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DOCUMENTING HELICOPTER OPERATIONS FROM AN ENERGY STANDPOINT

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ABSTRACT

This document contains the results of a study of the relative and absolute energy consumption of helicopters, including limited comparisons with fixed-wing aircraft, and selected surface transportation vehicles. In the case of the helicopters, additional comparisons were made to determine the level of reduction in energy consumption expected from the application of advanced technologies to the helicopter design and sizing process.

FOREWORD

This report was prepared by the Boeing Vertol Company for The National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13142. Mr. W. Snyder was technical monitor for this work. The Boeing project manager was W. Z. Stepniewski and the project engineer was S. J. Davis.

SUMMARY

The study reported in this document provides relative and absolute energy consumption data for helicopters, including limited comparisons with fixed-wing aircraft and selected surface transportation vehicles. Air vehicles, due to their inherent higher power requirements (compared to ground vehicles), will always exhibit higher energy intensities when compared solely on an energy consumption basis. Current levels of air vehicle energy intensity can be reduced, however, through the infusion of advanced aeronautical technology into the design process, as exemplified by the fixed-wing aircraft in Reference 15.

Current helicopters are competitive with ground vehicles on the basis of useful energy utilization in a number of situations (referred to great circle distance). In areas where ground transportation systems do not presently exist (or surface geography precludes easy construction of such facilities), the helicopter offers the potential of both reduced travel time and lower overall energy consumption than a comparable surface transportation system could achieve (especially if the energy consumed in initial construction of such a system is considered). Additionally, unique missions exist (e.g., resupply of off-shore oil rigs and utilization in logging

operations that can be performed by no other vehicle with such a combination of flexibility and speed.

Improvements in helicopter energy consumption characteristics can be accomplished through the utilization of advanced technology to reduce drag, structures weight, and powerplant fuel consumption. The optimum "mix" of these technology applications which results in the maximum amount of energy consumption reduction for the minimum cost is presently not known.

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1.0 INTRODUCTION

The energy crisis, which affects all forms of transportation, raises significant questions with respect to the energy consumption characteristics of all VTOL transport aircraft and especially with helicopters which are presently the only operationally available representatives of that group. The two basic questions concerning the energy utilization of helicopters are as follows:

- In what areas of operation is helicopter energy consumption competitive with alternate modes of transporation, or is considered acceptable because of unique operational characteristics or specialized mission requirements?
- Will advances in the state-of-the-art bring appreciable improvement in the energy consumption aspects of helicopters?

On the basis of an over-simplified approach, Figure 1.1, which takes into consideration only energy expended per passenger miles in cruise, the present generation of transport helicopters appears inferior to other aircraft and many forms of ground transportation.

To make a more meaningful comparison of helicopters with other forms of transportation, it is necessary to investigate the energy (fuel) utilization per passenger mile under realistic operating conditions for the same missions or scenarios. This

ENERGY CONSUMPTION INDEX

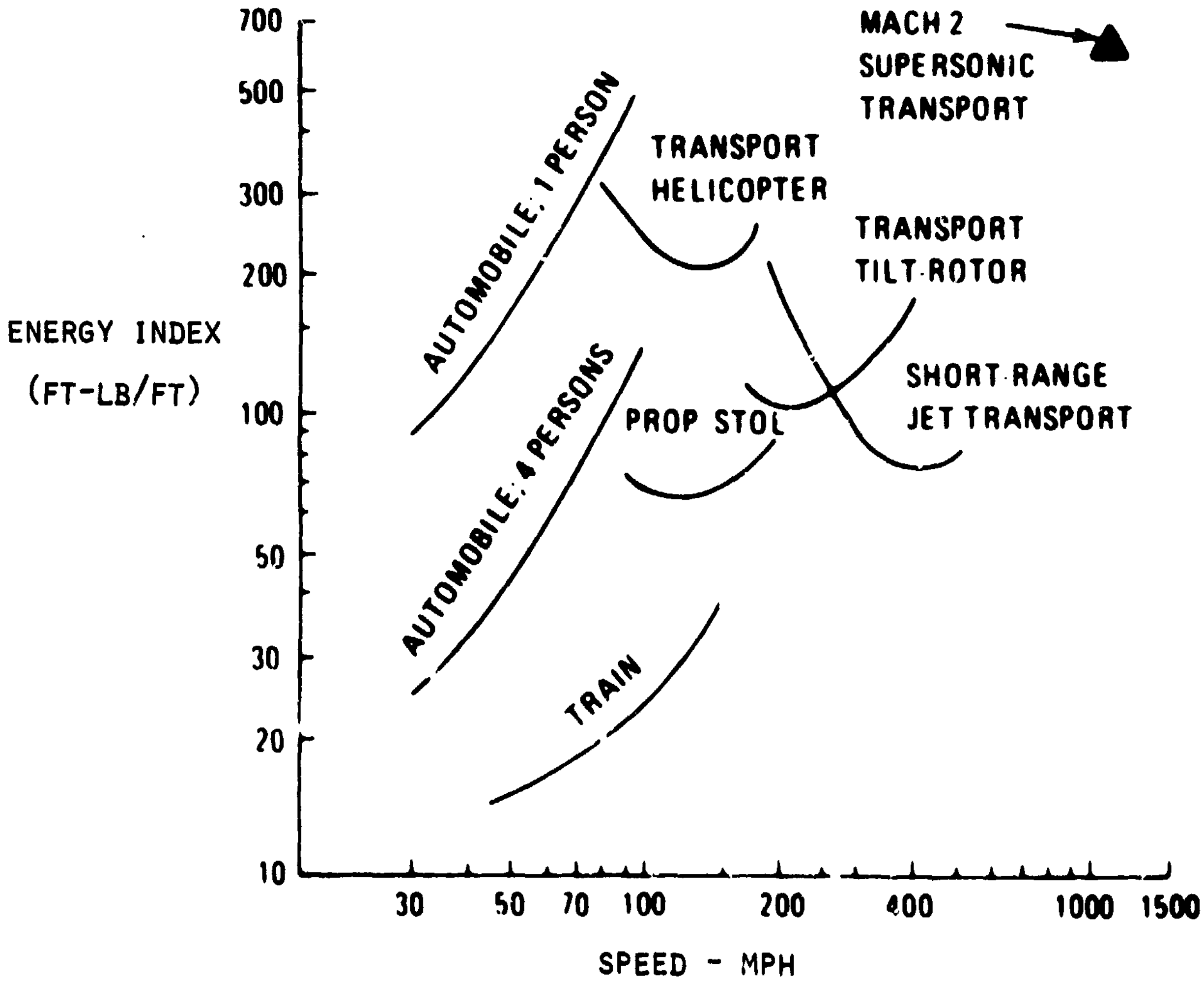


FIGURE 1.1 ENERGY CONSUMPTION INDEX VS SPEED

implies, in the case of fixed wing aircraft, that it is necessary to base energy consumption estimates on the block distance and actual fuel consumption from the startup of engines at one gate to shutting down the engines at the destination. In this way, all the energy expenditures resulting from ground movement and traffic delays are taken into consideration.

For ground transportation such as automobiles, taxis, buses and trains, the comparison should be based upon the use of existing highways and/or roadbeds with allowances for traffic delays.

For very short-haul distances where conventional (CTOL) or even short takeoff and landing (STOL) aircraft cannot usually be used, the logical comparison would be with such representatives of ground transportation as automobiles, (taxis, buses) and trains. It may be anticipated that in this comparison, the pure energy consumption per passenger mile would favor trains and buses. Automobiles and taxis might present a closer competition with the helicopter when realistic mile-per-gallon figures as caused by traffic delays, etc., are used. Nevertheless, even anticipating the energetic inferiority of the helicopter to some means of mass ground transportation, other aspects of the helicopters should not be overlooked. The strongest advantage would be the relative ease of starting new transportation links as well as the flexibility of changing routes should the necessity arise. It should also be kept in mind that in those cases when the right-of-way for ground transportation is not available, large expenditures in capital, time and energy would usually be required. The initial expenditure of energy for the construction of those new rights-of-way, when distributed over a long period of utilization, would represent only a small fraction of the energy requirements per passenger mile. However, during the period of construction work, it may represent considerable energy requirement peaks which, in addition, might occur just at the time of acute shortages.

Section 2.0 describes the mission scenarios utilized and ground rules employed in this study. Section 3.0 summarizes the data base surveyed for the study and lists the data actually employed (e.g., vehicle fuel consumption rates, passenger load factors, vehicle weight and power characteristics, etc.). Section 4.0 discusses the results of the energy consumption comparison for the different scenarios and the interplay of advanced technology and various operational and design variables on helicopter energy consumption. In addition, a typical advanced technology helicopter (see Reference 5) is described. Appendix A contains a brief description of the

V/STOL Aircraft Sizing and Performance Computer Program (VASCOMP II) and the Helicopter Sizing and Performance Computer Program (HESCOMP) utilized in this study. Appendix B provides a summary of study data results in tabular form. Appendix C presents a description of an advanced technology helicopter utilized in this study. It should be emphasized that this study is limited to passenger operations only, and no freight-carrying aspects are considered.

2.0 MISSION SCENARIOS

2.1 Ground Rules

The mission scenarios employed in this study are summarized in Table 2.1. With the exception of scenario IV, all are based on realistic operating conditions in the Northeast Corridor. As indicated by Table 2.2, the distances travelled by the ground transportation vehicles were generally greater than those travelled by the air vehicles, due to the constraints of geography imposed on them by the utilization of existing highways/roadbeds. For example, scenarios I and II, which are based on operations in the New York City Metropolitan area exhibit ground travel distances approximately 30 to 40% greater than the corresponding point-to-point air distances.

As noted in Table 2.3, not all study vehicles are compared in all mission scenarios. Those vehicles selected for comparison in a particular scenario represent those most likely to be used in a realistic situation. For example, for mission scenario I, which is essentially an air taxi operation with individual flight legs as short as 10 n.mi., it makes little sense to include a fixed-wing aircraft, such as the 737-100 in the comparison, since they are not readily employable in this type of operation. In the New York area and other areas, such as San Francisco, the helicopter performs a specialized link

TABLE 2.1 SUMMARY OF MISSION SCENARIOS UTILIZED

I.	VERY SHORT HAUL
II.	INTERMEDIATE SHORT HAUL
III.	SHORT HAUL
IV.	OIL RIG

TABLE 2.2 MISSION SCENARIO AIR AND GROUND VEHICLE TRAVEL DISTANCES

MISSION SCENARIO	GROUND VEHICLE TRAVEL DISTANCE NAUT. MI./STAT. MI.	AIR VEHICLE TRAVEL DISTANCE NAUT. MI./STAT. MI.
VERY SHORT HAUL	67.8/78	52.1/60
INTERMEDIATE SHORT HAUL	154.7/178	111.2/128
OIL RIG	-	86.9/100
SHORT HAUL	219/252(AUTOMOBILE) 197.3/227(TRAIN)	210/242 (HELICOPTERS) 225/259 (FIXED WING A/C)

TABLE 2.3 VEHICLES COMPARED IN PARTICULAR SCENARIOS

SCENARIO	VEHICLES
VERY SHORT HAUL	S-61L HELICOPTER, STANDARD AND COMPACT AUTOMOBILES
INTERMEDIATE SHORT HAUL	S-61L HELICOPTER, STANDARD AND COMPACT AUTOMOBILES, BUS
OIL RIG	S-61L, 347-108-IIA HELICOPTERS
SHORT HAUL	S-61L HELICOPTER, ADVANCED TECHNOLOGY (TH-100) HELICOPTER, TRAIN, BUS, STANDARD AUTOMOBILE, BOEING 737-100 AND CONVAIR 580 FIXED WING A/C

in the air transport system and can only be successful where a combination of factors exist, primarily where more than one major airport exists in combination with geographical barriers or other traffic obstructions. A bus would be far superior to the helicopter or taxi from an energy consideration but would be totally infeasible for meeting airplane connections and was, therefore, not considered in this scenario. Similarly, mission scenario IV, because of geographical requirements (operation over the open sea), does not require comparison of other than air or marine vehicles.

2.2 Mission Scenario Description

2.2.1 The Very Short Haul Mission Scenario

As noted in Figure 2.1, the Very Short Haul Mission Scenario is based on operations in the New York Metropolitan area. The helicopter operations are based on statistical data obtained from New York Airways, Inc. (NYA). These statistics (for the month of May 1973) show that NYA helicopters operate over thirteen different routes averaging 55.5 n.mi. per route. On closer inspection, one particular route is observed to be used more frequently (68 times a week) than any of the others. This route, illustrated by Figure 2.2 is the one selected for use in this scenario. Table 2.4 shows the time (based on NYA statistics) spent on the ground (engines running) at each stop and the distance flown between stops. The corresponding ground transportation route, illustrated by Figure 2.3, is based on selection of the most convenient existing major highway arteries between stops (JFK, LaGuardia, etc.). Note especially the circled areas on the map. These indicate natural geographic features (the East and Hudson Rivers) which in the case of an accident or traffic congestion on the bridge or tunnel crossing them, represent potential barriers to ground traffic, resulting in serious delays and/or complete blockage of normal movement, and consequent large increases in energy expenditure. Table 2.5 illustrates the time spent at each stop and the ground vehicle speeds and distances between stops.

2.2.2 Intermediate Short Haul Mission Scenario

This scenario as illustrated by Figure 2.4 is an offshoot of

- MISSION SCENARIO BASED ON MOST FREQUENTLY USED NEW YORK AIRWAYS ROUTE, WHICH IS:

J. F. KENNEDY INTERNATIONAL AIRPORT
TO
LA GUARDIA
TO
NEWARK
TO
LA GUARDIA
TO
J. F. KENNEDY INTERNATIONAL AIRPORT

(TOTAL DISTANCE TRAVELLED - 52.1 N.MI.)

- GROUND TRAVEL DISTANCE EQUIVALENT OF THIS SCENARIO IS ILLUSTRATED BY THE **ATTACHED MAP.**

(TOTAL DISTANCE TRAVELLED - 67.8 N.MI.)

FIGURE 2.1 VERY SHORT HAUL MISSION SCENARIO

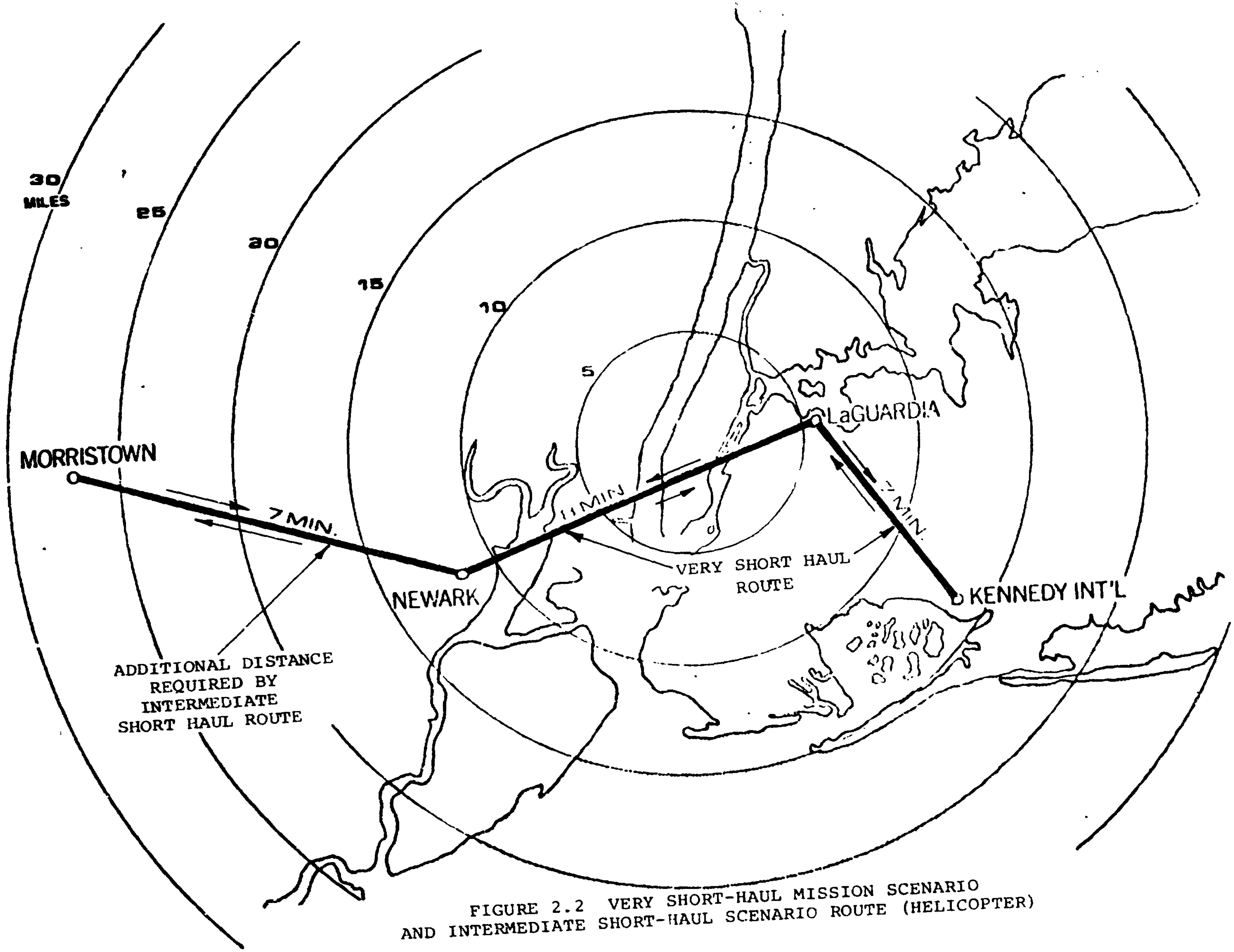


FIGURE 2.2 VERY SHORT-HAUL MISSION SCENARIO AND INTERMEDIATE SHORT-HAUL SCENARIO ROUTE (HELICOPTER)

TABLE 2.4 HELICOPTER FLIGHT PROFILE DATA FOR VERY SHORT HAUL MISSION SCENARIO

PASSENGER STOPS	JFK	LGA	NEW	LGA	JFK
TIME SPENT LOADING/ UNLOADING AT EACH STOP (HR)	.0385	.0585	.1185	.0585	.03
DISTANCE FLOWN BETWEEN STOPS (N.MI.)	10.43	15.64	15.64	10.43	

NOTES:

JFK - J. F. Kennedy International Airport
LGA - La Guardia Airport
NEW - Newark

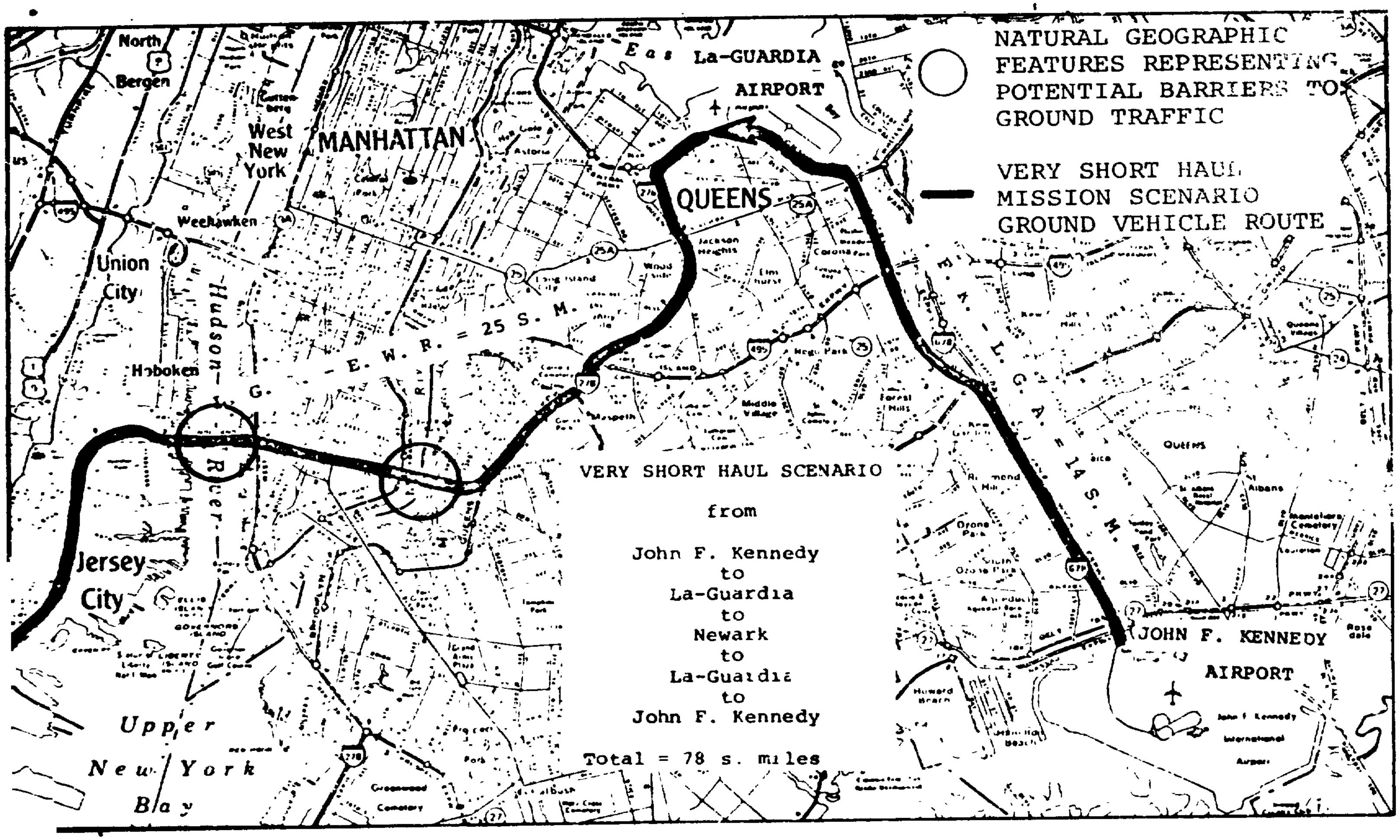


FIGURE 2.3 VERY SHORT HAUL MISSION SCENARIO ROUTE (GROUND VEHICLES)

TABLE 2.5 GROUND VEHICLE (AUTOMOBILE, BUS) MISSION

DATA FOR VERY SHORT HAUL MISSION SCENARIO

STOPS / DISTANCE/SPEED DRIVEN BETWEEN STOPS	JFK	LGA	NEW	LGA	JFK
AIRPORT "TYPE" TRAFFIC	5MI/15 MPH	4MI/15MPH	4MI/15MPH	5MI/15MPH	
URBAN "TYPE" TRAFFIC	----	6MI/40MPH	6MI/40MPH	----	
INTERCITY "TYPE" TRAFFIC	9MI/50MPH	15MI/50MPH	15MI/50MPH	9MI/50MPH	

NOTE

Distance in Statute Miles
Speed in MPH

JFK - J. F. Kennedy International Airport
LGA - La Guardia Airport
NEW - Newark

- MISSION SCENARIO BASED ON NEW YORK AIRWAYS ROUTE FROM:

J. F. KENNEDY INTERNATIONAL AIRPORT
TO
LA GUARDIA
TO
NEWARK
TO
MORRISTOWN, N.J.
TO
NEWARK
TO
LA GUARDIA
TO
J. F. KENNEDY INTERNATIONAL AIRPORT

(TOTAL DISTANCE TRAVELLED - 111.2 N.M.)

- GROUND TRAVEL EQUIVALENT DISTANCE - 154.7 N.M.

FIGURE 2.4 INTERMEDIATE SHORT HAUL MISSION SCENARIO the Very Short Haul scenario. It is the longest route flown by NYA and is only operated three times a week. Table 2.6 shows the time (based on NYA statistics) spent on the ground (engines running) at each stop and the distance flown between stops.

The corresponding ground route, incorporating the Very Short Haul ground route but extending to Morristown, N. J., is illustrated by referring to Figures 2.3 and 2.5. Table 2.7 provides the time spent at each stop and the ground vehicle speeds and distances between stops. Additionally, a hypothetical mission scenario based on covering the same distance overall, but making fewer stops has been derived. Table 2.8 outlines the air vehicle time and distance characteristics for this scenario.

