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SMALL V/STOL AIRCRAFT ANALYSIS

Volume II Appendices

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SMALL V/STOL AIRCRAFT ANALYSIS

Volume II

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FOREWORD

This report on the study of small V/STOL aircraft analysis is published in two volumes. Volume I contains five sections covering:

Introduction

Summary and Conclusions

General Aviation Missions

Aircraft Configurations and Capabilities

Aircraft Cost Benefit Analyses

This document, Volume II, contains appendices with supporting reference data and methodology as follows:

Appendix A: Survey of General Aviation Activities

Appendix B: Aircraft in Current General Aviation Use

Appendix C: Urban Area Access Study

Appendix D: Aircraft Economics

Appendix E: Cost Benefit Analysis Methodology

APPENDIX A

SURVEY OF GENERAL AVIATION ACTIVITIES

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APPENDIX A

SURVEY OF GENERAL AVIATION ACTIVITIES

The survey of general aviation activities in the United States was principally conducted through interviews with users, manufacturers, trade associations, and government organizations. Table A-1 lists the organizations and firms interviewed with a view to identifying current general aviation missions, aircraft operated in these missions, use factors, costs and cost benefits, and desired aircraft characteristics for the 1975 to 1980 period. The interview data became the basis for defining the current and future general aviation missions and aircraft performance and economic characteristics that are used throughout the main body of Volume I. Additionally, the desires of each organization contacted regarding future aircraft characteristics are summarized in Tables A-2 through A-7. There was considerable variation in the requirements identified by these organizations. In some instances, desired future characteristics were stated by referring to specific aircraft; they are identified in the tables.

Table A-1. General Aviation Activities

	Activity	Location
I	Trade Associations	
	Aircraft Owners and Pilots Association	Washington, D.C.
	General Aviation Manufacturers Association	Washington, D.C.
	Helicopter Association of America	Washington, D.C.
	National Air Transportation Conferences	Washington, D.C.
	National Business Aircraft Association	Washington, D.C.
II	Government Organizations	
	CAB, Bureau of Statistics	Washington, D.C.
	FAA, Bureau of Statistics and Economics	Washington, D.C.
	Los Angeles City Fire Department	Los Angeles, California
	Los Angeles County Sheriff Department	Los Angeles, California
III	Aircraft Manufacturers	
	Beech Aircraft Company	Wichita, Kansas
	Bell Helicopter Company	Fort Worth, Texas
	Cessna Aircraft Company	Wichita, Kansas
	Gates Lear Jet Corporation	Wichita, Kansas
	Hughes Tool Company	Culver City, California
	Sikorsky Aircraft Division	Stratford, Connecticut
	Vought Helicopter Company	Dallas, Texas
IV	Commuter Air Carriers	
	Allegheny Commuter	Washington, D.C.
	Amistad Commuter	Houston. Texas
	Golden West Airlines	Los Angeles, California
	Houston Metro Airlines	Houston, Texas
V	Executive Aircraft Operators	
	Airesearch Aviation Company	El Segundo, California
	California Land and Investment Company	Los Angeles, California
	Freeport Sulphur Company	New Orleans, Louisiana
	North American Rockwell Corporation	Los Angeles, California
	Shell Oil Company	Houston, Texas
	Southern California Edison Company	Long Beach, California
	Tenneco, Incorporated	Houston, Texas
VI	Commercial Aircraft Operators	
	Aero Services	Wichita, Kansas
	Briles Helicopter Service	Santa Monica, California
	Coastal Ag Chemical	Ventura, California
	Geo Data Systems	Orange County, California
	Helicopter and Airplane Services Corporation	Gaithersburg, Maryland
	Helix Air Service	Dallas, Texas
	Missionary Aviation Fellowship	Fullerton, California
	Okanagan Helicopters, Limited	Vancouver, B.C.
	Petroleum Helicopters, Incorporated	Lafayette, Louisiana
	Schultz Enterprises	Los Angeles, California
	Utility Helicopters	Long Beach, California

Table A-2. Desired Aircraft Characteristics -- Executive Short-Distance Missions

Characteristic	Executive User		Commercial Operator	Aviation Associations			Helicopter Manufacturers		Helicopter Manufacturer (short-term)	Helicopter Manufacturer (long-term)	Aircraft Manufacturers	
Referenced aircraft	--	--	--	--	--	--	--	--	--	--	Gates Twin Jet	--
Capacity, passengers	5	7	10 to 15	--	--	8 to 12	--	7	5[a] 15[b]	8 to 10	8	8
Range, s. mi	350	275	Stage lengths up to 100	Stage lengths up to 100	Short stage lengths	Stage lengths of 50 to 60	400 to 500	400	400	800	215	600
Speed, mph	130	118	150	--	--	200	200	200	175 to 185	275	180	250
Takeoff and landing mode	VTOL	STOL (parking lot)	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL (compound helicopter)
Propulsion	--	Single turbine	Turbine	Twin turbine	--	Twin turbine	Hot cycle	Twin turbine	Single turbine;[a] twin turbine[b]	Twin tilt rotor	Twin turbine	Twin turbine
Avionics	--	--	--	Full IFR	--	Full IFR	--	--	Full IFR	Full IFR	Full IFR	Full IFR
Initial cost, $	200K	--	100K[a] 600K[b]	--	--	--	--	--	1.3M	--	450K	--
Operating Cost, $/hr	Less	Less	Less	Less	Less	Less	Less	Less	Less	Less	Less	Less
Other	--	--	More heliports	Need more heliports	More heliports, less noise, and less cost	More heliports	More heliports and less noise	--	--	--	--	Compound helicopter

[a]Small corporation
[b]Large corporation

Table A-3. Desired Aircraft Characteristics -- Executive Medium-Distance Missions

Characteristic	Executive Users			Aviation Association	Aircraft Manufacturers		
Referenced aircraft	Hawk Commander	King Air 90 and 100	F-27	King Air 100	King Air 100	--	--
Capacity, passengers	8 to 9	6 to 15	42	8 to 15	8 to 15	8 to 10	8
Range, s. mi	1000	>1100 to 1300	1600	1100	1100	800	600
Speed, mph	250	250 to 285	300	285	285	275	250
Takeoff and landing mode or distance, ft	2500	1435	<3150	1435	1435	VTOL	VTOL (compound helicopter)
Propulsion	Twin turboprop	Twin turboprop	Twin turboprop	Twin turboprop	Twin turboprop	Tilt rotor	Twin turbine
Avionics	Full IFR	--	Full IFR	Full IFR (including Cat III); collision avoidance system	Full IFR	Full IFR	Full IFR
Pressurization	Yes	--	Yes	Yes	Yes	--	--
Air conditioning and heating	Yes	--	Yes	Yes	Yes	--	--
Beverage service	Yes	--	Yes	Yes	Yes	--	--
Lavatory	Yes	--	Yes	Yes	Yes	--	--
Initial Cost, $	370K	400 to 600K	1M	400 to 600K	600K	1.3M	--
Other	--	--	Like speed and comfort	--	--	--	--

Table A-4. Desired Aircraft Characteristics -- Executive Long-Distance Missions

Characteristics	Executive Users			Aviation Association	Aircraft Manufacturers		
Referenced aircraft	Saberliner	--	Falcon	--	--	Citation	--
Capacity, passengers	12	6	--	--	6 to 8	6 to 8	--
Range, s.mi	2490	3000	>1900 (i.e., greater than Falcon)	3000	1800 to 2400	1540	--
Speed, mph	520	600	--	--	650	400	--
Balanced field length, ft	4950	4000	<5000 (i.e., less than Falcon)	--	5000	2950	3000 to 4000 (static high lift devices)
Propulsion	Twin turbojet	Twin fan jet	--	--	Twin fan jet	Twin fan jet	Twin fan jet
Avionics	Full IFR	Full IFR	--	0-0 Landing: collision avoidance system	--	Full IFR	Full IFR, collision avoidance system
Pressurization	Yes	--	--	--	--	Yes	--
Airconditioning/heating	Yes	--	--	--	--	Yes	--
Beverage service	Yes	--	--	--	--	Yes	--
Lavatory	Yes	--	--	--	--	Yes	--
Initial cost, $	1.4M	--	--	--	--	695K	--
Other	--	--	--	Less noise	--	Single pilot certification desired	Need better noise control, stability and control systems, and better deicing

Table A-5. Desired Aircraft Characteristics -- Commuter Intercity Service

Characteristic	Commuter Air Carriers				Aviation Associations		An Aircraft Manufacturer's Survey of Commuters
Referenced aircraft	DHC-7	DHC-7	--	Heron	--	--	--
Capacity, passengers	48	48	25 to 30	17	20 to 30	25 to 30	> 18
Range, s.mi	400 to 500	230	Stage lengths of 130	1550	200 to 300 (operate efficiently at 20 to 30)	600	300 to 500
Speed, mph	275	275	250 to 300	183	230	--	425
Takeoff and landing distance, ft	<2000	1950	1500	2875	2000 1500 (offloaded)	--	3000 to 4000
Propulsion	4 Engine-turboprops	4 Engine-turboprops	--	4 Engine-piston	Twin turboprops	Twin turboprops	Twin turbojet[a]
Avionics	Full IFR	Full IFR	Full IFR	--	Full IFR	Full IFR; 0-0 landing	Full IFR (including area navigation)
Pressurization	Yes	Yes	Yes	No	Partial OK if inexpensive	Yes	Yes
Air conditioning/heating	Yes	Yes	Yes	--	Yes	Yes	Yes
Beverage service	Yes	--	--	--	--	Yes	Yes (optional)
Lavatory	Yes	Yes	Yes, but not a problem to date	--	Yes	Yes	Yes (optional)
Initial cost, $	1.6M	1.6M	<500K	--	--	--	<800K
Operating cost, $/hr	--	--	--	--	--	--	IOC 75% of DOC
Other	Retractable gear (passenger appeal), carry-on baggage, and good maintainability	--	--	--	Carry-on baggage space and headroom	--	Part 25 certification, seat pitch of 30 to 31 in., and carry-on baggage
Ride Quality	--	--	--	--	B-99 and DHC-6 OK	--	--
Noise Levels	--	--	--	--	DHC-6 levels maximum	--	--

[a]Except for short range, congested hub feeders.

Table A-6. Desired Aircraft Characteristics -- Commuter CBD Service

Characteristic	Commuter Air Carriers			Aviation Associations			Aircraft Manufacturers			
Capacity, passengers	a	b	13	c	40 to 50	d	40 to 50	15 to 18	18	12
Range, s. mi			300		NY to Wash		--	800	300 to 400	215
Speed, mph			115		200		--	300	170	180
Takeoff and landing mode			VTOL		VTOL		VTOL	VTOL	VTOL	VTOL
Propulsion			Twin turbines		Twin turbines		Hot cycle	Tilt rotor (turbine)	Twin turbine	Twin turbine
Avionics			IFR		IFR		--	IFR	IFR	--
Pressurization			No		No		--	--	No	--
Air conditioning/ heating			Yes		Yes		--	Yes	Yes	--
Initial Cost, $			485K		--		--	1.2M	1M	450K
Operating cost, $/hr			246		Needs reduction for scheduled service		Hot cycle will reduce cost	--	330 and crew ≈350	--

[a]High operating costs and vibration/fatigue of current helicopters preclude wide-scale commercial operations.
[b]STOL is more attractive now, but VTOL may be attractive if more heliports are available.
[c]Helicopter is strictly a complement to fixed wing for shorter stage lengths; lack of heliports is a major problem.
[d]Commuter business difficult is enough with fixed wing; high operating cost of helicopters will preclude their use.

Table A-7. Desired Aircraft Characteristics -- Industrial Personnel Transport

Characteristic	Commercial Helicopter Operators				Executive Users		Helicopter Manufacturers	
Capacity, passengers	6 to 10	6 to 7[a] 15 to 20[b]	30	10 to 15	5 to 7	6	5[a] 15[b]	7 to 15
Range, s.mi	400	320 and 30 minutes	>400	Stage lengths up to 100	700 to 800	Stage lengths up to 100	400	400
Speed, mph	--	150	120	150	150	180	175 to 185	200
Takeoff and landing mode	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL	VTOL
Propulsion	Twin turbine	Twin turbine	Twin turbine	Turbine	Twin turbine	Turbine	Single;[a] twin[b] turbine	Twin turbine
Avionics	IFR desirable	Limited IFR[c]	Full IFR	--	--	--	Full IFR	--
Initial cost, $	--	<400K	200K	--	--	--	--	--
Operating cost, $/hr	--	--	--	Less	--	Less	--	--

[a]Supervisor transport
[b]Crew change
[c]Navaid, autopilot, weather radar

APPENDIX B

AIRCRAFT IN CURRENT GENERAL AVIATION USE

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TABLES

APPENDIX B

AIRCRAFT IN CURRENT GENERAL AVIATION USE

A tabulation was prepared of the more popular aircraft currently used in various general aviation missions based upon total hours flown in each category. These data identified the current aircraft performance and investment cost characteristics for comparison with desired future mission characteristics and aircraft concepts. The data were also used to help identify predominant performance or economic features that would explain the popularity of a particular aircraft model for the various missions investigated.

The aircraft types and missions selected for emphasis relate to commercial, personnel transport operations. They include the multiengine and rotary wing aircraft used in Air Taxi operations (Commuter and non-scheduled), business applications (Executive and Business Transportation) and personnel transport missions in the Industrial Special and "Other" (ISO) categories. The aircraft and missions selected were judged to have the best potential for the introduction of aircraft innovations. The mission categories selected employ professional pilots who are more likely to accept and safely operate potentially complex modified CTOL, STOL, and VTOL aircraft.

B.1 SUMMARY OF MOST POPULAR AIRCRAFT

Table B-1 lists the most popular general aviation aircraft in the following categories: Executive/Business, Air Taxi, and, for rotary wing aircraft, personnel transport missions in ISO. This table was developed from References B-1 and B-2 based on hours flown in 1969. Since professional crews normally fly the turboprop and jet aircraft (even though some hours are listed in the Business Transportation category), Executive and Business

Table B-1. General Aviation Aircraft Use in 1969

Aircraft Type	Total Eligible in 1969[a]	Executive/ Business Transportation Hours Flown[b]	Executive Rank	Air Taxi Hours Flown[c]	Air Taxi Rank	Number Used by Commuter Air Carriers	ISO Hours Flown - Personnel Transport Only[d]	ISO Rank	Capacity, seats[e]
TWIN PISTONS									
Beech 18 Series	1345	61,818	1	154,204	2	167	NA	NA	7 to 9
Beech Queen Air 65	475	36,160	2	37,559	6	32	NA	NA	7 to 11
Cessna 310	2108	30,919	3	64,876	3	9	NA	NA	6
Beech Baron 55	1461	26,329	4	25,329	9	2	NA	NA	4 to 6
Piper Aztec	3111	26,262	5	175,489	1	99	NA	NA	6
Cessna 401/402	608	25,454	6	60,562	4	49	NA	NA	6 to 8
Aero Commander 680F	365	23,315	7	13,791	18	1	NA	NA	5 to 7
Piper Navajo	373	16,596	8	32,495	7	28	NA	NA	6 to 9
Cessna 421	251	15,274	9	f	--	0	NA	NA	6 to 8
Piper Comanche	1335	7,066	11	59,193	5	13	NA	NA	4 to 6
TURBOPROPS									
Beech King Air	371	156,462	1	795	--	0	NA	NA	8
Gulfstream I	188	92,045	2	f	--	0	NA	NA	16
Turbo Commander	126	34,298	3	3,048	--	1	NA	NA	8
Swearingen 226T[g]	95	27,298	4	f	--	0	NA	NA	17
Fairchild F-27	39	23,294	5	f	--	0	NA	NA	20 to 42
deHavilland DHC-6	128	f	--	125,387	1	77	NA	NA	20
Beech 99	114	f	--	81,391	2	97	NA	NA	17
TURBOJETS									
Lear Jet	212	56,621	1	f	--	0	NA	NA	8
Saberliner 60	130	56,237	2	f	--	0	NA	NA	12
Lockheed Jetstar	101	46,122	3	f	--	0	NA	NA	12
Dassault Falcon	106	44,588	4	f	--	0	NA	NA	12
Jet Commander	102	39,886	5	f	--	0	NA	NA	8
DH-125[h]	96	38,759	6	f	--	0	NA	NA	6 to 11
HELICOPTERS									
Bell 206	283	45,339	1	39,168	2	5	8,364	4	5
Bell 47 Series	932	8,242	2	150,921	1	1	50,656	1	3
Fairchild Hiller FH-1100	74	6,185	3	4,318	7	0	2,807	6	5
Sikorsky S55	59	2,119	4	7,349	5	0	1,850	7	12
Bell 204/205	60	1,977	5	25,251	3	0	16,160	2	15
Sikorsky S62	19	1,152	6	2,873	8	0	1,288	11	12
Hiller H12E	122	971	7	16,519	4	0	3,431	5	12
Sikorsky S58	12	860	8	f	--	0	1,643	9	4
Hughes 269 Series	257	723	9	6,732	6	0	14,009	3	2

[a]Met FAA airworthiness criteria

[b]Flown by professional crews only

[c]Includes both commuter air carriers and nonscheduled operators

[d]Based on operator survey data this value is 50 percent of the ISO total hours flown

[e]Includes crew

[f]Negligible

[g]FAA group designation for the "Merlin" series

[h]Currently marketed by Beech Aircraft as BH-125

transportation hours are included for those aircraft. As the twin piston aircraft are often flown by an owner-pilot, only the professionally flown Executive Transportation hours are included for these smaller aircraft. For rotary wing aircraft ISO hours reflect 50 percent of the FAA statistics; this is compatible with operator survey data about hours devoted to personnel transport. Based upon the hours flown in each category, the aircraft are ranked in order of "popularity" for that category.

The Beech 18 and Queen Air series aircraft are the predominating twin piston aircraft in the Executive Transportation category with the Piper Aztec and Beech 18 series being the most popular with air taxi operators. In the turboprop category, the Beech King Air was the primary choice of executive users and the deHavilland DHC-6 was the first choice of the combined nonscheduled air taxi operators and commuter air carriers. The Lear Jet and Sabreliner are the jet aircraft most used by executive operators. The Bell 206 and 47 series helicopters are the most popular with both executives and air taxi operators. The Bell 47 series and Bell 204/205 helicopters predominate for personnel transport missions in the ISO category.

B.2 COMPARISON OF CURRENT AIRCRAFT FEATURES

Comparisons of selected performance features of the previously identified more popular aircraft are shown in Table B-2. Performance and economic data for these aircraft were obtained from References B-3 and B-4. From this table, an attempt was made to isolate characteristics that might consistently explain the popularity of an aircraft.

The executive user of the small four- to six-place twin piston aircraft is apparently willing to pay a premium for the faster Beech Baron when compared with the comparably sized, but less expensive Piper Comanche. The air taxi operator, however, specifically favors the less costly Comanche Also in the six-place aircraft category, the faster Cessna 310 is preferred by executives over the comparably priced Piper Aztec. Air taxi operators, however, prefer the roomier Aztec and are apparently willing to sacrifice

Table B-2. General Aviation Aircraft Characteristics

Aircraft Type	Total Eligible in 1969[a]	Executive Rank	Air Taxi Rank	ISO Rank	Capacity, seats[b]	Cruise Speed, mph	Range, s.mi[c]	Required Takeoff Distance, ft	Cost, $000[d]
TWIN PISTONS									
Beech 18 Series	1345	1	2	NA	7 to 9	204	600	2000[e]	20 (used)
Beech Queen Air 65	475	2	6	NA	7 to 11	223	600	2017[e]	160
Cessna 310	2108	3	3	NA	6	220	789	1800[e]	70
Beech Baron 55	1461	4	9	NA	4 to 6	225	761	1400[e]	70
Piper Aztec	3111	5	1	NA	6	208	882	1620[e]	70
Cessna 401/402	608	6	4	NA	6 to 8	240	212	2200[e]	116
Aero Commander 680F	365	7	18	NA	5 to 7	225	910	1780[e]	80 (used)
Piper Navajo	373	8	7	NA	6 to 9	247	264	2270[e]	116
Cessna 421	251	9	--	NA	6 to 8	270	626	2325[e]	192
Piper Comanche	1335	11	5	NA	4 to 6	198	322	1870[e]	47
TURBOPROPS									
Beech King Air	371	1	--	NA	8	253	1000	1340[e]	400
Gulfstream I	188	2	--	NA	16	348	2000	4350[e]	1000
Turbo Commander	126	3	--	NA	8	254	851	2500[e]	400
Swearingen 226T[f]	95	4	--	NA	17	295	770	2600[e]	400
Fairchild F-27	39	5	--	NA	20 to 42	306	900	3150[e]	1000
deHavilland DHC-6	128	--	1	NA	20	209	191	1200[e]	500
Beech 99	114	--	2	NA	17	254	531	3900[g]	400
TURBOJETS									
Lear Jet	212	1	NA	NA	8	507	1670	3900[h]	800
Sabreliner 60	130	2	NA	NA	12	520	2480	4950[h]	1400
Lockheed Jetstar	101	3	NA	NA	12	507	2200	6000[h]	1800
Dassault Falcon	106	4	NA	NA	12	460	1340	5000[h]	1400
Jet Commander	102	5	NA	NA	8	500	1182	5450[h]	i
DH-125[j]	96	6	NA	NA	6 to 11	443	2040	3350[h]	1100
HELICOPTERS									
Bell 206	283	1	2	4	5	131	351	VTOL	112
Bell 47 Series	932	2	1	1	3	82	240	VTOL	55
Fairchild Hiller FH-1100	74	3	7	6	5	133	420	VTOL	98
Sikorsky S55	59	4	5	7	12	91	400	VTOL	384
Bell 204/205	60	5	3	2	15	127	311	VTOL	425
Sikorsky S62	19	6	8	11	12	92	400	VTOL	i
Hiller H12E	122	7	4	5	4	84	225	VTOL	i
Sikorsky S58	12	8	--	9	15	98	280	VTOL	i
Hughes 269 Series	257	9	6	3	2	75	220	VTOL	35

[a] Met FAA airworthiness criteria
[b] Includes crew
[c] At maximum payload
[d] Basic aircraft
[e] Takeoff over 50-ft obstacle
[f] FAA group designation for the "Merlin" series
[g] Accelerate-stop distance
[h] Balanced field length
[i] Not in production, price of used aircraft varies
[j] Currently marketed by Beech Aircraft as BH-125

some speed. In the larger twin piston category, the inexpensive Beech 18 series aircraft is preferred by both executives and air taxi operators. Part of the Beech 18 popularity is, of course, related to its earlier introduction and longer term availability. The faster and more expensive Beech Queen Air is a second choice by executives, but is flown only 50 percent of the hours flown by the Beech 18. Air taxi operators favor the Cessna 402 as a second choice in the larger twin piston category even though the comparably priced Piper Navajo is slightly larger and faster.

