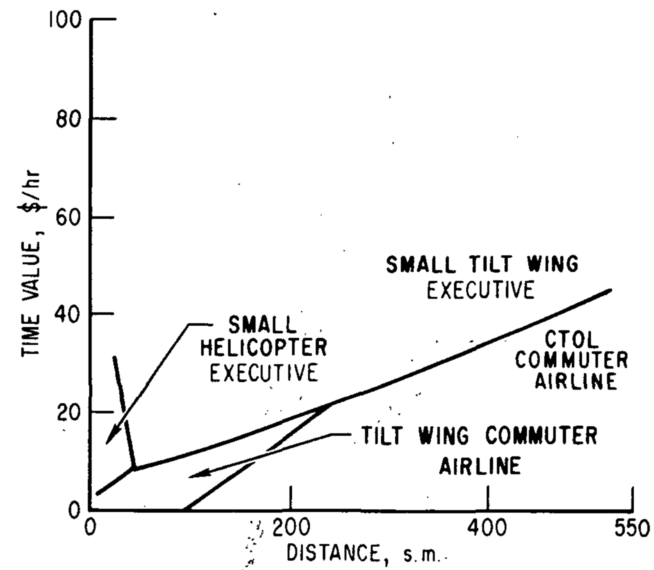
(1) "BREAK-EVEN" (NO RETURN ON INVESTMENT CONSIDERED)