2.2.3 Short Haul Mission Scenario

As noted by Figure 2.6, the short haul mission scenario is based on operation in the Northeast Corridor between Washington, D. C. and New York City. The flight profile utilized by the helicopters assumes the use of an advanced V/STOL aircraft Air Traffic Control (ATC) system defined in Reference 3. This system operates independently of existing fixed wing ATC systems, providing direct airport to airport

TABLE 2.6 HELICOPTER FLIGHT PROFILE DATA FOR INTERMEDIATE SHORT HAUL MISSION SCENARIO

PASSENGER STOPS	JFK	LGA	NEW	LGA	NEW	MMU	NEW	LGA	JFK
TIME SPENT LOADING/ UNLOADING AT EACH STOP (HR)	.0385	.0385	.1585	.0385	.0585	.1285	.1285	.0385	.13
DISTANCE FLOWN BETWEEN STOPS (N.MI)	10.43	15.64	15.64	15.64	13.9	13.9	15.64	10.43	

NOTES:

JFK - J. F. Kennedy International Airport
LGA - La Guardia Airport
NEW - Newark
MMU - Morristown, New Jersey

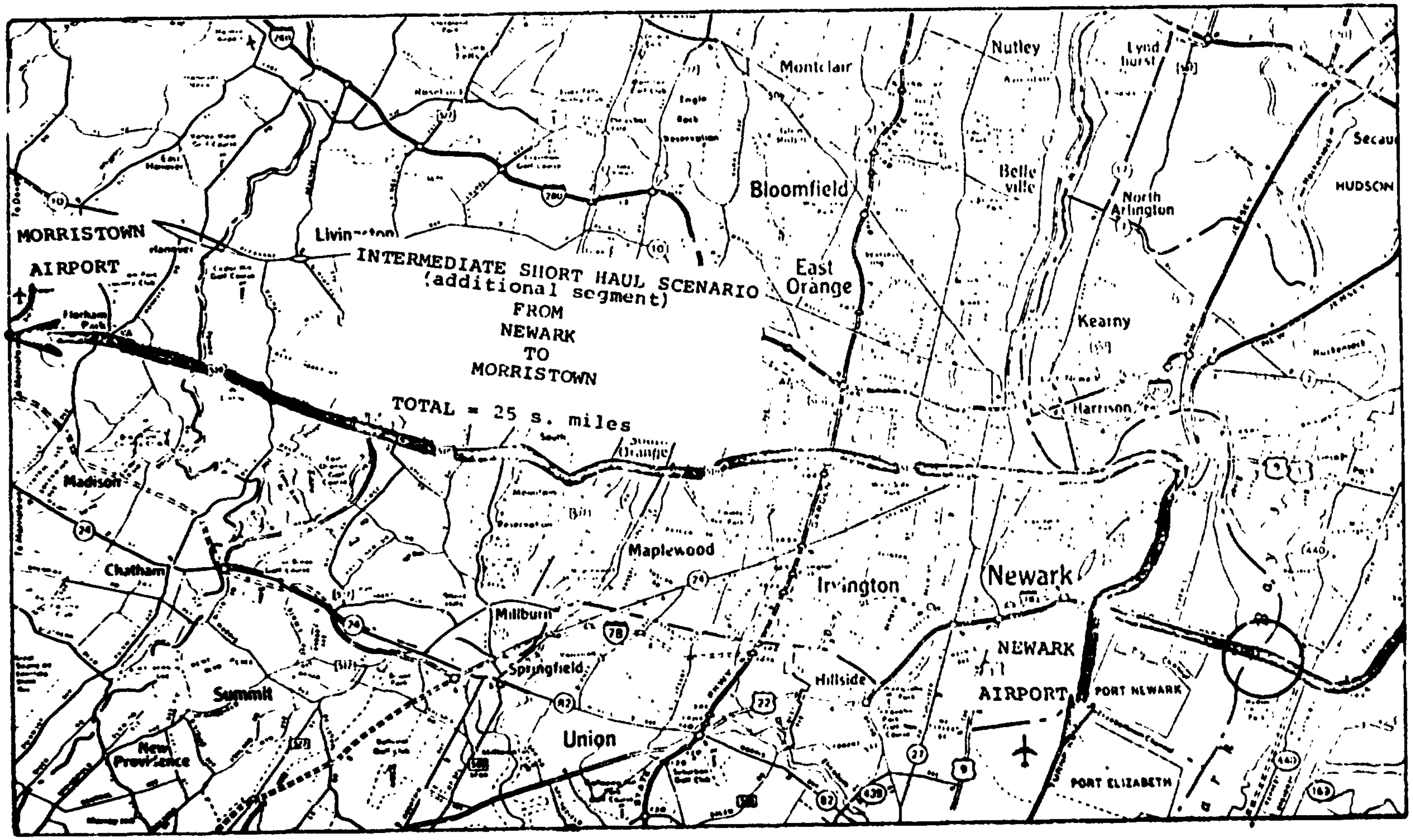


FIGURE 2.5 CONTINUATION OF MAP SHOWING ADDITIONAL GROUND VEHICLE ROUTE FOR INTERMEDIATE SHORT-HAUL MISSION

TABLE 2.7 GROUND VEHICLE (AUTOMOBILE, BUS) MISSION DATA

FOR INTERMEDIATE SHORT HAUL MISSION SCENARIO

DIST/ SPD DRIVEN BETWEEN STOPS / STOPS	JFK		LGA		NEW		LGA		NEW		MMU		NEW		LGA		JFK
AIRPORT "TYPE" TRAFFIC		5Mi/15mph		4Mi/15mph		4Mi/15mph		4Mi/15mph		4Mi/15mph		4Mi/15mph		4Mi/15mph		5Mi/15mph	
URBAN "TYPE" TRAFFIC		-		6Mi/40mph		6MI/40mph		6Mi/40mph		5Mi/25mph 16Mi/35mph		5Mi/25mph 16Mi/35mph		6Mi/40mph		-	
INTERCITY "TYPE" TRAFFIC		9Mi/50mph		15Mi/50mph		15Mi/50mph		15Mi/50mph		-		-		15Mi/50mph		9Mi/50mph	

DISTANCE IN STATUTE MILES
SPEED IN MPH

JFK - J. F. KENNEDY INTERNATIONAL AIRPORT
LGA - LA GUARDIA
NEW - NEWARK
MMV - MORRISTOWN, N. J.

TABLE 2.8 HELICOPTER FLIGHT PROFILE DATA FOR HYPOTHETICAL INTERMEDIATE SHORT HAUL MISSION SCENARIO

PASSENGER STOPS	1	2	3	4	5
TIME SPENT LOADING/UNLOADING AT EACH STOP (HR.)	.0385	.0385	.1285	.0385	.13
DISTANCE FLOWN BETWEEN STOPS (N.MI.)	10.43	45.18	15.18	10.43	

- MISSION SCENARIO BASED ON FLIGHT BETWEEN WASHINGTON NATIONAL AIRPORT AND J. F. KENNEDY INTERNATIONAL AIRPORT

- HELICOPTER FLIGHT PROFILE BASED ON ROTARY-WING FLIGHT PROFILE DEFINED IN AEROSPACE SYSTEMS, INC. TR-74-17 RPT (AV. ALT 2000 FT)

- FIXED WING AIRCRAFT FLIGHT PROFILE BASED ON CLIMB TO TYPICAL CRUISE ALTITUDE (20→25,000 FT) WITH TYPICAL DELAYS AT DESTINATION (JFK) OF 0→30 MIN.

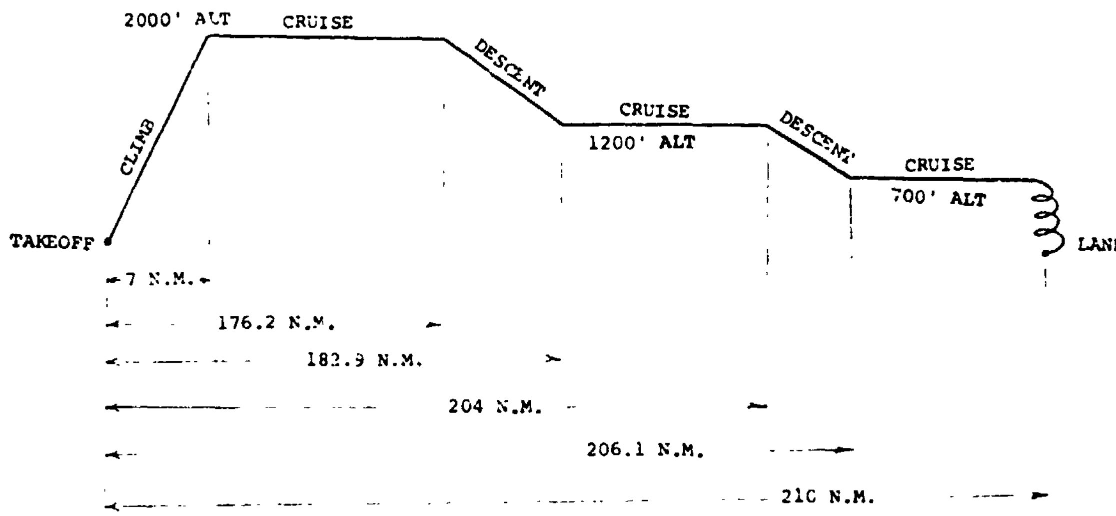
- GROUND TRAVEL EQUIVALENT OF THIS SCENARIO OBTAINED BY USE OF EXISTING HIGHWAYS BETWEEN WASHINGTON - NEW YORK (E.G., ROUTE 495, BALTIMORE - WASHINGTON PARKWAY, I-95, NEW JERSEY TURNPIKE, ETC.)

FIGURE 2.6 SHORT HAUL MISSION SCENARIO DESCRIPTION service with no traffic delays due to interaction with CTOL aircraft. Figure 2.7 illustrates the helicopter flight profile. Specific details as to area navigation waypoints and other details of the navigation system can be obtained from Reference 3. Figures 2.8 and 2.9 outline the fixed wing aircraft flight profiles. These were arrived at after conversations with commercial CTOL operators (United Air Lines, Allegheny Air Lines).

Table 2.9 describes the ground vehicle route, time, distance, and speed for the short-haul route scenario.

2.2.4 Oil Rig Scenario

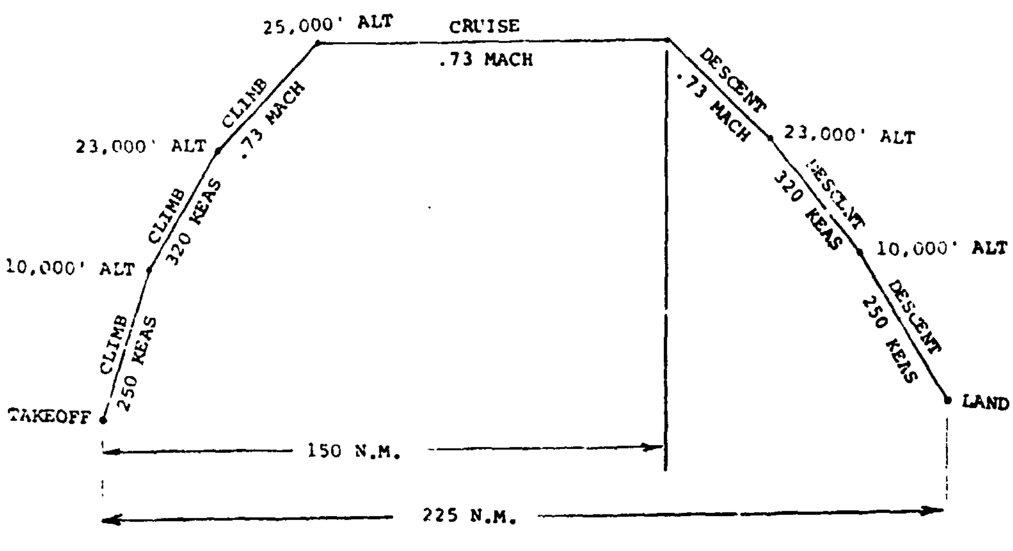
Mission scenario IV assumes operation over the open sea to provide transportation of equipment and personnel to offshore oil rigs. Study vehicles compared include both marine (boats, ACV) and air (helicopter vehicles). In the case of the marine vehicles, direct point to point operation with no delays due to weather is assumed. The operating radius and helicopter flight profile employed were selected on the basis of conversations with Petroleum Helicopters, Inc. (PHI). Figure 2.10 illustrates the typical radius of operation superimposed on a map of the Gulf of Mexico. Figure 2.11 summarizes the helicopter flight path characteristics.



START AT WASHINGTON NATIONAL AIRPORT

1. LOAD, TAXI OUT AIRCRAFT (A/C) - 10 MINUTES (MIN)
2. HOVER FOR 2 MIN AT SEA LEVEL STANDARD (SL STD)
3. CLIMB TO 700 FEET (FT) ALTITUDE (ALT) (STD DAY) REACHING 700 FT AT 2.1 NAUTICAL MILES (N.M.) FROM START
4. CONTINUE CLIMB TO 2000FT ALT (STD DAY) REACHING 2000 FT AT 7.0 N.M. FROM START
5. CRUISE AT 99% BEST RANGE SPEED (99% V_{NMPP}) AT 2000 FT (STD) TO 176.2 N.M.
6. DESCEND TO 1200 FT ALT (STD DAY) REACHING 1200 FT AT 182.9 N.M.
7. CRUISE AT 99% V_{NMPP} AT 1200 FT (STD) TO 204 N.M.
8. DESCEND TO 700 FT ALT (STD DAY) REACHING 700 FT AT 206.1 N.M.
9. CRUISE TO 210 N.M. AT 99% V_{NMPP} AT 700 FT ALT (STD)
10. DESCEND TO SL STD AT 500 FEET PER MINUTE (FPM) AT 60 TO 80 KNOTS (KTS) IN SPIRAL DESCENT
11. HOVER FOR 2 MIN AT SL STD
12. TAXI IN, UNLOAD (A/C) - 10 MIN

FIGURE 2.7 HELICOPTER MISSION PROFILE
SHORT HAUL MISSION SCENARIO

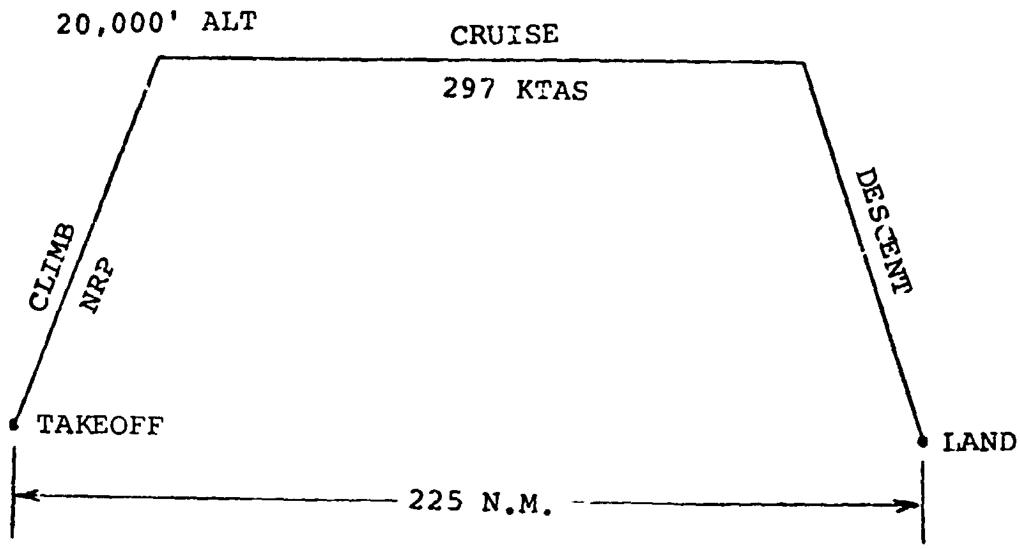


START AT WASHINGTON NATIONAL AIRPORT

1. TAXI FOR 6.5 MIN
2. CLIMB TO 10,000 FT AT 250 KT EQUIVALENT AIRSPEED (EAS)
3. CLIMB TO 23,000 FT AT 320 KT EAS
4. CLIMB TO 25,000 FT AT .73 MACH
5. CRUISE OUT TO 150 N.M. AT .73 MACH (439.2 KTS TRUE AIRSPEED, TAS) AT 25,000 FT
6. DESCEND TO 23,000 FT AT .73 MACH
7. DESCEND TO 10,000 FT AT 320 KT EAS
8. DESCEND TO SL AT 250 KT EAS (MISSION TERMINAL RANGE IS 225 N.M.)
9. TAXI FOR 4.5 MIN (SL, STD)

(ENTIRE MISSION FLOWN AT STD DAY)

FIGURE 2.8 FIXED WING AIRCRAFT (TURBOFAN) MISSION PROFILE SHORT HAUL MISSION SCENARIO



START AT WASHINGTON NATIONAL AIRPORT

1. TAXI FOR 6.5 MIN

2. CLIMB TO 20,000 FT AT MAX RATE OF CLIMB (R/C) NORMAL RATED POWER (NRP)

3. CRUISE AT 20,000 FT AT 297 KT TAS

4. DESCENT TO S.L. (MISSION TERMINAL RANGE IS 225 N.M.)

5. TAXI FOR 4.5 MIN (SL, STD)

FIGURE 2.9 FIXED WING AIRCRAFT (TURBOPROP) MISSION PROFILE
SHORT HAUL MISSION SCENARIO

TABLE 2.9 GROUND VEHICLE (AUTOMOBILE, BUS) MISSION DATA FOR SHORT HAUL MISSION SCENARIO

TYPE OF DRIVING	LOCATION	DISTANCE/SPEED
Urban	Leaving Washington National Airport	2 MI/15 MPH
Urban	City Streets to Highway	6 MI/20 MPH
Intercity	Route 495	9 MI/45 MPH
Intercity	Baltimore-Washington Parkway	29 MI/50 MPH
Intercity	I-95 to N. J. Turnpike	70 MI/50 MPH
Intercity	N. J. Turnpike to Exit 13	105 MI/55 MPH
Intercity	Exit 13 to Belt Parkway	11 MI/50 MPH
Intercity	Belt Parkway to JFK International Airport	17 MI/45 MPH
Urban	Enter JFK International Airport	3 MI/15 MPH

NOTE:

Distance is in statute miles.

Speed is in MPH.

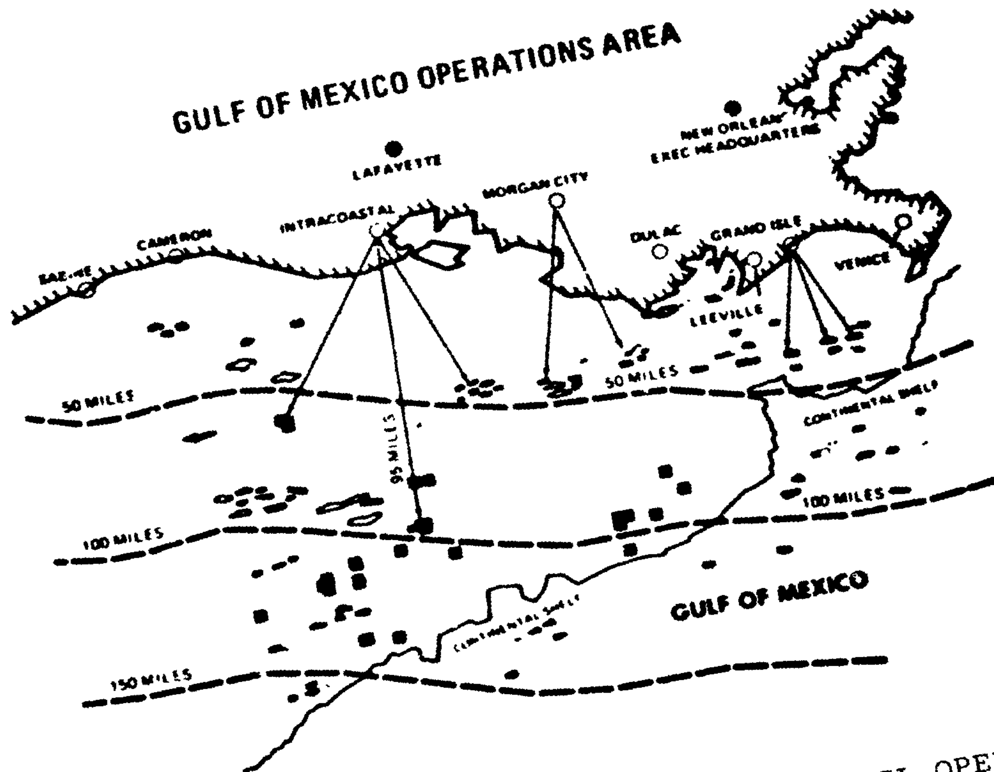


FIGURE 2.10 TYPICAL SUPPORT OF OFFSHORE OIL OPERATIONS

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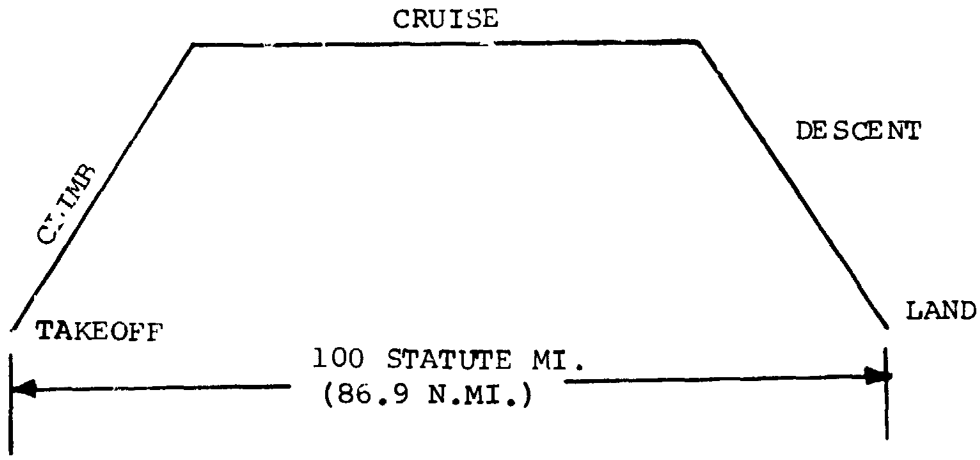


1. HOVER FOR 2 MIN. AT SL, STD

2. CLIMB TO 1000' AT MAX R/C, NRP

3. CRUISE AT NRP @ 1000' TO MAXIMUM RANGE (R_{MAX}) = 86.9 N.M.

4. DESCEND AT MAX. RATE OF DESCENT, 1000 FPM IN SPIRAL DESCENT

5. HOVER FOR 2 MIN. AT SL, STD & LAND

* SIMPLE UNCONSTRAINED FLIGHT PATH BASED ON CONVERSATIONS WITH PETROLEUM HELICOPTERS, INC. (PHI)

FIGURE 2.11 HELICOPTER MISSION PROFILE - OIL RIG SCENARIO*

3.0 DATA BASIS

3.1 Literature Surveyed

The data used as a basis for this study has been derived from three categories. These are:

(1) Currently existing reports and technical papers dealing with energy consumption and related subjects.

(2) Actual operational data.

(3) Informal conversations with aircraft/helicopter operators.

3.2 Ground Vehicle Characteristics

3.2.1 Automobiles

Table 3.1 illustrates typical vehicle fuel consumption rates for automobiles obtained from several data sources. The first set of data (See Reference 1) does not reflect any sensitivity to the type of driving (urban or intercity), or the vehicle speed. It does, however, provide some indication of fuel consumption variation with automobile market classes. The second set of data was obtained from actual comparative road testing of several 1973 Model year automobile classes in an intercity driving situation. The third set of data (Reference 10) was obtained from two sources, the intercity driving data being obtained from Chrysler Corp. test data and the urban driving data coming from the results of the Federal Test Procedure Driving (FTPD) cycle.

