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IDENTIFYING AND ANALYZING METHODS FOR REDUCING THE ENERGY CONSUMPTION OF HELICOPTERS

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National Aeronautics and Space Administration

Langley Research Center

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IDENTIFYING AND ANALYZING METHODS FOR REDUCING THE ENERGY CONSUMPTION OF HELICOPTERS

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Boeing Vertol Company
(a Division of The Boeing Company)
Philadelphia, Pennsylvania 19142

for

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Langley Research Center

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ABSTRACT

This document contains the results of a study to identify those helicopter technology areas which would result in the largest energy (or fuel) savings when applied to large tandem (100 passenger) civil helicopters in the 1985 time frame. Baseline aircraft using 1975 technology in the areas of powerplant, rotor efficiency, parasite drag and structure were sized to a very short haul mission of 100 N.M. and a short haul mission of 200 N.M. A systematic parametric analysis was then conducted to assess the impact of technology improvements. Projections of the technology levels that could be obtained in the 1985 time frame were made and the resources estimated to achieve them. Based on these data, the highest payoff (lowest energy) helicopter technologies are identified.

FOREWORD

This report was prepared by the Boeing Vertol Company for the National Aeronautics and Space Administration, Langley Research Center, under NASA Contract NAS1-13624. Mr. W. Snyder was technical monitor for this work. The Boeing project manager was W. Wiesner and the project engineer was H. Rosenstein.

SUMMARY

Previous studies have shown that, on the basis of fuel efficiency, current production helicopters can be competitive with other forms of transportation. Reductions in helicopter energy consumption can be accomplished through the use of advanced technology in the areas of powerplant design, improved rotor efficiency, reduced parasite drag and reduced structural weight empty.

In this study, baseline helicopters incorporating todays' technology were designed for a short range (200 NM) and a very short haul (100 NM) mission scenario. Parametric analyses were then conducted to determine the impact of technology improvement. Today's technology levels were projected to the 1985 time frame and the research and development costs to achieve them were estimated. On the basis of the minimum development cost/unit energy intensity (EI) for the maximum percent EI reduction, the best mix of advanced technologies were selected. Development programs for each are discussed. They result in a 38.7 percent reduction in EI for the short haul mission and a 36.6 percent reduction in EI for the very short haul mission. On the basis of passenger miles per gallon, advanced technology offers the potential for making future helicopters comparable to fixed wing aircraft.

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LIST OF SYMBOLS

C_L	Airfoil lift coefficient
C_P	Rotor power coefficient - $550\ HP/\rho\pi R^2 V_{TIP}^3$
C_T	Rotor thrust coefficient - $T/\rho\pi R^2 V_{TIP}^2$
C_T/σ	Ratio of rotor thrust coefficient to rotor solidity
D_{MR}	Main rotor diameter
D.L	Rotor download in hover
DOC	Direct operating cost - \$/seat mile
EI	Energy Intensity - BTU/passenger - n.m.
EW_{STR}/GW	Structural empty to gross weight ratio
FC	Vehicle flyaway cost ~ \$
F_e	Equivalent flat plate drag area ~ ft^2
F.M.	Helicopter rotor figure of merit ~ $.707\ C_T^{3/2}/C_P$
F/W	Force to weight ratio
g/s	Tandem rotor gap to stagger ratio
KTAS	Knots true airspeed
L/D_E	Rotor lift to effective drag ratio
MLF	Maneuver load factor (g's)
N.M.	Nautical miles
OEI	One engine inoperative
O/L	Tandem rotor overlap ratio
SH	Short haul
SHP*	Total configuration installed power (sea level, std. day, max. power)

1.0 INTRODUCTION

On the basis of an over-simplified approach, Figure 1.1, which takes into consideration only energy expended per passenger mile 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 was necessary to investigate the energy (fuel) utilization per passenger mile under realistic operating conditions for the same missions or scenarios. This type of comparison was made in the study of Reference 1. Figure 1.2 is a typical result of that study.

The conclusions drawn from that study were that current day helicopters, if compared to ground vehicles on the basis of useful energy utilization (i.e., useful miles traveled), are competitive with them. 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 (assuming the energy consumed for initial construction of such 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.

The study indicated that improvements in helicopter energy consumption could be accomplished through the utilization of advanced technology. In order to determine the mix of advanced technology resulting in the maximum reduction of energy consumption for the minimum cost, the current study was undertaken.

Sections 2.0 and 3.0 describe, respectively, the vehicle sizing ground rules and the mission scenarios used in this study. Section 4.0 deals with the identification of those design parameters affecting helicopter energy consumption, the sensitivity of energy consumption to their variation, and the definition and selection of two baseline helicopters representative of current technology. Section 5.0 discusses the resizing of the baseline helicopters using advanced technologies and presents data showing the effects of this resizing on vehicle energy consumption, gross weight, direct operating cost, and flyaway cost. Section 6.0 describes the technology areas important in the helicopter resizing of Section 5.0 and provides projections of their possible development with time and the estimated development costs required to attain the values shown in the projections. Based on the results of Sections 5.0 and 6.0, Section 7.0 provides recommendations for further development of advanced civil transport helicopters.

Appendix A provides a summary of the sizing ground rules referred to in Section 2.0 and Appendix B contains plots of the advanced technology vehicle parametric resizing data referred to in Section 5.0. Appendix C provides a brief description of the Helicopter Sizing and Performance Program (HESCOMP) utilized in this study, and Appendix D describes the cost methodology used for the determination of direct operating and vehicle flyaway costs.

ENERGY CONSUMPTION INDEX

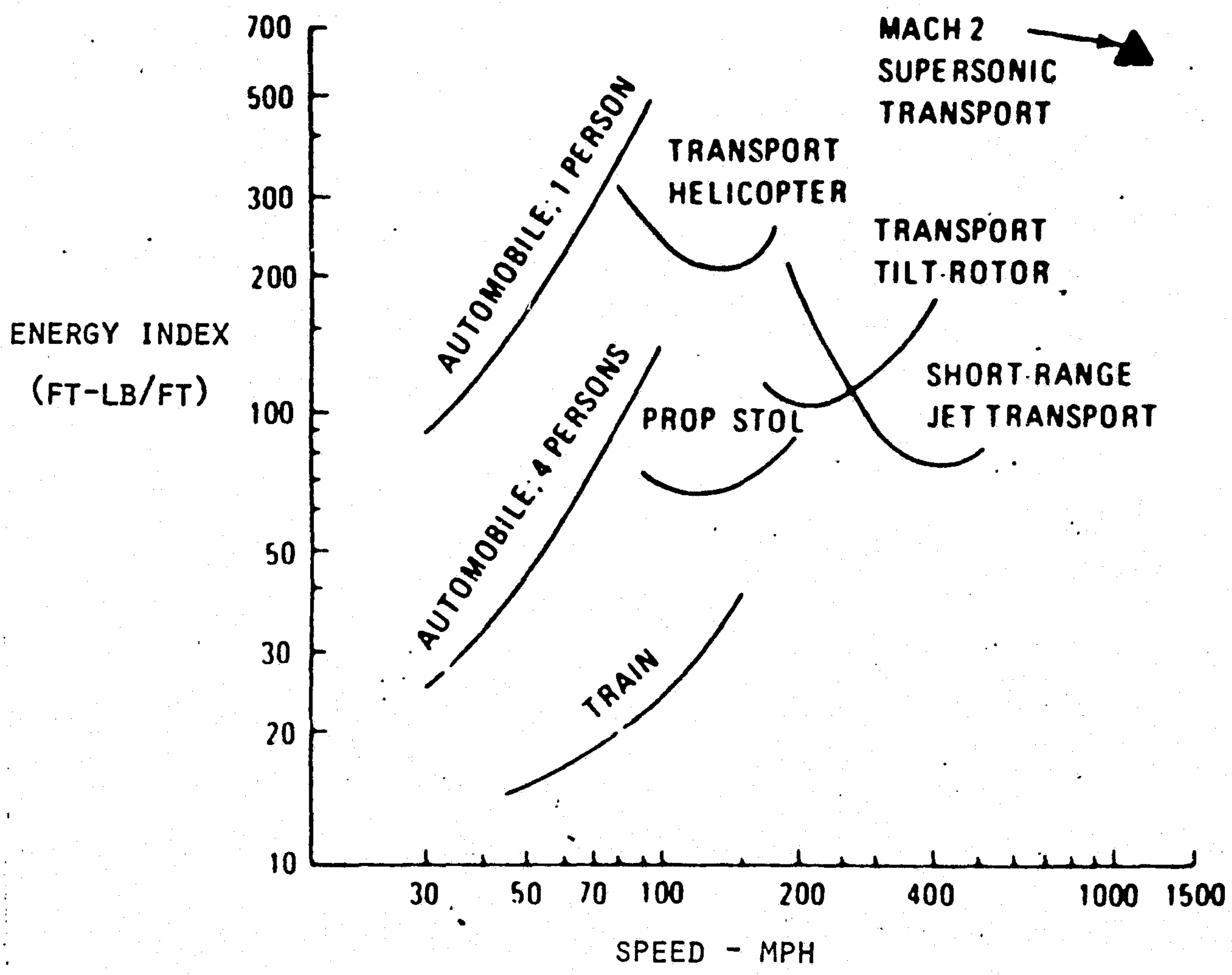


FIGURE1.1 ENERGY CONSUMPTION INDEX VS SPEED

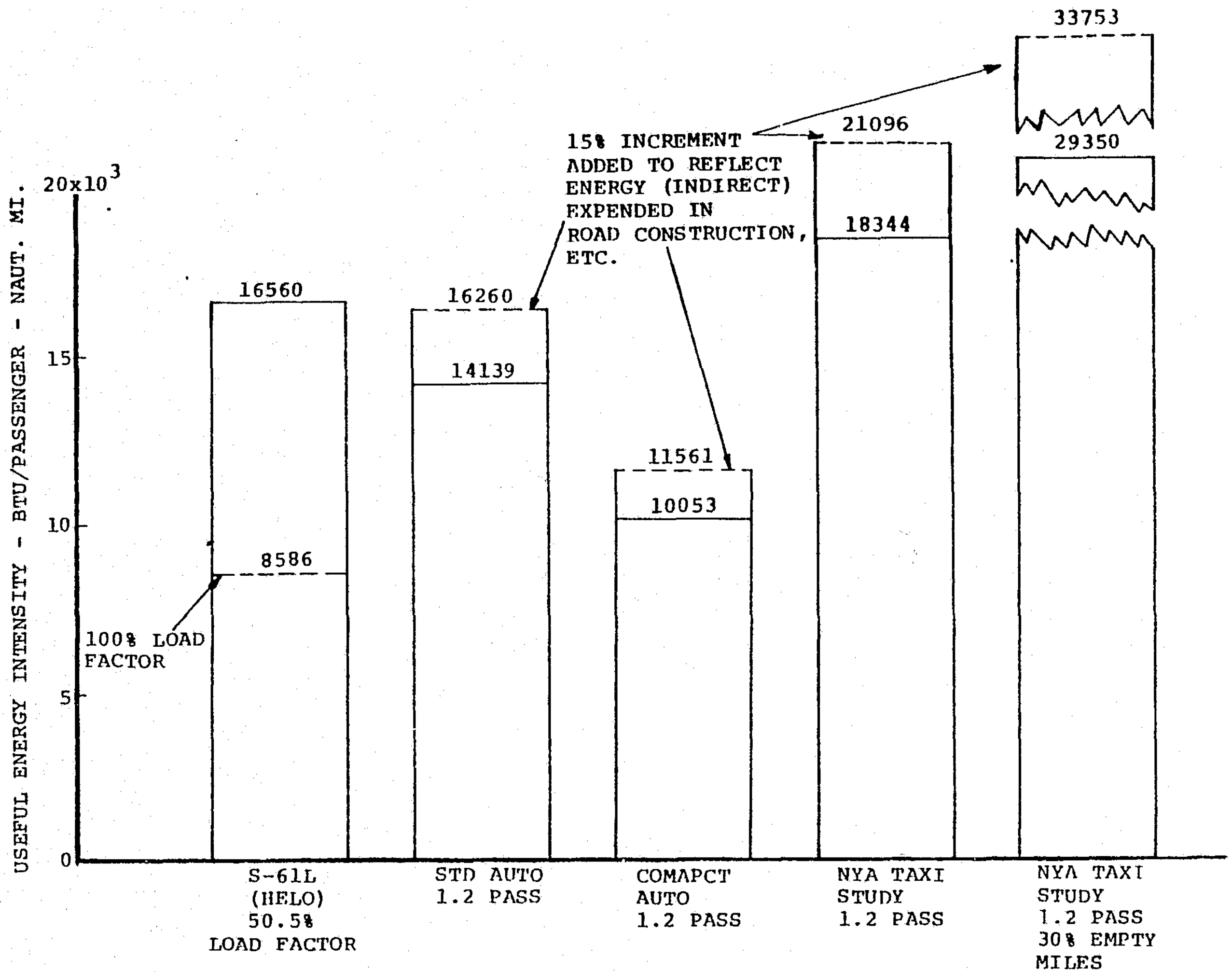


FIGURE 1.2 VEHICLE USEFUL ENERGY INTENSITY COMPARISON
VERY SHORT HAUL MISSION

2.0 GROUND RULES

The ground rules utilized in sizing the helicopters of this study are for the most part based on those employed in NASA Contract NASA 2-8048, "Conceptual Design Studies of 1985 Commercial VTOL Transports That Utilize Rotors" (Reference 4). They are divided between those dealing with the configuration design and sizing and those dealing with vehicle costs and energy consumption. The former can be further separated into the categories of:

(1) Fuselage Configuration
(2) Rotor Solidity Sizing
(3) Engine Sizing
(4) Transmission Sizing
(5) Parasite Drag Level
(6) Vehicle Fixed Equipment and Subsystem Weights
(7) General

Assumptions pertaining to the specific areas listed above are briefly summarized in Appendix A in Tables A-1, A-8 and Figures A-1 and A-2. Figures 2.1 and 2.2 illustrate the general configurations layout and the layout of the passenger accommodations of the 100 passenger baseline commercial helicopter resulting from the commercial VTOL transport study of Reference 4. This tandem helicopter configuration, with some modifications, was utilized as the starting point for this study.

As noted in Table A-1, the use of the two-aisle passenger cabin configuration results in a relatively wide elliptical fuselage cross-section. In order to reduce parasite drag in cruise flight and download in hover, the passenger cabin was changed to a single-aisle circular cross-section fuselage configuration. Table A-2 illustrates the estimated difference in parasite drag and download obtained by this modification. Detailed information on the methodology used to estimate hover download and vehicle subsystem weights is found in References 2 and 4.

Energy Intensity (EI) is defined by the relationship

$$\text{EI} = \frac{\text{Mission Fuel Weight X Fuel Heating Value}}{\text{Passengers Carried X Distance Travelled}}$$

Mission fuel is the fuel actually consumed in travel (i.e., total fuel required minus the reserve fuel) and the fuel heating value is assumed to be 18,400 BTU/lb.

The methodology used in calculating vehicle direct operating and flyaway costs is shown in Appendix D. Table D-1 lists the values used for those calculations. Table D-2 illustrates the variations in airframe and dynamic system price/pound due to the use of advanced materials technology. The $/pound values listed were obtained from consideration of the structural weight empty trends developed in Section 6.0.

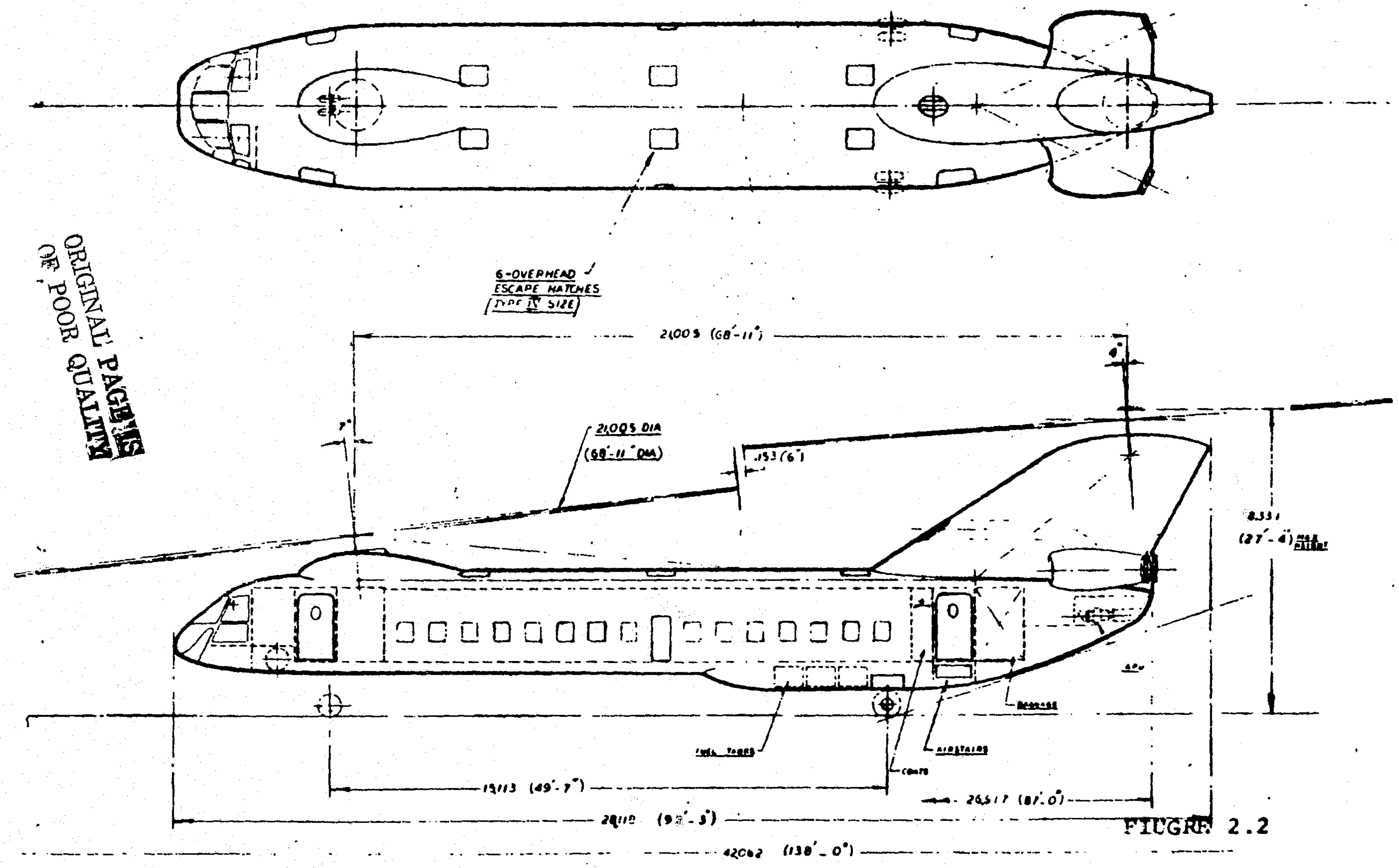
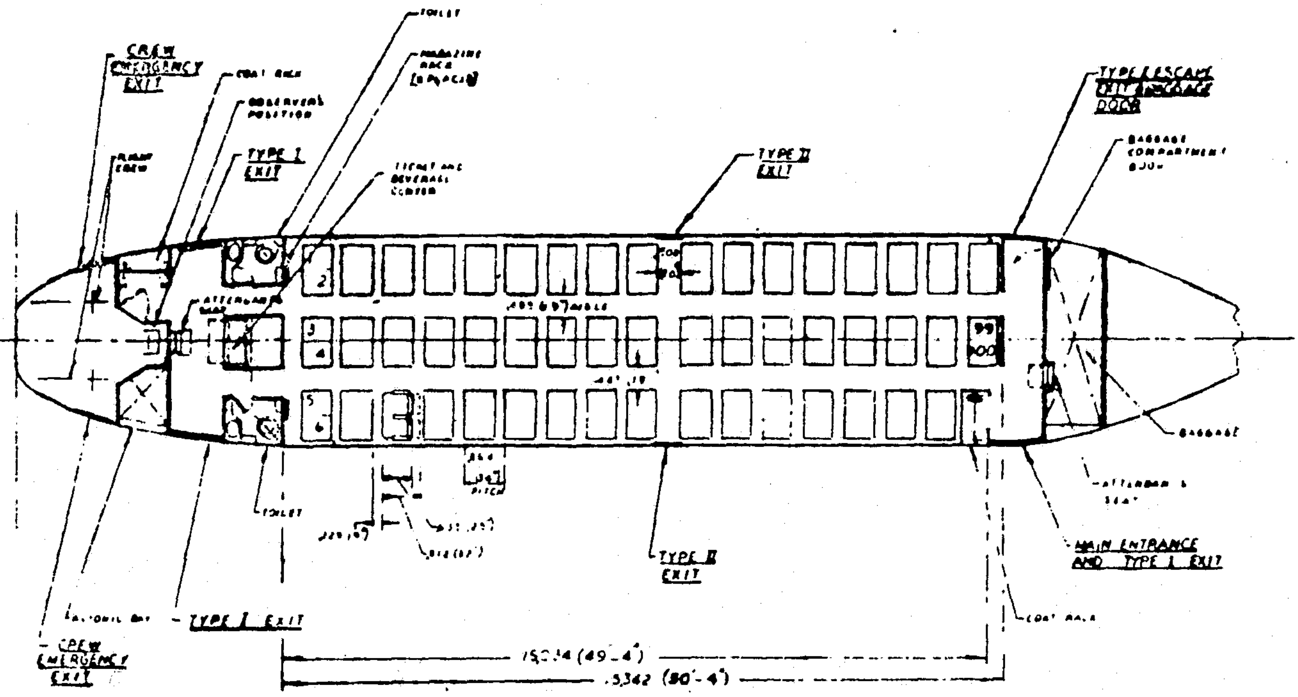


FIGURE 2.1 BASELINE, 100 PASSENGER – TANDEM HELICOPTER – COMMERCIAL TRANSPORT FROM REFERENCE 4 STUDY (NASA CR 137600) (Sheet 1 of 2)



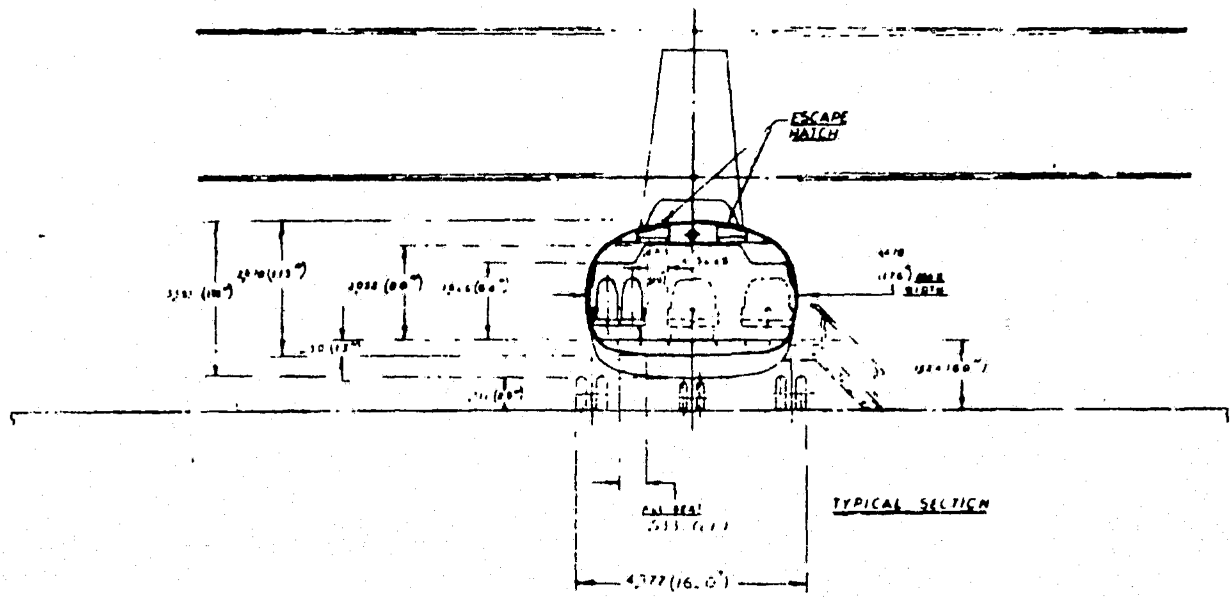
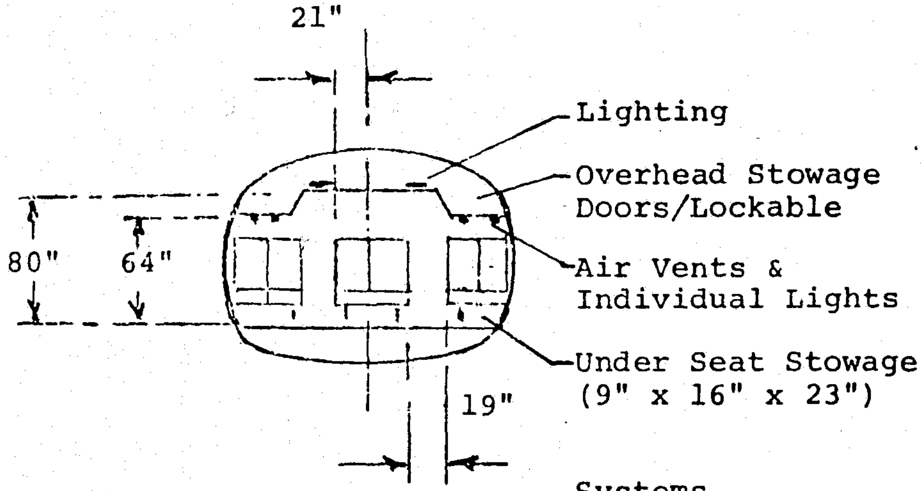
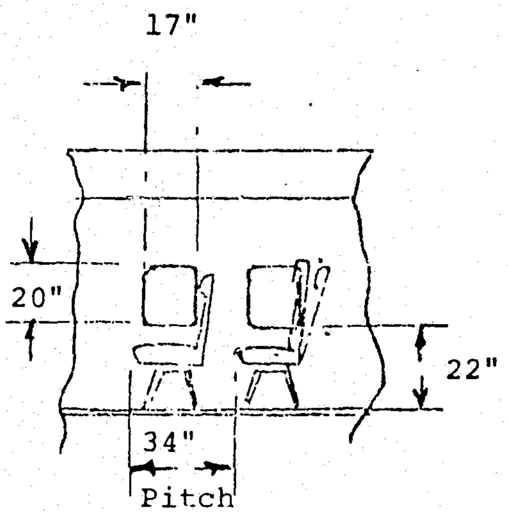


FIGURE 2.1 BASELINE, 100 PASSENGER – TANDEM HELICOPTER – COMMERICAL TRANSPORT FROM REFERENCE 4 STUDY (NASA CR 137600) (Sheet 2 of 2)

Cabin



Windows



Systems

- Air Conditioning - Dual Bleed Air
- Unpressurized

Escape Provisions

- Two Type I Exits, Each Side
- One Type II Exit, Each Side
- Six Type IV Escape Hatches On Top

Entrances

- Two Main Entrances L. H. Side
- Air Stairs, Aft At Entrance
- Service Entrance, R. H. Side, Fwd.

Miscellaneous

- Coat Racks for 80 Passengers
- Two Magazine Racks
- Two Lavatories
- Beverage Service, Fwd.
- Ticket Center, Fwd.

FIGURE 2.2 TANDEM ROTOR HELICOPTER PASSENGER ACCOMMODATIONS

3.0 MISSION SCENARIOS

3.1 General

The mission scenarios chosen for use in this study represent two very different but realistic operating arenas. The Very Short Haul Mission is representative of a typical air-taxi operation in a large urban area, while the Short Haul Mission depicts air operations between major city centers. Table 3.1 presents a summary of mission scenario ground rules for both mission scenarios.

3.2 Mission Scenario Description

3.2.1 The Very Short Haul Mission Scenario

As noted in Table 3.1, the Very Short Haul Mission Scenario is based on a corresponding mission in Reference 1 which, in turn, is based on operations in the New York Metropolitan area. Figure 3.1 illustrates the flight profile, including time spent at each stop. More specific details regarding the derivation of this scenario can be obtained from Reference 1.

3.2.2 Short Haul Mission Scenario

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 service with no traffic delays due to interaction with CTOL aircraft. Figure 3.2 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. As noted in Table 3.1, the total mission distance has been rounded off to 200 N.M., but the mission segments have been proportioned to the original mission.

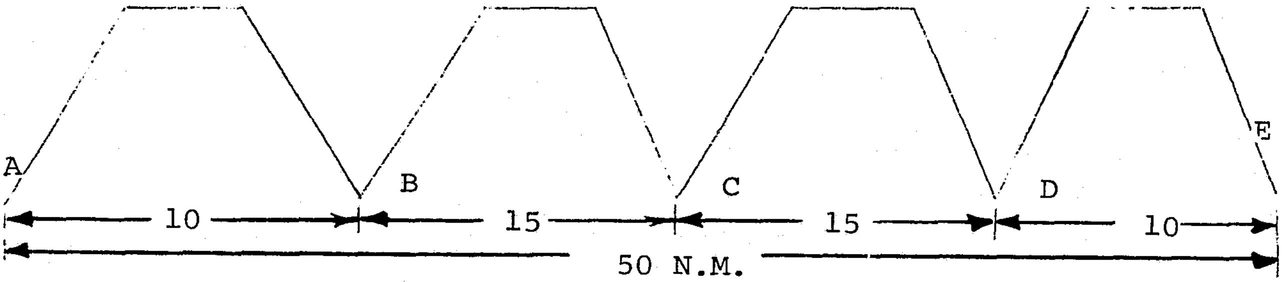
TABLE 3.1 MISSION SCENARIO GROUND RULES SUMMARY

VERY SHORT HAUL MISSION SCENARIO IS BASED ON THE VERY SHORT HAUL MISSION SCENARIO OF NASA CR-132578 (NASA CONTRACT NO. NAS1-13142).

- THIS MISSION SCENARIO HAS A TOTAL STAGE LENGTH OF 100 N.M. AND IS COMPOSED OF TWO COMPLETE 50 N.M. LEGS EACH CONSISTING OF MULTIPLE HOPS. THE RATIO OF FLIGHT TIME/BLOCK TIME IS AS DETERMINED IN NASA CR-132578 FOR THIS SCENARIO. A REALISTIC RESERVE FUEL REQUIREMENT IS UTILIZED.

SHORT HAUL MISSION SCENARIO IS BASED ON SHORT HAUL MISSION OF NASA CONTRACT NAS1-13142

- LOADING AND UNLOADING TIMES ARE THE SAME
- NUMBER OF TAKEOFF AND LANDINGS ARE THE SAME
- THIS MISSION PROFILE IS BASED ON NASA-LANGLEY ADVANCED NAVIGATION SYSTEM USED IN A PREVIOUS STUDY (NAS1-13142)
- DESIGN MISSION DISTANCE HAS BEEN ROUNDED OFF TO 200 N.M. (IT WAS 210 N.M.), BUT SEGMENTS ARE PROPORTIONED TO SAME PROPORTIONS AS IN ORIGINAL MISSION
- A RESERVE FUEL REQUIREMENT BASED ON FAR AND USED IN NASA CONTRACT NAS2-8048 HAS BEEN ADDED



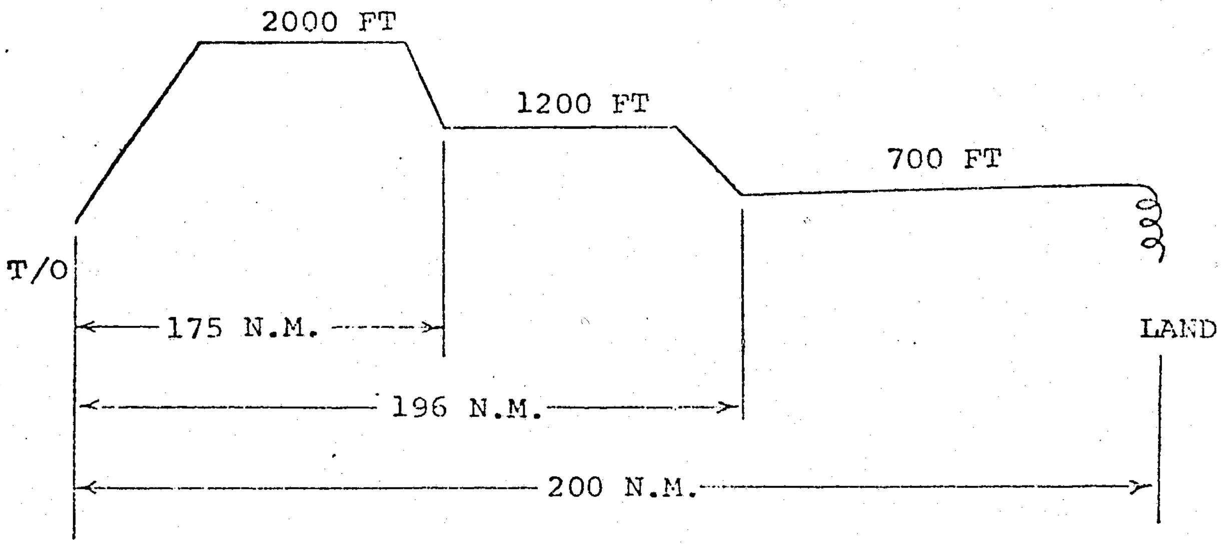
1. TAXI (.03 HR) & T/O (.0085 HR) @ (A)
2. CLIMB TO 500 FT
3. CRUISE FOR 10 N.M. @ V_{BR}
4. MAKE SPIRAL DESCENT TO S.L.
5. LAND @ (B)
6. TAXI (.05 HR) & (T/O (.0085 HR) @ (B)
7. CLIMB TO 500 FT
8. CRUISE FOR 15 N.M. @ V_{BR}
9. MAKE SPIRAL DESCENT TO S.L.
10. LAND @ (C)
11. TAXI (.11 HR) & T/O (.0085 HR) @ (C)
12. CLIMB TO 500 FT
13. CRUISE FOR 15 N.M. @ V_{BR}
14. MAKE SPIRAL DESCENT TO S.L.
15. LAND @ (D)
16. TAXI (.05 HR) & T/O (.0085 HR) @ (D)
17. CLIMB TO 500 FT
18. CRUISE FOR 10 N.M. @ V_{BR}
19. MAKE SPIRAL DESCENT TO S.L.
20. LAND @ (E)
21. TAXI (.03 HR) & T/O (.0085 HR)
22. FLY REVERSE OF PRECEDING MISSION (FROM PT (E) TO PT (A))
23. UPON DESCENT TO S.L. @ (A), TAXI (.03 HR)
24. RESERVE FUEL (SEE NOTE)

TOTAL MISSION DISTANCE - 100 N.M.

RESERVE FUEL REQUIREMENT

1. LOITER FOR 20 MIN. @ 500 FT
2. CRUISE AT CRUISE ALTITUDE (500 FT) FOR 50 N.M. @ $V_{.99BR}$

FIGURE 3.1 VERY SHORT HAUL MISSION SCENARIO



1. TAXI (10 MIN) (.167 HR)
2. **TAKEOFF (2 MIN) (.0333 HR)**
3. CLIMB TO 700 FT.
4. CLIMB TO 2000 FT.
5. CRUISE AT V_{NRP} @ 2000 FT TO 175 N.M.
6. DESCEND TO 1200 FT @ THE END OF 175 N.M. LEG
7. CRUISE AT V_{NRP} @ 1200 FT TO 196 N.M.
8. DESCEND TO SL @ 200 N.M. (THE END OF THIS LEG IS A SPIRAL DESCENT)
9. LAND (HOVER) (2 MIN) (.0333 HR)
10. TAXI (10 MIN) (.167 HR)
11. RESERVE FUEL (SEE NOTE)

TOT MISSION DISTANCE - 200 NAUTICAL MILES (NM)

RESERVE FUEL REQUIREMENT

1. CRUISE @ CRUISE ALT (2000 FT) FOR 50 N.M. @ $V_{.99BR}$
2. LOITER FOR 20 MIN @ 2000 FT (.3333 HR)

FIGURE 3.2 SHORT HAUL MISSION SCENARIO

4.0 SIZING OF A TANDEM ROTOR HELICOPTER BASED ON CURRENT TECHNOLOGY LEVELS

4.1 Identification of Design Parameters Affecting Helicopter DOC and Energy Consumption

Design parameters affecting helicopter direct operating cost and energy consumption can be divided into two categories:

(1) Configuration geometric and dimensional characteristics.

(2) Configuration technology areas.

The former include:

(1) Disc loading

(2) Rotor tip speed

(3) Vehicle passenger capacity

(4) Vehicle seating arrangement (number of passengers abreast)

The baseline current technology helicopters described later in this section were obtained by systematic variations of these parameters.

The second category includes:

(1) Parasite drag level

(2) Rotor efficiency (L/D_E and F.M.)

(3) Structural empty weight

(4) Specific fuel consumption (SFC)

The effects of the application of advanced technology to current technology helicopters were assessed by resizing the current technology baseline vehicles to reflect variations in the technology levels of the latter category.

4.2 Vehicle Sizing Process

The helicopters analyzed in this study were sized using the HESCOMP computer program. A brief description of this analytical tool is presented in Appendix C.

Figure 4.1 depicts the design evolution process followed to arrive at the current technology baseline helicopters. As shown by figure 4.1, the 100 passenger design point vehicle from the study of Reference 4 was utilized as a starting point. At the outset, in order to investigate the potential savings in energy consumption realizable through reduction in parasite drag and download by configuration redesign, the vehicle cabin arrangement was modified as noted in Section 2.0 (Table A-2 provides a comparison of the relative download and drag levels of both cabin arrangements.). Vehicle energy consumption and operating cost were then determined for a

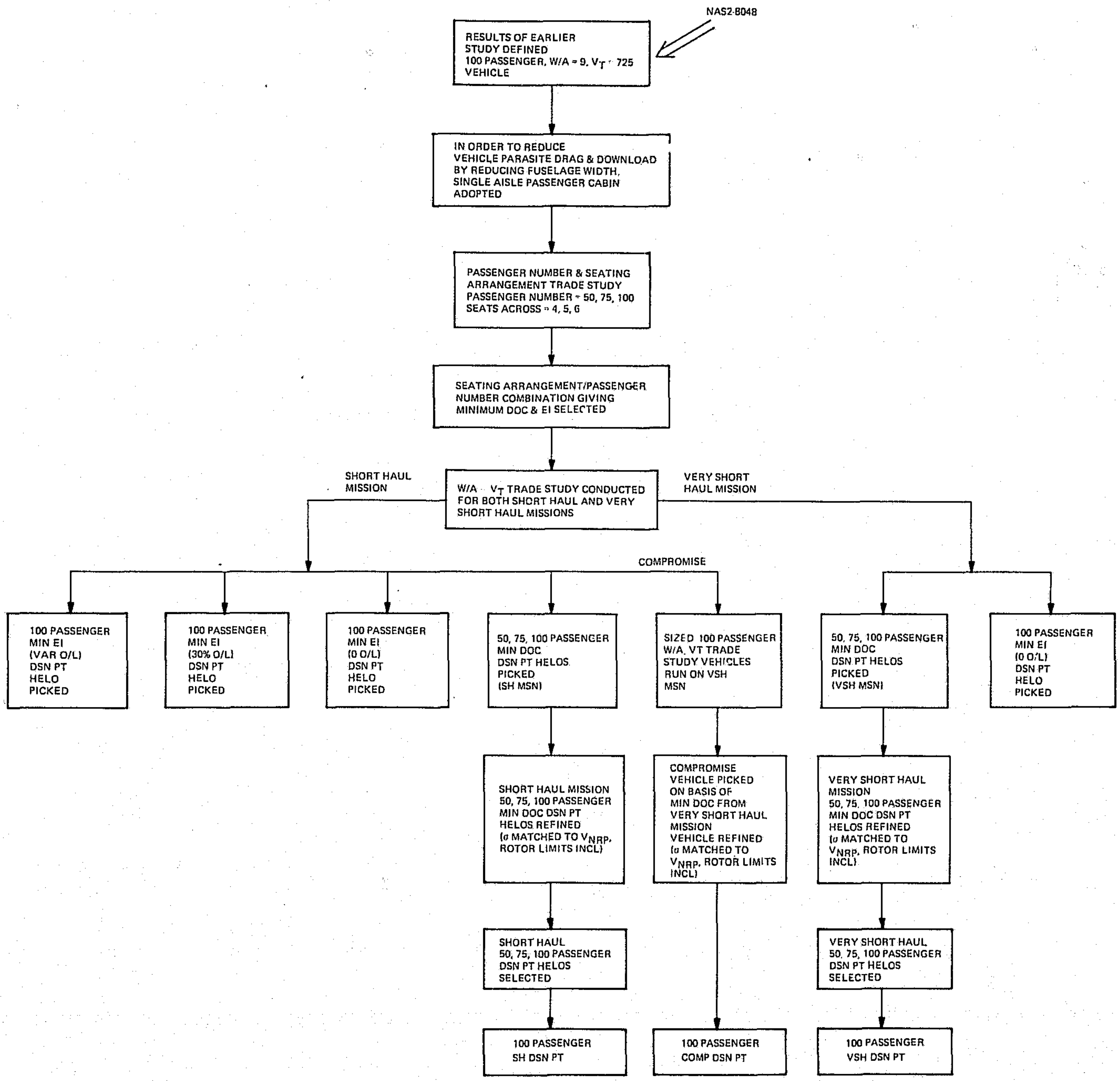


FIGURE 4.1 VEHICLE DESIGN EVOLUTION

matrix of helicopters employing the modified cabin arrangement in conjunction with 4, 5, and 6 abreast seating for passenger capacities of 50, 75, and 100. Figures 4.2 and 4.3 illustrate the effect of various seating arrangements—passenger capacity combinations on vehicle dimensions, download and parasite drag. Figure 4.4 shows vehicle energy consumption and operating cost for these combinations. The selection of the passenger capacity - seating arrangements finally chosen is summarized in Table 4.1. Note that 6 abreast seating was chosen for the 75 passenger vehicle.

This selection was made on the basis of the actual closeness of the minimum EI and DOC values for 5 and 6 abreast seating and the desire to retain commonality between the 75 and 100 passenger configurations. Figure 4.5 illustrates the comparative fuselage sizes and shapes of the selected vehicles.

4.3 Effect of Vehicle Design Parameters on Configuration Characteristics, Operating Cost, and Energy Consumption

4.3.1 Disc Loading - Tip Speed Trade Study

Figures 4.6 and 4.7 illustrate the variation of EI and DOC for various combinations of tip speed and disc loading for passenger capacities of 50, 75, and 100 in the Short Haul Mission Scenario. Note that even though increases in the vehicle passenger capacity result in increases in the physical dimensions and weight, both EI and DOC are reduced. Note also that the data plots illustrated do not differ appreciably in shape with varying vehicle passenger capacity — only in the absolute value of EI and DOC. Thus, further data plots illustrated will be for the 100 passenger capacity vehicles.

Figures 4.8 and 4.9 illustrate the variation of EI and DOC for various combinations of tip speed and disc loading for the 100 passenger Very Short Haul mission scenario helicopters.

Rotor tip speed and disc loading are very important parameters in the determination of a vehicle's energy consumption and operating costs. For example, note in Figure 4.6 the variation of energy intensity with rotor tip speed at a fixed disc loading. Initially, as tip speed is reduced, power required decreases as advancing blade compressibility effects are reduced, therefore lowering the values of mission fuel and energy intensity. However, as tip speed continues to decrease, increases in rotor C_T result in corresponding increases in the induced and retreating blade stall components of power required. This ultimately is reflected in the growth of power required, leading to a higher value of fuel consumption, gross weight, and energy intensity. This increase in power required tends to be further accelerated by the fact that as rotor tip speed decreases, rotor torque increases, causing an increase in the vehicle propulsion/drive system weight - and ultimately an increase in vehicle empty and gross weights.

Thus, for each disc loading, there is one unique tip speed which results in a minimum energy consumption point. This characteristic is best illustrated in Figure 4.10 which is simply an extension of the data of Figure 4.6 to lower tip speeds and disc loadings.

Figure 4.7 illustrates the DOC values of the helicopter configurations whose EI's are plotted in Figure 4.6. Each carpet plot represents a given vehicle passenger capacity. It can be seen

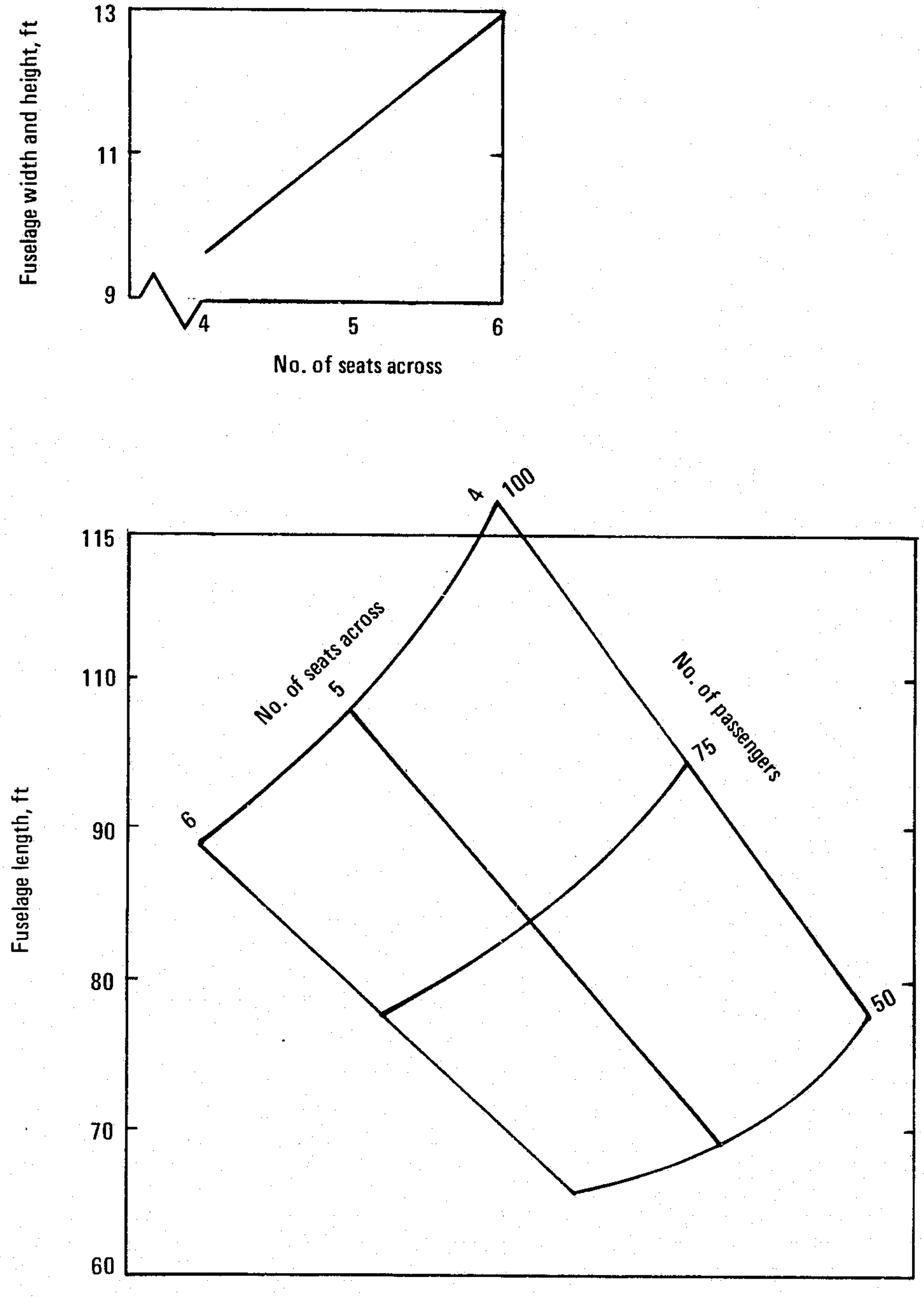


FIGURE 4.2 HELICOPTER FUSELAGE DEMENSIONS VS VEHICLE PASSENGER CAPACITY AND SEATING ARRANGEMENT

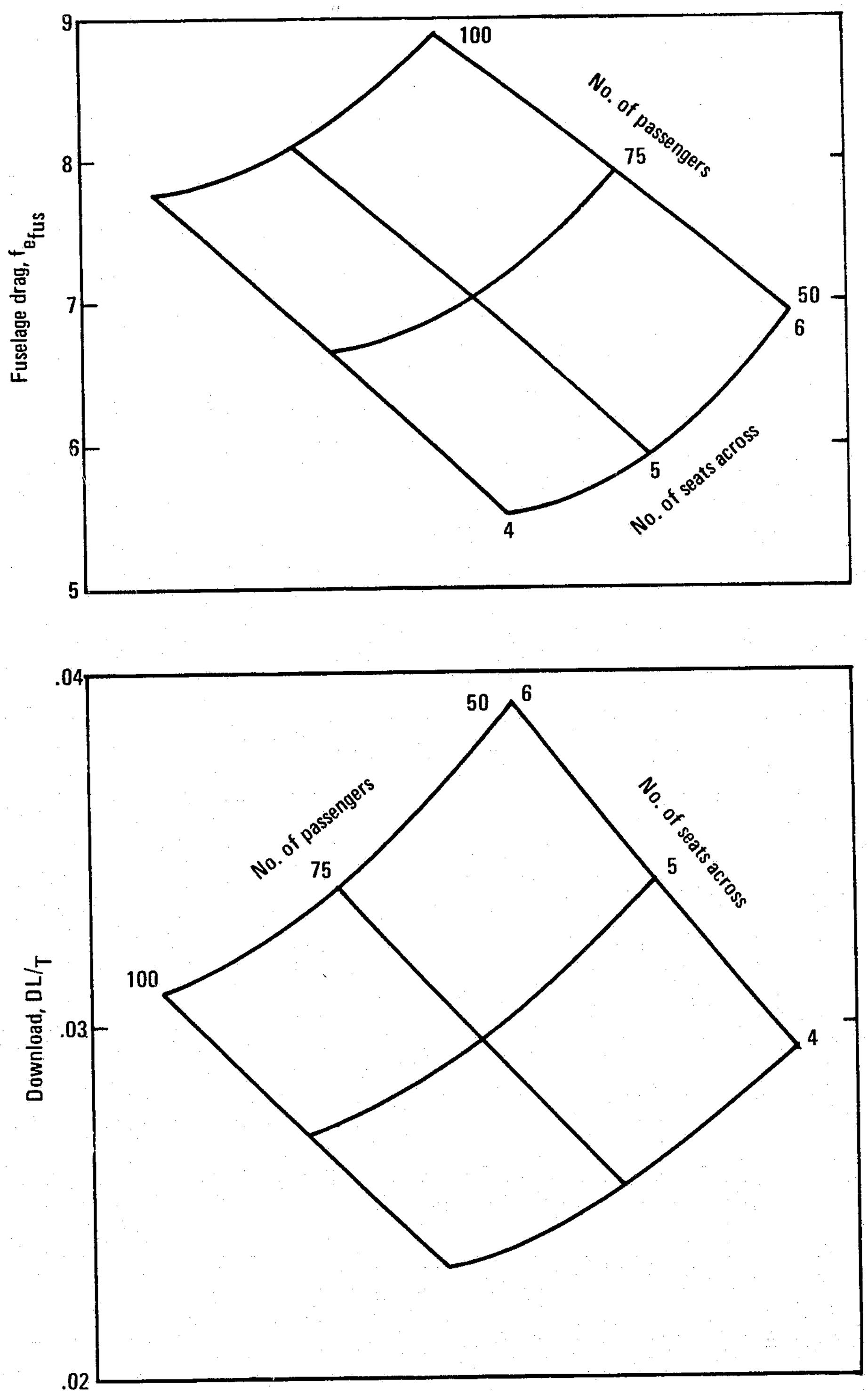
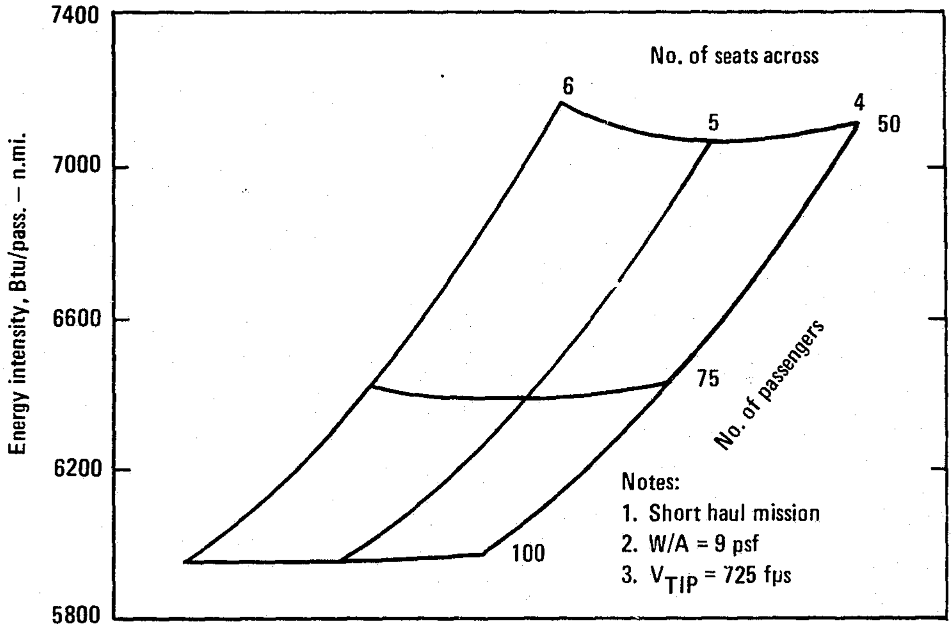


