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STUDY OF OPERATIONAL PARAMETERS IMPACTING HELICOPTER FUEL CONSUMPTION

BY

JEFFREY L. CROSS AND DARIENE D. STEVENS

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16. Abstract

A computerized study of operational parameters affecting helicopter fuel consumption was conducted as an integral part of the NASA Civil Helicopter Technology Program. The study utilized the Helicopter Sizing and Performance Computer Program (HESCOMP) developed by the Boeing-Vertol Company and NASA Ames Research Center. An introduction to HESCOMP is incorporated in this report.

The results presented were calculated using the NASA CH-53 civil helicopter research aircraft specifications. Plots from which optimum flight conditions for minimum fuel use can be obtained are presented for this aircraft. The results of the study are considered to be generally indicative of trends for all helicopters.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

STUDY OF OPERATIONAL PARAMETERS IMPACTING HELICOPTER FUEL CONSUMPTION

by Jeffrey L. Cross and Dariene D. Stevens

Langley Research Center

SUMMARY

A study of operational parameters affecting helicopter fuel consumption is presented with an introduction to the Helicopter Sizing and Performance Computer Program (HESCOMP). HESCOMP, developed by the Boeing-Vertol Company and NASA Ames Research Center, is a dual purpose program designed to size a helicopter to a specific mission or compute performance of a given helicopter for a given mission. The study of fuel consumption is an integral part of the NASA Civil Helicopter Technology Program. It is presented here to serve as both a source of information regarding significant operational considerations in helicopter fuel utilization and as a sample case in the use of HESCOMP. Range, cruise speed, altitude, descent profiles, extended taxi time, and aircraft weight were parameters examined in the study. The scope of values was determined by the anticipated flight environment in short-haul civil helicopter passenger operations.

The results are presented for two aircraft gross weight conditions of 15,422 kg (34,000 lb) and 17,236 (38,000 lb) for the NASA CH-53 Civil Helicopter Research Aircraft. Plots from which optimum flight conditions for minimum fuel use can be obtained are presented for this aircraft and are felt to be generally indicative of trends for all helicopters.

INTRODUCTION

Since the inception of commercial helicopter operation, its uses have been restricted to applications where the helicopter's unique capabilities made it the only viable candidate. Increasingly, however, helicopter use is expanding into head-to-head competition with established methods in a wide variety of fields. This is particularly true in the field of short-haul passenger and freight transportation, where the helicopter has many significant advantages. As fuel costs have escalated, helicopter fuel consumption has become a serious drawback in its competitiveness. It is therefore important to study techniques for reducing fuel consumption of not only future helicopters but also of current helicopters. This topic is well documented in the study reported in reference 1.

This report concerns helicopter fuel consumption parameters as analyzed by the Helicopter Sizing and Performance Computer Program (HESCOMP) for the NASA Civil Helicopter Technology Program. HESCOMP is utilized in this study to establish the most fuel-efficient mission conditions for the CH-53 helicopter, which is the primary flight vehicle of the NASA Civil Helicopter Technology Program. Hence, all values contained herein are given for the CH-53 Civil Helicopter Research Aircraft and a heavier version of the CH-53; however, the data should be indicative of fuel use trends for other helicopters.

The purpose of this report is to examine the cause and effect relationship between mission profiles and fuel consumption trends. Operating parameters such as speed and altitude and their effects on fuel use are examined in the study. Improvements in helicopter design, that is, reduced parasite and induced drag, engine improvements, etc., are not considered in this report.

An extensive study of these parameters is presented in reference 2. A brief overview of HESCOMP is discussed to provide insight into the requirements and capabilities of the program.

Detailed instructions for HESCOMP are located in the HESCOMP User's Manual (ref. 3). References 4 and 5 contain comprehensive descriptions of the CH-53. Appendix A is a general description of the CH-53 research aircraft. Appendix B is a sample computer output of HESCOMP as used in this study. Appendix C is a list of input contained in a standard HESCOMP data deck.

SYMBOLS

sfc - specific fuel consumption

HESCOMP Output Terminology

Alpha D/L		- angle of total thrust
BHP		- total power required
CT		- main rotor thrust coefficient
CT/Sigma		- CT/main rotor solidity
CT Prime/Sigma		- main rotor cruise lift coefficient/main rotor solidity
FM		- main rotor overall hover figure of merit
Gamma		- flightpath angle in degrees
Mu		- main rotor advance ratio
(NMPP)		- specific range in nautical miles per pound
P	Primary Engine Code	- power (or thrust) required
T		- turbine temperature (engine rating)
PEHF		- primary engine horsepower fraction

Normal Power Setting	-	maximum continuous operation
Maximum Power Setting	-	maximum for 10-minute continuous operation
Military Power Setting	-	maximum for 30-minute continuous operation
R/C	-	rate of climb in feet per minute
R/S	-	rate of descent in feet per minute
TAS	-	true airspeed
EAS	-	equivalent airspeed

COMPUTER PROGRAM DESCRIPTION

The computer program, HESCOMP (Helicopter Sizing and Performance Program), developed by the Boeing-Vertol Company and NASA Ames Research Center, is written in FORTRAN IV and is set up for a CDC 6000 series computer. The computer core storage requirement is $120{,}000_8$ locations, and the computer running time of a typical mission is 1.3 central processing (CP) seconds. The program operates in English units.

The program has the capability for two independent applications. It may be used for sizing a helicopter where the type of aircraft and mission profile are specified or, as utilized in this study, for mission calculations for a particular aircraft where sizing details are known.

The input data to the program can be grouped into four basic categories:

Category I - General Information: Includes all primary indicators, mission initial conditions, and constraints.

Category II - Aircraft Characteristics: Includes dimensional, propulsion, aerodynamics, and weight information.

Category III - Engine Cycle Information: Includes tables of referred horsepower, referred fuel flow, and gas generator RPM.

Category IV - Mission Profile Information: Includes details for each segment of a mission. The various segments are (1) taxi, (2) takeoff, hover, and landing, (3) climb, (4) cruise, (5) descent, (6) loiter, and (7) change of weight or transfer of altitude.

The output data from the program consist of a detailed analysis of each segment of the mission. A sample output is included in appendix B.

PARAMETRIC STUDY VARIABLES

The variables selected for investigation in this study are: range, cruise speed, cruise altitude, rate of descent, descent profiles, number of landings per mission, delayed ground time (taxi time), and aircraft weight. The primary investigative approach taken was to compile a matrix of altitude and cruise speeds at three distinct ranges. These three elements were studied in-depth as it was anticipated that these would comprise the bulk of fuel usage and possible fuel savings. Separate data decks were composed for the descent profile and multiple stop missions. The remaining variables were alternately entered into a standardized data deck so that their individual effects could be observed. The standardized deck, listed in appendix A, is a representative case drawn from the matrix previously mentioned.

The three principal parameters are varied as follows: altitudes from 609.6 m (2000 ft) to 2438.4 m (8000 ft) in 609.6-m (2000-ft) intervals; cruise speeds as shown in table I; and ranges of 185.2 km (100 n.mi.), 277.8 km (150 n.mi.), and 370.4 km (200 n.mi.). These values are representative of a commercial helicopter flight envelope.

TABLE I. - INVESTIGATED CRUISE SPEEDS

km/hr	knots	km/hr	knots
129.6	70	222.2	120
148.1	80	240.7*	130
166.6	90	259.2	140
185.2	100	277.8*	150
203.7*	110	296.3	160
		314.8	170

* Emphasis placed on these values.

The remaining parameters are varied as follows: descent rates of 152.4 m/min (500 ft/min), 213.3 m/min (700 ft/min), 304.8 m/min (1000 ft/min), and 426.7 m/min (1400 ft/min). Mission and descent profiles utilized are shown in figure 1.

The variations in delayed ground time investigated during the study are shown in table II. The delayed ground time is in addition to two 10-minute taxi segments included in the aforementioned standardized deck.

TABLE II. - DELAYED TIME COMBINATIONS

Before Flight	After Flight
5 min	0 min
10 min	0 min
15 min	0 min
20 min	0 min
5 min	5 min
10 min	10 min
15 min	15 min

Aircraft weight inputs correspond to the 15.422.1-kg (34,000-lb) research aircraft and a 17,236.5-kg (38,000-lb) proposed passenger version of the CH-53.

RESULTS AND DISCUSSION

Presentation of Results

The results of the study are presented in tables, cross plots, and carpet plots of the variables investigated in the program. Figure 2 presents the calculated power required curve for all of the flight conditions investigated. The values for required power correspond to the initial cruise condition value. These values were selected such that the results are independent of any appreciable fuel consumption.

Figures 3 and 4 present the basic trends of fuel consumption versus cruise speed for 185.2-km (100-n.mi.), 277.8-km (150-n.mi.), and 370.4-km (200-n.mi.) ranges at an aircraft gross weight of 15,422.1 kg (34,000 lb) and 17,236.5 kg (38,000 lb), respectively. Each of the presented data curves contains that value for maximum range per pound of fuel as calculated by HESCOMP. The comprehensive investigation of the 277.8-km (150-n.mi.) case presented in figure 3 allowed for the reduction of computation for remaining missions.

Figures 5(a), 5(b), and 5(c) present carpet plots of fuel used for each of the primary variables - mission time, cruise speed, and cruise altitude - for ranges of 185.2 km (100 n.mi.), 277.8 km (150 n.mi.), and 370.4 km (200 n.mi.) at a takeoff weight of 15,422.1 kg (34,000 lb). Figures 6(a), 6(b), and 6(c) represent corresponding carpet plots for a 17,236.5-kg (38,000-lb) gross weight. Figures 7 and 8 are summary plots showing the relationships of the variables for the three range conditions for the 15,422.1-kg (34,000-lb) and 17,236.5-kg (38,000-lb) aircraft, respectively. Figure 9 presents the fuel required as a function of ground delay time for the

185.2-km (100-n.mi.) case. Tables III through VI present the fuel required for the various mission profiles flown.

All values of fuel consumption in this report include 172.4 kg (390 lb) of reserve fuel, except tables V and VI.

Discussion of Results

Figure 2 illustrates the calculated power required curve versus cruise speed for the 15,422.1-kg (34,000-lb) and 17,236.5-kg (38,000-lb) aircraft. Maximum power available with the engines powering the CH-53 is 2.9455×10^6 W (3950 hp). The graph indicates that, for 15,422.1 kg (34,000 lb) and 203.7 km/hr (110 knots), at higher altitude less power is required. As the speed increases, the power required at an altitude begins to increase such that the minimum power required centers around 1219.2 m (4000 ft) and the maximum power required corresponds to 2438.4 m (8000 ft). This trend is such that with the heavier aircraft there is a 3.73×10^5 W (500 hp) increase in power, while with the lighter aircraft the increase is only 7.76×10^4 W (100 hp).