Table 3.2 is a listing, by market class and model year of

TABLE 3.1 TYPICAL FUEL CONSUMPTION RATES (AUTO)

REFERENCE	URBAN DRIVING	INTERCITY DRIVING
ASME PAPER 73-ICT-24	LUXURY 12.5 mpg FULL SIZE 13.2 mpg INTERMEDIATE 14.1 mpg COMPACT 17.3 mpg (5-20 mph)	12.5 13.2 14.1 17.3 (40-60 mph)
ACTUAL 1973 MODEL YEAR TEST DATA - FEB., MAR. 1973 CONSUMER RPTS. MAG.	-	STD. SIZE 13.0 mpg COMPACT 17.5 mpg
AEROSPACE CORP. RPT. NO. ATR-74(7307)-1	STD. SIZE 9.5 mpg* COMPACT 14.1 mpg	STD. SIZE 15.0 mpg** COMPACT 20.5 mpg

NOTES:

* - BASED ON DOT FEDERAL TEST PROCEDURE DRIVING CYCLE DATA (URBAN)

** - BASED ON CHRYSLER CORP. TESTS

TABLE 3.2 AVERAGE LOADED WEIGHT (BY MARKET CLASS) OF AUTOMOBILES IN USE IN THE UNITED STATES

Model Year	Loaded Weight by Market Class					U.S. Total, all market classes	
	Standard	Intermediate	Compact	Subcompact	Specialty	Loaded wt	Inertia wt
1958	4115	3491	3341	2268	4245	4014	3967
1959	4273	4076	3197	2269	4263	3971	3955
1960	4367	4056	2979	2344	4230	3863	3836
1961	4275	3287	2955	2389	4284	3712	3712
1962	4278	3234	3023	2388	4468	3751	3743
1963	4223	3345	3013	2341	4418	3735	3742
1964	4241	3480	3021	2087	3600	3742	3726
1965	4305	3618	3128	2098	3454	3829	3805
1966	4361	3663	3123	2209	3508	3878	3831
1967	4425	3750	3154	2243	3597	3888	3857
1968	4452	3803	3241	2302	3445	3891	3863
1969	4548	3805	3174	2323	3915	3934	3941
1970	4588	3955	3174	2393	3939	3870	3876
1971	4708	3982	3278	2439	4136	3869	3886
1972	4781	4087	3327	2514	4253	3960	3942
1973	4907	4309	3424	2589	4348	3972	3968

the average loaded weight of automobiles in use in the U.S. Typical brand name 1973 model year automobiles which fall into the two market classes used in this study (Standard and Compact) are listed in Table 3.3.

Table 3.4 illustrates the results of the Federal Test Procedure Driving (FTPD) cycle as a function of automobile weight and model year. This cycle consists of a 23 min., 7.5 mi. test under simulated commuter-type urban driving conditions. Top speed attained is 57 mph, with the average speed about 20 mph.

In the case of automobiles, as stated in Ref. 2, direct consumption of gasoline is only part of the automotive energy picture. Indirectly - to manufacture, sell, maintain, repair, insure, refine petroleum, and build highways for it - the automobile consumes about 3/5 as much energy as it does directly in gasoline. It is obvious that in a comparison of the indirect energy consumption of helicopters (as well as other aircraft) with automotive vehicles, some charges may be common to both categories. However, the level of energy expenditure for sales, insurance, etc., for helicopters would probably be lower than for automobiles. Furthermore, energy required for the construction of highways would be much higher than that required for the preparation of heliports.

TABLE 3.3 1973 AUTOMOBILE MARKET CLASSES

(STANDARD AND COMPACT)

MARKET CLASS	REPRESENTATIVE VEHICLES
STANDARD	AMC (AMBASSADOR) CHEVROLET (CAPRICE, IMPALA, BISCAYNE, BEL AIR) DODGE (POLARA, MONACO) FORD (LTC, GALAXIE, CUSTOM) PLYMOUTH (FURY, GRAN SEDAN) PONTIAC (CATALINE, BONNEVILLE, GRAND VILLE)
COMPACT	AMC (HORNET) CHEVROLET (NOVA) DODGE (DART) FORD (MAVERICK) PLYMOUTH (VALIANT)

TABLE 3.4 URBAN FUEL ECONOMY (MPG) FOR AUTOMOBILE

FEDERAL TEST PROCEDURE DRIVING CYCLE DATA

Model Year	Inertia Weight, lb										
	1750	2000	2250	2500	2750	3000	3500	4000	4500	5000	5500
57	--	26.4	--	--	--	--	14.7	13.0	--	--	12.5
58	--	25.3	18.2	--	13.2	--	13.6	15.2	12.5	8.6	--
59	--	28.6	--	--	--	15.2	15.0	13.2	12.7	13.8	--
60	--	20.4	-	22.3	24.5	--	15.7	12.4	10.8	10.9	--
61	--	29.4	--	20.9	16.3	17.2	11.4	14.0	10.5	10.6	--
62	--	25.8	--	--	18.0	16.3	13.0	13.8	12.6	10.8	--
63	--	23.2	19.5	--	16.1	14.7	12.6	12.0	11.1	10.6	--
64	--	22.8	--	--	17.3	16.2	13.7	12.9	11.4	11.0	--
65	--	23.8	--	--	18.3	15.2	13.7	12.3	11.7	10.3	--
66	--	20.9	--	12.7	14.9	14.6	13.9	12.3	12.1	11.3	9.3
67	--	22.6	25.7	--	18.7	15.9	13.1	12.1	11.6	11.2	10.3
68	--	19.3	20.5	18.5	19.7	15.6	13.3	12.0	11.3	9.3	--
69	--	22.2	20.3	18.8	--	15.4	13.3	11.9	11.3	9.1	10.8
70	--	23.4	19.3	17.5	18.5	15.9	13.3	12.0	10.9	10.1	9.9
71	27.2	22.6	21.4	19.3	18.3	14.8	12.2	11.7	10.7	9.6	10.9
72	--	23.0	21.9	19.6	20.0	14.4	13.3	11.1	10.7	9.6	9.3
73	24.8	23.8	21.9	19.7	17.5	15.6	13.9	10.8	10.1	9.3	8.6
74	--	--	19.2	19.3	19.7	16.9	15.2	11.1	10.3	9.4	8.3
75	--	--	20.1	17.4	16.6	--	14.3	--	10.1	9.6	8.4

Table 3.5 shows the total energy requirements for automobiles in the U.S. as presented in Reference 2. Note that highway construction alone consumes 1×10^{15} BTU per year, or an additional 11.2% (1/8.94) above that consumed in direct operation. Thus, it would appear that at least 15% of the directly consumed energy can be additionally charged to the direct operating energy expenditure of automotive vehicles to account for highway construction and other indirect expenditures not required for helicopters. In order to appreciate the importance of the absolute value of energy used each year on highway construction, it is sufficient to note that 10^{15} BTU amounts to about 2.4×10^8 barrels of diesel fuel per year, or 8.7×10^5 per day.

Table 3.6 lists bus fuel consumption data from several of the documents surveyed in the literature search. As can be seen, data from all sources surveyed are remarkably consistent. The values selected for use in this study (indicated in Table 3.7) are for a 46 passenger Eagle Coach as operated by Continental Trailways. It should be pointed out that these data can be considered quite typical of intercity buses in use in the U. S. As noted in Reference 10, government regulations prescribed vehicle external dimensions and engine sizes, so that although different bus lines rely on various coach manufacturers for their equipment, the resulting vehicles are very similar in size and performance.

TABLE 3.5 TOTAL ENERGY REQUIREMENTS FOR

AUTOMOBILES IN THE UNITED STATES

	(10^{15} BTU)
GASOLINE CONSUMPTION	8.94
GASLINE REFINING AND RETAIL SALES	2.07
OIL CONSUMPTION, REFINING, RETAIL SALES	0.11
AUTOMOBILE MANUFACTURING	0.80
AUTOMOBILE RETAIL SALES	0.21
REPAIRS, MAINTENANCE, PARTS	0.37
PARKING, GARAGING	0.44
TIRE MANUFACTURING AND RETAIL SALES	0.23
INSURANCE	0.31
HIGHWAY CONSTRUCTION	1.00
TOTAL	14.48

NOTE: This data is for calendar year 1970 and is based on the following sources:

(1) Federal Highway Administration, "Highway Statistics, 1970"
(2) U.S. Bureau of the Census, "Statistical Abstract of the U.S., 1971"
(3) Federal Highway Administration, "Cost of Operating an Automobile," Feb. 1970
(4) Automobile Manufacturers Assn., "Automobile Facts and Figures, 1971"
(5) American Petroleum Institute, "Petroleum Facts & Figures", 1971

TABLE 3.6 TYPICAL BUS FUEL CONSUMPTION RATES

REFERENCE	URBAN DRIVING	INTERCITY DRIVING
AEROSPACE CORP. RPT. NO. ATR-74(7307)-1	4.2 mpg	7.0 mpg (55 mph)
ASME PAPER 73-ICT-24	4.1 mpg (5-15 mph)	7.0 mpg (40-60 mph)
MISCELLANEOUS UNPUBL. DOT/COMMERCIAL DATA	4.6 mpg	5.6 - 6 mpg

TABLE 3.7 GROUND VEHICLE FUEL CONSUMPTION

VALUES SELECTED FOR STUDY

VEHICLE	URBAN DRIVING	INTERCITY DRIVING
STD. AUTO.	9.5 S.M./GAL* (PER VEHICLE)	13.0 S.M./GAL** (PER VEHICLE)
COMPACT AUTO.	14.1 S.M./GAL* (PER VEHICLE)	17.5 S.M./GAL** (PER VEHICLE)
BUS	4.2 S.M./GAL** (PER VEHICLE) (.656 GAL/HR - IDLE)	7.0 S.M./GAL** (PER VEHICLE)

NOTE: DURING COMPUTATION OF FUEL USED IN MSN SCENARIOS, 10% PENALTY ADDED TO ACCOUNT FOR CURVES, HEADWINDS, ETC.

* BASED ON DOT FEDERAL TEST PROCEDURE DRIVING CYCLE DATA
** BASED ON ACTUAL VEHICLE TEST DATA

Energy consumption for a typical train is based on data developed in Reference 10. This data, in turn, was calculated based on the performance and operational characteristics of the Penn Central Metroliner, operating between Washington, D.C. a, New York City.

3.3 Air Vehicle Characteristics

Of the air vehicles chosen for comparison, the S-61L, Convair 580, and Boeing 737 represent aircraft technology of the 1960 time period. The Boeing Vertol Model 347-108 helicopter is also representative of 1960 technology, but with updates in the area of propulsion and controls. The TH-100 (92.3) is representative of a vehicle designed to utilize advanced technology, and is based on technology trends projected for the 1985 time period. Although not considered in this study, it is conceivable that the future will bring substantial improvements in CTOL aircraft fuel consumption. Table 3.8 provides fuel consumption values for the engines utilized by the air vehicles referenced to sea level standard. Note that these are for reference only. The actual fuel consumption during the mission is dependent on aircraft throttle settings employed during the mission. Table 3.9 is a summary of study vehicle characteristics (i.e., weight, installed power, etc.).

3.4 Passenger Load Factor Selection

Table 3.10 illustrates the range of load factors values obtained (and their sources) from the literature surveyed. From these data, the load factors shown in Table 3.11 were selected for use in the study. Load factors actually

TABLE 3.8 TYPICAL AIR VEHICLE FUEL CONSUMPTION RATES

	VEHICLE	ENGINE	INSTALLED POWER (SHP)	SPECIFIC FUEL CONSUMPTION (#/HR/HP) @ MAX PWR (SL,STD)
HELICOPTERS	S-61L	GE CT58-140-2	1534	.61
	347-108-I	ALL. T-701	8870	.424
	TH-100 (92.3)	ADVANCED ENGINE BASED ON AVCO LYCOMING LTC4V-1	4824	.415
FIXED WING A/C	BOEING 737-100	P&WA JT8D-7	14,000 LB*	.59 (TSFC)**
	CONVAIR 580	ALL 501-D13	3750	.54

* - THRUST
** - THRUST SPECIFIC FUEL CONSUMPTION (# FUEL/HR/# THRUST)

NOTE: SFC's ARE FOR REFERENCE ONLY. THEY ARE NOT CRUISE SFC's.

TABLE 3.9 STUDY VEHICLE CHARACTERISTICS

CLASS	VEHICLE	TYPICAL GW (LB)	EMPTY WEIGHT (LB)	INSTALLED POWER (HP)	NO. OF ENGINES	PASS. CAPAC.
T/SHAFT HELOS	S-61L	19,000	11,191	3068	2	28
	347-108-I	52,100	32,816	17740	2	50
	347-108-II	52,100	31,656	8870	2	50
	347-108-IIa	52,100	31,656	8870	2	50
	TH-100(92.3)	67,175	40,181	14472	3	100
T/FAN F/W A/C	737-100	111,000	59,650	28,000 LB (THRUST)	2	112
T/PROP F/W A/C	CONVAIR 580	54,600	32,333	7500	2	53
DIESEL	BUS	38,000	-	290	1	46
GASO.	STD AUTO	4,900	-	250	1	5
GASO.	COMPACT AUTO	3,400	-	140	1	4
ELECTRIC	TRAIN	186,000*	-	2400*	4*	386

* PER METROLINER CAR

TABLE 3.10 TYPICAL PASSENGER VEHICLE LOAD FACTORS

	TYPE OF VEHICLE	LOAD FACTOR
URBAN	AUTOMOBILE[2]	28% (1.4 pass/car)
	AUTOMOBILE[10]	30% (1.5 pass/car)
	TAXI[11]	24% (1.2 pass/car)
	PUBLIC TRANSPORT[2] (BUS, ETC.)	20%
	HELICOPTER	50.5%
INTERCITY	AUTOMOBILE[2]	48% (2.4 pass/car)
	AUTOMOBILE[10]	52% (2.6 pass/car)
	AUTOMOBILE	44% (2.2 pass/car)
	BUS[1,2,7]	40 → 45%
	TRAIN[1,2,7]	33 → 35%
	AIR VEHICLES (HELICOPTER AND FIXED-WING)	45 → 80%

TABLE 3.11 VEHICLE LOAD FACTORS SELECTED FOR STUDY

	TYPE OF VEHICLE	LOAD FACTOR
URBAN	AUTOMOBILE	1.2 pass/car
	PUBLIC TRANSPORT (BUS, ETC.)	20%
	HELICOPTER	50.5%
INTERCITY	AUTOMOBILE	2.2 pass/car
	BUS	45%
	TRAIN	35%
	AIR VEHICLES (HELICOPTER & FIXED-WING)	60,70,80,100%

encountered depend on many operational and psychological factors. Where public transportation is concerned, it is usually impossible to adjust the number of seats available to the fluctuations of the traffic flow between rush hours and slack periods. For this reason, the average load factors of urban public transportation is relatively low.

In inter-urban transportation, the load factors of railroads and buses are somewhat higher, but still appear lower than in short-haul aviation. The automobile shows quite low statistical load factors, both in urban and inter-urban transportation (1.2 to 1.4 passengers/vehicle in the first case and less than 2 in the second one). These low load factors are strongly influenced by psychological aspects which, until recently, represented an accepted way of life. Because of the extreme operational flexibility of the automobile and, until recently, very small out-of-pocket costs (in 1970, amounting to about 5¢ per mile in urban and 2¢ per mile in inter-urban travel), there is a natural tendency to use the automobile regardless of whether there is a need or simply a desire to move from one place to another. The increasing cost of gasoline, parking, road tolls, etc., may change or curtail the indiscriminate use of automobiles and thus, contribute to an increase of the load factor. However, as indicated in Reference 2, statistics obtained for 1970 show a nationwide average factor of 1.9 passengers per car and 1.4 in urban operations. Surveys conducted in New York in 1973-74 (reported in Reference 11) gives an even lower figure of 1.2 passengers per vehicle as a level for urban load factor.

It should be noted that the assumption of a 35% passenger load factor for the train compared in the short haul scenario does not necessarily reflect the actual operational load factor values for the Metroliner itself, but only the observed load factors for typical intercity trains in the period 1950 → 1970, as reported in References 1, 2 and 7. In fact, current observations of passengers riding the Metroliner between New York City and Washington, D. C. would support the assumption of load factors on the order of 60 → 80%. Therefore, in the short haul mission scenario comparison, energy consumption values are illustrated for the train at both 35 and 80% passenger load factors.

For the very short haul scenario, the 50.5% load factor used is based on actual operational data obtained from New York Airways. Table 3.12 illustrates typical variations in passenger load factors as reported by the CAB. These numbers serve to illustrate the variation in passenger load factor that occurs when the overall average data is broken down and compared in different ways. However, even these "broken down" numbers reflect an overall average of the various stage length routes within a given category. Therefore, since load factors for individual routes were so difficult to isolate, energy consumption values for the various air vehicles were computed for a range of assumed load factors (60 → 100%).

TABLE 3.12 TYPICAL VARIATION IN AIRLINE PASSENGER LOAD FACTORS

PASSENGER (%) LOAD FACTOR AV. BASED ON	TOTAL DOMESTIC OPERATIONS	LOCAL SERVICE ONLY	BY AIRLINE ONLY	
			ALLEGHENY	UNITED
AIRCRAFT UTILIZED				
BOEING 737	55.3	51.7	—	57.5
CONVAIR 580	49.3	49.3	51.0	48.6

REF: HANDBOOK OF AIRLINE STATISTICS, 1973 EDITION

4.0 RESULTS

4.1 Mission Scenario Energy Consumption Calculations

Energy Intensity, referred to in the following sections is a measure of the energy consumed per unit passenger carried and unit distance travelled, or

$$\text{Energy Intensity} = \frac{\text{Energy Consumed}}{\text{Passenger carried} \times \text{Distance travelled}}$$

where the energy consumed is calculated from the amount of fuel consumed times the fuel heating value. Table 4.1 lists the heating values obtained from the literature search, used in this study.

Fuel consumption for the rotary-wing and fixed-wing aircraft was calculated, based on the Mission scenarios, using the HESCOMP and VASCOMP II computer programs, respectively. (see Appendix A and References 17 and 18) Fuel consumption for the surface transportation vehicles was calculated using the vehicle miles per gallon and mission scenarios discussed.

4.1.1 Very Short Haul Mission Scenario

Figure 4.1 illustrates the comparative energy expenditures of the vehicles considered in this study on the very short haul mission scenario. As discussed previously, the mission scenario (including air and ground routes) and helicopter passenger load factor (50.5%) utilized is based on New York Airways' operational data. The automobile passenger load factor (1.2 passengers/vehicle) is based on statistical surveys of urban driving habits. The dashed line increment added to the bar charts for

TABLE 4.1 ENERGY CONVERSION FACTORS

ENERGY UNIT	BTU/LB	BTU/GAL	DENSITY (LB/GAL)
JET FUEL (LB) (AV. OF VALUES FOR JP-4, JP-5, A-1	18,400	123,648	6.72
DIESEL FUEL (GAL)	18,500	138,195	7.47
GASOLINE (GAL)	20,000	117,400	5.87
ELECTRICITY (KWHR)	3413 BTU/KWHR	-	-

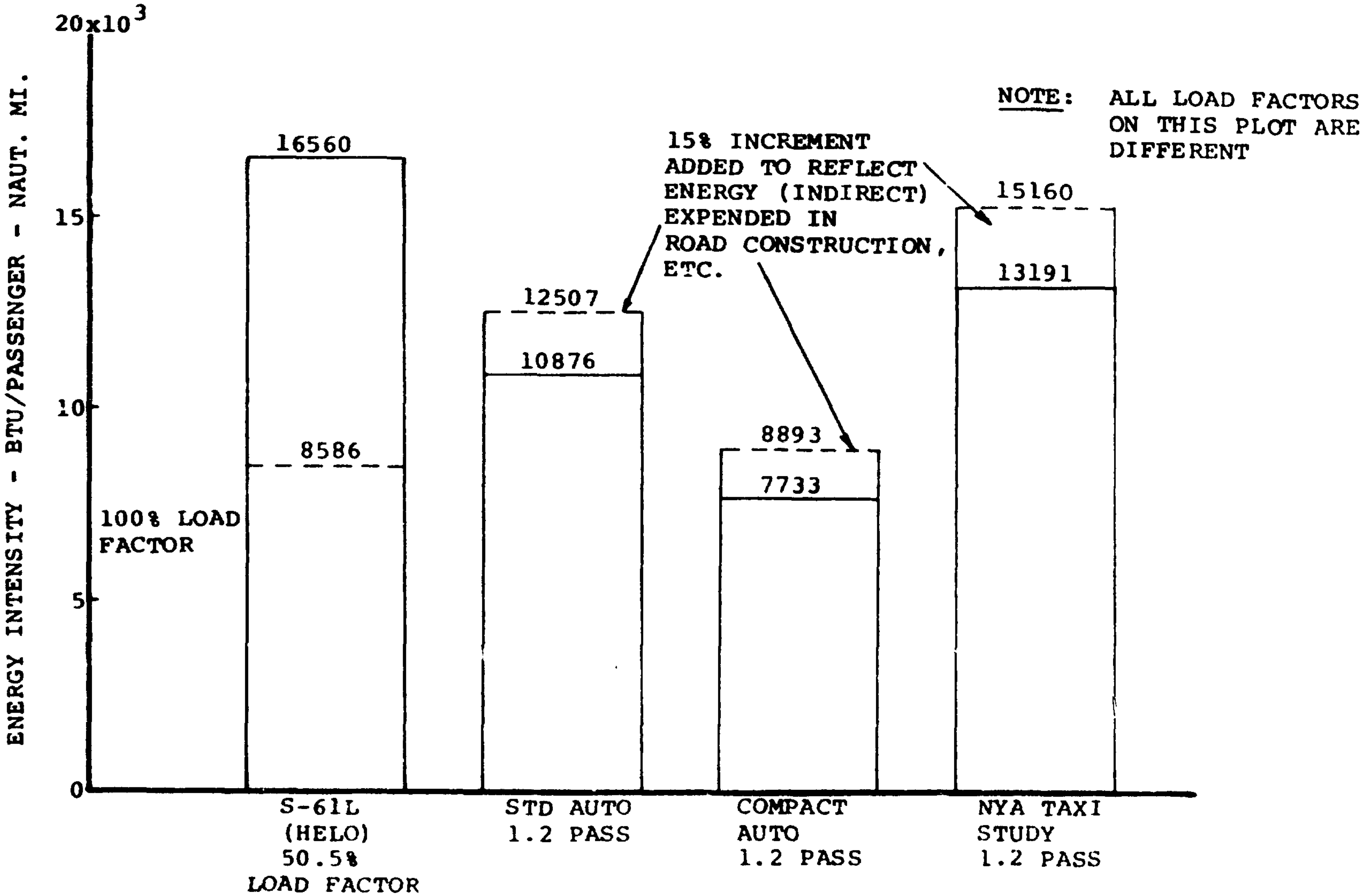
REFERENCE DATA

MARK'S ENGR. HANDBOOK, 7TH ED. 1967
P&W A/C AERO HANDBOOK 1966
AIRCRAFT FUELS

$1 \text{ GAL} = 7.481 \text{ FT}^3$

FIGURE 4.1 VEHICLE ENERGY INTENSITY COMPARISON

VERY SHORT HAUL MISSION



the three ground vehicles compared reflects the added increment in energy (15%) required if the indirect energy expenditures (road construction, etc.) discussed previously are considered.

The NYA-Taxi bar chart was obtained from the results of a recent study conducted for New York Airways. Note that the energy consumption is approximately 20% higher than that of the standard size automobile considered in the present study. This serves to illustrate the variation in results that is possible due to variation in automobile fuel consumption, which is heavily influenced by factors such as model year, vehicle maintenance, etc.