FIGURE 4.3 HELICOPTER FUSELAGE PARASITE DRAG AND HELICOPTER ROTOR DOWN LOAD VS VEHICLE SEATING CAPACITY ARRANGEMENT



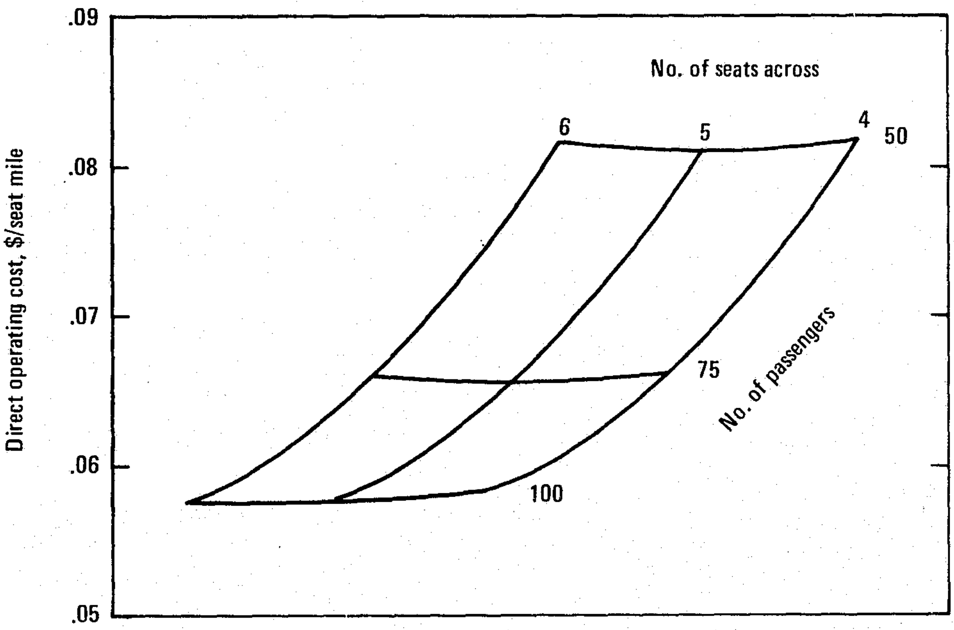


FIGURE 4.4 HELICOPTER ENERGY INTENSITY AND DIRECT OPERATING COST VS VEHICLE PASSENGER CAPACITY & SEATING ARRANGEMENT

TABLE 4.1 COMPARING DIRECT OPERATING COST (DOC), ENERGY INTENSITY (EI), AND GROSS WEIGHT (GW)

THE MINIMUMS OCCUR AS FOLLOWS:

DIRECT OPERATING COST (DOC)	ENERGY INTENSITY (EI)	GROSS WEIGHT (GW)
50 passengers - 5 abreast	50 passengers - 5 abreast	50 passengers - 5 abreast
75 passengers - 5 abreast	75 passengers - 5 abreast	75 passengers - 6 abreast
100 passengers - 6 abreast	100 passengers - 6 abreast	100 passengers - 6 abreast

On this basis, the seating arrangement selected is:

50 passengers - 5 abreast
75 passengers - 6 abreast
100 passengers - 6 abreast

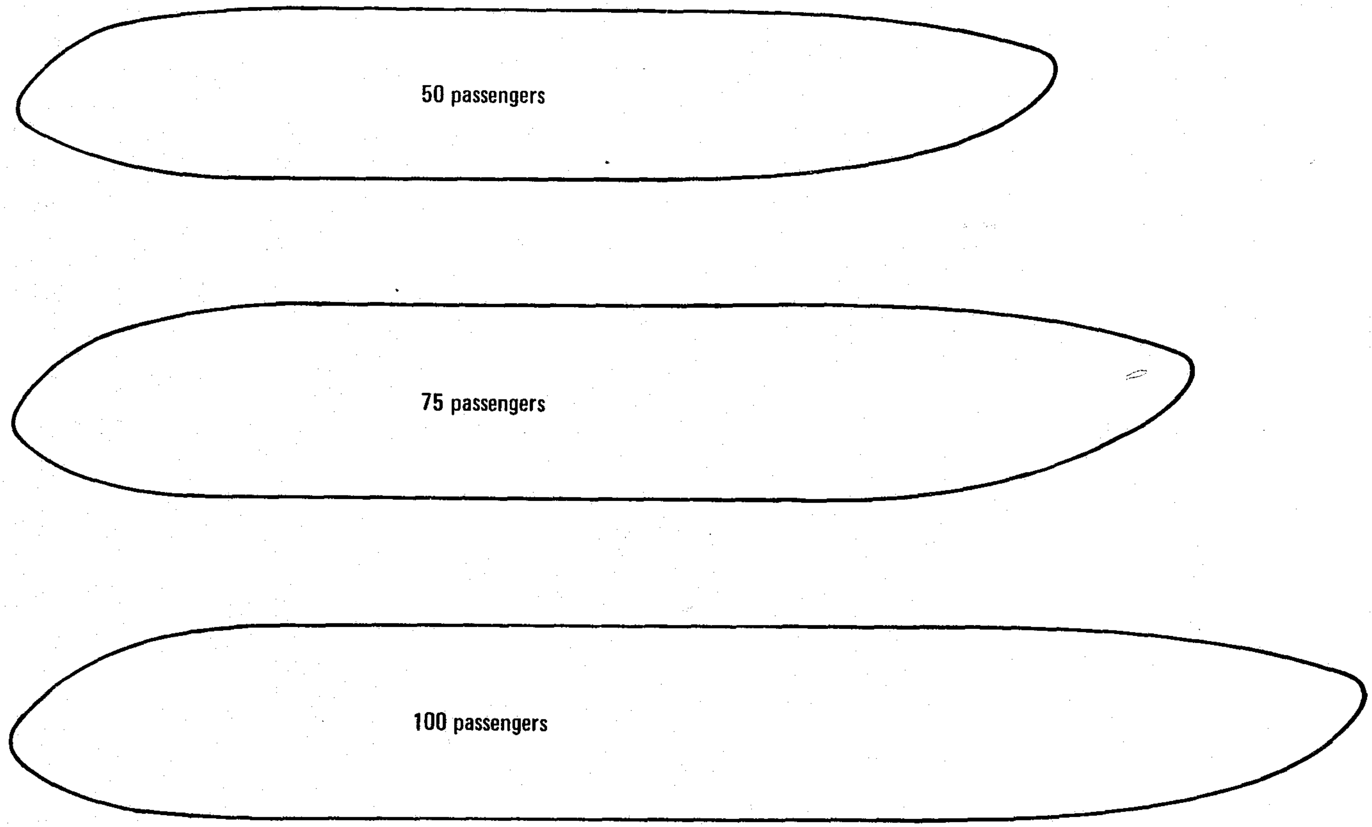


FIGURE 4.5 COMPARATIVE FUSELAGE SHAPES OF SELECTED 50, 75 AND 100 PASSENGER VEHICLES

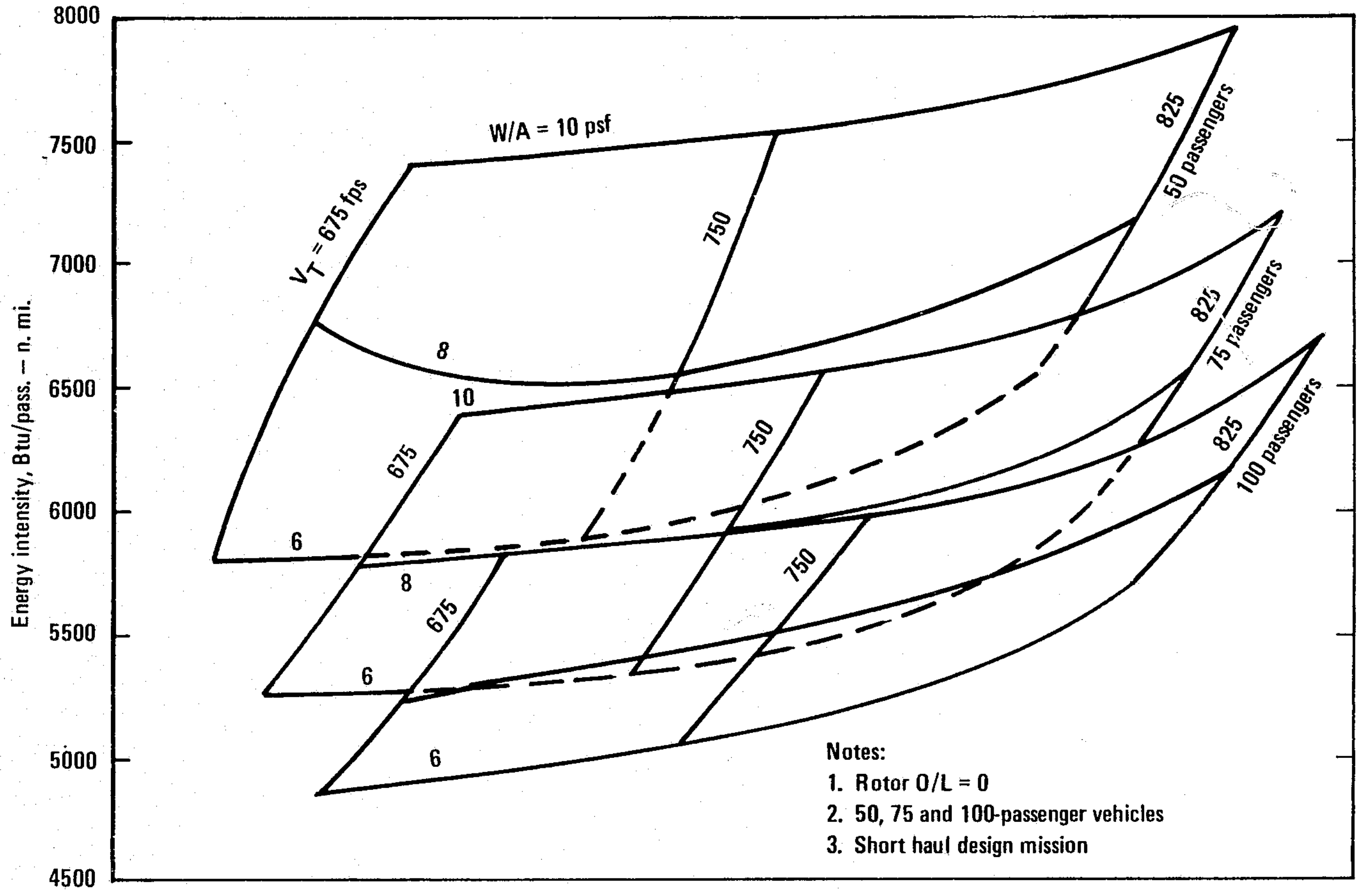


FIGURE 4.6 VEHICLE DISC LOADING – TIP SPEED TRADE STUDY (SHORT HAUL MISSION) – ENERGY INTENSITY

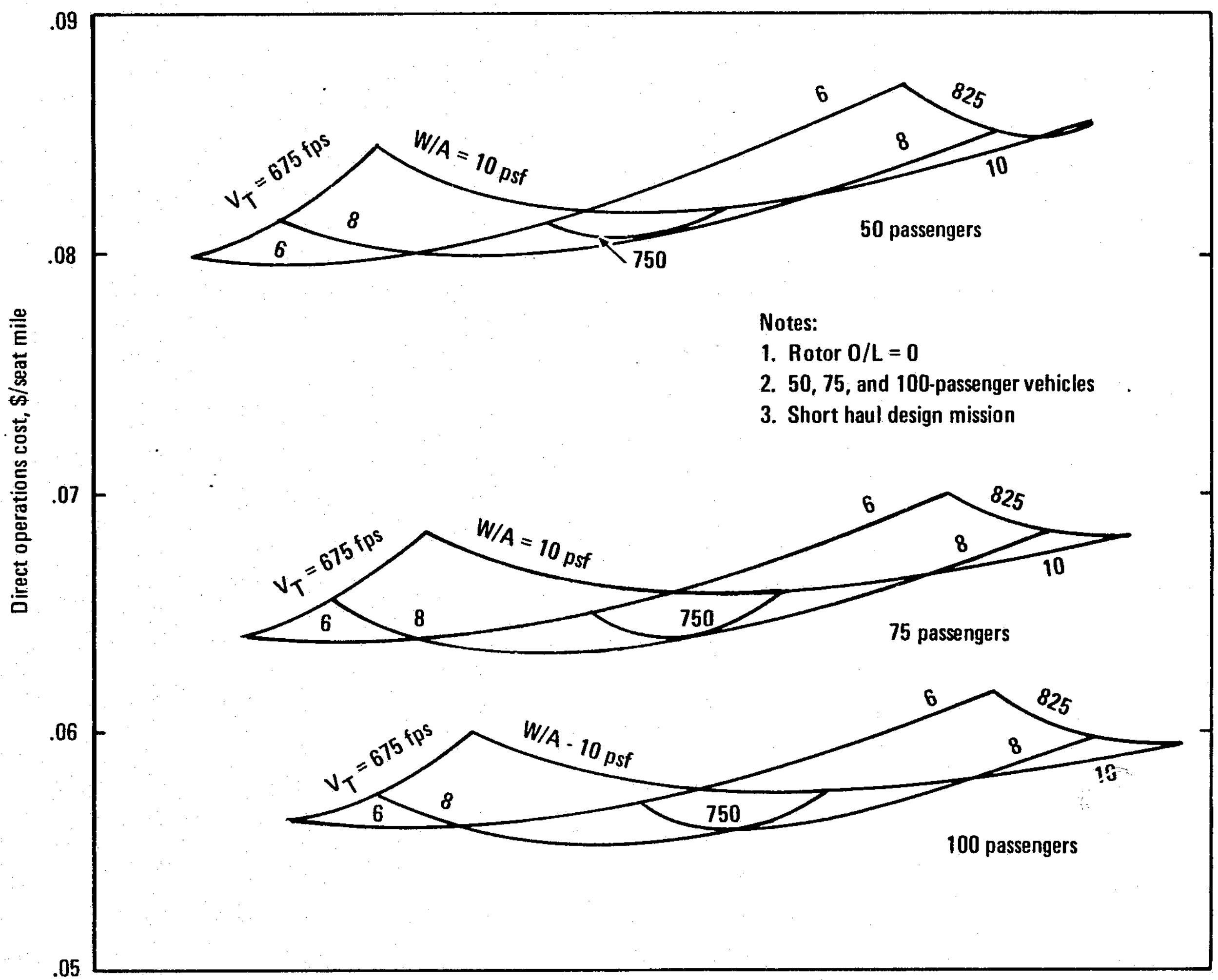


FIGURE 4.7 VEHICLE DISC LOADING – TIP SPEED TRADE STUDY (SHORT HAUL MISSION) – DIRECT OPERATING COST

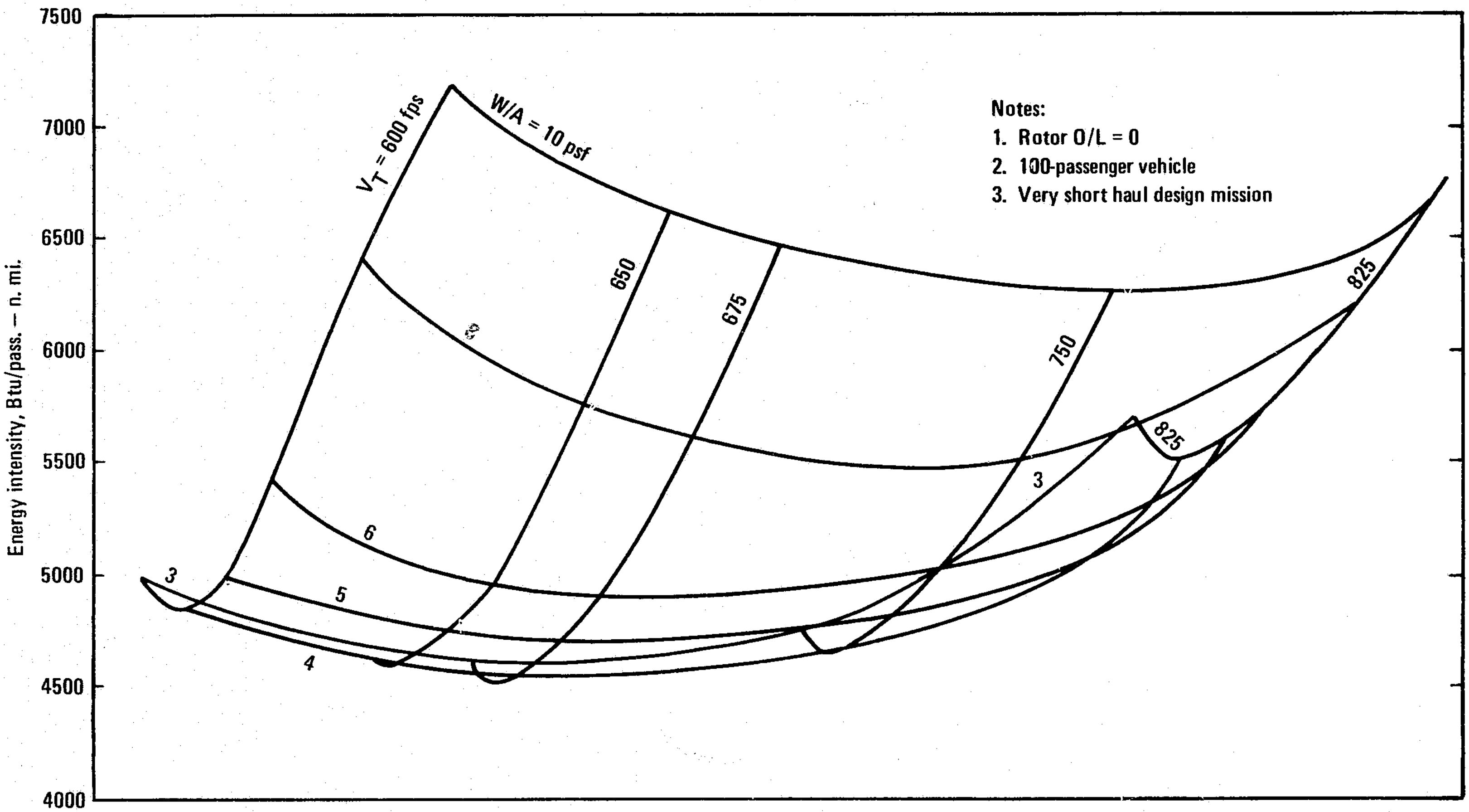


FIGURE 4.8 VEHICLE DISC LOADING — TIP SPEED TRADE STUDY (VERY SHORT HAUL MISSION) — ENERGY INTENSITY

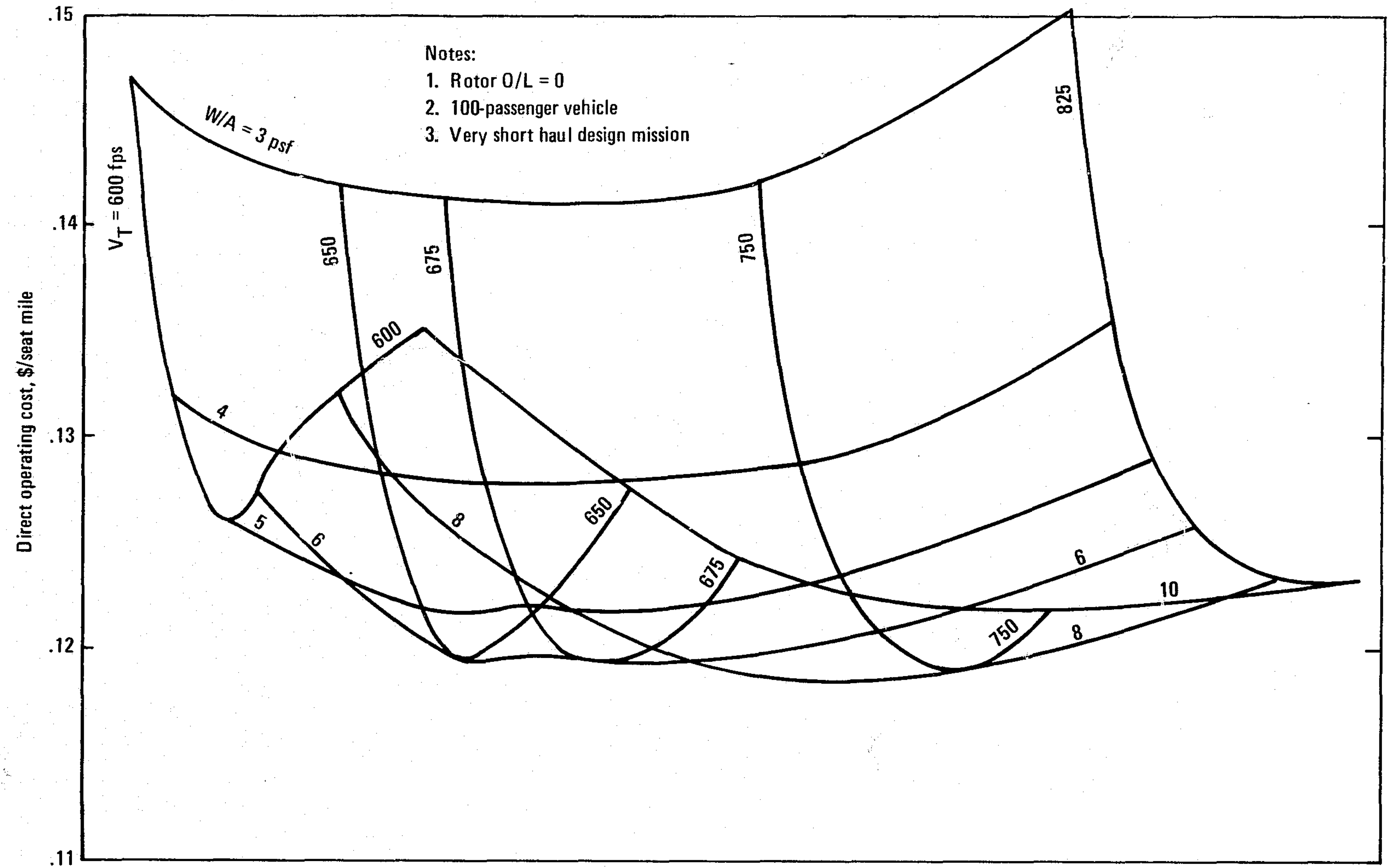


FIGURE 4.9 VEHICLE DISC LOADING – TIP SPEED TRADE STUDY (VERY SHORT HAUL MISSION) – DIRECT OPERATING COST

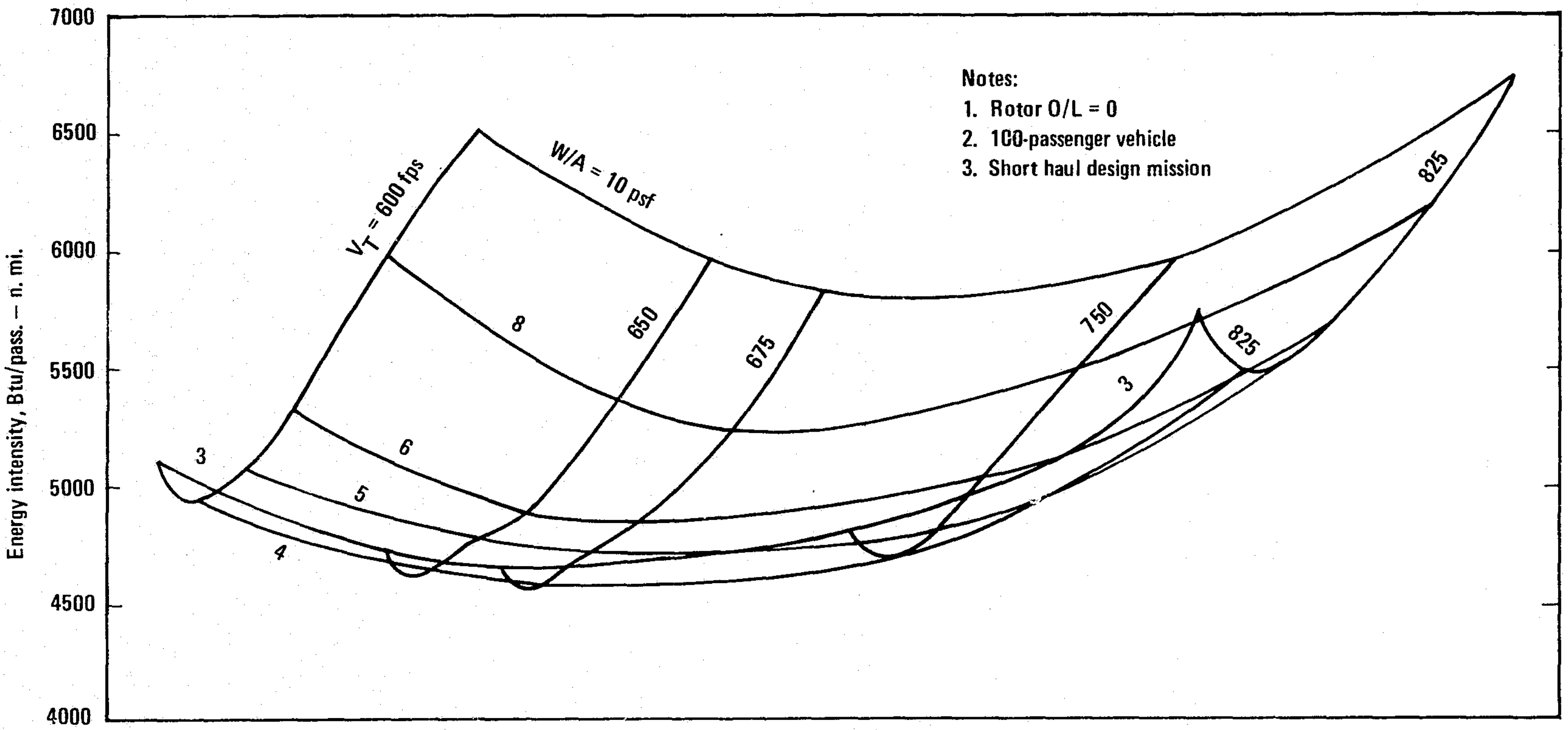


FIGURE 4.10 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) – 100 PASSENGER, 0 ROTOR OVERLAP VEHICLE – ENERGY INTENSITY

that for each disc loading there is one tip speed that results in a minimum DOC value. Furthermore, for each vehicle passenger capacity, there is one combination of disc loading and tip speed which results in a minimum DOC value for that vehicle size.

Note that for each of the passenger capacities shown in Figure 4.7, the minimum DOC occurs at a disc loading of from 6 to 8 psf and a rotor tip speed of approximately 700 ft/sec. Also, note in Figure 4.6, for each of the vehicle passenger capacities plotted, that a minimum EI is not reached above a disc loading of 6 psf and a rotor tip speed of 675 ft/sec., indicating that the combinations of disc loading and tip speed required for a minimum EI helicopter is substantially below that needed for a helicopter designed for minimum DOC.

Since DOC is directly related to design gross weight, and the minimum EI vehicles appear to occur at combinations of disc loading and rotor tip speed considerably below the values associated with a minimum DOC (and therefore minimum gross weight), this intuitively suggests that minimum EI vehicles will have large design gross weights and large physical dimensions (rotor diameter, etc.) due to their low design disc loadings and tip speeds. Thus, minimum DOC helicopters look like the more attractive choice from both the aspect of operating costs and vehicle size.

Accordingly, one minimum DOC design point helicopter representative of each of the vehicle sizes (50, 75, and 100 passenger) from both the Very Short Haul and Short Haul mission scenarios of the disc loading - tip speed trade study were selected for further refinement. At the same time, however, a minimum EI trade study based on the 100 passenger Short Haul vehicle was conducted.

4.3.2 Minimum EI Study

Although the energy intensity of the minimum DOC vehicles (current technology) is lower than earlier technology vehicles, such as the S-61L, improvement is still needed. Therefore, the preceding tip speed - disc loading trade study was extended to include still lower values of tip speed and disc loading. Figure 4.10 illustrates the variation of energy intensity (EI) with disc loading and tip speed for a matrix of 100 passenger, zero overlap rotor, Short Haul Mission helicopters. Note that, below a disc loading of 4 psf, energy intensity climbs quickly due to a rapid vehicle weight growth. This growth is, in turn, a by-product of higher propulsion system weight increments arising from the effects of large diameter - low RPM (i.e. high torque) rotors. The resulting minimum EI helicopter exhibits a 12% decrease (see Table 4.2) in energy intensity relative to the baseline vehicle, but at a considerable configuration penalty (12% gross weight increase, 47% rotor diameter increase). This configuration penalty is even more graphically illustrated by the vehicle geometry comparison of Figure 4.16. Retention of zero rotor overlap, although beneficial from the point of view of reduced rotor/rotor induced/interference power effects, results in a vehicle that is very large (rotor diameter = 118 ft.), awkward, and structurally inefficient.

Figures 4.11, 4.12, and 4.13 depict, respectively, the variation of vehicle direct operating cost, gross weight, and installed power, for the same disc loading and tip speed combinations as Figure 4.10. Note that at the low disc loading and tip speed required for minimum EI operation, the vehicle direct operating cost and gross weight are far from being minimum values. Note also (Figure 4.13) that the region of minimum EI operation coincides with region of minimum vehicle installed power.

TABLE 4.2 100 PASSENGER VEHICLE CHARACTERISTICS COMPARISON

	W/A	V_{TIP}	O/L	g/S	GW	D_{mR}	σ	EI	DOC ($/STA.MI.)
SHORT HAUL MISSION (MIN DOC)	7.75	715	0	.123	78,820	80.5	.078	5225	.0557
COMPROMISE	7	705	0	.117	79,257	84.9	.073	5060	.0557 (SH) .1214 (VSH)
SH MSN (MIN EI, 0 O/L)	4	685	0	.0833	88,400	118.6	.046	4580	.0611
SH MSN (MIN EI, VAR O/L)	5	663	.338	.142	87,700	105.7	.0635	5080	.0605
SH MSN (MIN EI, 30% O/L)	4	705	.30	.1176	90,800	120.2	.0425	4990	.0632

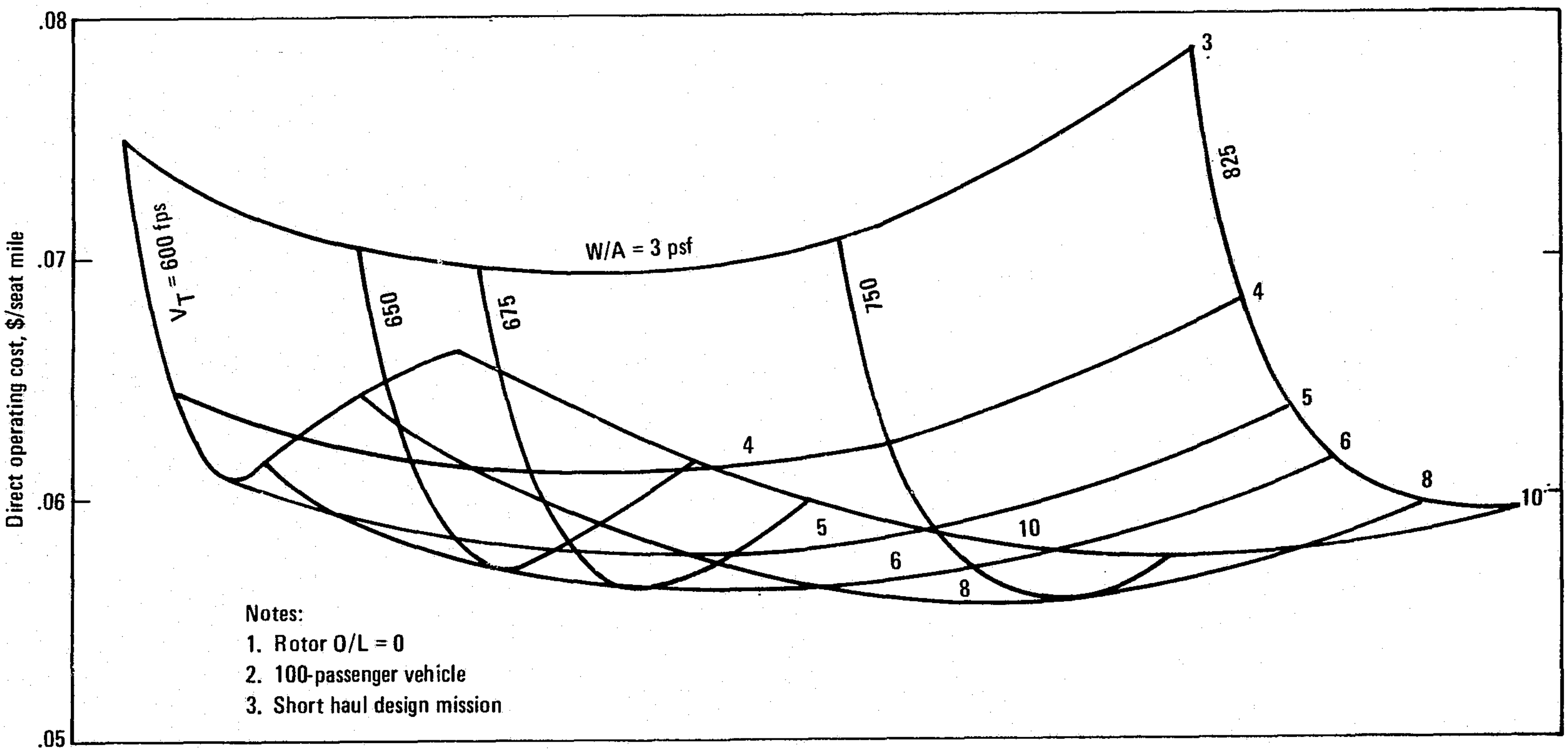


FIGURE 4-11 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) — 100 PASSENGER, 0 ROTOR OVERLAP VEHICLE — DIRECT OPERATING COST

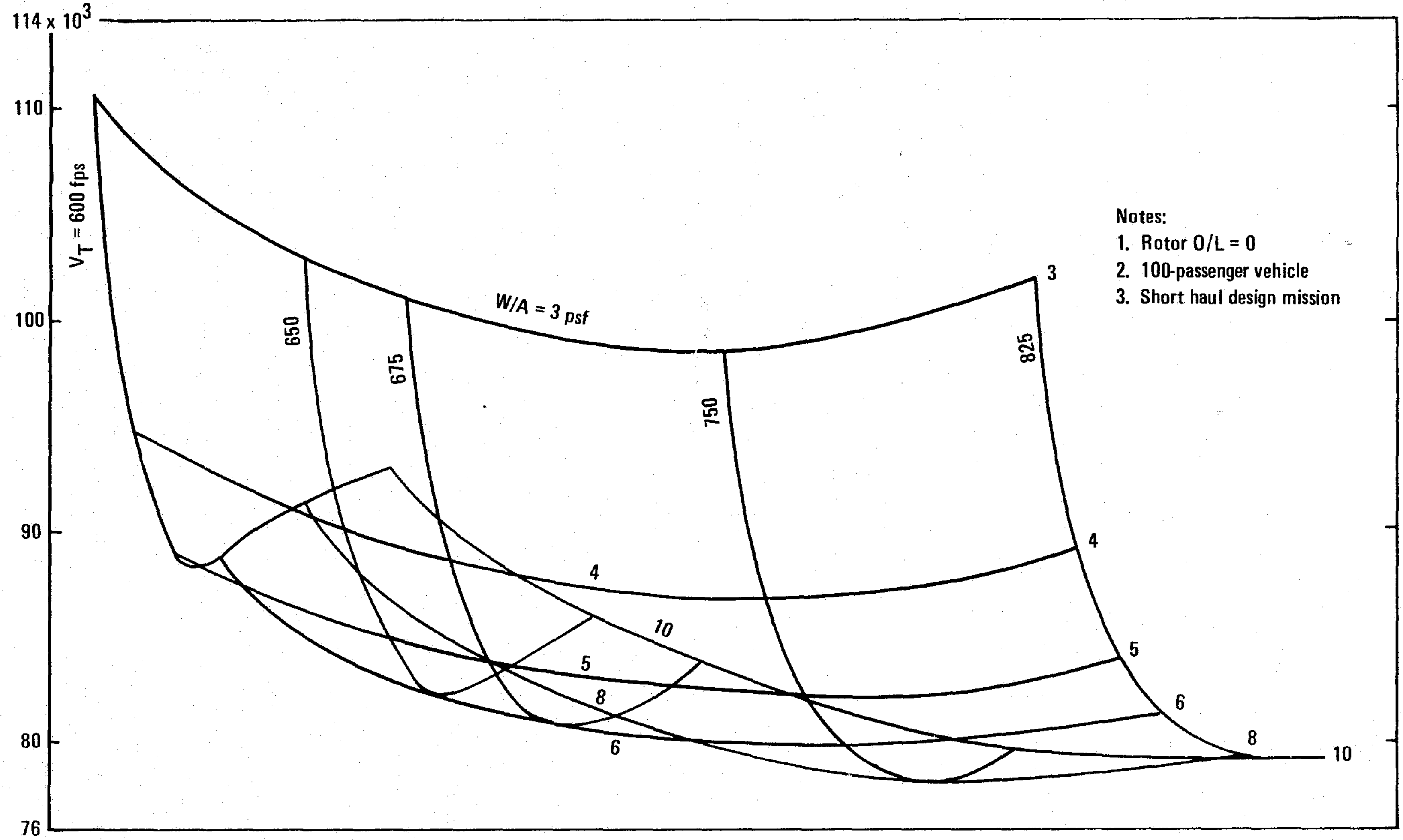


FIGURE 4.12 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) — 100 PASSENGER, 0 ROTOR OVERLAP VEHICLE — GROSS WEIGHT

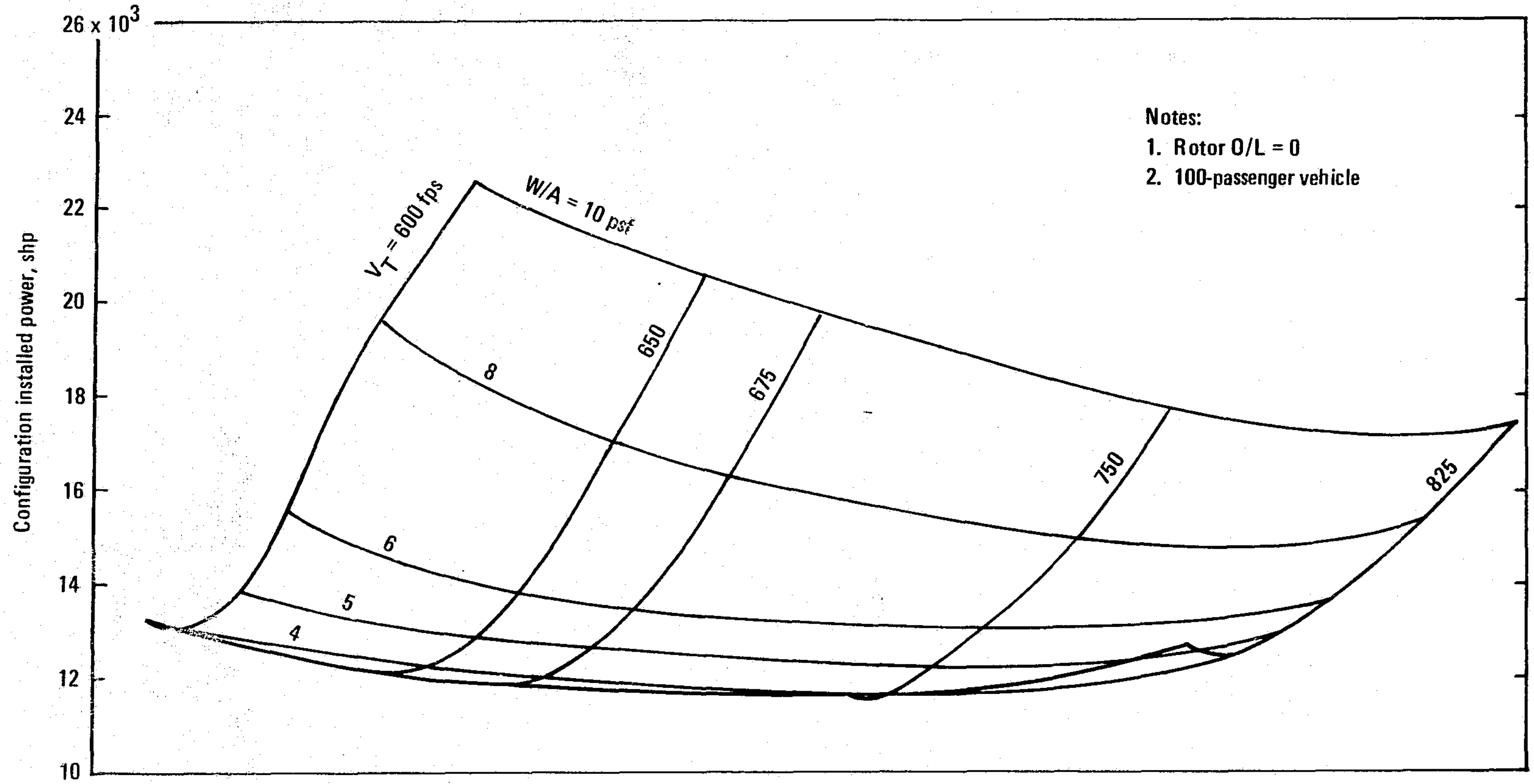


FIGURE 4.13 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) – 100 PASSENGER, 0 ROTOR OVERLAP VEHICLE – INSTALLED POWER

Obviously, the next step would be to introduce some amount of rotor overlap in an attempt to reduce the vehicle size/configuration penalties, knowing that some induced power penalty would be incurred. The results are shown in Figures 4.14 and 4.15 and Table 4.2.

Figure 4.14 illustrates the variation in vehicle EI which occurs when the vehicle disc loading and tip speed combinations of Figure 4.10 are reconfigured to incorporate a tandem rotor overlap of 30%. Note that compared to the EI data of Figure 4.10 the shape of the data plot is unchanged; but the overall EI level is increased. As observed earlier, this is a result of increased induced power due to tandem rotor interference. Figure 4.15 results from the same sort of configuration modifications, except that in this case, the distance between rotors has been fixed and the overlap has been allowed to vary, causing both an upward shift in EI and a change in the shape of the data plot (compared to Figure 4.10).

Although these minimum EI vehicles are more compact and structurally efficient (see Figure 4.16 and Table 4.2), they still suffer considerable size penalties (11 to 15% increase in gross weight and 31 to 49% increase in rotor diameter) for considerably less reduction in energy intensity (3 to 4.5%). This latter fact is of course, a result of reduced hover and cruise efficiency due to increased rotor/rotor induced interference power effects.

Figure 4.17 summarizes the results of the minimum EI trade study in bar chart format. Note that the incorporation of overlap to reduce overall vehicle size (as depicted in Figure 4.16) results in an increase of minimum EI that substantially negates the initial reduction in energy intensity achieved by resizing a vehicle at lowered disc loadings and tip speeds.

The conclusion is inescapable, then, that optimization of a vehicle for reduction of EI only by lowering the disc loading and/or rotor tip speed is not justifiable for that reason alone due to the attendant large configuration penalties accompanying such a reduction.

4.3.3 Energy Intensity Reduction by Modification of Design Ground Rules

Another method for potential reduction of EI is by modification of vehicle sizing ground rules. What would be the effect on EI, for example, of simply eliminating the one-engine-inoperative (OEI) in hover requirement for engine sizing and designing the helicopter with only two engines instead of three? In order to find out, the disc loading - tip speed trade study (Short Haul Mission) referred to earlier was repeated with those modifications to the engine sizing ground rules. Figures 4.18, 4.19, 4.20 and 4.21 show the resulting values of energy intensity, direct operating cost, gross weight, and installed power. Comparison of this data with the corresponding plots for the helicopters sized to the original ground rules (Figures 4.10, 4.11, 4.12 and 4.13) reveals substantial reductions in all four parameters. Table 4.3 illustrates a comparison between the baseline minimum DOC helicopter and a minimum DOC design point picked from Figure 4.18. Note that the "revised ground rules" design point helicopter exhibits a 23% reduction in EI, lower even than the minimum EI helicopters studied earlier - a point emphasized by Figure 4.22.