Figures 5(a), 5(b), 5(c), 6(a), 6(b), and 6(c) are carpet plots of fuel used versus mission time, incorporating altitude, speed, and range. These graphs allow for the optimization of tradeoffs between mission time and mission fuel, important factors in commercial helicopter aviation. For any stagelength with the 15,422.1-kg (34,000-lb) gross weight aircraft, the flight conditions yielding the highest fuel use and flight time are an altitude of 609.6 m (2000 ft) and a cruise speed of 203.7 km/hr (110 knots). For the 17,236.5-kg (38,000-lb) gross weight aircraft, the flight conditions yielding the highest fuel use are 277.8 km/hr (150 knots) at 2438.4 m (8000 ft). Flight conditions yielding the highest mission time are 2438.4 m (8000 ft) and 203.7 km/hr (110 knots). Figure 7 illustrates the relative positions of figures 5(a), 5(b), and 5(c); figure 8 illustrates the relative positions of figures 6(a), 6(b), and 6(c). Figures 7 and 8 show that the greater the mission range the more significant are the fuel savings achievable by the methods contained in this study. Figures 7 and 8 also highlight the linear relationship which exists among the five parameters - (1) fuel used, (2) flight time, (3) cruise speed, (4) altitude, and (5) range. The linearity can be utilized in projecting fuel consumption at other than the specified ranges.

In figure 8, it is obvious that at 150 knots the trend of better fuel economy at altitude is reversed. This can be attributed to the substantial increase in horsepower required between 609.5 m and 2438.4 m (2000 ft and 8000 ft). (See fig. 2.) At lower airspeeds and lower gross weight conditions, the greater horsepower requirements at higher altitudes are overcome by a substantial decrease in specific fuel consumption (sfc). At 277.8 km/hr (150 knots), the horsepower requirement becomes the dominant factor and, hence, the reversing trend.

The slopes of the curves in figures 7 and 8 increase as the range increases, indicating that the greater the range the more critical the cruise speed. The bucket shaped curves result from high sfc values at low airspeeds, large power required values (BHP) at high airspeeds, and relatively moderate values of sfc and BHP at the intermediate airspeed values. Table III is a related investigation concerning the effect of flying at 152.4 m (500 ft) versus 609.6 m (2000 ft) over 185.2 km (100 n.mi.).

The largest decrease in fuel utilization for the 17,236.5-kg (38,000-lb) aircraft configuration achieved in this study was 9 percent. This result was obtained at 1828.8 m (6000 ft), 240.8 km/hr (130 knots) as opposed to 609.6 m (2000 ft), 203.7 km/hr (110 knots). The primary results of this study - significant fuel savings and time loss - are presented in tables VII through X.

Figure 9 is a graph of fuel versus ground delay time. The values of ground delay are in two groups. The first is with the indicated elapsed time prior to flight; the other is with the indicated time split evenly before and after flight. These delays are in addition to a standard 10-minute taxi before and after flight. Over a 185.2-km (100-n.mi.) mission, a 20-minute delay (10 minutes before and 10 minutes after flight) caused approximately a 9-percent increase in fuel consumed. By placing the delay time prior to flight rather than splitting it around the flight, a 7-percent increase in fuel consumed is noted over a nondelayed flight.

Table IV contains information gathered from multilanding missions. The variations of this table are landing locations, taxi time, and altitude. The following are the percentage increases for a triple stop mission versus a nonstop mission of 370.4 km (200 n.mi.): 609.6-m (2000-ft) altitude - 21.2-percent increase; 1219.2-m (4000-ft) altitude - 22.5-percent increase; 1828.8-m (6000-ft) altitude - 23.8-percent increase. Of the triple stop missions with landings at 92.6 km (50 n.mi.), 231.5 km (125 n.mi.), and 370.4 km (200 n.mi.), the fuel consumption at 1828.8 m (6000 ft) was the most conservative. The triple stop missions at 1219.2 m (4000 ft) and 609.6 m (2000 ft) consumed 1.6 percent and 3.8 percent more fuel, respectively, than the 1828.8-m (6000-ft) case. For the triple stop mission, the one with landings at 18.5, 333.3, and 370.4 km (10, 180, and 200 n.mi.) was the most fuel conservative. This is a projection of a typical intercity helicopter mission that originates in a downtown area, stops at a nearby urban area airport, cruises to the destination area's urban airport, and then terminates in the downtown area.

Possible gains by alternating the rate of descent were tested; the results are shown in table V. Forty seconds and one pound of fuel are gained by descending at 304.8 m/min (1000 ft/min) in place of 213.3 m/min (700 ft/min). There is a 1.2-percent increase in fuel consumed and a 58-second increase in flight time by descending at 152.4 m/min (500 ft/min) versus 213.3 m/min (700 ft/min). In view of such minimal advantages in the more rapid descents, passenger comfort would likely be the qualifying factor in this aspect of operations.

Table VI concerns the descent paths and their influence on fuel consumption. The descent paths studied were the standard constant and a staggered rate wherein descents were made to 60.9 m (200 ft), level flight for 1.8 km (1 n.mi.), and a rapid rate of descent to landing. The staggered descent has an initial rate of descent of 152.4 m/min (500 ft/min) at 240.7 km/hr (130 knots) with a second descent at 129.6 km/hr (70 knots). The staggered descent consumes 0.2 percent (5 lb) more fuel with a time savings of 0.7 percent (43 sec).

CONCLUSIONS

HESCOMP has been successfully used in an analytical parametric study of helicopter fuel consumption. As was anticipated, range, altitude, and cruise speed were the prime factors in fuel consumption. Given a range and speed, the following are in order of decreasing significance: altitude, number of en route landings, delayed ground time, aircraft weight, descent rate, and descent profile (dual sloped descent). The effect of descent rate and descent profile was so slight that passenger acceptance and/or operating conditions would likely be the determining factors. For missions where mission time is not a critical item, substantial benefits of up to 10 percent in fuel use can be gained by flying at a somewhat reduced speed and higher altitude.

Other factors to be considered are the air traffic control environment and the impact of helicopters operating at 6000 to 8000 ft, and consideration of the effect decreased speed has on productivity and operating costs. If fuel prices continue to escalate, the fuel cost may offset the effect of decreased speed on operating costs. HESCOMP contains one drawback for a study such as this. During the ascent aspect of the mission, rate of climb is not a control variable. Only by power settings, of which HESCOMP has only three, can the rate of climb be varied. Thus, one potential fuel consumption factor cannot be studied in-depth by this program. With this exception, the program is well adapted to studies of this nature.

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APPENDIX A

CH-53 PHYSICAL DESCRIPTION

	Metric	English
Empty weight	11575.0 kg	25525.0 lb
Gross weight	16329.3 kg	36000.0 lb
Overall length	17.2 m	56.46 ft
Overall height	5.1 m	16.63 ft
Overall width	4.7 m	15.50 ft
Cabin volume	52.2 m^3	1843.0 ft^3
Tail rotor radius	2.4 m	8.0 ft
Number of blades	4	4
Blade chord	0.4 m	1.28 ft
Main rotor station	8.5 m	336.40 in.
Waterline	6.5 m	257.0 in.
Radius	11.0 m	36.0 ft
Number of blades	6	6
Blade chord	0.7 m	2.16 ft
Shaft tilt long	8.7×10^{-2} R	5^o
Shaft tilt lateral	0	0^o
Disc loading	394.0 N/m^2	8.23 lb/ft^2
Engine horsepower	2.9455×10^6 W	3950.0 hp/engine
Maximum cruise speed	314.8 km/hr	170.0 knots

APPENDIX B

HESCOMP COMPUTER PRINTOUT

CIVIL HELICOPTER MISSION PROFILES 1 PAGE 2

H E S C O M P
HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM B-91

SINGLE ROTOR PURE HELICOPTER

MISSION PERFORMANCE DATA

TAXI FOR .166 HRS. AT GROUND IDLE ENGINE RATING

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRESS. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PEHF	TOTAL FUEL FLOW (LBS/HR)	AUX. TURB. TEMP. (R)	AUX. ENG. CODE	AUX. ENG. PEHF	AUX. ENG. FUEL FLOW (LBS/HR)
0.000	0.00	0.0	34000.	0.	0.0	1156.0	T	.033	508.	----	----	----	----
.166	0.00	84.3	33916.	0.	0.0	1156.0	T	.033	508.	----	----	----	----

TAKEOFF, HOVER, OR LAND AT T/W = 1.050 FOR .033 HRS.

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PEHF	TOTAL FUEL FLOW (LBS/HR)	THRUST TO WEIGHT	FM	BHP	CT	CT/SIGMA
.166	0.00	84.3	33916.	0.	0.0	1417.6	P	.777	2454.	1.050	.665	5026.	.0075	.065
.182	0.00	122.3	33878.	0.	0.0	1417.2	P	.776	2451.	1.050	.665	5018.	.0075	.065
.197	0.00	160.3	33840.	0.	0.0	1416.8	P	.775	2448.	1.050	.665	5011.	.0075	.065
.199	0.00	165.2	33835.	0.	0.0	1416.8	P	.775	2448.	1.050	.665	5010.	.0075	.065

CLIMB TO 6000. FT. WITH CONSTANT TAS AT NORMAL ENGINE RATING
** TAS(AND EAS) IS THE HORIZONTAL COMPONENT OF THE FLIGHT PATH SPEED

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PEHF	EAS (KTS)	MU	CT PRIME OVER SIGMA	ALPHA D/L (DEG)	GAMMA (DEG)	BHP	R/C (FPM)
.199	0.00	165.2	33835.	0.	90.0	1437.0	T	.816	90.0	.218	.062	-2.1	15.7	5373.	2571.
.202	.29	173.6	33826.	500.	90.0	1437.0	T	.819	89.3	.218	.063	-2.1	15.7	5353.	2557.
.206	.59	182.1	33818.	1000.	90.0	1437.0	T	.823	88.7	.218	.064	-2.1	15.6	5332.	2542.
.209	.88	190.5	33809.	1500.	90.0	1437.0	T	.828	88.0	.218	.065	-2.0	15.5	5310.	2525.
.212	1.18	198.9	33801.	2000.	90.0	1437.0	T	.834	87.4	.218	.066	-2.0	15.4	5288.	2508.
.215	1.48	207.4	33793.	2500.	90.0	1437.0	T	.843	86.7	.218	.067	-2.0	15.3	5281.	2503.
.219	1.78	215.8	33784.	3000.	90.0	1437.0	T	.852	86.1	.218	.068	-2.0	15.3	5271.	2495.

.222	2.08	224.2	33776.	3500.	90.0	1437.0	T	.860	85.5	.218	.069	-1.9	15.2	5255.	2482.
.225	2.38	232.6	33767.	4000.	90.0	1437.0	T	.867	84.8	.218	.070	-1.9	15.1	5236.	2465.
.229	2.68	241.0	33759.	4500.	90.0	1437.0	T	.874	84.2	.218	.071	-1.9	15.0	5212.	2444.
.232	2.99	249.5	33751.	5000.	90.0	1437.0	T	.880	83.5	.218	.072	-1.8	14.9	5185.	2419.
.236	3.30	257.9	33742.	5500.	90.0	1437.0	T	.886	82.9	.218	.073	-1.8	14.7	5153.	2391.
.239	3.62	266.4	33734.	6000.	90.0	1437.0	T	.892	82.3	.218	.074	-1.8	14.5	5118.	2359.