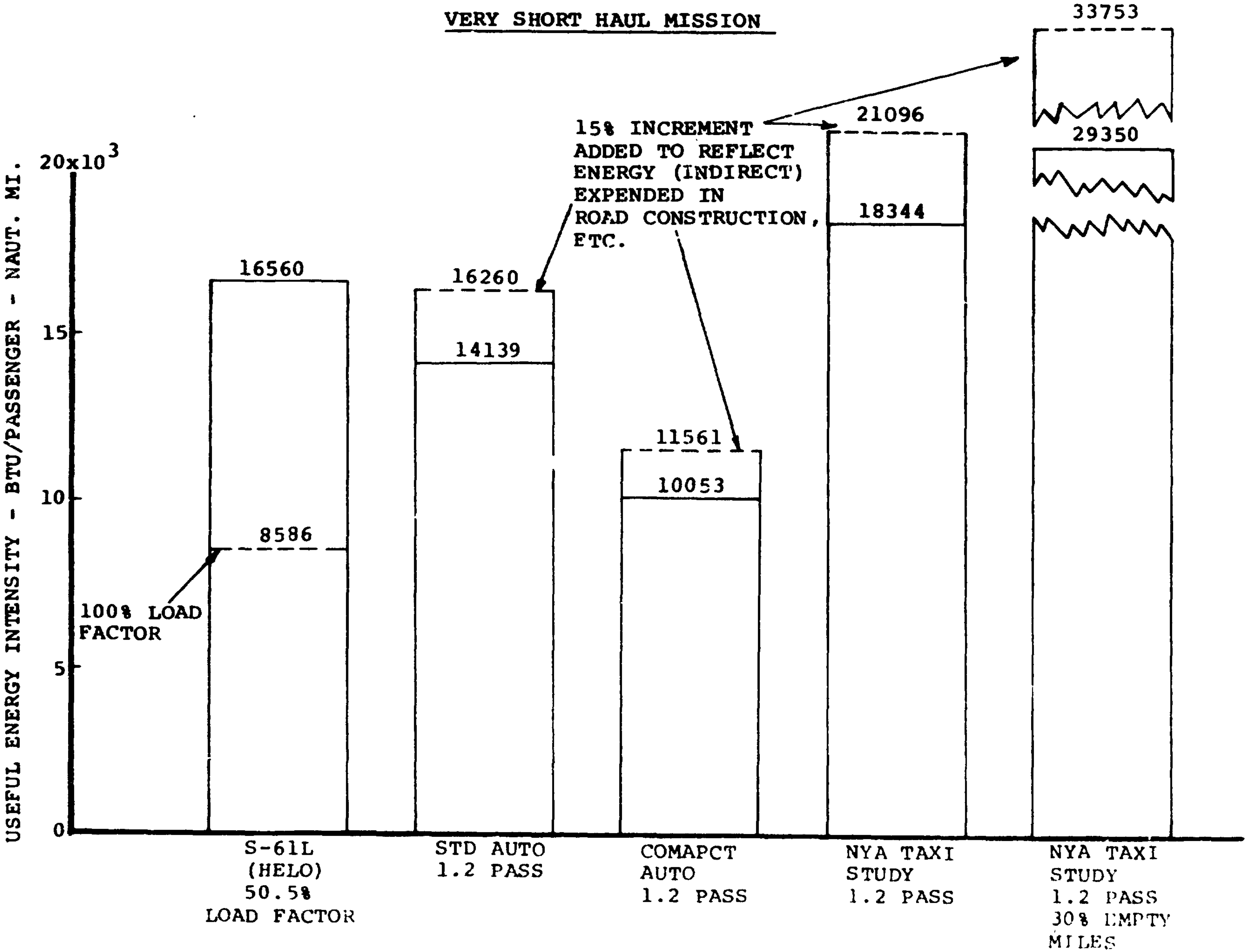
Note that if the helicopter passenger load factor was increased to approximately 75%, the energy intensity of the standard-size automobile and helicopter would be equal.

Figure 4.2 illustrates comparative energy consumption related on a "useful" energy intensity basis.

As previously noted, energy intensity is simply a measure of energy consumed per passenger - mile. Therefore, useful energy intensity, by definition, implies that not all energy expended by a vehicle performs a useful task (i.e. part of it is wasted). For the purpose of this study, useful energy intensity will be determined on the basis of useful mileage travelled. As an example, consider the following. In the very short haul

FIGURE 4.2 VEHICLE USEFUL ENERGY INTENSITY COMPARISON

VERY SHORT HAUL MISSION



mission scenario, the ratio of surface/air miles travelled is 1.3. The increased surface mileage between the starting point and the final destination is simply a reflection of physical constraints (e.g. geographical features, existing roadways, etc.) on surface travel between these two points. In comparison, the helicopter is subject to none of these constraints and follows a straight line path between the starting and ending points. Therefore, in any comparison of ground and air vehicles, the extra ground mileage travelled relative to the air mileage must be considered wasted since it in no way adds to that vehicle's ability to perform its function, but instead constitutes a penalty.

In this scenario, the useful ground mileage is only 77% (1/1.3) of the total surface distance travelled. Rereferencing the ground vehicle energy intensity data of Figure 4.1 (The helicopter data remains unchanged, since 100% of its travel distance is useful.) in terms of useful distance travelled, viz

$$\text{Useful Energy Intensity} = \frac{\text{Energy Consumed}}{\text{Passenger Carried} \times \text{Useful Distance Travelled}}$$

results in the data of Figure 4.2. When considered on this basis, the helicopter is competitive with the automobile, and is in fact superior when compared with the NYA-Taxi Study data.

The last bar graph in Figure 4.2 represents the energy consumption of a taxi when empty miles are subtracted from the useful mileage. (Empty miles are those miles driven by the taxi in which no passenger is carried, say between fares.)

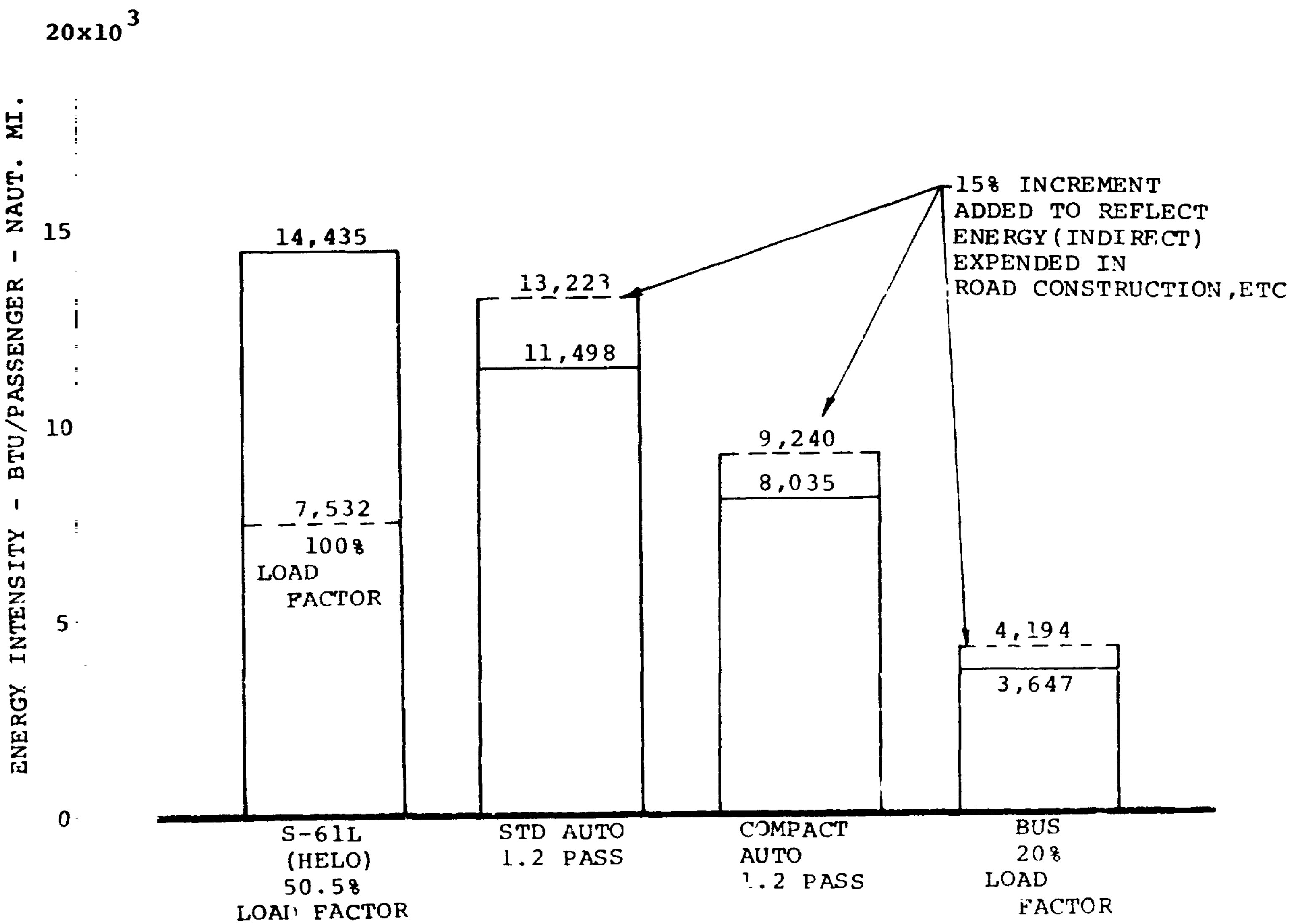
4.1.2 Intermediate Short Haul Mission Scenario

Figure 4.3 illustrates the relative energy consumption employed in a hypothetical intermediate short-haul mission. The data for the New York Airways intermediate short-haul mission described in Section 2.2.2 is not shown as it included an unrealistic number of stops resulting in an increase in fuel consumption over the very short-haul scenario. In addition to the other ground vehicles, a diesel-powered intercity bus is added for comparison. Even though possessing poor vehicle fuel consumption (4.2 mpg [statute] - urban driving, 7.0 mpg [statute] - intercity driving), because of the larger number of passengers carried, (compared to the automobile), the resulting energy intensity of the bus is quite low. Its major disadvantage, as with all ground vehicles, however, are the physical constraints placed upon it by having to operate within existing raodways, with consequent wasted miles and increased travel times.

The hypothetical intermediate short-haul mission scenario more accurately reflects the flight time/block time ratio that would be expected in an intermediate short-haul mission. This

FIGURE 4.3 VEHICLE ENERGY INTENSITY COMPARISON

HYPOTHETICAL INTERMEDIATE SHORT HAUL MISSION



scenario has the same stage length, but eliminates some of the stopovers, resulting in an increase in the flight time/block time (71.8%) ratio. Figure 4.3 illustrates the relative energy consumption of the vehicles employed in this modified scenario. Note that the energy intensity is now less than that for the Very Short Haul mission scenario and the helicopter is much more competitive with the automobile. Figure 4.4 illustrates the useful energy intensity of the study vehicles for both the primary and modified Intermediate Short Haul Mission Scenarios.

Note that on a useful energy basis, the helicopter operating at a 50.5% load factor with the modified mission scenario is definitely superior to the standard size automobile.

4.1.3 Short Haul Mission Scenario

Figure 4.5 shows the relative energy consumption of vehicles employed in the short haul mission scenario. As outlined previously in Section 3.4, all passenger load factors are based on results quoted from references surveyed during the literature search. Note that energy consumption data for a train has been included in this comparison. Energy consumption data for this train, an improved metroliner, was obtained from Reference 10.

FIGURE 4.4 USEFUL VEHICLE ENERGY INTENSITY COMPARISON

HYPOTHETICAL INTERMEDIATE SHORT HAUL MISSION

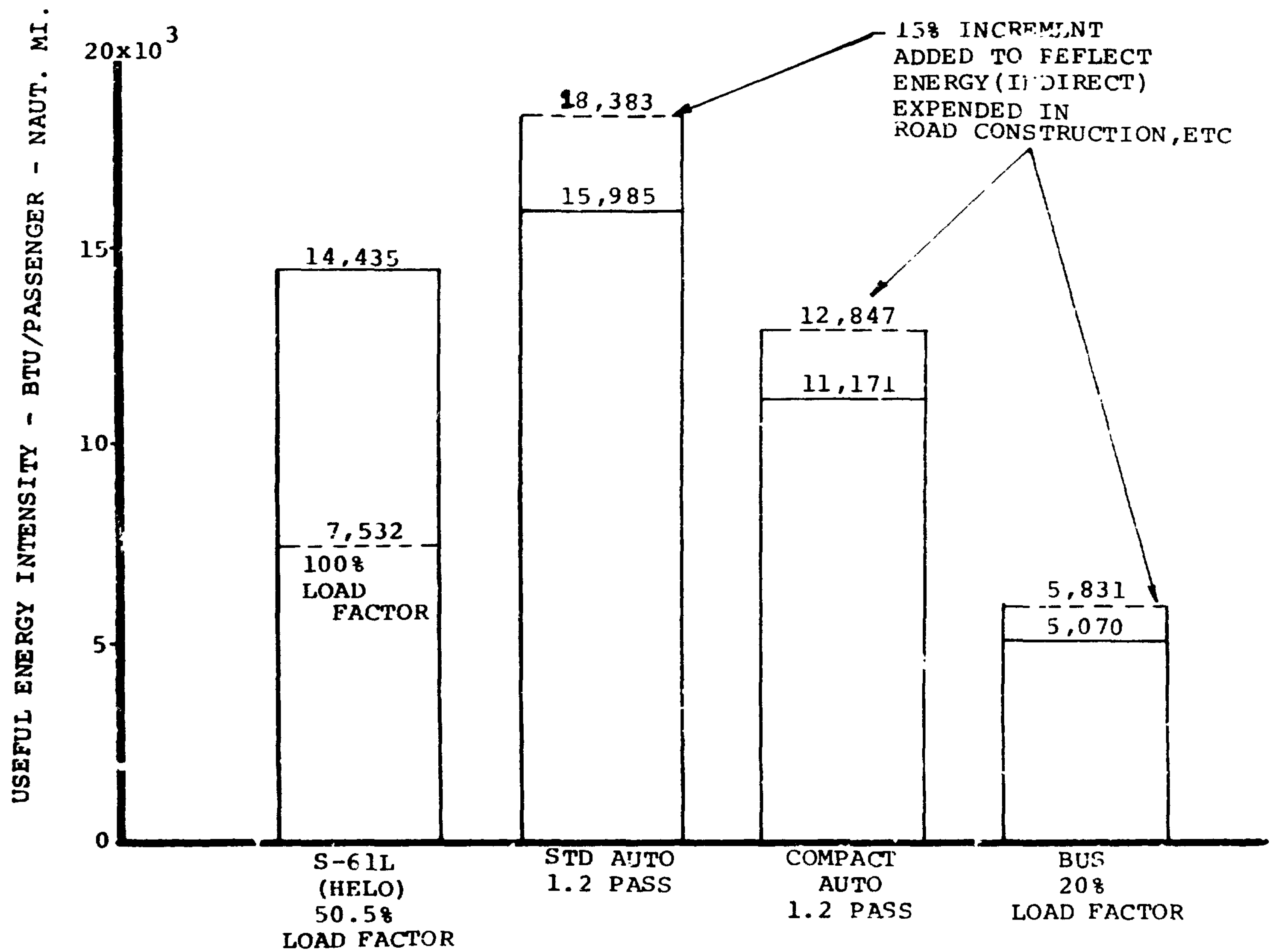
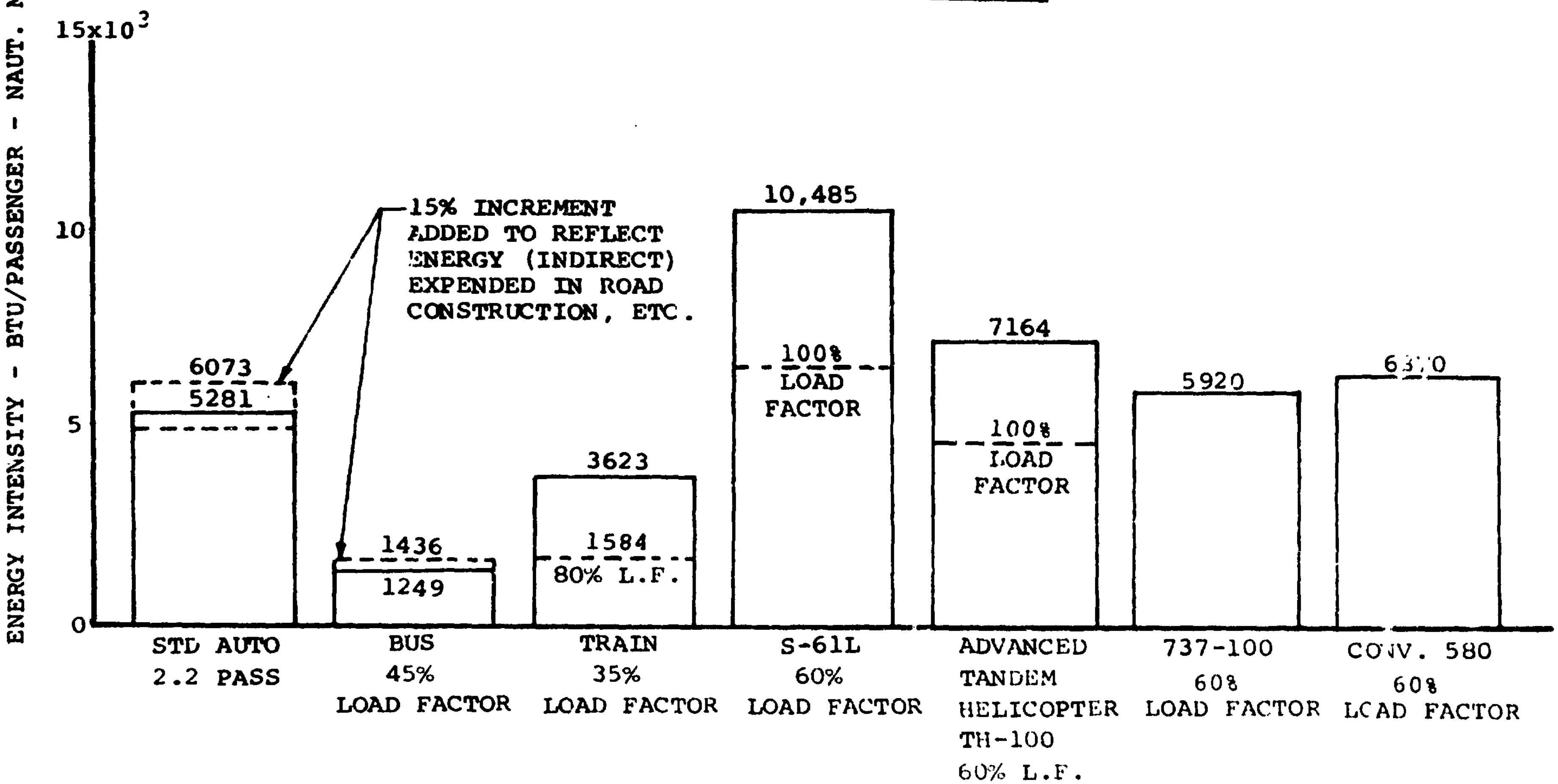


FIGURE 4.5 VEHICLE ENERGY INTENSITY COMPARISON

SHORT HAUL MISSION (NEW YORK-WASHINGTON)



Note that with the increase in flight time/block time ratio (82.2%), helicopter energy consumption has decreased. To indicate the potential for improvement in helicopter energy consumption, an advanced technology tandem rotor helicopter (covered in more detail in Section 4.2.1 and Reference 5) is included in the comparison.

As discussed previously, helicopters utilize an Air Traffic Control (ATC) network which is independent of the conventional aircraft air traffic control system resulting in direct airport to airport travel with no delays. The fixed wing aircraft data presented assumes a representative maneuvering (or traffic pattern) time of 13 min., and with extreme weather or traffic conditions actual delays of 1/2 hour or more, with resulting large increases in energy consumption, are possible. Figures 4.6 and 4.7 show fixed-wing aircraft energy intensity as a function of maneuver time. Figure 4.8 shows vehicle energy consumption in terms of "useful" energy. In actual operations, the helicopter could be further enhanced over fixed-wing aircraft and trains by operating from multiple near city-center heliports eliminating substantial amounts of ground transport energy that would be expended by travelers traveling to suburban airports or a single train station.

FIGURE 4.6 FIXED WING AIRCRAFT (TURBOFAN) ENERGY INTENSITY AS A FUNCTION OF MANEUVER TIME

(SHORT HAUL MISSION SCENARIO)

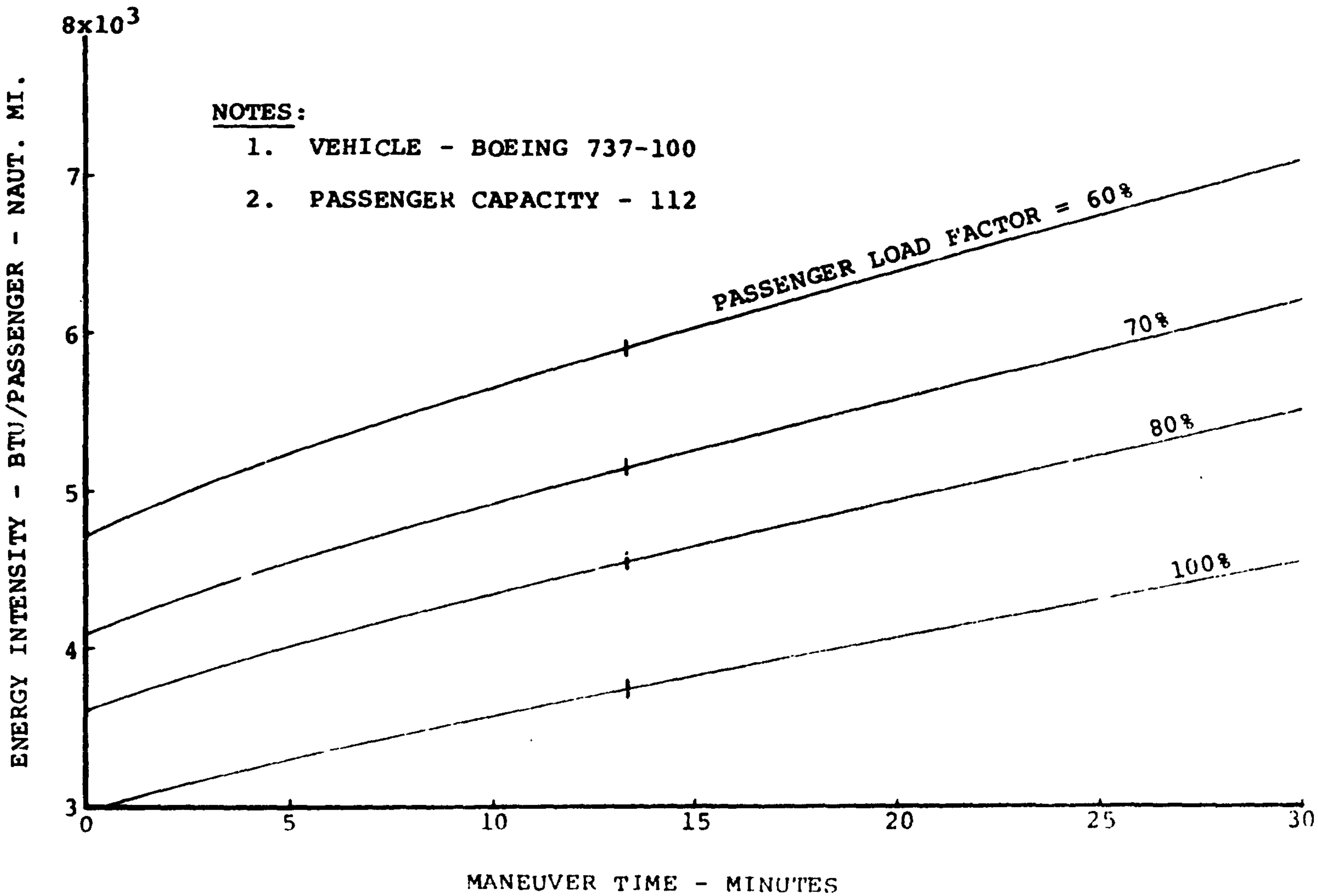


FIGURE 4.7 FIXED WING AIRCRAFT (TURBOPROP) ENERGY INTENSITY AS A FUNCTION OF MANEUVER TIME (SHORT HAUL MISSION SCENARIO)