Executive users of small turboprop aircraft apparently prefer the shorter field length of the Beech King Air over the comparably priced, but otherwise equally performing Turbo Commander. In the larger turboprop category, however, the Grumman Gulfstream I appears more accepted although it requires more runway for takeoff than the less expensive Swearingen 226T[1] or the larger Fairchild F-27 (which is comparably priced to the Gulfstream I, but more expensive to operate). The higher speed and longer range of the Gulfstream I are apparently desired features for aircraft in this category; part of its popularity is because it was available prior to the introduction of the Swearingen. Air taxi operators fly more hours in the large, but slow, deHavilland DHC-6 when compared to the Beech 99; however, based upon number of aircraft owned these operators appear to prefer the faster, but smaller Beech 99.

Executive users of jet aircraft typically favor the relatively inexpensive Lear Jet partly because it was one of the first executive jets on the market; the larger, faster, and more expensive Sabreliner is a close second on the basis of hours flown. The slower, more expensive jet aircraft appear less favored even though they may require less field length (e.g., DH-125 versus Lear Jet).

In the three-place helicopter category, executives, air taxi operators, and commercial operators favor the Bell 47 series for personnel

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[1] FAA group designation for the "Merlin" series.

transport missions. Although more expensive than the comparably sized Hughes 269 series helicopters, it is slightly faster and has more range. In the five-place helicopter category, the Bell 206 dominates the market even though the comparably sized Fairchild Hiller FH-100 is slightly faster, less expensive, and has more range. Users of the larger helicopters prefer the faster, but more expensive, Bell 204/205 aircraft when compared to other comparably sized helicopters.

These observations show that it is extremely difficult to quantitatively correlate any single aircraft feature (or even group of features) that will consistently enable prediction of the popularity of an aircraft. Although cost certainly is a consideration in any aircraft selection, many nonquantifiable, intangible factors influence the purchaser decision. Such factors as aesthetics; furnishings; reputation, marketing techniques, and service policies of the manufacturer; pilot preferences; comfort; etc., may affect a buyer's selection. When performance and cost are reasonably equivalent between aircraft, these intangible factors may be the deciding factors.

REFERENCES

B-1 National Summary of General Aviation Aircraft and Hours Flown, 1969, Office of Management Systems, Federal Aviation Administration, Washington, D.C.

B-2 Commuter Air Carrier Operators as of September 1970, Office of Management Systems, Federal Aviation Administration, Washington, D.C.

B-3 Flying Annual and Pilot's Guide, Ziff-Davis (1971).

B-4 John W. R. Taylor, Janes All the World's Aircraft (1968-69).

APPENDIX C

URBAN AREA ACCESS STUDY

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FIGURES

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APPENDIX C

URBAN AREA AIR ACCESS STUDY

An evaluation was made of the possible benefits of improving the short field takeoff capabilities of current jet aircraft by determining whether shorter airport access times would result from the use of available shorter runway airports. Figure C-1 shows the required takeoff distance for current conventional fixed-wing aircraft related to delivery quantity, as determined from References C-1 and C-2. Figure C-2 identifies the number of airports as a function of runway length. From these, it can be seen that a significant number of additional airports could be made available to a jet aircraft user if the balanced field length of the aircraft is less than 4000 feet.

To determine whether these additional airports would significantly benefit the executive traveler, an access time analysis was made for 34 United States metropolitan areas. Each metropolitan area was divided into zones determined by its urban outline and by boundaries reflecting equidistant points between the existing airports of varying runway lengths. Figure C-3 shows the resulting zones for one urban area. Ground access time was then estimated from the geometric center of the urban area in each zone to the nearest airport; Figure C-4 and Table C-1 summarize the results. A maximum time saving of 13 minutes can be realized through direct access to the airports with the shortest runways. This small time saving did not appear to be a significant factor in influencing the selection of an aircraft intended for executive transportation, particularly over the medium and long ranges. Hence, for the executive mission, VTOL aircraft were emphasized rather than reduced take-off and landing CTOL or STOL aircraft.

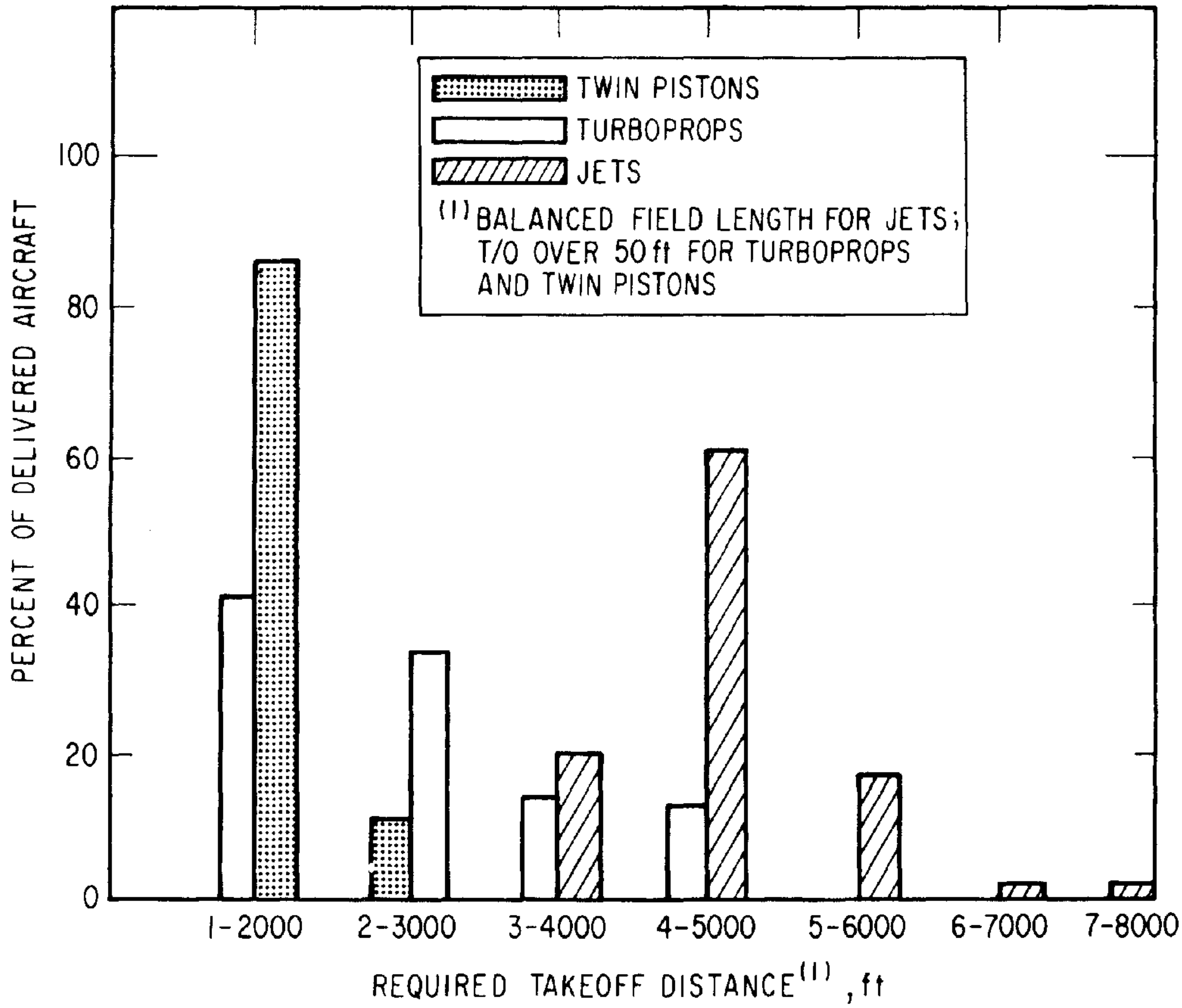


Figure C-1. Takeoff Distance of General Aviation Aircraft as a Percent of Delivered Aircraft

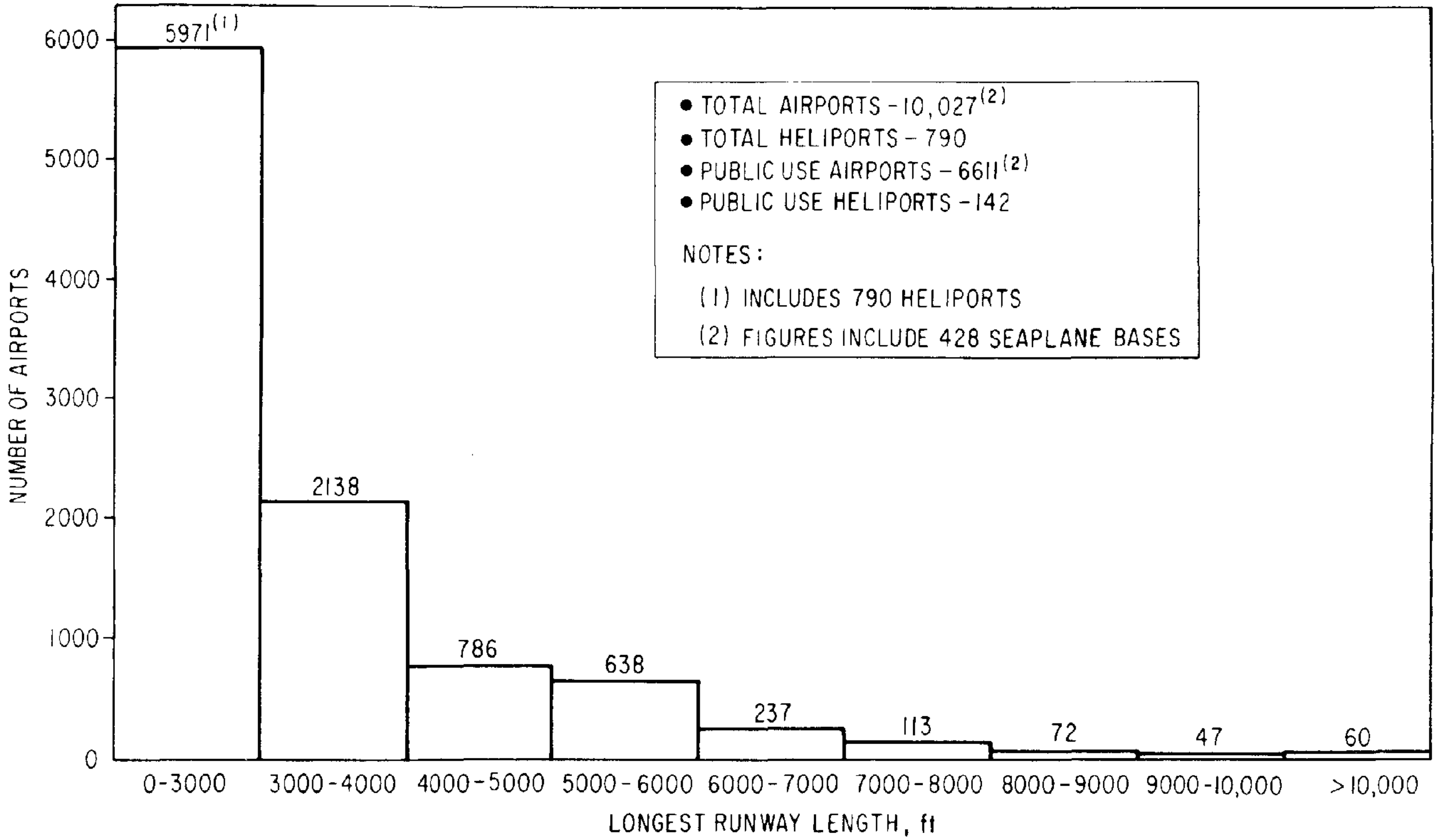
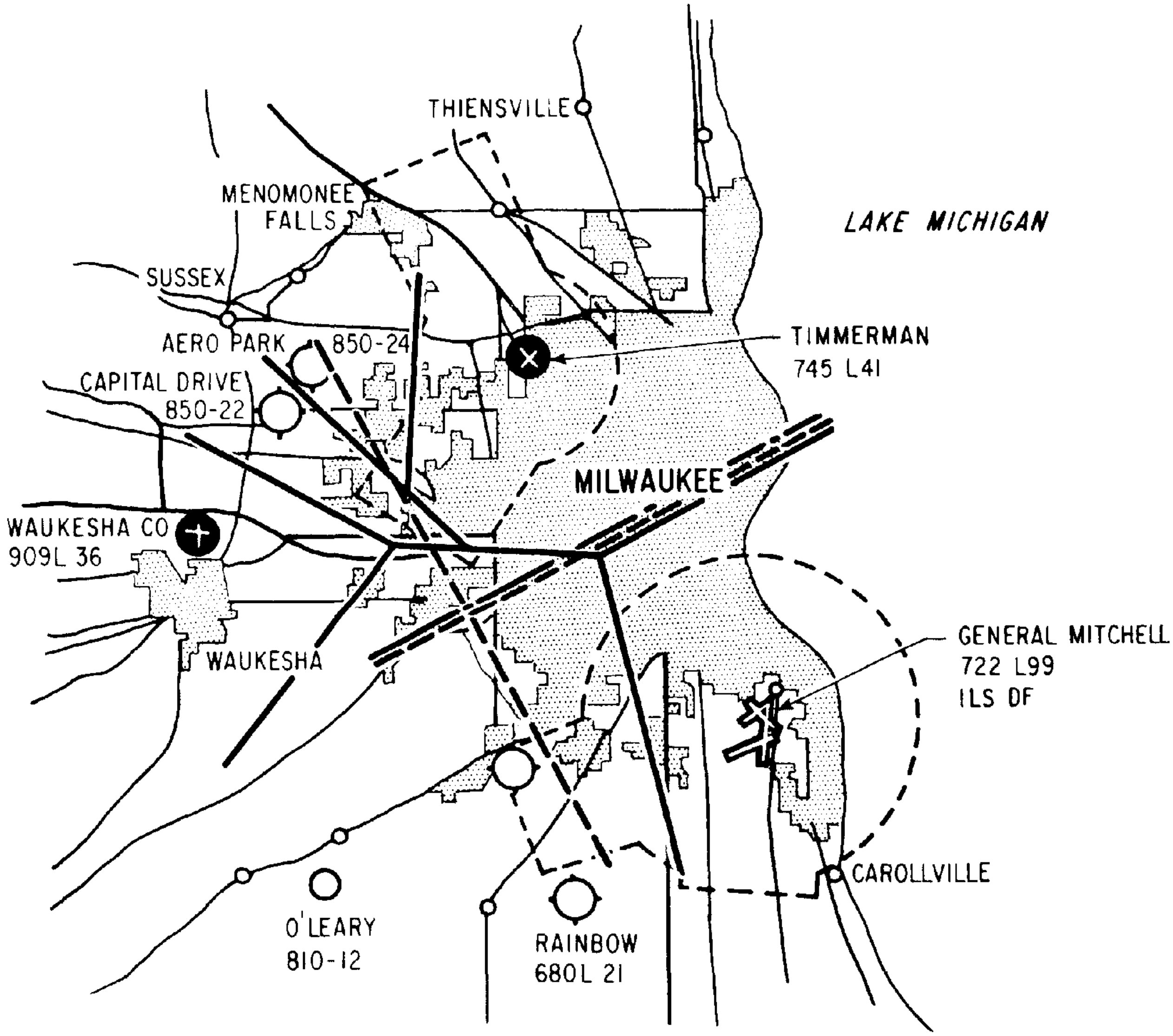


Figure C-2. Runway Lengths of United States Airports as of January 1970



— - —	ZONE DIVISION BETWEEN > 5000 ft RUNWAY AIRPORTS AND 4-5000 ft RUNWAY AIRPORTS
— — —	ZONE DIVISIONS BETWEEN 3-4000 ft RUNWAY AIRPORTS AND > 4000 ft RUNWAY AIRPORTS
———	ZONE DIVISIONS BETWEEN 2-3000 ft RUNWAY AIRPORTS AND > 3000 ft RUNWAY AIRPORTS
745 L41	Field Elevation, Lights, Runway Length - Ft (00)