CRUISE AT 130.0 KNOTS TAS, LIMITED BY NORMAL ENGINE RATING

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PERF	EAS (KTS)	MU	CT PRIME OVER SIGMA	ALPHA D/L (DEG)	SPEC. RANGE (NMPP)	BHP
.239	3.62	266.4	33734.	6000.	130.0	1300.5	P	.520	118.9	.322	.077	-3.7	.08082	3026.
.431	28.62	575.7	33424.	6000.	130.0	1299.1	P	.516	118.9	.322	.077	-3.8	.08122	3002.
.624	53.62	883.5	33116.	6000.	130.0	1297.7	P	.512	118.9	.322	.076	-3.8	.08162	2980.
.816	78.62	1189.8	32810.	6000.	130.0	1296.4	P	.508	118.9	.322	.075	-3.8	[illegible]	2957.
.876	86.46	1285.5	32714.	6000.	130.0	1296.0	P	.507	118.9	.322	.075	-3.9	[illegible]	2951.

DESCEND TO H = 0. FT. ,R = 100.00 N.MI. AT CONSTANT TAS

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PERF	EAS (KTS)	MU	CT PRIME OVER SIGMA	ALPHA D/L (DEG)	GAMMA (DEG)	BHP	R/S (FPM)
.876	86.46	1285.5	32714.	6000.	95.0	1192.5	P	.254	[illegible]	.235	.075	2.1	-4.2	1460.	700.
.888	87.59	1296.9	32703.	5500.	95.0	1192.4	P	.254	[illegible]	.235	.075	2.1	-4.2	1460.	700.
.900	88.72	1308.3	32692.	5000.	95.0	1192.4	P	.254	86.9	.235	.075	2.1	-4.2	1459.	700.
.912	89.85	1319.7	32680.	4500.	95.0	1192.4	P	.254	86.9	.235	.075	2.1	-4.2	1459.	700.
.924	90.98	1331.1	32669.	4000.	95.0	1192.3	P	.254	86.9	.235	.075	2.1	-4.2	1458.	700.
.936	92.10	1342.4	32658.	3500.	95.0	1192.3	P	.254	86.9	.235	.075	2.1	-4.2	1458.	700.
.948	93.23	1353.8	32646.	3000.	95.0	1192.3	P	.253	86.9	.235	.075	2.1	-4.2	1457.	700.
.960	94.36	1365.2	32635.	2500.	95.0	1192.2	P	.253	86.9	.235	.075	2.1	-4.2	1457.	700.
.972	95.49	1376.5	32623.	2000.	95.0	1192.2	P	.253	86.9	.235	.075	2.1	-4.2	1456.	700.
.984	96.62	1387.9	32612.	1500.	95.0	1192.2	P	.253	86.9	.235	.075	2.1	-4.2	1456.	700.
.995	97.74	1399.2	32601.	1000.	95.0	1192.1	P	.253	86.9	.235	.075	2.1	-4.2	1456.	700.
1.007	98.87	1410.6	32589.	500.	95.0	1192.1	P	.253	86.9	.235	.075	2.1	-4.2	1455.	700.
1.019	100.00	1422.0	32578.	0.	95.0	1192.1	P	.253	86.9	.235	.075	2.1	-4.2	1455.	700.

TAKEOFF, HOVER, OR LAND AT T/W = 1.050 FOR .033 HRS.

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)	TAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PERF	TOTAL FUEL FLOW (LBS/HR)	THRUST TO WEIGHT	FM	BHP	CT	CT/SIGMA
1.019	100.00	1422.0	32578.	0.	0.0	1351.6	P	.533	1962.	1.050	.685	3445.	.0075	.066
1.035	100.00	1452.7	32547.	0.	0.0	1351.4	P	.532	1961.	1.050	.685	3440.	.0075	.066
1.050	100.00	1483.4	32517.	0.	0.0	1351.2	P	.531	1980.	1.050	.685	3436.	.0075	.065
1.052	100.00	1487.4	32513.	0.	0.0	1351.2	P	.531	1980.	1.050	.685	3435.	.0075	.065

TAXI FOR .166 HRS. AT GROUND IDLE ENGINE RATING

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRESS. ALT. (FT)	IAS (KTS)	PRIM. TURB. TEMP. (R)	PRIM. ENG. CODE	PRIM. ENG. PEHF	TOTAL FUEL FLOW (LBS/HR)	AUX. TURB. TEMP. (R)	AUX. ENG. CODE	AUX. ENG. PEHF	AUX. ENG. FUEL FLOW (LBS/HR)
1.052	100.00	1487.4	32513.	0.	0.0	1156.0	T	.033	508.	----	----	----	----
1.218	100.00	1571.6	32428.	0.	0.0	1156.0	T	.033	508.	----	----	----	---

MISSION FUEL REQUIRED = 1571.64
RESERVE FUEL REQUIRED = 390.00
TOTAL FUEL REQUIRED = 1961.64

END OF SUCCESSFUL CASE

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX C

MISSION PROFILE INFORMATION

The following is a listing of the mission profile information input of a standardized HESCOMP data deck:

Taxi 1

Atmosphere	-	standard
Duration	-	10 minutes

Takeoff

Atmosphere	-	standard
T/W	-	1.05
Duration	-	1 minute

Climb

Atmosphere	-	standard
Power setting	-	normal
Forward speed	-	constant TAS
Value	-	166.7 km/hr (90 knots)
Δh	-	152.4 m (500 ft)

Cruise

Atmosphere	-	standard
Power setting	-	normal
Cruise speed	-	constant TAS
Value	-	240.8 km/hr (130 knots)
Range	-	277.8 km (150 n.mi.)
Δ range	-	46300 m (25 n.mi.)

Descent

Atmosphere	-	standard
Power setting	-	normal
R/D	-	213.4 m/min (700 ft/min)

Forward speed	-	constant TAS
Value	-	175.9 km/hr (95 knots)
Terminating range	-	277.8 km (150 n.mi.)
Δh	-	152.4 m (500 ft)

Land

See takeoff.

Taxi 2

See taxi 1.

TABLE III. - COMPARISON OF FUEL CONSUMPTION FOR 500 FT AND 2000 FT CRUISE ALTITUDES

ALTITUDE	RANGE	CRUISE SPEED	TIME*	FUEL USED
152.4 m (500 ft)	185.2 km (100 n.mi.)	203.7 km/hr (110 knots)	1.309 hr	1018.3 kg (2245 lb)
152.4 m (500 ft)	185.2 km (100 n.mi.)	240.8 km/hr (130 knots)	1.172 hr	977.9 kg (2156 lb)
152.4 m (500 ft)	185.2 km (100 n.mi.)	277.8 km/hr (150 knots)	1.071 hr	989.3 kg (2181 lb)
609.6 m (2000 ft)	185.2 km (100 n.mi.)	203.7 km/hr (110 knots)	1.316 hr	957.1 kg (2110 lb)
609.6 m (2000 ft)	185.2 km (100 n.mi.)	240.8 km/hr (130 knots)	1.184 hr	924.9 kg (2039 lb)
609.6 m (2000 ft)	185.2 km (100 n.mi.)	277.8 km/hr (150 knots)	1.087 hr	934.4 kg (2060 lb)

* Includes ground delay time.

Aircraft weight: 15422.1 kg (34000 lb)
(390 lb reserve fuel included)

TABLE IV. - MISSION PROFILES

1ST LEG				2ND LEG				3RD LEG					
Range at Touchdown	Altitude	Cruise	Taxi	Range at Touchdown	Altitude	Cruise	Taxi	Range at Touchdown	Altitude	Cruise	Taxi	Fuel	Time
18.5 km (10 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.166 hr	333.4 km (180 n.mi.)	1828.8 m (6000 ft)	240.8 km/hr (130 knots)	.166 hr	370.4 km (200 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.166 hr	1651.1 kg (3640 lb)	2.669 hr
92.6 km (50 n.mi.)	1828.8 m (6000 ft)	240.8 km/hr (130 knots)	.166 hr	231.5 km (125 n.mi.)	1828.8 m (6000 ft)	240.8 km/hr (130 knots)	.166 hr	370.4 km (200 n.mi.)	1828.8 m (6000 ft)	240.8 km/hr (130 knots)	.166 hr	1780.3 kg (3925 lb)	2.735 hr
92.6 km (50 n.mi.)	1219.2 m (4000 ft)	240.8 km/hr (130 knots)	.166 hr	231.5 km (125 n.mi.)	1219.2 m (4000 ft)	240.8 km/hr (130 knots)	.166 hr	370.4 km (200 n.mi.)	1219.2 m (4000 ft)	240.8 km/hr (130 knots)	.166 hr	1805.3 kg (3980 lb)	2.686 hr
92.6 km (50 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.166 hr	231.5 km (125 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.166 hr	370.4 km (200 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.166 hr	1841.1 kg (4059 lb)	2.636 hr
92.6 km (50 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.25 hr	231.5 km (125 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.25 hr	370.4 km (200 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.25 hr	1898.3 kg (4185 lb)	2.888 hr
92.6 km (50 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.33 hr	231.5 km (125 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.33 hr	370.4 km (200 n.mi.)	609.6 m (2000 ft)	240.8 km/hr (130 knots)	.33 hr	1955.0 kg (4310 lb)	3.137 hr

Aircraft weight: 15422.1 kg (34000 lb)
(390 lb reserve fuel included)

TABLE V. - DESCENT RATES

RATE OF DESCENT	RANGE	TIME	FUEL USED	INITIAL ALTITUDE	TAS
152.4 m/min (500 ft/min)	185.2 km (100 n.mi.)	1.234 hr	721.2 kg (1590 lb)	1828.8 m (6000 ft)	175.9 km/sec (95 knots)
213.4 m/min (700 ft/min)	185.2 km (100 n.mi.)	1.218 hr	713.0 kg (1572 lb)	1828.8 m (6000 ft)	175.9 km/sec (95 knots)
304.8 m/min (1000 ft/min)	185.2 km (100 n.mi.)	1.207 hr	712.6 kg (1571 lb)	1828.8 m (6000 ft)	175.9 km/sec (95 knots)
426.7 m/min (1400 ft/min)	185.2 km (100 n.mi.)	1.199 hr	714.9 kg (1576 lb)	1828.8 m (6000 ft)	175.9 km/sec (95 knots)

Aircraft weight: 15422.1 kg (34000 lb)

(reserve fuel not included)

TABLE VI. - STANDARD DESCENT VS. STAGGERED DESCENT

RANGE AT COMMENCEMENT OF DESCENT	INITIAL R/S	TAS	FINAL R/S	TAS	MISSION TIME	MISSION FUEL
244.9 km (132.2 n.mi.)	152.4 m/min (500 ft/min)	240.8 km/hr (130 knots)			1.557 hr	1049.2 kg (2313 lb)
277.4 km (149.8 n.mi.)			304.8 m/min (1000 ft/min)	129.6 km/hr (70 knots)		
269.5 km (145.5 n.mi.)	213.4 m/min (700 ft/min)	175.9 km/hr (95 knots)	---	---	1.569 hr	1046.9 kg (2308 lb)

Altitude: 609.6 m (2000 ft)

Mission range: 277.8 km (150 n.mi.)