The reduction in EI is a direct result of the iterative nature of the vehicle sizing process. That is, for a vehicle sized to meet specific mission requirements at a fixed payload, any reduction in empty weight results in a corresponding reduction in vehicle gross weight and therefore a decrease in the total fuel required to fly the mission. This means that the helicopter can be

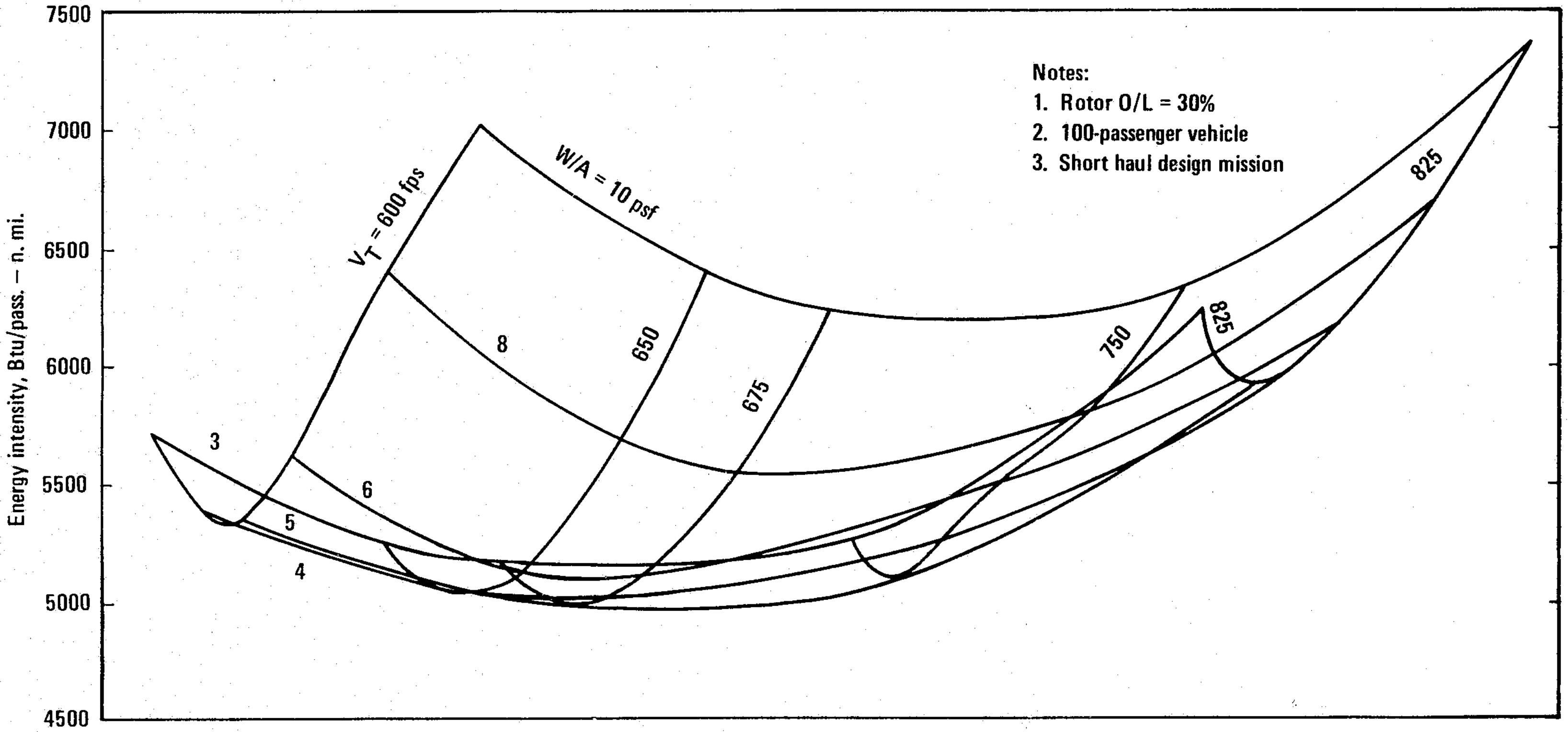


FIGURE 4.14 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) — 100 PASSENGER, 30% ROTOR OVERLAP VEHICLE–ENERGY INTENSITY

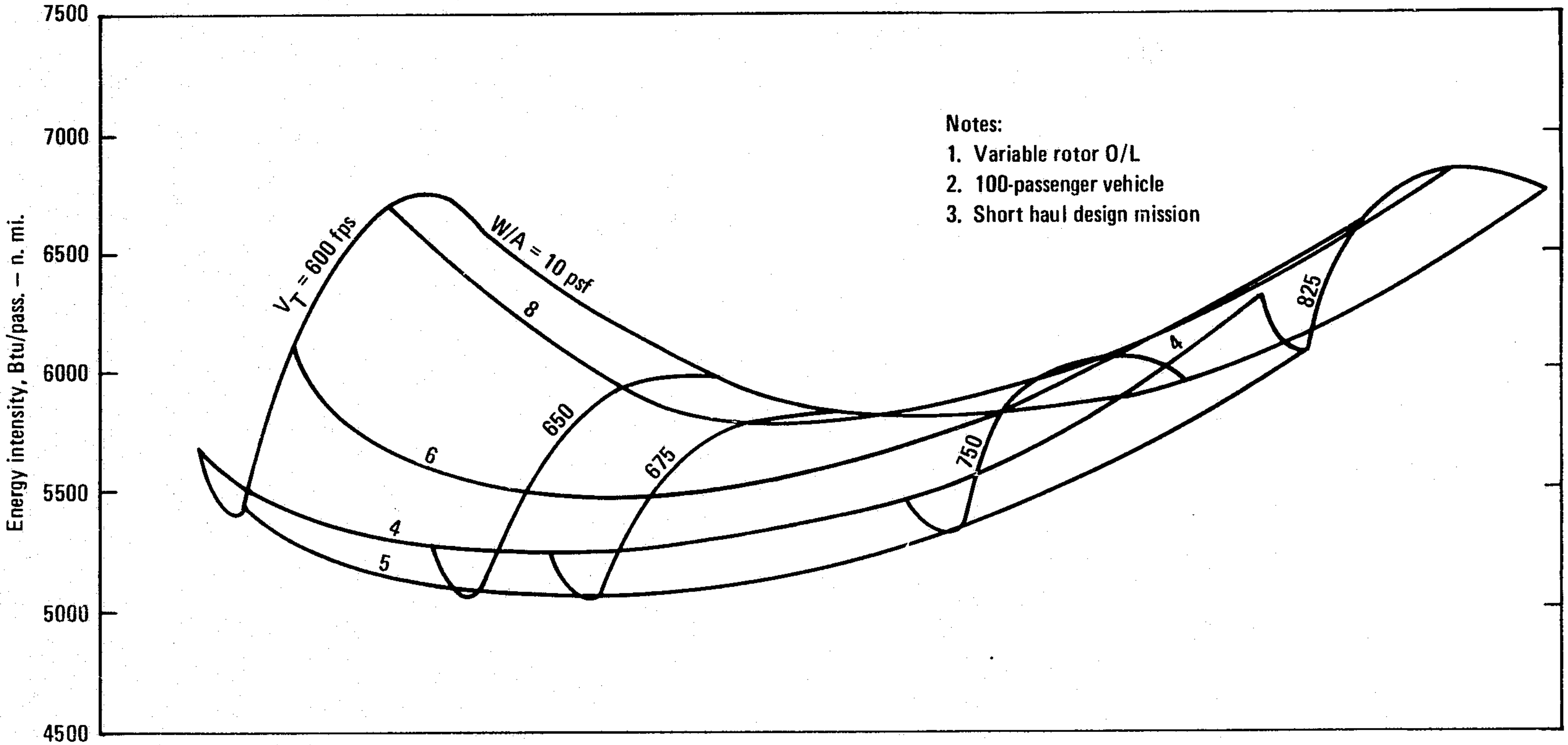


FIGURE 4.15 VEHICLE MINIMUM EI TRADE STUDY (SHORT HAUL MISSION) – 100 PASSENGER; VARIABLE ROTOR OVERLAP VEHICLE–ENERGY INTENSITY

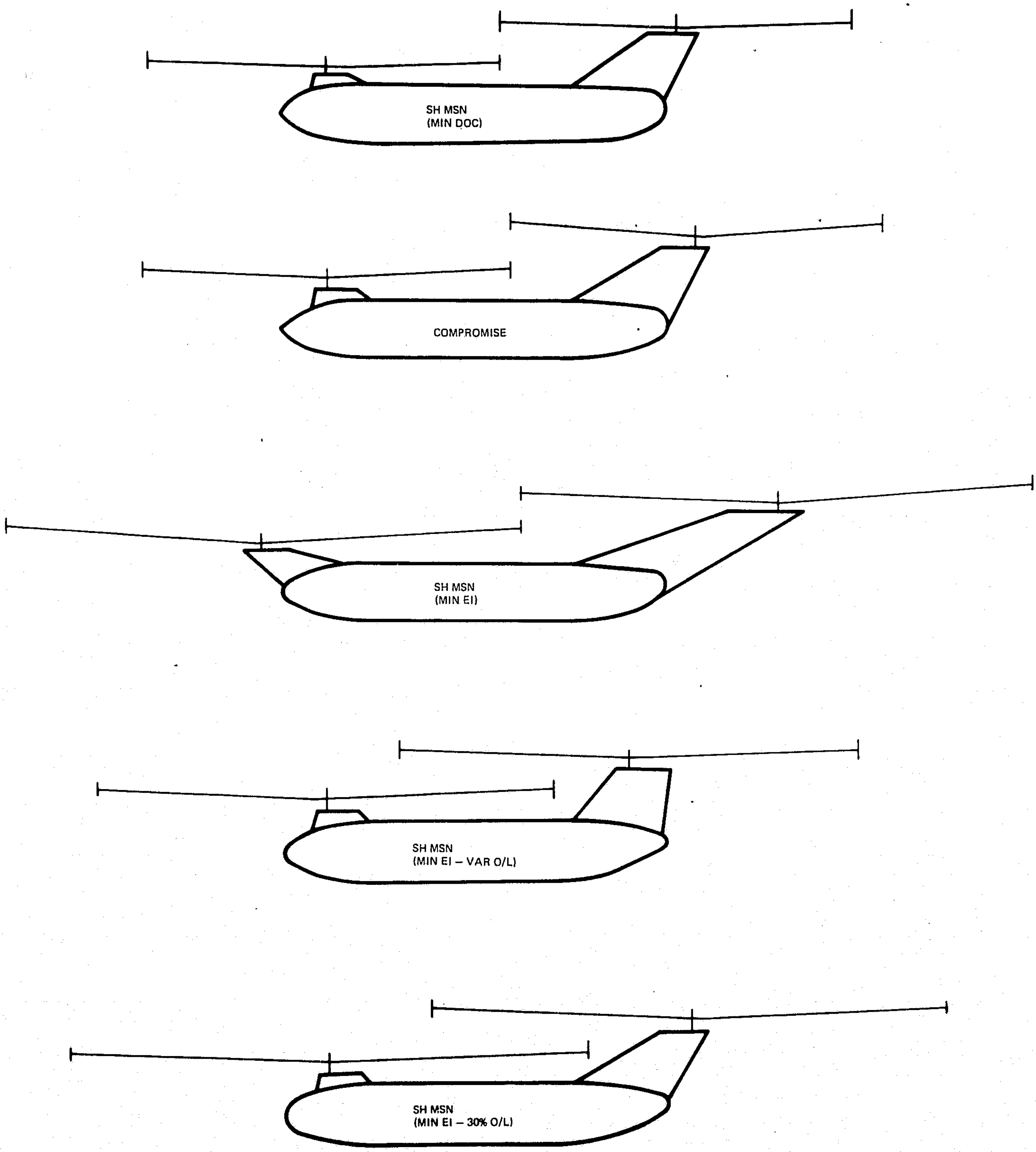


FIGURE 4.16 CONFIGURATION GEOMETRY COMPARISON

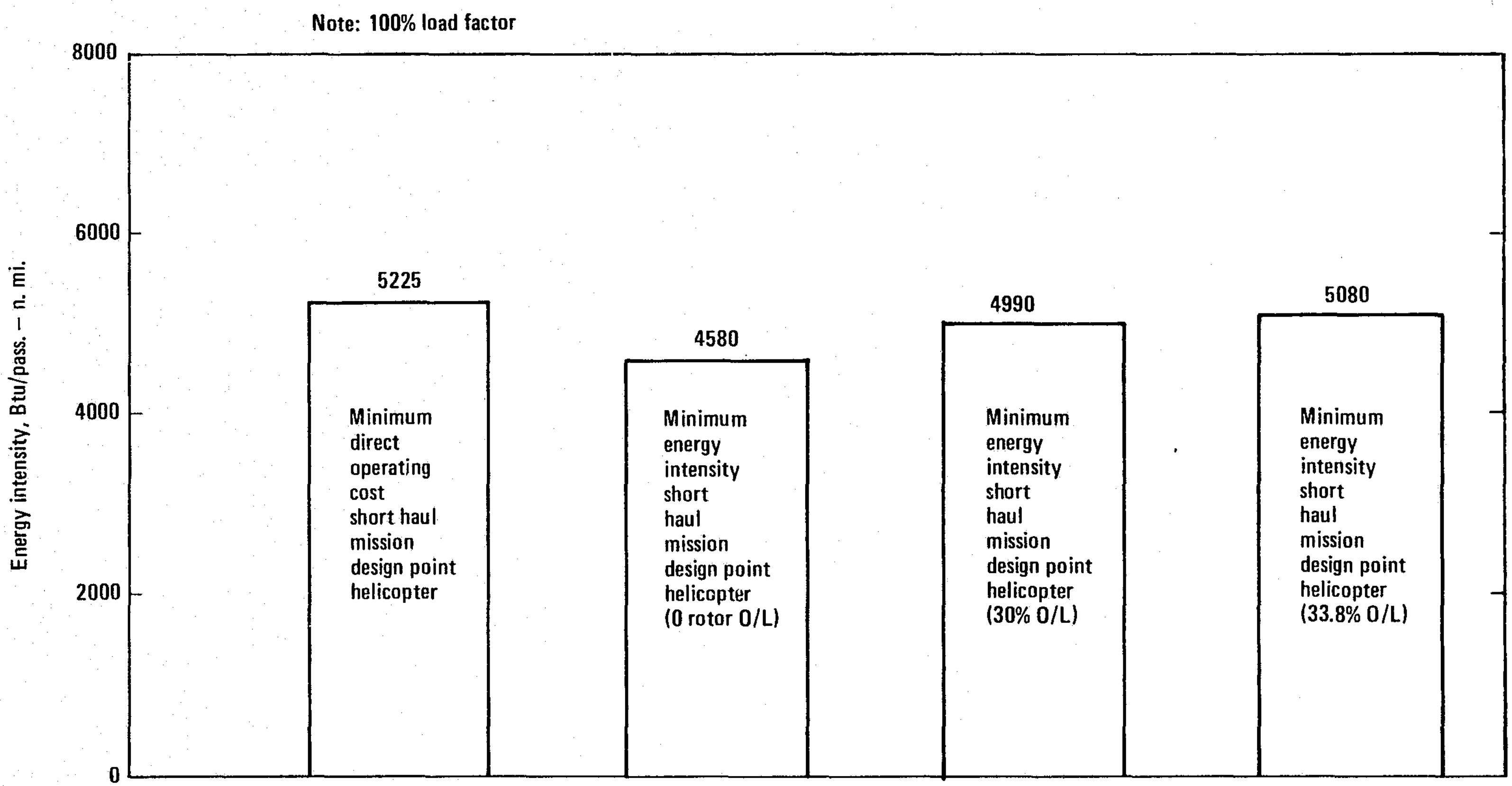


FIGURE 4.17 MINIMUM EI TRADE STUDY – VEHICLE ENERGY INTENSITY COMPARISON – VARIOUS 100 PASSENGER DESIGN POINT VEHICLES

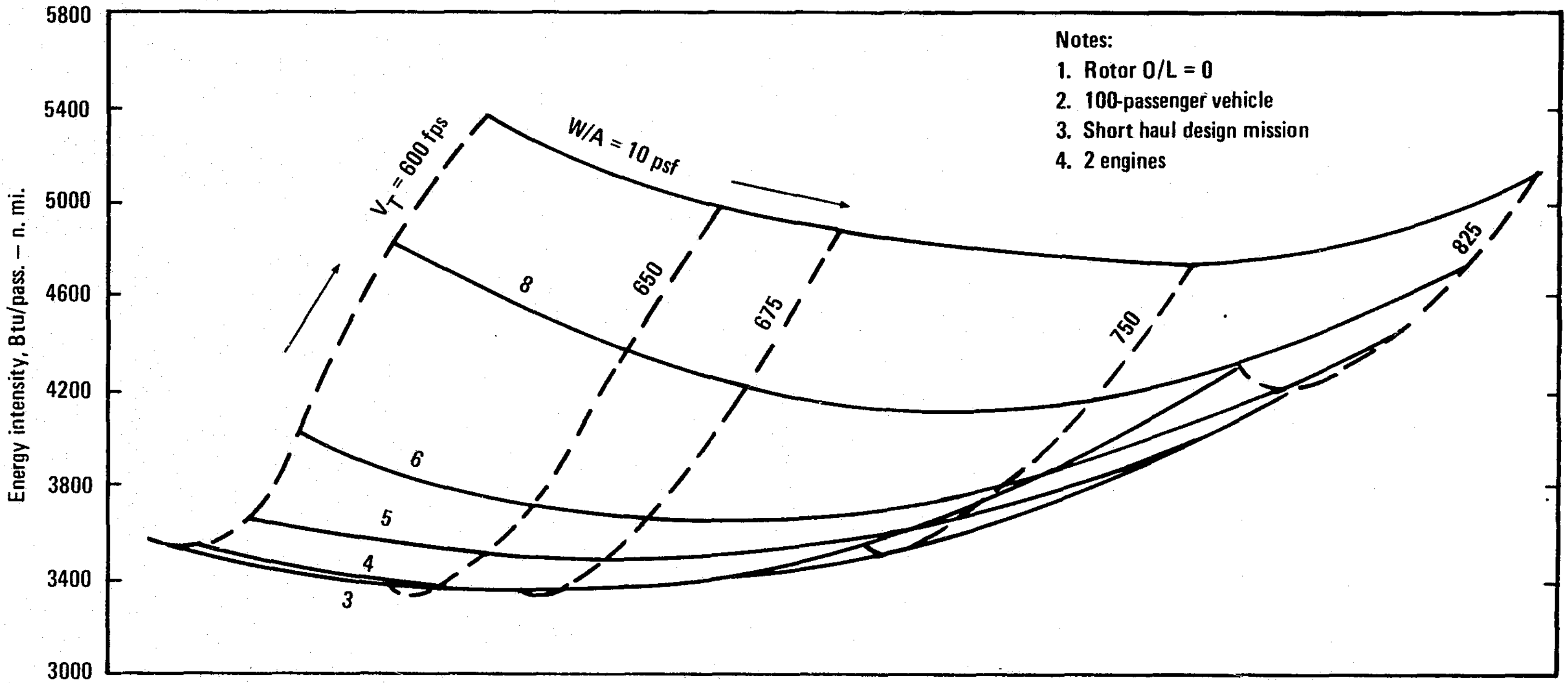


FIGURE 4.18 EFFECT OF OEI REQUIREMENTS ON VEHICLE SIZING (SHORT HAUL MISSION) – ENERGY INTENSITY

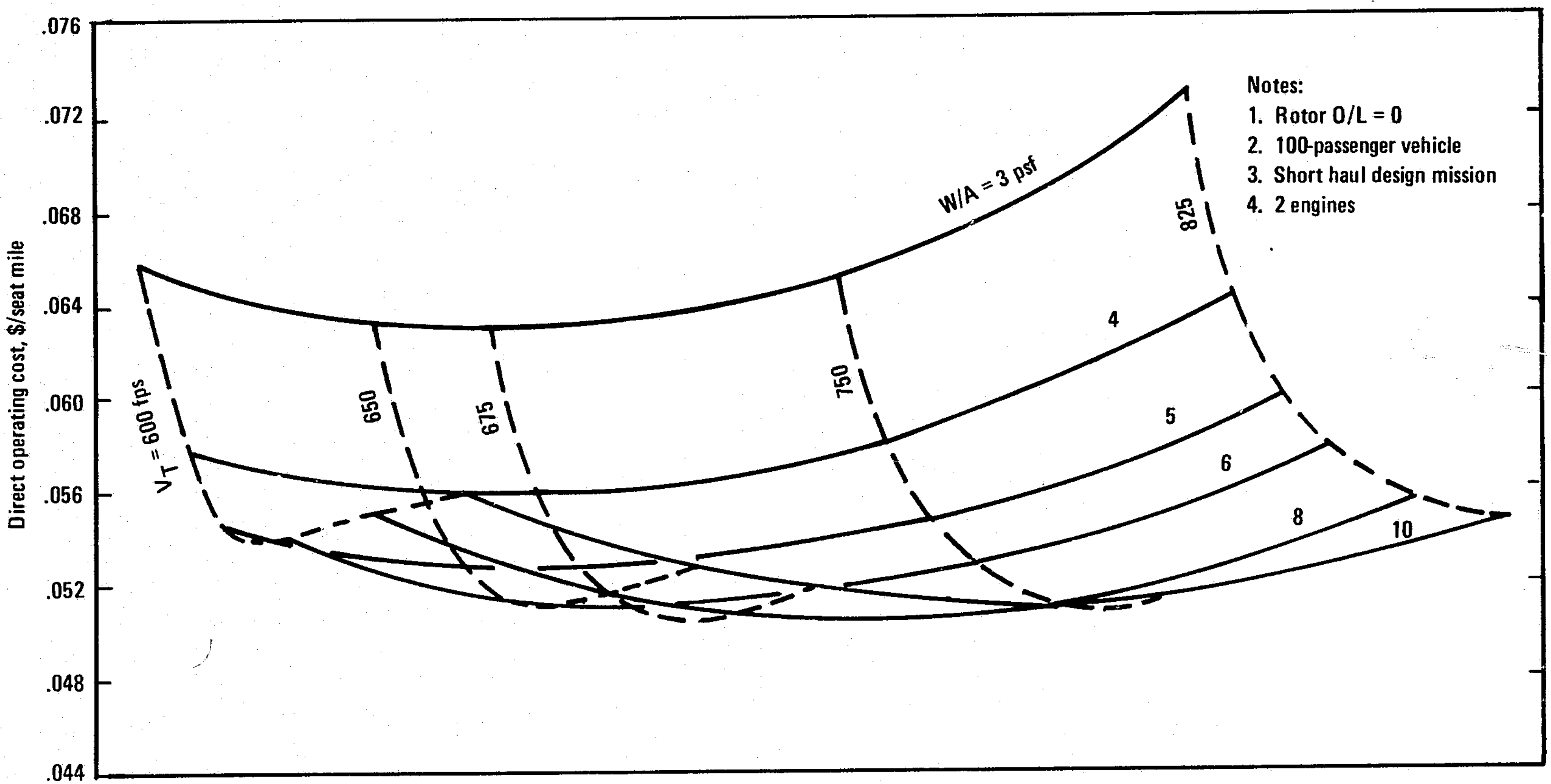


FIGURE 4.19 EFFECT OF OEI REQUIREMENTS ON VEHICLE SIZING (SHORT HAUL MISSION) – DIRECT OPERATING COSTS

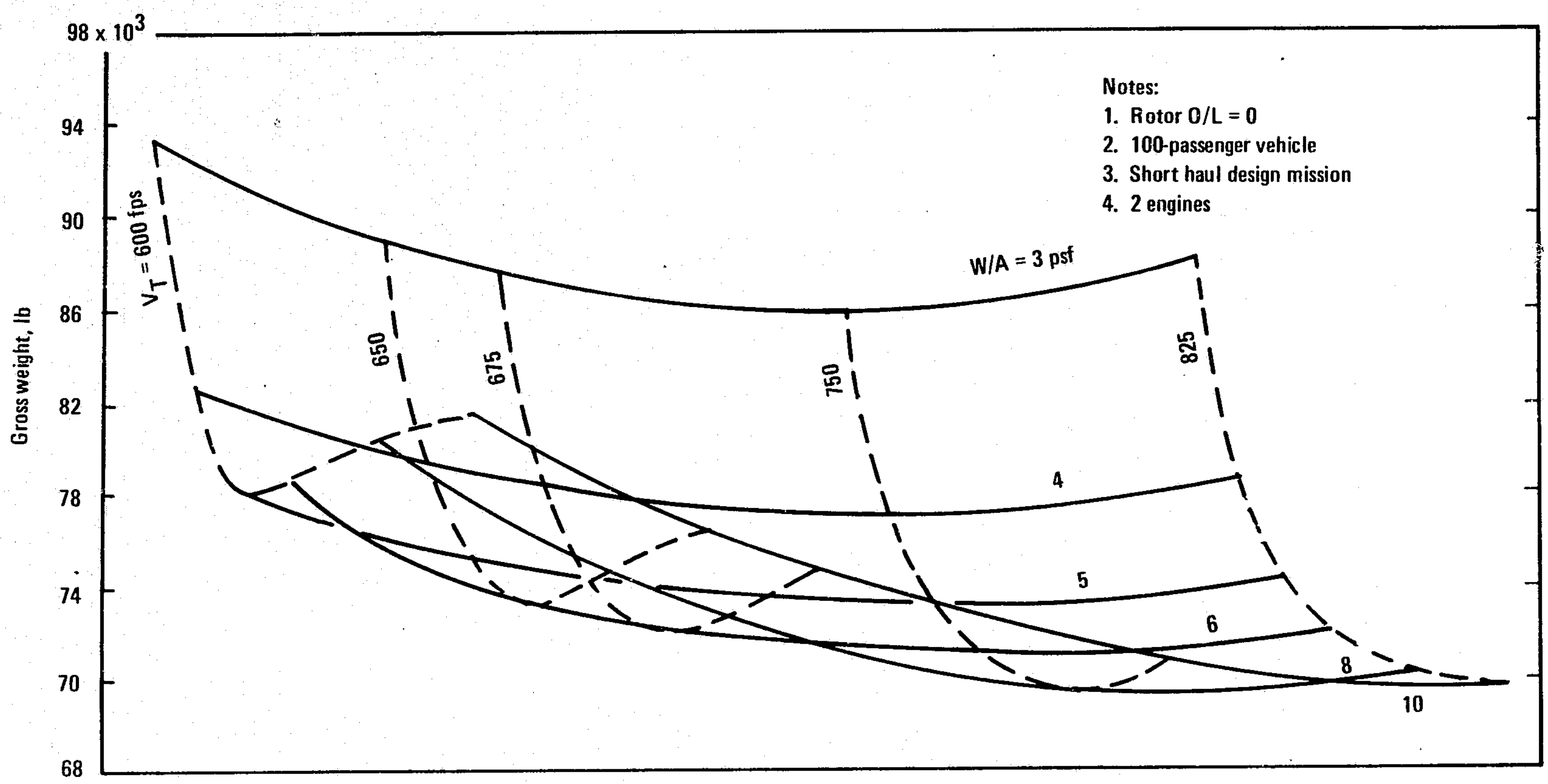


FIGURE 4.20 EFFECT OF OEI REQUIREMENTS ON VEHICLE SIZING (SHORT HAUL MISSION) – GROSS WEIGHT

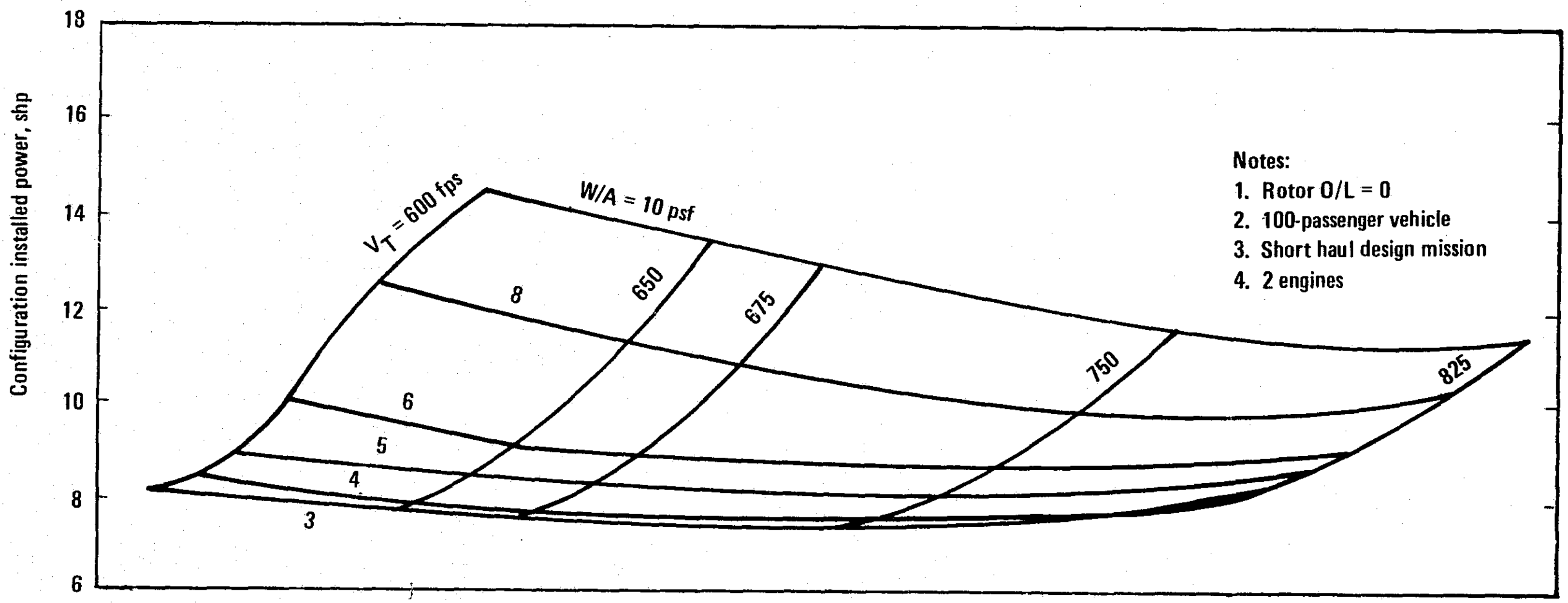


FIGURE 4.21 EFFECT OF OEI REQUIREMENTS ON VEHICLE SIZING (SHORT HAUL MISSION) – INSTALLED POWER

TABLE 4.3 EFFECT OF OEI SIZING REQUIREMENT ON VEHICLE CHARACTERISTICS

VEHICLE	GW	D_{MR}	σ	EI	DOC ($/STA.MI.)
SH MSN (MIN DOC)	78,820	80.5	.078	5225	.0557
SH MSN (MIN DOC) (SIZED WITH NO OEI RQMT - 2 ENG)	71,300 (9.5% REDUCTION)	76.53	.078	4040 (22.7% REDUCTION)	.0504 (9.5% REDUCTION)

BOTH VEHICLE MINIMUM DOC'S OCCUR AT W/A = 7.75

V_T = 715

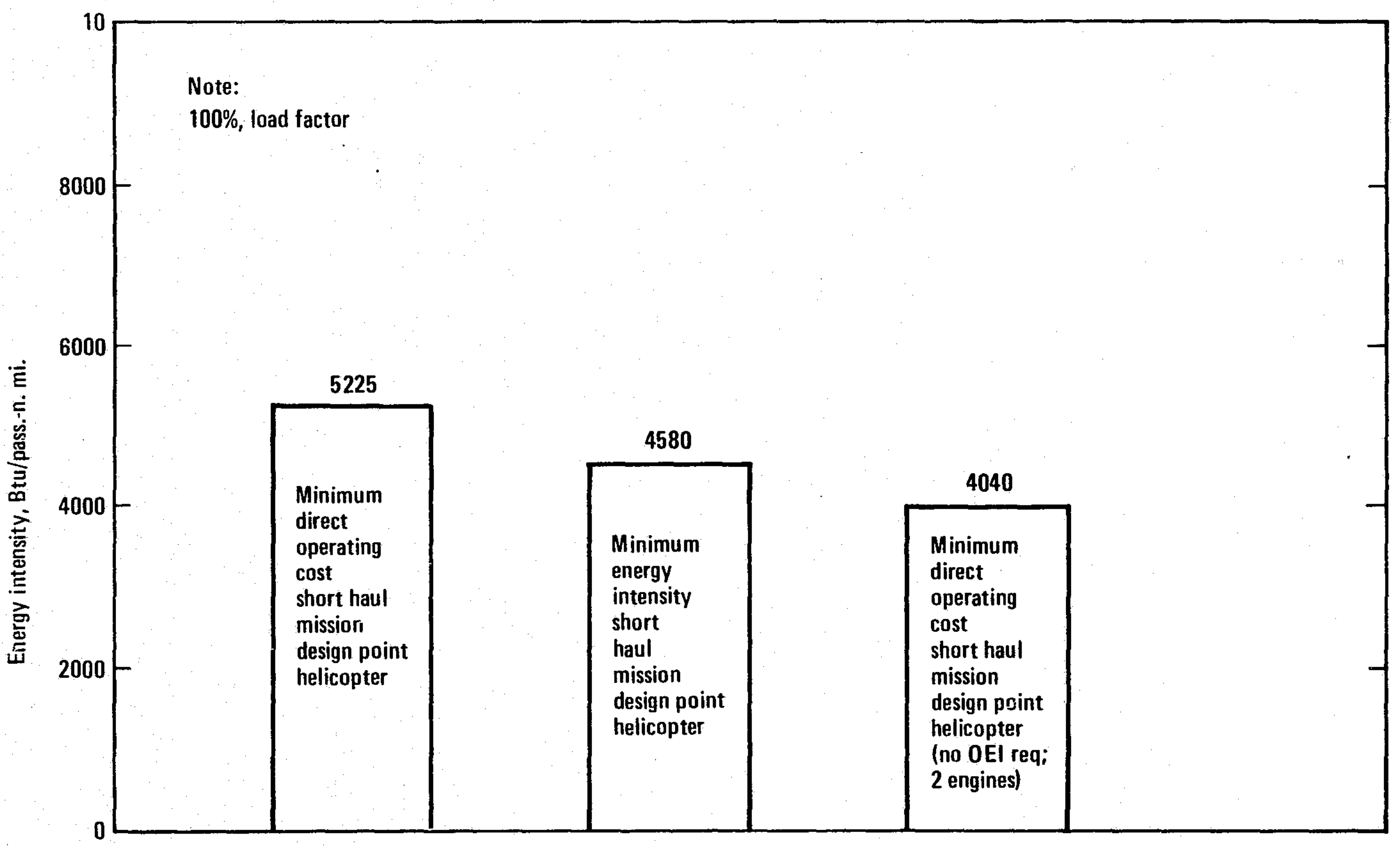


FIGURE 4.22 EFFECT OF OEI SIZING REQUIREMENTS ON VEHICLE EI – A COMPARISON

further reduced in size to achieve a match of empty weight plus payload plus mission fuel equal to some lower design gross weight.

In this particular case, the revision in mission ground rules dictates a smaller propulsion system (engines, drive system, rotors, etc.) with a resulting reduction in empty weight and therefore gross weight and EI, as noted above.

4.4 Selection of Design Point Vehicles for Further Study

4.4.1 Refinement of Initial Design Point Vehicles

As part of the mission scenario ground rules initially set forth is the requirement for the helicopter to cruise at normal rated power (NRP). Another requirement (in this case, a sizing ground rule) is that the vehicle should have sufficient rotor solidity to maintain 1.0 g level flight at this speed. Thus a perfectly matched vehicle has sufficient rotor solidity to insure that the cruise speed at which the rotor limit is reached coincides with V_{NRP}. A helicopter with less capability is rotor limited. One with more capability is power limited.

The initial minimum DOC design point vehicles resulting from the disc loading - rotor tip speed trade study referred to in Section 4.3.1 were not completely matched vehicles. That is, these helicopters' rotor solidities were sized based on the rotor limits shown in Figure A-1, but at cruise speeds which turned out to be less than V_{NRP}, making them rotor limited. Further refinement involved the resizing of the rotor solidity to increase the rotor limit cruise speed so as to match V_{NRP} speed. This resulted in an increase in solidity which in turn caused escalations in vehicle empty and gross weights — and therefore EI.

4.4.2 Influence of External Noise Criteria In the Selection of Design Point Vehicles

The effect of external noise criteria on the design of helicopter configurations is extremely pertinent since external noise and community acceptance may become governing parameters if operations with V/STOL aircraft are to achieve the advantages of potential block time savings for the short haul traveller. Such time savings will require operation from high population density urban and suburban areas as well as major airports.

The primary design parameters which dictate the rotor rotational and broad band noise are tip speed and blade area or solidity.

The effect of decreasing solidity and increasing the tip speed reduces the aircraft design gross weight and increases the sideline perceived noise level and vice versa. Decreasing solidity also provides decreased direct operating costs.

Figure 4-23 (from Reference 4) shows typical design points from Reference 4 plotted vs. 500 ft sideline noise level. The baseline vehicle is a minimum DOC design point helicopter flying a short haul mission. Note that attempts to further reduce the baseline vehicle noise level by the lowering of rotor tip speed and the addition of solidity results in rapid increases in DOC.

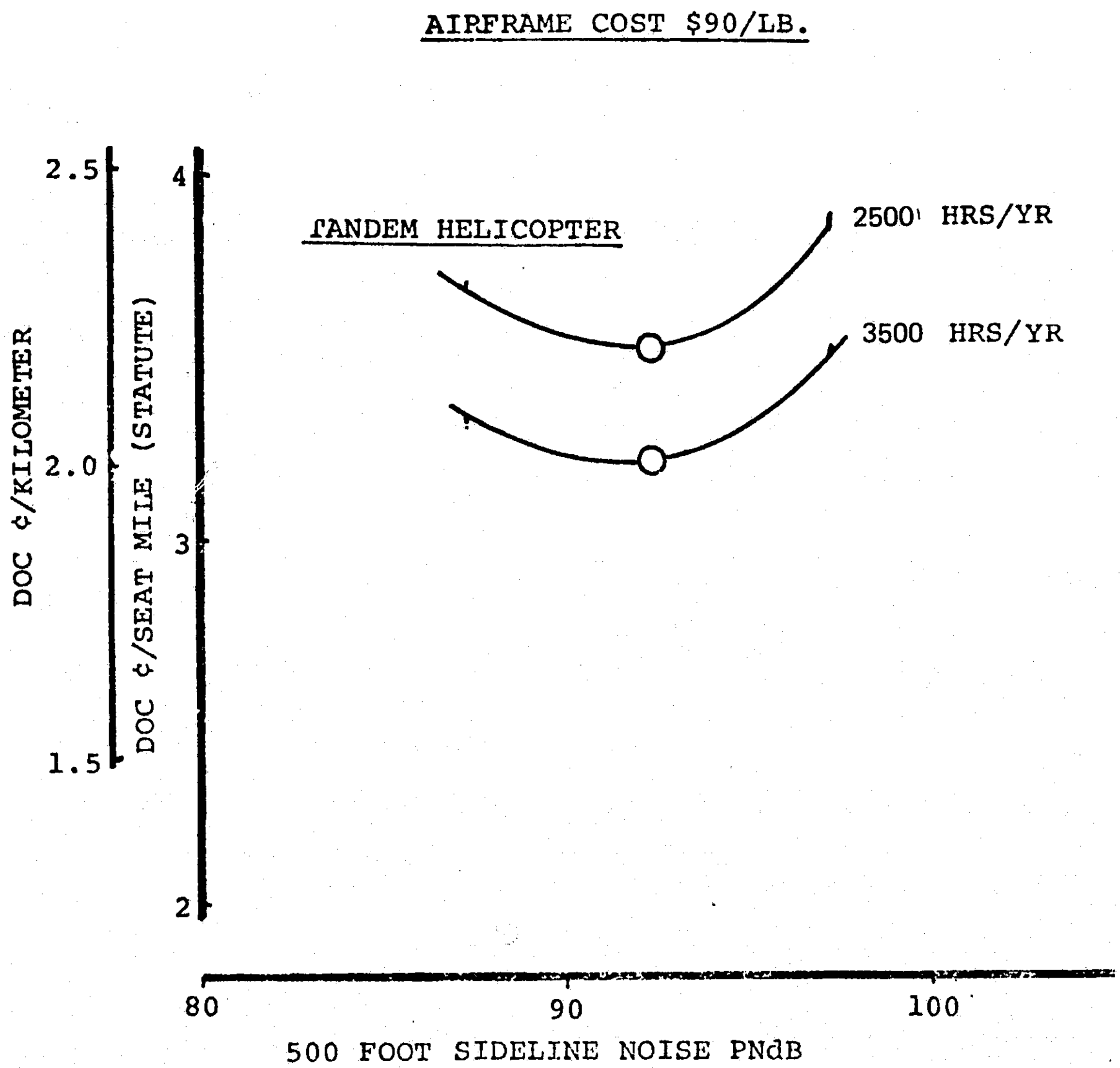


FIGURE 4.23 EFFECT OF EXTERNAL NOISE CRITERIA ON DOC AT 200 NAUTICAL MILES RANGE

Referring back to Figures 4.6 and 4.11 in Section 4.3.1, it can be seen that the minimum DOC vehicles always occur at moderate values of disc loading and tip speed. Therefore, it can be inferred that optimizing a helicopter for minimum DOC dictates a choice of moderate disc loadings and tip speeds which insures that the resulting vehicle falls below the 95PNdB level.

4.4.3 Selection of a Compromise Design Point Helicopter

Up to this point in the vehicle design evolution, the helicopters have been sized for either the Very Short Haul Mission or the Short Haul Mission. Obviously, a vehicle sized for the Short Haul Mission can also perform the Very Short Haul Mission at some alternate (lighter) takeoff gross weight.

Thus, at this point, it was decided to study a third helicopter configuration which was sized to perform the Short Haul Mission but was selected on its minimum DOC characteristics when operated on the Very Short Haul Mission. This was accomplished in the following manner.

First, each one of the configurations in the already sized matrix of helicopters of the Short Haul Mission disc loading - tip speed trade study (Figure 4.6) was operated on the Very Short Haul Mission at the (lower) alternate gross weights required to accomplish that particular mission scenario. From the resulting Very Short Haul Mission DOC data a disc loading - tip speed combination for each of the passenger capacities (50, 75, and 100) was selected on the basis of minimum DOC.

Note that the vehicles resulting from this choice are not resized vehicles, but are simply a different set of Short Haul helicopters selected by different ground rules (minimum VSH DOC's instead of minimum SH DOC's).

Since this particular set of helicopters are Short Haul helicopters chosen on the basis of Very Short Haul operational characteristics, they have been designated compromise design helicopters.

Table 4.4 lists the 50, 75, and 100 passenger VSH and SH design point helicopters and the 100 passenger compromise design helicopter. Note that the characteristics for the compromise design helicopter listed in this table are for the Short Haul Mission.

Note that the 100 passenger compromise design vehicle is superior in both EI and DOC characteristics to the corresponding 100 passenger Short Haul vehicle. This is simply a reflection of the relative flatness of the DOC curves near the minimum point and the difficulty of precisely picking the correct disc loading - tip speed combinations from data plots such as Figure 4.7.

Figure 4.24 illustrates the comparative values of EI for the S-61L and the VSH and SH design point helicopters. That the difference in the values of EI for the S-61L and the study helicopters is not greater is due, in large part, to the OEI hover requirement, which the S-61L is not required to meet.

Figure 4.25 shows the comparison between the EI's of the three 100 passenger design point vehicles.

TABLE 4.4 DESIGN POINT VEHICLE CHARACTERISTICS SUMMARY

MSN	PAX CAPAC	W/A	V_T	G/S	GW	D_{MR}	σ	F_e	SHP*	EI	DOC	FC
SH	50	7	708	.156	45102	64	.090	42.5	8459	6377	$.0808	$3,856,731
	75	7	712	.130	64297	76.5	.093	45.6	12011	5859	$.0653	$5,269,882
	100	7.75	715	.119	84207	83.2	.106	47.95	16666	5917	$.0581	$6,772,858
VSH	50	7.25	712	.165	41647	60.5	.088	40.9	7938	6550	$.1736	$3,656,672
	75	7.50	707	.139	60168	71.5	.100	44.12	11751	6175	$.1402	$5,077,112
	100	8	720	.127	77300	78.4	.104	46.01	15524	5998	$.1236	$6,363,188
COMPR	100	7	705	.113	84133	87.5	.100	47.93	15710	5612	$.0578	$6,754,787

*INSTALLED POWER

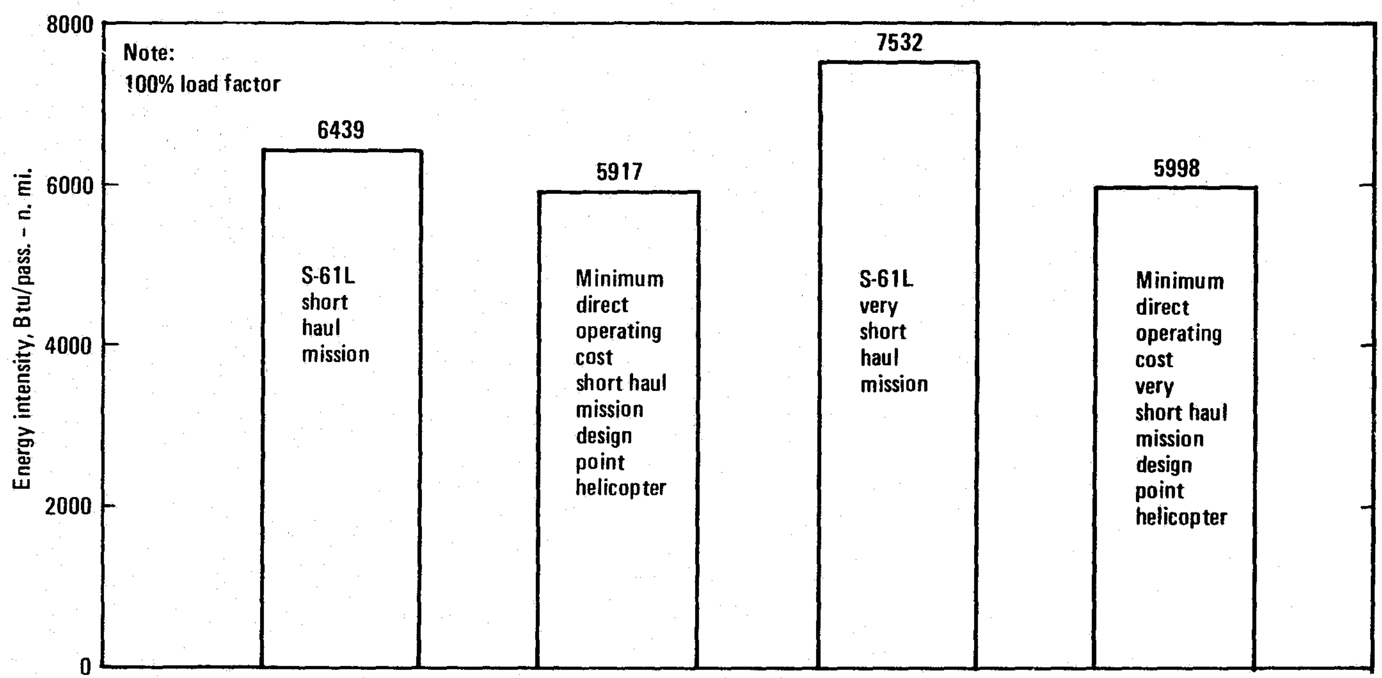


FIGURE 4.24 VEHICLE ENERGY INTENSITY COMPARISON S-61L AND DESIGN POINT VEHICLES

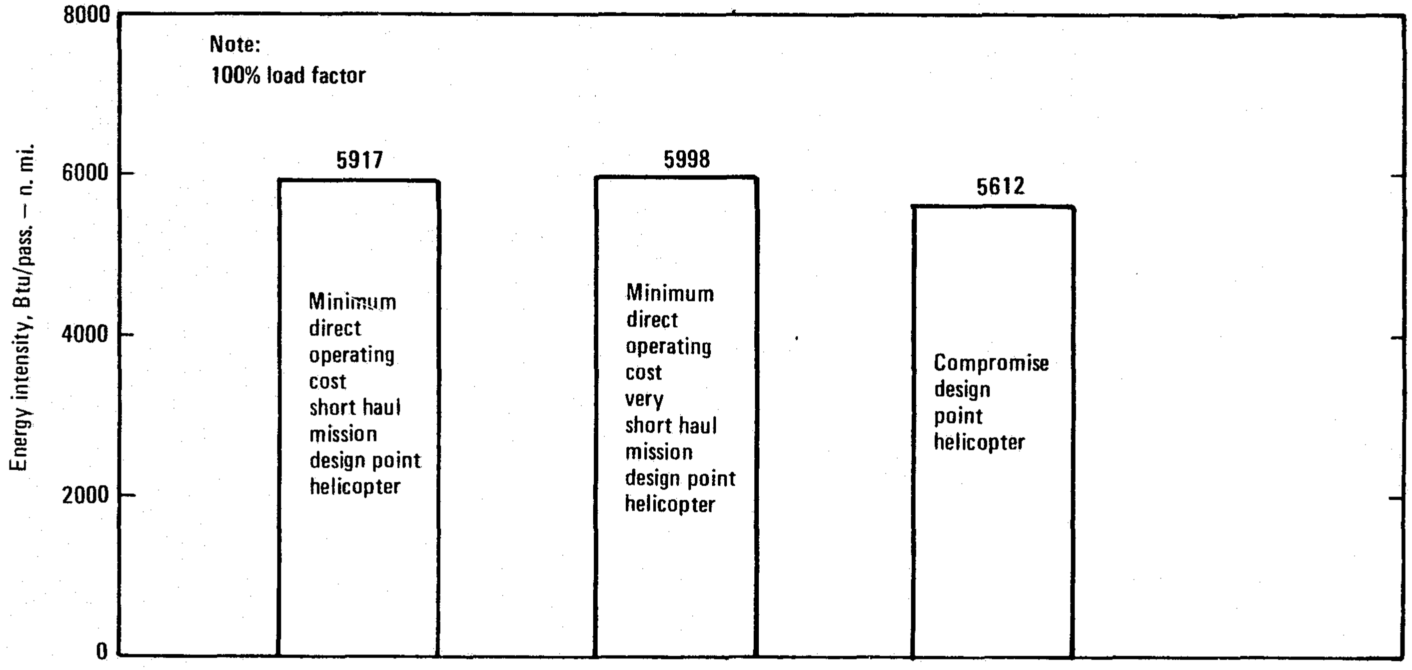


FIGURE 4.25 VEHICLE ENERGY INTENSITY COMPARISON 100 PASSENGER DESIGN POINT VEHICLES

The compromise helicopter is the more efficient approach since it results in one configuration capable of performing either the Short Haul or Very Short Haul missions. However, in order to illustrate the relative characteristics of two classes of helicopters (one capable of performing both missions, the other sized specifically for the air taxi mission), both a 100 passenger compromise design helicopter and a Very Short Haul Mission minimum DOC design point helicopter have been chosen for further study.

4.5 Design Point Helicopter Description

Tables 4.5, 4.6, 4.7 and 4.8 list, respectively, the major vehicle characteristics, weight breakdowns, initial and direct operating costs, and drag breakdowns of the selected VSH and Compromise design point vehicles. Figure 4.26 illustrates a comparison of the fuel consumption of some existing fixed and rotary-wing vehicles. Spotted on this data are the "mileage" figures for both the VSH and Compromise design points. Note that both vehicles are more efficient than most of the currently operating rotary-wing aircraft shown, reflecting the differences between the underlying technology base of these earlier designed vehicles and current technology. The one exception is the UTTAS helicopter, which, of course, utilizes the same technology as the design points. Figure 4.27 shows DOC vs range for the baseline tandem rotor helicopter of Reference 4. Note that the DOC values from Table 4.7, if superimposed on this data, follow the same trend, but at higher levels. The difference, of course, is that the data of Reference 4 represents a fully developed advanced technology helicopter, while the data of Table 4.7 represents helicopters designed with current technology.

4.6 Summary of Current Technology Levels Applied to the Design Point Helicopters

4.6.1 Vehicle Structural/Design Technology

The airframe and dynamic systems of the two design point vehicles are wholly conventional in their design. Table 4.9 lists their underlying design assumptions. The actual weight trends used in calculating subsystem weights are as defined in Reference 2. The values of the fixed equipment weights are as given in Table A-2, Appendix A.

4.6.2 Powerplant Technology

The powerplant utilized in this study is the AVCO Lycoming LTC4V-1. This engine is an outgrowth of the T-55L-11 and should be considered representative of current technology axial flow turboshaft engines in the 5000 to 10,000 SHP class. Its characteristics include an overall pressure ratio of 16, a maximum turbine inlet temperature (TIT) of 2660°R, a weight/power ratio of 0.15 lb/SHP (uninstalled), and a specific fuel consumption (SFC) of .42 lb/hp/hr (SL, 90°F takeoff rating). The installation factors applied include inlet and exhaust losses and a 1% compressor bleed for air conditioning and pressurization.

4.6.3 Rotor Performance Technology

The rotor employed in this study is of constant chord and has linear twist from cutout to tip. Airfoil thickness/chord ratio and camber vary along the blade span. The airfoil sections utilized are Boeing Vertol developed high speed (transonic) sections developed from the NACA

TABLE 4.5 CURRENT TECHNOLOGY (1975) DESIGN POINT HELICOPTER CHARACTERISTICS

	VERY SHORT HAUL MSN HELICOPTER	COMPROMISE DSN PT. HELICOPTER
WEIGHTS		
DESIGN GROSS WEIGHT	77,300 LB.	84,133 LB.
WEIGHT EMPTY	52,011 LB.	56,073 LB.
FUEL	5,346 LB.	8,117 LB.
NO. OF PASSENGERS	100	100
ROTOR		
DISC LOADING	8.0 PSF	7.0 PSF
DIAMETER	78.4 FT.	87.5 FT.
SOLIDITY	.104	.100
NO. OF BLADES	4	4
TWIST	-12 DEG.	-12 DEG.
TIP SPEED	720 FT/SEC	705 FT/SEC
POWER		
NO. OF ENGINES	3	3
RATED POWER (S.L.,STD)/ ENGINE	5175 SHP	5237 SHP
FUSELAGE		
LENGTH	88.2 FT.	88.2 FT.
WIDTH	12.92 FT.	12.92 FT.
ROTOR GAP/STAGGER	.127	.113
PERFORMANCE		
V_{NRP}	203.3 KTAS	200.8 KTAS
CRUISE ALTITUDE	500 FT.	2000 FT.
BLOCK SPEED	77.04 KTAS	136.6 KTAS
BLOCK TIME	1.298 HR.	1.464 HR.
FLIGHT TIME	0.724 HR.	1.064 HR.
ENERGY INTENSITY	5998 BTU/PASS-N.M.	5612 BTU/PASS-N.M.

TABLE 4.6
CURRENT TECHNOLOGY (1975)
DESIGN POINT HELICOPTER
WEIGHT BREAKDOWN

		VERY SHORT HAUL DESIGN POINT	COMPROMISE DESIGN POINT	
WING				
ROTOR		8624	10190	
TAIL				
SURFACES				
ROTOR				
BODY		10815	11174	
BASIC				
SECONDARY				
ALIGHTING GEAR GROUP		3092	3365	
ENGINE SECTION		708	716	
PROPULSION GROUP		11961	13074	
ENGINE INST'L		2360	2388	
EXHAUST SYSTEM		47	48	
COOLING				
CONTROLS		94	96	
STARTING		165	167	
PROPELLER INST'L				
LUBRICATING		24	24	
FUEL		369	560	
DRIVE		8902	9791	
FLIGHT CONTROLS		3455	4198	
AUX. POWER PLANT		940	940	
INSTRUMENTS		575	575	
HYDR. & PNEUMATIC		680	680	
ELECTRICAL GROUP		1230	1230	
AVIONICS GROUP		846	846	
ARMAMENT GROUP				
FURN. & EQUIP. GROUP		7535	7535	
ACCOM. FOR PERSON.				
MISC. EQUIPMENT				
FURNISHINGS				
EMERG. EQUIPMENT				
AIR CONDITIONING		1150	1150	
ANTI-ICING GROUP		400	400	
LOAD AND HANDLING GP.				
WEIGHT EMPTY		52011	56073	
CREW & Equip.		770	770	
TRAPPED LIQUIDS		115	115	
ENGINE OIL		132	132	
Emerg. Equip.		16	16	
Passenger Accom.		910	910	
Passengers		18000	18000	
FUEL		5346	8117	
GROSS WEIGHT		77300	84133	

REV.