a. CTOL Aircraft in Commuter Mission--Airline with One Hour Connecting Delay

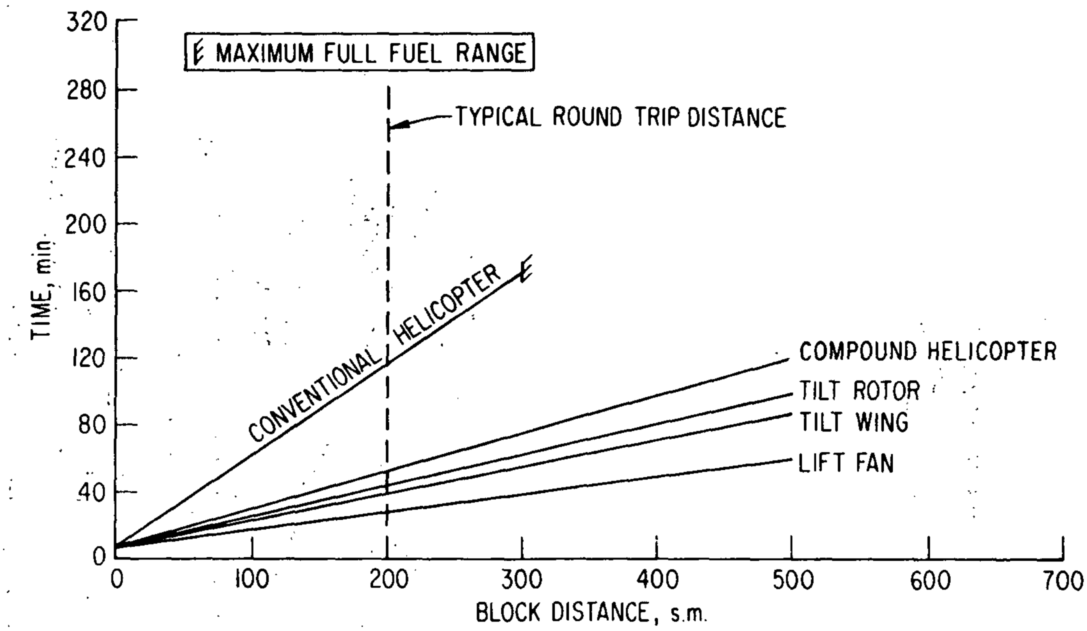
COMMUTER FARES

DISTANCE (s.m.)	CTOL COMMUTER FARE ($)
50	13.40
100	18.80
200	29.60

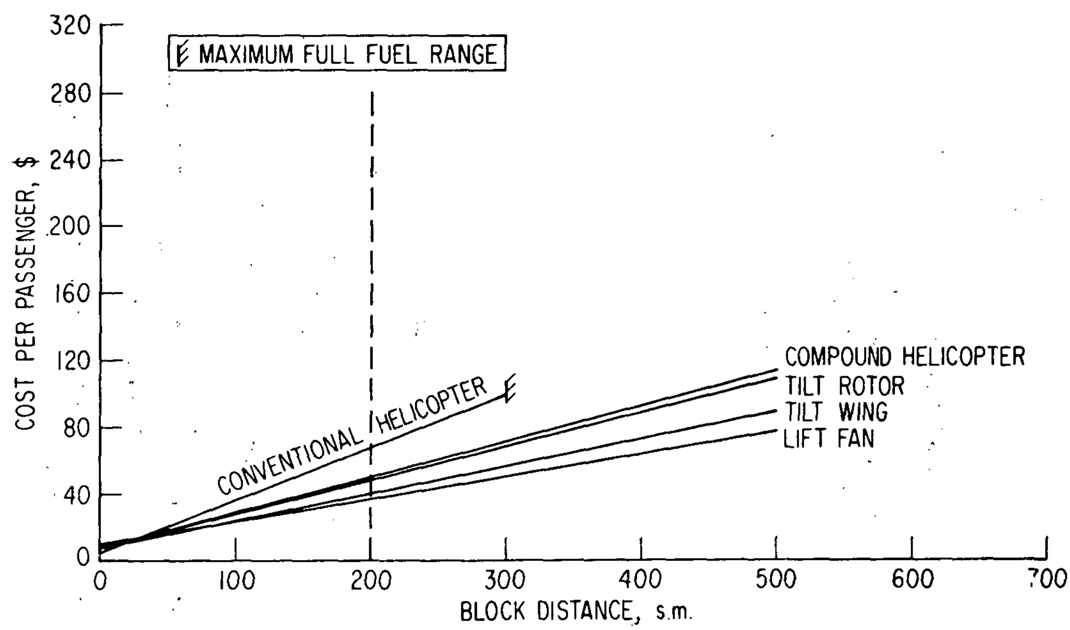


b. Tilt Wing in Commuter Mission--CTOL and Tilt Wing Commuter Airline with One Hour Connecting Delay

Figure 28. Advanced Large Tilt Wing Aircraft in Commuter Mission



a. Time Line



b. Equivalent Passenger Cost

Figure 29. Offshore Mission--Crew Change with Large Aircraft

concepts have significant advantages over today's helicopter for this purpose. Further, limited range of the current helicopter precludes safe use for longer stage lengths as offshore distance requirements increase. The advanced VTOL aircraft can safely operate at round trip ranges over 400-500 miles.

The time line and cost analysis for the Offshore Mission of transporting supervisory personnel presented in Figure 30 also shows the advanced VTOL concepts to be time saving in operations over the helicopter. The helicopter, however, has a small cost advantage. In general the tilt wing and lift fan concepts appear the most attractive for this mission. The two Offshore Missions require the use of different size vehicles; hence, the operator would most likely make his choice within a given size and not between sizes. Therefore a direct comparison of large and small aircraft time and cost is not presented herein.