Aircraft weight: 15422.1 kg (34000 lb)

(reserve fuel not included)

TABLE VII. - CALCULATED FUEL SAVINGS FOR 15422.1-kg (34000-lb) GROSS WEIGHT AIRCRAFT AT 240.7 km/hr (130 knots)

RANGE	FUEL CONSUMED AT 609.6 m (2000 ft)	FUEL CONSUMED AT 2438.4 m (8000 ft)	% FUEL SAVINGS
185.2 km (100 n.mi.)	925.0 kg (2040 lb)	875.4 kg (1930 lb)	5.4
277.8 km (150 n.mi.)	1220.2 kg (2690 lb)	1140.8 kg (2515 lb)	6.5
370.4 km (200 n.mi.)	1519.5 kg (3350 lb)	1397.1 kg (3080 lb)	8.1

(includes reserve fuel)

TABLE VIII. - CALCULATED FUEL SAVINGS FOR 17236.5-kg (38000-lb) GROSS WEIGHT AIRCRAFT AT 240.7 km/hr (130 knots)

RANGE	FUEL CONSUMED AT 609.6 m (2000 ft)	FUEL CONSUMED AT 1828.8 m (6000 ft)	% FUEL SAVINGS
185.2 km (100 n.mi.)	966.1 kg (2130 lb)	938.9 kg (2070 lb)	2.8
277.8 km (150 n.mi.)	1274.6 kg (2810 lb)	1229.2 kg (2710 lb)	3.6
370.4 km (200 n.mi.)	1581.7 kg (3487 lb)	1510.5 kg (3330 lb)	4.5

(includes reserve fuel)

TABLE IX. - CALCULATED FUEL SAVINGS AND TIME LOSS FOR
15422.1-kg (34000-lb) GROSS WEIGHT AIRCRAFT

RANGE	Airspeed 277.8 km/hr (150 knots)	Altitude 609.6 m (2000 ft)	Airspeed 240.7 km/hr (130 knots)	Altitude 2438.4 m (8000 ft)	% SAVINGS	
	TIME	FUEL	TIME	FUEL	TIME	FUEL
185.2 km (100 n.mi.)	65.4 min	938.9 kg (2070 lb)	74.4 min	875.4 kg (1930 lb)	-13.8	6.8
277.8 km (150 n.mi.)	85.2 min	1233.8 kg (2720 lb)	97.2 min	1140.3 kg (2514 lb)	-14.1	7.6
370.4 km (200 n.mi.)	105.2 min	1533.1 kg (3380 lb)	120.6 min	1397.1 kg (3080 lb)	-14.9	8.9

(includes reserve fuel)

TABLE X. - CALCULATED FUEL SAVINGS AND TIME LOSS FOR 17236.5-kg (38000-lb) GROSS WEIGHT AIRCRAFT

RANGE	Airspeed 277.8 km/hr (150 knots)	Altitude 609.6 m (2000 ft)	Airspeed 240.7 km/hr (130 knots)	Altitude 1828.8 m (6000 ft)	% SAVINGS	
	TIME	FUEL	TIME	FUEL	TIME	FUEL
185.2 km (100 n.mi.)	65.4 min	980.7 kg (2162 lb)	73.2 min	938.9 kg (2070 lb)	-13.8	4.3
277.8 km (150 n.mi.)	85.2 min	1298.2 kg (2862 lb)	96.2 min	1229.2 kg (2710 lb)	-14.1	5.3
370.4 km (200 n.mi.)	105.2 min	1614.8 kg (3560 lb)	119.2 min	1510.5 kg (3330 lb)	-14.9	6.5

(includes reserve fuel)

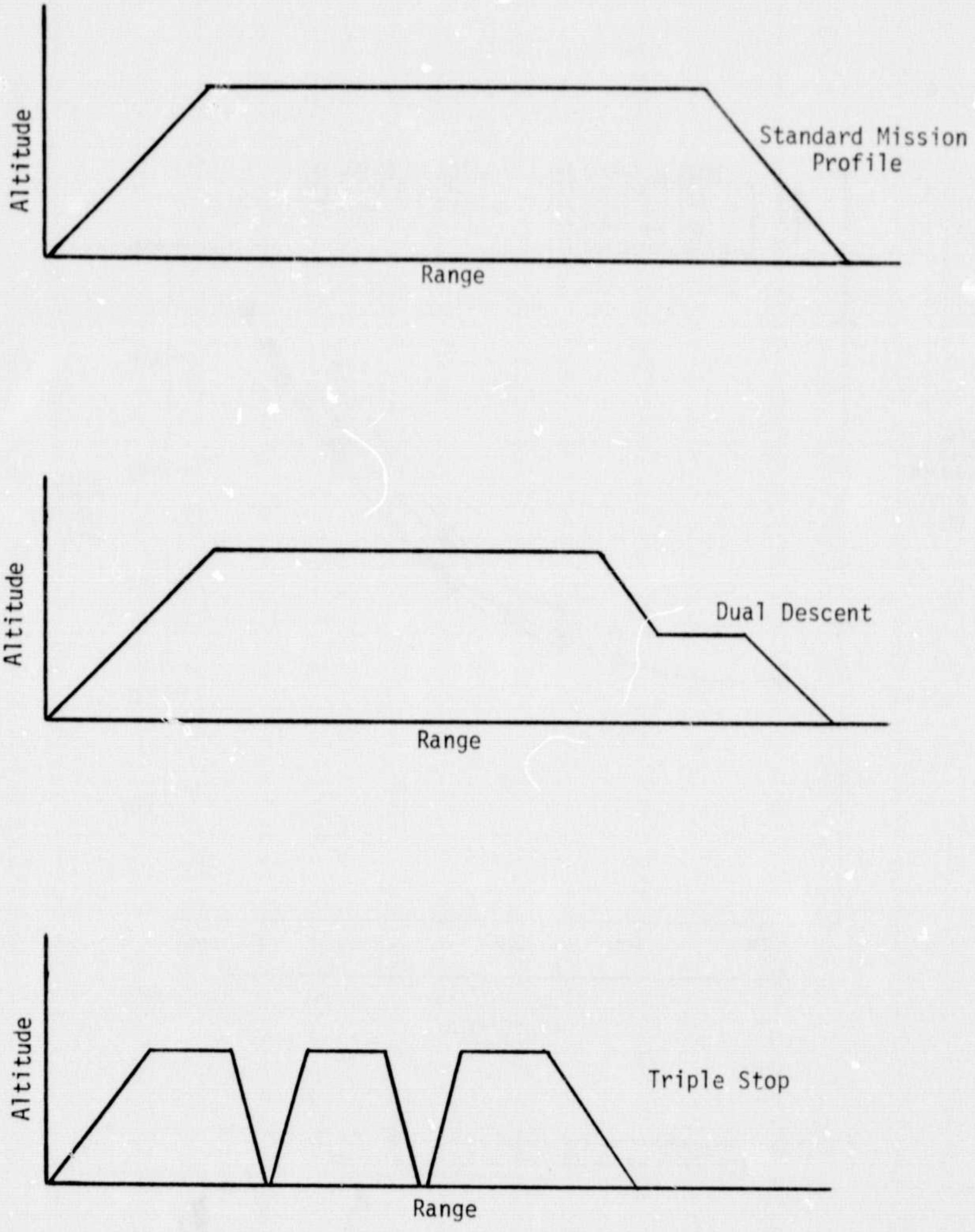


Figure 1.- Typical mission profiles studied.

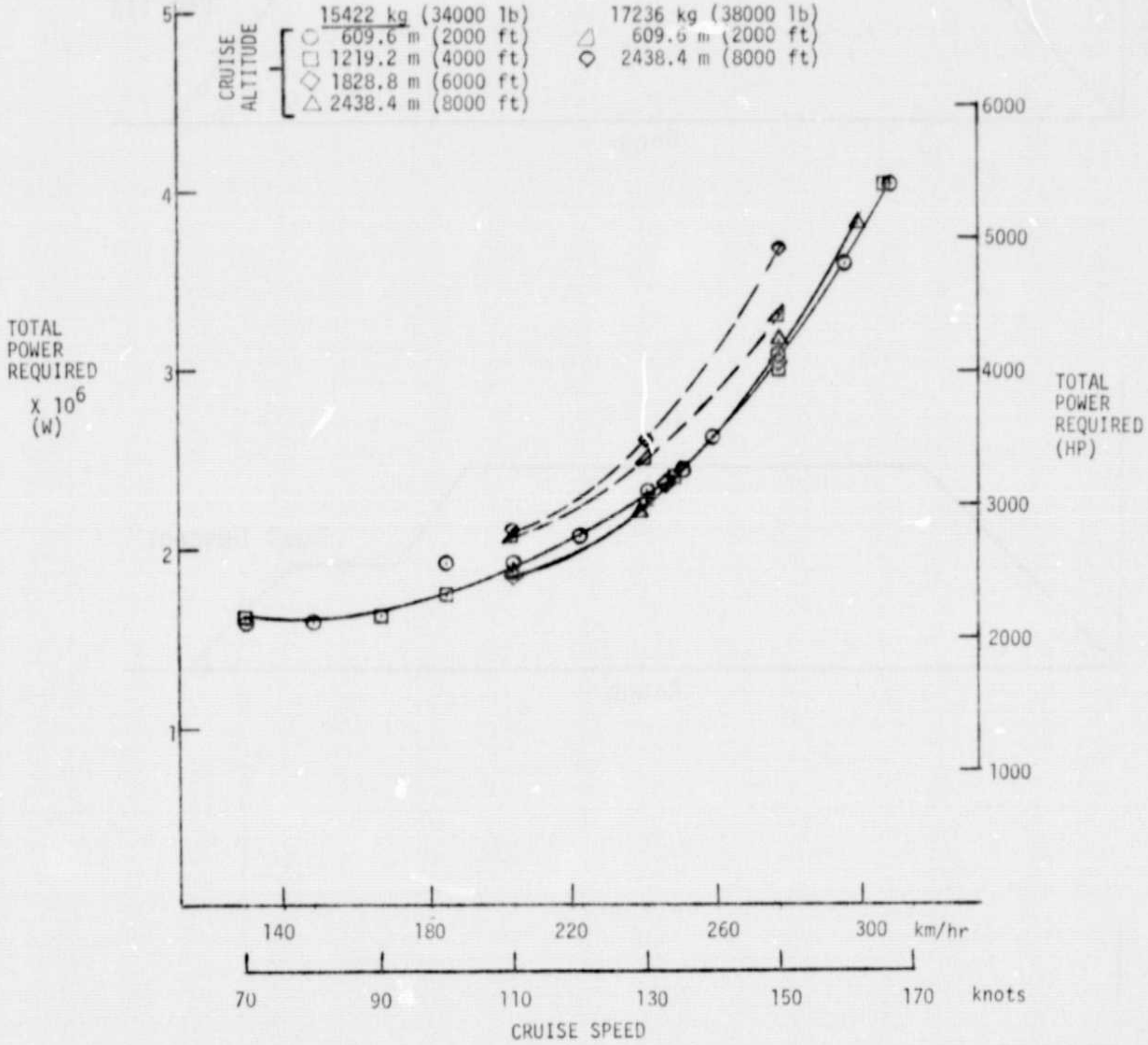


Figure 2.- Total power required during level flight for 15,422 and 17,236 kg (34,000 and 38,000 lb) aircraft.