TABLE 4.7 CURRENT TECHNOLOGY (1975) DESIGN POINT HELICOPTER INITIAL AND DIRECT OPERATING COSTS

VEHICLE (DESIGN POINT)	FLYAWAY COSTS	
	VSH MISSION	COMPROMISE (DESIGN POINT)
Airframe Cost	$100/Lb	$100/Lb
Airframe	$3,127,923	$3,285,814
Dynamic System	1,577,316	1,798,309
Engines	1,357,950	1,370,664
Avionics	300,000	300,000
Total	$6,363,188	$6,754,787

VEHICLE (DESIGN POINT)	DIRECT OPERATING COSTS (DOLLARS/SEAT-MILE)	
	VSH MISSION	COMPROMISE (DESIGN POINT)
Block Distance	115.16 S.M.	230.31 S.M.
Flying Operations		
Flight Crew	.021411	.01208
Fuel and Oil	.010838	.01012
Hull Insurance	.004781	.00286
Total Flying Operations	.037030	.02505
Direct Maintenance		
Airframe - Labor	.011553	.00223
Material	.007439	.00139
Engines - Labor	.003576	.000997
- Material	.007641	.001866
Dynamic System -		
Labor	.002912	.002095
Material	.003001	.002151
Total Direct Maintenace	.036123	.010728
Maintenance Burden	.027062	.007986
Total Maintenance	.063184	.018713
Depreciation	.023390	.013992
Total Direct Costs	.123604	.057758
3000 HR/YEAR UTILIZATION		

TABLE 4.8 CURRENT TECHNOLOGY (1975) DESIGN POINT TANDEM HELICOPTER DRAG BREAKDOWN

DESIGN POINT	VERY SHORT HAUL MISSION	COMPROMISE DESIGN POINT
ITEM	DRAG AREA F_e-Ft^2	DRAG AREA F_e-Ft^2
Fuselage	8.886	8.886
Forward Pylon	2.884	2.884
Aft Pylon	3.0609	3.0609
Nacelles	1.4618	1.4618
Miscellaneous		
Oil Cooler Momentum Loss	0.3	0.3
Air Conditioning	0.5	0.5
Trim	0.09	0.09
Sub Total	17.183	17.183
Rotor Hubs	28.83	30.75
TOTAL DRAG AREA	46.01	47.93
Drag Loading $\frac{GW}{Fe}$	$\frac{77300}{46.01} = 1680$ lb/ft^2	$\frac{84133}{47.93} = 1755$ lb/ft^2

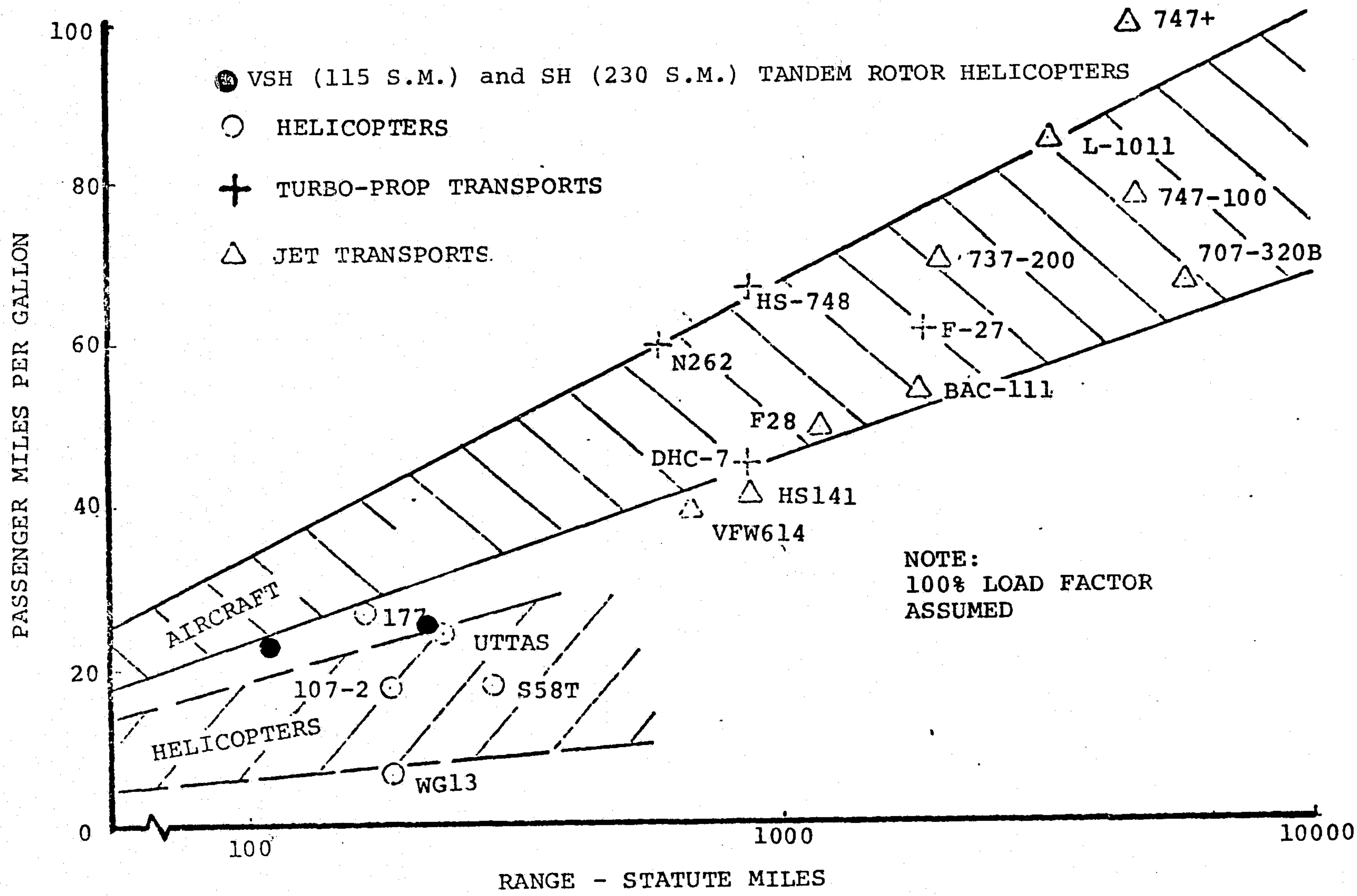


FIGURE 4.26 SUMMARY PLOT — FUEL CONSUMPTION COMPARISON OF EXISTING FIXED AND ROTARY—WING AIRCRAFT

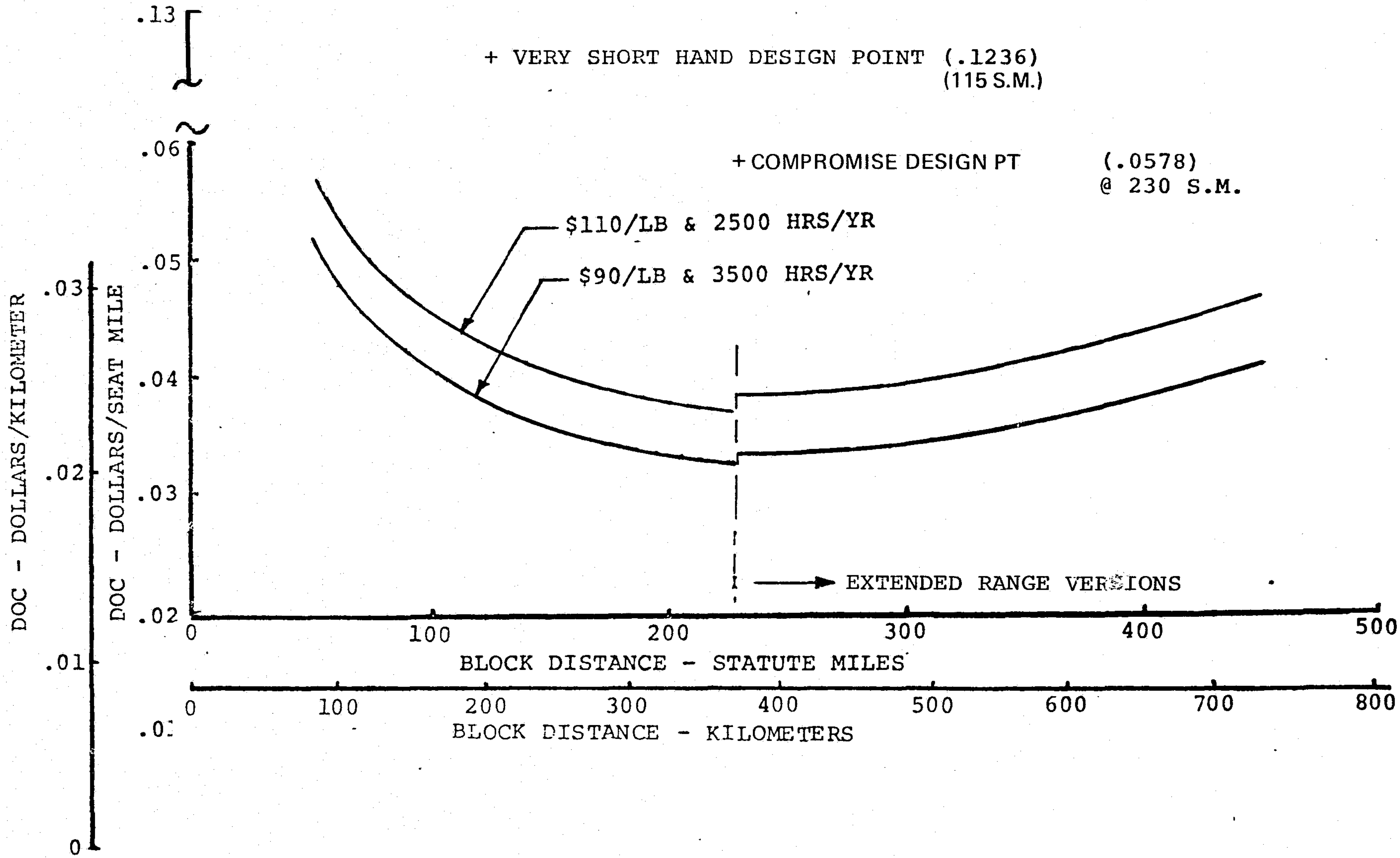


FIGURE 4.27 DIRECT OPERATING COST AS A FUNCTION OF RANGE

TABLE 4.9 CURRENT TECHNOLOGY (1975) HELICOPTER ASSUMED MATERIAL AND STRUCTURAL DESIGN PRACTICES

VEHICLE COMPONENT	MATERIAL/STRUCTURAL DESIGN PRACTICES
VERTICAL TAIL	ALUMINUM SHEET AND EXTENSIONS
ROTORS	TITANIUM AND FIBERGLASS
BODY	ALUMINUM BEAMS, SKIN, STRINGERS AND FRAMES
LANDING GEAR	STEEL
FLIGHT CONTROLS	CONVENTIONAL MECHANICAL SYSTEM
ENGINE SECTION	ALUMINUM SHEET
DRIVE SYSTEM MAIN BOXES	CONVENTIONAL
DRIVE SYSTEM OTHER BOXES	CONVENTIONAL
SHAFTING	CONVENTIONAL, ALUMINUM

6-series airfoils, and optimized for maximum lift and low pitching moment. Rotor performance characteristics are a hover efficiency (F.M.) of approximately 75%, a maximum L/DE of approximately 8 and an L/D_E cruise (at 200 KTAS) of approximately 6. Specific values for these parameters are listed for each of the design point vehicles in Table 5.1. Rotor stall flutter limits are as specified in Figure A-1, Appendix A.

4.6.4 Parasite Drag Technology

Figure 4.28 is a plot of parasite drag loading versus gross weight. For reference, the drag value of the YUH-61A (UTTAS) helicopter is spotted on the data. The difference in drag trend level between the UTTAS point and tne trend employed in this study (1975 technology tandem helicopters drag trend) reflects the difference between fixed and retractable landing gear.

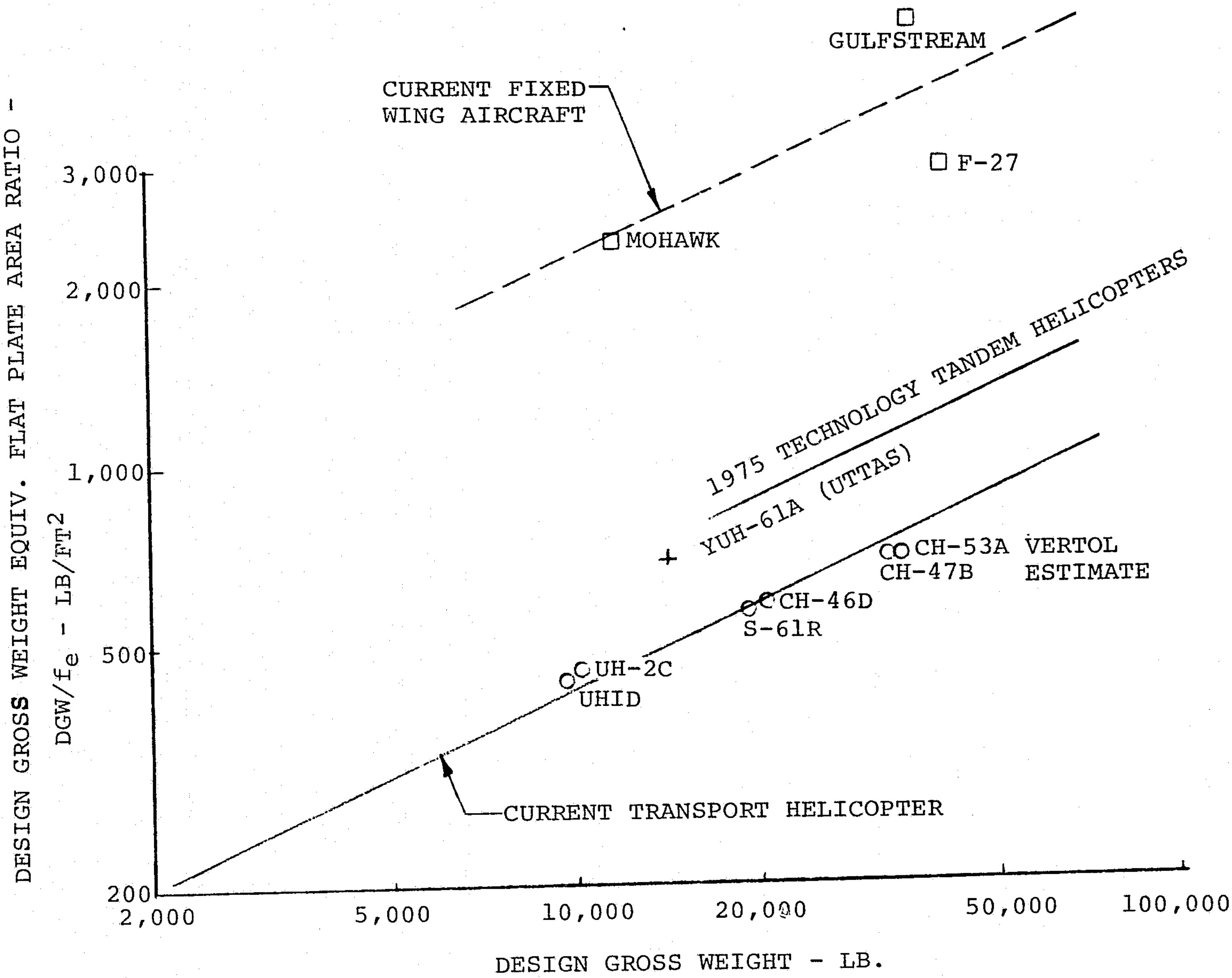


FIGURE 4.28 CURRENT TECHNOLOGY PARASITE DRAG LEVEL

5.0 RESIZING OF DESIGN POINT VEHICLES USING ADVANCED TECHNOLOGIES

5.1 Advanced Technology Resizing Data Format

As noted in Section 4.4, the design points chosen for resizing by application of advanced technologies are the 100 passenger Very Short Haul Mission and Compromise design point helicopters. Each of these vehicles was resized by allowing only one parameter at a time to be varied. Figure 5.1 is a diagrammatic representation of the typical format employed in presenting the resulting matrix of design point vehicle characteristics (in this case, percentage reductions in vehicle EI). Note the variety of combinations of independent variables whose effect on the dependent variable can be assessed. For example, if Point A is assumed to be a baseline design point, movement from Point A to Point B demonstrates the effect on EI of a 10% reduction in vehicle structural empty/gross weight. Continued movement to Point D shows the further effect of a 5% reduction in fuel flow.

5.2 Parameter Variation

The parameters (and their variation) utilized in this study are as follows:

Parasite Drag	- 0, 25, 50% Reduction
Fuel Consumption	- 0, 5, 10% Reduction
Structural Empty/ Gross Weight Ratio	- 0, 5, 10, 15% Reduction
Rotor Hover Efficiency (F.M.)	- 0, 5, 10, 15% Increase
Rotor Cruise Efficiency (L/D_E)	- 0, 10, 20% Increase

The parametric value levels assumed for this study are for the purpose of defining the sensitivity of energy consumption—and should not necessarily be assumed to be attainable. The actual technology levels estimated to be attainable are defined in Section 6.0.

5.3 Parameter Definitions

5.3.1 Parasite Drag

Parasite drag is the total configuration drag (including rotor hub(s)) which must be overcome by the helicopter in forward flight. As used in this study, it is expressed as equivalent parasite drag area (drag/dynamic pressure), or F_e, whose units are square feet. Values of the baseline vehicle parasite drags are given in Tables 4.8 and 5.1.

5.3.2 Fuel Consumptions

No attempt is made to reflect fuel consumption reductions due to improvement in specific fuel consumptions only over a limited range of power settings (i.e., a modification of SFC vs. power characteristics). Rather it is assumed that SFC is reduced over the entire operating range of the engine. For example, a 5% reduction in fuel consumption (compared to the baseline vehicles) refers to an across the board reduction of 5% in engine SFC.

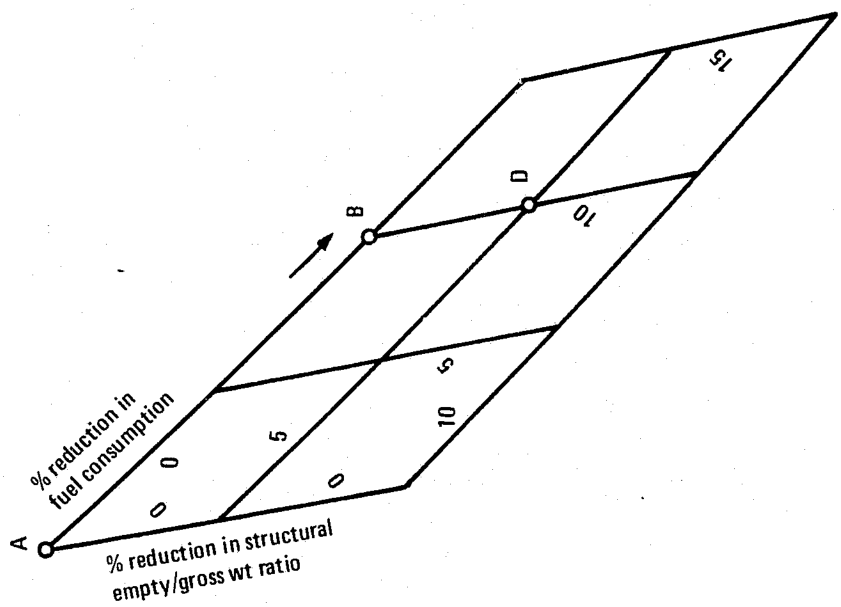


FIGURE 5.1 ENERGY INTENSITY DATA PLOT FORMAT

5.3.3 Structural Empty/Gross Weight Ratio

Structural empty weight is defined as empty weight minus the fixed equipment weight. For example, the structural empty weight of the compromise design point helicopter is 56,073 lb -13,356 lb = 42,717 lb. For comparisons of vehicle weight reductions due to materials/structures technology improvements, structural empty weight is a more meaningful parameter than total empty weight, since it is freed of the obscuring effect of fixed equipment weight, which itself is only a function of the design mission. Likewise, percentage reductions in the structural empty/gross weight ratio are a more meaningful means of evaluating materials/structures technology improvements than percentage reductions in empty weight, since the structural empty/gross weight ratio automatically reflects the iterative scaling effect of empty weight reduction on gross weight in the sizing process. Therefore, all the empty weight reductions presented will be in terms of percentage reductions in structural empty/gross weight.

5.3.4 Rotor Hover Efficiency

Hover efficiency or F.M. is a measure of a rotor's efficiency in converting power into static (hover) thrust. The F.M.'s referred to in this study are the design point condition (SL, 90°F) values used in configuration engine sizing. Note that the percentage improvement in F.M. referred to in Section 5.2 is not a ΔF.M. to be added to the baseline F.M., but is a percentage change of that baseline value. For example, a 10% improvement to a baseline F.M. of .75 is .75 + .075 = .825, not .75 + .10 = .85.

5.3.5 Rotor Cruise Efficiency

Rotor cruise efficiency, or L/D_E, is a measure of a rotor's efficiency in producing lift while overcoming its own equivalent drag. The L/D_E's varied in this study are the cruise L/D_E's occurring at the vehicle normal rated power speed. As such, they are lower than the rotor's maximum L/D_E value which occurs at a lower speed.

It should also be noted that these are isolated rotor L/D_E's. This is of interest since inherently a tandem rotor configuration suffers from mutual rotor interference effects (reduced to some extent by decreasing rotor overlap), which results in a lowering of the overall L/D_E for both rotors. Percentage improvements in L/D_E are defined in the same manner as for F.M. in Section 5.3.4.

5.4 Baseline Vehicle Characteristics

Table 5.1 summarizes the major vehicle characteristics of the baseline vehicles and their reduced parasite drag derivatives. Table 5.2 provides a summary of the baseline values of rotor hover efficiency (F.M.), rotor cruise efficiency (L/D_E), vehicle structural empty weight fraction, and normal rated power speed for these vehicles. These tables also present somewhat of an anamoly in that the vehicles with reduced parasite drag levels are heavier and exhibit a reduction in EI substantially less than would be expected for the decrease in parasite drag level shown. The explanation, however, is simple. As briefly noted in section 4.4.1, there is a groundrule requirement for all vehicles to be rotor limit/cruise power matched. Now, initially when the baseline design point vehicles were resized to reduced parasite drag levels, it was found that the resulting vehicles were lighter and had reduced values of EI. However, it was noted that because of the

TABLE 5.1 SUMMARY OF MAJOR VEHICLE CHARACTERISTICS CURRENT TECHNOLOGY DESIGN POINT VEHICLES AND THEIR REDUCED PARASITE DRAG DERIVATIVES

DESIGN POINT VEHICLES	LOADING PSF	ROTOR TIP SPEED FPS	ROTOR GAP/ STAGGER RATIO	GROSS WEIGHT LB	ROTOR DIAMETER FT	ROTOR SOLIDITY	F_e FT^2	INSTALLED POWER SHP	ENERGY INTENSITY BTU/ PASS. N.M.	OPERATING COST $/S.MILE	FLYAWAY COST $
Compromise (0% Reduction in F_e)	7	705	.113	84133	87.5	.100	47.93	15710	5612	.0578	6,754,787
Compromise (25% Reduction in F_e)	7	705	.113	84507	87.7	.103	36.02	15864	5547	.0571	6,809,659
Compromise (50% Reduction in F_e)	7	705	.113	84702	87.8	.106	24.04	15970	5456	.0564	6,847,939
Very Short Haul Msn (0% Reduction in F_e)	8	720	.127	77300	78.4	.104	46.01	15524	5998	.1236	6,363,188
Very Short Haul Msn (25% Reduction in F_e)	8	720	.126	77604	78.6	.108	34.57	15661	5890	.1220	6,408,248
Very Short Haul Msn (50% Reduction in F_e)	8	720	.126	77803	78.7	.111	23.08	15770	5748	.1202	6,444,674

TABLE 5.2 SUMMARY OF PERFORMANCE CHARACTERISTICS CURRENT TECHNOLOGY DESIGN POINT VEHICLES AND THEIR REDUCED PARASITE DRAG DERIVATIVES

DESIGN POINT VEHICLE	GROSS WEIGHT (LB)	STRUCTURAL EW/GW	ROTOR SOLIDITY	F_e (FT^2)	DESIGN FIGURE OF MERIT	ROTOR L/D_e @ V_{NRP}	V_{NRP} (KTAS)
Compromise (0% Red. in F_e)	84133	.508	.100	47.93	.749	5.95	200.8
Compromise (25% Red. in F_e)	84507	.511	.103	36.02	.746	5.50	206.6
Compromise (50% Red. in F_e)	84702	.514	.106	24.04	.743	5.20	211.2
Very Short Haul Mission (0% Red. in F_e)	77300	.500	.104	46.01	.745	5.55	203.3
Very Short Haul Mission (25% Red. in F_e)	77604	.503	.108	34.57	.741	5.25	208.1
Very Short Haul Mission (50% Red. in F_e)	77803	.506	.111	23.08	.739	4.75	215.4

reduced parasite drag power requirements, rotor limits were encountered before the NRP cruise speed was attained.

As noted in section 4.4.1, strict adherence to the study groundrules therefore dictated an increase in rotor solidity to allow matching of the rotor limit cruise speeds and NRP cruise speeds. However, the increase in solidity resulted in an increase in the rotor and rotor system weights plus a degradation in hover performance resulting in more engine growth—all contributing to a net increase in the design gross weight of the vehicle and a subsequent reduction in the relative EI savings realized.

5.5 Data Utilization and Interpretation

This data is meant to be used in determining the effect of various technology improvements on the energy consumption, gross weight, and developmental and operating costs of a tandem rotor commercial helicopter. Used in conjunction with a given set of technology improvement estimates and the baseline vehicle data of Tables 5.1 and 5.2, the data enables a quick, accurate estimate of the size, energy usage, and cost of such a vehicle.

It should be noted that although this study was performed assuming a tandem rotor configuration, the overall trends of EI, gross weight, and DOC obtained are just as applicable to single rotor helicopter configurations.

For example, although the single rotor helicopter does not suffer a rotor interference power penalty in cruise flight, it does have a tail rotor power increment to consider. Thus, comparing single and tandem rotor vehicles of equal capabilities, the power required characteristics are almost identical (and so are the EI's).

Now, the major component of the vehicle empty weight which reflects configuration differences is the propulsion system. Although a single rotor helicopter has only one main rotor (compared to the two of the tandem), it also has the smaller tail rotor which operates at a different RPM than the main rotor, necessitating extra gear reduction boxes, etc. Thus, the total propulsion system weights of comparable tandem and single rotor helicopters are very close, considering all configuration differences. Obviously this results in very similar values of structural/empty gross weight for both configurations.

Since EI (or mission fuel consumed) and the structural empty/gross weight ratio (and ultimately gross weight) do not differ greatly for comparable vehicles of either configurations it can be inferred that the same applies to DOC, which depends strongly on both mission fuel consumed and vehicle gross weight. Thus, although the points for minimum DOC and EI operation of a single rotor helicopter may occur at different combinations of top speed and disc loading than those for a tandem rotor helicopter, the minimum points themselves will be at the same level.

Consider Table 5.3. The values shown are the projected technology improvements attainable by 1985 (see Section 6.0) and the values of energy intensity reduction realized for the compromise design point helicopter assuming each technology improvement is individually obtained. As illustrated in Figure 5.1, the determination of the energy intensity reduction, based on the variation of one parameter at a time, is simply a matter of "sliding" along the applicable data plot.

TABLE 5.3 PROJECTED TECHNOLOGY IMPROVEMENTS AND THEIR EFFECT ON ENERGY INTENSITY

Technology Improvement	% Reduction in Energy Intensity
4.76% reduction in SFC	5.8%
9.3% increase in F.M.	9.2%
20% increase in L/DE	6.5%
54% reduction in parasite drag	3.1%
12.1% reduction in structural EW/GW	12.5%

At times, data interpolation is required, since each data plot is for a given combination of parasite drag reduction and rotor figure of merit improvement. For example, the figure of merit improvement projected by 1985 is 9.3%. Determination of the corresponding energy intensity reduction requires that data be read from Figures B-1, B-2 and B-4, Appendix B (figure of merit improvements = 0, 5 and 10%, parasite drag reductions = 0%), assuming zero change in the other parameters (EW/GW, fuel consumption, and L/D_E), and cross plotted.

More extensive interpolation and cross plotting is needed if the effect of the simultaneous variation of several parameters on energy intensity is to be obtained. For example, determination of the energy intensity reduction resulting from the combined effect of all the technology improvements listed in Table 5.3 is as follows:

(1) Data is read from Figures B-1, B-2 and B-3 for values of fuel consumption reduction, EW/GW reduction, and L/D_E improvement of 4.76, 12.1 and 20%, respectively. The resulting percentage energy intensity reductions are plotted versus figure of merit improvement and the percentage energy intensity reduction for a figure of merit improvement of 9.3% determined.

(2) The procedure of (1) is repeated for parasite drag reductions of 25 and 50% using Figures B-5, B-6, B-7, B-9, B-10 and B-11.

(3) The resulting values of percentage energy intensity reduction are plotted versus parasite drag reduction and the value of energy intensity reduction for a 54% reduction in parasite drag read off.

It is <u>very important</u> to note that the effect of combined parameter variation on the data of this study is not obtainable by simple addition of the individual components. For example, summation of the individual energy intensity reductions listed in Table 5.3 results in a total value of 37.1% compared to the actual value of 30.35% obtained by the interpolation process discussed above.

Inspection of the data reveals that, comparatively speaking, the largest decreases in energy intensity are obtained when the structural empty/gross weight ratio is reduced and the rotor hover efficiency is improved. The former is due to the beneficial influence that reducing the structural empty weight fraction has on the vehicle sizing process itself. The latter is simply a manifestation of improved fuel consumption due to the smaller sized engines dictated by the higher figure of merit.

5.6 Data Presentation

The technology improvement resizing data, contained in Appendix B, is grouped in the following manner:

Energy Intensity (Compromise Design)	Figure B-1 → B-12
Gross Weight (Compromise Design)	Figure B-13 → B-24
Direct Operating Cost (Compromise Design)	Figure B-25 → B-36
Flyaway Cost (Compromise Design)	Figure B-37 → B-48
Energy Intensity (Very Short Haul Mission)	Figure B-49 → B-60

Gross Weight (Very Short Haul Mission)	Figure B-61 → B-72
Direct Operating Cost (Very Short Haul Mission)	Figure B-73 → B-84
Flyaway Cost (Very Short Haul Mission)	Figure B-85 → B-96

6.0 PROJECTION OF HELICOPTER TECHNOLOGY TRENDS

In this section, the salient helicopter technologies which impact energy consumption are identified. The current state of the art for each is given and then improvements are projected as a function of time to the 1985 time frame. The actions needed to achieve the projected levels and the resources required are then quantified.

For the purpose of this study, the resources consist of the estimated research, development and test dollars required to develop each technology to the point where it could be applied to civil helicopter applications. Production tooling, engineering and other production related costs are not considered. It should be noted, however, that the production costs could significantly increase total development costs. Estimation of production costs was beyond the scope of this study since they depend strongly on production quantities and individual contractors facilities. The areas which are discussed are generally applicable to both single and tandem rotor helicopters, although they will be applied only to the tandem rotor helicopters discussed in previous sections.

Powerplant improvements, increased rotor efficiency, improved materials and reduced parasite drag levels have the potential for reducing energy consumption. These technology improvements will enhance the helicopter's capabilities to perform the specified missions. The technology projections presented form the basis for determining the most cost effective mix of advanced technology for reducing energy consumption.

6.1 Powerplant Improvements

Technology advances in turboshaft engines are directed toward achieving lower engine SFC and weight. The primary factor driving reduced to .42 lb/hp-hr. Typically, these engines operate at turbine inlet temperatures of approximately 2200°F with pressure ratios between 12 and 16. For example, the Allison T701 derivative engine developed for the Heavy Lift Helicopter has a pressure ratio of 12.8 and a turbine inlet temperature of 2240°F operating at military power. Because this engine was optimized to operate at 50% part power, its SFC was increased to .47 lb/hp-hr. If it had been optimized for rated power, the SFC would have been reduced to .43 .b/hp-hr. The Lycoming LTC4V-1 engine, under development since 1967 has a design pressure ratio of 16 and a trubine inlet temperature of 2200°F. It has achieved an SFC of .425 lb/hp-hr. Currently, there is no active development program for this engine.

For this study, two engine concepts have been examined to determine which concept has the greatest potential for reduced SFC for the 1985 time frame. The two concepts are the conventional turboshaft engine operating at higher design pressure ratios and turbine inlet temperatures and the second is a regenerative turboshaft engine. The advanced conventional turboshaft engine was selected because the technology is available and the regenerative engine concept was chosen because it offers reduced SFC, both at design power rating and at part powers. This feature could be important for some mission applications.

Figure 6.1 shows the trend of engine SFC with time for conventional turboshaft engines and for regenerative engines. For the conventional turboshaft engine, an SFC of 0.4 can be reached by the late 1980's. The improvement in SFC is accomplished principally by increasing compressor design pressure ratio and turbine inlet temperature. For the regenerative engine concept, the

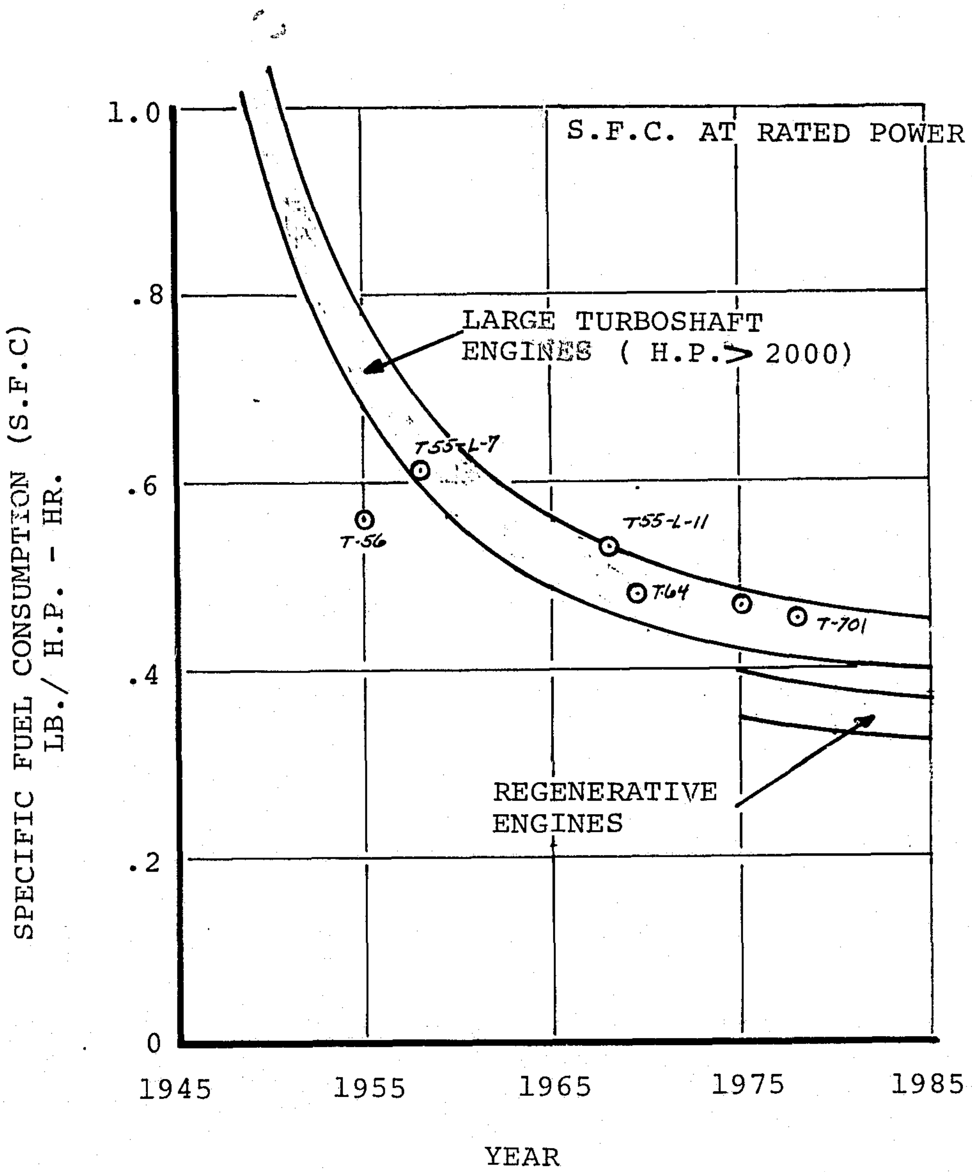


FIGURE 6.1 PROJECTED IMPROVEMENTS IN GAS TURBINE FUEL CONSUMPTION

figure shows a potential SFC of .36 lb/hp-hr. This is accomplished by the addition of a heat exchanger between the engine exhaust gas and the compressor exit airflow which improves the thermal efficiency of the engine by recovering some of the heat energy normally lost in the exhaust.

6.1.1 Conventional Turboshaft Engine Concepts

Figure 6.2 shows the design point performance relationships for the conventional turboshaft engine. The figure shows higher turbine inlet temperature and compressor pressure ratios result in decreased fuel consumption. It is expected that increases in compressor component capability will decrease the number of stages required to obtain a desired overall pressure ratio and higher turbine inlet temperatures can be achieved with air-cooled nozzle vanes, turbine blades, and disks. For the 1985 time frame, overall compressor pressure ratios between 16 and 20 and turbine inlet temperatures between 2400°F and 2500°F should be attainable. This is shown on the figure. Also shown on the figure is today's technology. It should be noted from Figure 6.2 that further reductions in conventional turboshaft SFC can only be achieved by extremely large changes in pressure or temperature — well beyond the projected state of the art.

Although Figure 6.2 is for design-point performance, it is useful also to indicate part-power performance of an engine (indicated by the dash line). Lower compressor pressure ratio and turbine-inlet temperature at part-power result in higher SFC than the design point. The trend in advanced-technology engines is to optimize the output shaft speed at a part-power condition, and minimize the penalty associated with nonoptimum free turbine speed.

6.1.2 Regenerative Engine Concepts

The conventional turboshaft engine dissipates a large proportion of the input fuel energy as exhaust heat. The regenerative turboshaft engine uses a heat exchanger to recover much of the energy normally lost in the exhaust gases. The addition of a heat excahnger between the engine exhaust gas and the compressor exit air improves the thermal efficiency of the engine by recovering some of this energy, transferring heat to compressor discharge air, and reducing the amount of fuel required by the combustor to achieve desired turbine-inlet temperatures. The result is an improvement in the SFC of the regenerative engine compared to the conventional turboshaft engine.

The design-point SFC of the regenerative engine is lower than that of the conventional engine, but even more significant than the improvement in design-point performance is the further improvement in SFC at part-power conditions.

Figure 6.3 illustrates design-point performance trends for conventional and regenerative turboshaft engines for a given level of component technology, and shows the improvement in SFC as a function of compressor pressure ratio. The 2500°F turbine-inlet temperature is projected for the 1985 time period.

The major characteristic of the regenerative engine is that the SFC optimizes at a relatively low pressure ratio. The relatively low pressure ratio results in a simpler compressor design with fewer stages required.

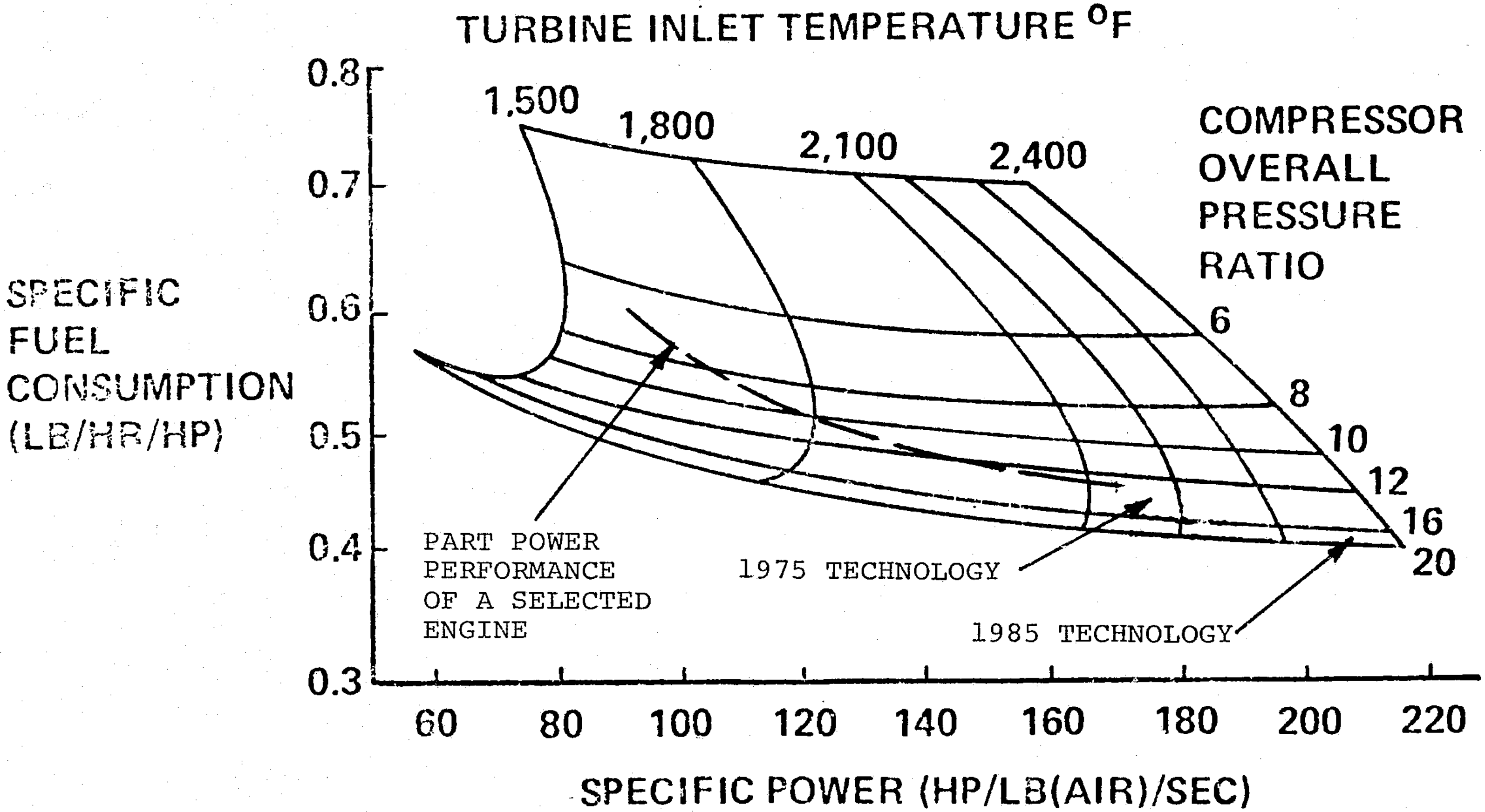


FIGURE 6.2 TURBOSHAFT ENGINE DESIGN POINT PERFORMANCE TRENDS

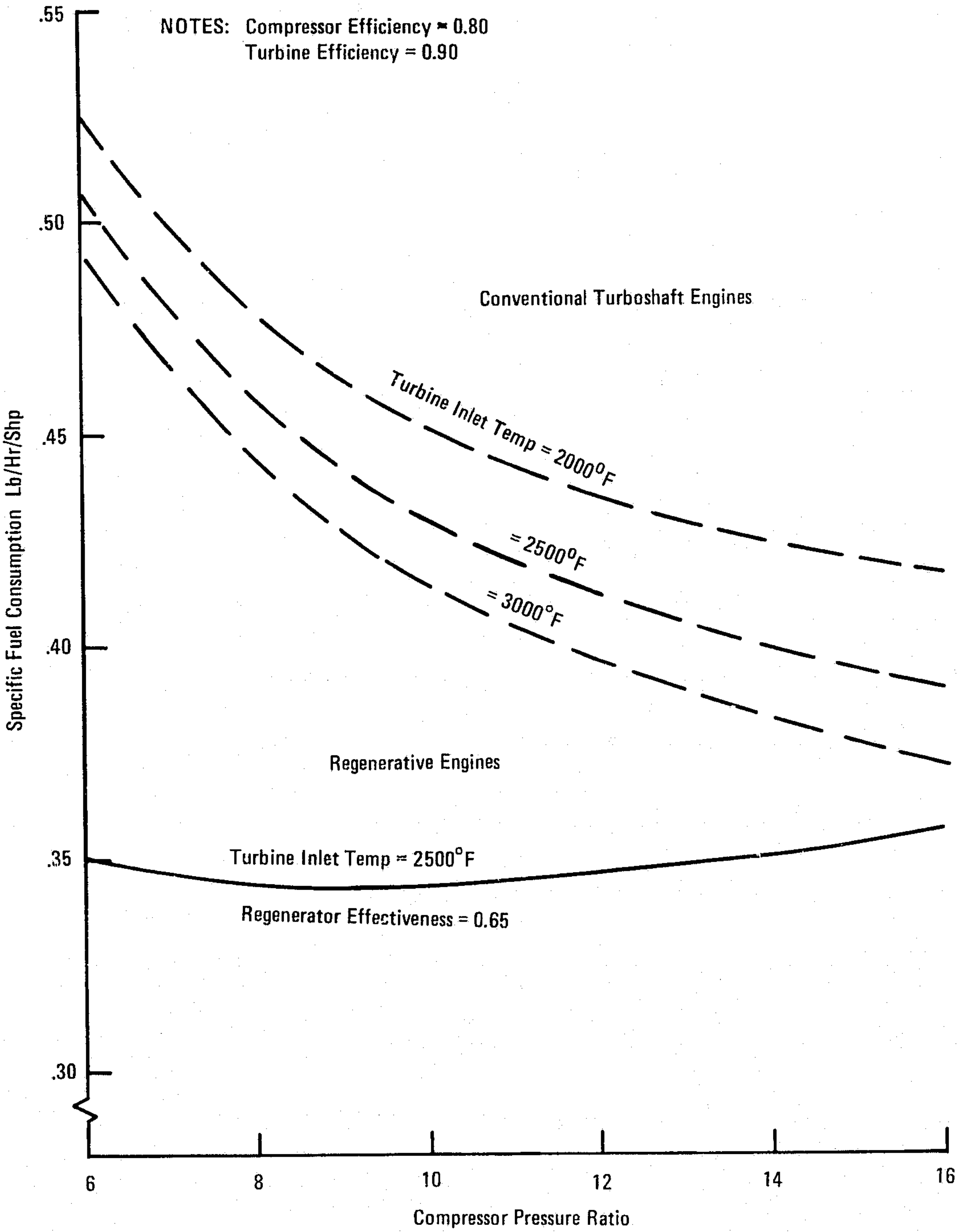


FIGURE 6.3 DESIGN POINT PERFORMANCE FOR CONVENTIONAL AND REGENRATIVE ENGINES

Although Figure 6.3 presents design-point performance, it is representative of off-design performance as well. The regenerative engine trend curves illustrate the advantage of maintaining a high turbine-inlet temperature down to part-power operation. Part-power operation at a constant high turbine inlet temperature requires variable flow characteristics for the turbine and variable turbine stator vanes are necessary. Variable power turbine stator vanes permit engine part-power operation at design turbine temperature and result in a flat SFC characteristic over most of the operating range. Figure 6.4 (from Reference 5) illustrates the SFC characteristics that can be anticipated for a hypothetical variable geometry engine with a design compressor ratio of 10.

6.1.3 Development Costs

Estimated engine development costs as a function of shaft horsepower were presented in Reference 6 as a function of rated horsepower. They were originally developed by the RAND Corporation (Reference 7) and updated by Boeing. They included the research and development, military qualification testing and production tooling costs. Estimated production tooling costs were substracted. Fiugre 6.5 shows the estimated development costs for conventional and regenerative engines. They included initial contractor preliminary design, engineering, prototype tooling, material, fabrication, assembly and bench testing, and a 50 hour endurance test. At this point the engine could be used for prototype anf flight testing. Regenerative engines are 20% higher than conventional turboshaft engines. This increase reflects the increased costs associated with developing the regenerator, since the costs would be the same. If a new advanced engine of approximately 5000 horsepower, with reduced SFC were to be developed for the 1985 time frame, Figure 6.5 shows the development cost for a conventional turboshaft engine to be 61 million dollars and a regenerative engine to be 73 million dollars. The development time required is typically 4 years.

6.2 Improved Rotor Efficiency

Rotor efficiency is measured by Figure of Merit for the static condition and the ratio of lift to effective drag (L/D_E) in cruise flight. In this section, both Figure of Merit and cruise (L/D_E) are discussed.

6.2.1 Improvement in Rotor Figure of Merit

During the first thirty years after the first successful helicopter flights in the 1930's, Figure of Merit had only increased from the high 60%'s to the low 70%'s. But in the last few years, motivated by the U.S. Army to develop the lifting capability of cargo carrying helicopters, the slope of Figure of Merit improvement versus time has been increasing. A Figure of Merit of 75% has been demonstrated on a whirl tower for an HLH rotor. This is by no means the maximum obtainable, and figures of merit of 83% can be achieved by the mid 1980's.

The two major components of Figure of Merit which have to be improved are the induced and profile powers. The induced power is the theoretical power used to generate lift in the absence of any airfoil profile drag. Momentum theory shows that the induced drag is minimized when a uniform distribution of perpendicular induced or downwash velocity is ahcieved through the rotor. Increasing the number of blades and/or having nonlinear values of twist result in more uniform induced velocities with the associated increase in Figure of Merit.

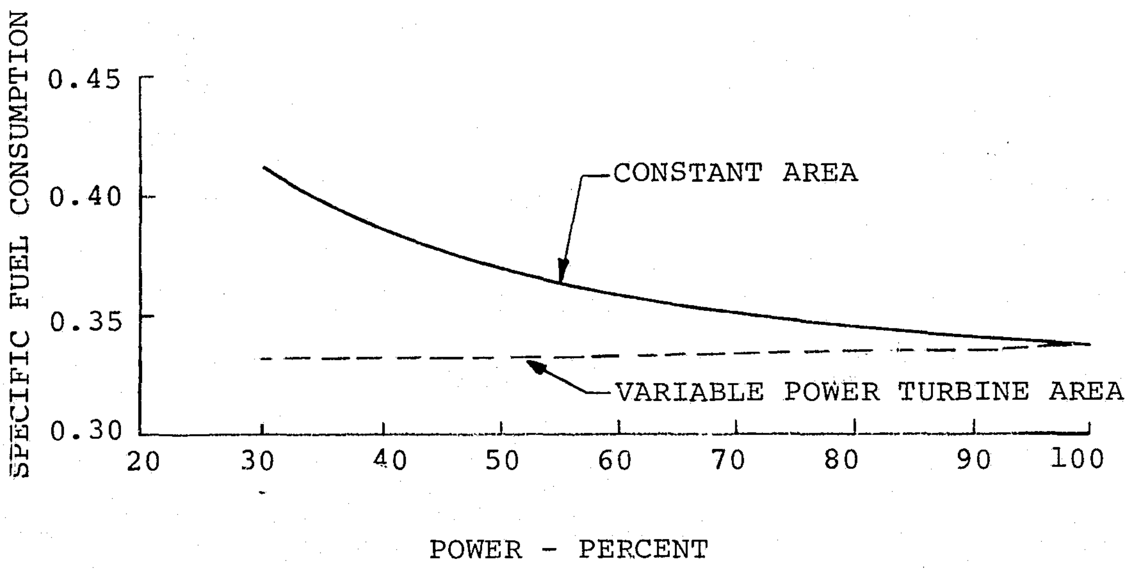


FIGURE 6.4 SPECIFIC FUEL CONSUMPTION AS A FUNCTION OF PERCENT POWER

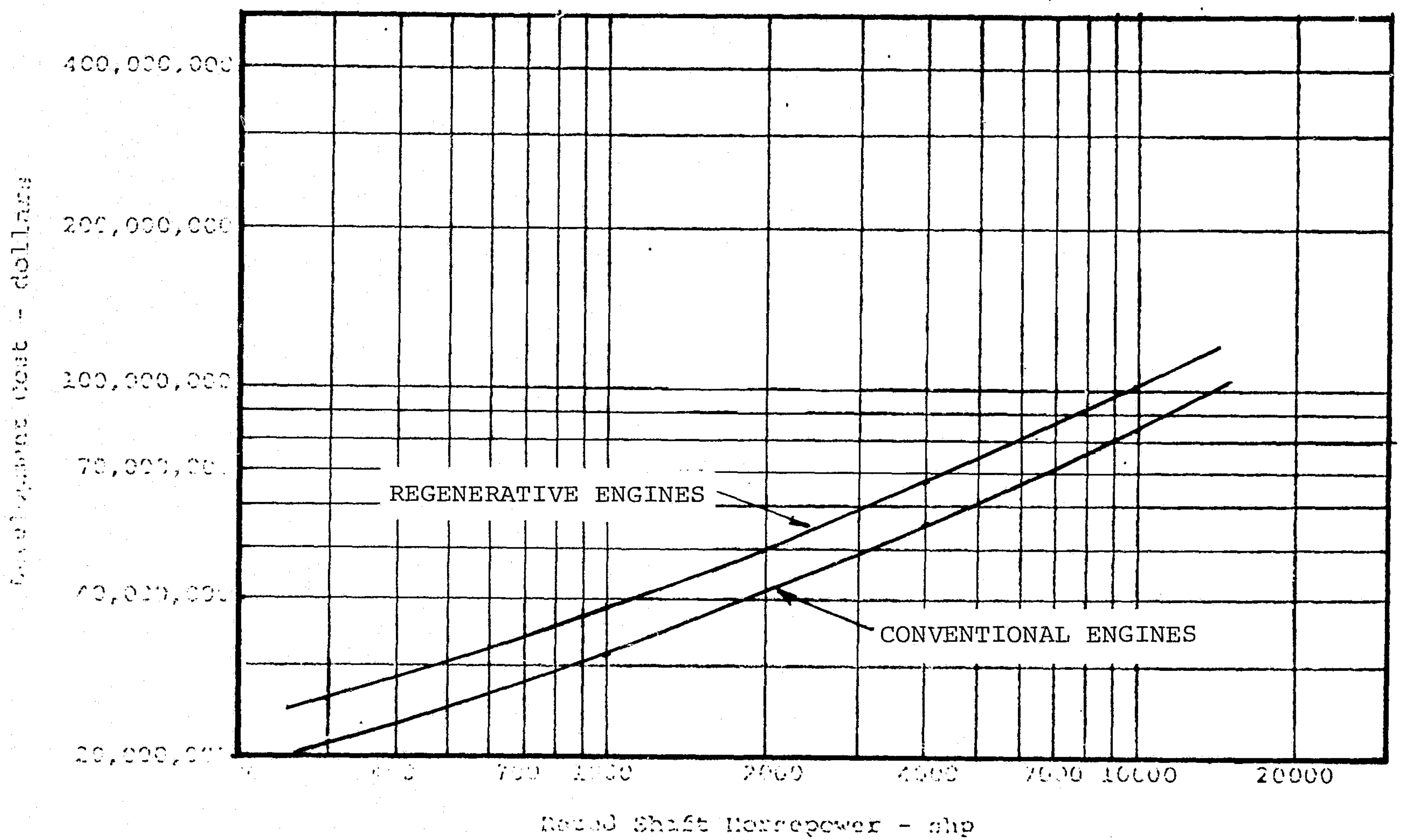


FIGURE 6.5 ESTIMATED TURBOSHAFT ENGINE DEVELOPMENT COST
(1975 DOLLARS — PRODUCTION COSTS NOT INCLUDED)

The other major component of actual hover power, the profile power, is dependent on the best obtainable lift-to-drag ratio. This is a function of local Mach number. For the airfoils in use today, blade sections would have to operate at $C_L = 0.8 \rightarrow 0.9$ to achieve the highest lift-to-drag ratio.