Figure C-3. Airport Access Zones--Milwaukee

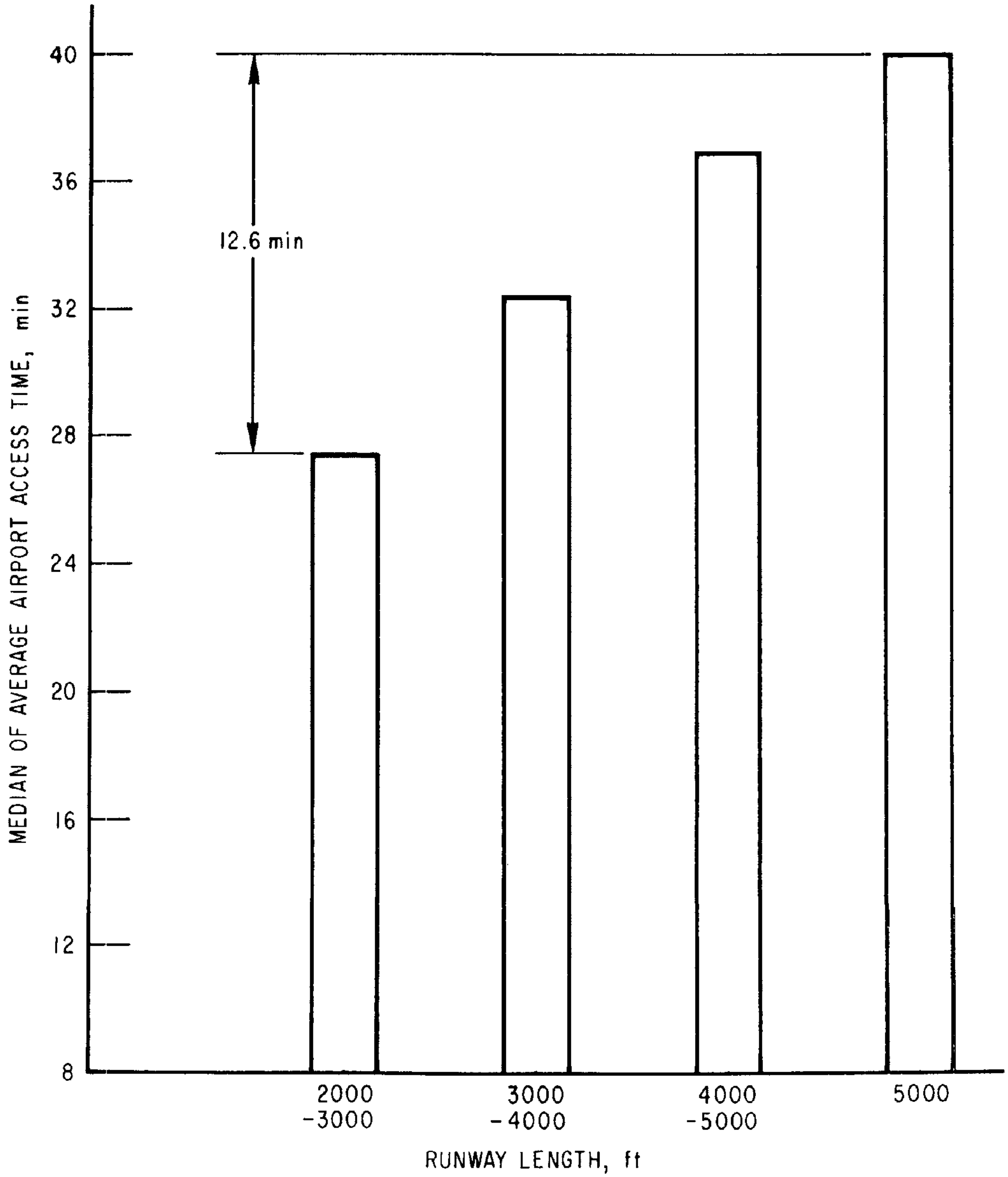


Figure C-4. Round Trip Ground Access Time to Airports

Table C-1. Metropolitan Areas Investigated for Airport Access Time

Metropolitan Area	Minutes to Airport							
	Peak at 20 mph				Off-Peak at 25 mph			
	Runway Length, ft				Runway Length, ft			
	>5000	>4000	>3000	All	>5000	>4000	>3000	All
New York	27.0	25.5	24.3	23.1	21.5	20.4	19.4	18.4
Chicago	16.9	16.9	11.8	10.5	12.1	12.7	8.9	7.9
Los Angeles (Long Beach)	22.4	22.4	16.1	7.5	16.8	16.8	11.2	5.6
Philadelphia	32.1	32.1	29.6	20.8	25.7	25.7	23.7	16.6
San Francisco (Oakland)	12.5	12.5	12.5	10.8	9.4	9.4	9.4	8.1
Boston	27.0	25.8	25.8	25.8	21.5	20.6	20.6	20.6
Washington, D.C.	24.6	22.2	22.2	10.8	19.7	17.7	17.7	8.7
Baltimore	32.7	32.7	32.7	29.1	26.2	26.2	26.2	23.3
Houston	27.0	27.0	21.1	21.1	21.6	21.6	16.9	16.8
Milwaukee	32.7	15.6	16.3	14.3	22.0	12.5	12.5	11.5
Dallas	20.3	16.1	12.3	12.3	16.2	12.9	9.6	9.9
Seattle	16.8	16.8	15.4	14.3	13.5	13.2	12.3	11.5
San Diego	7.2	7.2	6.8	6.8	6.9	6.9	6.5	6.5
Atlanta	18.4	18.4	17.8	17.8	14.7	14.7	14.3	14.3
Denver	29.9	29.9	25.5	25.5	23.9	23.9	22.0	22.0
New Orleans	29.7	20.8	20.8	20.8	23.8	16.6	16.6	16.6
Portland	27.9	27.9	27.9	18.8	22.3	22.3	22.3	15.1
San Bernardino (Riverside-Ontario)	17.0	13.2	8.3	7.5	12.8	9.9	6.2	5.7
Birmingham	24.6	24.6	21.2	21.2	19.7	19.7	17.0	17.0
San Antonio	17.1	14.7	13.4	13.3	13.7	11.8	10.7	10.6
Phoenix	26.4	26.1	18.9	14.1	21.1	20.9	15.1	11.3
Sacramento	10.1	10.1	10.1	5.8	9.7	9.7	9.7	5.5
Fort Worth	20.9	20.9	20.0	14.8	16.7	16.7	16.0	11.8
Salt Lake City	30.3	28.7	23.0	19.8	24.2	23.0	18.4	15.8
Wichita, Kansas	29.2	29.2	15.3	13.7	23.5	23.5	12.3	11.0
El Paso	17.6	17.6	17.6	17.6	14.1	14.1	14.1	14.1
Bakersfield	24.6	24.6	11.7	11.7	19.7	19.7	9.4	9.4
Tucson	23.0	8.9	8.9	8.9	18.4	7.1	7.1	7.1
Albuquerque	16.4	16.4	16.4	16.4	13.1	13.1	13.1	13.1
Austin, Texas	10.9	9.2	9.2	9.2	8.7	7.4	7.4	7.4
Santa Barbara	19.7	19.7	19.7	19.7	16.4	16.4	16.4	16.4
Pueblo	20.0	20.0	15.0	10.0	16.0	16.0	12.0	8.9
Boise	8.7	8.7	5.0	5.0	7.0	7.0	4.0	4.0
Great Falls	7.5	7.5	7.5	7.5	6.0	6.0	6.0	6.0

REFERENCES

C-1 Business Flying, National Business Aircraft Association (1971).

C-2 Flying Annual and Pilots Guide, Ziff-Davis (1971).

APPENDIX D

AIRCRAFT ECONOMICS

CONTENTS

FIGURES

TABLES

TABLES (Continued)

APPENDIX D

AIRCRAFT ECONOMICS

This appendix provides supporting material for the summary costs presented in Volume I. The cost guidelines used were developed from many printed sources as indicated by the references and numerous interviews with members of the general aviation community.

Because this appendix has many figures and tables in proportion to the text, all the text is first, the figures are second, and the tables are third, followed by the references.

D.1 CURRENT AIRCRAFT INVESTMENT AND OPERATING COSTS

Table D-1 summarizes the investment and operating costs of current aircraft. The following paragraphs discuss the rationale for the development of those costs.

a. Investment Costs

The investment costs were obtained from data provided by manufacturers and a current publication (Reference D-1) and reflect 1971 basic aircraft prices. They were adjusted to account for additional equipment required to perform the missions listed in Table D-2. The avionics in Table D-2 are typical of those used on current aircraft, but may vary depending upon the aircraft size and application. Fixed wing aircraft used in the commuter air carrier and executive transport missions are normally well equipped. The $60,000 cost was assumed for all these aircraft for nominal comparison purposes. In the helicopter category, full IFR avionics are rarely used; therefore, an added equipment cost of only $16,000 was used.

b. Operating Costs

Table D-1 includes typical operating costs for aircraft operating in both executive and commuter missions. Operating costs for executive missions are in accordance with the cost elements generally included by industry (i.e., flight crew, fuel and oil, insurance, maintenance, depreciation, hangar rental, and miscellaneous fixed costs). The commuter air carrier mission costs contain similar elements, but do not include airline indirect operating costs. An aircraft has different operating costs depending upon the type of operator and the mission; therefore, costs for flight crew, fuel and oil, insurance, maintenance, and depreciation show considerable variances. The costs used reflect appropriate operator and mission cost factors.

A summary of operating cost elements is included in Tables D-3 and D-4 for the executive and commuter and offshore missions. Operating costs were derived from survey data plus References D-2, D-3, and D-4. Figure D-1 shows the relationship between aircraft empty weight and maintenance costs.

D.2 ADVANCED AIRCRAFT INVESTMENT AND OPERATING COSTS

a. Investment Cost Analysis

(1) Research and Development Costs

Research and development costs were based on manufacturer estimates and are shown in Table D-5. These costs were determined from References D-5 and D-6 and were projected for the various concepts and sizes; they formed the basis of the development costs shown in Figure D-2. For costing purposes in this study and on the basis of increasing R&D costs, the advanced VTOL designs were ranked in the following order:

a. Compound helicopter
b. Tilt rotor
c. Tilt wing
d. Lift fan

Engine development costs were excluded by a NASA Ames ground rule to enable making a clearer comparison of the basic aircraft concept costs independent of engine technology.

(2) Airframe and Dynamic System Unit Costs

Airframe and dynamic system[1] unit costs (Table D-6) were also based on prior manufacturer estimates. These data were obtained from References D-5, D-6, and D-7. The initial cost/pound derivations are adjusted to 1971 dollars and extrapolated to a 700 production quantity base using a 90 percent learning factor. The resulting airframe and dynamic system cost/lb relationships are plotted and projected for various sizes in Figures D-3 and D-4, respectively. The Sikorsky estimates were not used, but are noted. Figures D-5 and D-6, based on data from Reference D-8, represent the cost/size relationships used for turboprop and turbojet/turbofan engines, respectively. Table D-7 presents the investment costs for the advanced concepts used in these analyses.

b. Operating Cost Analysis

The rationale for the operating cost analysis for the advanced concepts follows very closely that of the current aircraft previously described. However, adjustments were made to account for the differences in skills required by the flight crews and the mechanical complexities of the new aircraft. Tables D-8 and D-9 provide the summaries of the cost elements used in the executive missions and commuter air carrier and offshore missions, respectively. Figure D-7 presents the maintenance cost relationship for the advanced concepts as a function of their empty weights based upon References D-5, D-6, and D-9. Table D-10 summarizes the operating costs for executive missions for all advanced aircraft. Because of the wide variations in use for the commuter air carrier and offshore missions, the operating costs for these missions are presented in Tables D-11 through D-14, one for each of the advanced aircraft.

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[1] Dynamic system consists of such parts as: rotors, transmission, propellers, drive train, and fans.