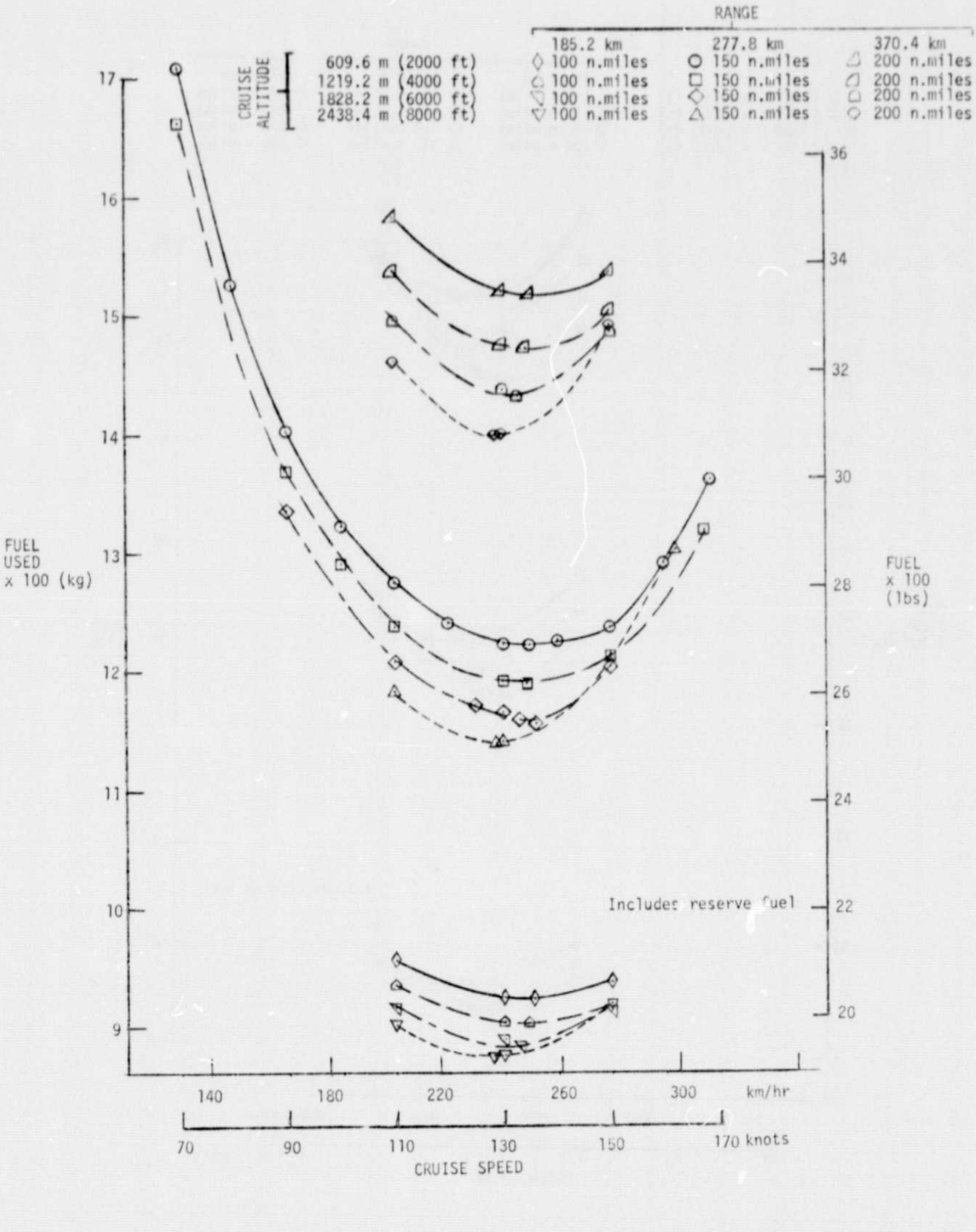


Figure 3.- Fuel usage curves with respect to cruise speeds for 15,422 kg (34,000 lb) gross weight.

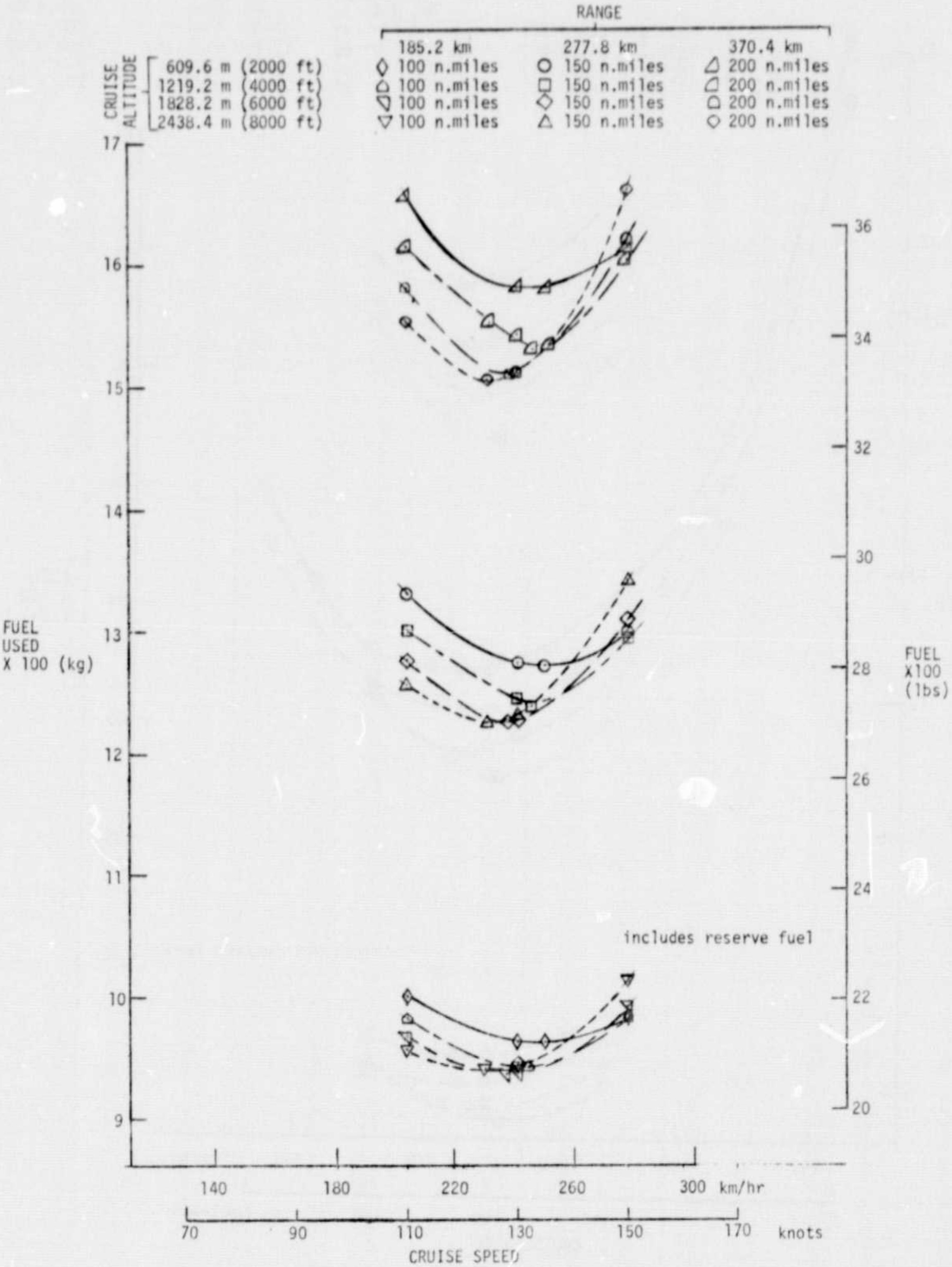
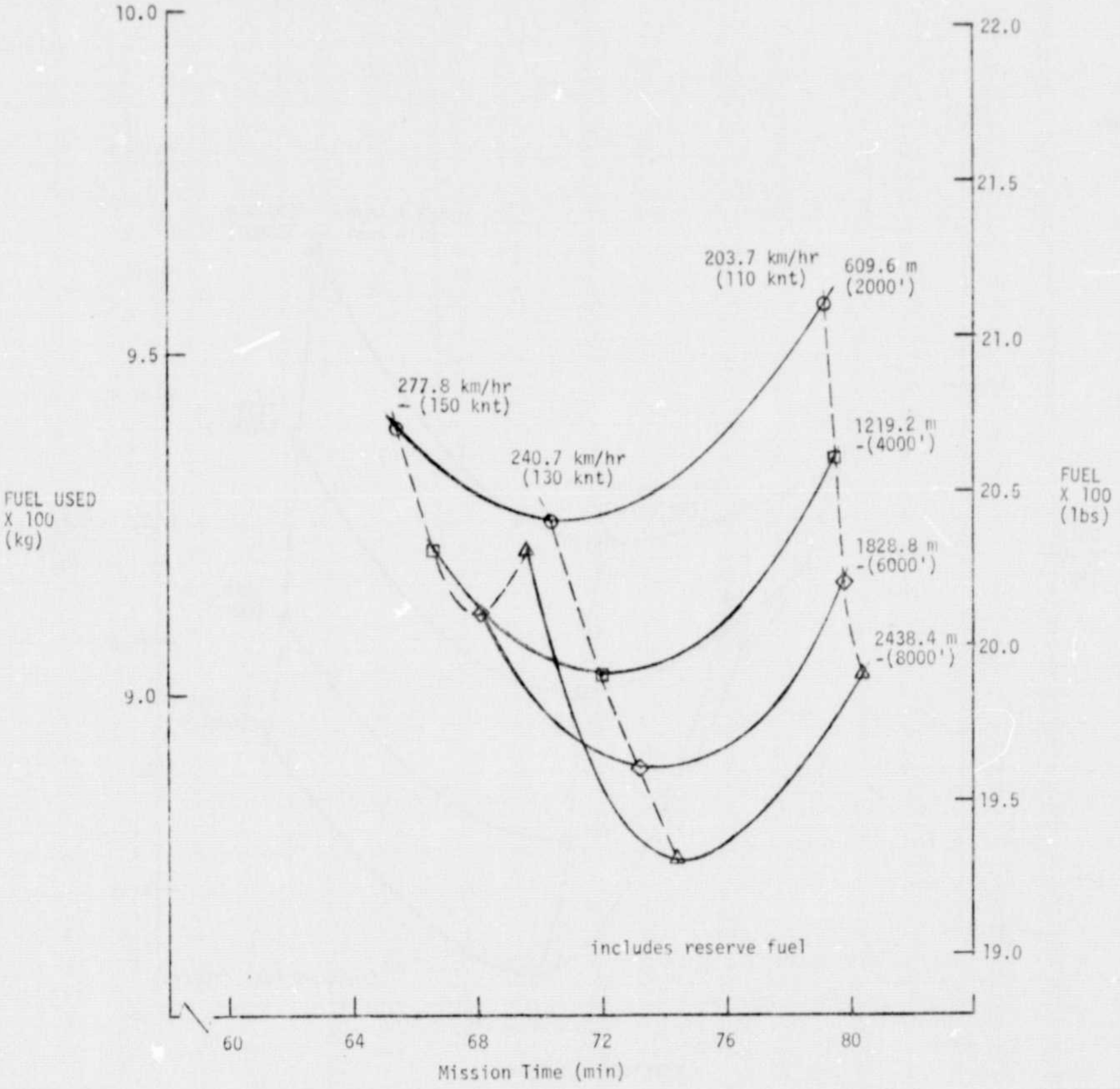
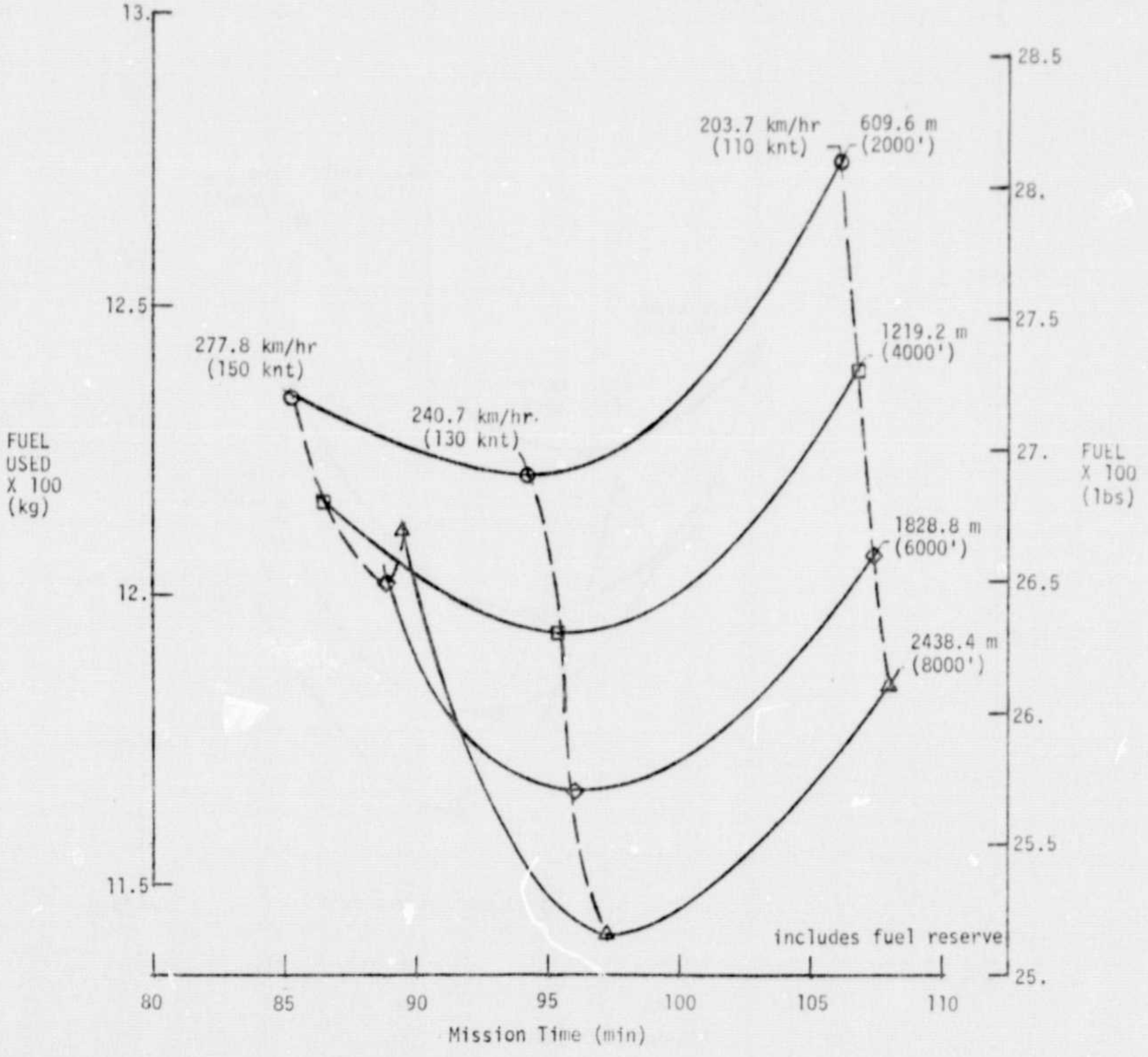