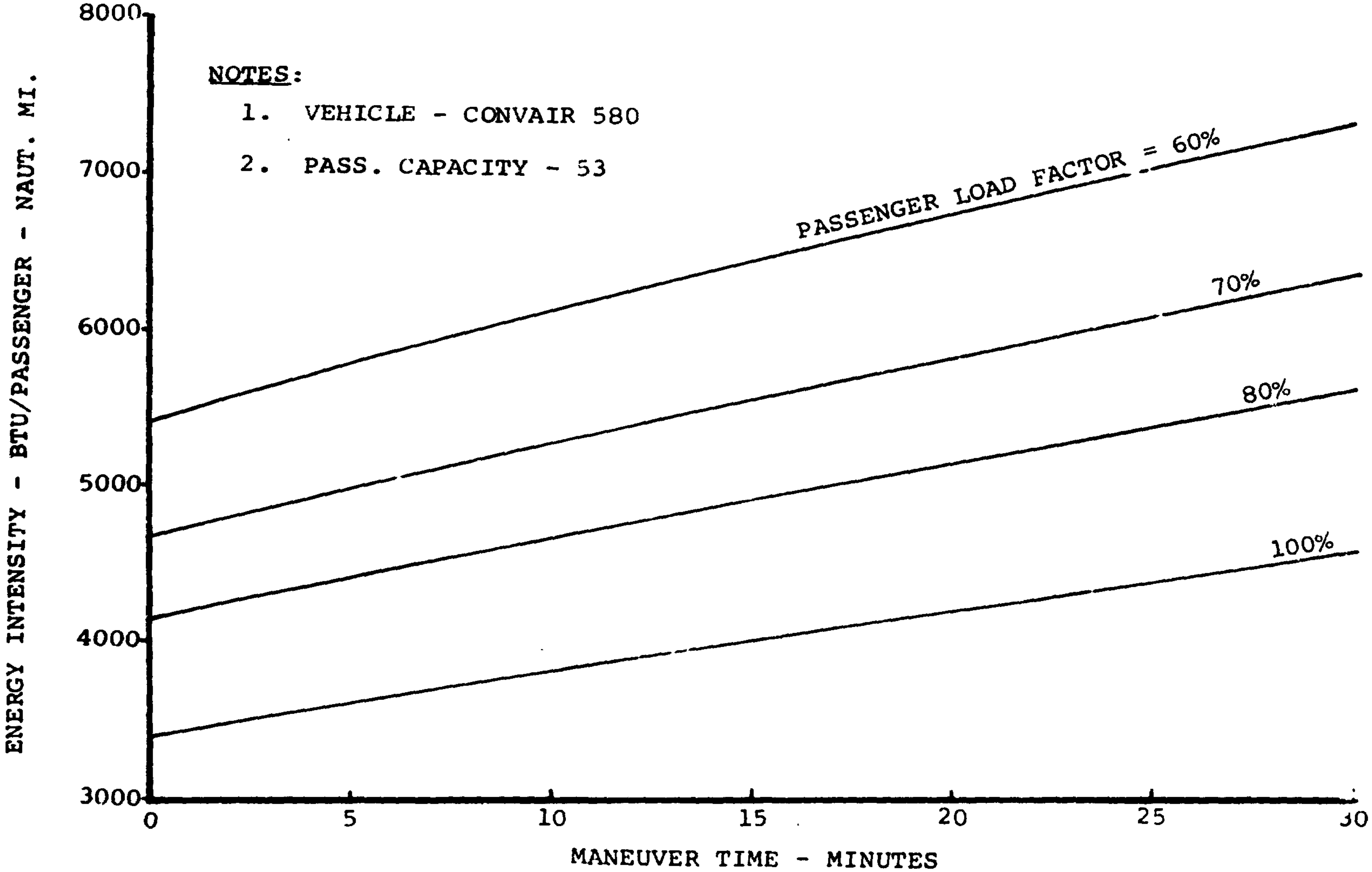
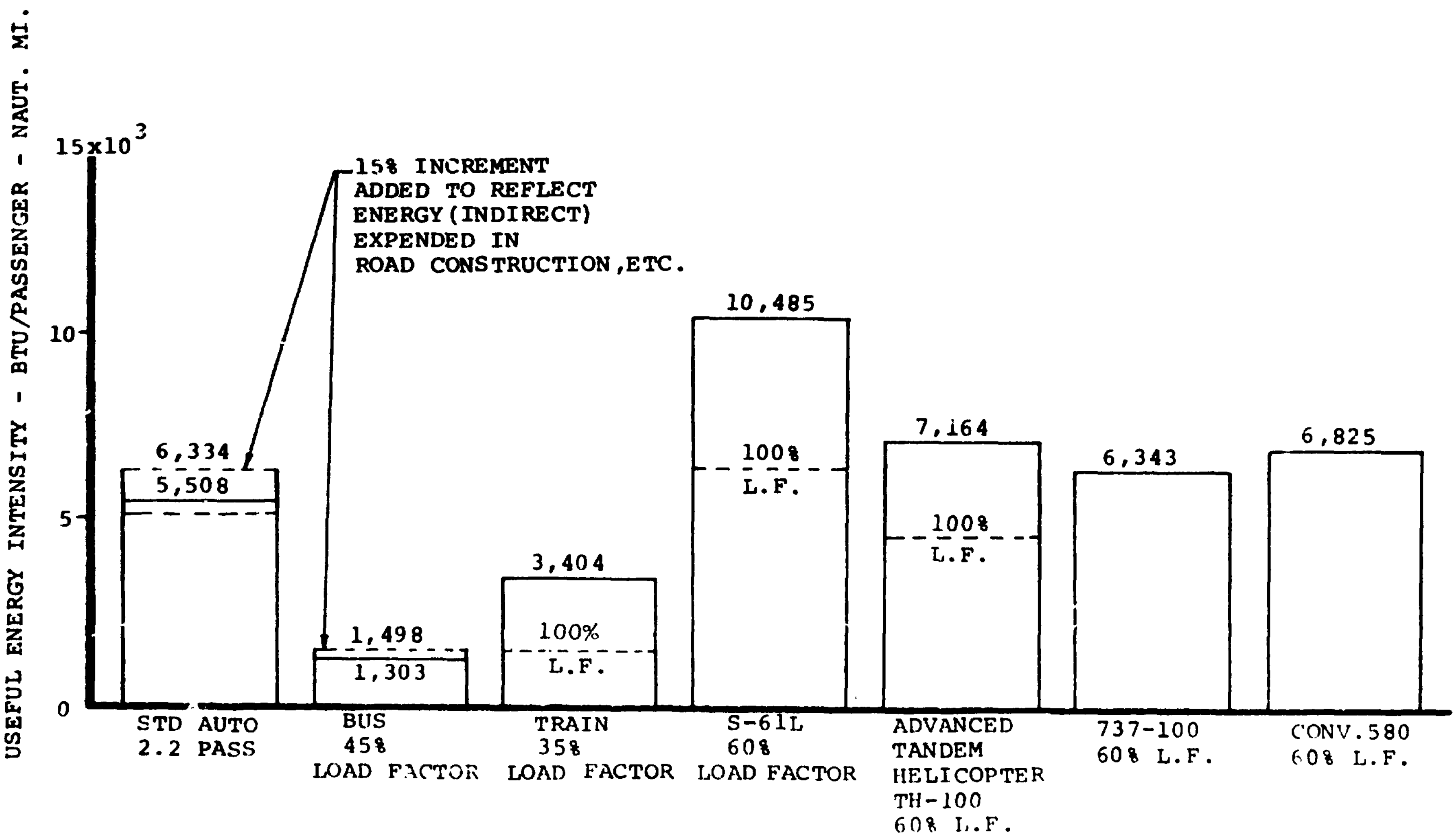


FIGURE 4.8 VEHICLE USEFUL ENERGY INTENSITY COMPARISON

SHORT HAUL MISSION

(NEW YORK - WASHINGTON)



4.1.4 Oil Rig Mission Scenario

Figure 4.9 illustrates the comparative energy expenditures of the vehicles operating in the oil rig mission scenario. As previously stated, the mission scenario is based on conversations with Petroleum Helicopters Inc. It is noteworthy that for this type of mission, the operator is more concerned with speed (minimizing travel time to the destination) than with possible economies in energy consumption. This is because of the high cost of labor and the resultant high costs incurred during delays in oil drilling operations.

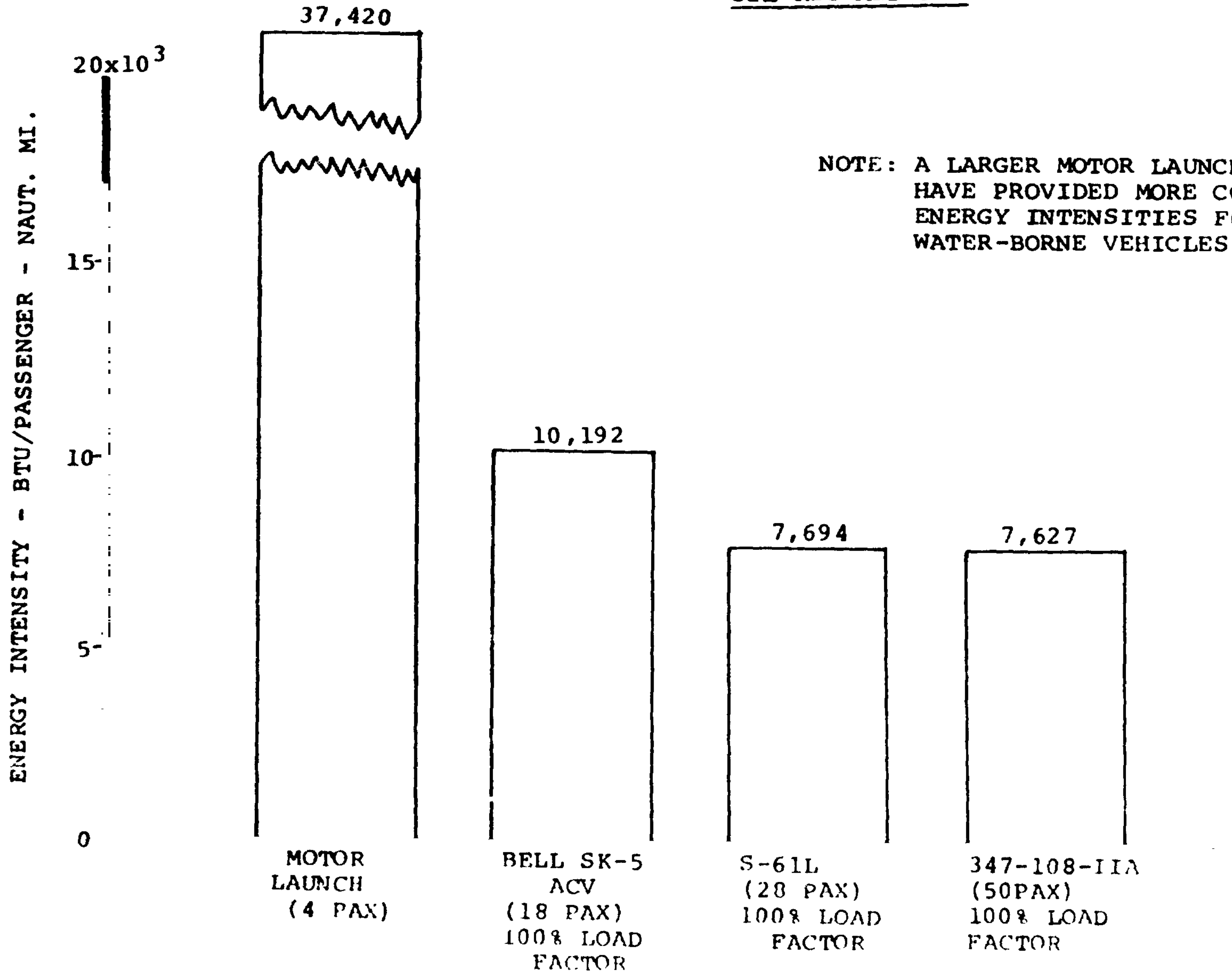
The motor launch energy consumption is based on data from Reference 8. The Bell Sk-5 ACV energy consumption is based on data from References 13 and 14. As shown in Figure 4.10, the vehicles with the lowest block time also exhibit the lowest energy intensity.

4.1.5 S61L Helicopter Energy Consumption Summary

Figure 4.11 is a summary plot of the energy intensity of the S-61L helicopter when operated on the three major mission scenarios. For reference, the 100% load factor level is noted in addition to the assumed study load factors. Table 4.2 relates energy intensity to helicopter flight/block time fraction. As might be expected, energy intensity decreases as a

FIGURE 4.9 VEHICLE ENERGY INTENSITY COMPARISON

OIL RIG MISSION



NOTE: A LARGER MOTOR LAUNCH WOULD HAVE PROVIDED MORE COMPETITIVE ENERGY INTENSITIES FOR THE WATER-BORNE VEHICLES

FIGURE 4.10 VEHICLE ENERGY INTENSITY AND BLOCK TIME COMPARISON

OIL RIG MISSION SCENARIO

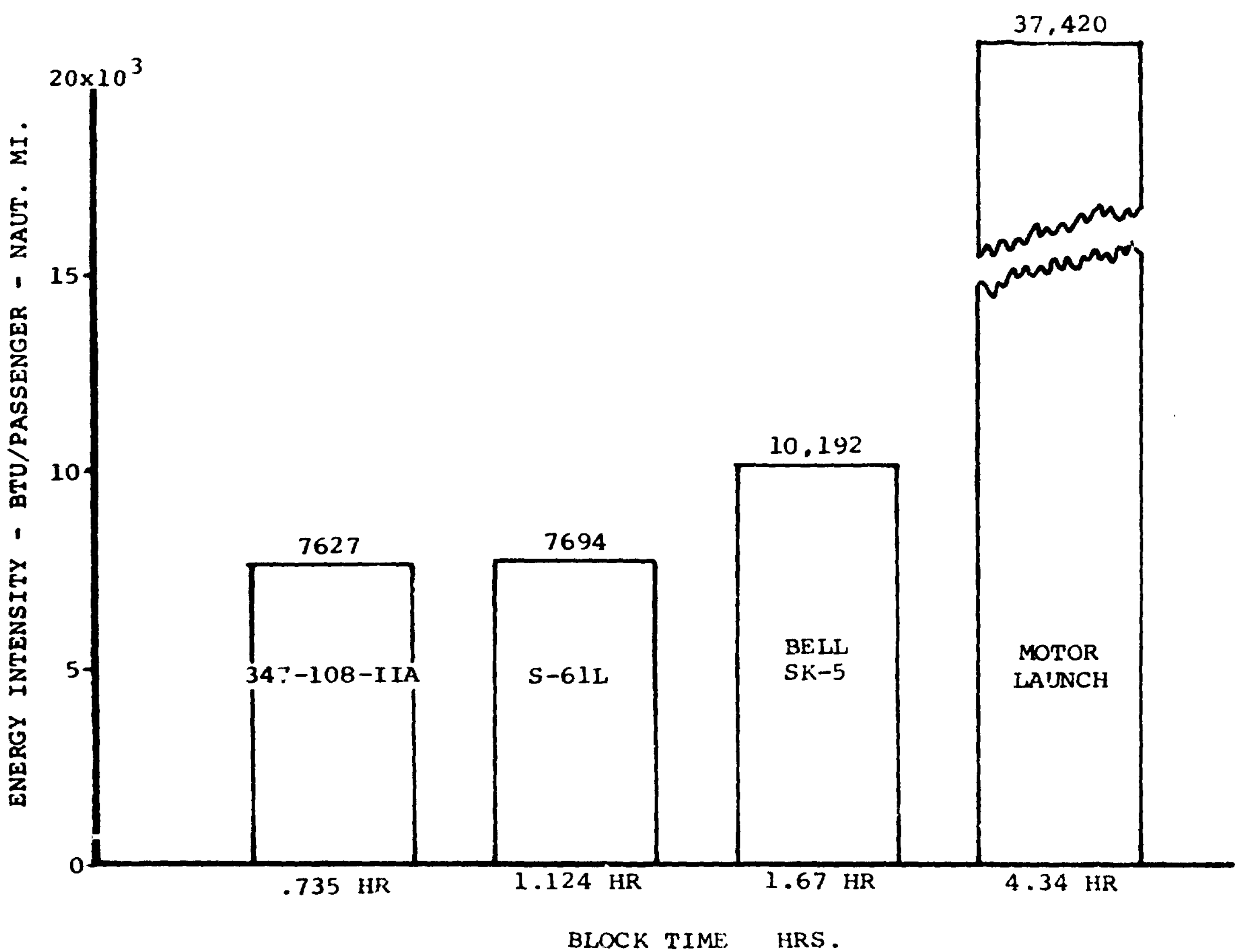


FIGURE 4.11 SUMMARY PLOT

HELICOPTER ENERGY INTENSITY AS A FUNCTION OF MISSION SCENARIO (S61L HELICOPTER)

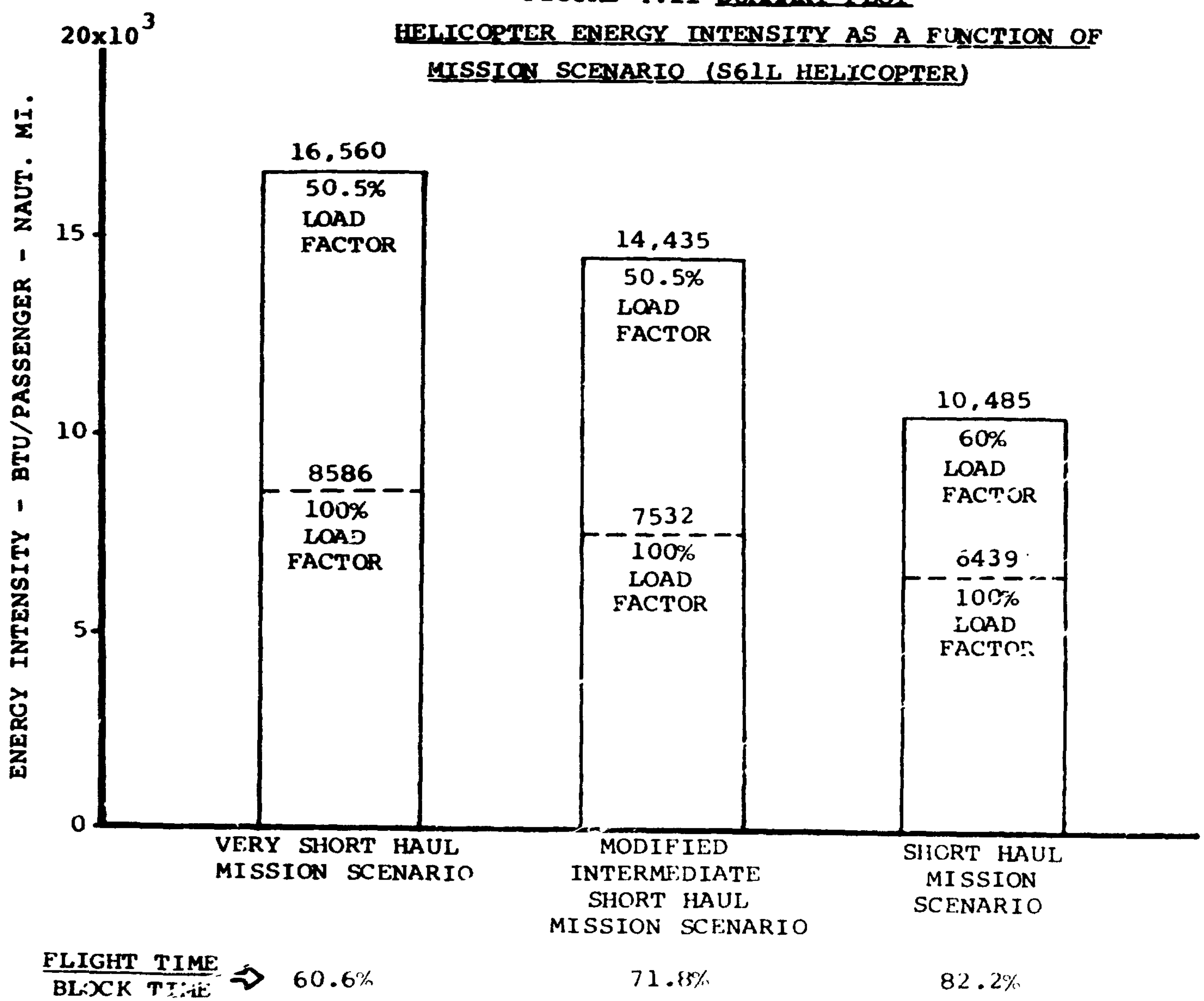


TABLE 4.2 HELICOPTER ENERGY INTENSITY AS A FUNCTION OF FLIGHT TIME/BLOCK TIME RATIO

SCENARIO	FLIGHT TIME/BLOCK TIME	ENERGY INTENSITY (BTU/PASS.-N.M.)
VERY SHORT HAUL (52.14 N.M.)	60.6%	8586*
HYPOTHETICAL INTERMEDIATE SHORT HAUL (111.32 N.M.)	71.8%	7532*
SHORT HAUL (210 N.M.)	82.2%	6439*

HELICOPTER: S-61L (100% L.F.)

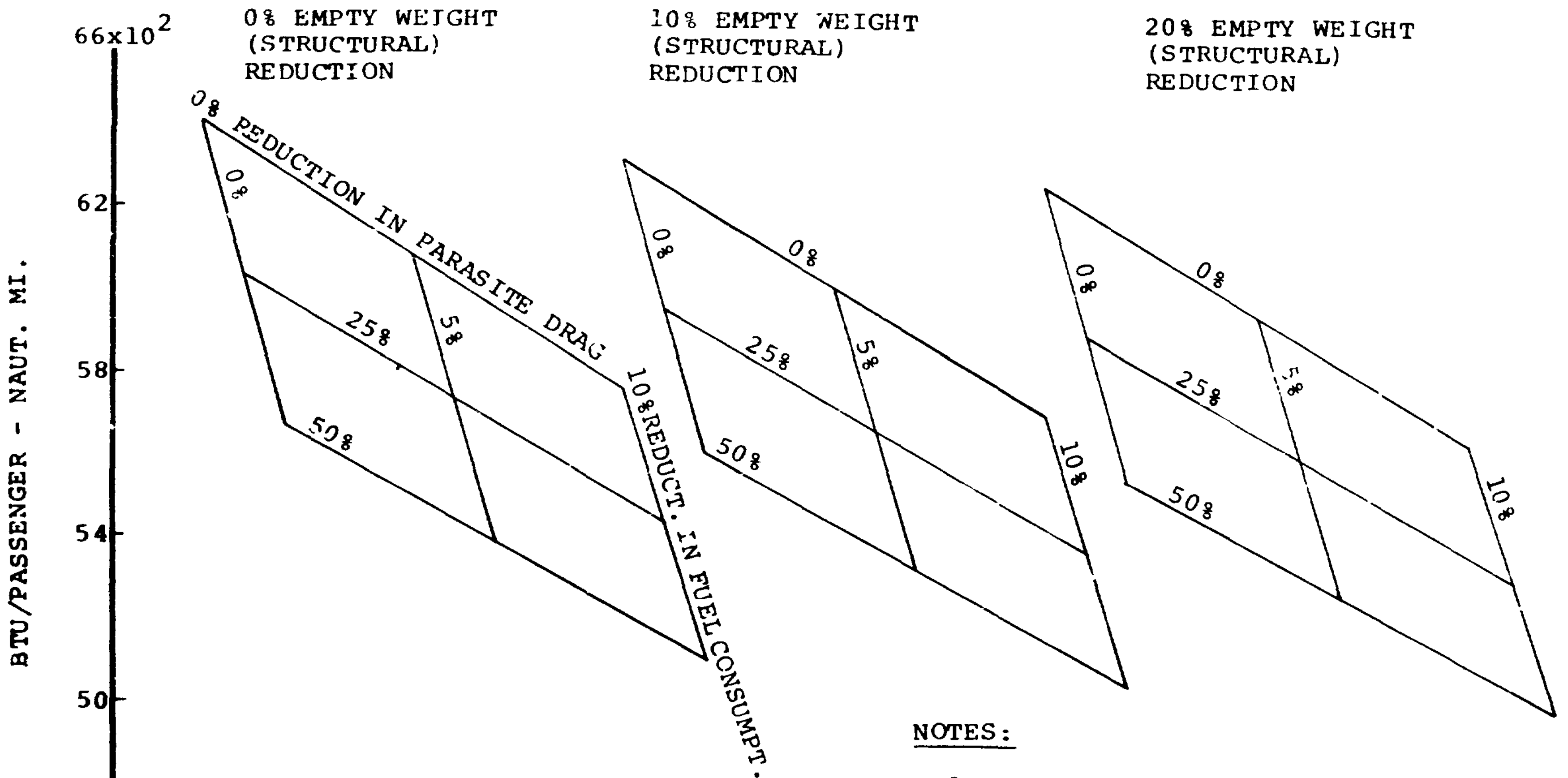
larger percentage of the helicopters block time is spent in forward flight.