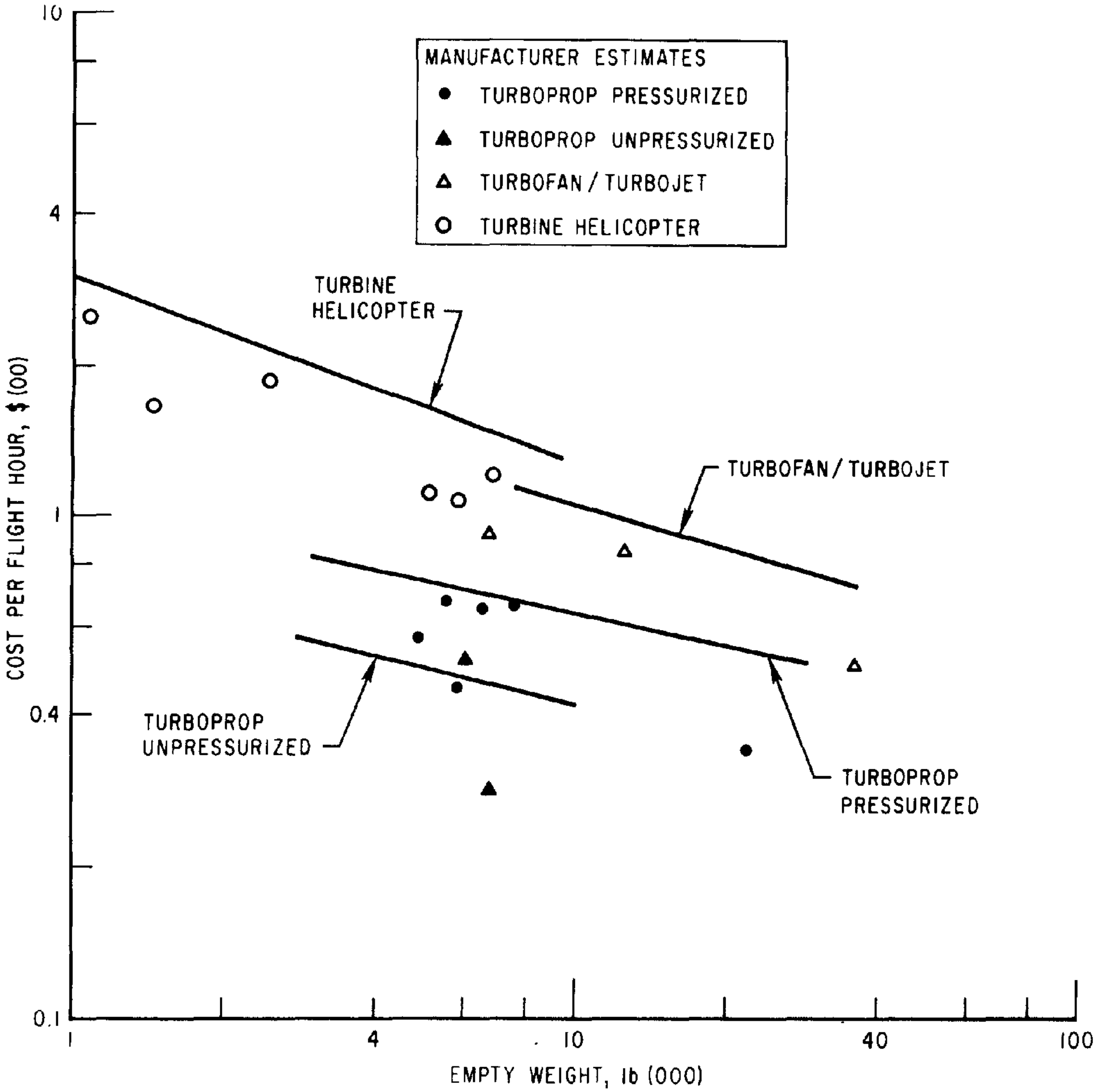


Figure D-1. Executive Aircraft Maintenance per Flight Hour

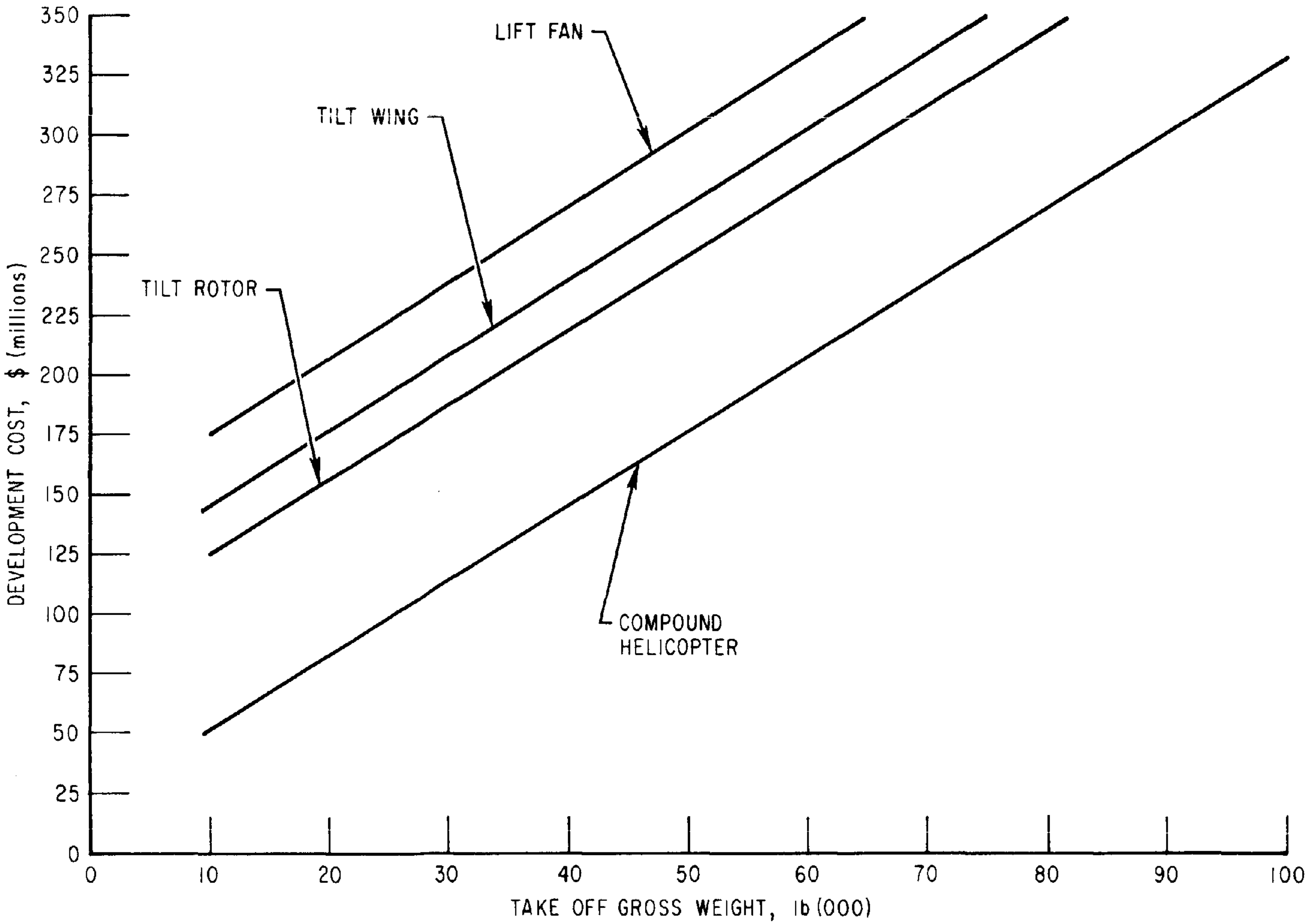


Figure D-2. Advanced Aircraft Airframe Research and Development Costs

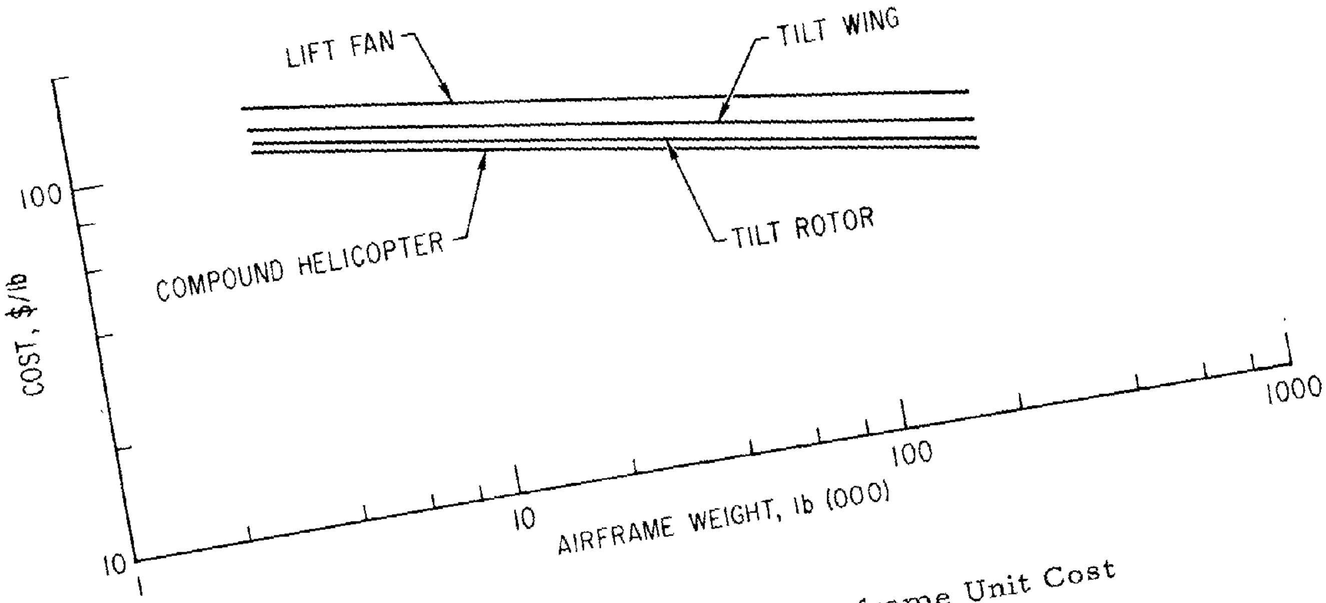


Figure D-3. Advanced Aircraft Airframe Unit Cost

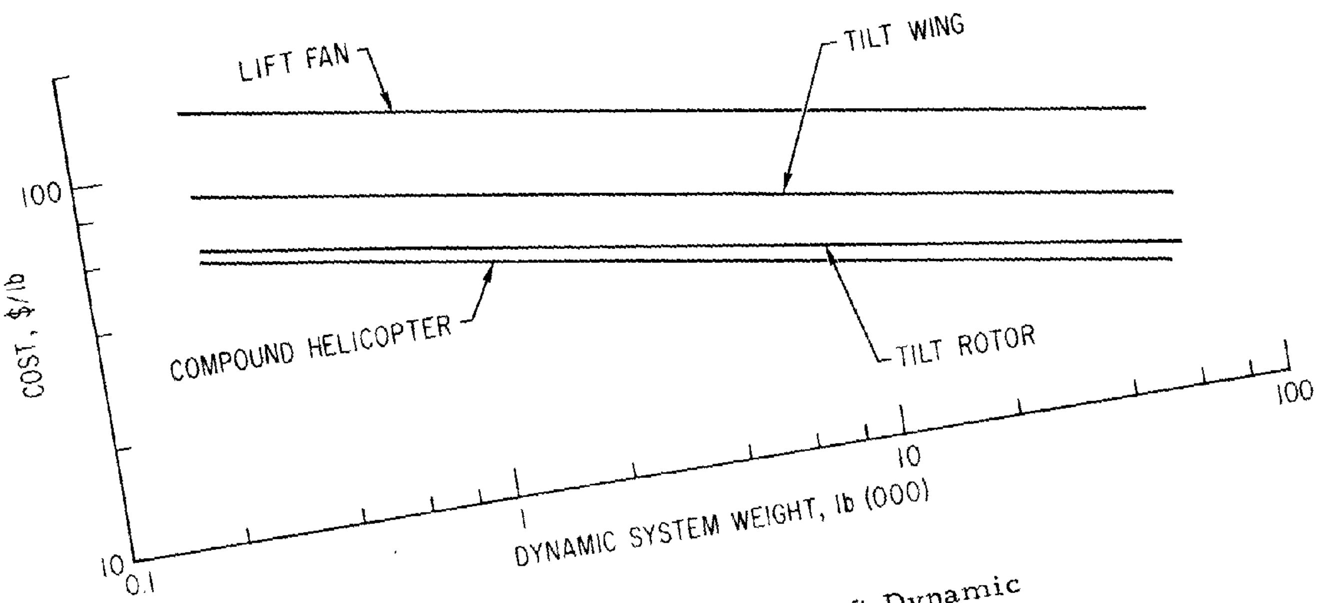


Figure D-4. Advanced Aircraft Dynamic System Unit Cost

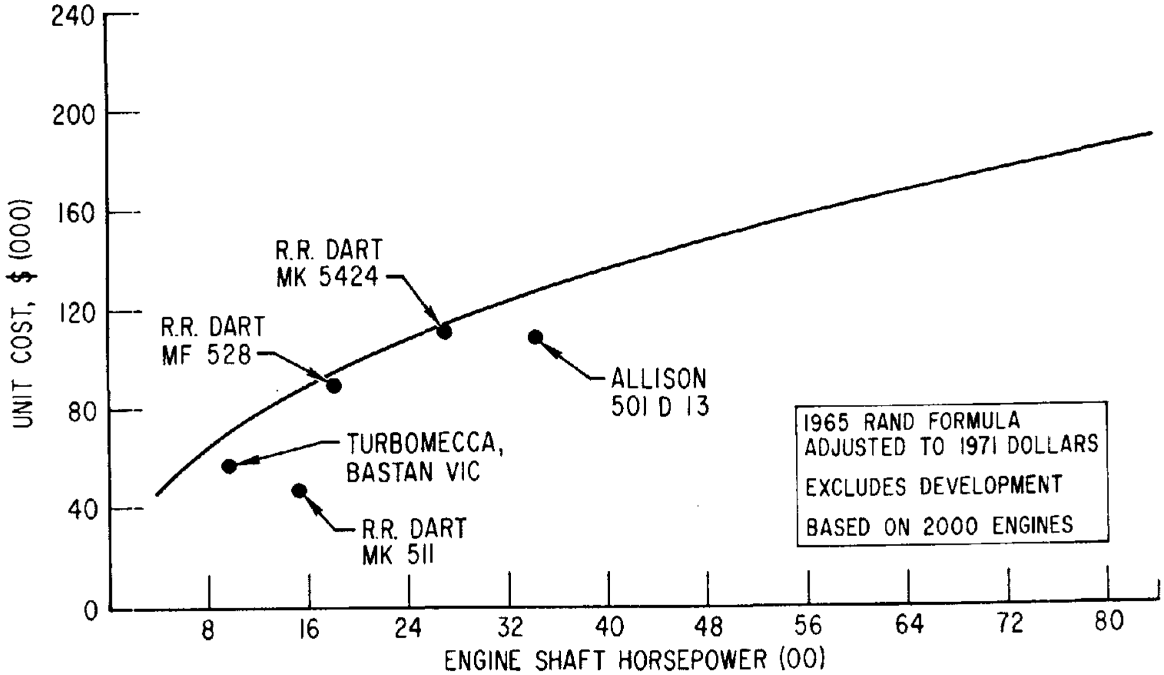


Figure D-5. Turboprop Engine Unit Cost

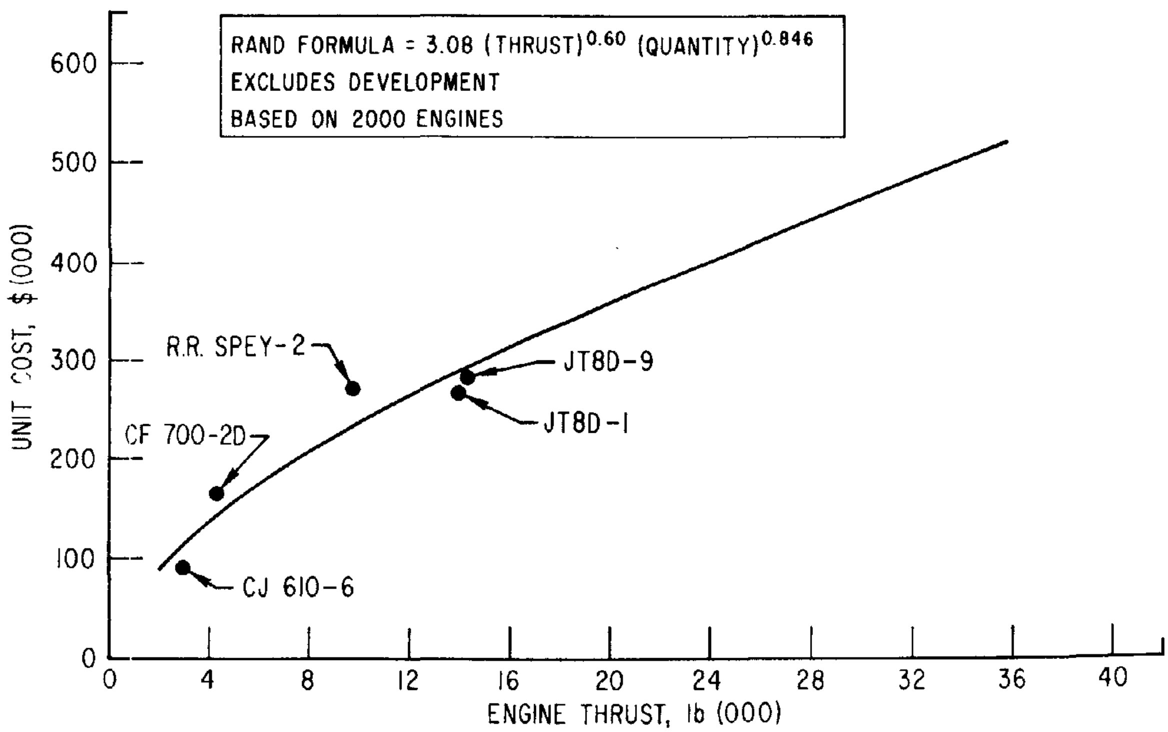


Figure D-6. Turbojet/Turbofan Engine Unit Cost

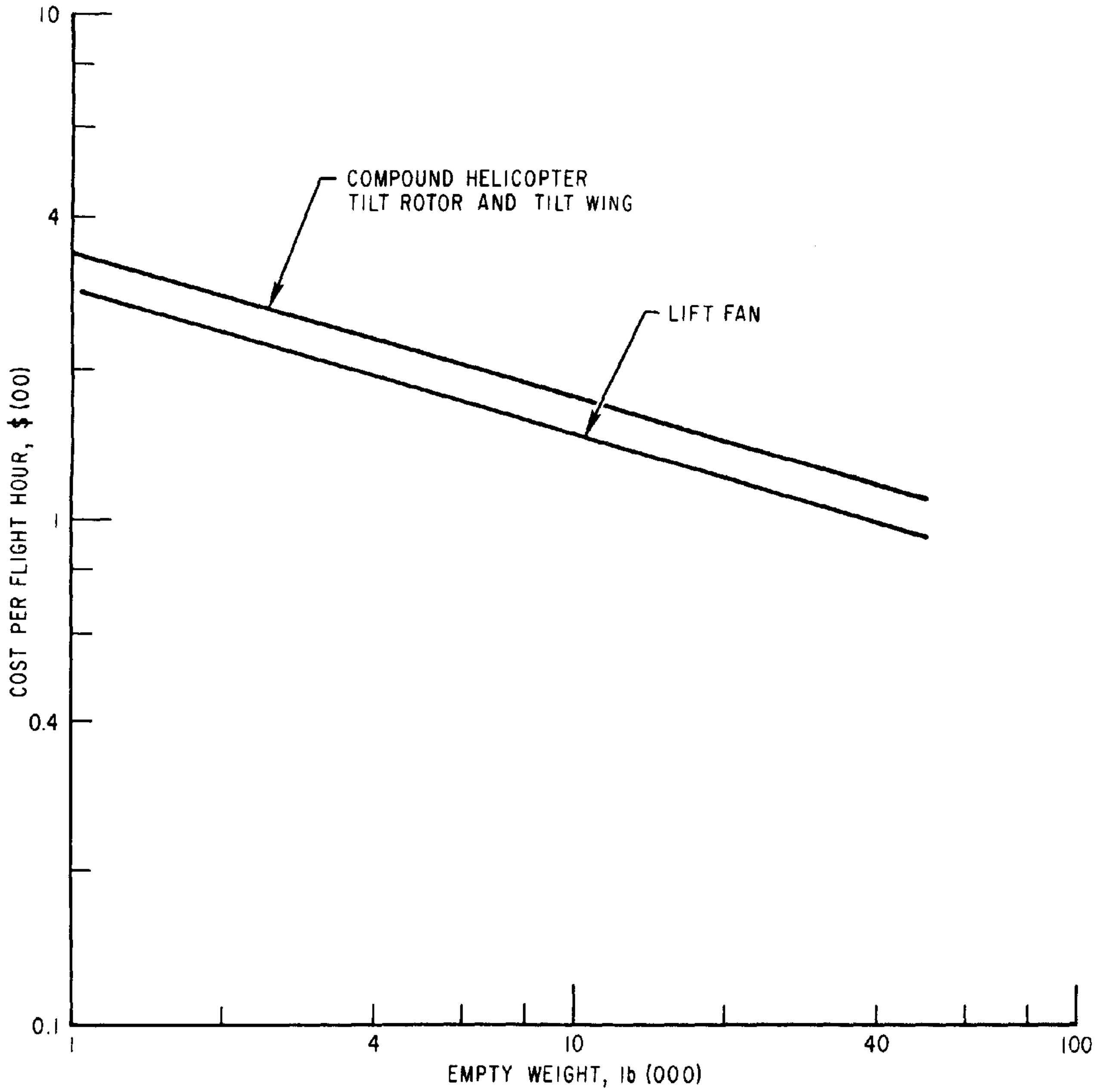


Figure D-7. Maintenance Cost per Flight Hour

Table D-1. Aircraft Investment and Operating Costs

Representative Aircraft	Eqp'd. Invest. Cost ($000)	Executive Transportation Mission						Commuter Air Carrier Mission				Industrial Special Mission (personnel transport)	
		Short Distance		Medium Distance		Long Distance		Intercity		CBD			
		Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)	Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)	Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)	Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)	Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)	Typical Utiliz. (hr/yr)	Operat. Cost ($/hr)
Small Helicopters													
Bell 206	128		211	--	--	--	--	--	--	--	--		132
Hughes 500	126	400	205	--	--	--	--	--	--	--	--	800	124
Alouette III	213		317	--	--	--	--	--	--	--	--		200
Large Helicopters													
Sikorsky S58T	441		631	--	--	--	--	--	--		242		340
Sikorsky S55	396	400	524	--	--	--	--	--	--	2000	200	1000	281
Bell 204/205	441		593	--	--	--	--	--	--		246		334
Bell 212	591		723	--	--	--	--	--	--		[illegible]		379
Small Twin Pistons													
Piper Aztec	130	--	--	400	175	--	--	2000	57	--	--	--	--
Cessna 310	130	--	--		160	--	--		55	--	--	--	--
Large Twin Pistons													
Piper Navajo	176	--	--	400	201	--	--	2000	75	--	--	--	--
Cessna 402	176	--	--		200	--	--		74	--	--	--	--
Small Turboprops													
Beech King Air	465	--	--		311	--	--	--	--	--	--	--	--
Hawk Commander	430	--	--		272	--	--	--	--	--	--	--	--
Merlin II	502	--	--	500	346	--	--	--	--	--	--	--	--
Mooney Mu2	429	--	--		305	--	--	--	--	--	--	--	--
Large Turboprops													
Beech 99	430	--	--	--	--	--	--	2000	144	--	--	--	--
DHC-6 (Twin Otter)	536	--	--	--	--	--	--		140	--	--	--	--
Small Turbojets													
Lear Jet	79	--	--	--	--		560	--	--	--	--	--	--
BH-125	1130	--	--	--	--		613	--	--	--	--	--	--
Sabreliner 40	1425	--	--	--	--	500	703	--	--	--	--	--	--
Hansa 9	1150	--	--	--	--		607	--	--	--	--	--	--

Table D-2. Equipment for Current Aircraft and Helicopters

Fixed Wing Aircraft	Price, $[a]
Dual VHF navigation and communication transceivers with remote VOR/ILS indicators, glide slope receiver, and marker beacon receiver	10,000
ADF (automatic direction finder)	3,000
DME (distance measuring equipment)	5,000
Transponder	3,000
RMI (radio magnetic indicator) system	6,000
3-axis automatic pilot with approach coupler	12,000
Weather radar	10,000
Air conditioning	7,000
Miscellaneous accessories (dual controls, electric trim, heated pitot, locator beacon, etc.)	4,000
Total	60,000
Helicopter	
Dual controls	1,000
Heating	2,000
Gyros	3,000
Emergency flotation	3,000
Custom interior	2,000
Avionics	4,000
Miscellaneous accessories	1,000
Total	16,000

[a]Based on typical manufacturers price lists

Table D-3. Current Aircraft Operating Costs--Executive Missions

VARIABLE COSTS ($/gal)

	Reciprocating Engines	Turbine Engines
Fuel	0.50	0.40
Oil	0.025	0.02
Total	0.525	0.42

Maintenance related to empty weight (see Figure D-1)

FIXED COSTS ($/yr)

Flight Crew	Captain	Copilot
Fixed Wing		
Piston	18,000	Not Applicable
Turboprop	21,000 - 24,000	15,000 - 16,000
Turbojet	24,000	16,000
Helicopter		
Piston	18,000	Not Applicable
Turbine	18,000 - 21,000	15,000

ITEM	Percentage of Equipped Cost		
	Fixed wing		Helicopters
	Reciprocating	Turbine	
Insurance	2.0	1.5	15.00
Depreciation	10.0[a]	10.0[a]	14.00[b]
Hangar Rental	0.7	0.5[c]	0.35

	Equipped Cost ($10³)			
Miscellaneous Costs	$200	$200-550	$550-1,500	$1,500
	$5000	$10,000	$20,000	$30,000

[a] 8 years, 20% residual

[b] 5 years, 30% residual

[c] Equipped cost greater than $1 million; 0.7% less than $1 million

Table D-4. Current Aircraft Operating Costs--Commuter and Offshore Missions

VARIABLE COSTS ($/gal)

Fuel	0.25
Oil	0.0125
Total	0.2625

Maintenance related to empty weight. (Figure D-1 data adjusted by a 128 percent factor to account for maintenance burden.)

FIXED COSTS ($/yr)

Flight Crew

	Captain	Copilot
Large Aircraft	$12,600	$7,200
Small Aircraft	11,400	Not Applicable

ITEM	Percentage of Equipped Cost	
	Fixed wing	Helicopters
Insurance	1.5	15
Depreciation	8.5 [a]	14 [b]

[a] 10 Years, 15% Residual

[b] 5 Years, 30% Residual

Table D-5. Advanced Aircraft Research and Development Cost Parameters

Aircraft Type	Takeoff Gross Weight, lb	Airframe and Dynamic Systems Weight, lb	R&D Cost, $000
Compound Helicopter			
Sikorsky S-65-200	63,600	36,645	176,000
Fan-In-Wing			
Lockheed	67,900	36,705	345,200
Tilt Rotor			
Lockheed	65,000	42,005	325,900

Table D-6. Advanced Aircraft Unit Cost Parameters (excluding development)

Cost Parameters	Compound Helicopter Sikorsky S65-200	Lift Fan		Tilt Rotor		Tilt Wing Boeing
		Boeing	Lockheed	Boeing	Lockheed	
AIRFRAME						
Airframe weight, lb	24,109	29,100	33,260	40,430	32,015	36,520
Unit Cost, $000	3,476	2,611	2,889	2,648	2,479	2,710
Cost/pound, $	144	90	87	65	77	74
Adjusted cost/pound,[a] $	119	96	93	69	83	79
DYNAMIC SYSTEM						
Dynamic System Weight, lb	12,536	3,140	3,445	6,700	9,990	8,430
Unit cost, $000	970	238	281	463	302	353
Cost/pound, $	77	76	82	69	30	42
Adjusted cost/pound,[a] $	64	81	88	74	32	45

[a]Adjusted to 1971 dollars and 700 production quantity.

Table D-7. Advanced Aircraft Flyaway Cost Analysis (based on 700 aircraft production base)

Parameters	Small Aircraft				Extended Range Lift Fan	Large Aircraft			
	Compound Helicopter	Tilt Rotor	Tilt Wing	Lift Fan		Compound Helicopter	Tilt Rotor	Tilt Wing	Lift Fan
R&D Cost, dollars in millions									
Airframe and Dynamic System	50	130	130	185	212	80	160	170	215
Unit Cost Excluding Development, $000									
Airframe	326	478	430	810	1260	584	830	772	1326
Dynamic System	82	110	113	144	233	147	158	155	233
Engines	116	180	196	300	435	246	280	320	435
Total	524	768	739	1254	1928	977	1268	1247	1994
Flyaway Cost Including Development, $000									
Airframe and Dynamic System	479	774	729	1218	1725	845	1217	1170	1866
Engines	116	180	196	300	435	246	280	320	435
Total	595	954	925	1518	2160	1091	1497	1490	2301
Performance									
Takeoff weight, lb	9600	11578	9300	12510	22000	18950	20273	17477	22040
Empty weight, lb	5925	8229	6600	9048	15500	11700	14715	11900	16200
Engine weight, lb	617	722	796	915	1608	939	1192	1458	1614
Dynamic system weight, lb	2146	2797	1964	1440	2536	4362	4296	2872	2536
Airframe weight, lb	3162	4710	3840	6693	11356	6399	9227	7570	12050
Engine shp (S) or thrust (T), lb/engine	690 S	1740 S	2010 S	2540 T	4470 T	1405 S	1065 S	1332 S	4480 T
Number of engines	2	2	2	3	3	3	4	4	3
Fuel consumption, gal/hr	100	129	142	171	258	278	159	176	315

Table D-8. Advanced Aircraft Operating Costs--
Executive Missions

VARIABLE COSTS ($/gal)

Fuel	0.40
Oil	0.02
Total	0.42

Maintenance related to empty weight. (see Figure D-5)

FIXED COST ($/yr)

Flight Crew

	Captain	Copilot
Large Compound Helicopter	21,400	14,700
Small Compound Helicopter	18,600	N/A
Large Tilt Rotor	23,700	16,300
Small Tilt Rotor	20,600	N/A
Large Tilt Wing	23,700	16,300
Small Tilt Wing	20,600	N/A
Large Lift Fan	26,300	18,100
Small Lift Fan	22,900	N/A

Item	Percentage of Equipped Cost
Insurance	10
Depreciation	10 [a]
Hangar Rental	10

	Small Aircraft	Large Aircraft
Miscellaneous	$10,000	$20,000

[a] 8 Years, 20% Residual

Table D-9. Advanced Aircraft Operating Costs--Commuter and Offshore Missions

VARIABLE COSTS ($/gal)

Fuel	0.25
Oil	0.0125
Total	0.2625

Maintenance related to empty weight. (Figure D-5 data adjusted by 160 percent factor to account for maintenance burden.)