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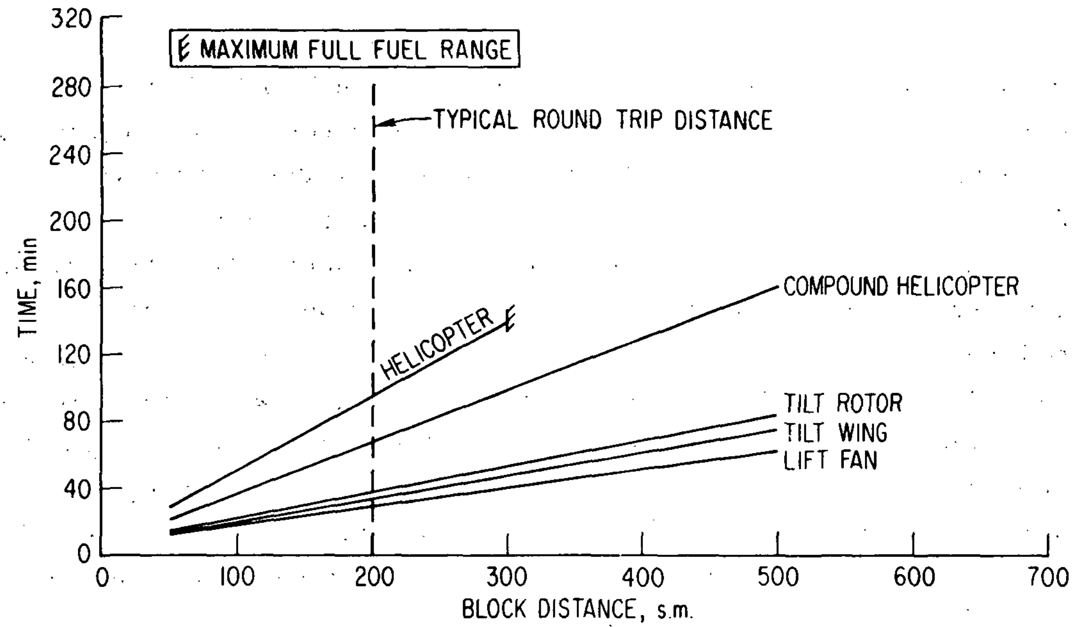
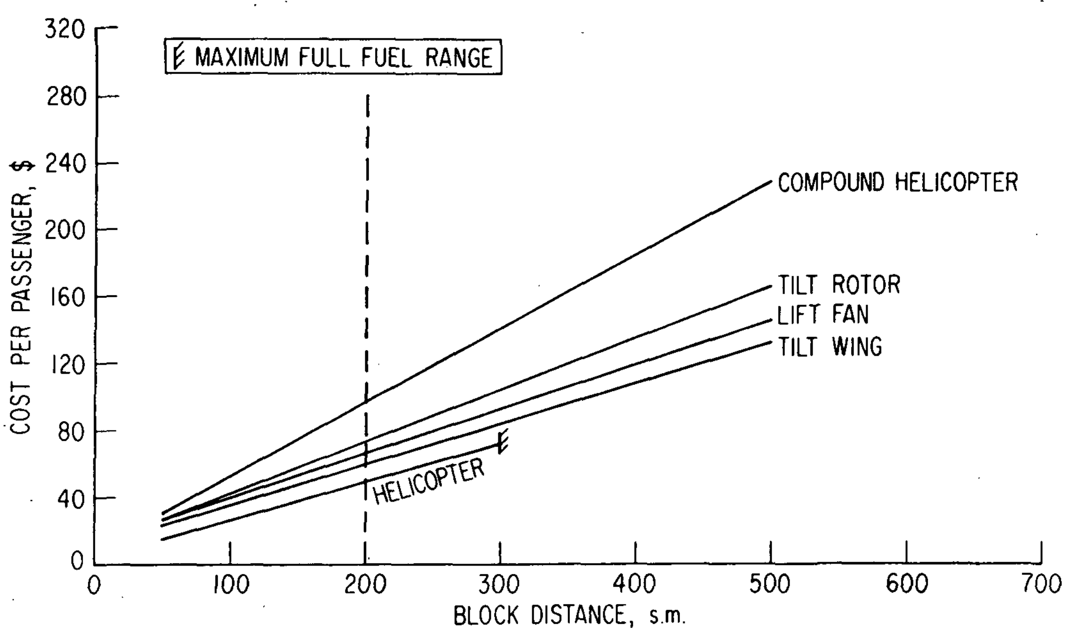


a. Time Line



b. Equivalent Passenger Cost

Figure 30. Offshore Mission--Supervisory Personnel Movement with Small Aircraft

VI. CONCLUDING REMARKS

This study was intended to delineate broad areas of economic viability in order to identify the advanced VTOL concepts worth pursuing. For this purpose, the level of aircraft design detail used was considered sufficient to compare the concepts by a cost-benefit analysis. Further investigation of the promising VTOL concepts would require more detailed configuration design tradeoff studies to identify those potential problem areas that might further influence the choice of VTOL concepts or suggest worthwhile areas of research. These analyses, as well as the investigation of other influencing factors such as noise, technical risk, and technical complexity were beyond the scope of this study.

There are a number of VTOL concepts that may be applicable to general aviation missions. This study evaluated the four representative advanced VTOL concepts that appear to be typical of the technology of the late 1970's. Due to the rapid advancement of VTOL technology, however, it is possible that the most appropriate VTOL aircraft for application to general aviation missions one to two decades from now may incorporate a concept or combination of concepts not yet recognized.

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