4.2 Effect of Technology Improvements on Helicopter Energy Consumption

It is clear, upon examination of the results of Section 4.1, that the helicopter can derive benefits from infusions of advanced technology. The question is, "How great are the potential savings in energy consumption for a given level of technology?" Figure 4.12 gives an indication of the potentially realizable reductions in energy consumption. This figure was obtained by computing the energy consumption of a 1960 technology level "S-61L" type helicopter operated at 100% load factor on the short haul mission. The aircraft was assumed to operate with a reduced level of parasite drag, fuel flow, and empty weight.

Table 4.3 illustrates the range of energy consumption values reflected by Figure 4.12. The reduction in energy consumption indicated by this figure and table should in no way be considered the maximum possible reduction, but only an indication of the possible reduction, since it does not reflect additional gains obtained through resizing and optimizing a configuration to take full advantage of technical advances.

FIGURE 4.12 EFFECT ON ENERGY INTENSITY OF REDUCTIONS IN PARASITE DRAG, FUEL FLOW AND EMPTY WEIGHT



NOTES:

1. BASED ON NYA-WASH (SHORT HAUL) SCENARIO
2. 100% LOAD FACTOR
3. BASED ON "S-61L" TYPE HELICOPTER
4. THIS DOES NOT REFLECT FURTHER IMPROVEMENTS AND/OR PENALTIES DUE TO REDESIGN AND RESIZING OF HELICOPTER

TABLE 4.3 POTENTIAL IMPROVEMENT IN HELICOPTER ENERGY INTENSITY

100% LOAD FACTOR
SHORT HAUL MISSION SCENARIO

VEHICLE	ENERGY INTENSITY (BTU/PASS.-N.M.)
BASIC S-61L (1960 TECHNOLOGY)	6439
BASIC S-61L WITH: 50% REDUCTION IN F_e, 10% REDUCTION IN SFC, 20% EMPTY WT REDUCTION	4960*

* THIS DOES NOT REFLECT FURTHER IMPROVEMENTS AND/OR PENALTIES DUE TO REDESIGN AND RESIZING OF AIRCRAFT

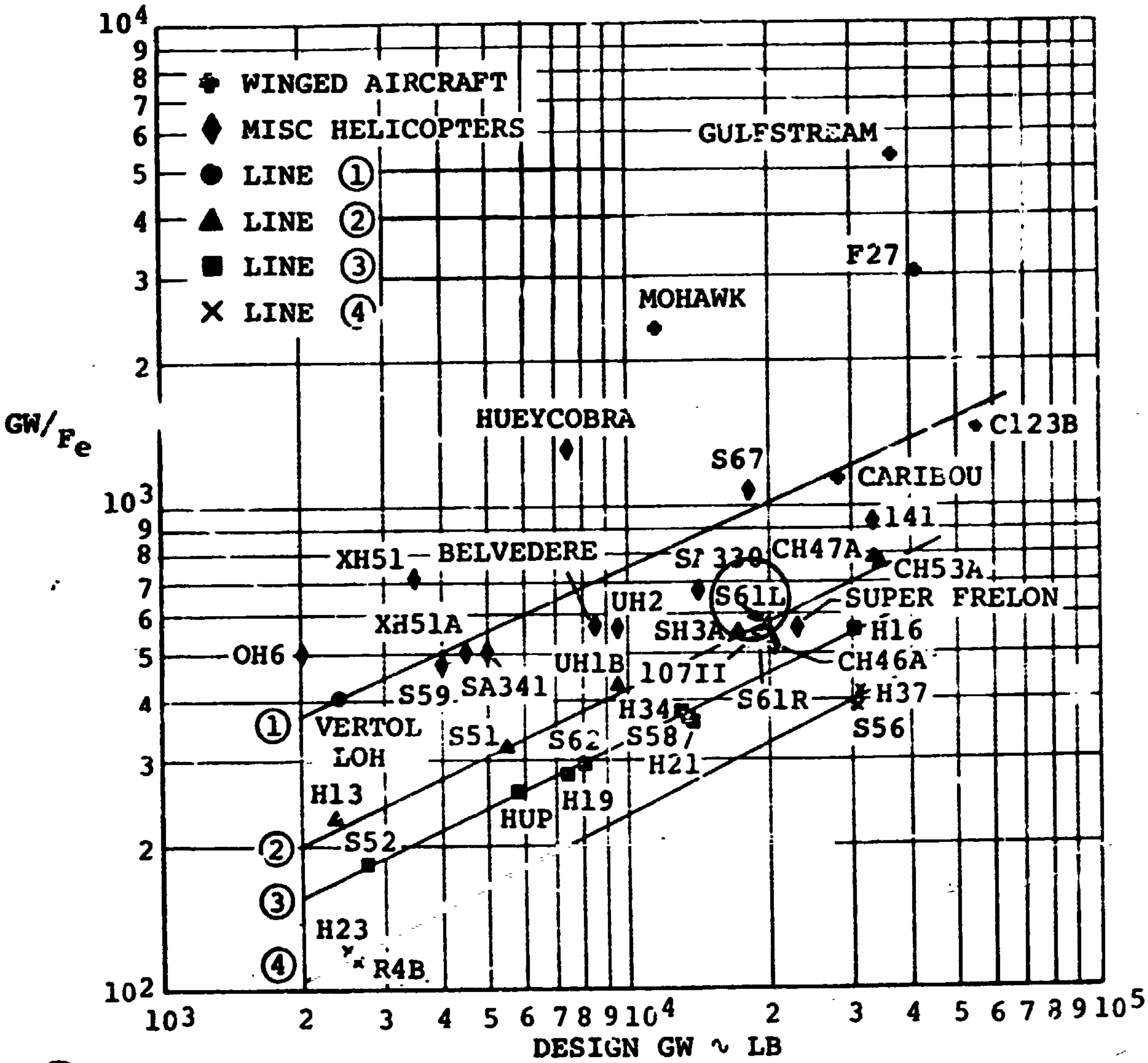
Bearing in mind the limitations upon which Figure 4.12 is based, it is of interest to examine the potential energy consumption of an advanced technology helicopter with realistic drag, fuel consumption, and empty weight levels.

Figure 4.13 illustrates some typical parasite drag trends. Note the position of the S-61L. Assume this helicopter is "cleaned up" sufficiently (with no change in DGW) so that it lies on trend line number one. This would represent a 43% reduction in parasite drag.

Figure 4.14 illustrates projected improvements in engine SFC as a function of year. Movement from a 1960 to 1985 technology base results in a 32% reduction in fuel consumption.

Assuming that the portion of helicopter empty weight attributable to structural components is 40%, a 25% reduction in structure weight, due to the use of composite materials, results in a 10% overall reduction in empty weight.

Extrapolating from the values shown on Figure 4.12 results in an energy intensity level of 3840 BTU/pass-N.M., a 40% reduction from the 1960 level. It is of interest to note that the advanced tandem rotor helicopter (TH-100) in the short haul mission scenario has an energy intensity of 4597 BTU/pass-N.M.



1. Advanced drag cleanup (e.g. faired hubs, low drag or retractable landing gear etc.).
2. Current standard of landing gear, hub design, skin finish etc.
3. Unfaired landing gear, hubs, protuberances, poor body shape, etc.
4. Exceptionally dirty configuration due to such things as open construction, exceptionally dirty engine installation, landing gear, etc.

NOTE: The drag area for the winged aircraft excludes the C_DA of the wings, to be compatible with the helicopters.

Figure 4.13 Typical Parasite Drag Trends.

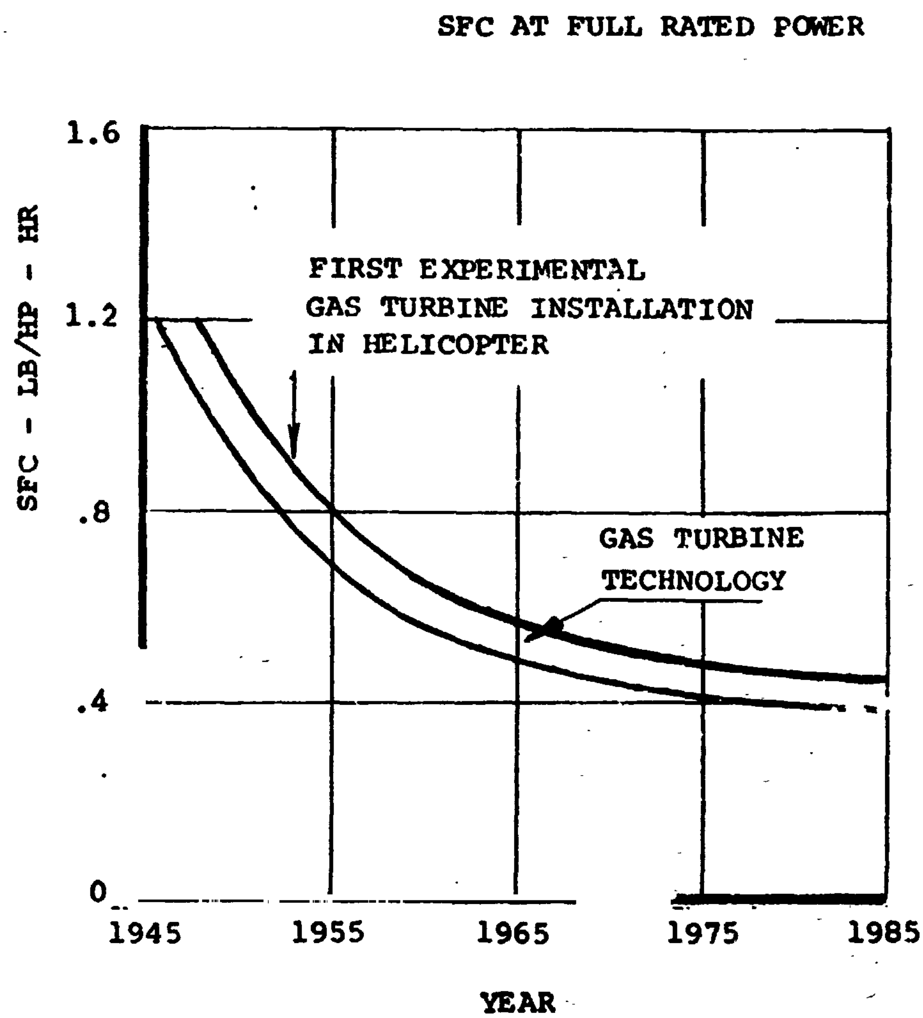


FIGURE 4.14 PROJECTED IMPROVEMENTS IN GAS TURBINE FUEL CONSUMPTION

at 100% load factor. The fact that the value for the TH-100 is higher than the extrapolated value based on Figure 4.12 reflects differences in sizing ground rules (e.g., the requirement to hover one engine out at design gross weight) and the more realistic interplay of technical benefits and penalties actually involved in the resizing process. Relaxation of the hover, one engine out, sizing ground rule and the resizing of a 2 engine version of the TH-100 results in a helicopter with an energy intensity of 4136 BTU/pass-N.M.

Appendix C gives a brief description of the advanced tandem rotor helicopter (TH-100). For a more complete description, see Reference 5.

4.3 Effect of Safety Requirements on Helicopter Energy Consumption

Designing a helicopter to meet hover one engine inoperative (OEI) requirements can incur severe energy consumption penalties because of the resultant engine oversizing. This effect is most noticeable in cruise flight where, because of the oversized engines, the throttle settings (ratio of power required/power available) are very low, with a consequent increase in SFC (see Figure 4.15). This situation can be partially offset in the sizing process by increasing the number of engines/configuration. For example, if a helicopter is

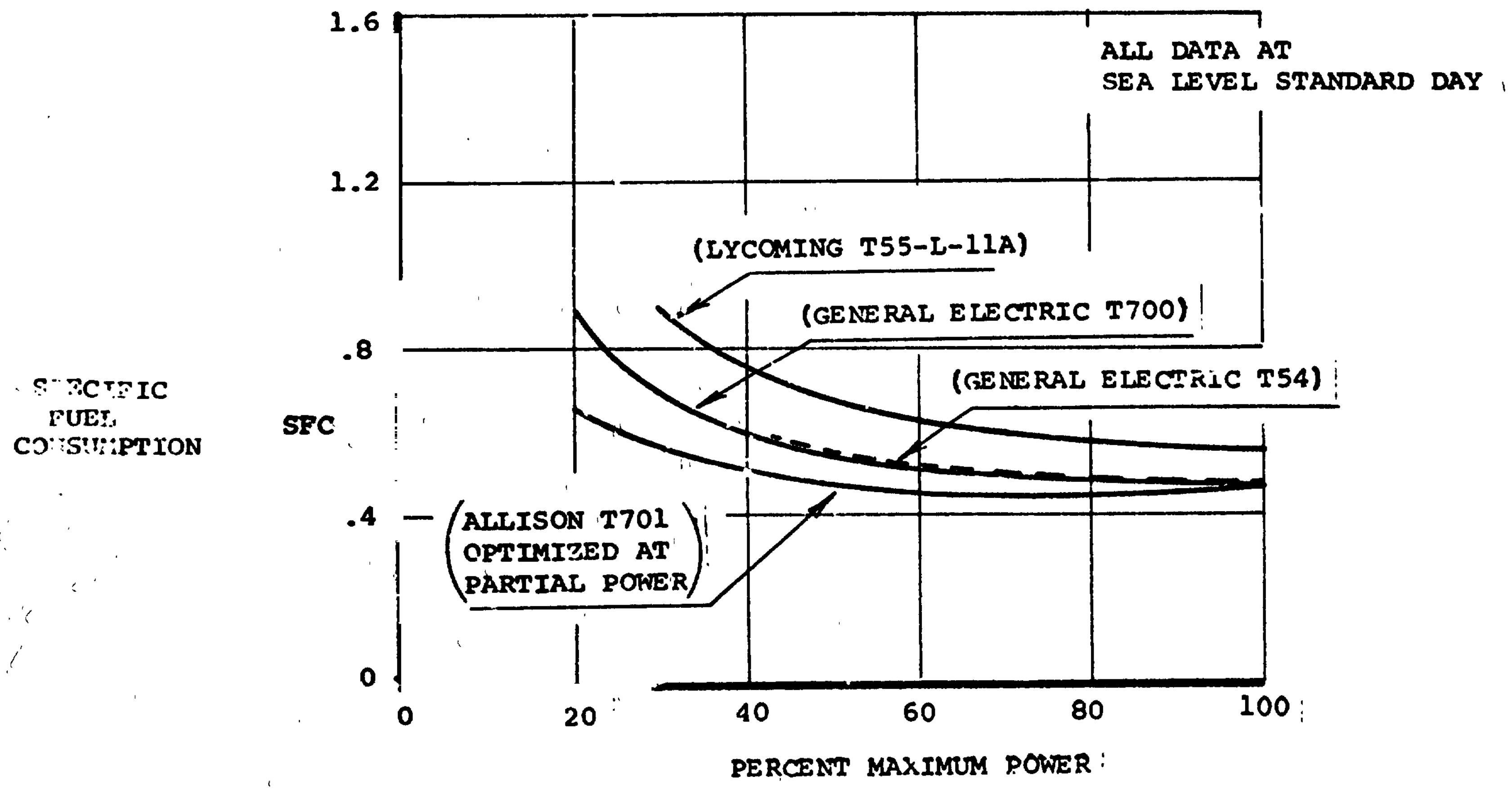


FIGURE 4.15 POWERPLANT SPECIFIC FUEL CONSUMPTION (SFC) AS A FUNCTION OF PARTIAL POWER OPERATION

sized to meet the OEI requirement with only two engines, each engine must be capable of providing 100% more power under hover OEI conditions. If three engines are specified, this requirement drops to 50%, and if four engines are used, each engine must only be oversized by 33%. However, although this results in more favorable energy consumption characteristics, potential maintenance problems are multiplied.

Figure 4.16 illustrates the effects of safety requirements on helicopter energy consumption. The first bar graph depicts the energy consumption of the 347 - 108-I, and is representative of a 1960 technology helicopter, constantly improved and updated and re-engined with the current available advanced engine (Allison T-701). This engine is capable of providing the helicopter with sufficient power to meet and, in fact, exceed hover OEI requirements with a full load of 50 passengers. Note that by halving the engine size of the 347 - 108-I (would result in a loss of hover OEI capability), a 15% reduction in energy consumption is realized.

As noted in Section 4.2, the potential for much greater improvement in energy consumption than shown in Figure 4.16 exists with a helicopter designed from "the ground up" to fully realize the benefits of advanced technology. By way of illustration, consider the 4th and 5th bar graphs in Figure 4.16.

Bar graph four shows the energy consumption of the TH-100 (referred to in Appendix C and also Reference 5). This helicopter, sized to meet a hover OEI requirement with a full load of 100 passengers and utilizing the advanced technology described previously, exhibits an energy consumption 47% less than the 50 passenger 347-108-I. Resizing the TH-100 (92.3) with two engines and no hover OEI capability results in a further 11% reduction as shown by the last bar graph. It should be noted that all configurations' energy consumption were analyzed based on the short haul mission scenario and an assumed load factor of 60%. It should further be emphasized that all future passenger-carrying transport helicopters must meet proper (safety) (engine out in hover) requirements. Consequently, the associated energy consumption aspects should be considered in the preliminary design phase.

4.4 Effect of Miscellaneous Design Variables on Energy Consumption

Table 4.4 illustrates vehicle energy intensity as a function of power loading. Now

$$\text{Energy Intensity} \sim \frac{(W/N)\ SFC}{(W/D_e)}$$

where:

- (W/N) = vehicle gross weight-to-passengers carried ratio
- (W/D_e) = vehicle weight-to-equivalent drag ratio (at vehicle cruise speed)
- SFC = powerplant specific fuel consumption (at vehicle cruise speed) (lb fuel/hour/horsepower)

It is apparent that the vehicle (W/D_e) ratio exerts an important effect on vehicle energy intensity. For ground vehicles

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TABLE 4.4 VEHICLE ENERGY INTENSITY AS A FUNCTION OF POWER LOADING

ASSUMED: SHORT HAUL MISSION SCENARIO
100% LOAD FACTOR (NO DELAYS)

VEHICLE	WT/POWER	INSTALLED HORSEPOWER/PASSENGER*	BTU/PASS.-N.M.	BLOCK TIME
BUS	131	6.304	562	5.65 HR
TRAIN	73.3	37.31	1267	2.35 HR
COMPACT CAR	24.3	35.0	2008	5.65 HR
STANDARD CAR	19.6	50.0	2172	5.65 HR
T/PROP A/C (CONV. 580)	7.28	141.5	3400	1.005 HR
S-61L	6.19	109.6	6439	2.09 HR
ADVANCED TECHNOLOGY HELICOPTER (T! -100(92.3)	4.64	144.7	4597	1.861 HR
737-100	2.79	355.	2980	.788 HR

* BASED ON SEATED PASSENGER CAPACITY

such as automobiles, buses, and trains, (W/D_e) is very high since D_e is but a small fraction of W (based on vehicle rolling friction) plus a small increment of aerodynamic drag. For air vehicles, the requirement to provide sufficient lift to offset weight (thus adding a "lift induced drag" component to the basic vehicle aerodynamic drag) results in considerably smaller W/De's as compared to the ground vehicles. For example, typical ground vehicle W/De's are on the order of 100. In comparison, fixed-wing aircraft generally exhibit W/D_e's on the order of 8-10 and helicopters 3-5. Thus, the combinations of increasing cruise speed and decreasing W/De results in an ever increasing installed power requirement (shown by the trend to decreasing weight/installed power ratio from ground vehicle to air vehicle (see Table 4.4). However, because of the helicopters unique requirement for hovering flight, its engine size may be dictated accordingly, as compared to the other vehicles whose engine sizes are dictated, in general, by cruise acceleration requirements.

Air vehicles have increased flexibility and greater speed potential than comparable ground vehicles, but this is obtained at the expense of considerably lower W/D_e ratios, and, therefore, results in greater energy intensity. This trend cannot be reversed. However, it is possible, in the case of helicopters, as well as fixed wing aircraft (Reference 15) to reduce its effect somewhat.

First, engine specific fuel consumption can be reduced through the use of advanced technology. A glance at Figure 4.14

indicates, however, that any future gains in SFC reduction may be small for the effort expended. Perhaps, as far as fuel consumption is concerned, even more important is the manner in which engines are sized and operated. Recalling Figure 4.15, it noted that if a configuration's engines are greatly oversized, a correspondingly large penalty in fuel consumption is incurred by operation at low throttle settings. Secondly, helicopter W/D_e can be increased by reducing parasite drag and increasing rotor efficiency. Finally, the passenger capacity for a given gross weight can be increased (reducing W/N ratio) by reducing the empty/gross weight fraction. This is obtained through the use of composite structures, advanced lightweight avionics and control systems, reductions in rotor and drive system weight through simplified design, etc.

The advanced technology tandem rotor helicopter (TH-100) listed in Table 4.4 is representative of a configuration to which many of the techniques listed above have been applied to reduce energy consumption.

Figure 4.17 illustrates the relative grouping of existing fixed-wing and rotary-wing aircraft compared in terms of passenger miles/gal. of fuel consumed. The lower range of the helicopters reflects the lower W/D_e's and higher empty/gross weight fractions associated with current machines. The position of the advanced technology tandem helicopter shows the improvements in helicopter efficiency which can be obtained through application of advanced technology to rotary-wing aircraft.

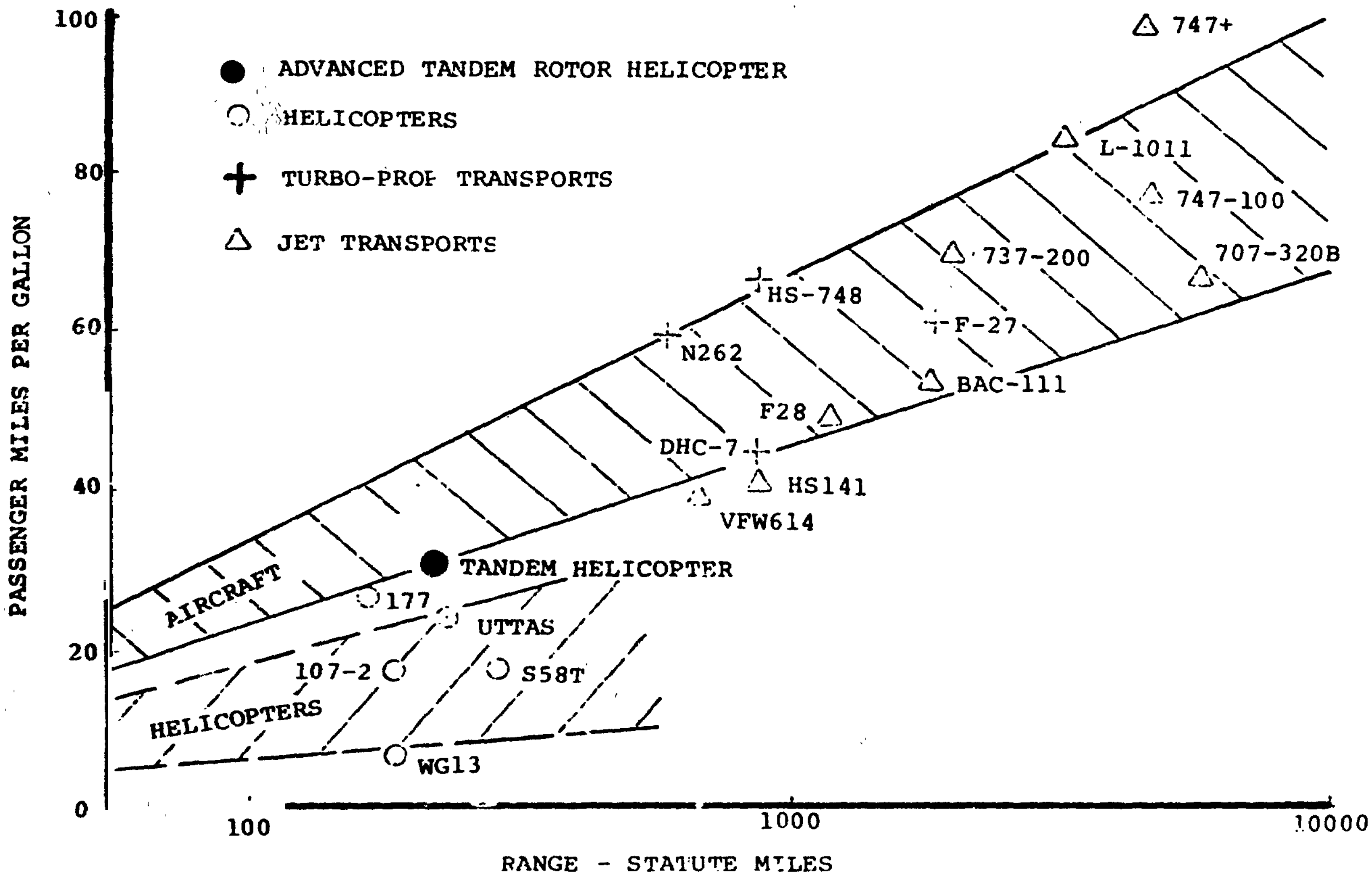

FIGURE 4.17 SUMMARY PLOT - FUEL CONSUMPTION COMPARISON OF EXISTING FIXED AND ROTARY-WING AIRCRAFT

Figure 4.18 presents a comparison of overall (total) trip times for various means of transportation. The time increment along the abscissa of the plot represents the total amount of time expended in travel to and from the points of utilization of the vehicles being compared. Inherent in this plot are the following assumptions:

(1) The automobile is within easy walking distance, with a consequently small increment in travel time required.