FIXED COSTS ($/yr)

Flight Crew

	Captain	Copilot
Large Compound Helicopter	15,900	9,400
Small Compound Helicopter	13,700	N/A
Large Tilt Rotor	17,600	10,400
Small Tilt Rotor	15,200	N/A
Large Tilt Wing	17,600	10,400
Small Tilt Wing	15,200	N/A
Large Lift Fan	19,500	11,600
Small Lift Fan	16,900	N/A

Item	Percentage of Equipped Cost
Insurance	6
Depreciation	8.5 [a]

[a] 10 years, 15% residual

Table D-10. Advanced Aircraft Operating Costs--Executive Missions (600 hr annual utilization)

Total Operating Cost	Small Aircraft				Extended Range Lift Fan	Large Aircraft			
	Compound Helicopter	Tilt Rotor	Tilt Wing	Lift Fan		Compound Helicopter	Tilt Rotor	Tilt Wing	Lift Fan
Variable Costs									
Fuel and Oil	$ 42.00	$ 54.18	$ 59.64	$ 71.82	$ 108.36	$116.76	$ 66.78	$ 73.92	$ 132.30
Maintenance	119.69	153.06	125.33	137.52	201.50	196.56	231.03	198.14	207.36
Total Variable Cost	$161.69	$207.24	$184.97	$209.34	$ 309.86	$313.32	$297.81	$272.06	$ 339.66
Fixed Costs									
Flight Crew	$ 37.20	$ 41.20	$ 41.20	$ 45.80	$ 88.80	$ 72.20	$ 80.00	$ 80.00	$ 88.80
Insurance	99.17	159.00	154.17	253.00	359.33	181.83	249.50	248.33	383.50
Depreciation	99.17	159.00	154.17	253.00	359.33	181.83	249.50	248.33	383.50
Hangar Rental	6.94	11.13	10.79	17.71	25.15	12.72	17.47	17.38	26.85
Miscellaneous	16.67	16.67	16.67	16.67	33.30	33.30	33.30	33.30	33.30
Total Fixed Cost	$259.15	$387.00	$377.00	$586.18	$ 865.91	$481.88	$629.77	$627.34	$ 915.95
Total Cost Per Flight Hour	$420.84	$594.24	$561.97	$795.52	$1175.77	$795.20	$927.58	$899.40	$1255.61

Table D-11. Compound Helicopter Direct Operating Costs (DOC)--
Commuter and Offshore Missions

	Small Aircraft			Large Aircraft		
Annual Utilization - Hours	800	1000	2000	800	1000	2000
Flying Operations						
Flight Crew	$ 15.22	$ 15.22	$ 15.22	$ 28.11	$ 28.11	$ 28.11
Fuel and Oil	26.25	26.25	26.25	72.98	72.98	72.98
Insurance	44.63	35.70	17.85	81.83	65.46	32.73
	$ 86.10	$ 77.17	$ 59.32	$182.92	$166.55	$133.82
Direct Maintenance						
Airframe and Engine	$119.69	$119.69	$119.69	$196.56	$196.56	$196.56
Maintenance Burden	71.81	71.81	71.81	117.94	117.94	117.94
	$191.50	$191.50	$191.50	$314.50	$314.50	$314.50
Depreciation	$ 63.22	$ 50.58	$ 25.29	$115.47	$ 92.74	$ 46.37
Total DOC Per Flying Hour	$340.82	$319.25	$276.11	$612.89	$573.79	$494.69

Table D-12. Tilt Rotor Direct Operating Costs (DOC)--
Commuter and Offshore Missions

	Small Aircraft			Large Aircraft		
Annual Utilization - Hours	800	1000	2000	800	1000	2000
Flying Operations						
Flight Crew	$ 16.89	$ 16.89	$ 16.89	$ 31.12	$ 31.12	$ 31.12
Fuel and Oil	33.86	33.86	33.86	41.74	41.74	41.74
Insurance	71.55	51.24	28.62	112.28	89.82	44.91
Total Flying Operations	$122.30	$107.99	$ 79.37	$185.14	$162.68	$117.77
Direct Maintenance						
Airframe and Engine	$153.06	$153.06	$153.06	$231.03	$231.03	$231.03
Maintenance Burden	91.84	91.84	91.84	138.62	138.62	138.62
Total Direct Maintenance	$244.90	$244.90	$244.90	$369.65	$369.65	$369.65
Depreciation	$101.36	$ 81.09	$ 40.55	$159.06	$127.25	$ 63.62
Total DOC Per Flying Hour	$468.56	$433.98	$364.82	$713.85	$659.58	$551.04

Table D-13. Tilt Wing Direct Operating Costs (DOC)-- Commuter and Offshore Missions

	Small Aircraft			Large Aircraft		
Annual Utilization - Hours	800	1000	2000	800	1000	2000
Flying Operations						
Flight Crew	$ 16.89	$ 16.89	$ 16.89	$ 31.12	$ 31.12	$ 31.12
Fuel and Oil	37.28	37.28	37.28	46.20	46.20	46.20
Insurance	69.38	55.50	27.75	111.75	89.40	44.70
Total Flying Operations	$123.55	$109.67	$ 81.92	$189.07	$166.72	$122.02
Direct Maintenance						
Airframe and Engine	$125.33	$125.33	$125.33	$198.14	$198.14	$198.14
Maintenance Burden	75.20	75.20	75.20	118.88	118.88	118.88
	$200.53	$200.53	$200.53	$317.02	$317.02	$317.02
Depreciation	$ 98.28	$ 78.63	$ 39.31	$158.31	$126.65	$ 63.33
Total DOC Per Flying Hour	$422.36	$388.83	$321.76	$664.40	$610.39	$502.37

Table D-14. Lift Fan Direct Operating Costs (DOC)--
Commuter and Offshore Missions

	Small Aircraft			Large Aircraft		
Annual Utilization - Hours	800	1000	2000	800	1000	2000
Flying Operations						
Flight Crew	$ 18.78	$ 18.78	$ 18.78	$ 34.56	$ 34.56	$ 34.56
Fuel and Oil	44.89	44.89	44.89	82.69	82.69	82.69
Insurance	113.85	91.08	45.54	172.58	138.06	69.03
Total Flying Operations	$177.52	$154.75	$109.21	$289.83	$255.31	$186.28
Direct Maintenance						
Airframe and Engine	$137.52	$137.52	$137.52	$207.36	$207.36	$207.36
Maintenance Burden	82.51	82.51	82.51	124.42	124.42	124.42
	$220.03	$220.03	$220.03	$331.78	$331.78	$331.78
Depreciation	$161.29	$129.03	$ 64.52	$244.48	$195.59	$ 97.79
Total DOC Per Flying Hour	$558.84	$503.81	$393.76	$866.09	$782.68	$615.85

REFERENCES

D-1 Flying Annual and Pilot's Guide, Ziff-Davis (1971).

D-2 National Business Aircraft Association Aircraft Operating Data Sheets

D-3 Corporate Pilots - What Do They Earn, Business and Commercial Aviation (September 1971).

D-4 Piloting Careers, Flying for the Commuters, Business and Commercial Aviation (May 1969).

D-5 S-65-200 Intercity VTOL, Sikorsky Aircraft, SPB 71 C-2432(1)AC (February 15, 1971).

D-6 Study on the Feasibility of V/STOL Concepts for Short Haul Transport Aircraft, Lockheed-California Company, Burbank, California, NASA CR-902 (October 1967).

D-7 Study of Aircraft in Short Haul Transportation Systems, The Boeing Company, Seattle, Washington, NASA CR-986 (January 1968).

D-8 J. P. Large, Estimating Aircraft Turbine Engine Costs, The Rand Corporation, Santa Monica, California, RM-6384/1 PR (September 1970).

D-9 E. L. Brown, and J. N. Fischer, Comparative Projections of Low Disk-Loading VTOL Aircraft for Civil Applications, Bell Helicopter Journal of Aircraft (September-October 1968).

APPENDIX E

COST BENEFITS ANALYSIS METHODOLOGY

CONTENTS

FIGURES

FIGURES (Continued)

TABLES

APPENDIX E

COST BENEFITS ANALYSIS METHODOLOGY

This appendix collects the principal details and supplementary charts associated with the analyses of the VTOL aircraft presented in Volume I. It comprises five major parts as follows:

- E. 1 Time and Cost Equations
- E. 2 Two-Aircraft Time Value Equations
- E. 3 Two-Aircraft Time Value Phase Diagrams
- E. 4 Multiaircraft Time Value Phase Diagram Explanation
- E. 5 Cost Savings Equations

Because this appendix has many figures and tables in proportion to the text, all the text is first, the figures second, and the tables third, followed by the references.

E. 1 TIME AND COST EQUATIONS

Section V of Volume I contains time and cost diagrams for various missions comparing the relative costs and the times required for variable trip distances depending on transportation modes. The interested reader may desire to make comparisons beyond those shown. For this reason, Table E-1 is provided, which contains the set of linear equations used to develop the figures for the various scenarios.

The commuter air carrier missions include the indirect operating costs (IOC) of the air carrier and the direct operating costs (DOC) shown in Tables D-4 and D-9. The IOCs are expressed as a function of block distance as shown in Figure E-1. The costs shown in Figure E-1 were added to those of Tables D-4 and D-9 to develop the commuter cost equations of Table E-1.

E.2 TWO-AIRCRAFT TIME VALUE EQUATIONS

This section presents the development of the equations used in computing the two-aircraft time value phase diagrams. The two-aircraft time value phase diagrams are plots of the locus of points of equal trip costs between the two-aircraft modes. The resulting boundary line divides the areas of economic preference for the two aircraft considered. Variables include: the ordinary elements associated with transportation problems (e.g., speed and operating cost) and the interface delays encountered in getting to or from the primary mode by the access or distribution trips. This causes the time value parameter to penalize those scenarios where delays result from poor access, distribution, interface delays, or slow primary transportation modes. Where the car is the access and distribution mode, its cost is considered insignificant when compared to the cost of the primary mode. In the special case where a helicopter is used for access, its cost is added to the cost of aircraft operation as a constant. Table E-2 presents the formulation of the break-even boundary equations for the time value diagrams. Time value is the dependent variable so that it may be considered parametrically.

Table E-3 lists the values used in computing the two-aircraft time value phase diagrams.

E.3 TWO-AIRCRAFT TIME VALUE PHASE DIAGRAMS

This section collects all the two-aircraft time value phase diagrams computed and plotted for this study that were not presented in Volume I. These diagrams were the basis of the multiaircraft time value phase diagrams presented in Volume I and, therefore, form an important part of the background material. Time value diagrams for combinations of aircraft not explicitly presented in Volume I can be constructed from these diagrams. (See E.4 for an explanation of how multiaircraft time value phase diagrams are constructed.)

Table E-4 is an index of all combinations computed. Numbers in the matrix are the figure numbers where the plotted results may be found in either Volume I or the appendix. Where a combination was computed, but no plot resulted because of the total predominance of one aircraft, the dominating aircraft is identified by its abbreviation. In all cases shown, large aircraft were compared to other large aircraft, and small aircraft were compared to other small aircraft.

E.4 MULTIAIRCRAFT TIME VALUE PHASE DIAGRAM EXPLANATION

The multiaircraft time value diagrams are a composite of several individual two-aircraft diagrams. Figure E-17 comprises the following two-aircraft diagrams:

Figure E-11b, Large Turboprop versus Large Turbojet
Figure E-10b, Large Turboprop versus Large Helicopter
Figure E-10c, Large Turbojet versus Large Helicopter

In Figure E-11b, the boundary line divides the area approximately equally between the turbojet and turboprop. The shorter ranges and lower time values being the domain of the turboprop. The addition of Figure E-10b establishes the dividing line between the turboprop and the large helicopter. Finally, Figure E-10c cuts out the large helicopter area from that of the turbojet and results in the diagram shown in Figure E-17. To construct the effect of adding the airline (Figure E-18) the following figures must be referenced in addition to those cited above:

Figure E-11a, Airline versus Large Turboprop
Figure E-12, Airline versus Larger Turbojet
Figure E-10a, Airline versus Large Helicopter

In each case, assume that a 1-hour airline schedule delay is applicable. This results in using the K_a = 1 hr line. In the lower half of Figure E-17 the turboprop is predominant. The lower portion of the line,

K_a = 1 from Figure E-2a, divides the lower area between the turboprop and the airline. Where this line intersects the line of Figure E-11b, both lines are terminated. Figure E-12 provides the boundary between the turbojet and the airline above the turboprop/turbojet boundary. Figure E-10a is not usable since the boundary between the large helicopter and the airline exists only in an area already determined to be the domain of either the turbojet or turboprop; therefore, the boundary of the large helicopter stays the same as in Figure E-17, as previously determined.

Figures E-19 and E-20 were similarly developed for the small current aircraft and included here for information and comparative purposes.

Interesting comparisons can be made from these four figures. The current large executive aircraft (without airline) may be compared in Figure E-17. The large helicopter predominates over all passenger time values for the short ranges. The turbojet and turboprop share the longer ranges (Figure E-19). Where airline service with a 1-hour schedule delay is available (Figure E-18), a slightly different division results for the large aircraft than for the small aircraft. In this case, the large turboprop retains a region of influence, whereas in the small aircraft diagram (Figure E-20), it disappears with the addition of airline service.

E.5 COST SAVINGS EQUATIONS

The cost savings analysis is a comparison of the annual costs of travel, including the value of the traveler's time, using a current aircraft (reference) with similar costs for an advanced aircraft. The saving (if any) is the difference between the annual costs of the two aircraft being compared. Table E-5 shows the steps in developing the equations used for the computation of the data presented in Section V of the Volume I (Figures 25 and 26). Note that the use of the reference aircraft is held constant and the use of the advanced aircraft varies as a function of the distance and its block speed (Step 8). Therefore, aircraft with higher block speeds than the reference aircraft (for a given average mission block distance) will be used fewer hours per year than the reference aircraft. (See Figure 24 in Volume I.)

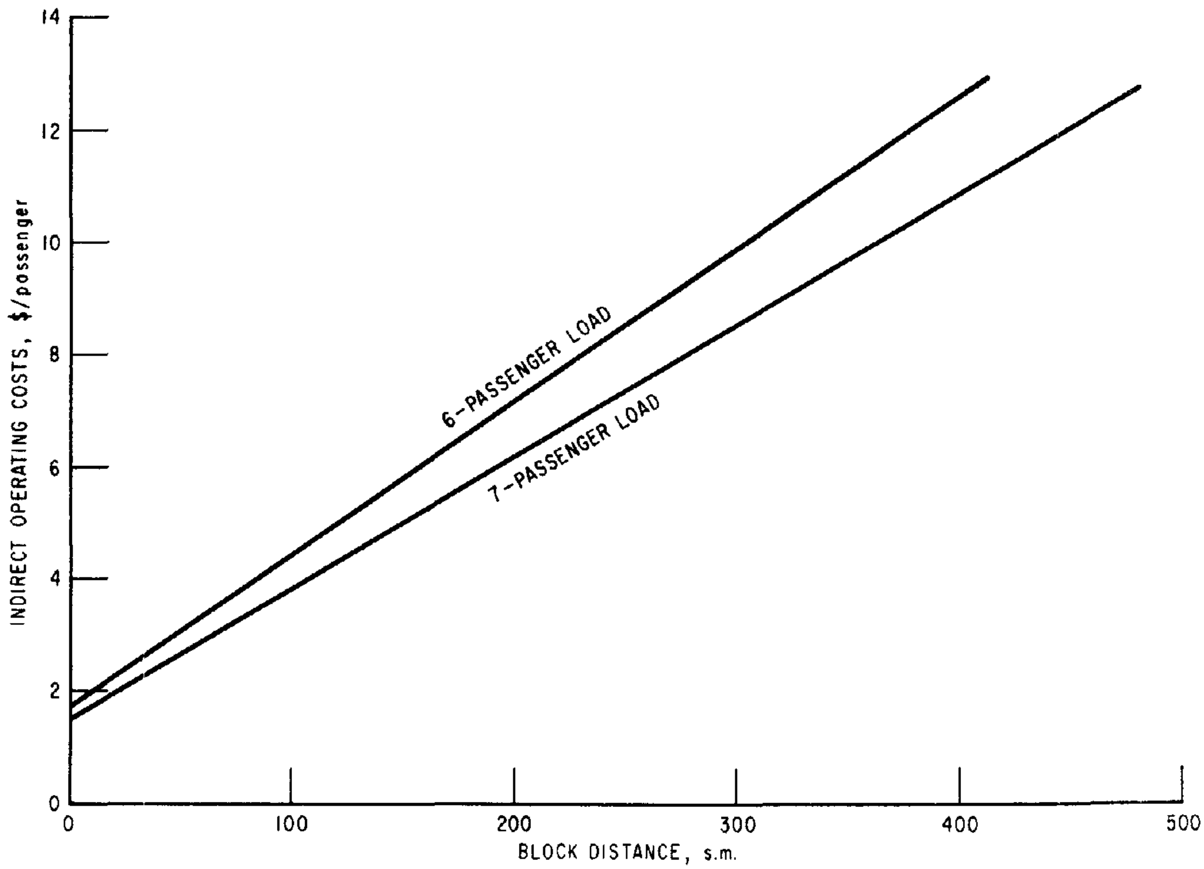
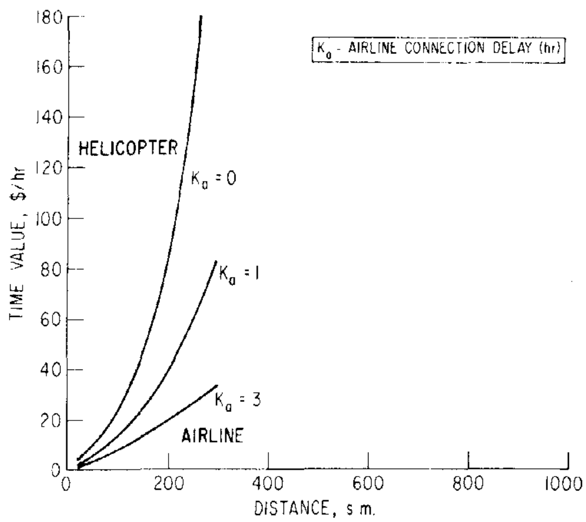
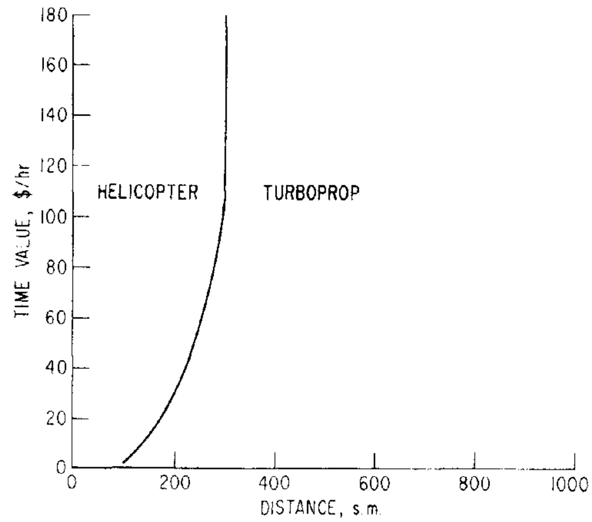


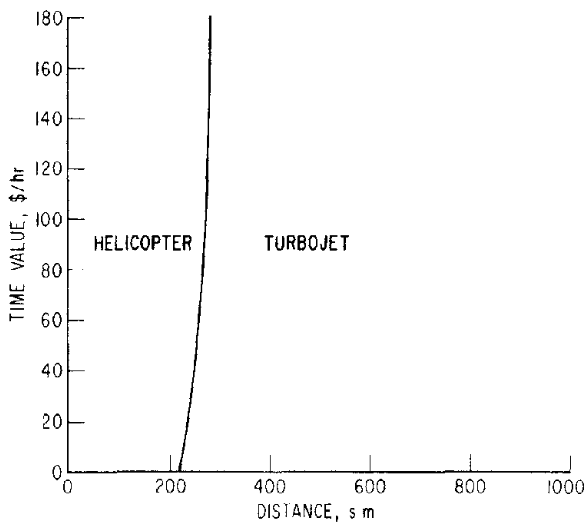
Figure E-1. Commuter Airline Indirect Operating Cost



a. Small Helicopter - Airline



b. Small Helicopter - Small Turboprop



c. Small Helicopter - Small Turbojet

Figure E-2. Two-Aircraft Time Value Phase Diagram--Small Helicopter (Executive Mission)

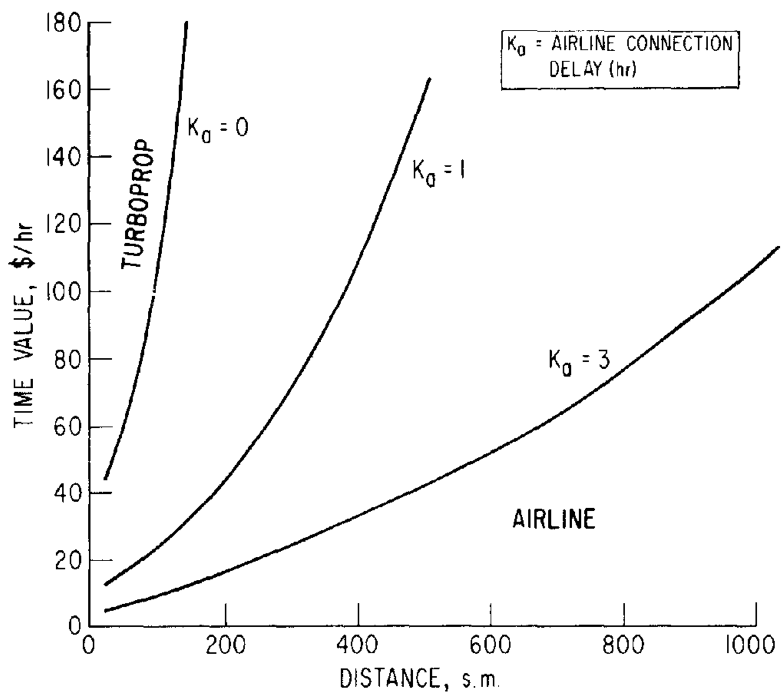


Figure E-3. Two-Aircraft Time Value Phase Diagram--Small Turboprop - Airline (Executive Mission)

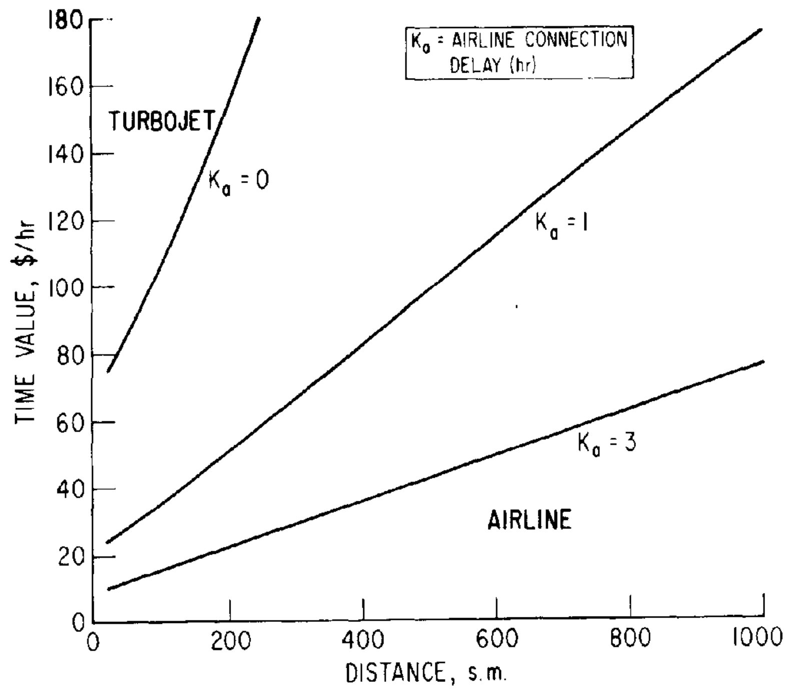
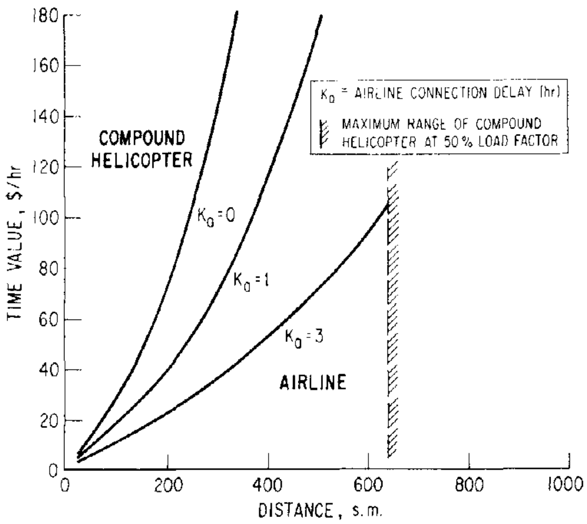
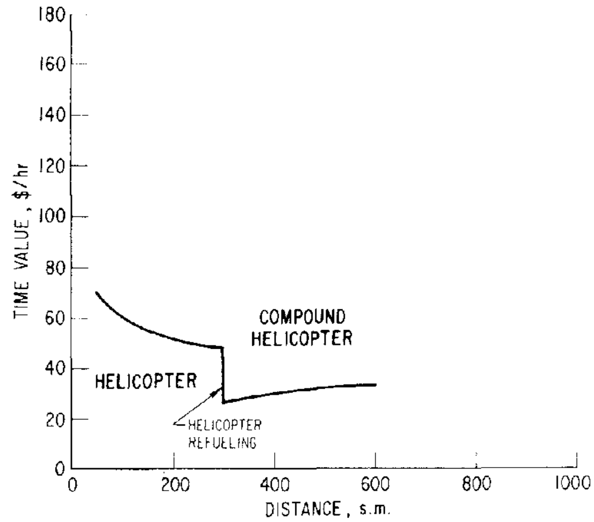