Rotors have traditionally avoided C_L's of this magnitude because of the difficulty of the structural requirements for high speed flight and because of the additional costs of resorting to a tapered planform which is also required. For an optimum hovering rotor, the outboard sections need to be more heavily loaded. This indicates the need for less chord outboard by tapering the blade. If it can be done without sacrificing forward flight capability, a potential exists for reducing profile power to about one-half of today's levels.

By twist and planform modifications, it should be possible to achieve Figures of Merit of 83%. Figure 6.6 shows the improvements obtained in a recent test (Reference 8) due to tailored geometry.

Initially, we need to further understand, by model tests, the effects of geometry (nonlinear twist and planform) and to understand the effects of Reynolds number by two-dimensional tests at the Reynolds number of the rotor model blades. Computer models need to be developed that will predict the results of model tests so that analyses can be used for selecting follow on model and full scale tests. These computer models should contain the necessary aeroelastic characteristics such that the high Figure of Merit rotor characteristics can be evaluated for their effects on high speed forward flight and performance. Finally, the optimized hovering rotor must be flight evaluated on the RSRA and guide lines prepared following such tests. Figure 6.7 depicts the required research and development program and Figure 6.8 shows the expected improvement in figure of merit as a function of time and the cumulative dollar expenditures.

6.2.2 Increased Rotor Lift/Effective Drag (L/D_E)

Work is in progress in industry, NASA, and the Army to increase the L/D_E (presently near 6) to values approaching 7 or 8. The most interesting of this work is that variable twist changes the span and azimuthal loading of the rotor and decreases the blade cyclic loads. With variable twist, both the aerodynamic and structural speed limits of rotors as well as increased L/D_E at a given airspeed can be obtained. The variable twist can be put in mechanically (Kaman) or through blade aeroelastic features of such nature as to favorably redistribute the loadings over the rotor disk (Boeing). Experiments and analyses are also being conducted (Boeing/Army) to extend efficient L/D_E values to higher advance ratios (.6). Preliminary test results show that rotor propulsive forces with adequate lift and L/D_E's of 7.5 can be developed by conventional rotors up to 250 kts forward speed by the use of high values of cyclic pitch. The direction of the increased rotor L/D_E research program in the future is assumed to require live twist and large cyclic pitch inputs at highspeed. In addition, higher harmonic cyclic pitch should be analyzed. The cost and schedule to develop a rotor with 20% higher L/D at high speeds is shown in Figure 6.9. We project that the research will yield design data such that rotors could be designed with L/D_E's vs time as shown on Figure 6.10. Research expenditures are also shown. It should be noted that although research in the next three years (limited to minor changes of existing rotor systems) will show 10-15% improvement in L/D_E, the rear progress substantiation will come only with full scale flight test of substantially changed rotor systems wherein the performance and handling qualities of this high speed rotor can be verified.

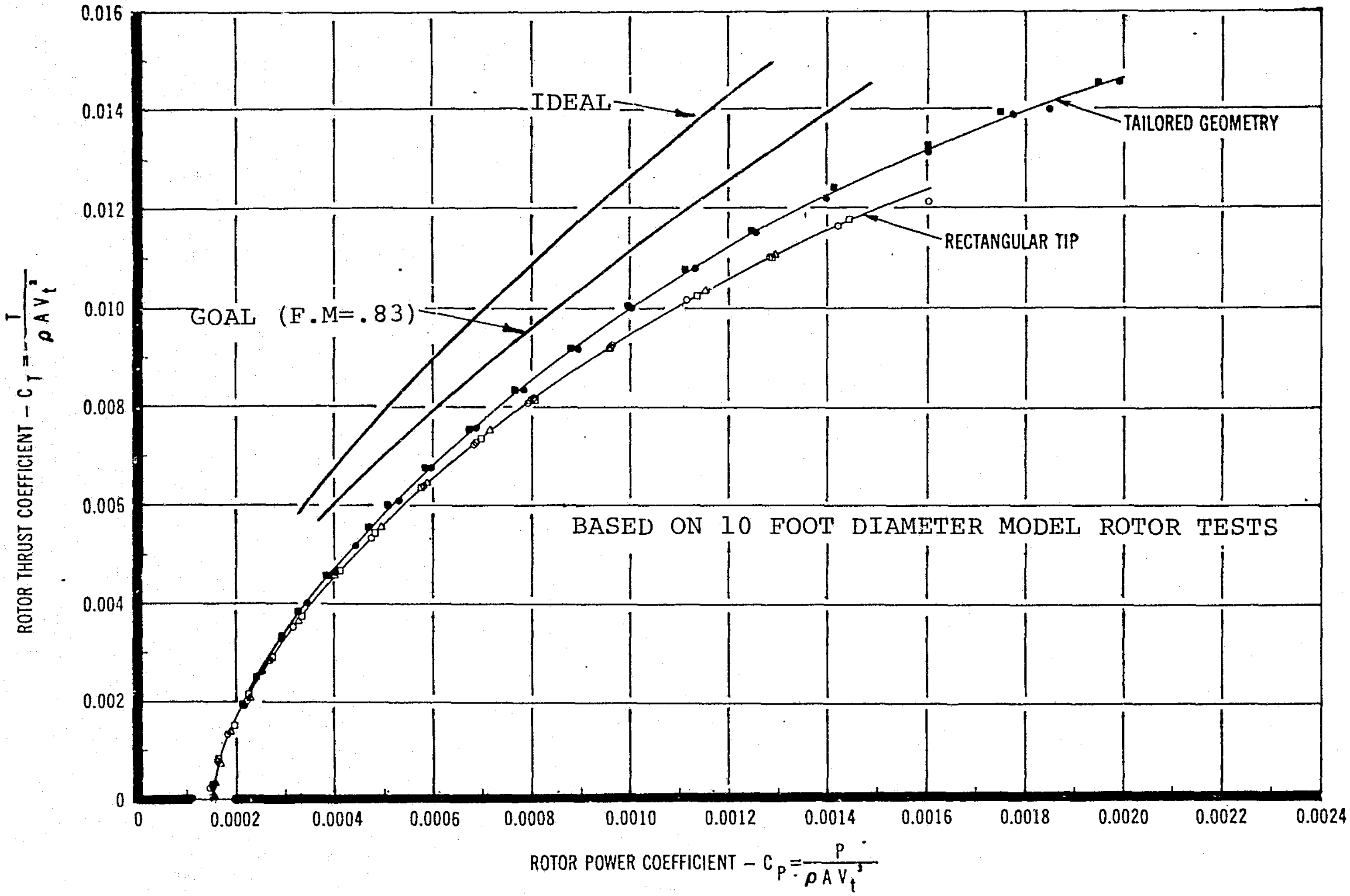


FIGURE 6.6 IMPROVEMENT IN HOVER PERFORMANCE WITH PLANFORM AND TWIST CHANGES

ITEM	SCHEDULE 1976	1977	1978	1979	1980	1981	1982	COST
HOVER TESTS (MODEL) TO ISOLATE GEOMETRY EFFECTS								$ 200,000
AIRFOIL TESTS TO OBTAIN CHARACTERISTICS AT SAME REYNOLDS NUMBER AS HOVER MODEL TESTS								50,000
DEVELOP COMPUTER MODEL THAT PREDICTS EFFECT OF TIP SHAPE, TWIST, PLANFORM, AND AIRFOIL								75,000
ASSESS THE LOADS AND PERFORMANCE OF THE HIGH FIGURE OF MERIT ROTOR IN HIGH SPEED FORWARD FLIGHT BY COMPUTER ANALYSES								100,000
DESIGN AND CONSTRUCT ROTOR MODEL THAT CONTAINS THE BEST BLADE SHAPES AND AIRFOILS FOR HOVER AND CRUISE								200,000
CONDUCT MODEL TESTS AND WRITE REPORT								200,000
DESIGN AND CONSTRUCT OPTIMUM FULL SCALE ROTOR FOR RSRA								4,000,000
INSTALL, TEST, AND EVALUATE OPTIMUM ROTOR ON RSRA								3,000,000
WRITE GUIDELINES								150,000

FIGURE 6.7 PROGRAM SCHEDULE AND ESTIMATED RESEARCH AND DEVELOPMENT COSTS FOR INCREASED FIGURE OF MERIT

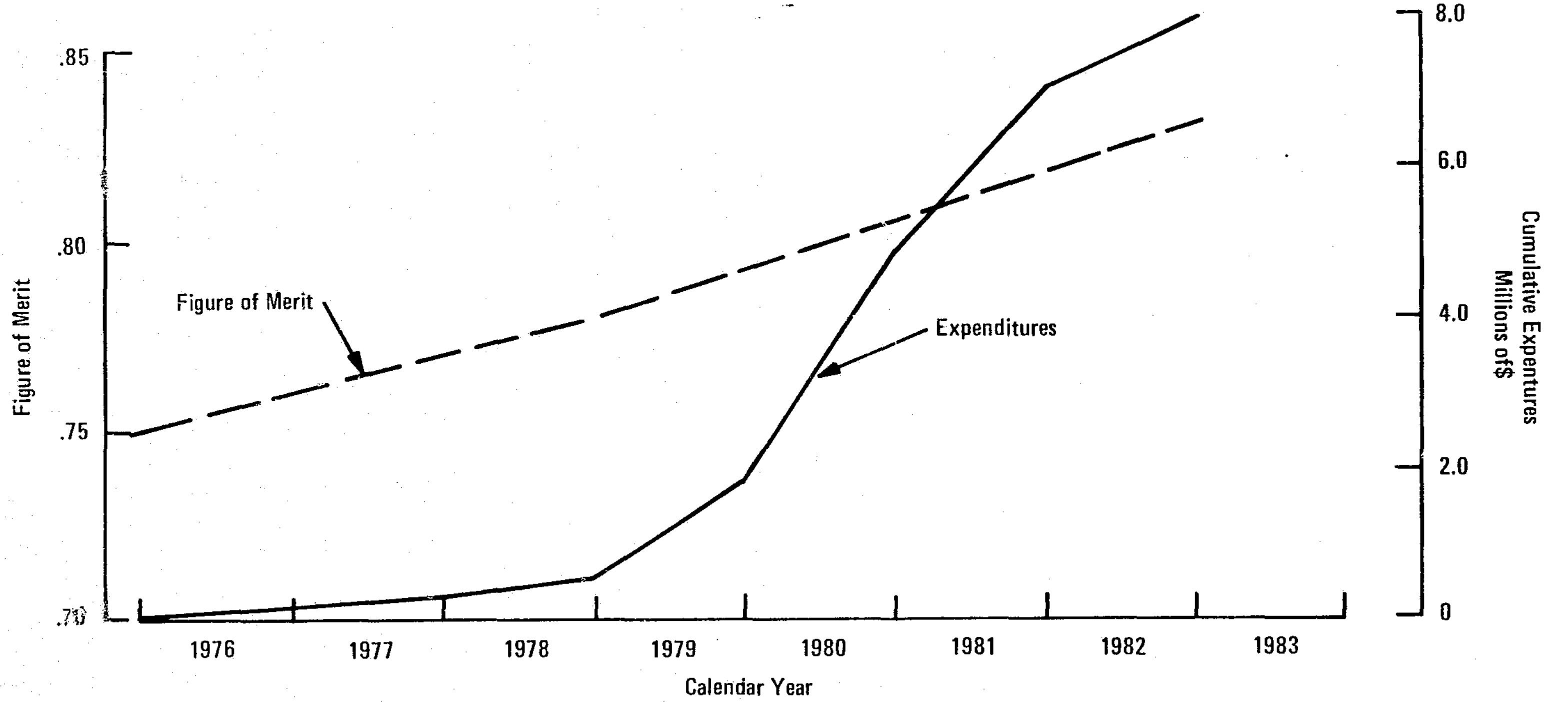


FIGURE 6.8 IMPROVEMENT OF FIGURE OF MERIT AND EXPENDITURES AS A FUNCTION OF TIME

ITEM	SCHEDULE							COST
	1976	1977	1978	1979	1980	1981	1982	
PREPARE COMPUTER PERFORMANCE PROGRAM TO CONTAIN "LIVE TWIST" ROTOR CHARACTERISTICS COUPLED WITH HIGH FORWARD TILT AND CYCLIC PITCH	▨							$ 200,000
DESIGN, BUILT, AND TEST WIND TUNNEL MODEL FOR OPTIMUM PERFORMANCE AND LOADS	▨	▨						150,000
REVISE COMPUTER PROGRAM		▨						50,000
CONDUCT FURTHER WIND TUNNEL TESTS TO EVALUATE EFFECTS OF AEROELASTIC ADAPTIVITY ON OPTIMUM SOLIDITY, AIRFOIL CRITERIA, ETC.		▨	▨					300,000
REVISE COMPUTER PROGRAM			▨	▨				175,000
DESIGN, BUILD, AND TEST FULL SCALE ROTOR FOR RSRA TO VERIFY PERFORMANCE AND HANDLING QUALITIES				▨	▨	▨		7,000,000
PREPARE DESIGN GUIDELINES BASED ON FULL SCALE TESTS AND ANALYSES							▨	150,000

FIGURE 6.9 PROGRAM SCHEDULE AND ESTIMATED RESEARCH AND DEVELOPMENT COSTS FOR INCREASED ROTOR L/D_E

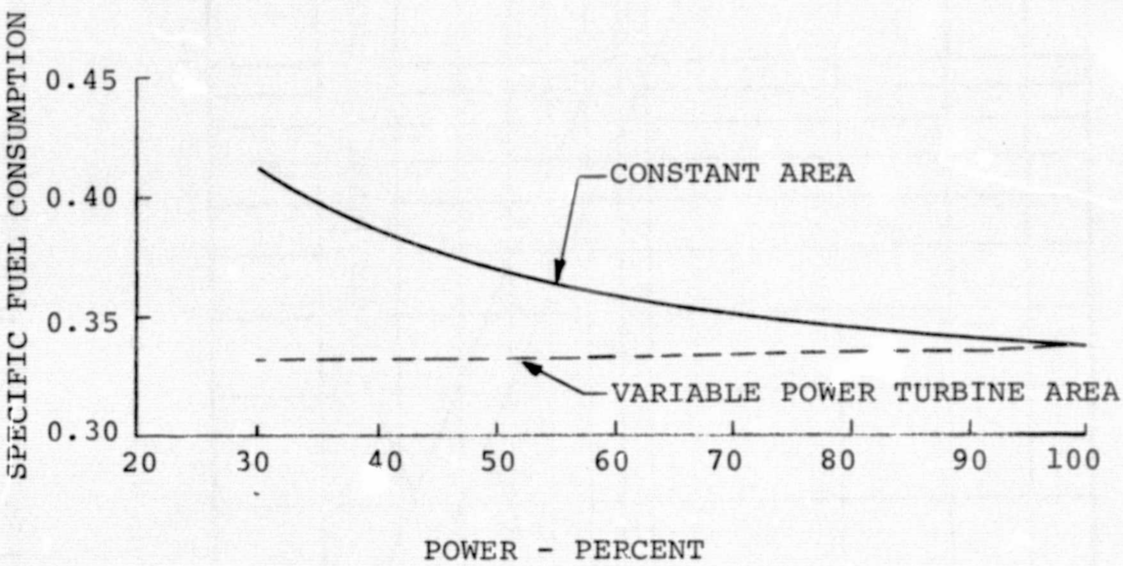


FIGURE 6.4 SPECIFIC FUEL CONSUMPTION AS A FUNCTION OF PERCENT POWER

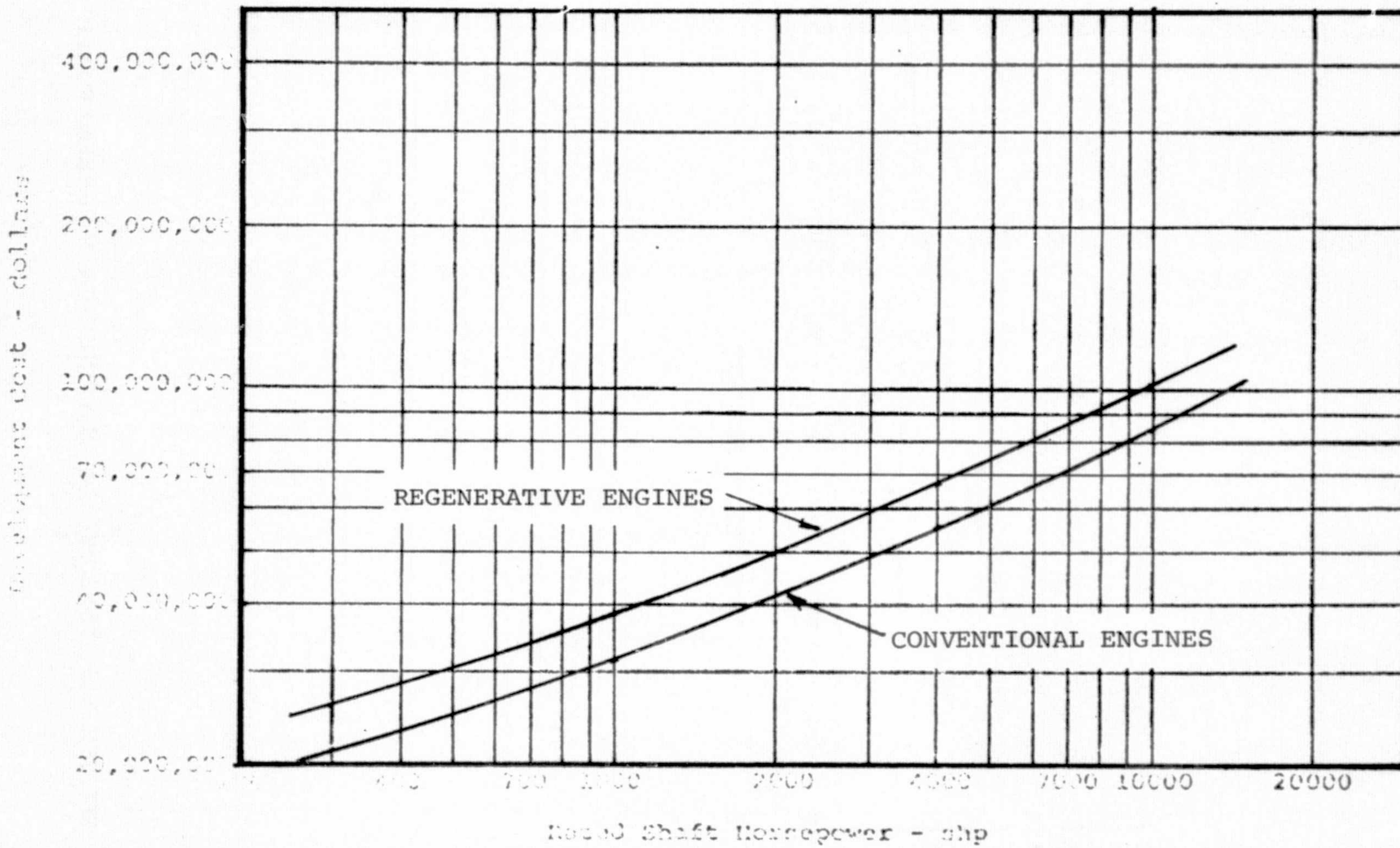


FIGURE 6.5 ESTIMATED TURBOSHAFT ENGINE DEVELOPMENT COST
(1975 DOLLARS – PRODUCTION COSTS NOT INCLUDED)

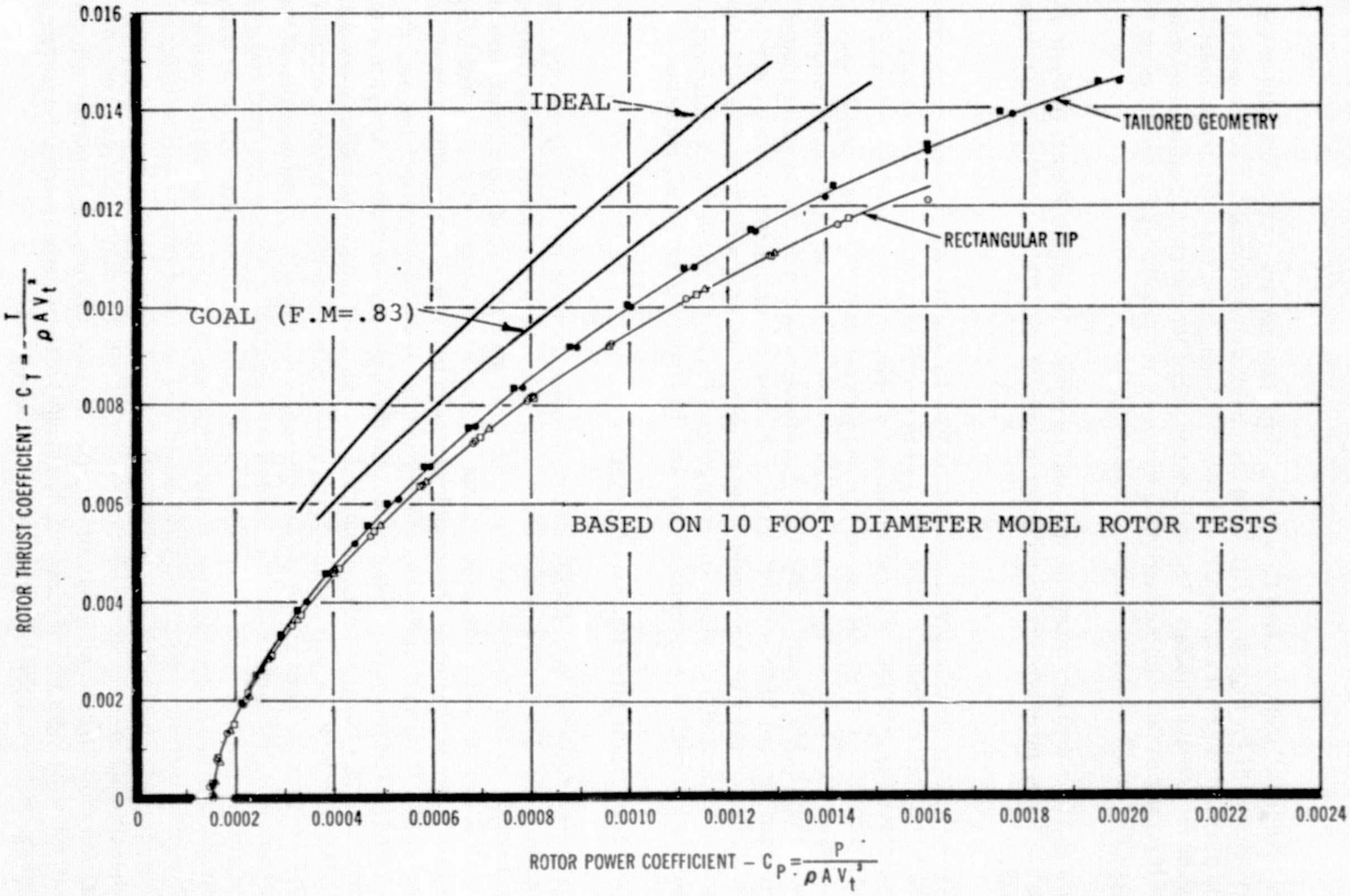


FIGURE 6.6 IMPROVEMENT IN HOVER PERFORMANCE WITH PLANFORM AND TWIST CHANGES

ITEM	SCHEDULE 1976	1977	1978	1979	1980	1981	1982	COST
HOVER TESTS (MODEL) TO ISOLATE GEOMETRY EFFECTS								$ 200,000
AIRFOIL TESTS TO OBTAIN CHARACTERISTICS AT SAME REYNOLDS NUMBER AS HOVER MODEL TESTS								50,000
DEVELOP COMPUTER MODEL THAT PREDICTS EFFECT OF TIP SHAPE, TWIST, PLANFORM, AND AIRFOIL								75,000
ASSESS THE LOADS AND PERFORMANCE OF THE HIGH FIGURE OF MERIT ROTOR IN HIGH SPEED FORWARD FLIGHT BY COMPUTER ANALYSES								100,000
DESIGN AND CONSTRUCT ROTOR MODEL THAT CONTAINS THE BEST BLADE SHAPES AND AIRFOILS FOR HOVER AND CRUISE								200,000
CONDUCT MODEL TESTS AND WRITE REPORT								200,000
DESIGN AND CONSTRUCT OPTIMUM FULL SCALE ROTOR FOR RSRA								4,000,000
INSTALL, TEST, AND EVALUATE OPTIMUM ROTOR ON RSRA								3,000,000
WRITE GUIDELINES								150,000

FIGURE 6.7 PROGRAM SCHEDULE AND ESTIMATED RESEARCH AND DEVELOPMENT COSTS FOR INCREASED FIGURE OF MERIT

C.2

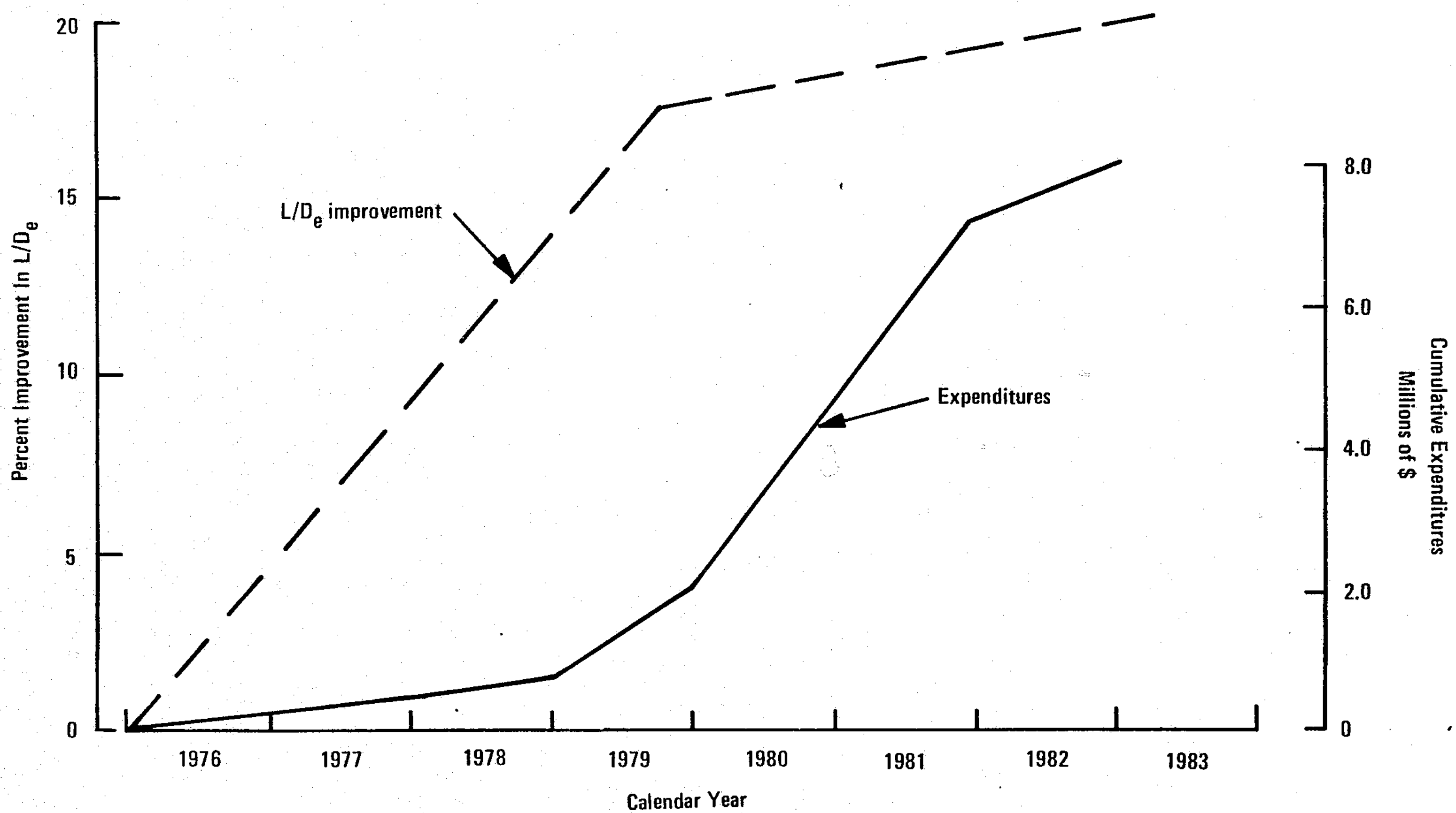


FIGURE 6.10 IMPROVEMENT GAIN AND EXPENDITURES FOR ROTOR LID_e AS A FUNCTION OF TIME

6.3 Reduced Parasite Drag

The importance of reducing helicopter cruise power requirements is increasingly evident in the light of higher speeds demanded of new helicopter designs. Means available to improve forward flight performance include optimizing the rotor geometry to reduce the induced and profile power requirements, and designing a low drag airframe to minimize parasite power requirements. As shown by the breakdown of level flight power required in Figure 6.11, the maximum reduction in power and, therefore, energy consumption is achieved by reducing parasite drag. This represents over 45% of the total power required. Figure 6.11 was computed for a 150 knot helicopter and, therefore, the parasite drag contribution will be larger as speed increases. A secondary benefit provided by the reduction in parasite drag is the improvement in the flow environment behind the fuselage. For single rotor aircraft, the increase in wake momentum will result in improved tail rotor and stabilizer effectiveness.

The drag levels of current production helicopters are summarized in Figure 6.12. As shown, current fixed landing gear transport helicopters have weight-to-drag (equivalent flat plate area) ratios of 1100 or less. For example, the CH-47C transport helicopter has weight-to-drag ratio of 1070 lb/ft^2. If the landing gear were retractable, the weight-to-drag ratio would be 1329 lb/ft^2. This corresponds to typical fixed wing levels in the 50,000 lb gross weight category of approximately 6000.

The component drag breakdown associated with a typical fixed landing gear, single rotor helicopter is illustrated in Figure 6.13. This data was developed from drag/weight trends and deflects an aircraft with side loading access, conventional articulated main and tail rotor hubs, and engine nacelles positioned adjacent to the airframe. The largest drag producing items are the hub and landing gear which account for over 50% of the drag. Also contained in Figure 6.13 are the component drag levels obtainable. These configuration improvements include such items as retractable gear, faired hingeless main rotor, flex strap tail rotor and streamlined fuselage with properly positioned and faired protuberances. Incorporation of these potential drag reductions will result in an aircraft with 66% lower drag (Reference 9), as shown in Figure 6.14, and will reduce the current disparity between fixed wing and helicopter drag levels. Also shown on the figure is the weight-to-drag ratio associated with retractable landing gear helicopters.

Based on the data and results presented in Reference 7 and shown in Figure 6.13, the following percent reductions in parasite drag (Figure 6.15) are attainable in the mid-1980 time frame. For a fixed landing gear configuration, a 66% drag reduction can be achieved, and for a retractable landing gear configuration a 54% reduction is achievable.

The solution of many helicopter drag problems are already known. For example, no new technology is needed to achieve large reductions of friction drag, leakage drag, or small protuberance drag. All that is needed in these areas is to systematically compile the information and develop a handbook of guide lines which designers and engineers can use.

The major unsolved problem areas are the rotor hub, shaft, blade shanks and controls. These are composed of aerodynamically bluff shapes which are not readily amenable to historical solutions. Figure 6.16 shows the program schedule and research and development costs required to solve the parasite drag problem. The program involves first, the compilation of existing design knowledge followed by a broad program of analytical development and systematic testing to solve the

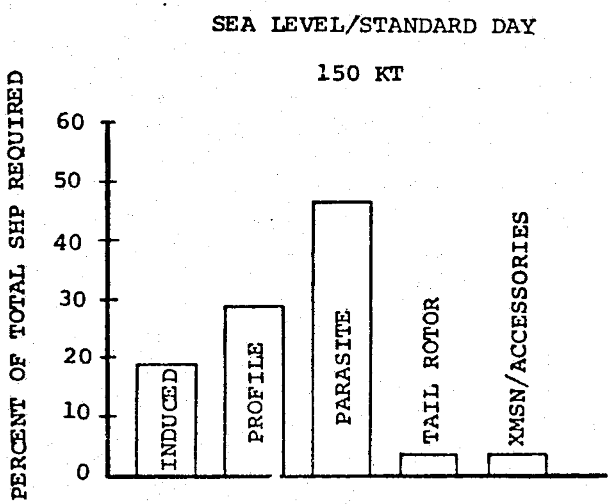


FIGURE 6.11 TYPICAL SINGLE—ROTOR HELICOPTER POWER REQUIRED BREAKDOWN

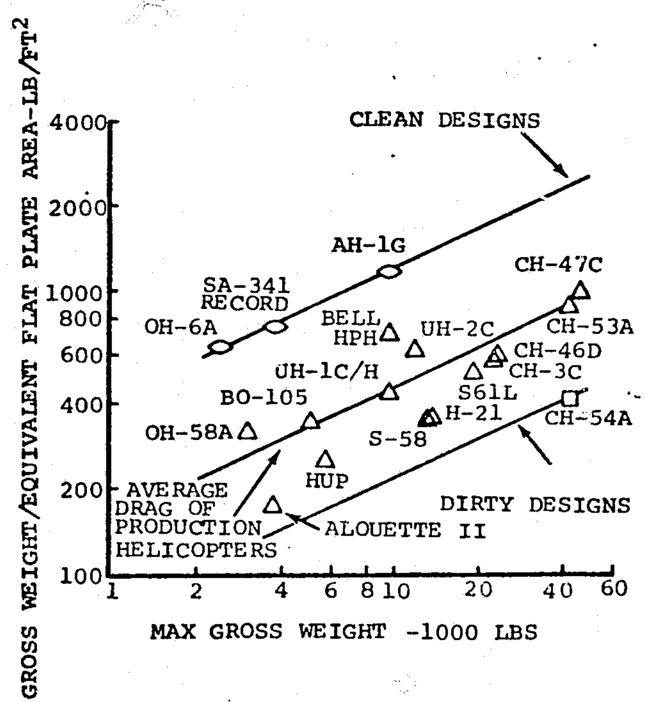


FIGURE 6.12 DRAG SUMMARY FOR CURRENT HELICOPTER CONFIGURATIONS

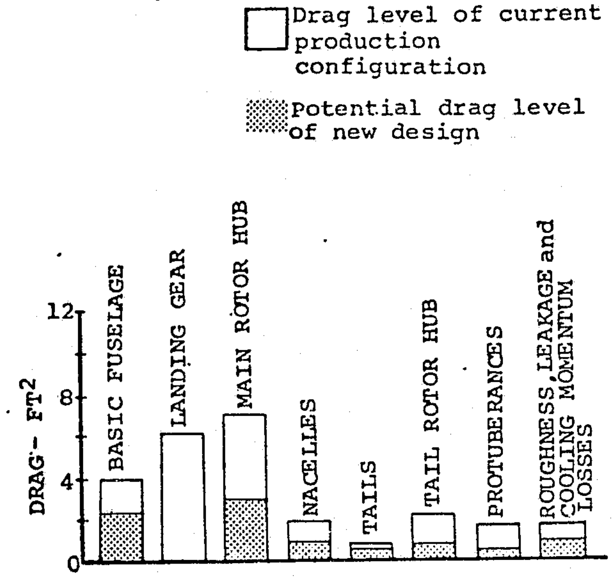


FIGURE 6.13 *Drag breakdown for typical 20,000-lb single rotor helicopter*

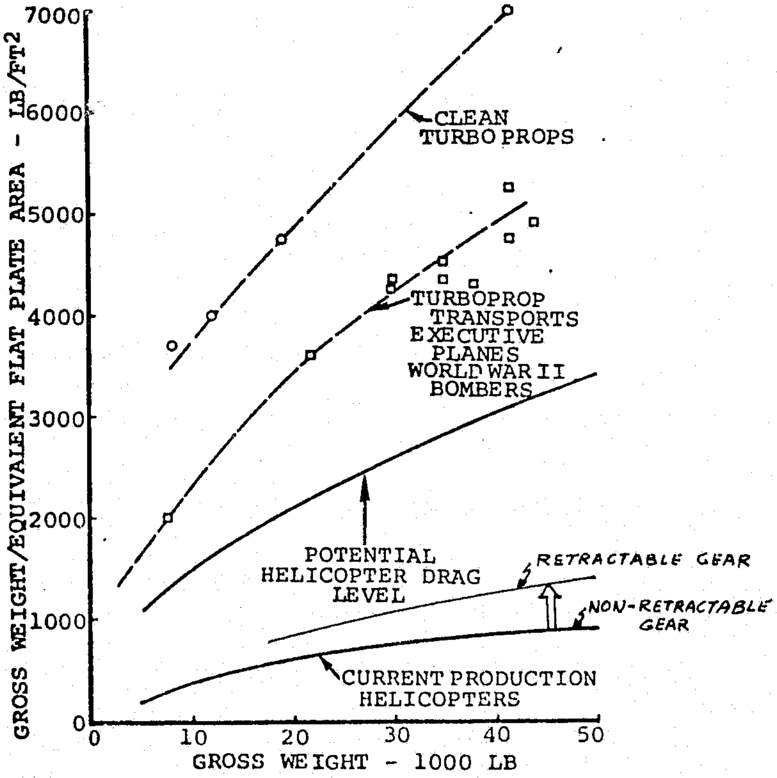


FIGURE 6.14 HELICOPTER/FIXED–WING AIRCRAFT DRAG TRENDS

	* DRAG REDUCTION ~ % FIXED GEAR	** DRAG REDUCTION ~ % RETRACTING GEAR
BASIC FUSELAGE	8	10
LANDING GEAR	24	NOT APPLICABLE
MAIN ROTOR HUB	16	21
NACELLES	5	6
TAILS	1	1
TAIL ROTOR HUB	6	8
PROTUBERENCES	4	5
ROUGHNESS, LEAKAGE AND COOLING MOMENTUN	2	3
TOTAL ~ %	66	54

* As a percentage of drag of the basic fixed gear aircraft

**As a percentage of drag of a basic retractable gear aircraft

FIGURE 6.15 PARASITE DRAG REDUCTION POTENTIAL FOR TYPICAL SINGLE ROTOR HELICOPTER

ITEM	SCHEDULE 1976	1977	1978	1979	1980	1981	1982	1983	1984	COST
Develop a handbook for use by designers and engineers which contains guidelines for use in designing low drag ratary wing aircraft (based on existing test data).										$ 75,000
Develop a drag prediction method to include separation, viscous effects, rotor wake effects, hub rotation, interference and cyclic and collective pitch effects										$ 200,000
Conduct experimental studies to understand bluff body separation, Reynolds numbers, rotation and interference effects. Test basic shapes and fairings.										$ 540,000
Integrate analytical and experimental studies to define guidelines for low drag hubs.										$ 75,000
Scale verification of low drag hubs										$ 150,000
Modify and Flight Test RSRA to demonstrate low drag										$3,000,000

FIGURE 6.16 PROGRAM, SCHEDULE AND ESTIMATED DEVELOPMENT COSTS FOR REDUCED PARASITE DRAG

bluff body three-dimensional flow problem. The analytical and experimental work is then integrated to define low drag hub/pylon/fuselage configuration. Scale testing is then required to verify the solutions. Following this, a flight vehicle such as the RSRA could be modified and used to demonstrate the achievement of low drag at full scale. Figure 6.17 shows the estimated cumulative cost and improvement gains as a function of time.

6.4 Weight Reduction Through Use of Composite Materials

Significant reductions in the structural weight of fatigue-critical airframes can have a major impact on aircraft size. For a given mission, each pound of weight reduced from the structure will result in approximately 1.7 pounds of weight removed from the total aircraft. A lighter structure dictates a lighter landing gear, smaller engines, smaller rotor, and less fuel. If a material having the same structural strength and stiffness as aluminum at half its weight can be used, the impact on airframe weight, size, acquisition cost, and operating cost will be significant. The potential weight reductions possible with composite materials compared to aluminum are shown in Figure 6-18; and research, development and use of composite materials and structures to reduce helicopter empty weight is progressing at a rapid rate as shown in Figure 6.19. The development and use of these materials will demand the resources of several government agencies as well as those of applicable industries such as materials suppliers and fabricators. The general magnitude of the research, development and test funding required and the breakdown of the job to be done is shown in Figure 6.20. These data assume that composite helicopter development will occur first with a military aircraft, with civil helicopters making use of the technology. It should be emphasized that these are only the estimated additional costs for achieving the flight evaluation of composite technology. Development costs for production could be substantially higher.

The end results of composite material research will result in the reduction in the ratio of structural empty weight to gross weight. Structural empty weight is defined as empty weight minus the fixed equipment weight. For example, the structural empty weight of the compromise design point helicopter is 56,073 lb. minus 13,356 lb. = 42,717 lb. It should be noted that the term "structural empty weight" is somewhat of a misnomer in that some non-structural items such as the rotor system, engines, and drive system are lumped together with obvious structural items such as the airframe. For comparisons of vehicle weight reductions due to materials/structures technology improvements, structural empty weight is a more meaningful parameter than total empty weight, since it is freed of the obscuring effect of fixed equipment weight, which itself is only a function of the design mission. Likewise, percentage reductions in the structural empty/gross weight ratio are a more meaningful means of evaluating materials/structures technology improvements than percentage reductions in empty weight, since the structural empty/gross weight ratio automatically reflects the iterative scaling effect of empty weight reduction on gross weight in the sizing process. A 12.1% reduction in the structural weight/gross weight ratio is possible for the 1985 time frame if composite materials are utilized in all the areas shown in Figure 6.20.

This reduction is based on the results of Reference 10, "Advanced Helicopter Structural Design Investigation".

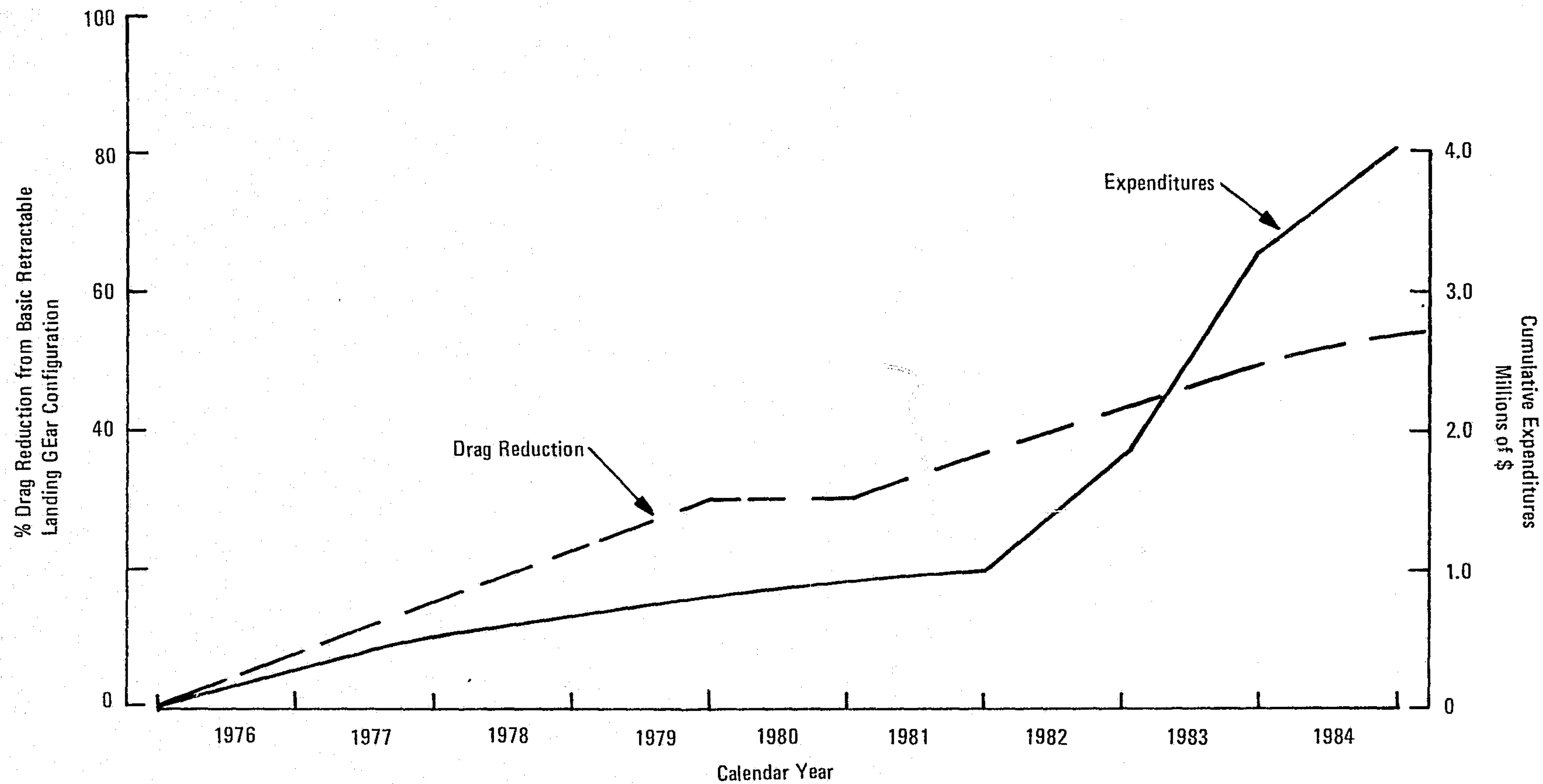


FIGURE 6.17 IMPROVEMENT GAIN AND EXPENDITURES FOR REDUCED PARASITE DRAG

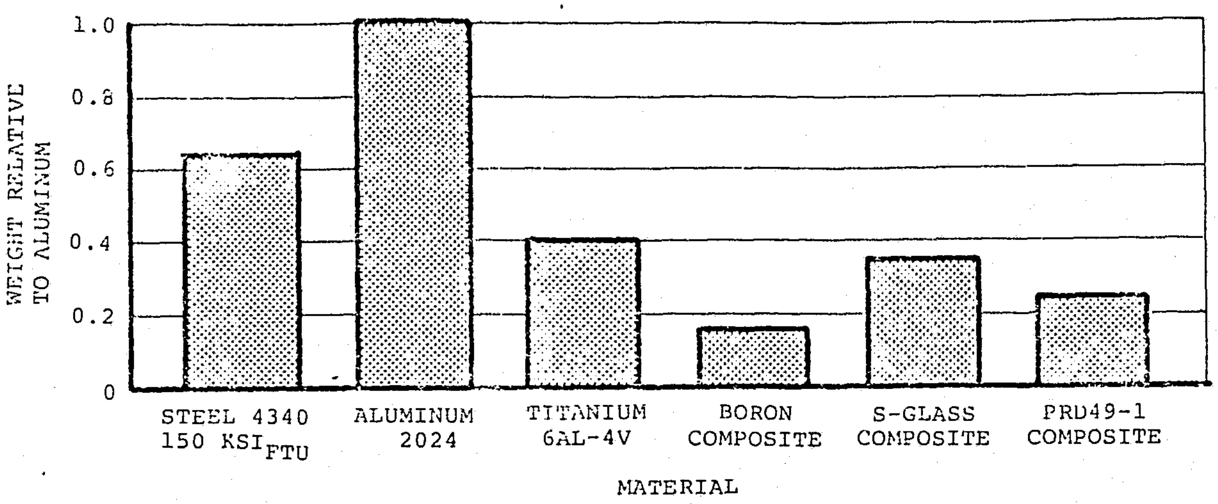


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FIGURE 6.18 RELATIVE WEIGHTS OF FATIGUE—CRITICAL STRUCTURES

COMPONENT	BASIC DEVELOPMENT	COMPONENT DEV. & TEST	FLIGHT EVALUATION	PRODUCTION ENGINEERING	IN USE ON MILITARY HELICOPTER	IN USE ON CIVIL HELICOPTER	COMMENTS
ROTOR BLADES	COMPLETE	IN PROCESS (1)	IN PROCESS (1)	IN PROCESS	YES (1)	YES (1)	(1) BOEING, MBB HAVE REDUCED TO PRACTICE (GLASS/GRAPHITE)
ROTOR HUBS	IN PROCESS	IN PROCESS (2)	IN PROCESS (3)	-	-	-	(2) KAMAN, SIKORSKY, BOEING (K-49) (3) BELL, SUD (PRELIM.)
LANDING GEAR	IN PROCESS (4)	IN PROCESS (4)	IN PROCESS (5)	-	-	-	(4) AF DEMO A-37B, YF-16 (B/AL) HUGHES/ARMY (5) A-37B/USAF (GRAPHITE)
TAIL ROTOR	COMPLETE	COMPLETE	COMPLETE	IN PROCESS	YES	YES	
TAIL BOOM	IN PROCESS	IN PROCESS	IN PROCESS (6)	-	-	-	(6) HUGHES/ARMY AH-1J (GRAPHITE)
VERTIC. STABIL.	COMPLETE	COMPLETE	COMPLETE	IN PROCESS	YES (7)	-	(7) B/V YUH-61A (GLASS)
SECONDARY STRUCT.	COMPLETE (8)	IN PROCESS	IN PROCESS	-	YES (9)		(8) WORK NEEDED IN THERMOPLASTICS AND TRI-AXIAL WEAVES (K-49) (9) SIKORSKY YUH-60A (K-49)
DRIVE SHAFTING	COMPLETE	IN PROCESS (10)	-	-	-	-	(10) USAAMRDL, IND. IR&D
GEAR CASES	IN PROCESS	IN PROCESS (11)	-	-	-	-	(11) USAAMRDL GRAPHITE
ADV. GEAR SYST.	IN PROCESS	IN PROCESS (12)	-	-	-	-	(12) STUDIES BEYOND ADV. DEV. OF HLH/UTTAS (METAL ONLY)
PRIMARY AIRFRAME	IN PROCESS	IN PROCESS (13)	-	-	-	-	(13) NASA/ARMY-SIKORSKY (LANGLEY) GRAPHITE/K-49
ENGINES	IN PROCESS	IN PROCESS	IN PROCESS	IN PROCESS	YES (14)	YES	(14) ROLLS ROYCE/SEA GRAPHITE BRITISH/FRENCH
CONTROL SYST. COMP.	COMPLETE	IN PROCESS	YES (15)	-	YES (15)		(15) BELL AAH FIBERGLASS

FIGURE 6.19 STATUS CHART – COMPOSITE MATERIAL APPLICATION

	BASIC	COMPONENT DEV/TEST	FLIGHT EVALUATION
ROTOR BLADES	0	5M	2M
ROTOR HUBS	1M	4M	2M
LANDING GEAR	0	1.5M	.5M
TAIL ROTOR	0	0	0
DRIVE SHAFTING	0	1.5M	1M
XMSN HOUSINGS	2M	4M	2M
ADV. GEAR SYST.	4M	5M	
<u>AIRFRAME</u>			
SECONDARY STRUCT.	1M	2M	1M
STABILIZERS	-	1M	1M
TAIL BOOMS	-	2M	2M
FUSELAGE	2M	4M	2M
ENGINES (3)	-	-	-
CONTROL SYSTEM	-	1M	.5M
	10M	31M	14M

$55 MILLION

FIGURE 6.20 ESTIMATED RESEARCH AND DEVELOPMENT COSTS FOR REDUCED STRUCTURAL WEIGHT EMPTY

In this study advanced structural helicopter configurations were defined using the latest analytical, material and fabrication technology to satisfy requirements of structural efficiency, fail safety, safety and producibility/cost. A risk/feasibility assessment of advanced structural concepts was made to determine the areas of greatest payoff and the supporting research to achieve the necessary advanced structural technology was made. This study showed the greatest benefits for composite material useage in the fuselage and drive system.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Baseline helicopters using 1975 technology were sized in Section 4.0 for a very short haul (100 NM) and a short haul (200 NM) mission. Characteristics of these baseline helicopters, which were selected on the basis of least energy and D.O.C., are shown in Table 7.1. A systematic parametric analysis was then conducted to determine the impact of technology improvements on the baseline vehicles. Projection of the technology levels that could be achieved in the 1985 time frame were made and the resources refer to the research, development and test dollars required to bring a given advanced technology to the point where it could be used in an advanced civil helicopter. Production costs are not included. Table 7.2 summarizes the technology improvements that could be achieved in the 1985 time frame, the resources required and the reduction in energy intensity for each of the technologies considered taken separately.