(2) Helicopters and hi-speed intercity trains operate from terminals (perhaps multimodal) which are conveniently accessible and widely dispersed throughout metropolitan areas. Therefore, travel times to and from these terminals is either by automobiles or existing mass transit.

(3) The conventional jet transport is operated from an airport located on the periphery of a metropolitan area, with a consequent large increment in travel time to and from the airport. This is deemed realistic due to the operating requirements of conventional jet transports (long runways, takeoff and landing approach patterns located away from heavily populated areas). Also reflected in this time increment is the time required for baggage and security checks, preboarding and passenger inspection.

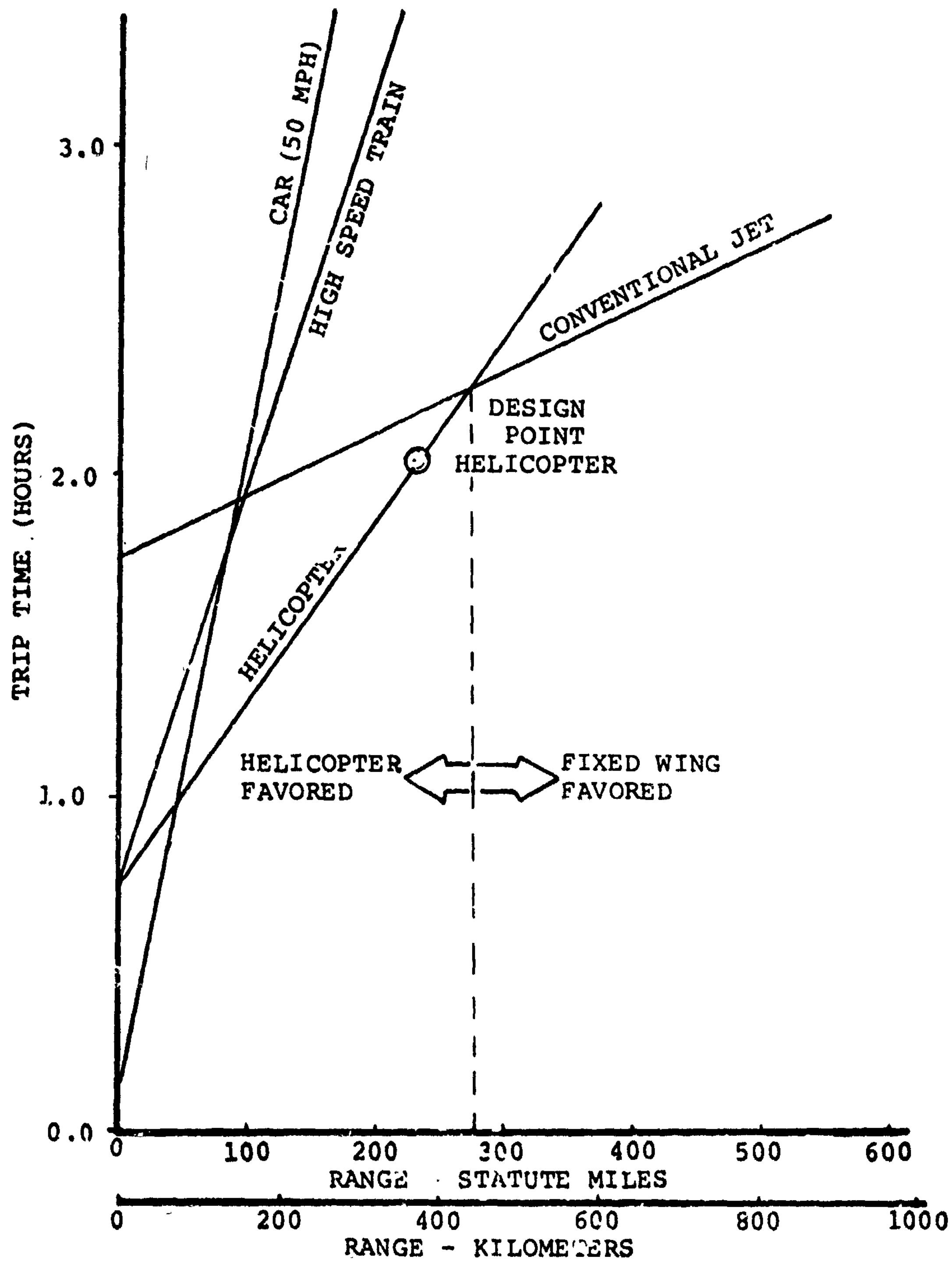

FIGURE 4.18 TRIP TIME COMPARISON

At travel distances of approximately 150 statute miles the total trip times for the automobile and train are considerably greater than for the air vehicles. This reflects the slower cruise speeds of the ground vehicles. Up to 280 statute miles the total trip time for the helicopter is less than that of the conventional jet transport because of the time penalty associated with getting to the airport. Beyond this point, however, the jet transport's higher cruise speed works to its advantage.

5.0 CONCLUSIONS AND RECOMMENDATIONS

As shown in Table 4.4, air vehicles, due to their inherent higher power requirements (compared to ground vehicles) exhibit higher energy intensities when compared solely on an energy consumption basis. Current levels of air vehicle energy intensity can be reduced, however, through the infusion of advanced aeronautical technology into the design process.

Current day helicopters, if compared to ground vehicles on the basis of useful energy utilization (i.e., useful miles traveled), are competitive with them, particularly if freed from operation within the constraints of the existing air traffic control system and their potential for reducing overall trip time is taken into account. Helicopters operating from city centers and disbursed heliports within a metropolitan area also offer substantial opportunity for reduced ground transport energy requirement by reducing distances to reach departure points. In areas where ground transportation systems do not presently exist (or surface geography precludes easy construction of such facilities), the helicopter offers the potential of both reduced travel times and lower overall energy consumption than comparable surface transportation system can achieve (assuming the energy consumed for initial construction of such a system is considered). In addition, unique missions exist (e.g., resupply of offshore oil rigs and logging operations) which cannot be performed effectively by other means of transportation.

Improvements in helicopter energy consumption can be accomplished through the utilization of advanced technology in the areas of drag, structure weight, and powerplants. The "mix" of these technology applications which results in the maximum amount of energy consumption reduction for the minimum cost is presently not known. It is suggested, therefore, that further studies be conducted to quantify the relative costs and technical risks associated with the application of these various technologies to the helicopter. It would then be possible to define an optimum helicopter from both a cost and energy consumption standpoint.

In particular, the following recommendations are made for future studies:

1. Identify and quantify the technology areas that offer the most cost effective means of reducing helicopter energy consumptions.

2. Develop the high payoff technologies so they can be incorporated into the next generation of transport helicopters.

C - 2

3. Based on the projected advanced technology levels of both helicopters and other passenger vehicles, perform a study to determine the optimum mix of vehicles required for an integrated transportation system for key geographical regions of the United States.

6.0 REFERENCES

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APPENDIX A

AIRCRAFT SIZING METHODS

The use of computerized aircraft sizing programs allows the configuration analyst to rapidly and systematically assess the effects of a multitude of design variables and display their impact on overall vehicle size and performance. Boeing Vertol currently utilizes a computer program called VASCOMP II, Reference 17, for non-helicopter aircraft. A similar program called HESCOMP is used for sizing helicopters.

The following descriptions of VASCOMP and HESCOMP details the flexibility of the programs as analytical tools in the preliminary design process. Symbolically the main input/output operations are shown in Figures A-1 and A-2. A more detailed review of the two programs capabilities is given in References 17 and 18.

The purpose of these programs is to serve as rapid computational tools, giving visibility to comparative design studies of V/STOL aircraft and helicopter systems. Program attributes include:

1. Capability to size V/STOL aircraft and helicopters of a wide range of rotor, propeller, and fan jet types for complex missions of up to 50 segments.

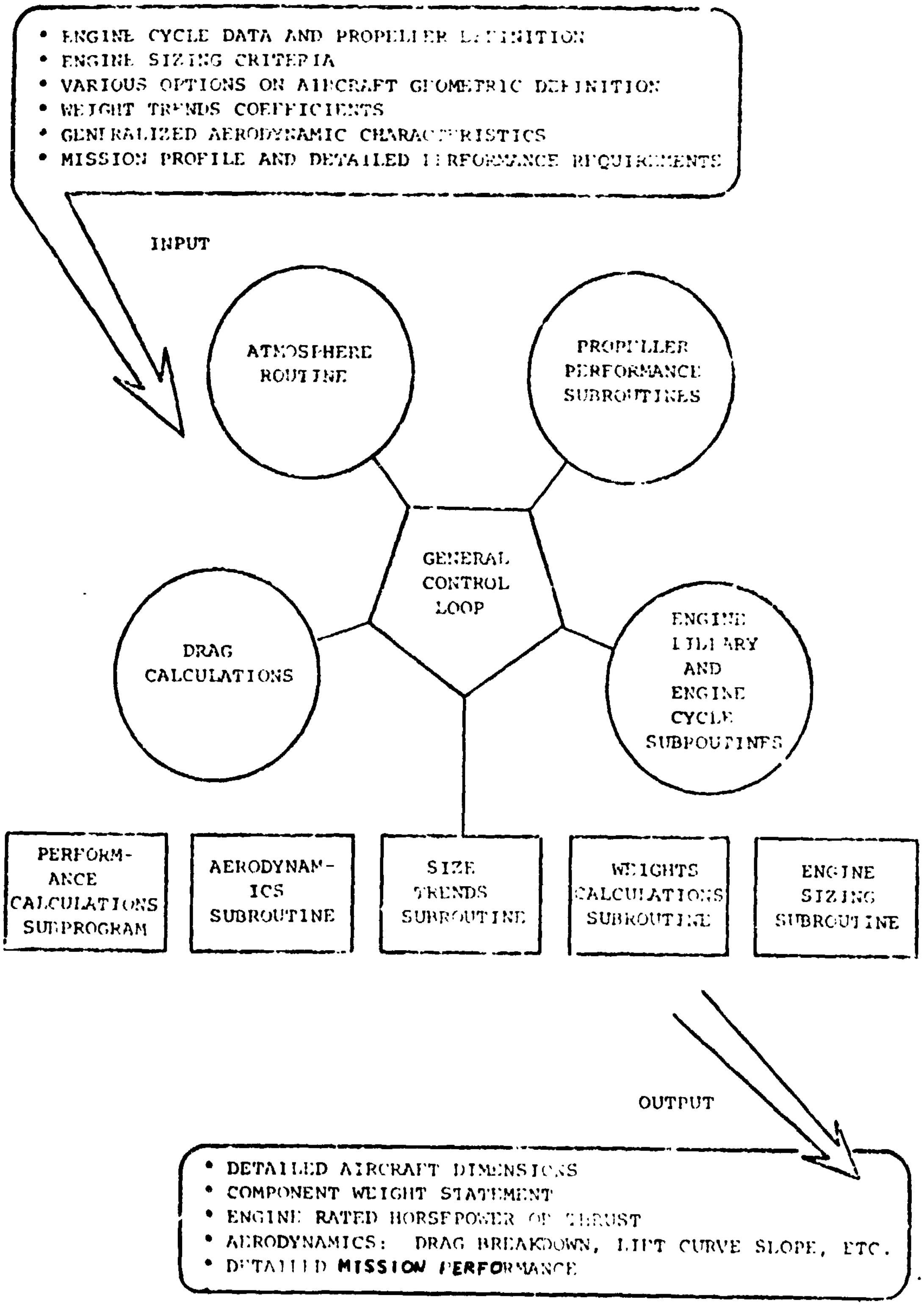

FIGURE A-1 VASCOMP II Logic Schematic.

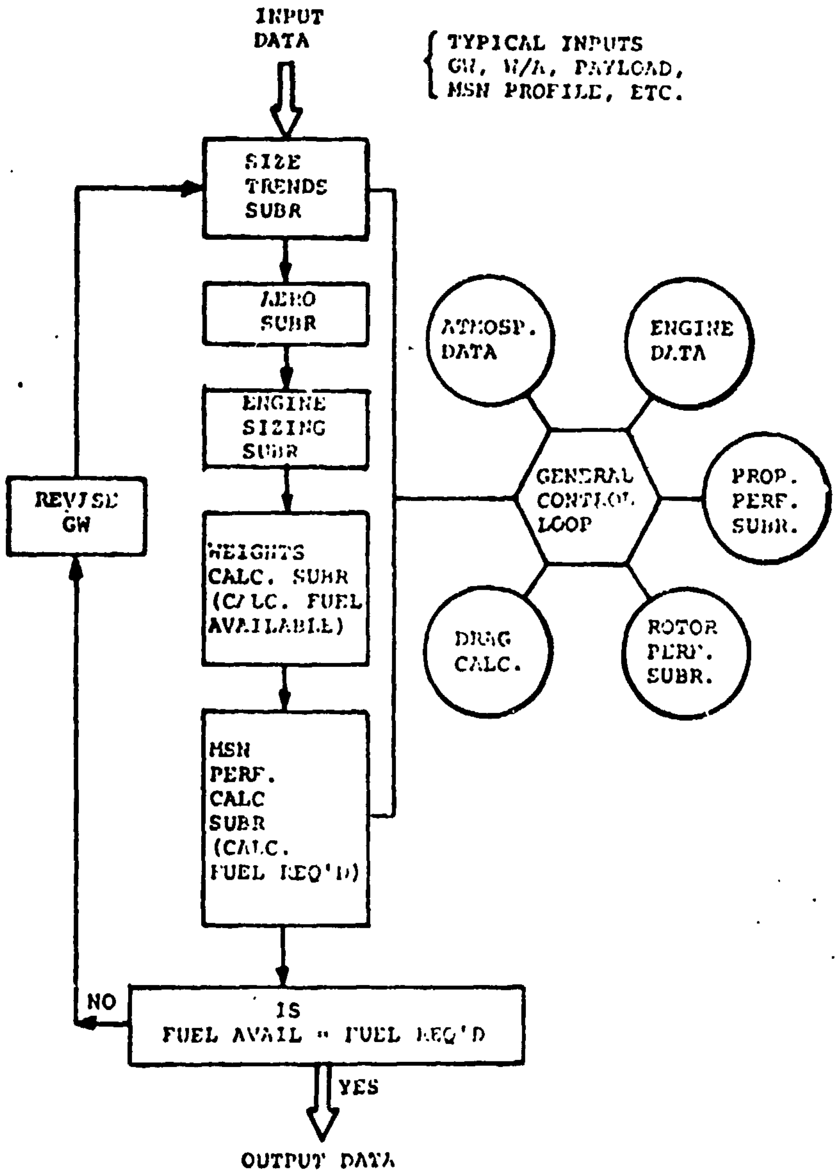

FIGURE A-2 HESCOMP LOGIC SCHEMATIC

2. Input description of aircraft layout can be in sufficient detail to evaluate subtle differences in design (over 100 input design parameters).

3. A wide variety of program mode options can be selected to minimize computation and input time.

4. Detailed performance assessment with mission time histories can be provided in any desired increments with instantaneous values of performance, engine condition and weight parameters.

5. Rapidly accomplished trade studies through supplementary computer input, of variable parameter(s) only, to a baseline case.

6. Detail printouts of aircraft dimensions, weights, propulsion system characteristics and performance.

These programs have two primary independent applications and a third which is a combination of the first two. They may be used for sizing of specified aircraft to a given mission profile. Alternatively, they may be used for mission calculations for aircraft whose sizing details (gross weight, fuel available, engine power and fuel consumption,etc.) are known. As a combination of these two capabilities, the programs may be used to first size an aircraft for a given mission and then calculate the off-design-point performance for other missions.

In the sizing mode these programs integrate the inputs from the main preliminary design areas of physical design (aircraft geometry) aerodynamics, weights, and propulsion utilizing size trend equations which reflect the variation of aircraft dimensions with gross weight, detailed statistical weight-trend equations, a routine for sizing engines to match airframe requirements, a comprehensive library of engine cycle data, and real engine performance data. These inputs to the program primarily consist of a series of single point values specifying, for example, the aspect ratio and taper ratio of the wing and tail surfaces, the geometry of the fuselage, the type of propulsion system, a description of the mission profile, weights of fixed equipment, fixed useful load and payload.

The engine performance data, referred power, gas producer speed, turbine speed and fuel flows are input as a function of Mach number and referred turbine temperature. The user may input limits on engine operation by setting maximum values of fuel flow, torque or gas generator or power turbine shaft rpm. In addition, non-linear scaling effects of real engines may be included by input of Reynolds number-based correction factors. Degradation in performance of turboshaft engines operating at non-optimum power turbine speed can be calculated by the program at the option of the user. The library engine cycles may thus be used with no additional input, or by appropriate additional input may be made to include the effects of multiple operating restrictions and other factors characteristic of real engine cycles.

Aircraft sizing, weights, propulsion and aerodynamic information are printed out during a sizing run and followed by mission performance data (for both sizing and performance runs). The performance data is a time history of the mission, including speed, distance, weight, power, fuel used, etc.

Variations in key parameters to establish sensitivity trades are accomplished by inputing the baseline aircraft or mission and inputing only that item to be studied as a supplemental case. All other inputs will remain unaltered and the program will resize the aircraft.

APPENDIX B

VERY SHORT HAUL MISSION SCENARIO

TABULAR DATA

THE BOEING COMPANY

PREPARED BY:
CHECKED BY:
DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES: CLASS	VEHICLES: VEHICLE	MISSION	LOAD FACTOR: PERCENT	LOAD FACTOR: NO OF PASS	OVERALL TIME: HOURS	DISTANCE TRAVELED: NAUT. MI.	DISTANCE TRAVELED: STAT. MI.	FUEL USED: Lb	FUEL USED: BTU $\times 10^{-7}$	ENERGY CONSUMED: BTU / PASS-S.M	ENERGY CONSUMED: BTU / PASS-N.M	EFFICIENCY: PASS-N.M / GAL	EFFICIENCY: PASS-S.M / GAL	FUEL FLOW: MPG
HELICOPTER	S-61L	VERY SHORT HAUL	90.55	14.15	.746	52.14	60.	663.9	1.22	14390.	16560.	1.47	[illegible]	.607
			100.	28.	.746			681.3	1.25	7462.	8586	14.40	16.51	.592
AUTOMOBILE	STANDARD	" "	24	1.2	3.33	67.79	78.	44.2	.0885	9451	10876	10.8	12.4	10.4
			44	2.2		" "				5155	5932	14.8	22.8	
			64	3.2		" "	"			3544	4078	28.8	33.1	
			100	5.0	3.33	"		44.2		2268	2610	45.0	51.8	10.4
AUTOMOBILE	COMPACT	" "	30.	1.2	3.33	" "	" "	31.5	.0629	6720	7733	15.2	[illegible]	14.6
			55.	2.2		" "				3665	4218	21.8	[illegible]	
			100.	[illegible]	3.33			31.5		2016	2320	50.6	58.2	14.6

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APPENDIX B

INTERMEDIATE SHORT HAUL MISSION SCENARIO

TABULAR DATA

THE BOEING COMPANY

PREPARED BY:
CHECKED BY:
DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES: CLASS	VEHICLES: VEHICLE	MISSION	LOAD FACTOR: PERCENT	LOAD FACTOR: NO OF PASS	OVERALL TIME: HOURS	DISTANCE TRAVELED: NAUT. MI.	DISTANCE TRAVELED: STAT. MI.	FUEL USED: Lb	FUEL USED: BTU x10^-7	ENERGY CONSUMED: BTU/PASS-S.M	ENERGY CONSUMED: BTU/PASS-N.M	EFFICIENCY: PASS-N.M/GAL	EFFICIENCY: PASS-S.M/GAL	FUEL FLOW: MPG
HELICOPTER	S-61L	INTERURBAN SHORT HAUL	50.55	14.15	1.699	111.2	128	1480	2.72	15029	17294	7.15	8.73	.581
			100.	28	1.619			1520	2.80	7801	8977	13.77	15.85	.566
AUTOMOBILE	STANDARD		24	1.2	5.99	154.7	178.	100.7	.213	9992	11498	10.11	11.75	4.79
			44	2.2						5450	6272	20.72	21.54	
			64	3.2						3747	4312	27.73	31.93	
			100	5						2398	2760	47.54	48.90	
AUTOMOBILE	COMPACT		30	1.2	5.99	[illegible]	178.	74.6	.149	6985	[illegible]	21.61	[illegible]	14.01
			55	2.2						3809	[illegible]	[illegible]	[illegible]	
			100	4.						2095	2411	[illegible]	[illegible]	
[illegible]			20	17.4	1.32	154.7	178.	281.5	.49	3169	3647	38.76	44.5	4.85
			60	27.4						[illegible]	[illegible]	116.3	133.6	
			80	36.8						775	892	[illegible]	178.4	
			100	46.						620	[illegible]	[illegible]	[illegible]	
HELICOPTER	S-76	[illegible] SHORT HAUL	50.55	14.15	1.317	111.2	128	1234	2.27	12544	14433	8.57	9.86	.697
			100.	28	1.317			1217	[illegible]	6440	[illegible]	[illegible]	[illegible]	.613

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OF POOR QU[illegible]

APPENDIX B

SHORT HAUL MISSION SCENARIO

TABULAR DATA

THE BOEING COMPANY

PREPARED BY:
CHECKED BY:
DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES			LOAD FACTOR		OVERALL TIME	DISTANCE TRAVELED		FUEL USED		ENERGY CONSUMED		EFFICIENCY		FUEL FLOW
CLASS	VEHICLE	MISSION	PERCENT	NO OF PASS	HOURS	NAUT. MI.	STAT. MI.	Lb	BTU $\times 10^{-7}$	BTU / PASS-S.M	BTU / PASS-N.M	PASS-N.M / GAL	PASS-S.M / GAL	MPG
AUTOMOBILE	STANDARD	SHORT HAUL	24.	1.2	3.65	218.9	252	118.9	.238	7843	9044	12.1[illegible]	14.43	12.44
			44.	2.2	"					4284	4935	[illegible]	21.31	
			64.	3.2						2919	[illegible]	34.6	[illegible]	
			100.	5.0						1897	2177	54.16	62.[illegible]	12.44
		INCL	24.	1.2	"			1772	.254	8114	9629	12.11	[illegible]	11.65
		70. INCH.	44.	2.2						4584	[illegible]	[illegible]	25.53	
		F.R. A/COND.	64.	3.2						3154	[illegible]	[illegible]	37.21	
		[illegible]	100.	5.0						[illegible]	2924	[illegible]	[illegible].14	11.65
BUS	INTERCITY BUS		45	20.7	"			306.	.566	[illegible]	1249	110.6	127.3	6.15
				27.6						814	937	147.5	169.8	
				36.8						611	703	196.7	226.4	
				46.						488	562	245.9	282.9	
TRAIN	ASTROLINER		35	135.1	2.35	197.3	227.	X	7.646	3148	3623	X	X	X
			60	231.6						1837	2112			
			80	308.8						1378	1584			
			100	386.0						1102	1267			