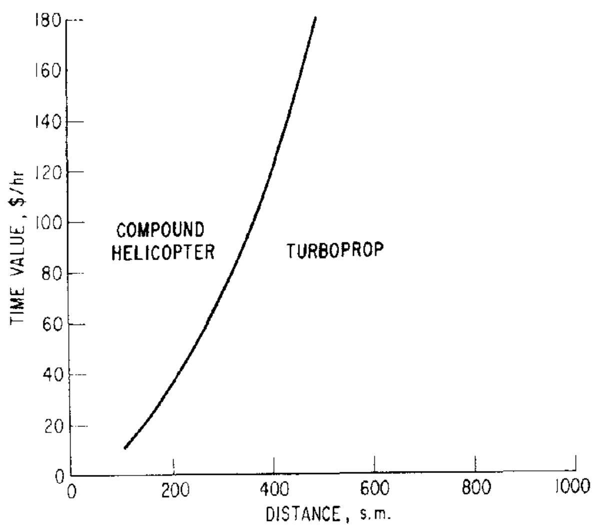
Figure E-4. Two-Aircraft Time Value Phase Diagram-- Small Turbojet - Airline (Executive Mission)



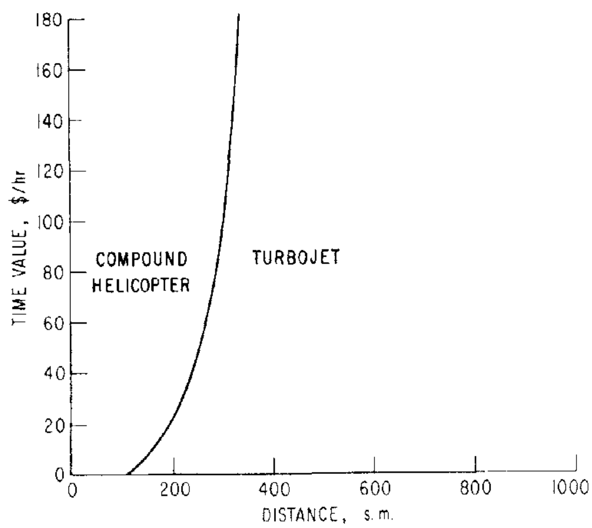
a. Small Compound Helicopter - Airline



b. Small Compound Helicopter - Small Helicopter

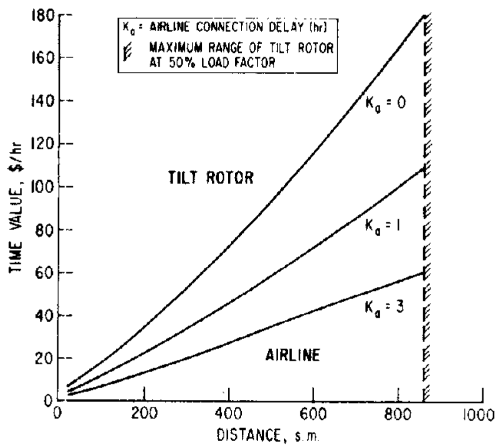


c. Small Compound Helicopter - Small Turboprop

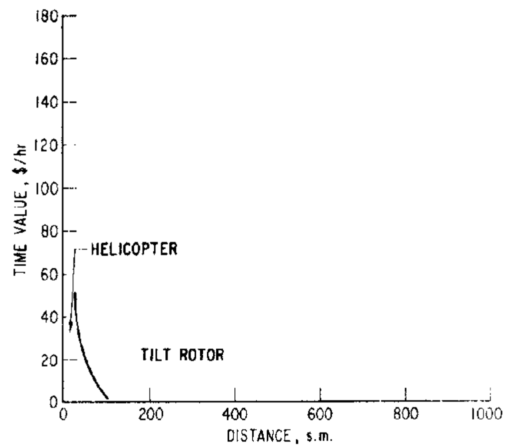


d. Small Compound Helicopter - Small Turbojet

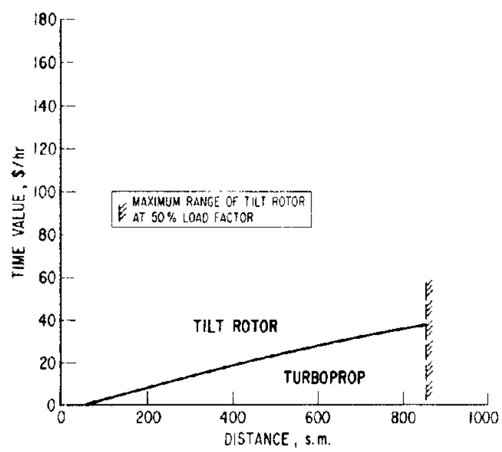
Figure E-5. Two-Aircraft Time Value Phase Diagram--Small Compound Helicopter (Executive Mission)



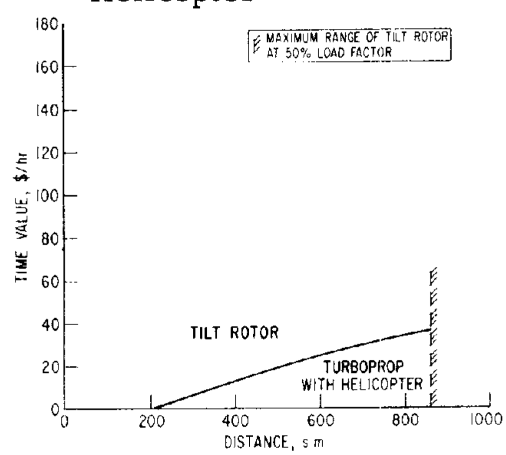
a. Small Tilt Rotor - Airline



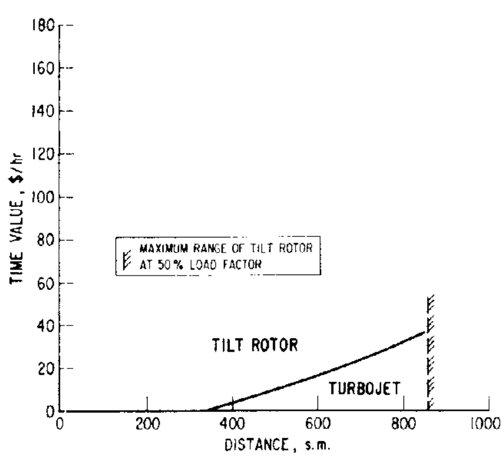
b. Small Tilt Rotor - Small Helicopter



c. Small Tilt Rotor - Small Turboprop

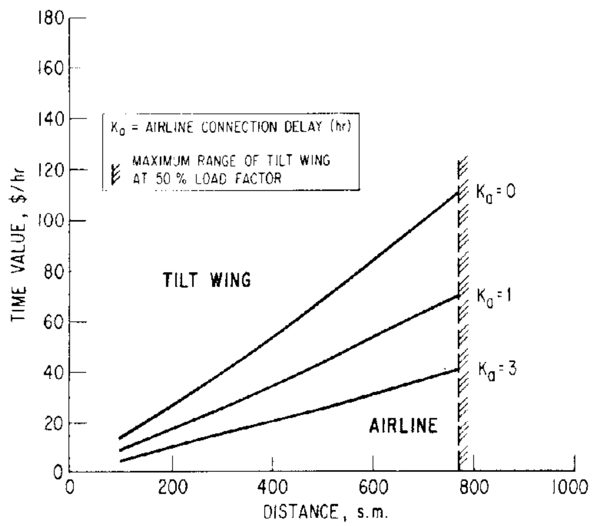


d. Small Tilt Rotor - Small Turboprop with Helicopter

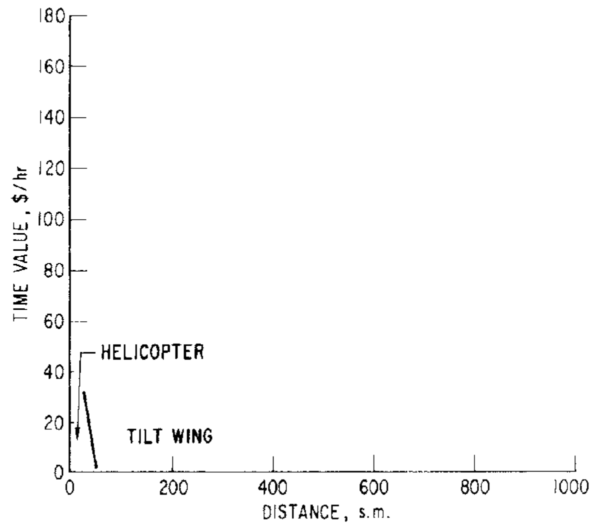


e. Small Tilt Rotor - Small Turbojet

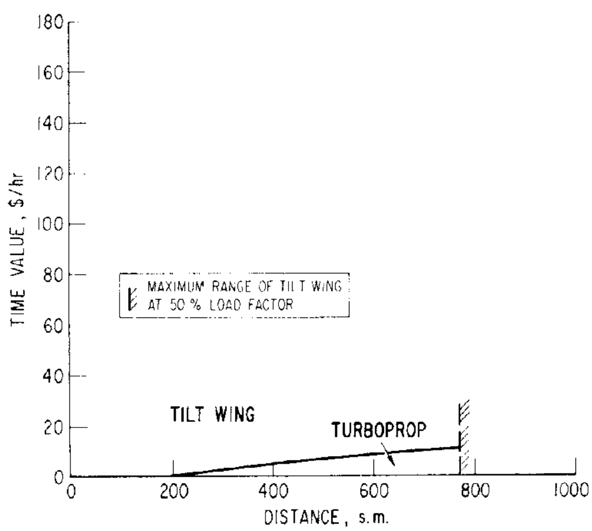
Figure E-6. Two-Aircraft Time Value Phase Diagram--Small Tilt Rotor (Executive Mission)



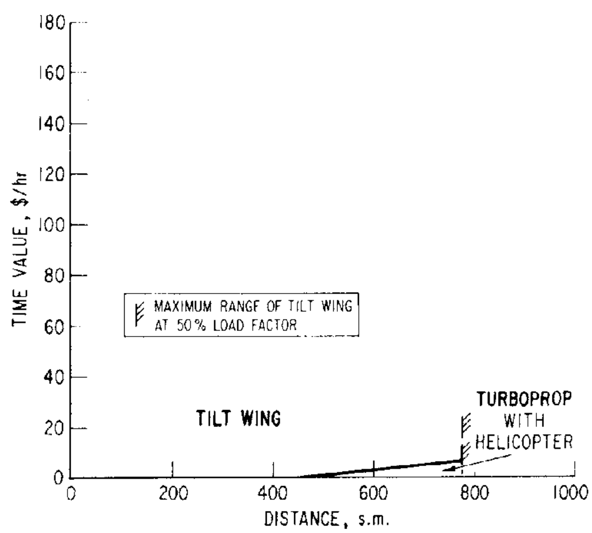
a. Small Tilt Wing - Airline



b. Small Tilt Wing - Small Helicopter

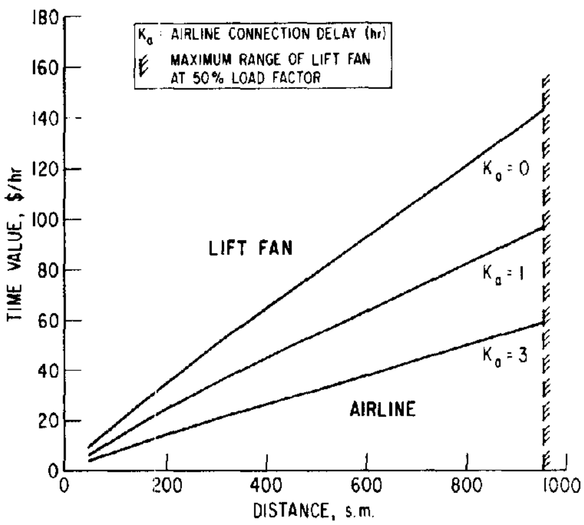


c. Small Tilt Wing - Small Turboprop

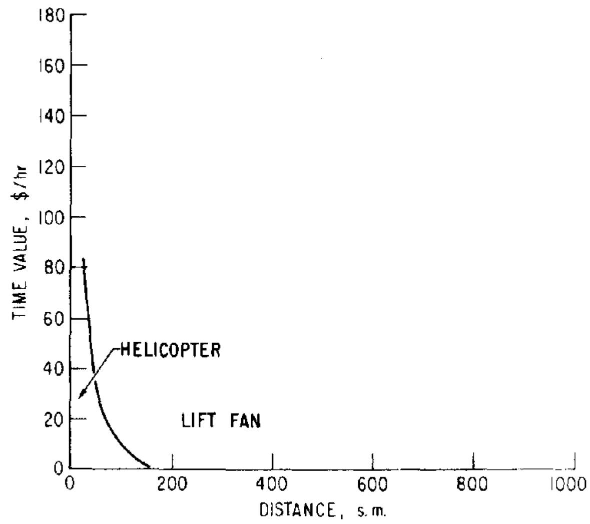


d. Small Tilt Wing - Small Turboprop with Helicopter

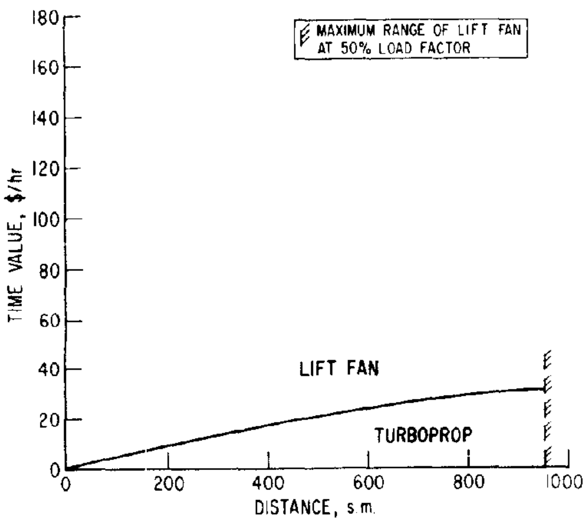
Figure E-7. Two-Aircraft Time Value Phase Diagram--Small Tilt Wing (Executive Mission)



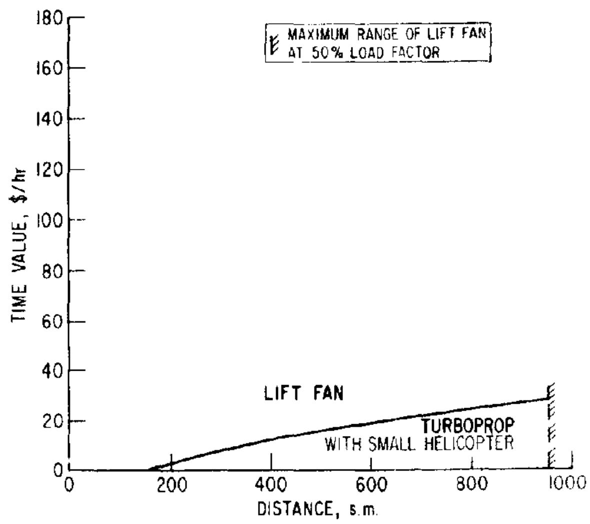
a. Small Lift Fan - Airline



b. Small Lift Fan - Small Helicopter

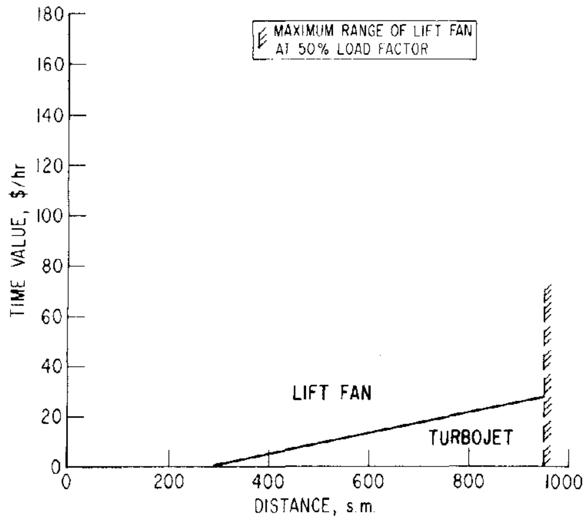


c. Small Lift Fan - Small Turboprop

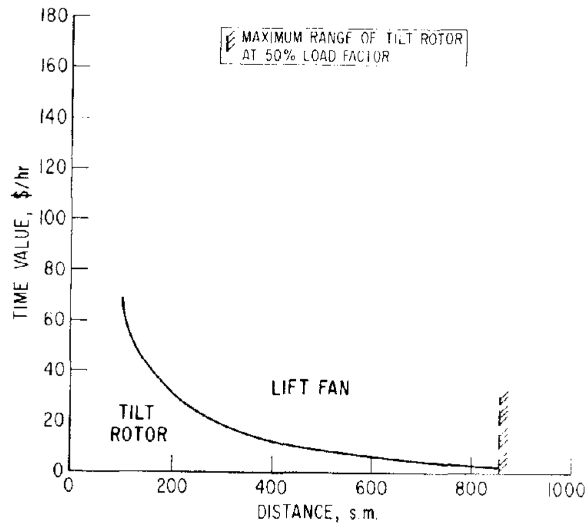


d. Small Lift Fan - Small Turboprop with Helicopter

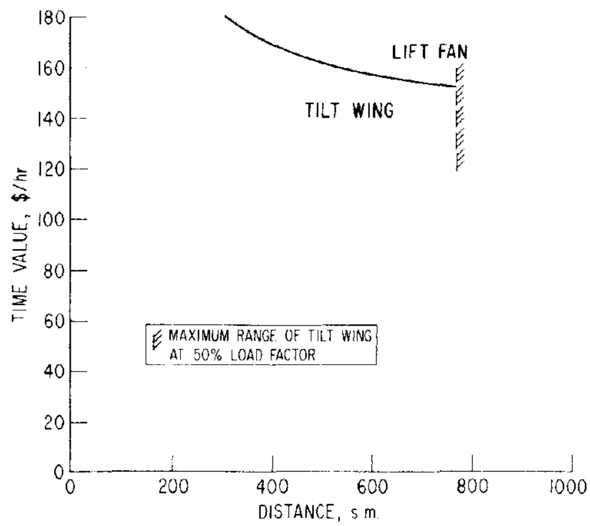
Figure E-8. Two-Aircraft Time Value Phase Diagram--Small Lift Fan, Part I (Executive Mission)



e. Small Lift Fan - Small Turbojet

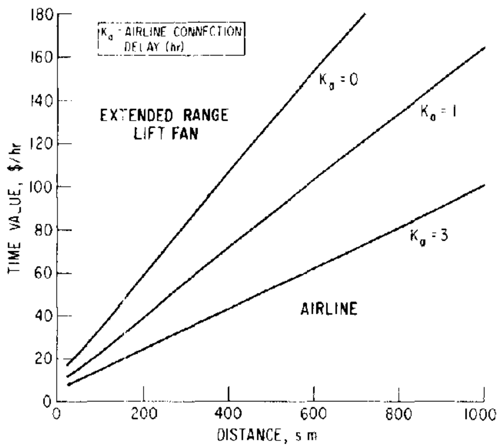


f. Small Lift Fan - Small Tilt Rotor

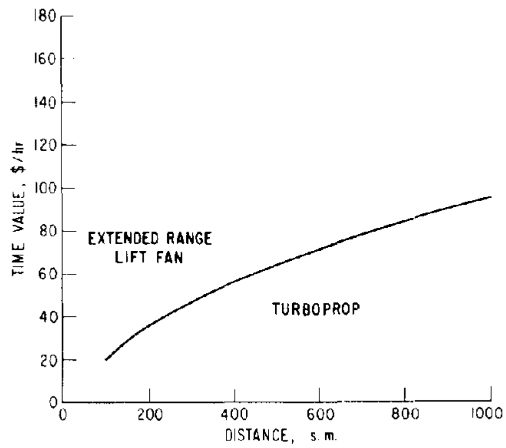


g. Small Lift Fan - Small Tilt Wing

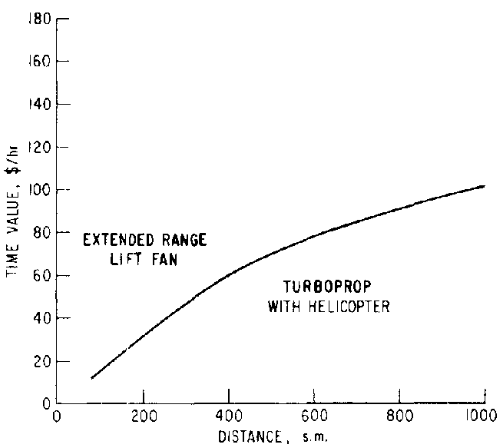
Figure E-8. Two-Aircraft Time Value Phase Diagram--Small Lift Fan, Part II (Executive Mission)