As noted in Table 7.2, there are six independent technology improvements possible, some combination of which results in the maximum reduction of EI for the minimum expenditure of Research and Development money. Determining the EI reduction for all the possible combinations would be a staggering task since the number of such combinations is 6! or 720. Therefore a judicious selection of possible high payoff combinations was made after careful scrutiny of the EI reductions obtained by individual technology improvements. The four combinations finally chosen for closer study, along with the resulting EI reductions and development cost/unit EI reduction are illustrated in Table 7.3. Note that the basis for comparison is development cost/unit EI reduction. This parameter is simply the total development cost of all the technology improvements divided by the total EI reduction realized. Obviously, the most cost effective combination will be the one resulting in the minimum development cost/unit EI reduction for the maximum percent EI reduction (which translates into savings of nonreplaceable fuel). Perusal of Table 7.3 reveals that the last combination meets this requirement. Although Table 7.3 was done for the compromise design mission, the results are similar for the very short haul mission.

Figures 7.1, 7.2, 7.3 and 7.4 illustrate respectively the percentage reduction in EI and unit development cost for the six individual technology improvements and the last two technology improvement combinations listed in Table 7.3 for both the Compromise Design point and Very Short Haul mission scenarios. It should be noted from Figures 7.1 and 7.3 that the sum of the individual reduction in energy intensity is greater than the overall reduction in energy intensity shown by the most cost effective combination. This points out the fact that technology improvements are not linearly additive. From these figures the most effective mix of technologies from an energy viewpoint is the one in which all of the projected improvements in technology are utilized. The percentage technology improvements are shown in the last group in Table 7.3 and the required development programs for each has been discussed in detail in Section 6.0. With this combination, a 38.1% reduction in EI is obtained for the short haul mission and a 36.6% reduction is obtained in the very short haul mission.

TABLE 7.1 CURRENT TECHNOLOGY (1975) DESIGN POINT HELICOPTER CHARACTERISTICS

	VERY SHORT HAUL MSN HELICOPTER	COMPROMISE DSN PT. HELICOPTER
WEIGHTS		
DESIGN GROSS WEIGHT	77,300 LB.	84,133 LB.
WEIGHT EMPTY	52,011 LB.	56,073 LB.
FUEL	5,346 LB.	8,117 LB.
NO. OF PASSENGERS	100	100
ROTOR		
DISC LOADING	8.0 PSF	7.0 PSF
DIAMETER	78.4 FT.	87.5 FT.
SOLIDITY	.104	.100
NO. OF BLADES	4	4
TWIST	-12 DEG.	-12 DEG.
TIP SPEED	720 FT/SEC	705 FT/SEC
POWER		
NO. OF ENGINES	3	3
RATED POWER (S.L.,STD)/ ENGINE	5175 SHP	5237 SHP
FUSELAGE		
LENGTH	88.2 FT.	88.2 FT.
WIDTH	12.92 FT.	12.92 FT.
ROTOR GAP/STAGGER	.127	.113
PERFORMANCE		
V_{NRP}	203.3 KTAS	200.8 KTAS
CRUISE ALTITUDE	500 FT.	2000 FT.
BLOCK SPEED	77.04 KTAS	136.6 KTAS
BLOCK TIME	1.298 HR.	1.464 HR.
FLIGHT TIME	0.724 HR.	1.064 HR.
ENERGY INTENSITY	5998 BTU/PASS-N.M.	5612 BTU/PASS-N.M.

TABLE 7.2 SUMMARY OF TECHNOLOGY IMPROVEMENTS

ITEM	1975 TECHNOLOGY LEVEL	1985 IMPROVEMENT GOAL	RESEARCH AND DEVELOPMENT $	% EI REDUCTION FOR EACH TECHNOLOGY INDIVIDUALLY	
				COMPROMISE MISSION	VERY SHORT HAUL
IMPROVED SFC	.42	.40 – Conventional Turboshaft .36 – Regenerative Engine	61,000,000 73,000,000	5.8 / 16.6	5.3 16.2
IMPROVED ROTOR EFFICIENCY					
FIGURE OF MERIT	.75	.83	7,975,000	9.2 /	6.9
L/D_E	6 (Cruise)	7.2	8,025,000	6.5 /	3.7
REDUCED PARASITE DRAG	$GW/f_e \cong 1750$ (Retractable Landing Gear, $W \cong 84000$ LB)	54% Reduction	4,040,000	3.1 /	4.7
REDUCED STRUCTURAL WEIGHT	Conventional Structure	12.1% Reduction from Conventional Structure	55,000,000	12.5 /	11.4

TABLE 7.3 COMPARISON OF SEVERAL TECHNOLOGY IMPROVEMENT COMBINATIONS (COMPROMISE DESIGN POINT MISSION)

TECHNOLOGY IMPROVEMENT	% CHANGE	TOTAL % EI REDUCTION	TOTAL DEVELOPMENT $/UNIT EI REDUCTION
IMPROVED F.M. IMPROVED L/D_E REDUCED F_e	9.3% INCREASE 20% INCREASE 54% DECREASE	15.9%	$22,459
IMPROVED F.M. IMPROVED L/D_E REDUCED F_e REDUCED EW_{STR}/GW	9.3% INCREASE 20% INCREASE 54% DECREASE 12.1% DECREASE	26.2%	$51,037
IMPROVED F.M. IMPROVED L/D_E REDUCED F_e REDUCED EW_{STR}/GW IMPROVED SFC (CONVENTIONAL ENGINES)	9.3% INCREASE 20% INCREASE 54% DECREASE 12.1% DECREASE 4.76% DECREASE	30.35%	$79,873
IMPROVED F.M. IMPROVED L/D_E REDUCED F_e REDUCED EW_{STR}/GW IMPROVED SFC (REGENERATIVE ENGINES)	9.3% INCREASE 20% INCREASE 54% DECREASE 12.1% DECREASE 14.3% DECREASE	38.1%	$69,235

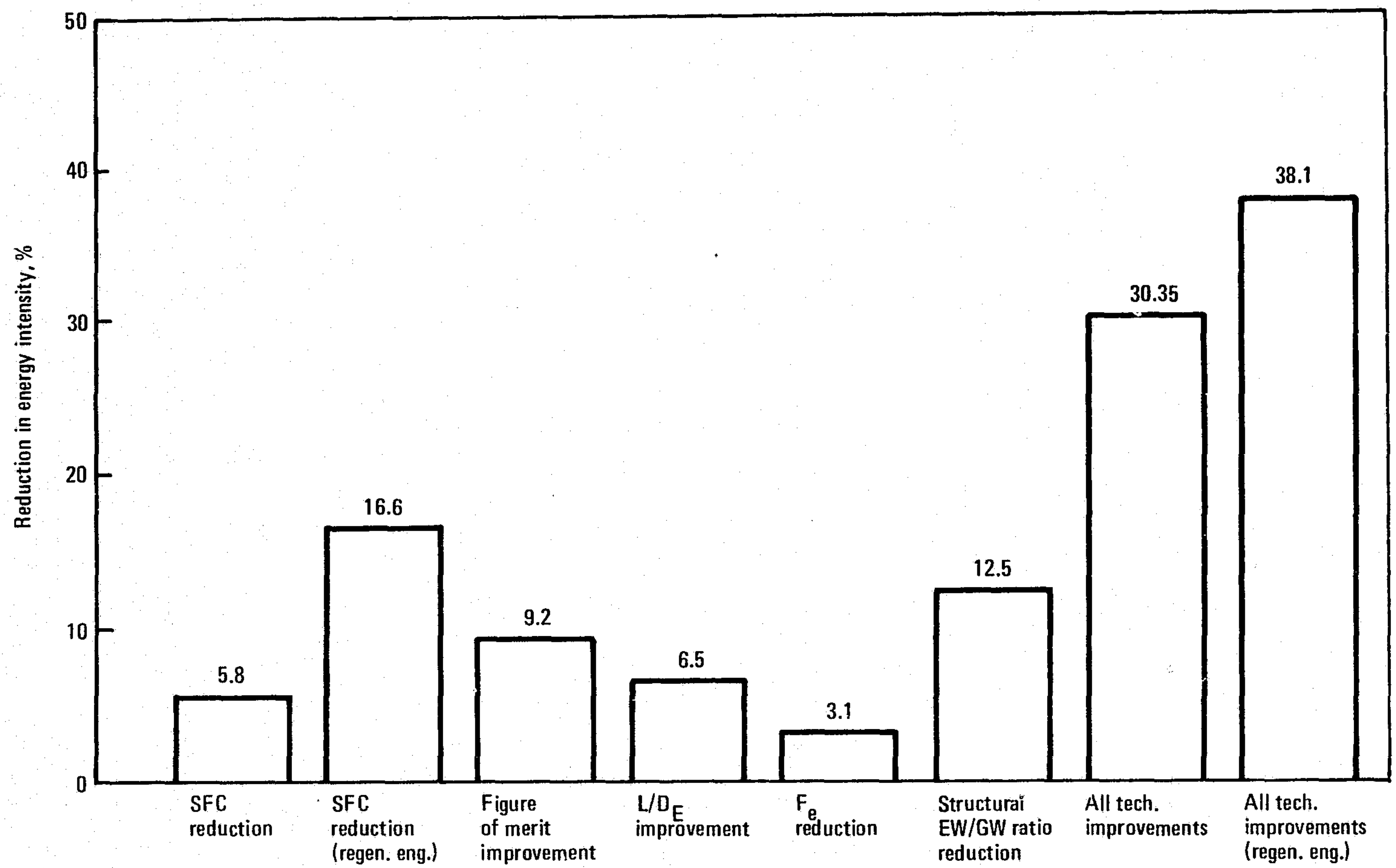

FIGURE 7.1 ENERGY INTENSITY REDUCTION COMPARISON – COMPROMISE DESIGN MISSION

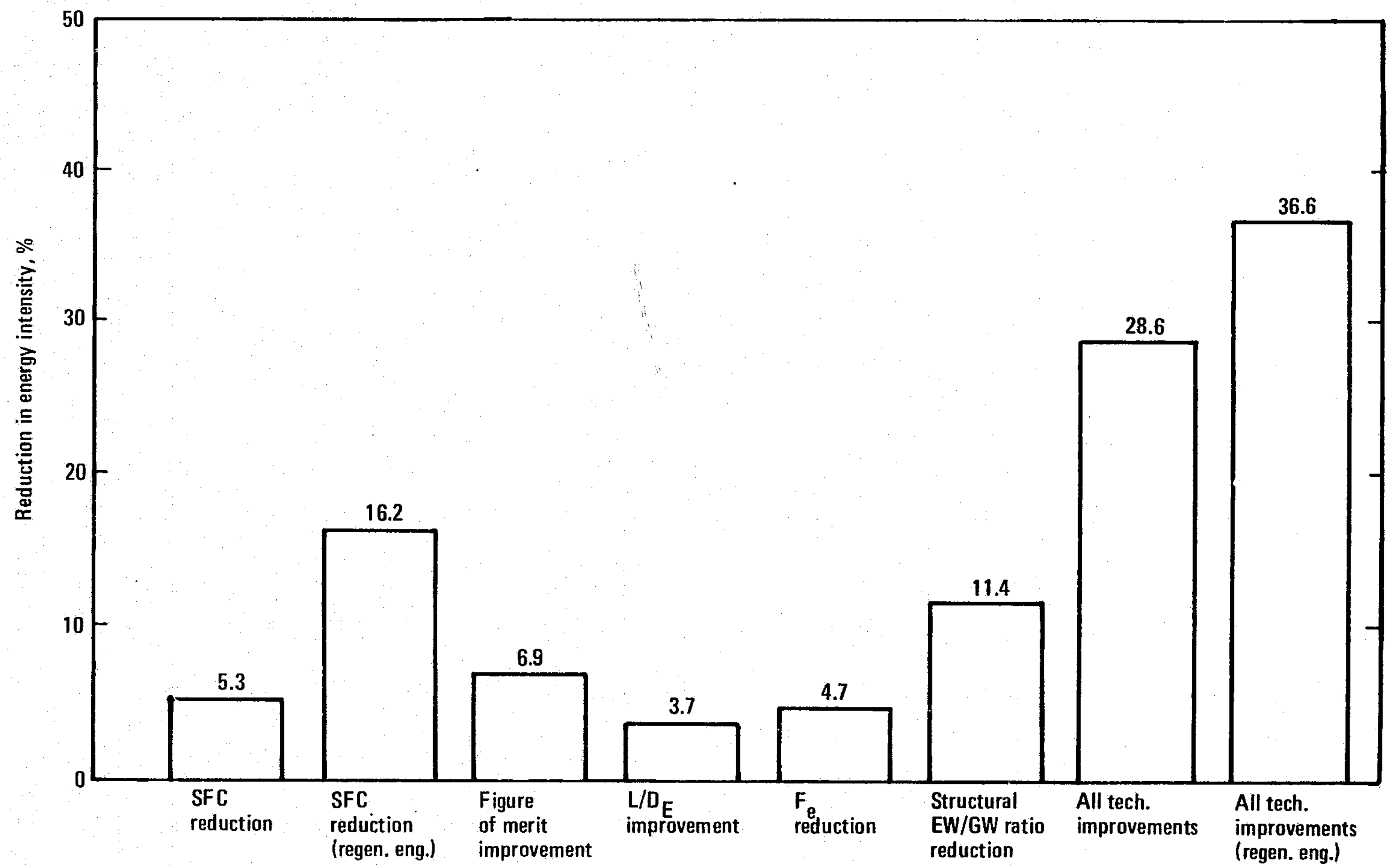

FIGURE 7.2 ENERGY INTENSITY REDUCTION COMPARISON VERY SHORT HAUL MISSION

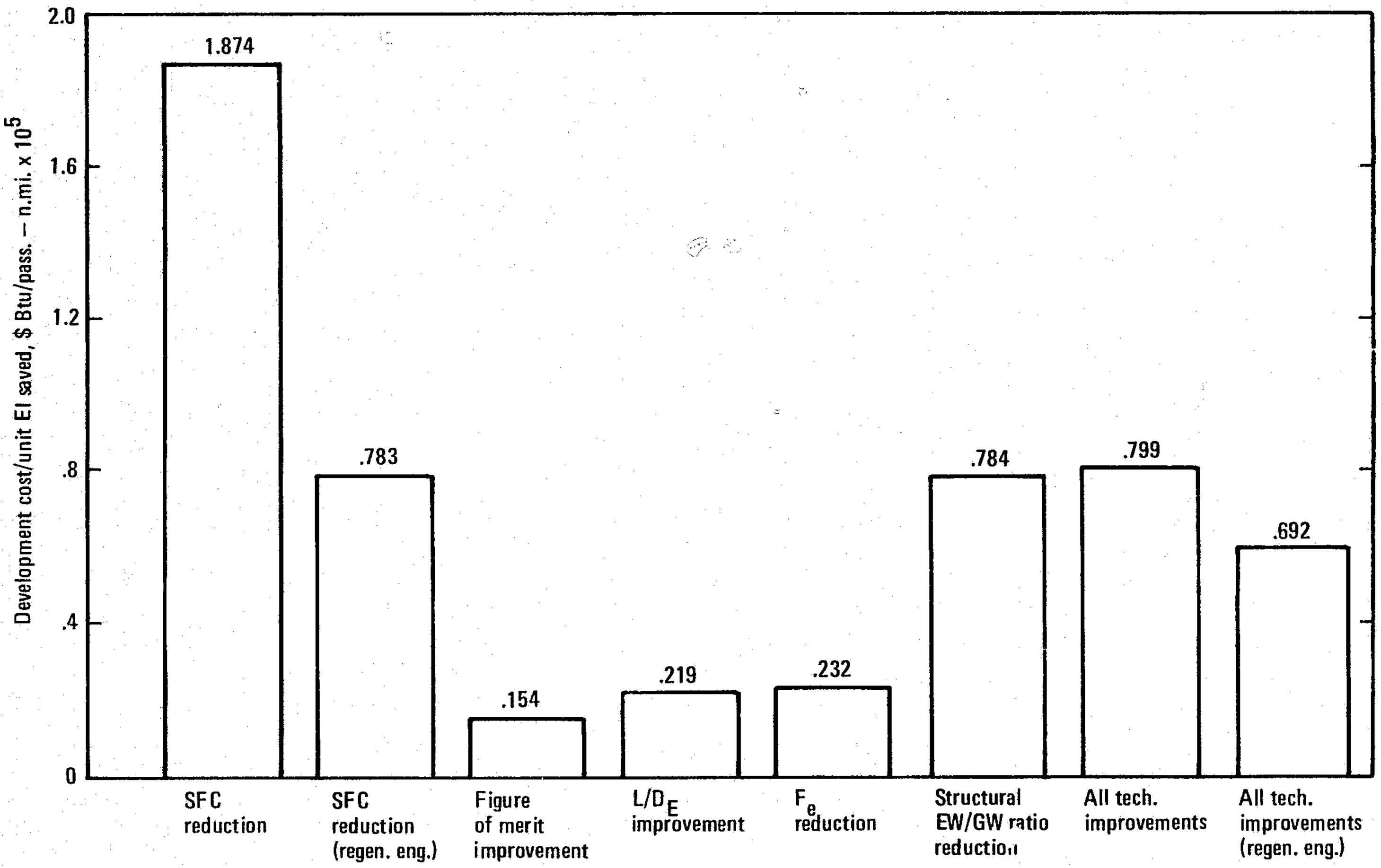

FIGURE 7.3 TECHNOLOGY DEVELOPMENT COST/UNIT EI SAVED COMPARISON—COMPROMISE DESIGN MISSION

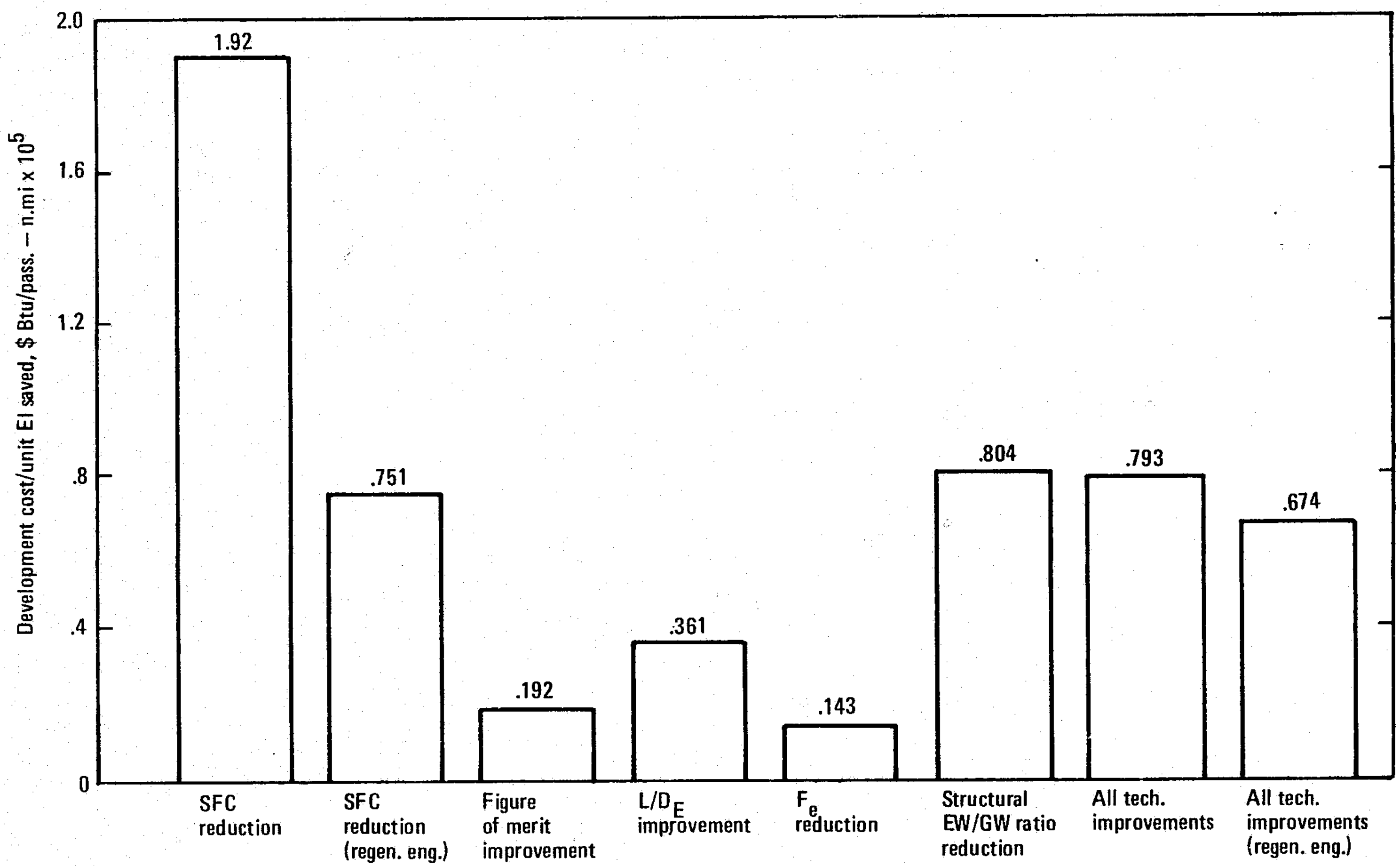

FIGURE 7.4 TECHNOLOGY DEVELOPMENT COST/UNIT EI SAVED COMPARISON – VERY SHORT HAUL MISSION

It is recommended that figure of merit, rotor L/D_E and vehicle parasite drag reduction should be pursued on an accelerated basis since they offer large payoffs with relatively little expenditures. Figures 7.5 and 7.6, which show how direct operating costs (DOC) vary with technology improvement, indicate that structural weight empty improvement using composite materials significantly reduces DOC. Much of the work in this area is currently being directed at military helicopters. It is recommended that additional work in composites be directed towards civil applications in order to achieve the benefits indicated. This study indicates a large payoff in energy reduction can be obtained by the use of regenerative engines. The technology related to developing the regenerator should be pursued and then if the civil helicopter market grows, an advanced engine could be available.

Two advanced technology civil helicopters, one for each mission, based on the best mix of technologies discussed in previous paragraphs have been sized. Design point characteristics are shown in Table 7.4. A comparison with the current technology helicopter shown in Table 7.1 shows a substantial reduction in weight empty and therefore design gross weight, engine size and energy intensity.

Another way of illustrating the benefits of technology improvements is shown by Figure 7.7. This figure shows passenger miles per gallon as a function of range. This data is from Reference 1I The calculation of passenger miles per gallon uses the published design load and the fuel consumed from takeoff to landing excluding reserve fuel. The data forms two bands, with helicopters falling into the lower grouping and Fixed Wing aircraft in the upper band. The 1975 baseline helicopters are plotted and fall into the upper side of the band for helicopters. When the advanced technologies discussed in this report are incorporated, the advanced vehicles (Table 7.4) show a nearly 50% increase in passenger miles per gallon which make them comparable to fixed wing aircraft.

7.2 Recommendations

Previous studies (Reference 1) have shown that, on the basis of fuel efficiency current production helicopters can be competitive with other forms of transportation in some missions. Current levels of helicopter energy utilizintio can be reduced, however, through the infusion of advanced technology into the design process. Improvements in helicopter energy consumption can be accomplished through the utilization of advanced technology in the areas of powerplant design, rotor efficiency, reduced parasite drag and reduced structural weight empty.

Based on this study, the following recommendations are made for future studies.

1. Develop the high payoff technologies identified in this study so they can be incorporated into the next generation of transport helicopters.
2. Perform a preliminary design study of the advanced technology civil transport helicopter identified in this study. Integrate all of the applicable technologies and ascertain whether additional problems exist which must be solved before a successful vehicle could be built.

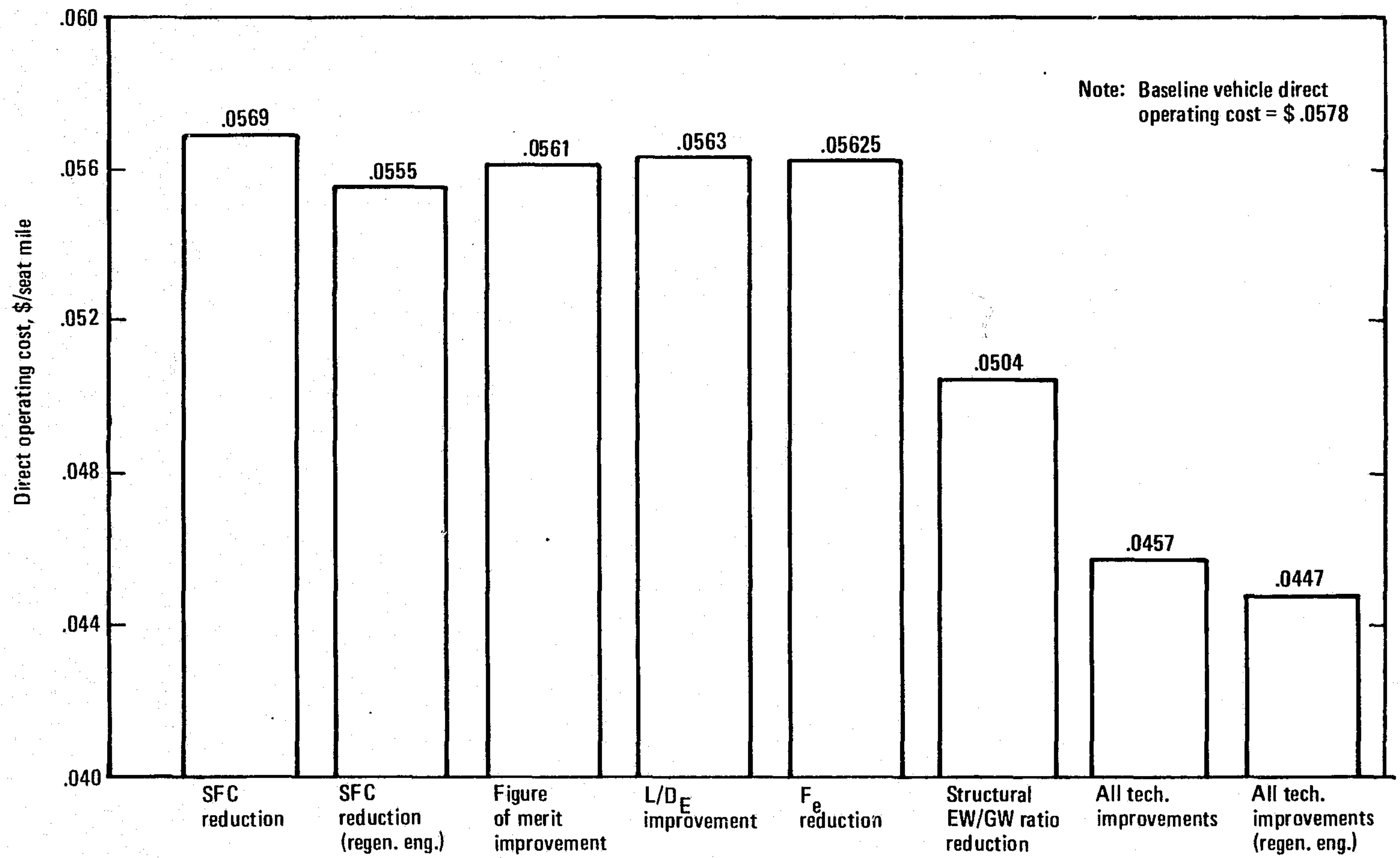

FIGURE 7.5 DIRECT OPERATING COST COMPARISON – COMPROMISE DESIGN MISSION

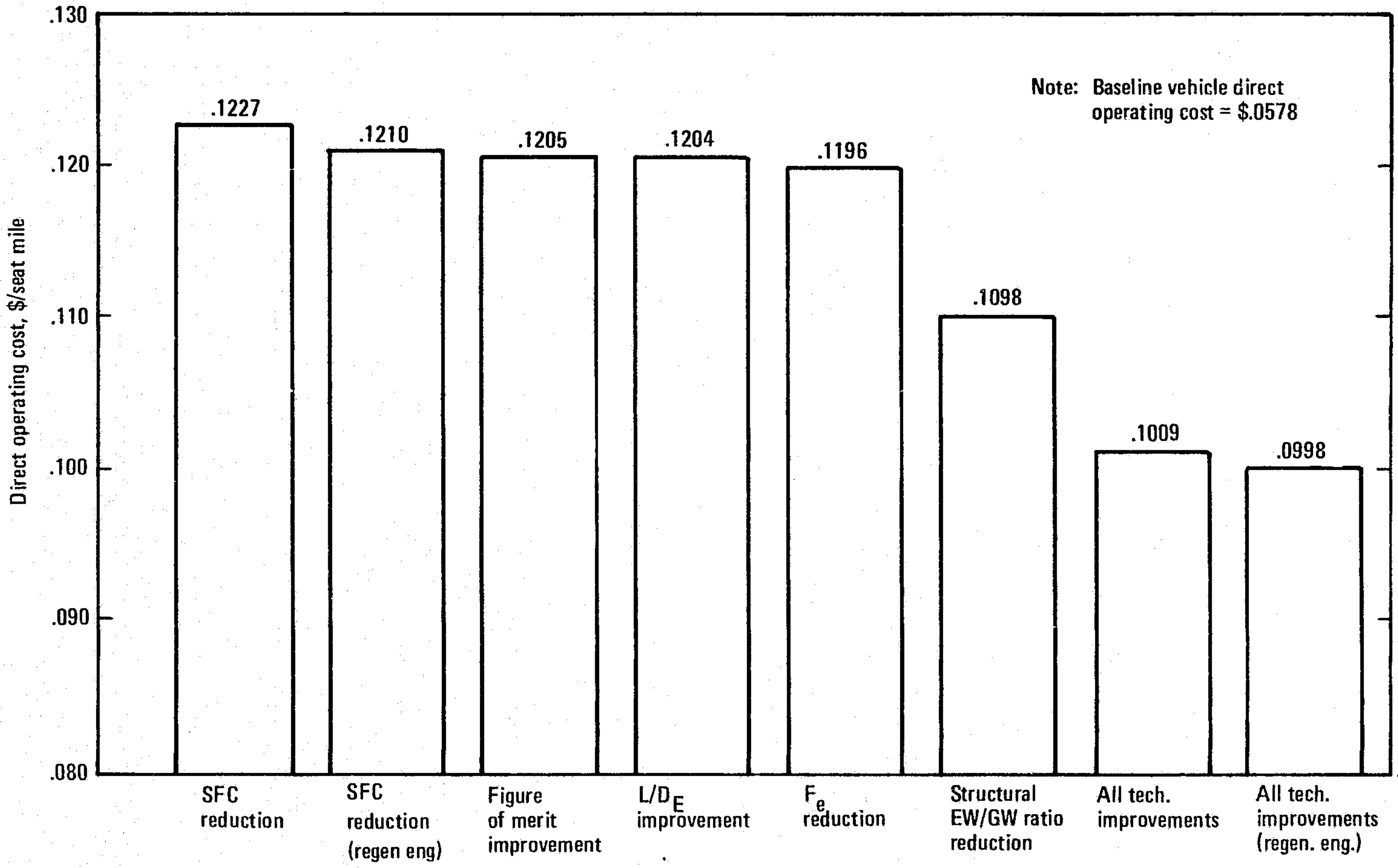

FIGURE 7.6 DIRECT OPERATING COST COMPARISON — VERY SHORT HAUL DESIGN MISSION

TABLE 7.4 ADVANCED TECHNOLOGY (1985) DESIGN POINT HELICOPTER CHARACTERISTICS

	VERY SHORT HAUL MSN HELICOPTER	COMPROMISE DSN PT. HELICOPTER
WEIGHTS		
DESIGN GROSS WEIGHT	65,101 LB.	68,924 LB.
WEIGHT EMPTY	41,741 LB.	43,910 LB.
FUEL	3,416 LB.	5,071 LB.
NO. OF PASSENGERS	100	100
ROTOR		
DISC LOADING	8.0 PSF	7.0 PSF
DIAMETER	72.0 FT.	79.2 FT.
SOLIDITY	.111	.106
NO. OF BLADES	4	4
TWIST	-12 DEG.	-12 DEG.
TIP SPEED	720 FT/SEC	705 FT/SEC
POWER		
NO. OF ENGINES	3	3
RATED POWER (S.L.,STD)/ENGINE	4037 SHP	3982 SHP
FUSELAGE		
LENGTH	88.2 FT.	88.2 FT.
WIDTH	12.92 FT.	12.92 FT.
ROTOR GAP/STAGGGER	.138	.125
PERFORMANCE		
VNRP	215 KTAS	213 KTAS
CRUISE ALTITUDE	500 FT.	2000 FT.
BLOCK SPEED	82.44 KTAS	142.6 KTAS
BLOCK TIME	1.213 HR.	1.403 HR.
FLIGHT TIME	0.639 HR.	1.003 HR.
ENERGY INTENSITY	3792 BTU/PASS-N.M.	3473 BTU/PASS-N.M.

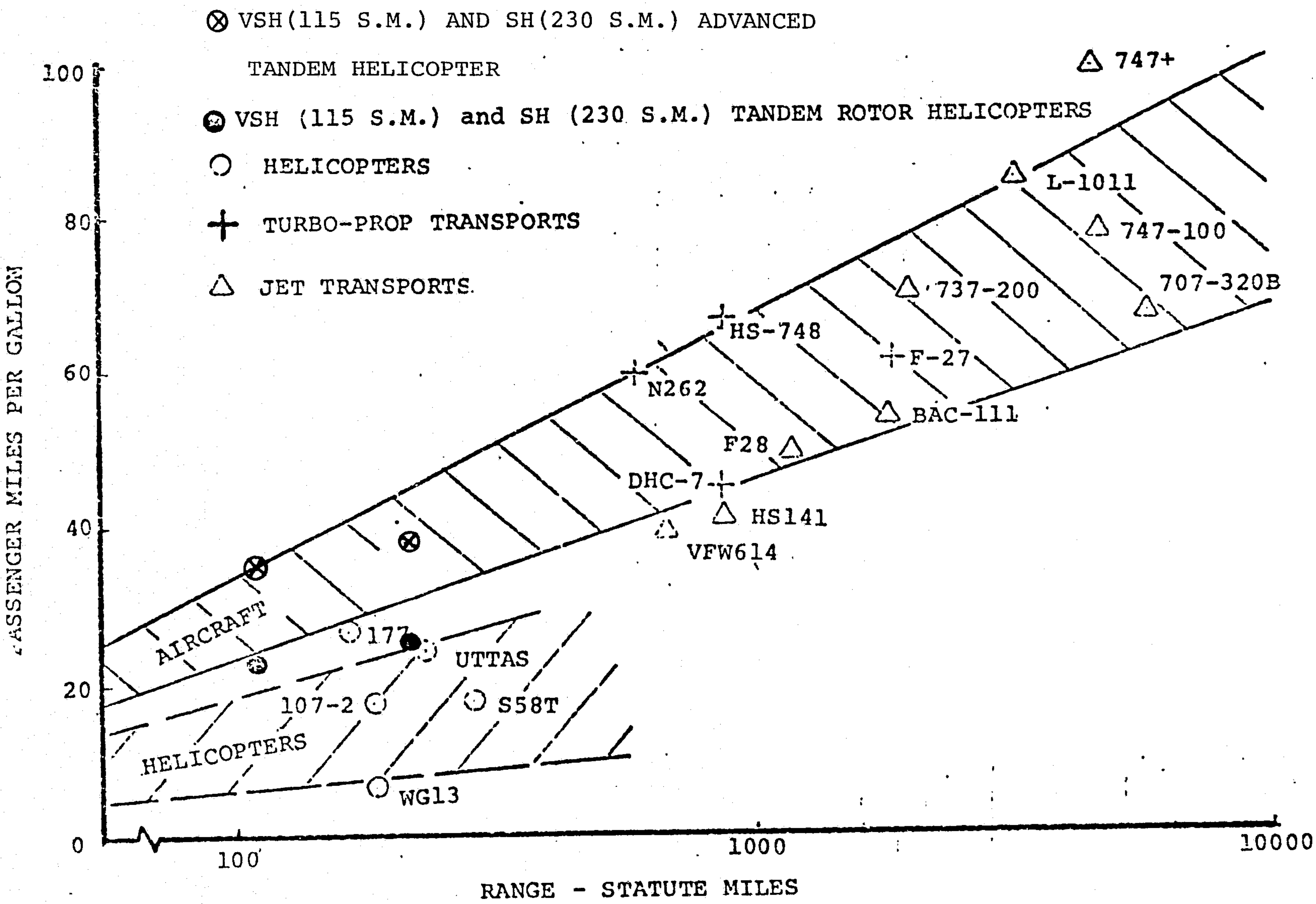

FIGURE 7.7 SUMMARY PLOT — FUEL CONSUMPTION COMPARISON OF EXISTING FIXED AND ROTARY—WING AIRCRAFT

8.0 REFERENCES

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APPENDIX A

VEHICLE SIZING GROUND RULES

Table A-1 summarizes the configuration design ground rules adhered to in the sizing of the helicopters of this study. These ground rules can be categorized under the following headings:

(1) Fuselage Configuration
(2) Rotor Solidity Sizing
(3) Engine Sizing
(4) Transmission Sizing
(5) Parasite Drag Level
(6) Vehicle Fixed Equipment and Subsystem Weights
(7) General

More detailed information pertaining to the specific headings listed above are presented by Tables A-2 thru A-8 and Figs. A-1 and A-2.

Table A-2 shows the comparative hover download and parasite drag characteristics of the 2-aisle cabin cross-section of Reference 4 and the 1-aisle circular cabin cross-section used in this study.

Table A-3 lists the vehicle Fixed Equipment weights for the 50, 75 and 100 passenger helicopters of this study - and for the Boeing 737-200 airliner on which they are based.

Tables A-4, A-5, A-6 and A-7 list respecitively the Flight Deck Accommodation, Passenger Accommodations, Cargo Accommodations and Emergency Equipment weights which are components of the Fixed Equipment weights of Table A-3 while Table A-8 lists the configurations Useful Load Weights.

Fig. A-1 depicts the rotor limit characteristics used for sizing these vehicles and Fig. A-2 shows the parasite drag levels assumed.

TABLE A-1 VEHICLE SIZING GROUND RULES SUMMARY

FUSELAGE CONFIGURATION

THE HELICOPTER DESIGN CHARACTERISTICS SPECIFIED UNDER NASA CONTRACT NAS2-8048 (SEE FIGURES 2.1 AND 2.2) UTILIZE A 2 AISLE, 6 SEAT ACROSS CONFIGURATION RESULTING IN A RELATIVELY WIDE FUSELAGE. THIS HAS BEEN MODIFIED TO A 1 AISLE CONFIGURATION, ACHIEVING A REDUCTION IN ROTOR DOWNLOAD AND PARASITE DRAG.

MANEUVER LOAD FACTOR (MLF) = 3.5 (REQUIRED BY FAR, PART 29)

ROTOR SOLIDITY SIZING

ROTOR SOLIDITY WILL BE SIZED FOR 1.25g OPERATION AT CRUISE ALTITUDE AND DESIGN CRUISE SPEED (SEE **FIGURE A-1** FOR TYPICAL ROTOR STALL FLUTTER - MAX C_T/σ LIMIT LINE)

ENGINE SIZING

3 ENGINES WILL BE USED

ENGINES WILL BE SIZED FOR OEI OPERATION @ SL, 90°F, WITH REMAINING ENGINES OPERATING @ EMERGENCY RATING OF 1.09X MAX TAKEOFF RATING

FOR CONTROL PURPOSES, THERE SHALL BE SUFFICIENT POWER INSTALLED TO ACHIEVE (@ SL, 90°F):

F/W = 1.05 (BOTH ENGINES)
F/W = 1.03 (OEI)

THIS RESULTS IN A DESIGN T/W OF:

$$T/W = 1 + D.L. + (F/W - 1.0)$$

TRANSMISSION SIZING

XMSN SIZED FOR 100% OF POWER REQUIRED @ SL, STD

PARASITE DRAG

PARASITE DRAG LEVEL(S) SHALL BE AS INDICATED IN FIGURE A-2, WITH ADVANCED TECHNOLOGY A/C HAVING DRAG REDUCED ACCORDINGLY.

WEIGHTS DATA

VEHICLE FIXED EQUIPMENT WEIGHTS (WITH THE EXCEPTION OF THOSE INDICATED) AND FIXED USEFUL LOAD WEIGHTS DEVELOPED UNDER CONTRACT NAS2-8048 WILL BE UTILIZED. THESE WEIGHTS ARE BASED ON DATA FOR THE STD BOEING 737-200 AIRLINER (WITH SUITABLE DEVIATIONS DICTATED BY HELICOPTER COMMERCIAL OPERATIONS).

A DETAILED BREAKDOWN OF THESE WEIGHTS IS GIVEN AS FOLLOWS:

TABLE A-3 - TOTAL FIXED EQUIPMENT WEIGHT
TABLE A-4 - FLIGHT DECK ACCOMMODATIONS
TABLE A-5 - PASSENGER ACCOMMODATIONS
TABLE A-6 - CARGO ACCOMMODATIONS
TABLE A-7 - EMERGENCY ACCOMMODATIONS
TABLE A-8 - TOTAL USEFUL LOAD

VEHICLE SUBSYSTEM WEIGHTS WILL BE DEVELOPED AS A FUNCTION OF TECHNOLOGY LEVEL.

GENERAL

DESIGN (SIZE) HELICOPTERS FOR BOTH THE VERY SHORT HAUL AND SHORT HAUL MISSION SCENARIOS.

- IN THE CASE OF THE HELICOPTER SIZED FOR THE SHORT HAUL MISSION, USE THE VSH MISSION AS A SECONDARY MISSION REQUIREMENT AND DETERMINE THE FUEL EXPENDED FLYING IT.

TABLE A-2 COMPARISON OF DOWNLOAD AND PARASITE DRAG OF TWO FUSELAGE CROSS–SECTIONS

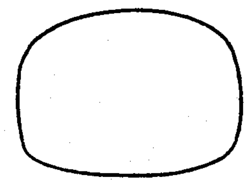
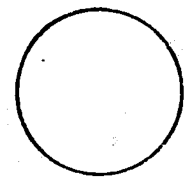
CABIN CROSS SECTION		
$\frac{\text{DOWNLOAD}}{\text{THRUST}}$	.086	.0309 (64% REDUCTION)
FUSELAGE PARASITE DRAG ~ FT^2	10.019	8.887 (11.3% REDUCTION)

TABLE A-3 FIXED EQUIPMENT WEIGHTS

	737-200	HELICOPTER		
	88 PASSENGERS Lbs	50 PASSENGERS Lbs	75 PASSENGERS Lbs	100 PASSENGERS Lbs
APU	830	470	700	940
Instruments	552	575	575	575
Electronics	846	846	846	846
Electrical	1,081	615	920	1,230
Hydraulics & Pneumatics	864	390	555	680
Flight Deck Accommod.	587	568	568	568
Passenger Accommodations	6,239	3,307	5,060	6,502
Cargo Accommodations	613	160	240	320
Emergency Accommodations	363	128	138	145
Air Conditioning	1,190	575	890	1,150
Anti-Icing	212	225	325	400
TOTAL FIXED EQUIPMENT	13,377	7,859	10,817	13,356

	737-200 88 PASSENGERS (Lbs)	HELICOPTERS 50 PASSENGER (Lbs)	HELICOPTERS 75 PASSENGER (Lbs)	HELICOPTERS 100 PASSENGER (Lbs)
Seats and Belts	129	(110)	(110)	(110)
Pilot-CoPilot 40*x2		80	80	80
Observer 30 xl		30	30	30
Instrument Boards	105	105	105	105
Control Stands	70	70	70	70
Sound-Proofing	98	98	98	98
Lining	62	62	62	62
Manuals	5	5	5	5
Windshield Wiper	9	9	9	9
Rain Repellent System	22	22	22	22
Misc. Equipment	(23)	(23)	(23)	(23)
Sun Visor	5	5	5	5
Mirror	1	1	1	1
Foot Rests	2	2	2	2
Waste Containers	3	3	3	3
Ash Trays & Cup Holders	3	3	3	3
Stowage & Holders	7	7	7	7
Overhead Drain Tube	2	2	2	2
Lighting	34	34	34	34
Wiring, Etc.	30	30	30	30
TOTAL FLIGHT DECK ACCOMMODATIONS	587	568	568	568

*Quote from Study Outline

TABLE A-4 WEIGHTS FOR FLIGHT DECK ACCOMMODATIONS

	737-200	HELICOPTER		
	88 PASSENGERS	50 PASSENGERS	75 PASSENGERS	100 PASSENGERS
	Lbs	Lbs	Lbs	Lbs
Seats and Belts	(2,285)	(1,144)	(1,694)	(2,244)
Passengers 22# Each	2,227	1,100	1,650	2,200
Attendants 22# Each	58	44	44	44
Lavatories	453	227	453	453
Stowage	(456)	(258)	(389)	(515)
Overhead	305	175	263	350
Magazine	8	4	8	8
Coat Racks	74	40	60	80
Food Trays	10	5	8	10
Under Seat	59	34	50	67
Soundproofing	686	390	585	780
Lining	989	563	844	1,125
Floor Covering	296	170	255	340
Beverage Service	424	240	361	482
Attendant's Panels	21	15	20	20
Partitions	89	45	90	90
Window Shades	55	30	45	60
Lowered Ceiling	130	---	---	---
Wash & Drinking Fac.	67	34	50	67
Signs and Markings	2	2	2	2
Lighting	243	160	230	280
Safety Straps	4	4	4	4
Finishing Panels	39	25	38	40
TOTAL PASSENGER ACCOMMODATIONS	6,239	3,307	5,060	6,502

TABLE A-5 PASSENGER ACCOMMODATIONS

	737-200 88 PASSENGERS (Lbs)	HELICOPTERS 50 PASSENGERS (Lbs)	75 PASSENGERS (Lbs)	100 PASSENGERS (Lbs)
Baggage Compartments	-	40	60	80
Insulation	134	40	60	80
Lining	247	80	120	160
Tie-Down	19	--	--	--
Mets	47	--	--	--
Partitions	73	--	--	--
Warm Air Ducts	17	--	--	--
Attachments	76	--	--	--
TOTAL CARGO ACCOMMODATIONS	613	160	240	320

TABLE A-6 CARGO ACCOMMODATIONS

	737-200 88 PASSENGERS (Lbs)	HELICOPTERS 50 PASSENGERS (Lbs)	75 PASSENGERS (Lbs)	100 PASSENGERS (Lbs)
Oxygen System	(132)	--	--	--
Passenger	95	--	--	--
Crew	37	--	--	--
Fire & Smoke Protection	(115)	(87)	(97)	(104)
Detection	58	42	50	58
Extinguishing	46	45	47	46
Viewers-Cargo Comp. & Gear Downlock	11	--	--	--
Escape Provisions	(75)	--	--	--
Slides	65	--	--	--
Ropes	10	--	--	--
Hand Fire Extinguishers	31	31	31	31
First Aid	6	6	6	6
Axes	4	4	4	4
TOTAL EMERGENCY EQUIPMENT	363	128	138	145

TABLE A-7 EMERGENCY EQUIPMENT — HELICOPTER

	737-200	HELICOPTER		
	88 PASSENGERS	50 PASSENGERS	75 PASSENGERS	100 PASSENGERS
	Lbs	Lbs	Lbs	Lbs
Flight Crew	340	340	340	340
Flight Attendants	390	140	280	280
Crew Baggage	125	94	125	125
Brief Cases & Navigational Equipment	25	25	25	25
Unusable Fuel	115	70	90	115
Oil	132	95	114	132
Emergency Equipment	(187)	(16)	(16)	(16)
Oxygen	36	--	--	--
Escape Slides	132	--	--	--
Fire Axe	3	--	--	--
Oranasal Masks	5	5	5	5
Smoke Goggles	1	1	1	1
Hand Megaphones	10	10	10	10
Passenger Accommodations	(1,464)	(455)	(696)	(910)
Water	179	100	150	200
Toilet Chemicals	50	25	50	50
Beverage	171	97	146	194
Serving Trays	12	7	11	14
Galley Structure	600	--	--	--
Galley Service Equip.	228	114	171	228
Passenger Service Equip.	224	112	168	224
Passengers	15,840	9,000	13,500	18,000
TOTAL USEFUL LOAD (NOT INCLUDING FUEL)	18,618	10,235	15,186	19,943

TABLE A.8 USEFUL LOAD

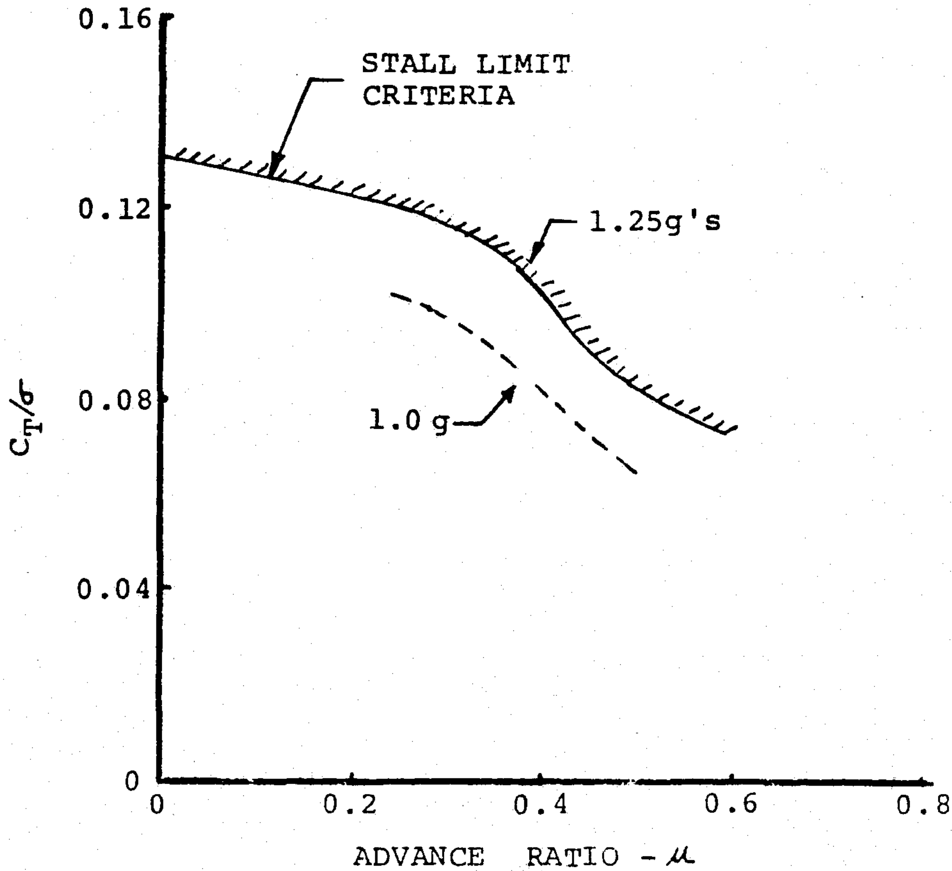


FIGURE A.1 TANDEM HELICOPTER – ROTOR SOLIDITY SIZING TREND; ROTOR LIMITS

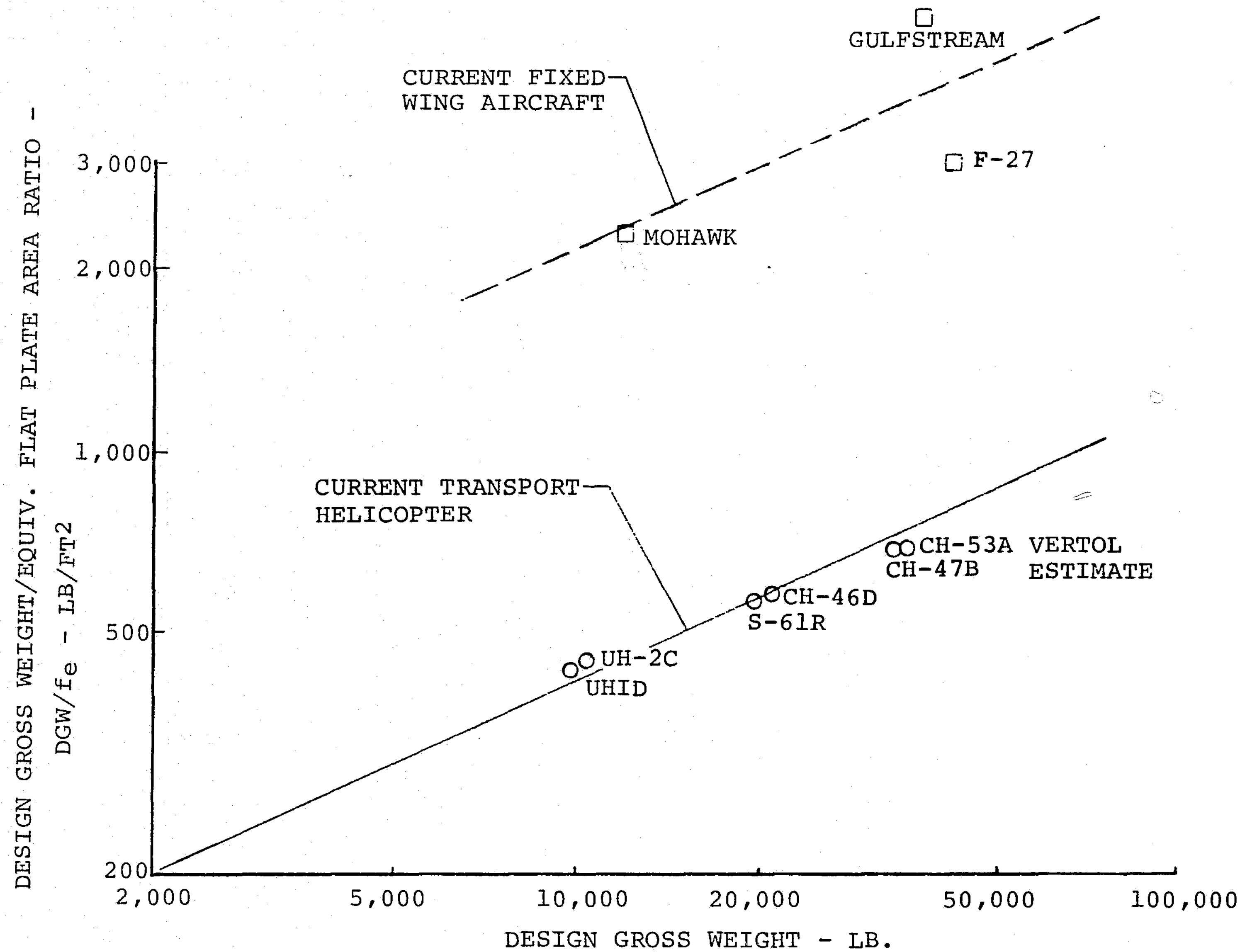


FIGURE A.2 PARASITE DRAG TRENDS

APPENDIX B

ADVANCED TECHNOLOGY VEHICLE PARAMETRIC RESIZING DATA

B.1 Parameter Variation

The parameters (and their variation) utilized in this study are as follows:

Parasite Drag	- 0, 25, 50% Reduction
Fuel Consumption	- 0, 5, 10% Reduction
Structural Empty/Gross Weight Ratio	- 0, 5, 10, 15% Reduction
Rotor Hover Efficiency (F.M.)	- 0, 5, 10, 15% Increase
Rotor Cruise Efficiency (L/D_E)	- 0, 10, 20% Increase

The parametric value levels assumed for this study are for the purpose of defining the sensitivity of energy consumption -- and should not necessarily be assumed to be attainable. The actual technology levels estimated to be attainable are defined in Section 6.0.