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THE BOEING COMPANY

PREPARED BY:
CHECKED BY:
DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES: CLASS	VEHICLES: VEHICLE	MISSION	LOAD FACTOR: PERCENT	LOAD FACTOR: NO. OF PASS	OVERALL TIME: HOURS	DISTANCE TRAVELED: N. MI.	DISTANCE TRAVELED: STAT. MI.	FUEL USED: Lb	FUEL USED: BTU $\times 10^{7}$	ENERGY CONSUMED: BTU / PASS-S.M	ENERGY CONSUMED: BTU / PASS-N.M	EFFICIENCY: PASS-N.M / GAL	EFFICIENCY: PASS-S.M / GAL	FUEL FLOW: MPG
HELICOPTER	S-61L	SHORT HAUL	60	16.8	2.086	210	241.7	2010	3.70	9111	10485	13.57	15.62	.808
			70	19.6	2.075	"		2015	3.71	7829	9010	13.72	15.79	.806
			80	22.4	2.068	"		2026	3.73	6846	7924	15.60	17.96	.802
			100	28.	2.065	"		2058	3.79	5995	6939	19.20	22.1	.789
HELICOPTER	TH-100		60	60	1.861	"		4906	9.03	6226	7164	17.26	19.81	.341
			100	100	1.861	"		5247	9.65	3995	4597	30.7	35.24	.352
T/FAN AIRPLANE	737-100	(NO LOITER)	60	67.2	.786	225	258.9	3890	7.16	4114	4734	26.12	30.05	.447
			70	78.4	.787	"	"	3936	7.24	3567	4105	30.12	34.66	.442
			80	89.6	.787			3982	7.33	3159	3635	34.02	39.15	.437
			100	112	.788	"		4081	7.51	2590	2980	41.49	47.75	.426
T/PROP AIRPLANE	CONV 580	(NO LOITER)	60	[illegible]	.995	"		2109	3.88	4718	5423	22.8	26.2	.875
			70	32.1	.997			2131	3.92	4042	4478	26.3	30.3	.816
			80	42.4	1.00			2155	3.96	3619	4156	[illegible]	34.8	.807
			100	53	1.005			2243	4.05	2751	[illegible]	34.4	[illegible]	.790

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THE BOEING COMPANY

PREPARED BY:
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DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES			LOAD FACTOR		OVERALL TIME	DISTANCE TRAVELED		FUEL USED		ENERGY CONSUMED		EFFICIENCY		FUEL FLOW
CLASS	VEHICLE	MISSION	PERCENT	NO OF PASS	HOURS	NAUT. MI.	STAT. MI.	Lb	BTU x10+7	BTU / PASS-S.M	BTU / PASS-N.M	PASS-N.M / GAL	PASS-S.M / GAL	MPG
T/FAN AIRPLANE	737-100	SHORT HAUL (WITH LOITER)				275	254.9							
		10 MIN L	60	67.2	.957			4658	8.57	4926	5648	21.82	[illegible]	.374
		20 MIN L	60		1.124			5294	9.67	5556	6394	19.34	22.15	.331
		30 MIN L	60		1.291			5854	10.77	6191	7124	17.35	19.97	.297
		10 MIN L	70	78.4	.958			4719	8.68	4277	[illegible]	25.12	28.91	.369
		20 MIN L	70		1.125			5331	9.81	4833	5564	22.24	25.59	.326
		30 MIN L	70		1.291			5948	10.94	5392	6204	19.93	22.93	[illegible]
		10 MIN L	80	89.6	.959			4781	8.80	3792	4363	28.34	32.61	.314
		20 MIN L	80		1.125			5410	9.95	4291	4938	25.04	28.82	[illegible]
		30 MIN L	80		1.292			6043	11.12	4792	5515	22.42	25.80	[illegible]
		10 MIN L	100	112	.957			4110	9.03	3116	3585	34.44	39.64	.354
		20 MIN L	100		1.170			5572	10.25	3535	4068	30.31	34.91	.312
		30 MIN L	100		1.213			1238	11.48	3958	4554	27.13	31.14	.279

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THE BOEING COMPANY

PREPARED BY:
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MODEL NO.

NUMBER
REV LTR

VEHICLES: CLASS	VEHICLES: VEHICLE	MISSION	LOAD FACTOR: PERCENT	LOAD FACTOR: NO OF PASS	OVERALL TIME: HOURS	DISTANCE TRAVELED: NAUT. MI.	DISTANCE TRAVELED: STAT. MI.	FUEL USED: Lb	FUEL USED: BTU X10^7	ENERGY CONSUMED: BTU/PASS-S.M	ENERGY CONSUMED: BTU/PASS-N.M	EFFICIENCY: PASS-N.M/GAL	EFFICIENCY: PASS-S.M/GAL	FUEL FLOW: MPG
T/PROP AIRPLANE	CONVAIR 580	SHORT HAUL (WITH OUTER)				225	258.9							
		10 MIN L	60	31.8	1.166			2378	4.37	5314	6114	20.22	23.27	.732
		20 MIN L	60		1.354			2614	4.81	5842	6723	18.39	21.16	.664
		30 MIN L	60		1.501			2850	5.24	6368	7328	16.87	19.42	.611
		10 MIN L	70	37.2	1.168			2403	4.42	4603	5297	23.34	26.86	.774
		20 MIN L	70		1.336			2643	4.86	5063	5827	21.22	24.42	.658
		30 MIN L	70		1.503			2882	5.30	5521	6353	19.16	22.1	.604
		10 MIN L	80	47.4	1.171			2428	4.47	4070	4684	26.4	30.38	.717
		20 MIN L	80		1.339			2670	4.91	4475	5150	24.01	27.63	.652
		30 MIN L	80		1.505			2911	5.36	4879	5615	21.02	25.34	.598
		10 MIN L	100	53	1.176			2473	4.55	3316	3816	32.4	37.3	.703
		20 MIN L	100		1.344			2719	5.00	3645	4195	29.5	33.9	.640
		30 MIN L	100		1.510			2963	5.45	3973	4572	27.05	31.12	.587

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THE BOEING COMPANY

PREPARED BY:
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DATE:

MODEL NO.

NUMBER
REV LTR

VEHICLES			LOAD FACTOR		OVERALL TIME	DISTANCE TRAVELED		FUEL USED		ENERGY CONSUMED		EFFICIENCY		FUEL FLOW
CLASS	VEHICLE	MISSION	PERCENT	NO OF PASS	HOURS	NAUT. MI.	STAT. MI.	Lb	BTU $\times 10^{-7}$	BTU / PASS-S.M	BTU / PASS-N.M	PASS-N.M / GAL	PASS-S.M / GAL	MPG
HELICOPTER	347-108 -I	SHORT HAUL	60	30	1.863	210.	241.7	4658	8.57	11921	13643	7.119	[illegible]	.349
	347-108 -II		60	30	2.053			3949	7.27	10072	11531	10.12	[illegible]	.411
	347-108 -IIA		60	30	1.983			3677	6.77	9332	10738	11.51	13.75	.412
	TH-100		60	60	1.861			4906	9.03	6226	7164	17.26	19.87	.331
	TH-160 (2 ENG)		60	60	1.927			4362	11.03	5936	6370	19.42	22.36	.373

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APPENDIX B

OIL RIG MISSION SCENARIO

TABULAR DATA

THE BOEING COMPANY

PREPARED BY:
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DATE:

MODEL NO.

NUMBER
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VEHICLES			LOAD FACTOR		OVERALL TIME	DISTANCE TRAVELED		FUEL USED		ENERGY CONSUMED		EFFICIENCY		FUEL FLOW
CLASS	VEHICLE	MISSION	PERCENT	NO OF PASS	HOURS	NAUT. MI.	STAT. MI.	Lb	BTU x10^-?	BTU / PASS-S.M	BTU / PASS-N.M	PASS-N.M / GAL	PASS-S.M / GAL	MPG
HELICOPTER	S-61L	[illegible]	60	16.8	1.074	86.9	100.	961.5	4.77	10530	12118	10.2	11.74	[illegible]
			100	28	1.124			1017.	1.87	6686	7694	16.07	18.44	.161
	347-108 -IIA		100	50	.735			1801	3.31	6628	7627	[illegible]	13.63	[illegible]

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APPENDIX C

ADVANCED TECHNOLOGY TANDEM ROTOR HELICOPTER

The advanced technology tandem rotor helicopter is shown in Figure C-1. The major dimensions and pertinent data are shown in Table C-1. Vehicle design takeoff gross weight is 30,470 Kg (67,175 pounds). It has an installed shaft horsepower of 3.597×10^6 watts (14,472 HP) at sea level standard day. The two 68.9 foot rotors are four-bladed articulated rotors with a solidity ratio of 0.099. The selection of rotor solidity has been made to provide freedom from stall flutter loads over the entire maneuver envelope. The rotor overlap has been held to zero to eliminate rotor "bang" due to the one rotor cutting the trailed vortices of the other, and also to eliminate the possibility of blade collision in the event of desynchronization failure.

Both rotor shafts are swept forward (7-degrees forward rotor/ 4-degrees aft rotor). This minimizes the floor angle range during hover and cruise flight, and also minimizes rotor loads. The pylon heights are arranged to provide a gap to stagger ratio of 0.145. This clearance is required to keep noise, rotor loads and induced power losses at a minimum.

The engines are sized to meet a requirement to hover OEI at 90°F at Sea Level. The transmission is sized to maximum Sea Level shaft horsepower, which provide OEI performance. In the all engines operating case, the torque limit is set such that both power and torque limit coincide at Sea Level/Standard Day.

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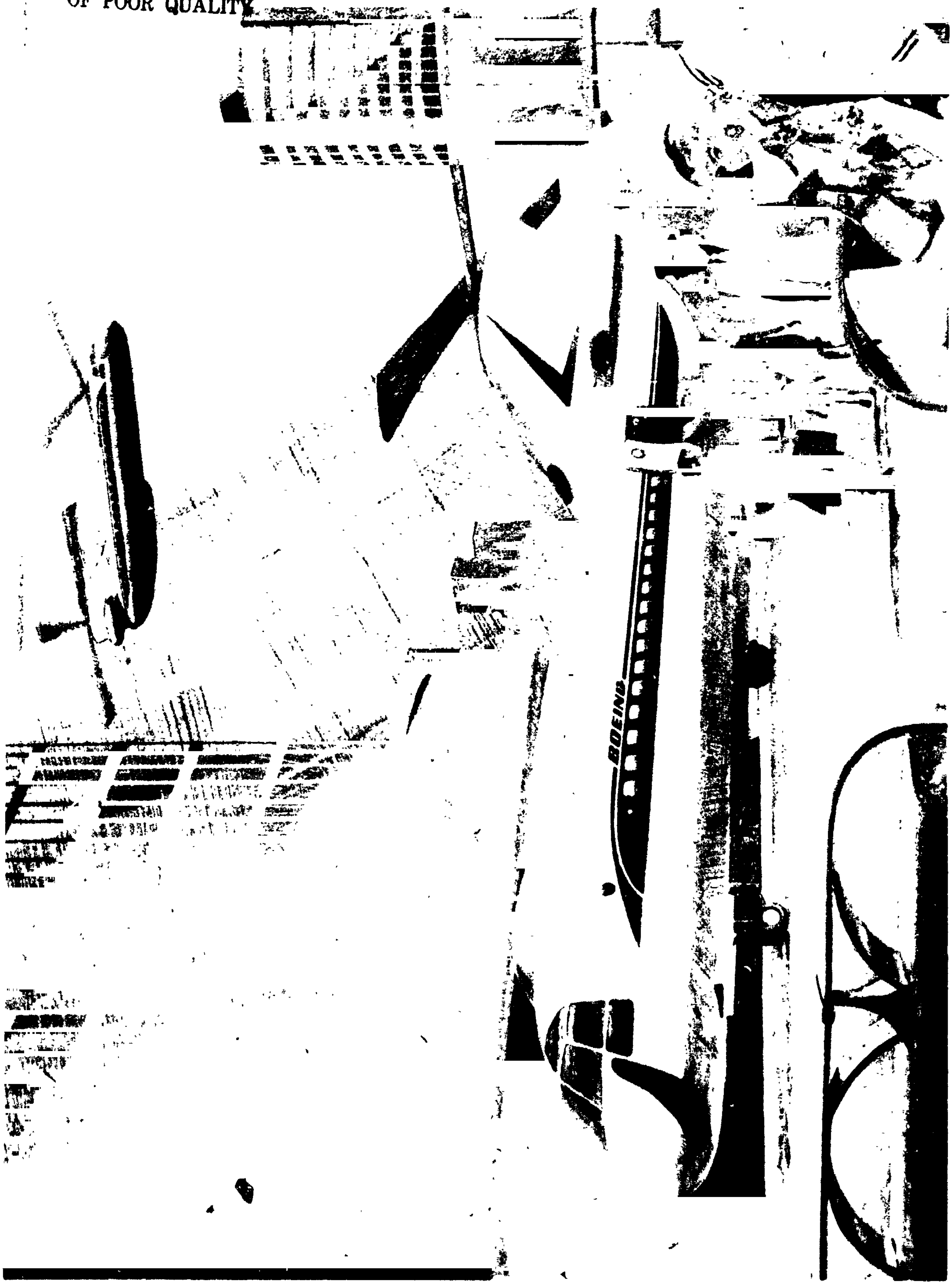

FIGURE C-1 ADVANCED TECHNOLOGY TANDEM ROTOR HELICOPTER

TABLE C-1 ADVANCED TECHNOLOGY TANDEM ROTOR HELICOPTER CHARACTERISTICS

	S.I. UNITS	U.S. UNITS
WEIGHTS		
DESIGN GROSS WEIGHT	30,470 Kg	67,175 Lbs
WEIGHT EMPTY	18,226 Kg	40,181 Lbs
FUEL	3,178 Kg	7,007 Lbs
NO. OF PASSENGERS	100	100
ROTOR		
DISC LOADING	39.4 Kg/m^2	9 Lbs/Ft^2
DIAMETER	21 m	68.9 FT
SOLIDITY	.099	.099
NO. OF BLADES	4	4
TWIST	12 Degs	12 Degs
TIP SPEED	221 m/s	725 Ft/Sec
POWER		
NO. OF ENGINES	3	3
RATED POWER (S.L., STD.)	3.597×10^6 Watts	4824 SHP
FUSELAGE		
LENGTH	26.5 m	87 Ft
WIDTH	4.48 m	14.7 Ft
CABIN/LENGTH	15.03 m	49.3 Ft
PERFORMANCE		
NVRP	85 m/s	165 Knots (TAS)
ALTITUDE CRUISE	1524 m	5000 Ft
t BLOCK	1.337 Hours	1.337 Hours
NOISE		
500 FOOT SIDELINE (HOGE)	92.3 PNdB	92.3 PNdB

Maintaining a one engine out requirement and operating at Standard Day out of ground effect, the aircraft can take off at a gross weight of 74,700 pounds, an increase of 7,525 pounds over the Design Takeoff Weight of 67,175 pounds. This increased weight does not represent increased payload capability since the FAA takeoff gross weight certification would limit the aircraft to 67,175 pounds.

The aircraft has three engines located aft, one on each side of the rear rotor pylon and the third buried in the pylon itself, similar to the XCH-62 (HLH). The intake for the third engine is in the leading edge of the rear rotor pylon.

The transmission layout is a three gearbox arrangement where three engines drive into a combiner gearbox located aft and above the passenger cabin. The combiner box is designed for easy removal through the baggage holding ceiling.

Power is transmitted to the aft rotor by shafting in the rear pylon which drives the aft rotor transmission, and to the forward rotor by shafting along a fuselage tunnel to the forward rotor transmission located forward of the passenger cabin. The APU (Auxiliary Power Unit) is located in the aft fuselage compartment in close proximity to the engines.

This arrangement has been selected for minimum complexity, cost, weight and performance losses as well as to minimize the effects of engine and transmission noise and vibration in the passenger cabin.

The landing gear is a tricycle type which provides excellent ground handling characteristics. The dual wheel gears are retractable into the fuselage for minimum drag and the system is designed for 500 feet per minute rate of sink on landing. The arrangement provides an overturning angle of 27-degrees and adequate fuselage clearance for flared landing.

The passenger cabin has seats for 100 passengers with an overall seat width of 21-inches and a seat pitch of 34-inches.

Each passenger has underseat stowage space (9-inches x 16-inches x 23-inches) and overhead rack stowage with lockable doors. Air vents, individual lights and folding table are provided for each passenger in accordance with normal commercial aircraft practice.

Two lavatories are located in the forward end of the cabin. In the center of the forward cabin is the beverage storage and service counter space which also incorporates ticketing facilities.

Table C-2 gives the weight breakdown of the helicopter in terms of structural components and aircraft systems. Weights of all structural components have been reduced by 25% from conventional technology weight trend data to reflect the use of composite materials.

The engine weights are based on a projected specific weight of .15 pounds per shaft horsepower which is expected to be

TABLE C-2 WEIGHT BREAKDOWN - ADVANCED TECHNOLOGY TANDEM ROTOR HELICOPTER

	KILOGRAMS	POUNDS
WING		
ROTOR	3029.1	6678
TAIL		
SURFACES		
ROTOR		
BODY	2950.1	6504
BASIC		
SECONDARY		
ALIGHTING GEAR GROUP	1218.8	2687
ENGINE SECTION	222.7	491
PROPULSION GROUP	4401.2	9703
ENGINE INST'L	997.9	2200
EXHAUST SYSTEM *		
COOLING		
CONTROLS *		
STARTING *		
PROPELLER INST'L	*82.6	*182
LUBRICATING *		
FUEL	219.1	483
DRIVE	3101.6	6838
FLIGHT CONTROLS	1031.9	2275
AUX. POWER PLANT	288.5	636
INSTRUMENTS	191.9	423
HYDR. & PNEUMATIC	308.4	680
ELECTRICAL GROUP	378.3	834
AVIONICS GROUP	293.9	648
ARMAMENT GROUP		
FURN. & EQUIP. GROUP	3206.9	7070
ACCOM. FOR PERSON.		
MISC. EQUIPMENT		
FURNISHINGS		
EMERG. EQUIPMENT		
AIR CONDITIONING	521.6	1150
ANTI-ICING GROUP	181.4	400
LOAD AND HANDLING GP.		
WEIGHT EMPTY	18224.8	40179
CREW	299.4	660
TRAPPED LIQUIDS	52.2	115
ENGINE OIL	59.9	132
CREW ACCOMMODATIONS	66.[illegible]	150
EMERGENCY EQUIPMENT	7.3	16
PASSENGER ACCOMMOD.	415.5	916
PASSENGERS (100)	8164.6	18000
FUEL	3178.3	7007
GROSS WEIGHT	30469.9	67175

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available for application to a 1985 commercial aircraft. The control system is a fly-by-wire system and the weight estimate for the controls is based upon recent Boeing experience with fly-by-wire controls on the Model 347 helicopter. The rotor gearboxes are designed for maximum engine power and torque under Sea Level/Standard Day conditions.

The landing gear is designed for a 500 foot per minute rate of descent and is 4% of weight empty.

Passenger and crew accommodations are based on Boeing 737 aircraft data since it will be necessary to provide passenger comfort to at least this standard by 1985. The overall aircraft is sized for a maneuver load factor of 3.5 and an ultimate load factor of 5.25 as recommended in FAR Part 29.

Figure C-2 and Table C-3 detail the helicopter design sizing mission.

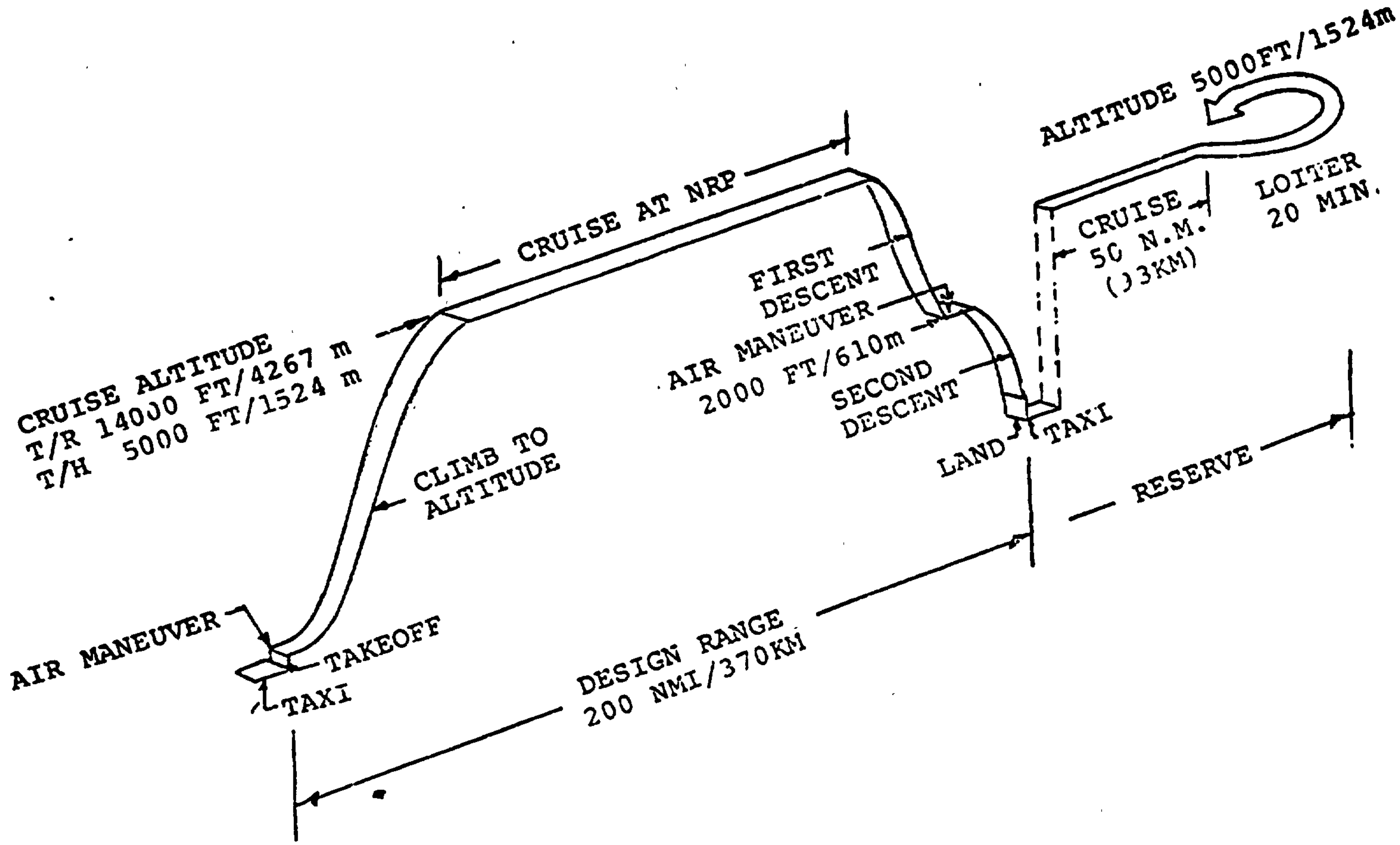

FIGURE C-2 DESIGN MISSION PROFILE - ADVANCED TECHNOLOGY TANDEM HELICOPTER

TABLE C-3 DESIGN MISSION PROFILE INFORMATION

ADVANCED TECHNOLOGY TANDEM ROTOR HELICOPTER

SEGMENT	TIME	DISTANCE	REMARKS
	VTOL	VTOL	
Taxi Out	1 min.	0	
Takeoff, Transition & Conversion to Conventional Flight	0.5 min.	0	
Air Maneuver (Origin)	0.5 min.	0	
Acceleration to Climb Speed	As Calculated		
Climb	As Calculated		At optimum Climb Spd
Cruise	As Calculated		At Constant Integral 1000 ft. Altitudes (No Enroute Altitude Change)
Descent to 2000 ft.	As Calculated		5000 fpm maximum rate of Descent
Air Maneuver at 2000 ft. (destination)	1.5 min.	0	
Decelerating Approach and Conversion to Powered Lift Flight 2000 ft. to 1000 ft.	As Calculated	0	1000 fpm maximum Rate of Descent
Transition and landing from 1000 ft. to Touchdown	As Calculated	0	1000 fpm maximum Rate of Descent Down to 35 ft. 600 fpm Maximum Rate of Descent Below 35ft.
Taxi In	1 min.	0	