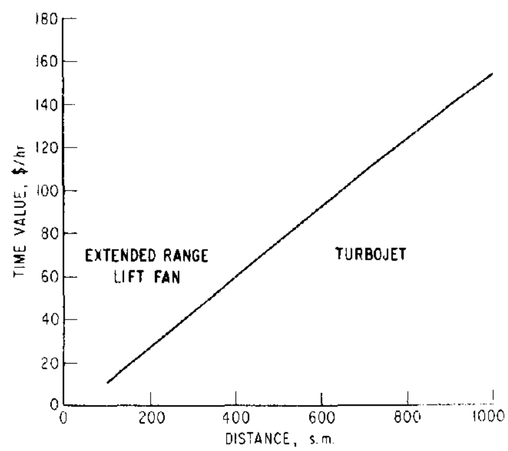
a. Extended Range Small Lift Fan - Airline



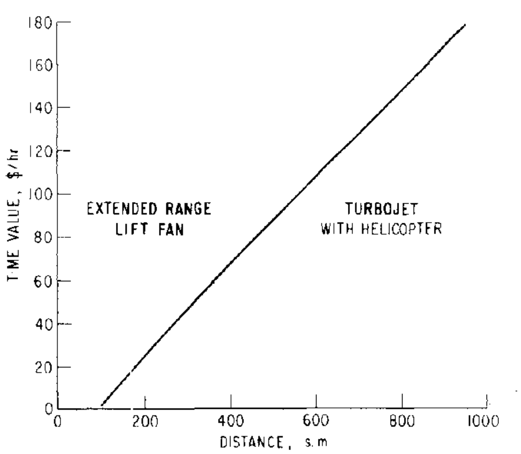
b. Extended Range Small Lift Fan - Small Turboprop



c. Extended Range Small Lift Fan - Small Turboprop with Helicopter

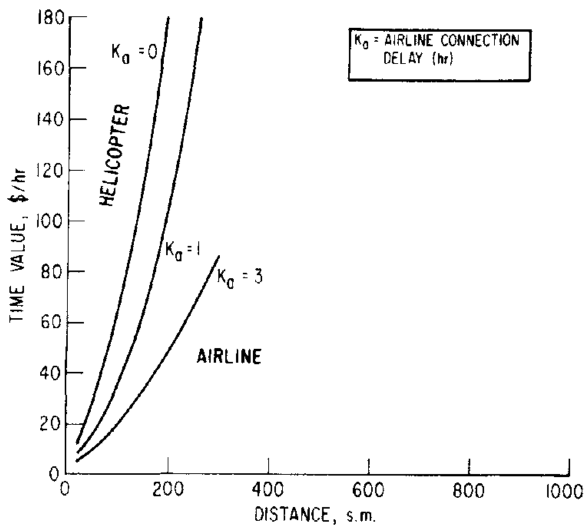


d. Extended Range Small Lift Fan - Small Turbojet

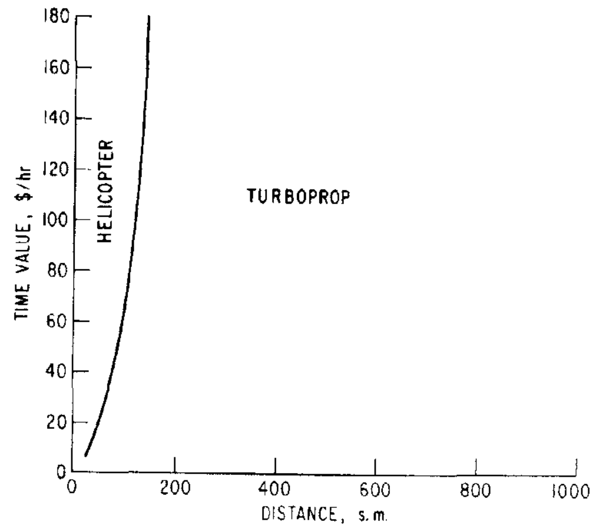


e. Extended Range Small Lift Fan - Small Turbojet with Helicopter

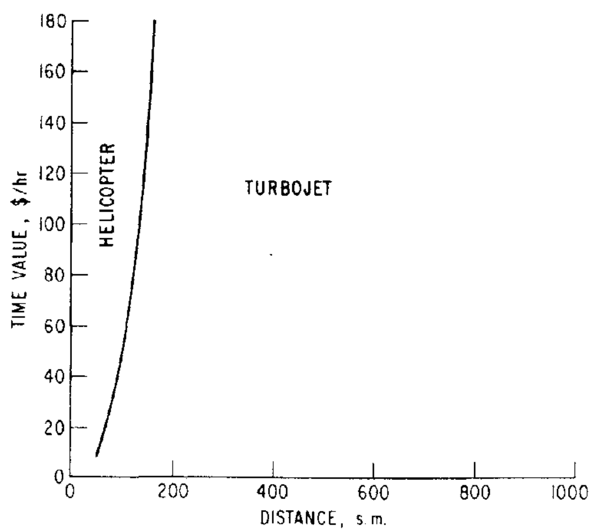
Figure E-9. Two-Aircraft Time Value Phase Diagram--Extended Range Small Lift Fan (Executive Mission)



a. Large Helicopter - Airline

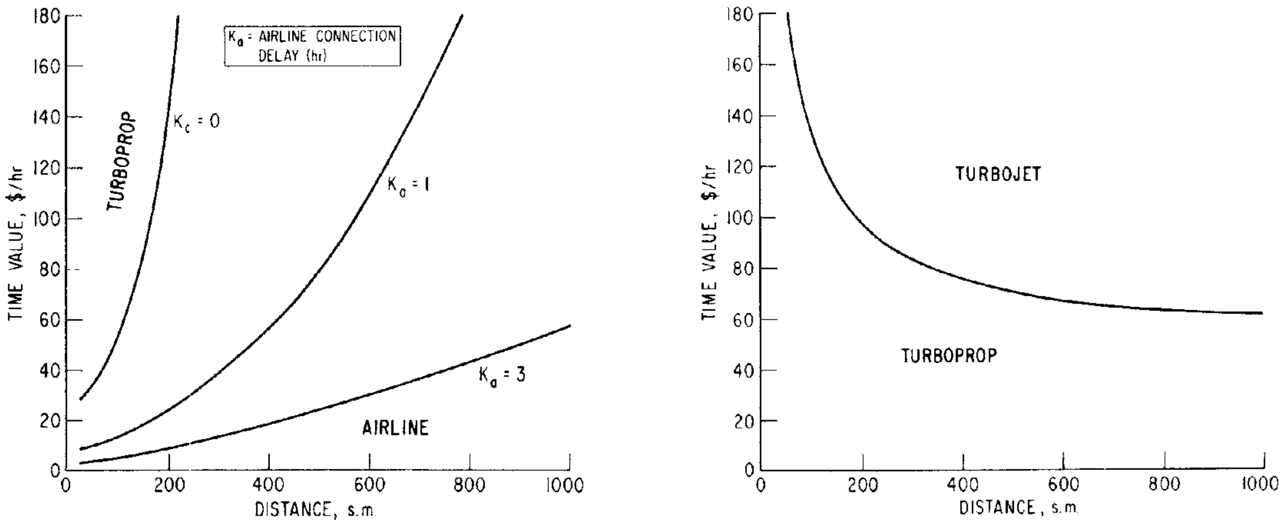


b. Large Helicopter - Large Turboprop



c. Large Helicopter - Large Turbojet

Figure E-10. Two-Aircraft Time Value Phase Diagram--Large Helicopter (Executive Mission)



a. Large Turboprop - Airline

b. Large Turboprop - Large Turbojet

Figure E-11. Two-Aircraft Time Value Phase Diagram--Large Turboprop (Executive Mission)

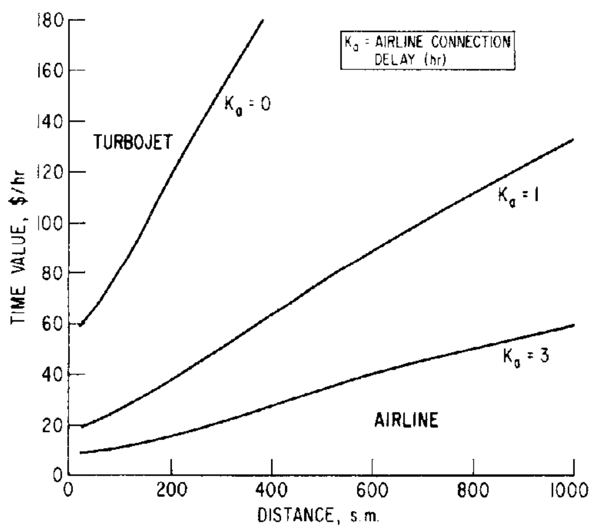
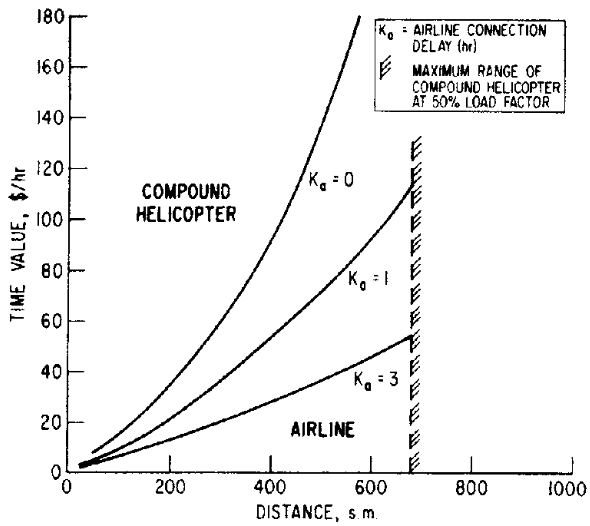
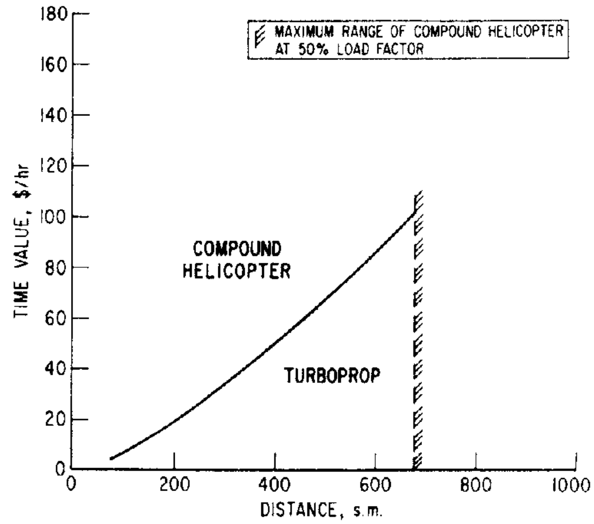


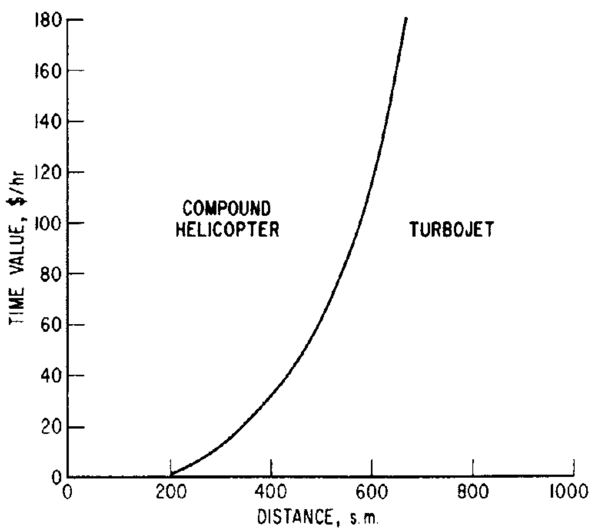
Figure E-12. Two-Aircraft Time Value Phase Diagram--Large Turbojet - Airline (Executive Mission)



a. Large Compound Helicopter - Airline

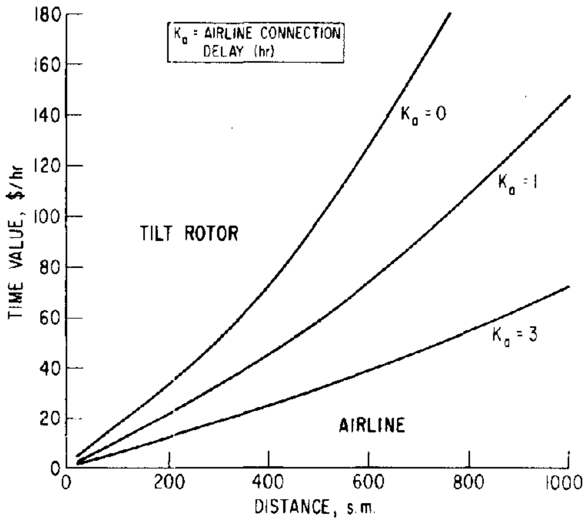


b. Large Compound Helicopter - Large Turboprop

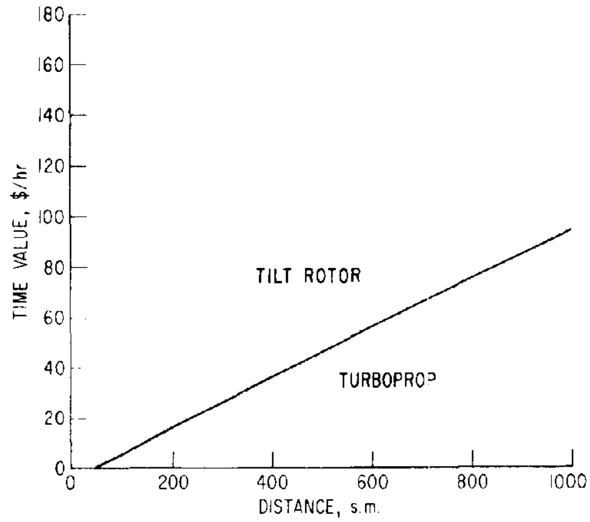


c. Large Compound Helicopter - Large Turbojet

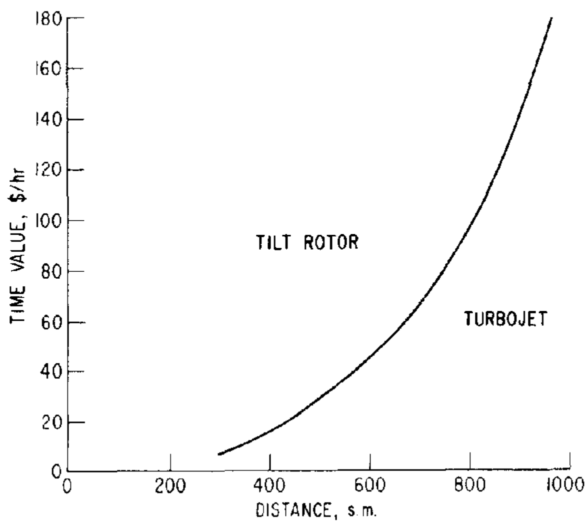
Figure E-13. Two-Aircraft Time Value Phase Diagram--Large Compound Helicopter (Executive Mission)



a. Large Tilt Rotor - Airline

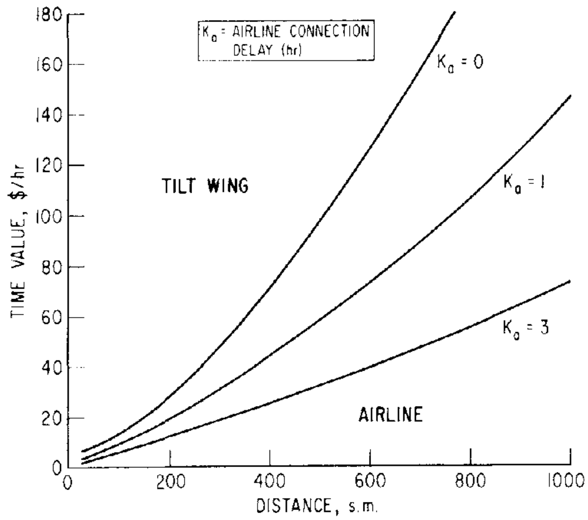


b. Large Tilt Rotor - Large Turboprop

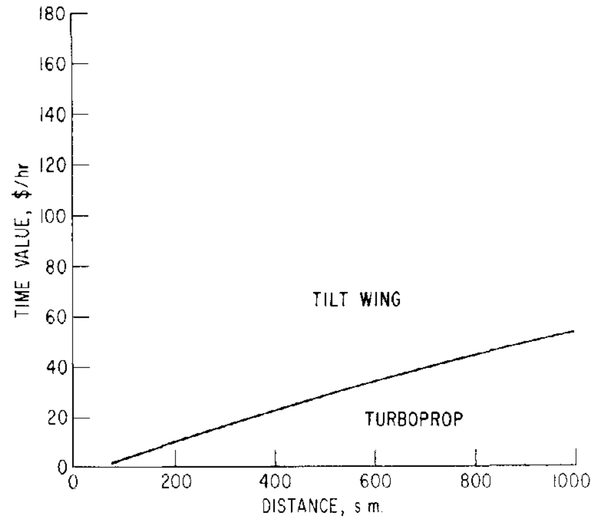


c. Large Tilt Rotor - Large Turbojet

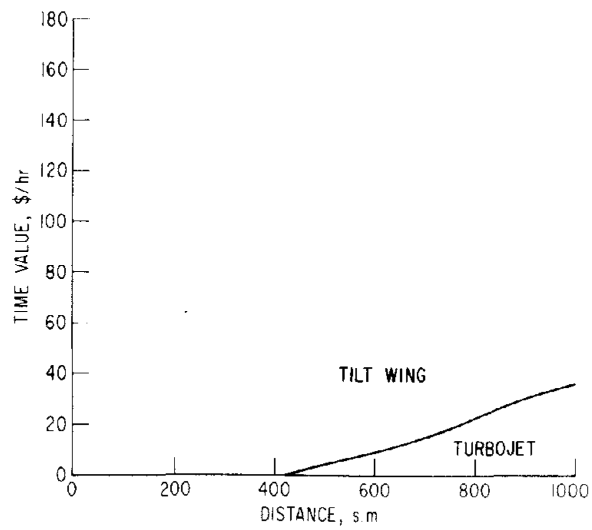
Figure E-14. Two-Aircraft Time Value Phase Diagram--Large Tilt Rotor (Executive Mission)



a. Large Tilt Wing - Airline

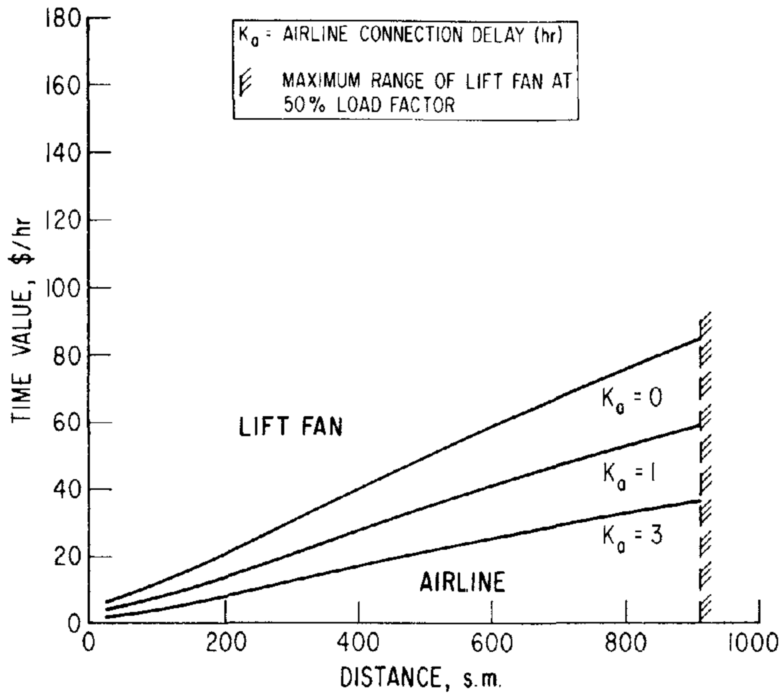


b. Large Tilt Wing - Large Turboprop

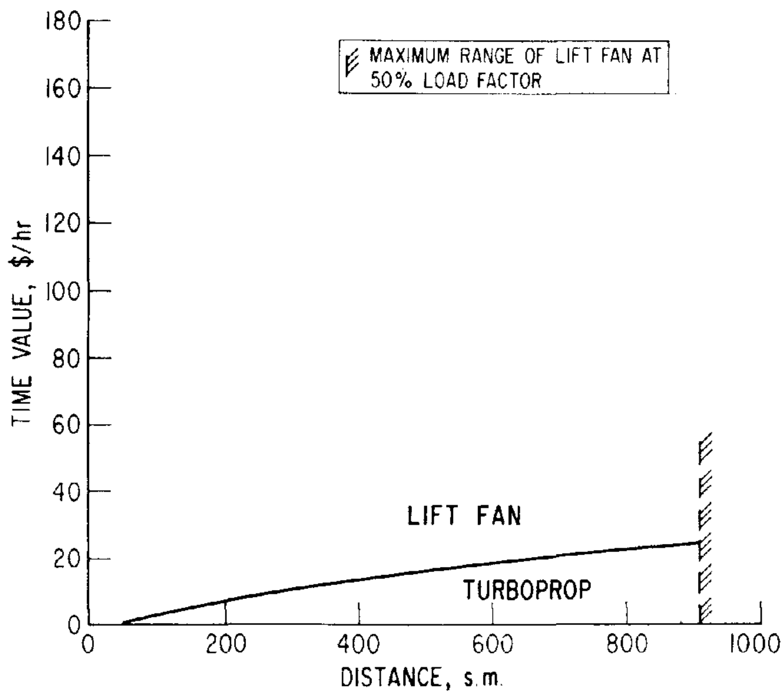


c. Large Tilt Wing - Large Turbojet

Figure E-15. Two-Aircraft Time Value Phase Diagram--Large Tilt Wing (Executive Mission)



a. Large Lift Fan-Airline



b. Large Lift Fan - Large Turboprop

Figure E-16. Two-Aircraft Time Value Phase Diagram--Large Lift Fan (Executive Mission)