B.2 Parameter Definitions

B.2.1 Parasite Drag

Parasite drag is the total configuration drag (including rotor hub(s)) which must be overcome by the helicopter in forward flight. As used in this study, it is expressed as equivalent parasite drag area (drag/dynamic pressure), or F_e, whose units are square feet. Values of the baseline vehicle parasite drags are given in Tables 4.8 and 5.1.

B.2.2 Fuel Consumption

No attempt is made to reject fuel consumption reductions due to improvements in specific fuel-consumption only over a limited range of power settings (i.e., a modification of SFC vs. power characteristics). Rather it is assumed that SFC is reduced over the entire operating range of the engine. For example, a 5% reduction in fuel consumption (compared to the baseline vehicles) refers to an across the board reduction of 5% in engine SFC.

B.2.3 Structural Empty/Gross Weight Ratio

Structural empty weight is defined as empty weight minus the fixed equipment weight. For example, the structural empty weight of the compromise design point helicopter is 56,073 lb -13,356 lb = 42,717 lb. For comparisons of vehicle weight reductions due to materials/structures technology improvements, structural empty weight is a more meaningful parameter than total empty weight, since it is freed of the obscuring effect of fixed equipment weight, which itself is only a function of the design mission. Likewise, percentage reductions in the structural empty/gross weight ratio are a more meaningful means of evaluating materials/structures technology improvements than percentage reductions in empty weight, since the structural empty/gross weight ratio automatically reflects the iterative scaling effect of empty weight reduction on gross weight in the sizing process. Therefore, all the empty weight reductions presented will be in terms of percentage reductions in structural empty/gross weight.

B.2.4 Rotor Hover Efficiency

Hover efficiency or F.M. is a measure of a rotor's efficiency in converting power into static (hover) thrust. The F.M.'s referred to in this study are the design point condition (SL, 90°F) values used in configuration engine sizing. Note that the percentage improvement in F.M. referred to in Section 5.2 is not a F.M. to be added to the baseline F.M., but is a percentage change of that baseline value. For example, a 10% improvement to a baseline F.M. of .75 is .75 + .075 = .825, not .75 + .10 = .85.

B.2.5 Rotor Cruise Efficiency

Rotor cruise efficiency, or L/D_E, is a measure of a rotor's efficiency in producing lift while overcoming its own equivalent drag. the L/D_E's varied in this study are the cruise L/D_E's occurring at the vehicle normal rated power speed. As such, they are lower than the rotor's maximum L/D_E value which occurs at a lower speed.

It should also be noted that these are isolated rotor L/D_E's. This is of interest since inherently a tandem rotor configuration suffers from mutual rotor interference effects (reduced to some extent by decreasing rotor overlap), which results in a lowering of the overall L/D_E for both rotors. Percentage improvements in L/D_E are defined in the same manner as for F.M. in Section B.2.4.

B.3 Data Utilization and Interpretation

This data is meant to be used in determinign the effect of various technology improvements on the energy consumption, gross weight, and developmental and operating costs of a tandem rotor commercial helicopter. Used in conjunction with a given set of technology improvement estimates and the baseline vehicle data of Tables 5.1 and 5.2, the data enables a quick, accurate estimate of the size, energy usage, and cost of such a vehicle. As illustrated in Figure 5.1, the determination of the energy intensity reduction, based on the variation of one parameter at a time, is simply a matter of "sliding" along the applicable data plot.

At times, data interpolation is required, since each data plot is for a given combination of parasite drag reduction and rotor figure of merit improvement. For example, the figure of merit improvement projected by 1985 is 9.3%. Determination of the corresponding energy intensity reduction requires that data be read from Figures B-1, B-2 and B-3 (figure of merit improvements = 0, 5 and 10%, parasite drag reductions = 0%), assuming zero change in the other parameters (EW/GW, fuel consumption, and L/D_E), and cross plotted.

More extensive interpolation and cross plotting is needed if the effect of the simultaneous variation of several parameters on energy intensity is to be obtained. For example, determining

More extensive interpolation and cross plotting is needed if the effect of the simultaneous variation of several parameters on energy intensity is to be obtained. For example, determination of the energy intensity reduction resulting from the combined effect of all the technology improvements listed in Table 5.3 is as follows:

(1) Data is read from Figures B-1, B-2, and B-3 for values of fuel consumption reduction, EW/GW reduction, and L/D_E improvement of 4.76, 12.1 and 20%, respectively. The resulting percentage energy intensity reductions are plotted versus figure of merit improvement and the percentage energy intensity reduction for a figure of merit improvement of 9.3% determined.

(2) The procedure of (1) is repeated for parasite drag reductions of 25 and 50% using Figures B-5, B-6, B-7, B-9, B-10, and B-11.

(3) The resulting values of percentage energy intensity reductin o are plotted versus parasite drag reduction and the value of energy intensity reduction for a 54% reduction in parasite drag read off.

It is very important to note tha the effect of combined parameter variation on the data of this study is not obtainable by simple addition of the individual components. For example, summation of the individual energy intensity reductions listed in Table 5.3 results in a total value of 37.1% compared to the actual value of 30.35% obtained by the interpolation process discussed above.

Inspection of the data reveals that, comparatively speaking, the largest decreases in energy intensity are obtained when the structural empty/gross weight ratio is reduced and the rotor hover efficiency is improved. The former is due to the beneficial influence that reducing the structural empty weight fraction has on the vehicle sizing process itself. The latter is simply a manifestation of improved fuel consumption due to the smaller sized engines dictated by the higher figure of merit.

B.4 Data Presentation

The technology improvement resizing data, is grouped in the following manner:

Energy Intensity (Compromise Design)	Figure B-1	→	B-12
Gross Weight (Compromise Design)	Figure B-13	→	B-24
Direct Operating Cost (Compromise Design)	Figure B-25	→	B-36
Flyaway Cost (Compromise Design)	Figure B-37	→	B-48
Energy Intensity (Very Short Haul MIssion)	Figure B-49	→	B-60
Gross Weight (Very Short Haul Mission)	Figure B-61	→	B-72
Direct Operating Cost (Very Short Haul Mission)	Figure B-73	→	B-84
Flyaway Cost (Very Short Haul Mission)	Figure B-85	→	B-96