Figure 4.- Fuel usage curves with respect to cruise speeds for 17,236 kg (38,000 lb) gross weight.



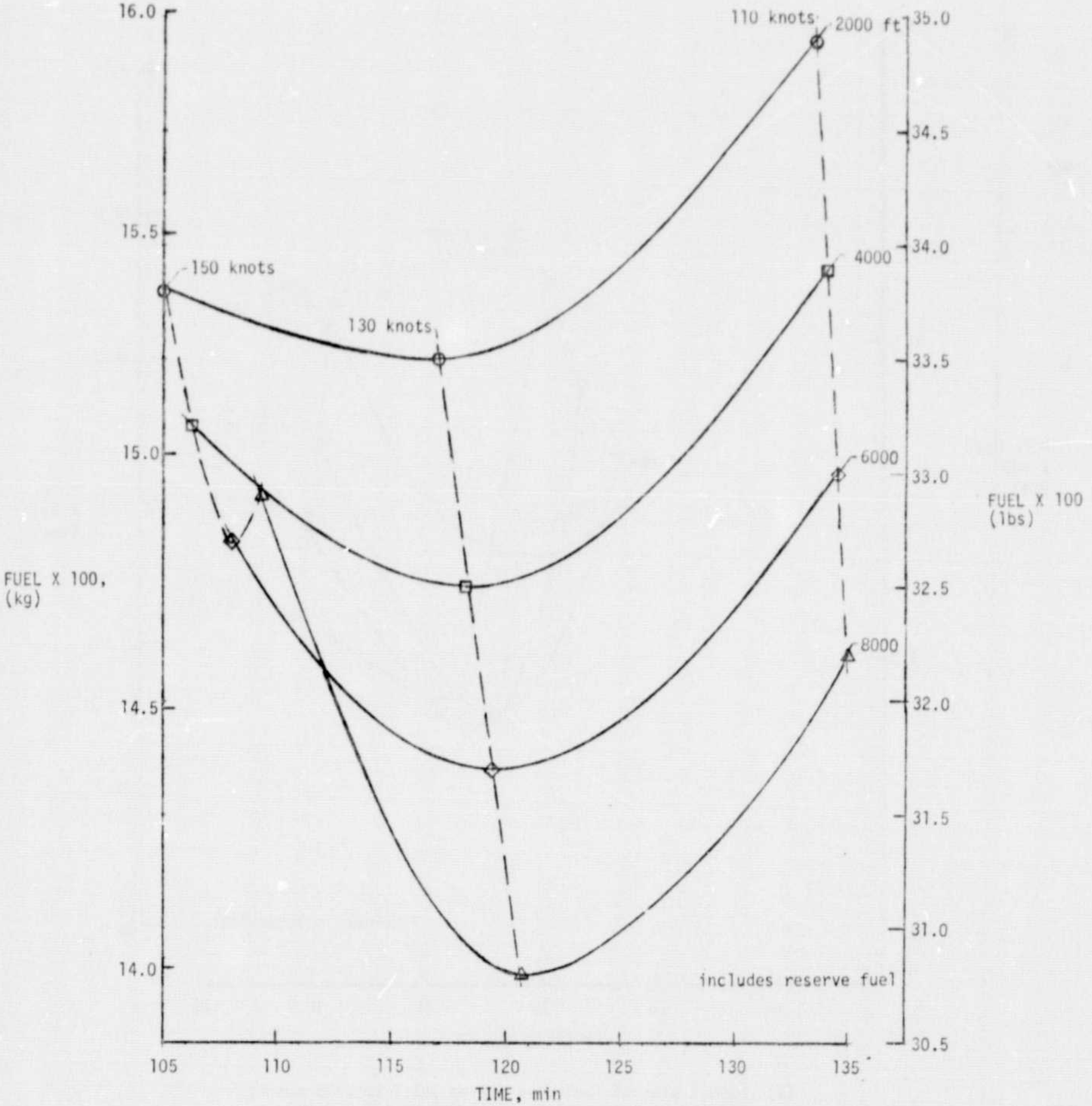
(a) Carpet plot of fuel used during 185.2 km (100 n.mi.) mission at gross weight of 15,422 kg (34,000 lb).

Figure 5.- Plots of mission time versus fuel used for CH-53 research aircraft.



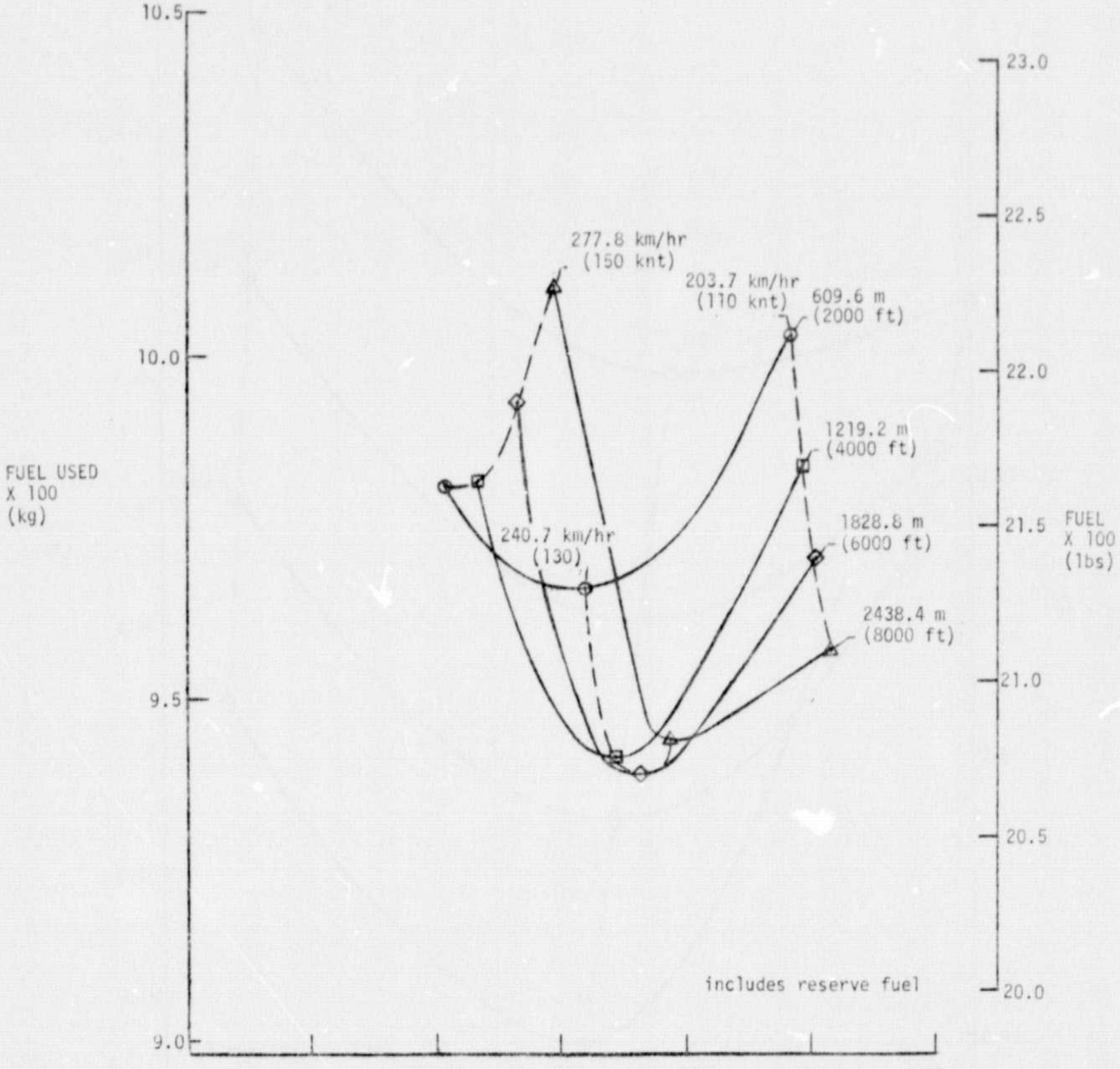
(b) Carpet plot of fuel used during 277.8 km (150 n.mi.) mission at gross weight of 15,422 kg (34,000 lb).