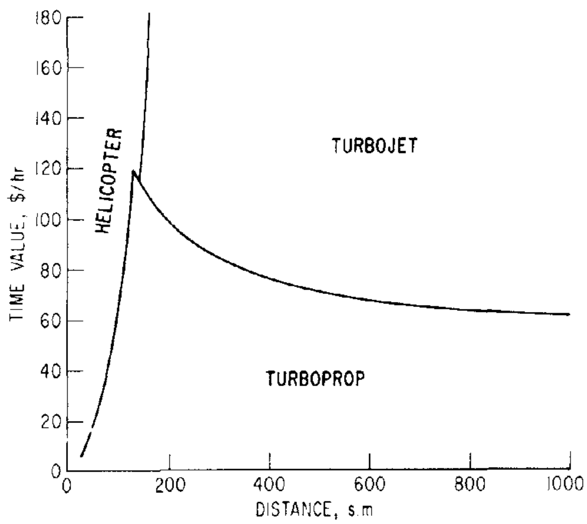


Figure E-17. Current Large Aircraft Serving Executive Mission

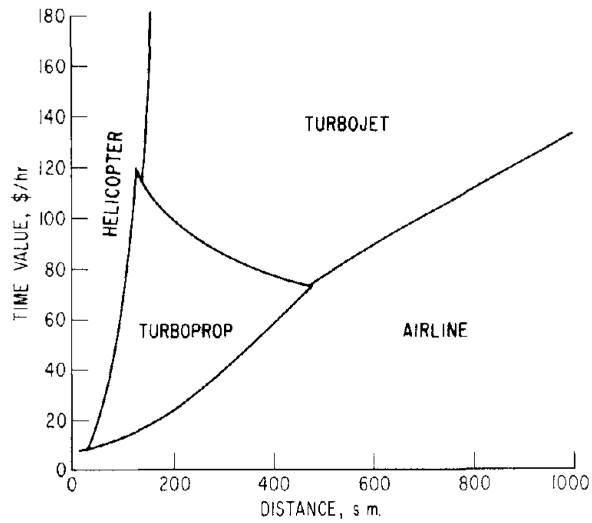


Figure E-18. Current Large Aircraft Serving Executive Mission--1-Hour Airline Connecting Delay

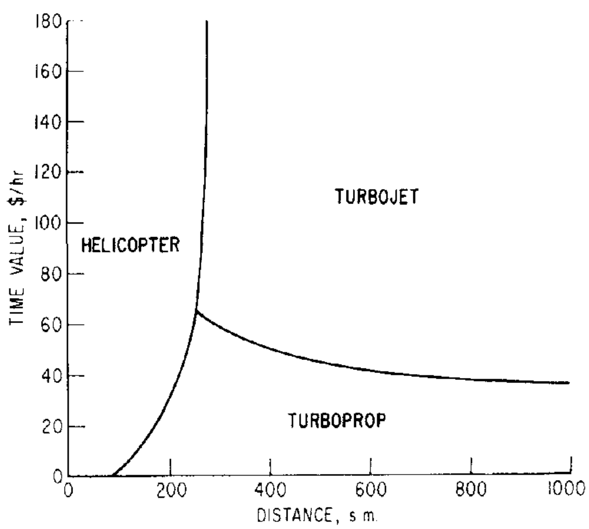


Figure E-19. Current Small Aircraft Serving Executive Mission

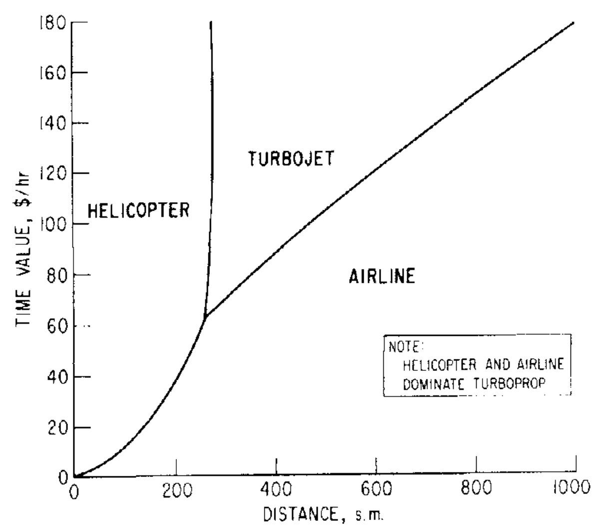


Figure E-20. Current Small Aircraft Serving Executive Mission--1-Hour Airline Connecting Delay

Table E-1. Time/Cost Equations

Mission and Mode	Time Equations (minutes)[a]	Cost/Passenger Equations ($)[b]
Executive		
Car-Airline-Car	T = 125+0.0124D	C = 12+0.0679D (D≥100 Mi.) C = 8+0.1079D (D≤100 Mi.)
Car-Turbojet-Car	T = 96+0.120D	C = 39+0.312D
Helic-Turbojet-Car	T = 75+0.120D	C = 54+0.312D
Car-Turboprop-Car	T = 98+0.211D	C = 22+0.274D
Helic-Turboprop-Car	T = 77+0.211D	C = 37+0.274D
Helicopter (Small)	T = 6+0.444D (to 300 mi. max range)	C = 6+0.451D (to 300 mi. max range)
Helicopter (Large)	T = 6+0.540D (to 300 mi. max range)	C = 10+0.931D (to 300 mi. max range)
Tilt Rotor (Small)	T = 6+0.155D	C = 15+0.387D
Tilt Rotor (Large)	T = 6+0.181D	C = 12+0.364D
Lift Fan (Small)	T = 6+0.111D	C = 20+0.371D
Lift Fan (Small) ER[c]	T = 6+0.111D	C = 29+0.540D
Lift Fan (Large)	T = 6+0.104D	C = 16+0.278D
Tilt Wing (Small)	T = 6+0.138D	C = 14+0.328D
Tilt Wing (Large)	T = 6+0.167D	C = 11+0.302D
Compound Helic (small)	T = 6+0.320D	C = 10+0.550D
Compound Helic (large)	T = 6+0.227D	C = 10+0.360D
Commuter		
Car-Helic(L)-Car	T = 72+0.515D (to 300 mi. max range)	C = 6+0.436D (to 300 mi. max range)
Car-Tilt Rotor(L)-Car	T = 51+0.186D	C = 8+0.272D
Car-Tilt Wing(L)-Car	T = 51+0.160D	C = 8+0.220D
Car-CompHelic(L)-Car	T = 51+0.224D	C = 7+0.314D
Car-Lift Fan(L)-Car	T = 51+0.107D	C = 9+0.180D
Offshore		
Helicopter(Large)	T = 6+0.536D (to 300 mi. max range)	C = 4+0.318D (to 300 mi. max range)
Helicopter(Small)	T = 6+0.448D (to 300 mi. max range)	C = 3+0.222D (to 300 mi. max range)
Tilt Rotor (Large)	T = 6+0.187D	C = 7+0.200D
Tilt Wing (Large)	T = 6+0.164D	C = 6+0.167D
Comp. Helic (Large)	T = 6+0.227D	C = 6+0.212D
Tilt Rotor (Small)	T = 6+0.158D	C = 12+0.307D
Tilt Wing (Small)	T = 6+0.140D	C = 10+0.242D
Comp. Helic (Small)	T = 6+0.311D	C = 8+0.450D
Lift Fan (Large)	T = 6+0.107D	C = 8+0.138D
Lift Fan (Small)	T = 6+0.111D	C = 14+0.260D

(a) T - Total travel time (including interface time)
D = Stage length (s.m.)

(b) C = Cost/passenger
D = Stage length

(c) ER = Extended range configuration

Table E-2. Equations for Two-Aircraft Time Value Phase Diagrams

1. Basic Equation

$C_1 = C_2$

where

C_1 = Total trip cost per passenger for aircraft 1

C_2 = Total trip cost per passenger for aircraft 2

2. Cost Equation

$C = C_a + C_t$

where

C = Total trip cost per passenger for any aircraft

C_a = Cost of aircraft operation per passenger

C_t = Cost of the traveler's time per trip

3. Cost of Aircraft Operation

$C_a = (\frac{D}{V} + T_d) R_t + k$

where

D = Door-to-Door Distance[a] (s.m.)
V = Aircraft Cruise Speed (mph)
T_d = Non-Productive Aircraft Time (hr.)
R_t = Aircraft Operating Cost Per Hr. Per Passenger (\$/hr/pass.)
k = Any significant access cost (e.g., helicopter)

4. Cost of Traveler's Time

$C_t = (\frac{D}{V} + T_d + T_a + T_e + K_a) V_t$

where

T_a = Access time (hr.)
T_e = Distribution time (hr.)
K_a = Additional delays (e.g., connecting time delays, etc.) (hr.)
V_t = Travelers time value (\$/hr.)

5. Substitution of Eqs. (3) and (4) into Eq. (2) results in

$$C = (\frac{D}{V} + T_d) R_t + (\frac{D}{V} + T_d + T_a + T_e + K_a) V_t + k$$

6. When Eq. (5) is substituted into Eq. (1) with proper subscript notation applied, it may be solved for V_t:

$$V_t = \frac{(\frac{D}{V_1} + T_{d_1}) R_{t_1} - (\frac{D}{V_2} + T_{d_2}) R_{t_2} + k_1 - k_2}{(\frac{D}{V_2} + T_{d_2} + T_{a_2} + T_{e_2} + K_{a_2}) - (\frac{D}{V_1} + T_{d_1} + T_{a_1} + T_{e_1} + K_{a_1})}$$

Two aircraft time value phase diagrams represent the solution of Eq. (6) as a function of trip distance D.

[a]Assumes no constructive time for any ground travel and expresses the desire to fly from door-to-door where possible.

Table E-3. Computation Parameters for Two-Aircraft Time Phase Diagrams (Executive Missions)

Aircraft	V (mph)	R_t ($/hr/pass.)	k ($)	T_d (hr)	T_e (hr)	T_a (hr)	K_a (hr)
Airline	486	a	0	b	0.75	1.0	0, 0.5, 1.0, 3
Small Helicopter	133	61	0	0.1	0	0	0.5(D>300)[c]
Large Helicopter	122	103	0	0.1	0	0	0.5(D>300)[c]
Small Turboprop	282	77	0	0.284	0.6	0.75	0
Small Turboprop/Small Helicopter	282	77	15	0.284	0.6	0.40	0
Large Turboprop	315	62	0	0.284	0.6	0.75	0
Small Turbojet	500	156	0	0.25	0.6	0.75	0
Small Turbojet/Small Helicopter	500	156	15	0.25	0.6	0.40	0
Large Turbojet	508	131	0	0.25	0.6	0.75	0
Small Compound Helicopter	190	105	0	0.1	0	0	0
Large Compound Helicopter	265	100	0	0.1	0	0	0
Small Tilt Rotor	380	145	0	0.1	0	0	0
Large Tilt Rotor	322	114	0	0.1	0	0	0
Small Tilt Wing	430	137	0	0.1	0	0	0
Large Tilt Wing	368	114	0	0.1	0	0	0
Small Lift Fan	530	200	0	0.1	0	0	0
Extended Range/Small Lift Fan	530	302	0	0.1	0	0	0
Large Lift Fan	564	154	0	0.1	0	0	0

[a]Cost = 8+.1079D (for D $\leq$ 100 s.m.)
= 12+.0679D (for D $\geq$ 100 s.m.)

[b]Time = .33 + .00206D

[c]Penalty for refueling at distance >300 s.m.

Table E-4. Summary and Locator of Two-Aircraft Time Value Phase Diagrams (Executive Scenarios)

	Helicopter		Turboprop		Turbojet		Compound Helicopter		Tilt Rotor		Tilt Wing		Lift Fan		
	Small (SH)	Large (LH)	Small (STP)	Large (LTP)	Small (STJ)	Large (LTJ)	Small (SCH)	Large (LCH)	Small (STR)	Large (LTR)	Small (STW)	Large (LTW)	Small (SLF)	E. Range (ERSLF)	Large (LLF)
Airline	E-2a	E-10a	E-3	E-11a	E-4	E-12	E-5a	E-13a	E-6a	E-14a	E-7a	E-15a	E 8a	E-9a	E-16a
Small Helicopter	--	--	E-2b	--	E-2c	--	E-5b	--	E-6b	--	E-7b	--	E-8b	--	--
Large Helicopter	--	--	--	E-10b	--	E-10c	--	LCH	--	LTR	--	LTW	--	--	LLF
Small Turboprop	E-2b	--	--	--	14d[a]	--	E-5c	-	E-6c	--	E-7c	--	E-8c	E-9b	--
Small Turboprop with Helicopter	--	--	--	--	--	--	23a[a]	--	E-6d	--	E-7d	--	E-8d	E-9c	--
Large Turboprop	--	E-10b	--	--	--	E-11b	--	E-13b	--	E-14b	--	E-15b	--	--	E-16b
Small Turbojet	E-2c	--	14d[a]	--	--	--	E-5d	--	E-6e	--	STW	--	E-8e	E-9d	--
Small Turbojet with Helicopter	--	--	--	--	--	--	--	--	--	--	--	--	23b[a]	E-9e	--
Large Turbojet	--	E-10c	--	E-11b	--	--	--	E-13c	--	E-14c	--	E-15c	--	--	LLF
Small Compound Helicopter	E-5b	--	E-5c	--	E-5d	--	--	--	STR	--	STW	--	SLF	--	--
Large Compound Helicopter	--	LCH	--	E-13b	--	E-13c	--	--	--	LTR	--	LTW	--	--	LLF
Small Tilt Rotor	E-6b	--	E-6c	--	E-6e	--	STR	--	--	--	STW	--	E-8f	--	--
Large Tilt Rotor	--	LTR	--	E-14b	--	E-14c	--	LTR	--	--	--	LTW	--	--	LLF
Small Tilt Wing	E-7b	--	E-7c	--	STW	--	STW	--	STW	--	--	--	E-8g	--	--
Large Tilt Wing	--	LTW	--	E-15b	--	E-15c	--	LTW	--	LTW	--	--	--	--	LLF

E-2a indicates figure containing phase diagrams

XXX indicates the dominating aircraft

-- indicates combination not computed

[a]Figure will be found in Volume I.

Table E-5. Formulation of Cost Savings Equations

1. Basic Cost Savings Formula

$$S = A_r - A_n$$

where

S = Annual savings (\$/yr./aircraft) for $A_r > A_n$

= Annual cost $A_r < A_n$

A_r = Annual cost of operating reference aircraft

A_n = Annual cost of operating a new aircraft.

2. Annual Cost of Operating Any Aircraft

$$A = N \times C$$

where

N = Number of flights per year

C = Cost of each trip.

3. Number of Flights Per Year

$$N_r = \frac{U_r}{D_r / v_r} = \frac{U_r v_r}{D_r}$$

where

U_r = Annual use of reference aircraft (hr./yr.)

D_r = Average distance per flight (reference aircraft)

v_r = Block speed of the reference aircraft (mph)

4. Block Speed

$$v = \frac{D}{T} = \frac{D}{T_d + \frac{D}{V}}$$

where

v = Block speed (mph)

T_d = Non-productive flight time (hr.)

V = Cruise speed (mph).

5. Substitution from Eq. (4) in Eq. (3) gives

$$N_r = \frac{U_r}{D}\left(\frac{D}{T_{d_r} + \frac{D}{V_r}}\right) = \frac{U_r}{T_{d_r} + \frac{D}{V_r}}$$

6. Cost per Trip

$$C = \left[\left(\frac{D}{v}\right)(r_t) + \left(\frac{D}{v} + T_a + T_e + K_a\right) K_b V_t\right]$$

where

r_t = Total aircraft operating cost (\$/hr.)

T_a = Ground access time (hr.)

T_e = Ground distribution time (hr.)

K_a = Miscellaneous delays (hr.)

K_b = Average no. passengers per flight (pass/flt)

V_t = Value of a traveler's time (\$/hr.)

Table E-5. Formulation of Cost Savings Equations (Continued)

7. Total Aircraft Operating Cost

$$r_t = C_v + \frac{C_f}{U}$$

where

C_v = Variable aircraft operating costs (\$/hr.)

C_f = Annual fixed aircraft operating costs (\$/yr.)

U = Annual aircraft use (hr./yr.)

8. Since the number of flights of the reference aircraft and the new aircraft are the same, it follows that

$$N_r = N_n = \frac{U_r}{D_r/v_r} = \frac{U_n}{D_n/v_n}$$

and that

$$D_r = D_n = D$$

Therefore:

$$U_n = U_r \frac{v_r}{v_n}$$

Substitution from Eq. (4) gives

$$U_n = U_r \left(\frac{D}{T_{d_r} + \frac{D}{v_r}}\right) \Bigg/ \left(\frac{D}{T_{d_n} + \frac{D}{v_n}}\right)$$

$$= U_r \frac{T_{d_n} + \frac{D}{v_n}}{T_{d_r} + \frac{D}{v_r}}$$

9. Substitution of Eq. (2) in Eq. (1) results in

$$S = N (C_r - C_n)$$

10. Substitution of Eqs. (4) and (7) in Eq. (6) gives

$$C = \left[\frac{D}{\frac{D}{\left(T_d + D/v\right)}}\right] \times \left[C_v + \frac{C_f}{u}\right] + \left[\frac{D}{\frac{D}{\left(T_d + D/v\right)}} + T_a + T_e + K_a\right] \times K_b \times V_t$$

$$= \left[\frac{D}{v} + T_d\right]\left[C_v + \frac{C_f}{U}\right] + \left[\frac{D}{v} + T_d + T_a + T_e + K_a\right] K_b V_t$$

11. C_r and C_n, aside from proper notation by subscripts, differ only in the use in the second quantity. Therefore, substitution in Eq. (10) from results of Eq. (8), with proper subscripts gives

$$C_n = \left[\frac{D}{v_n} + T_{d_n}\right] \left[C_{vn} + \frac{(C_{fn})(T_{d_r} + \frac{D}{v_r})}{U_r\ (T_{dn} + \frac{D}{v_n})}\right] + \left(\frac{D}{v_n} + T_{dn} + T_{an} + T_{en} + K_{an}\right) K_b \times V_t$$

12. Substitution in Eq. (9) of Eqs. (8) and (10) (with "r" subscripts) and (11) and solving for S, for D varying from 100 to 1000 (s.m.) and for V_t = 50, 100 and 150 (\$/hr.), produces the results shown in the cost savings graphs. Table E-6 contains parameters for each aircraft used in the analysis.

Table E-6. Parameters for Cost Savings Analysis (Executive Missions)

Aircraft	V (mph)	C_v (\$/hr)	C_f (\$/yr) (000)	T_d (hrs)	T_e (hrs)	T_a (hrs)	K_a (hrs)	K_b (pass/flt)
Small Turbojet	500	210	200	0.25	0.6	0.75	0	4
Large Turbojet	508	342	354	0.25	0.6	0.75	0	8
Small Compound Helicopter	190	162	156	0.1	0	0	0	4
Large Compound Helicopter	265	313	290	0.1	0	0	0	8
Small Tilt Rotor	380	207	225	0.1	0	0	0	4
Large Tilt Rotor	322	298	378	0.1	0	0	0	8
Small Tilt Wing	430	184	220	0.1	0	0	0	4
Large Tilt Wing	368	272	377	0.1	0	0	0	8
Small Lift Fan	530	214	352	0.1	0	0	0	4
Large Lift Fan	564	340	550	0.1	0	0	0	8