Figure 5.- Continued.



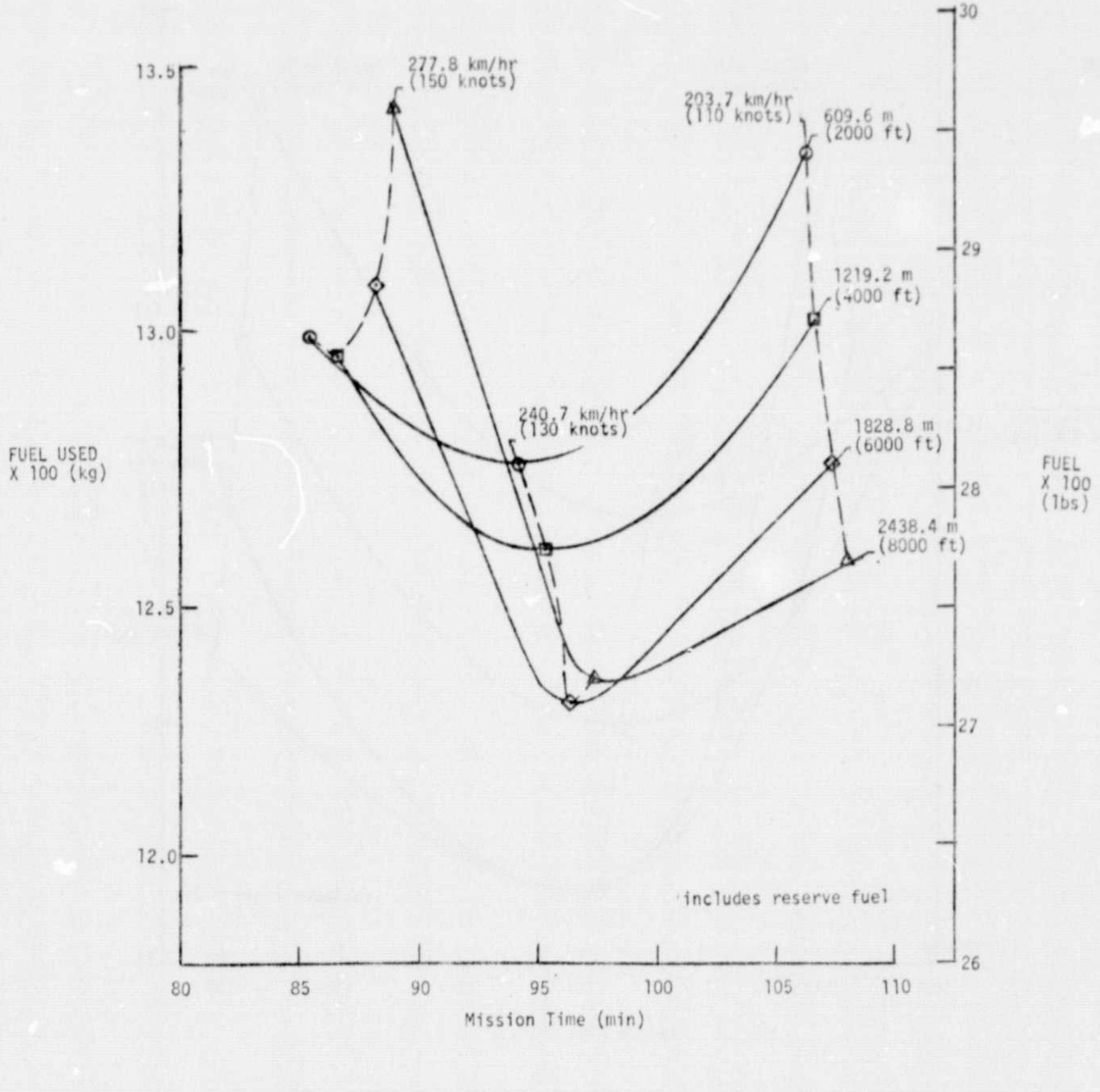
(c) Carpet plot of fuel used during 370.4 km (200 n.mi.) mission at gross weight of 15,422 kg (34,000 lb).

Figure 5.- Concluded.



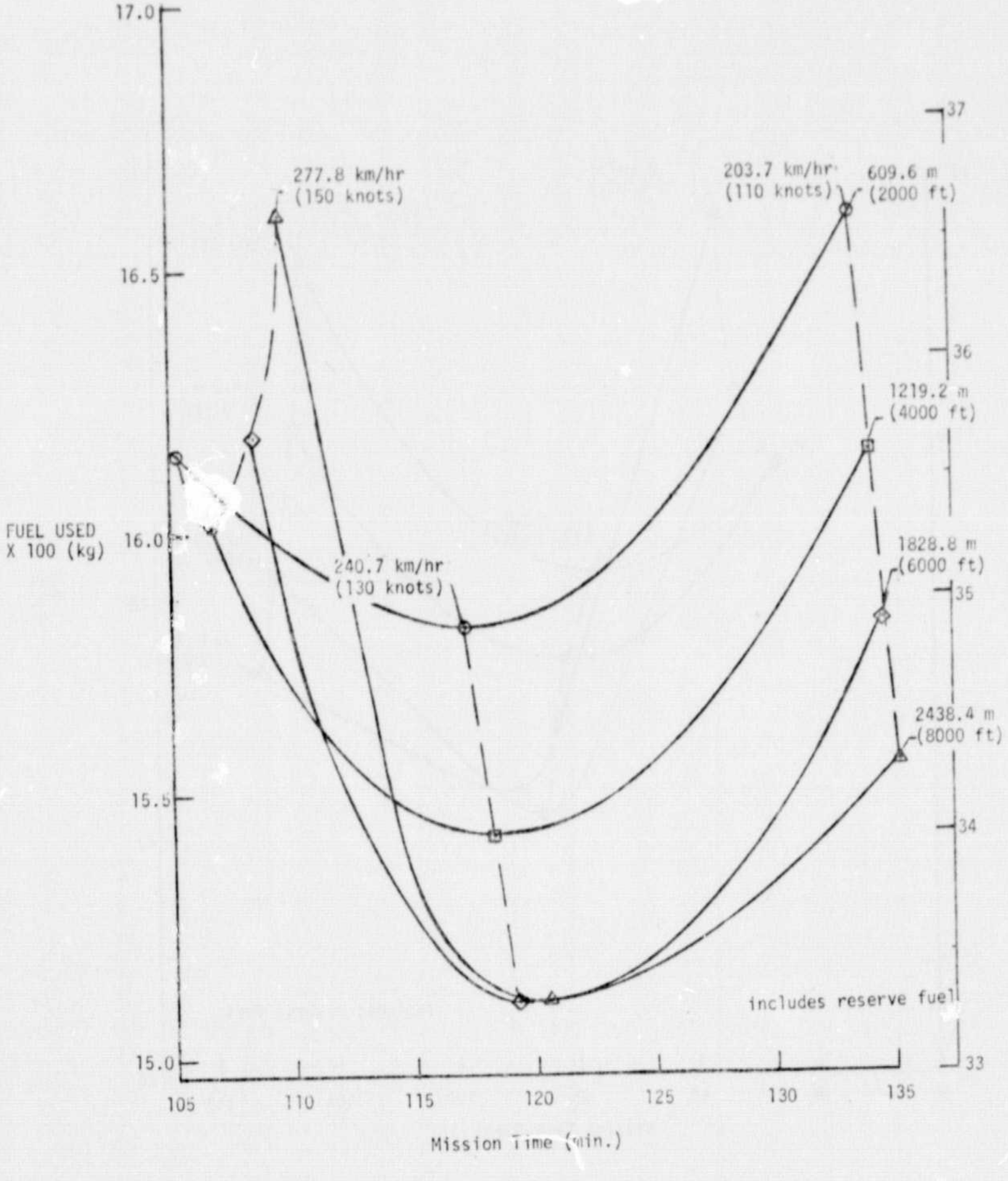
(a) Carpet plot of fuel used during 185.2 km (100 n.mi.) mission at gross weight of 17,236 kg (38,000 lb).

Figure 6.- Plots of mission time versus fuel used for passenger version of CH-53.



(b) Carpet plot of fuel used during 277.8 km (150 n.mi.) mission at gross weight of 17,236 kg (38,000 lb).

Figure 6.- Continued.



(c) Carpet plot of fuel used during 370.4 km (200 n.mi.) mission at gross weight of 17,236 kg (38,000 lb).

Figure 6.- Concluded.

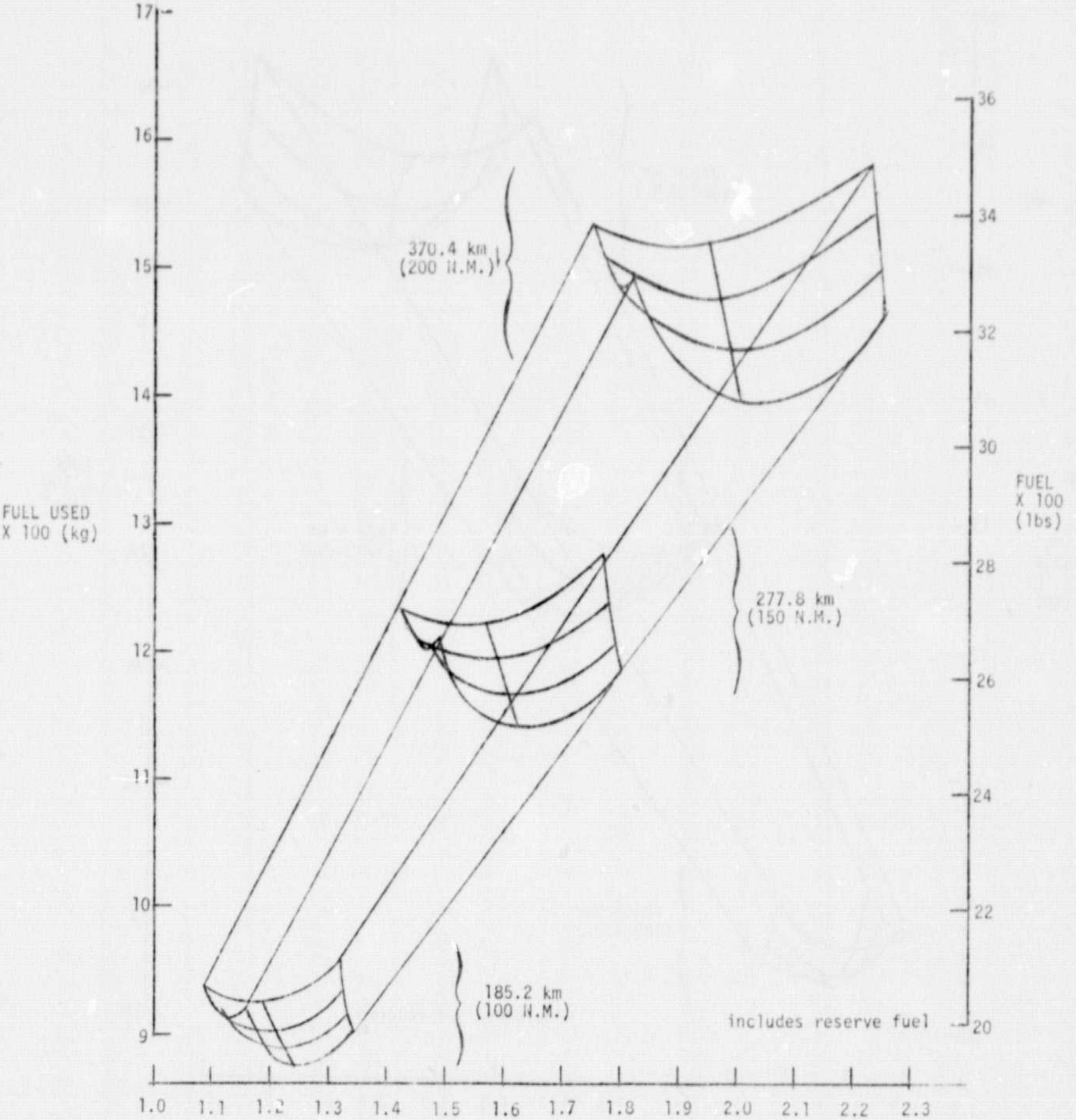


Figure 7.- Summary of fuel utilization of 15,422 kg (34,000 lb) configuration.

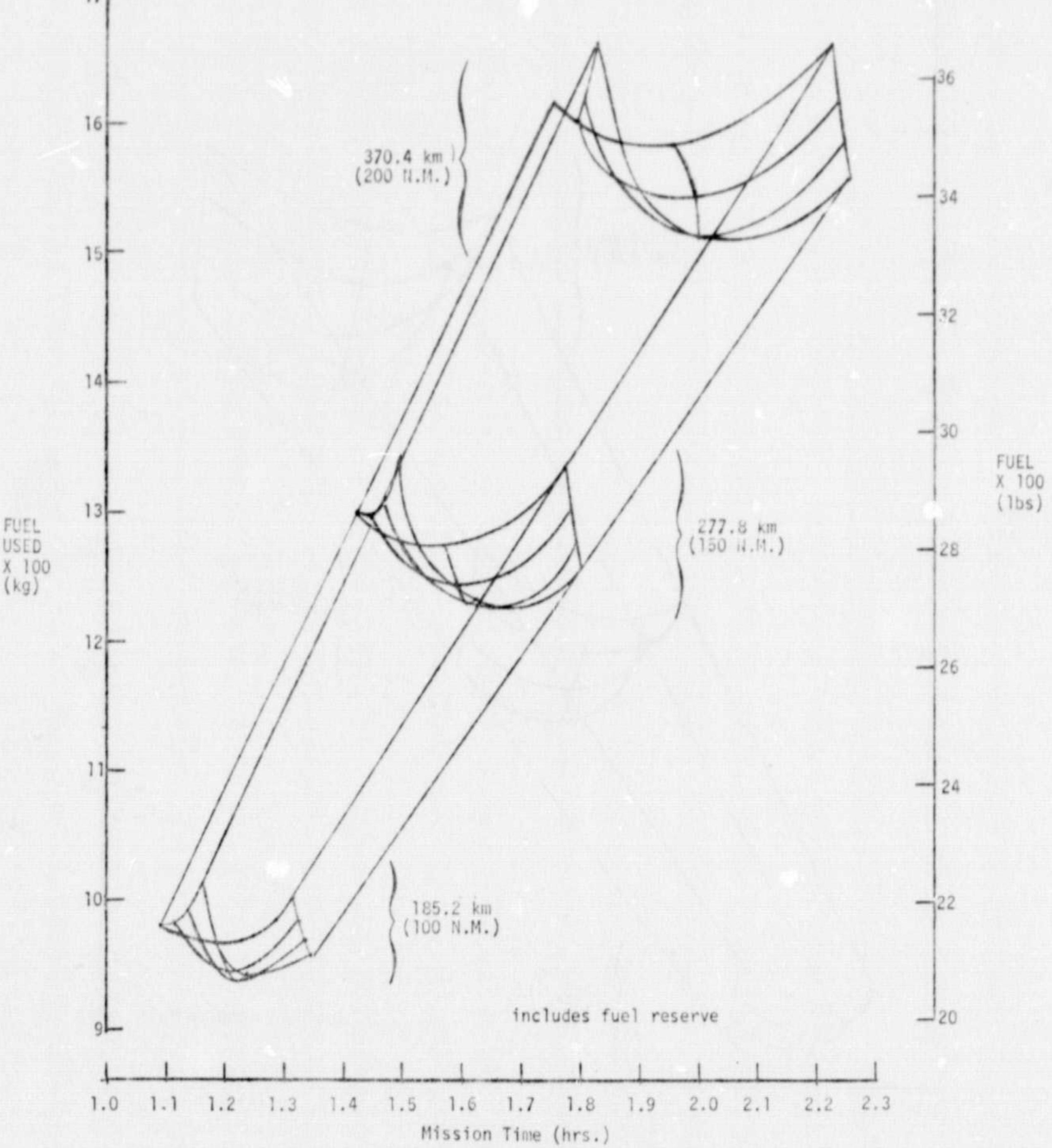


Figure 8.- Summary of fuel utilization of 17,236 kg (38,000 lb) configuration.

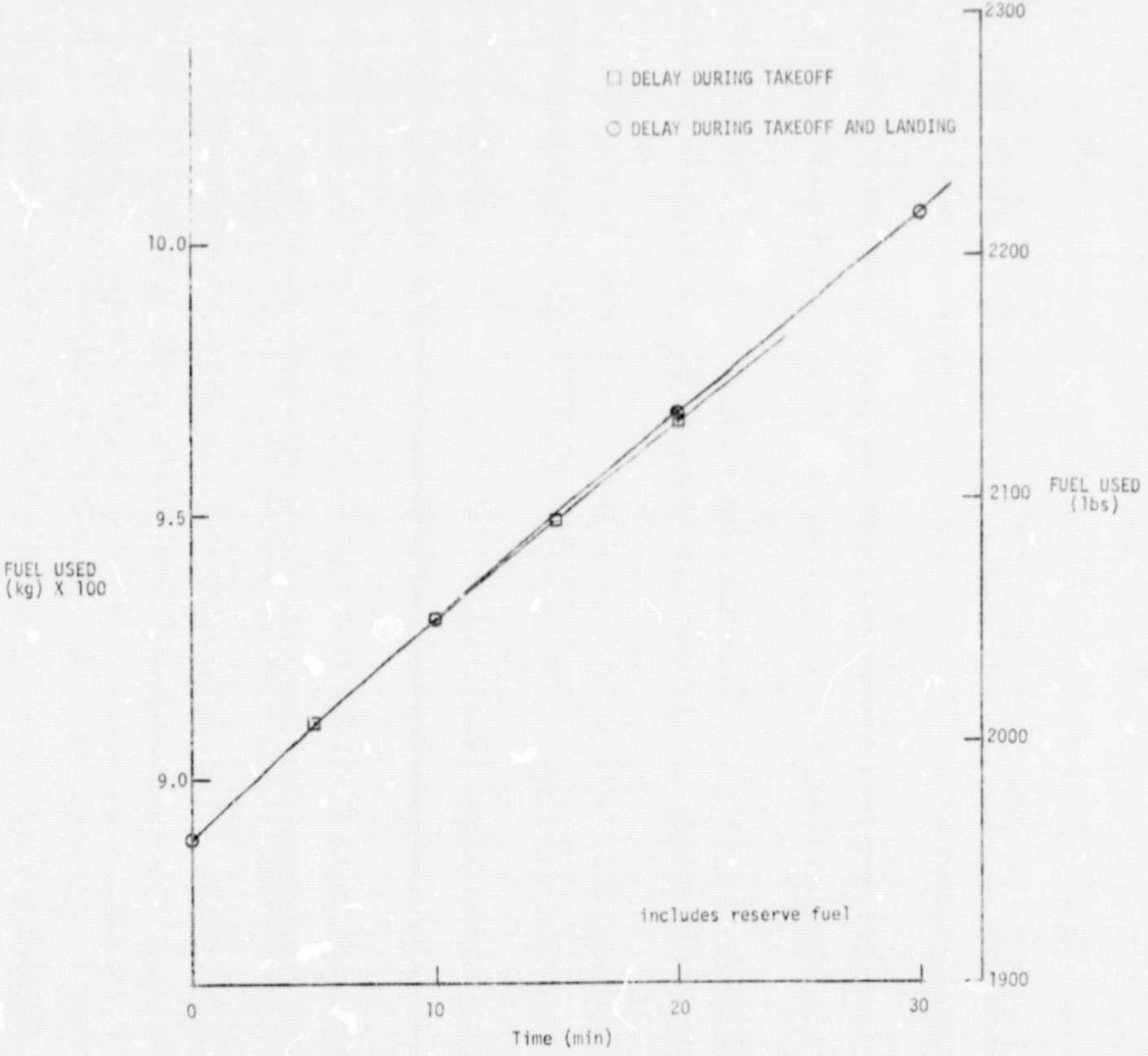


Figure 9.- Effect of taxi delays on fuel consumption.