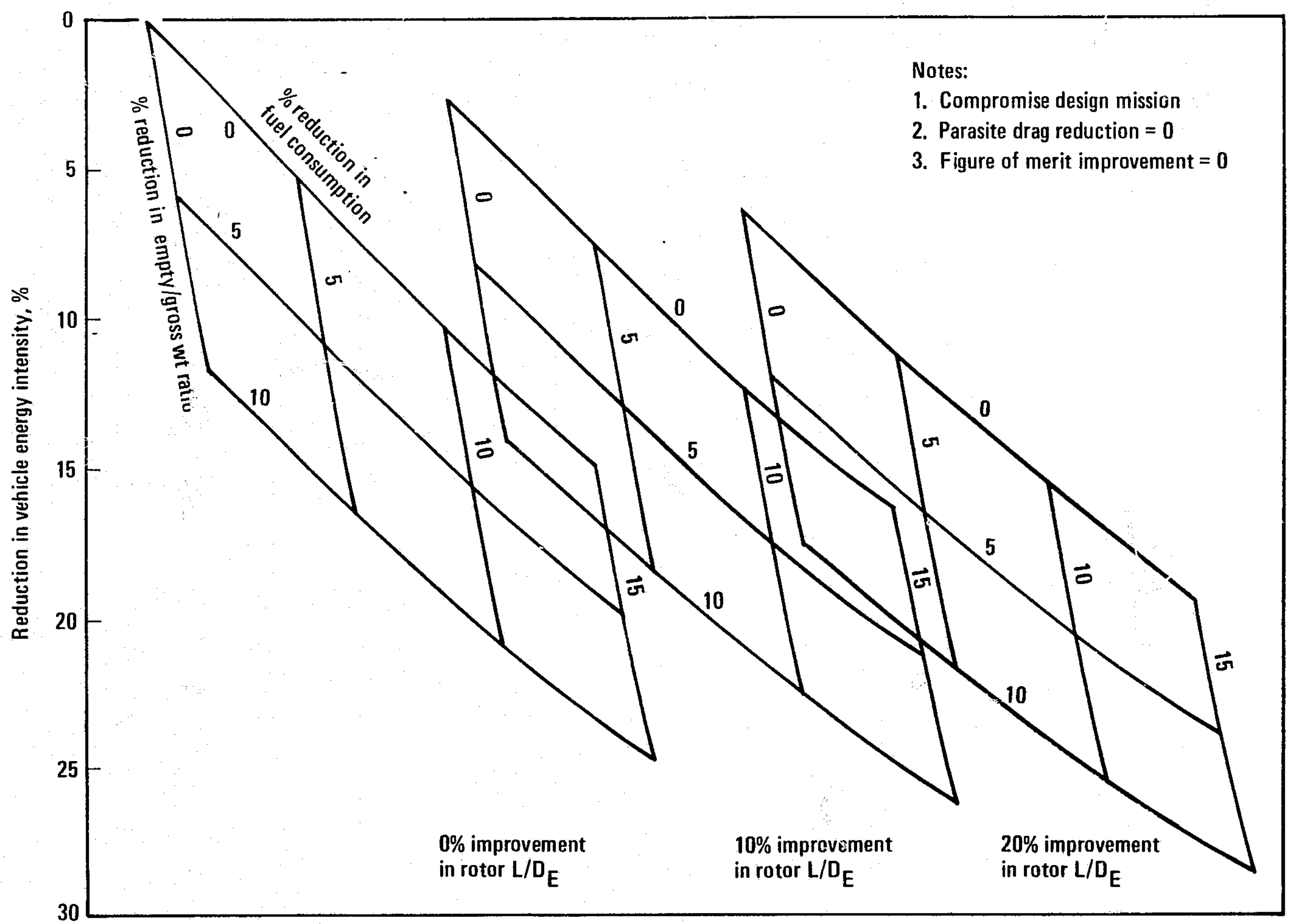


FIGURE B-1 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

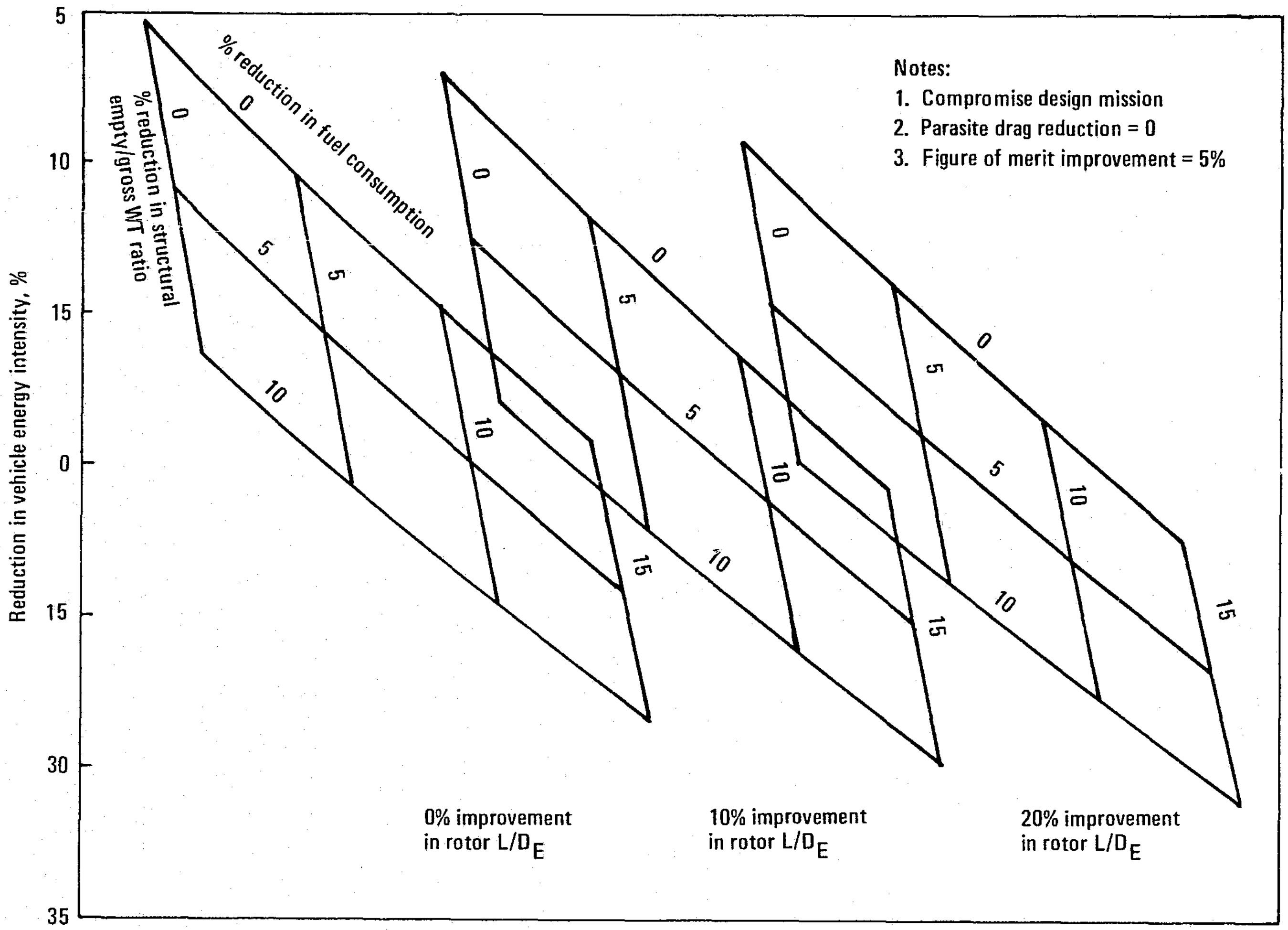


FIGURE B-2 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

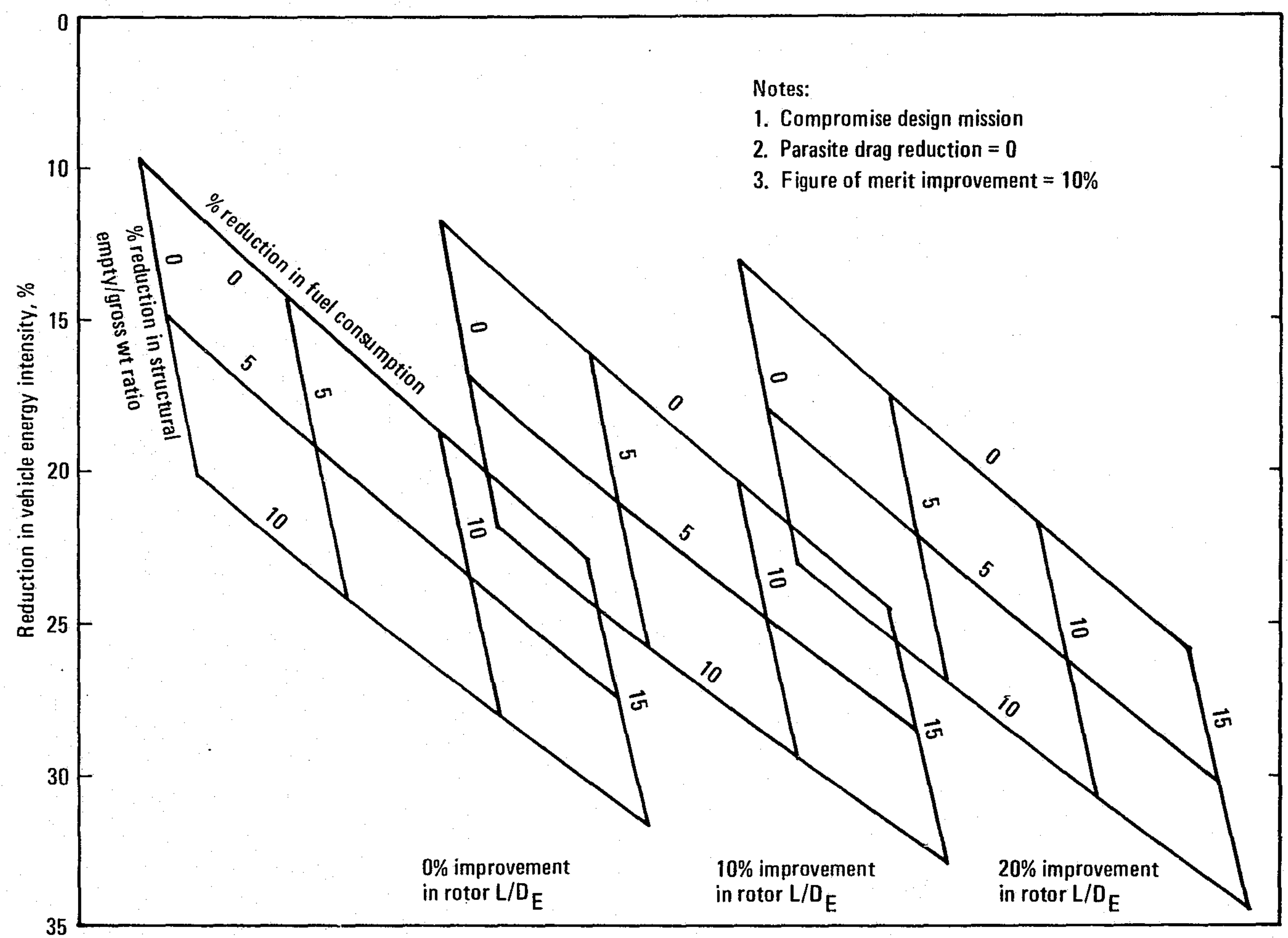


FIGURE B-3 EFFECT OF TECHNOLOGY IMPROVEMENTS ON ENERGY INTENSITY

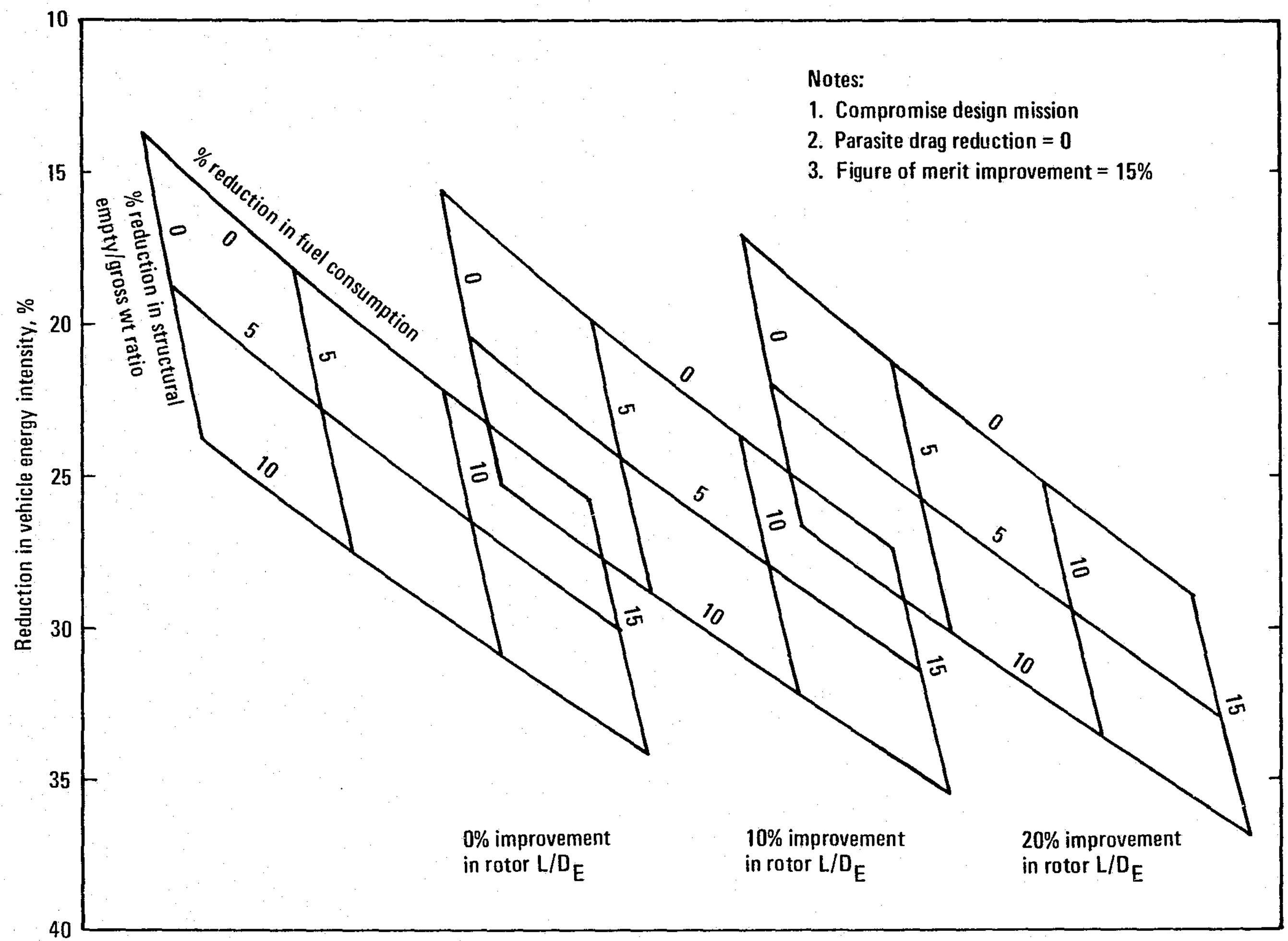


FIGURE B-4 EFFECT OF TECHNOLOGY IMPROVEMENTS ON ENERGY INTENSITY

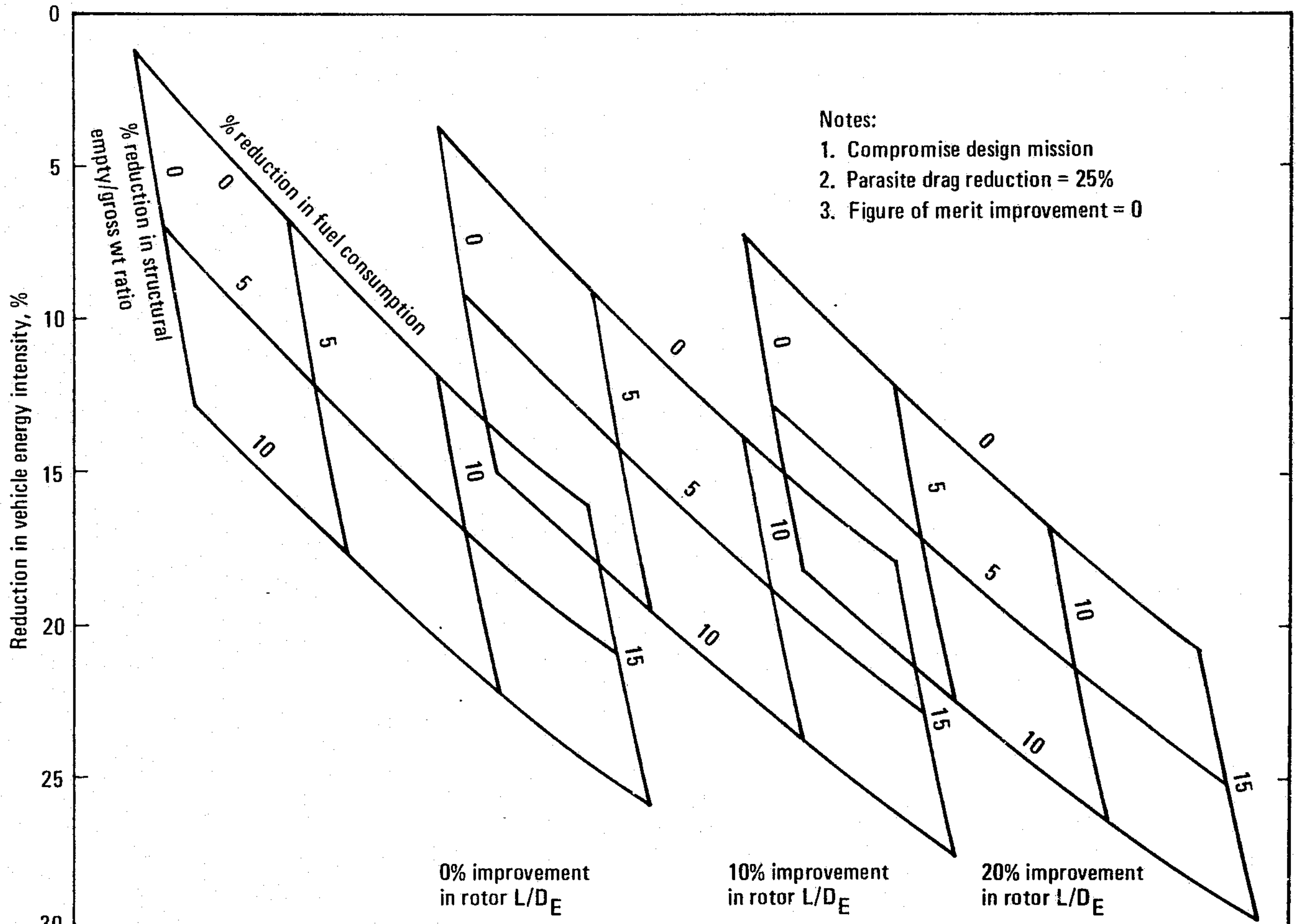


FIGURE B-5 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

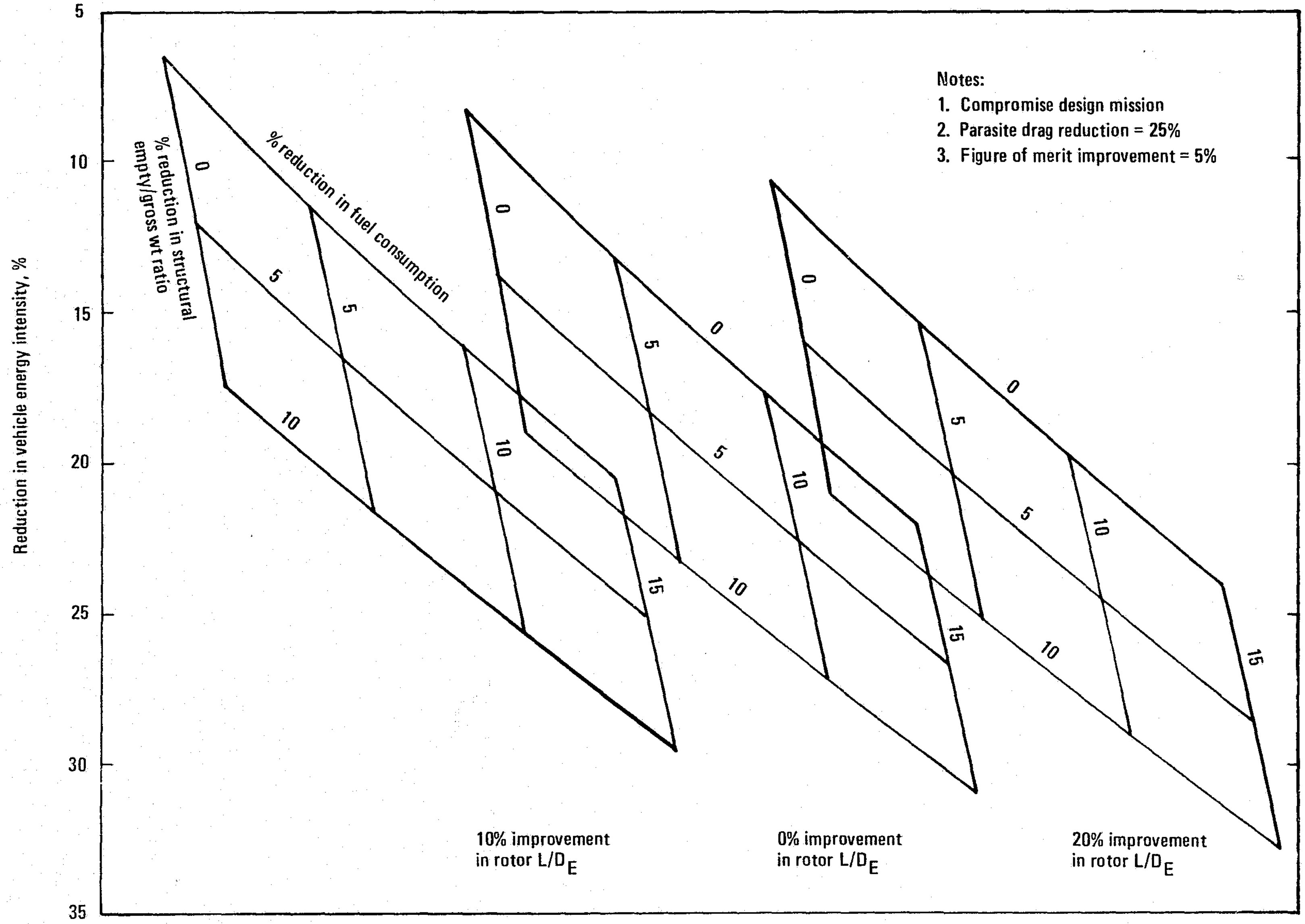


FIGURE B-6 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

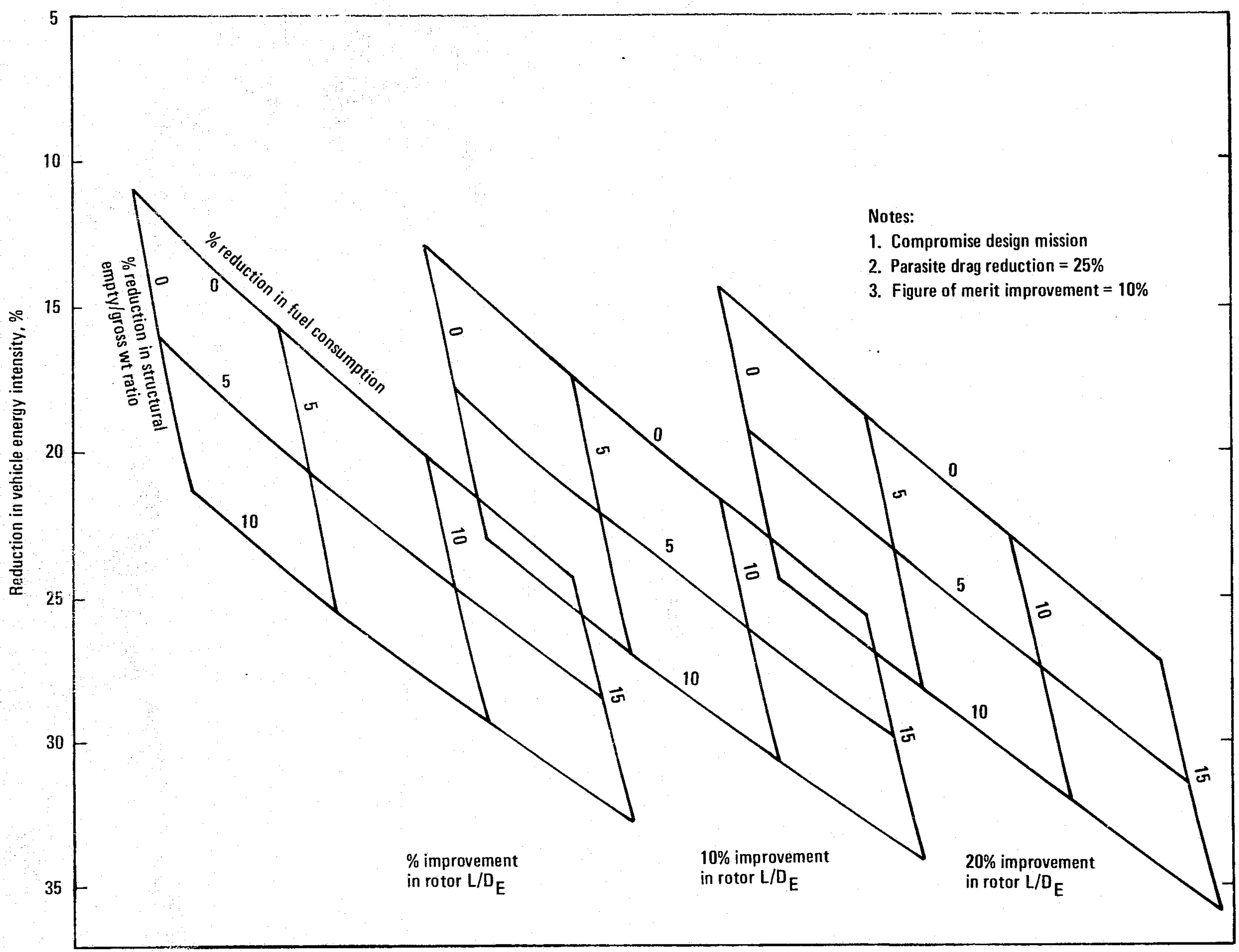


FIGURE B-7 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

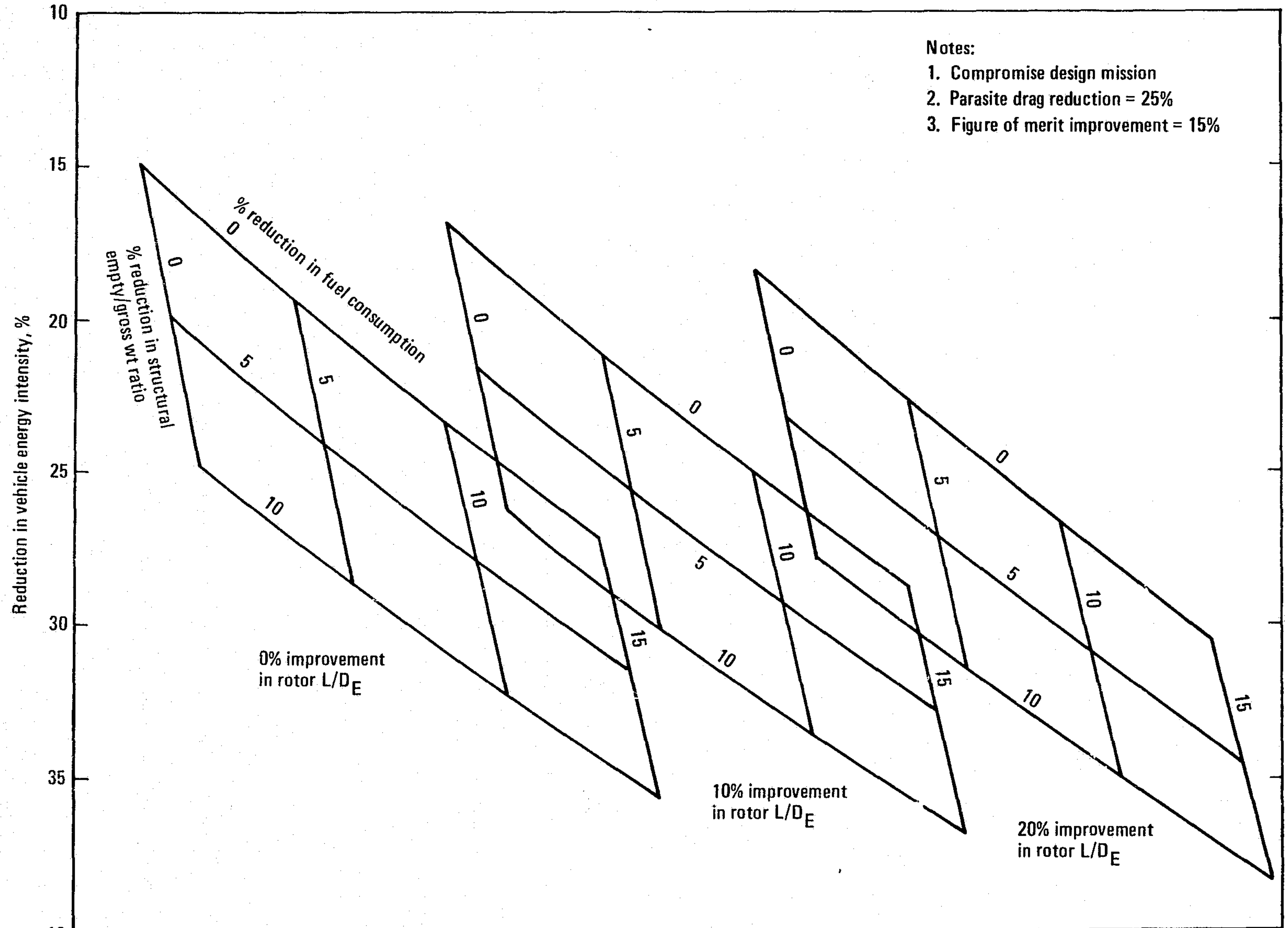


FIGURE B-8 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

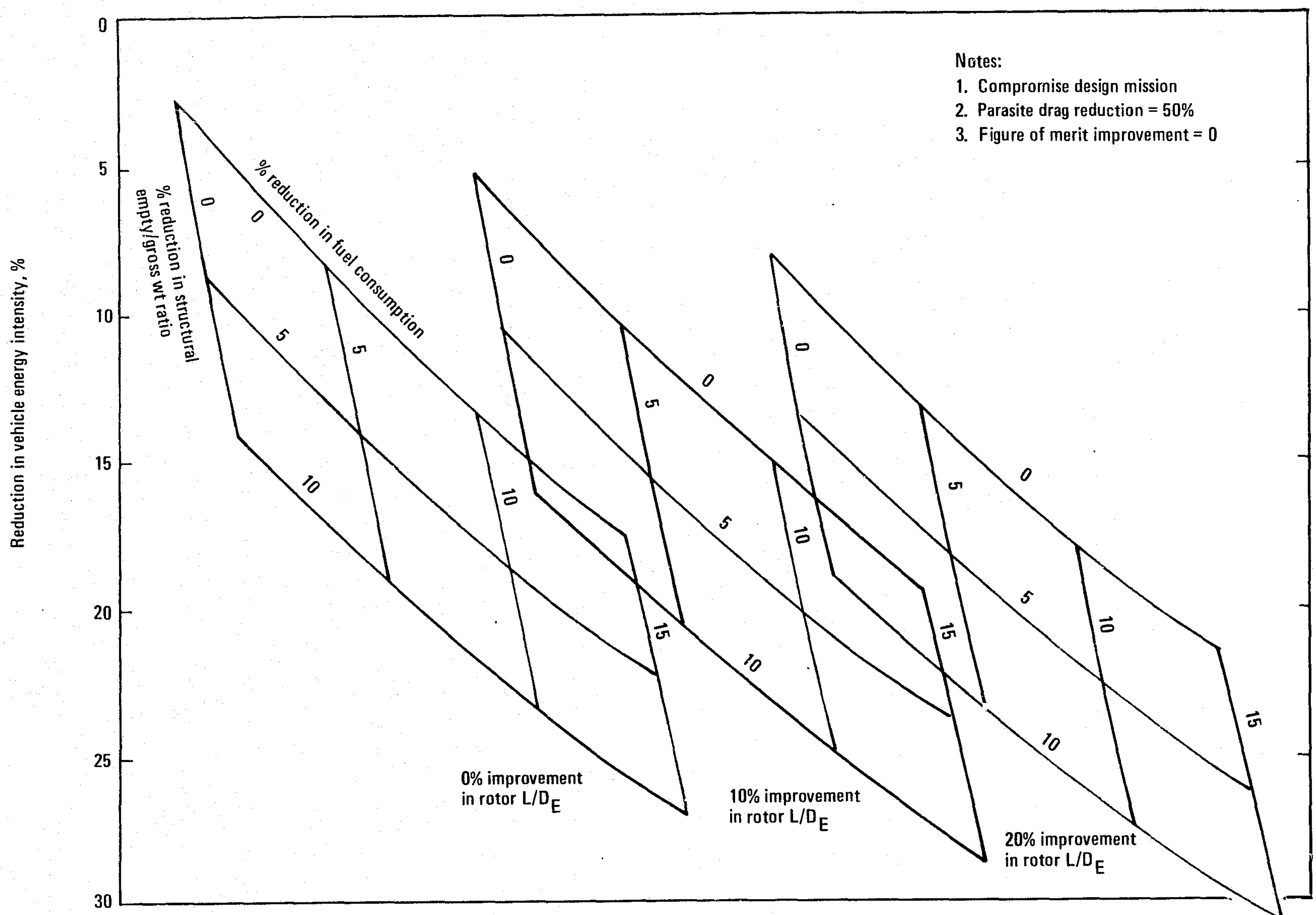


FIGURE B-9 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

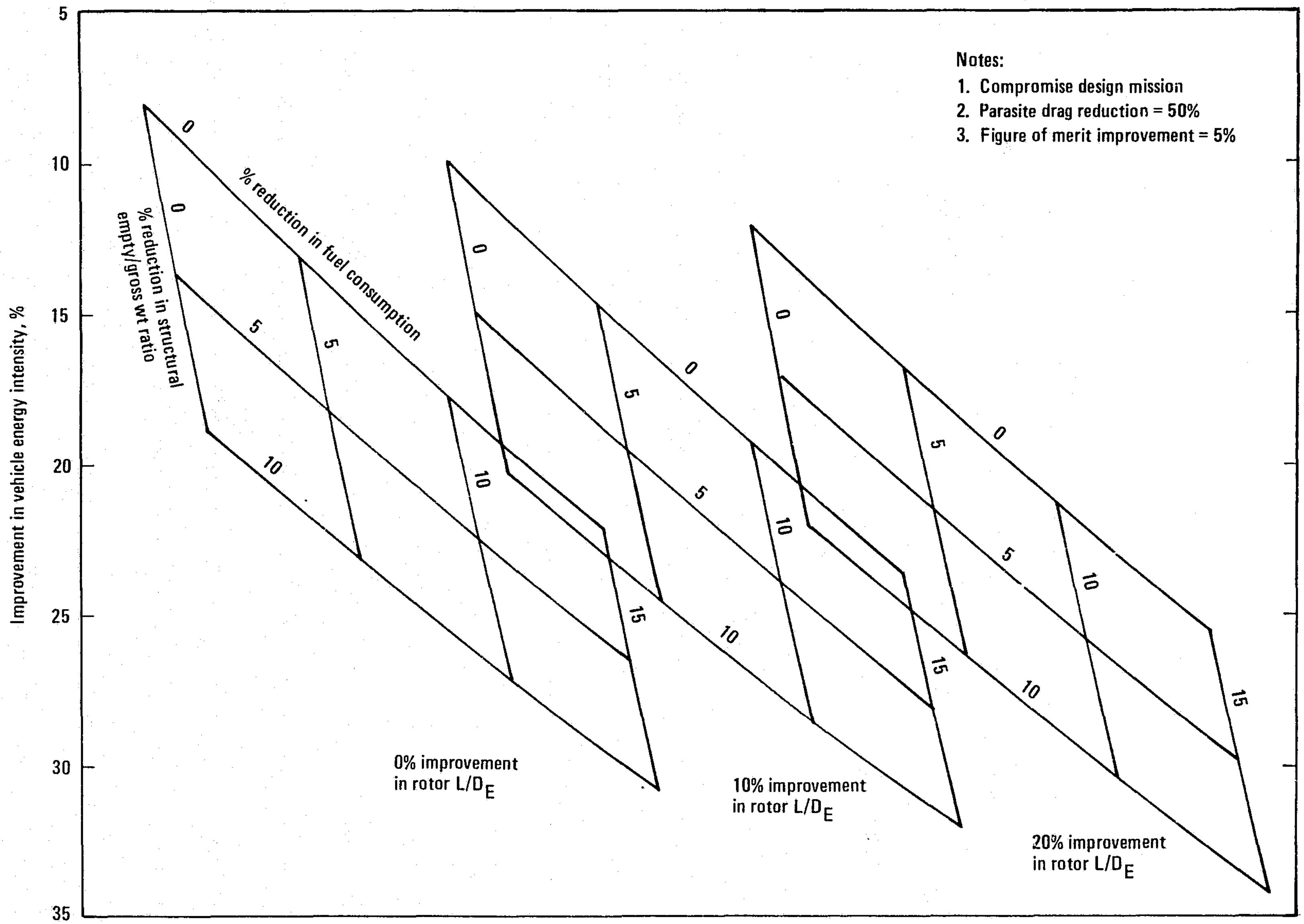


FIGURE B-10 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

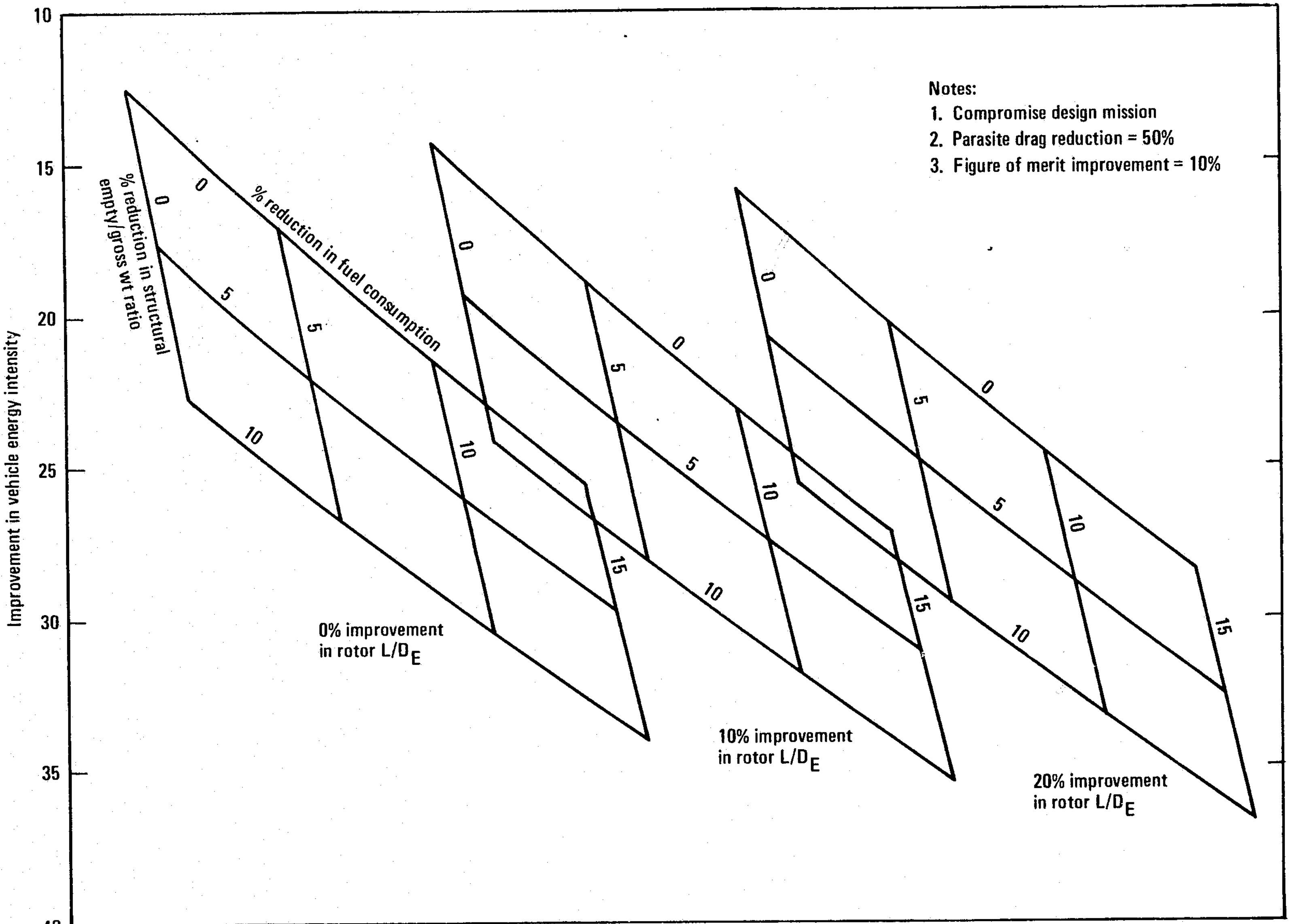


FIGURE B-11 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

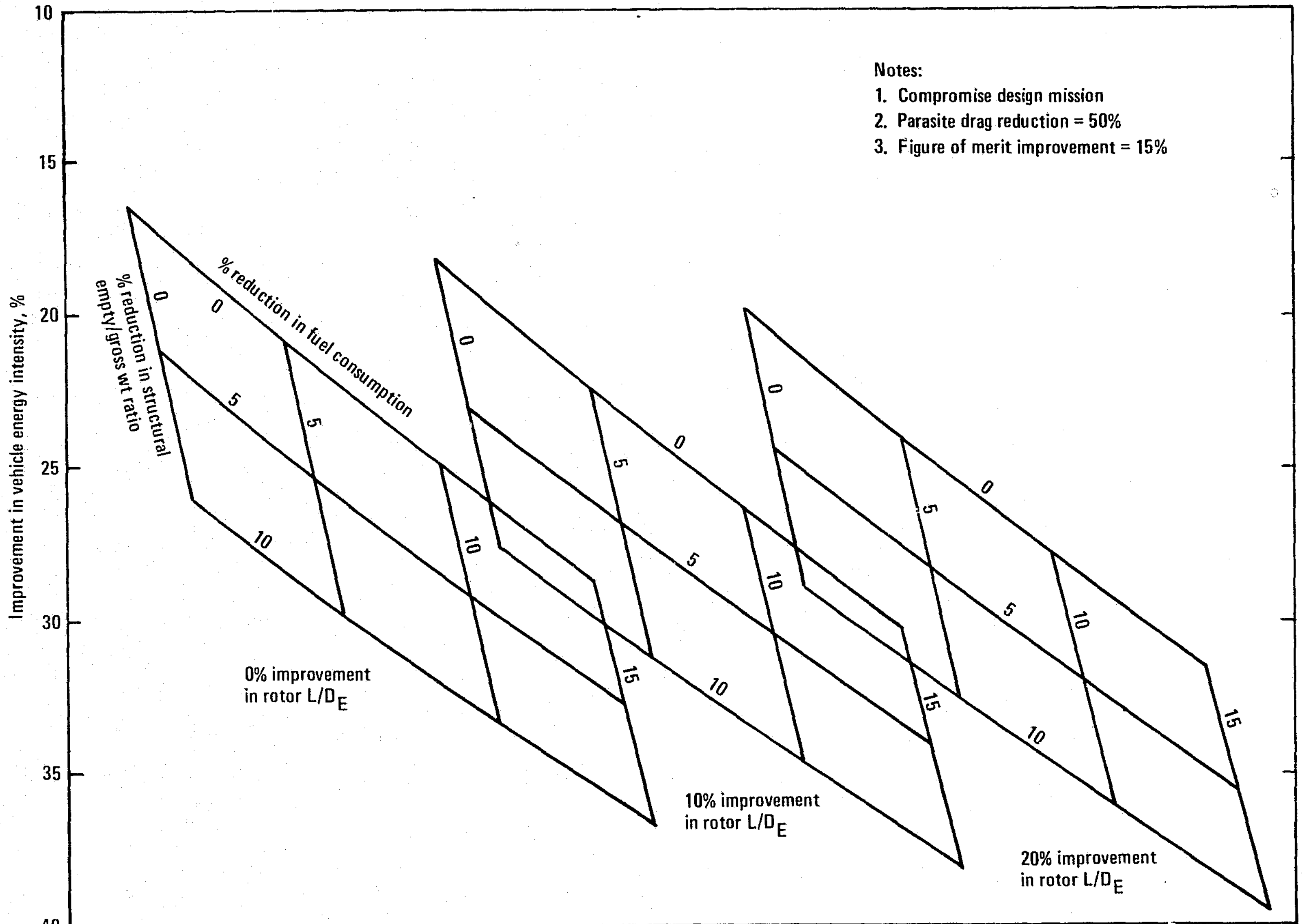


FIGURE B-12 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

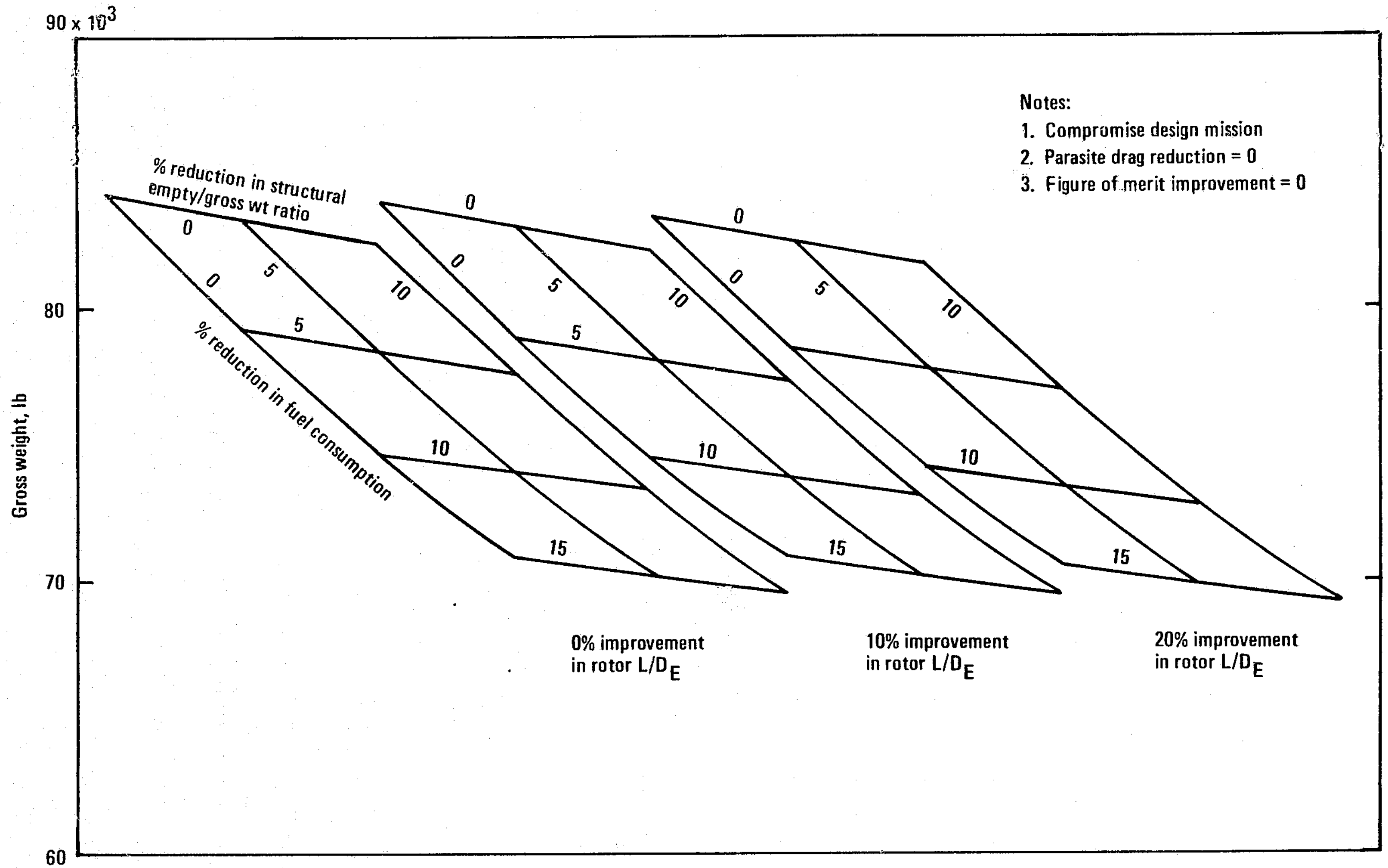


FIGURE B-13 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

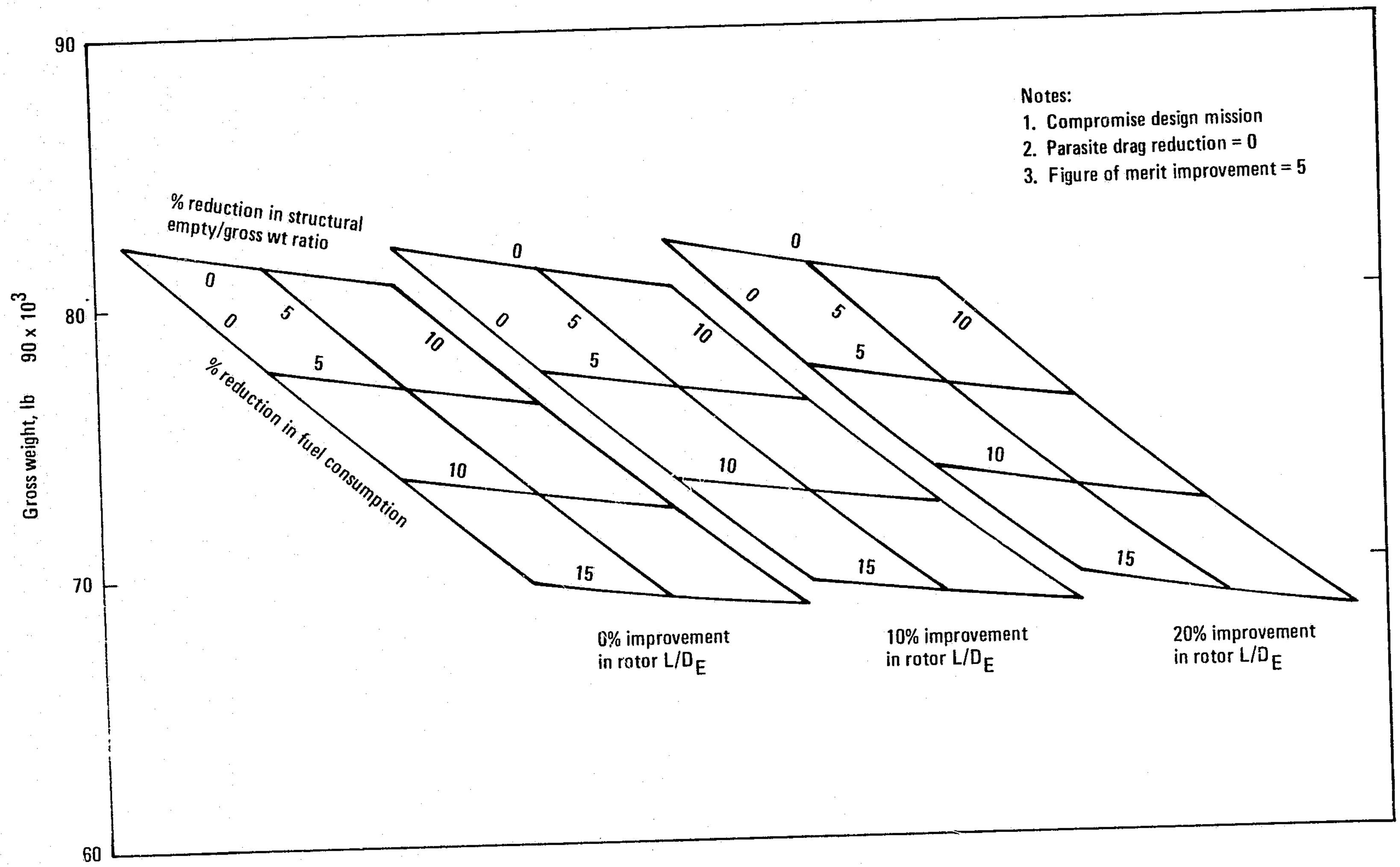


FIGURE B-14 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

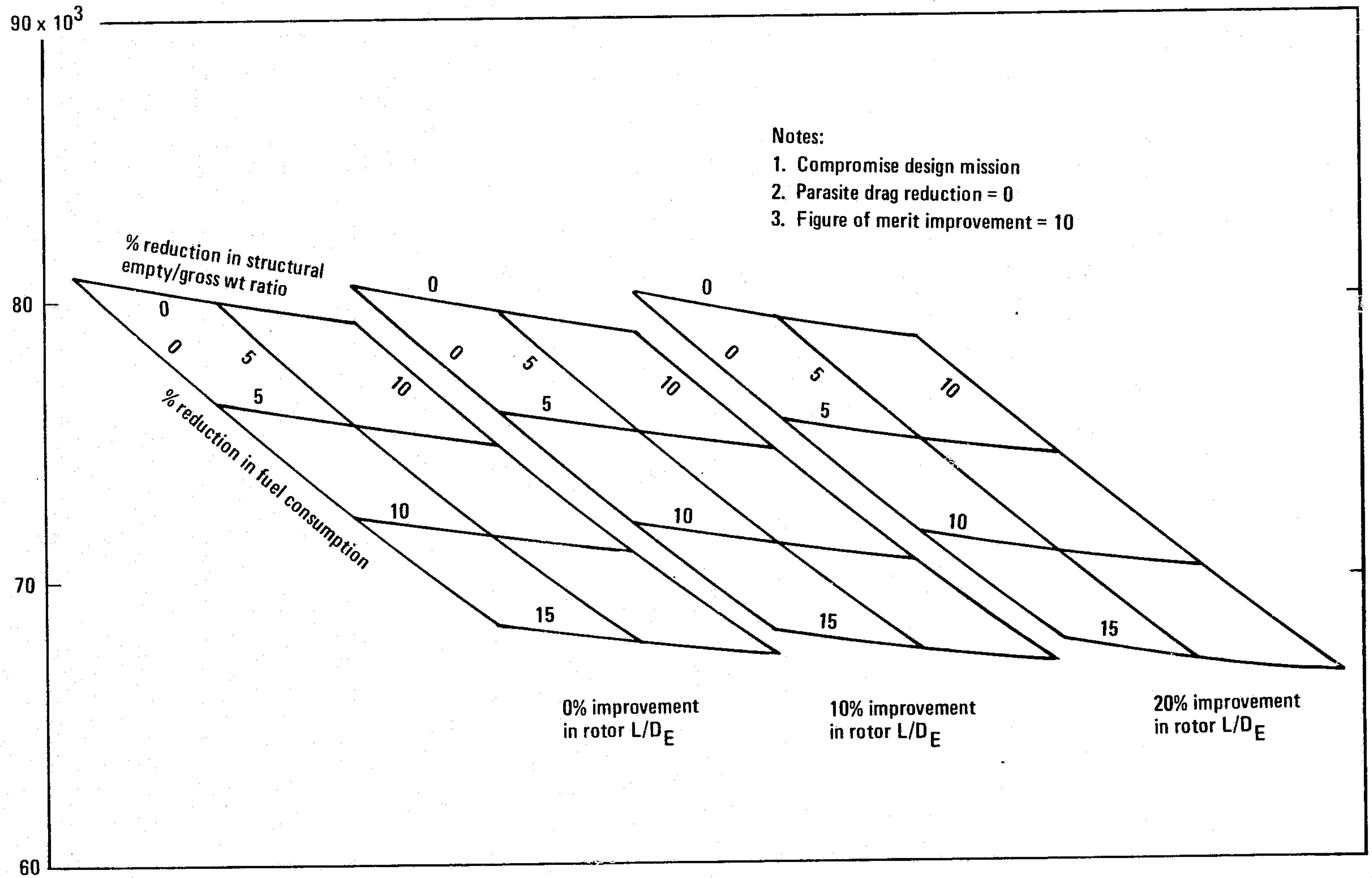


FIGURE B-15 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

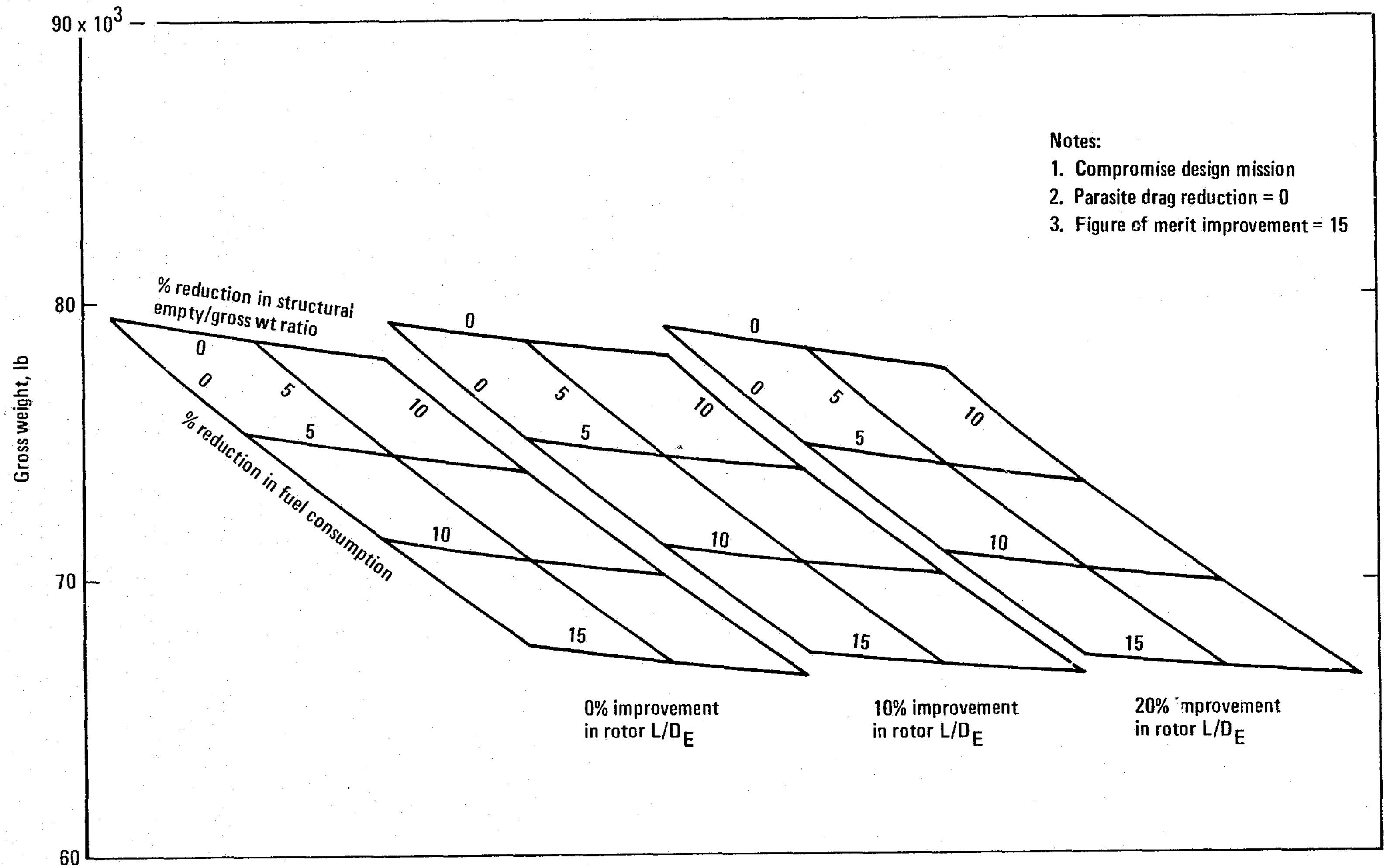


FIGURE B-16 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

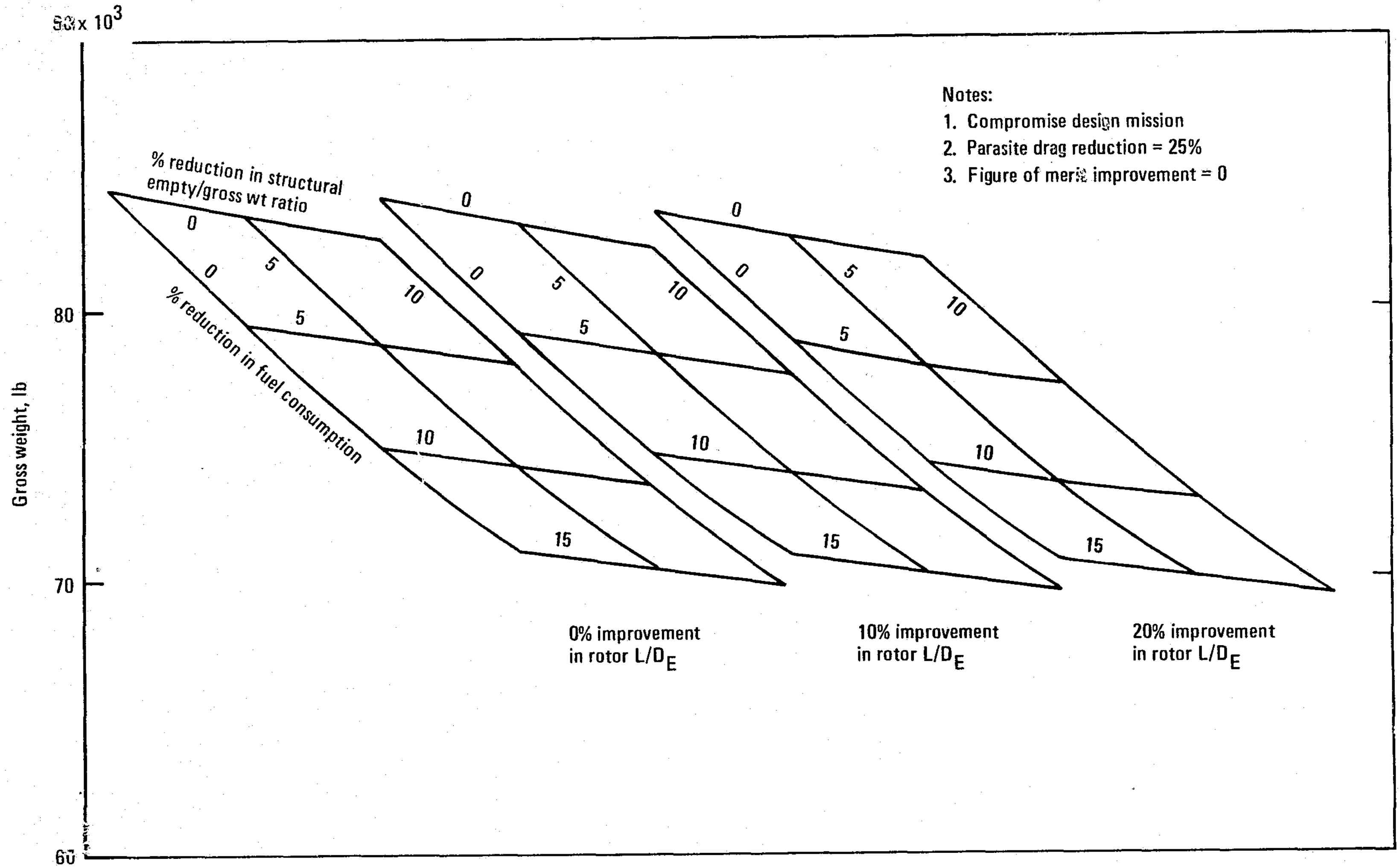


FIGURE B-17 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

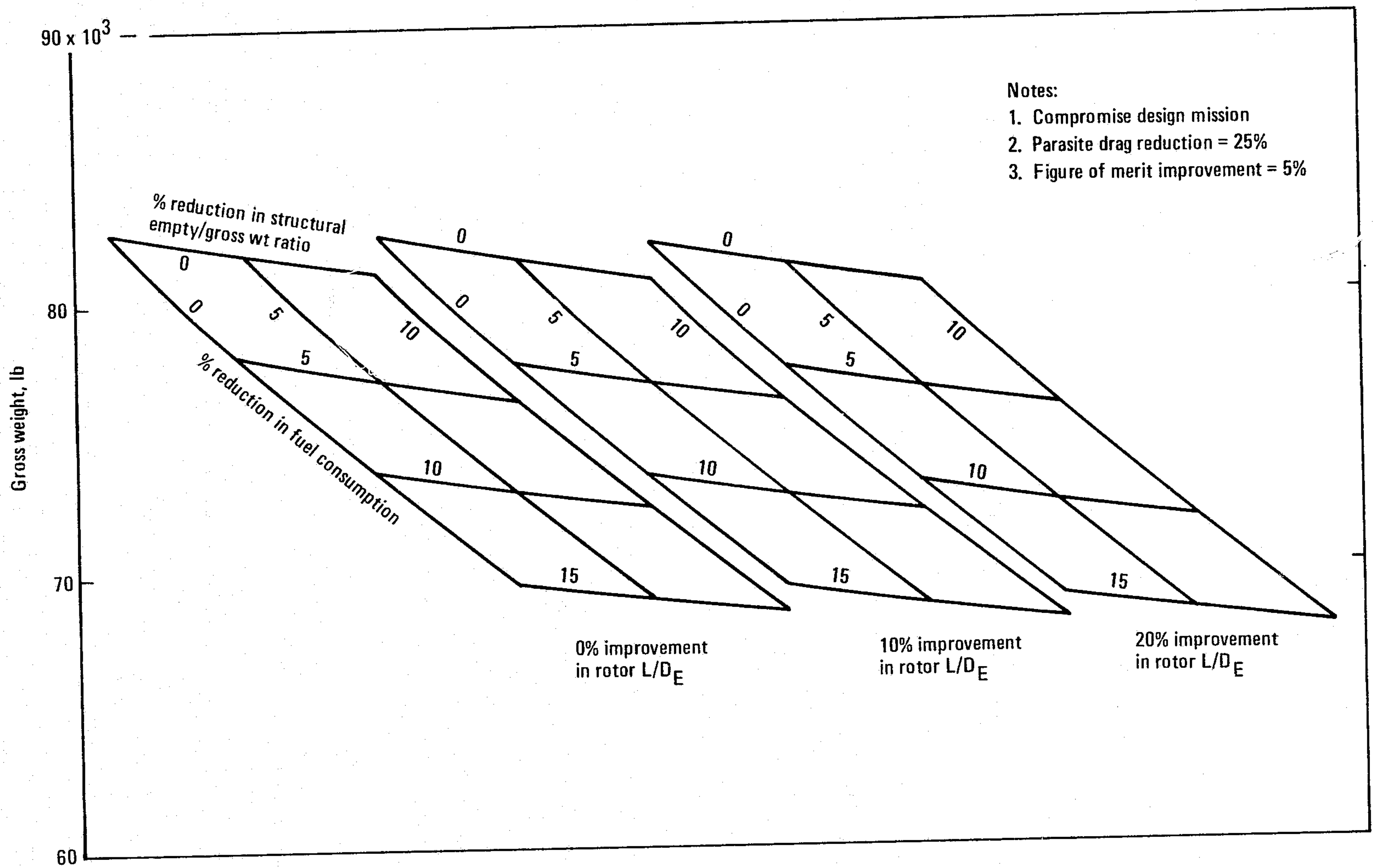


FIGURE B-18 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

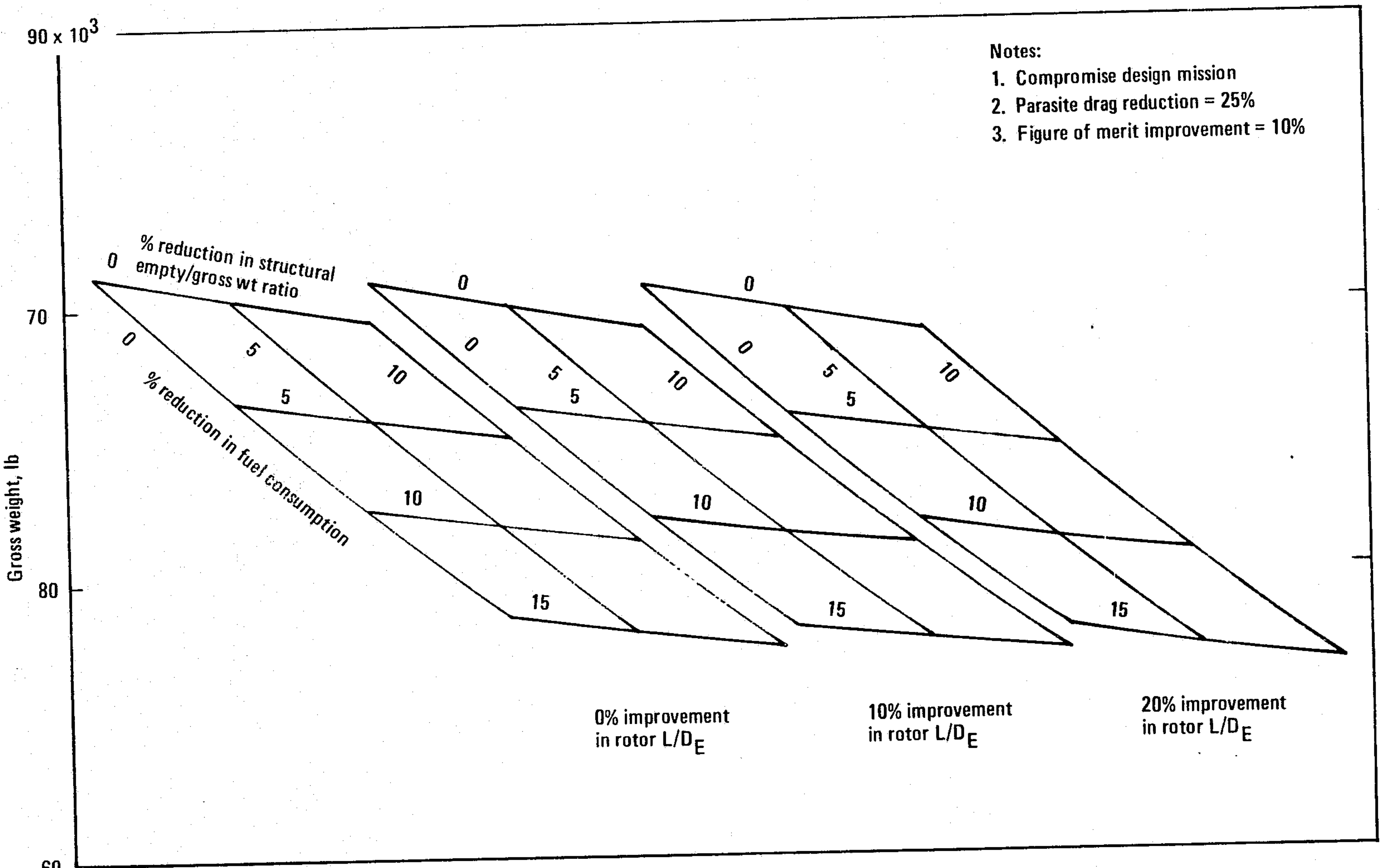


FIGURE B-19 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

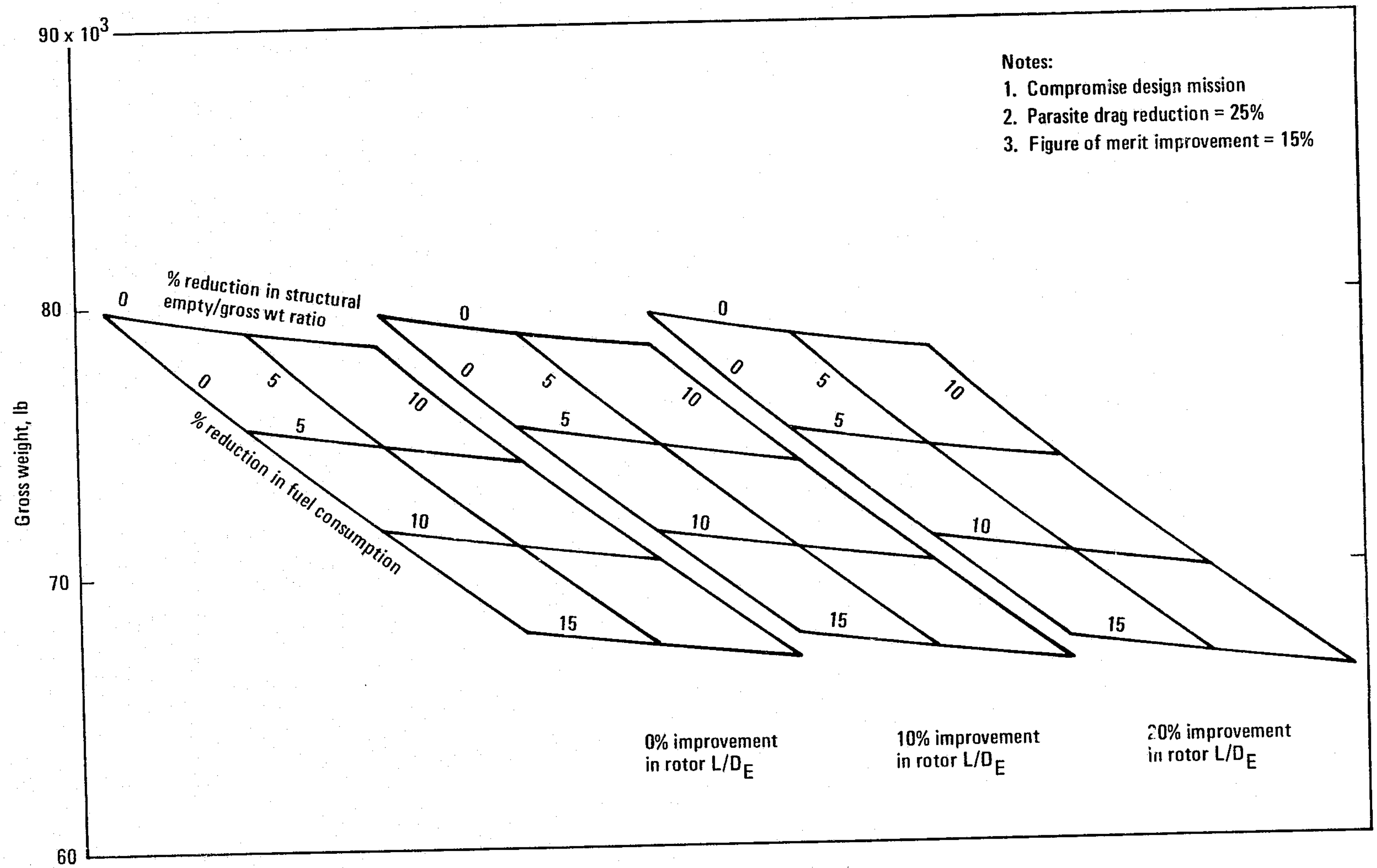


FIGURE B-20 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

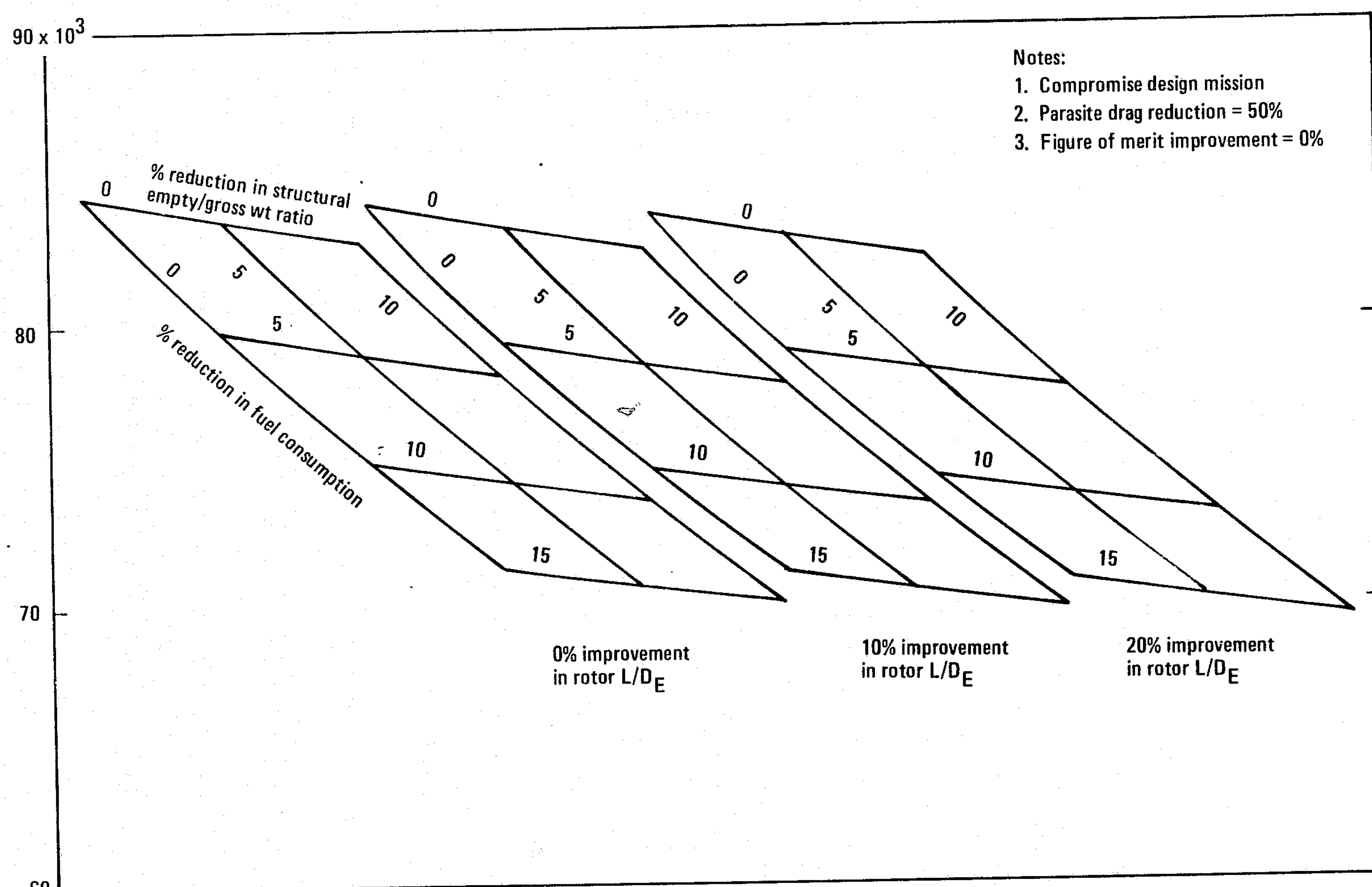


FIGURE B-21 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

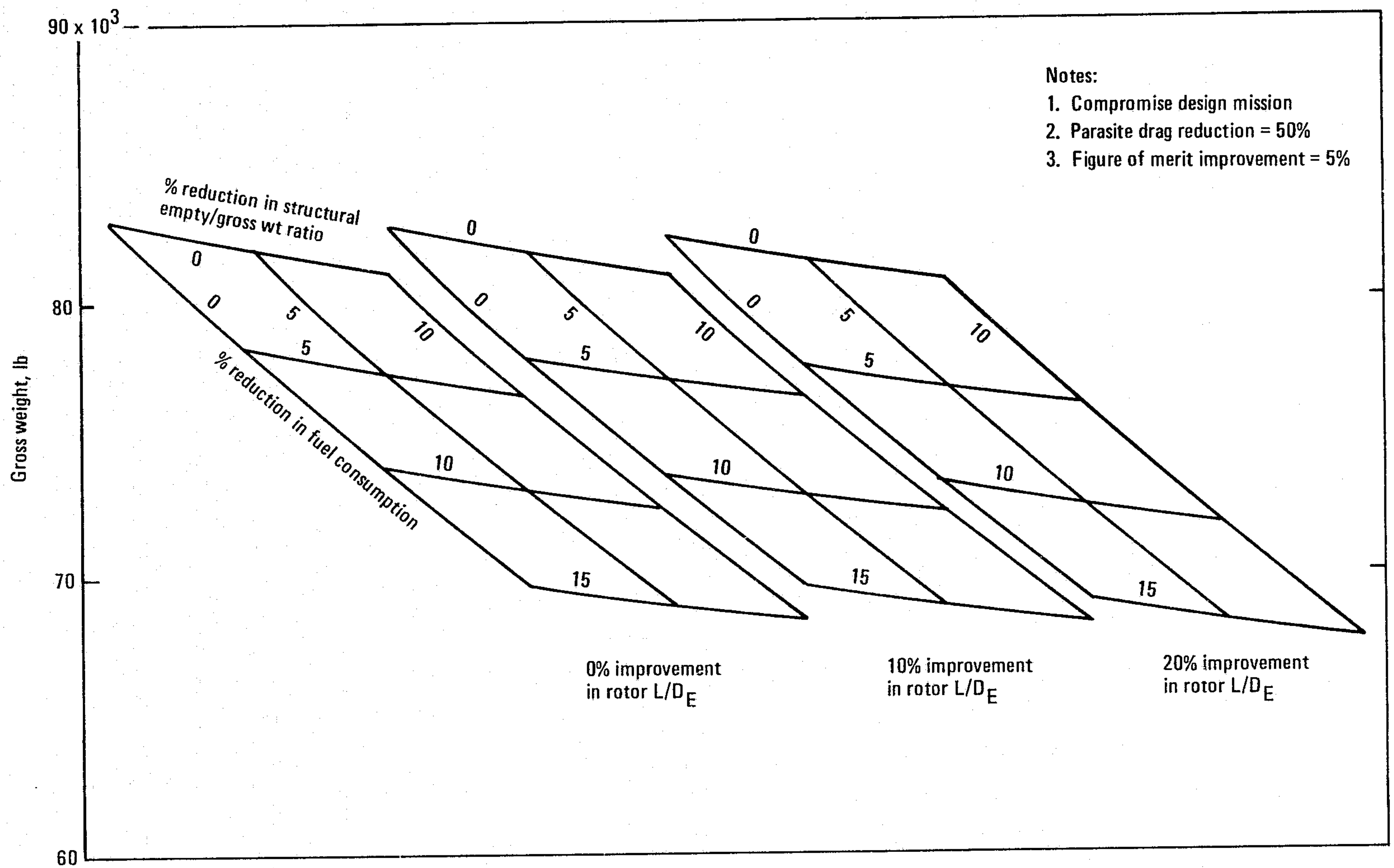


FIGURE B-22 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

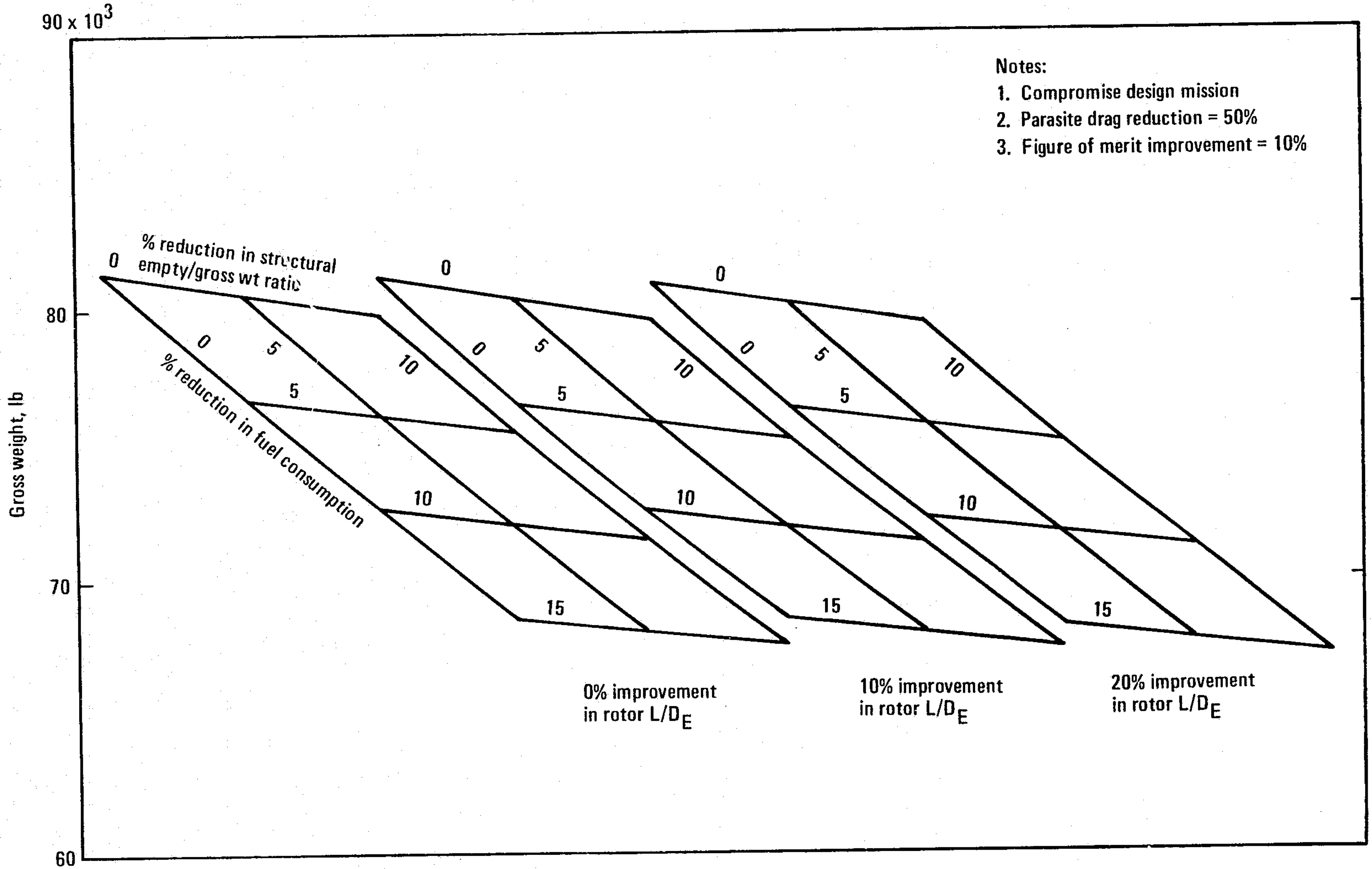


FIGURE B-23 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

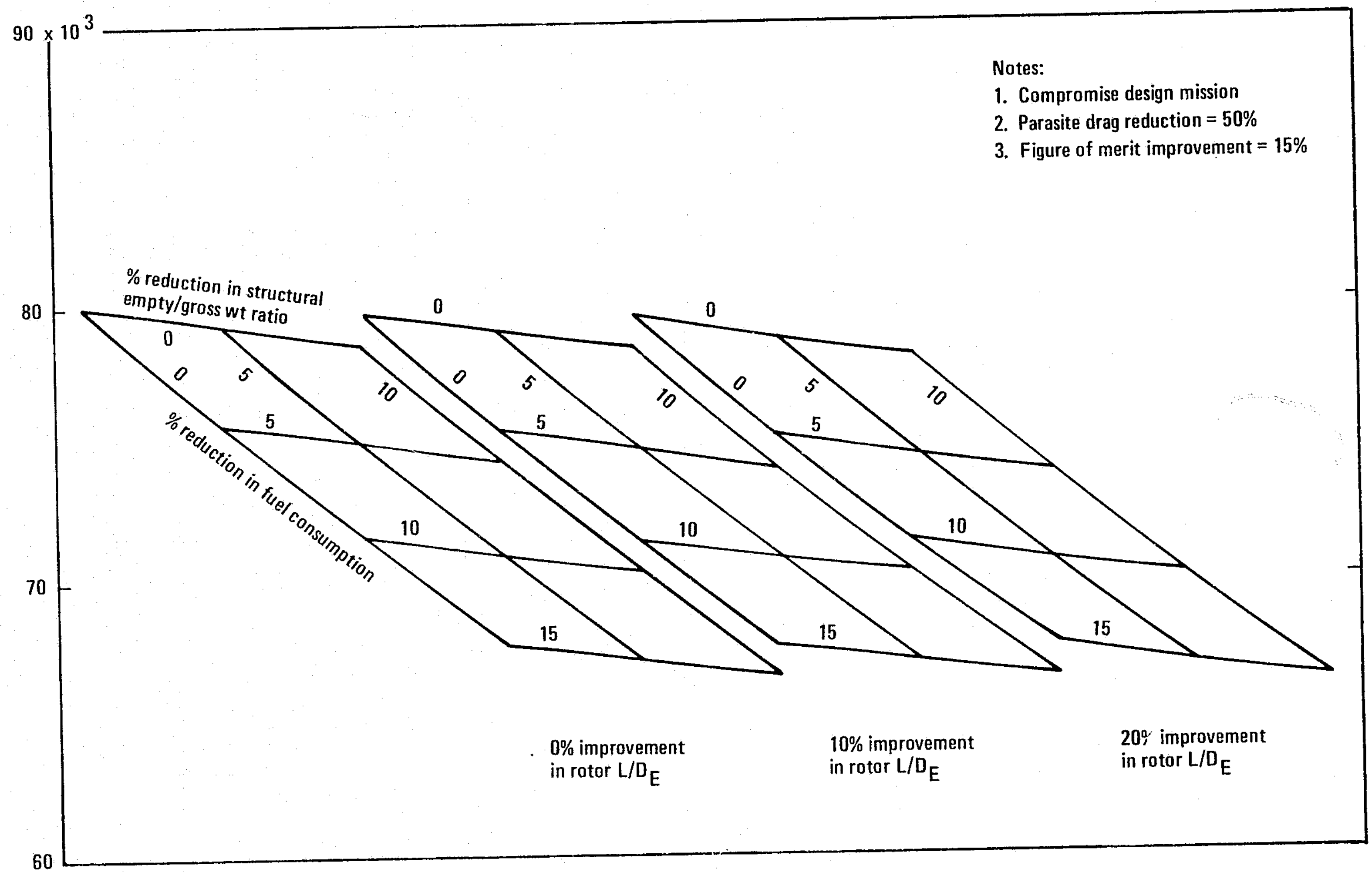


FIGURE B-24 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

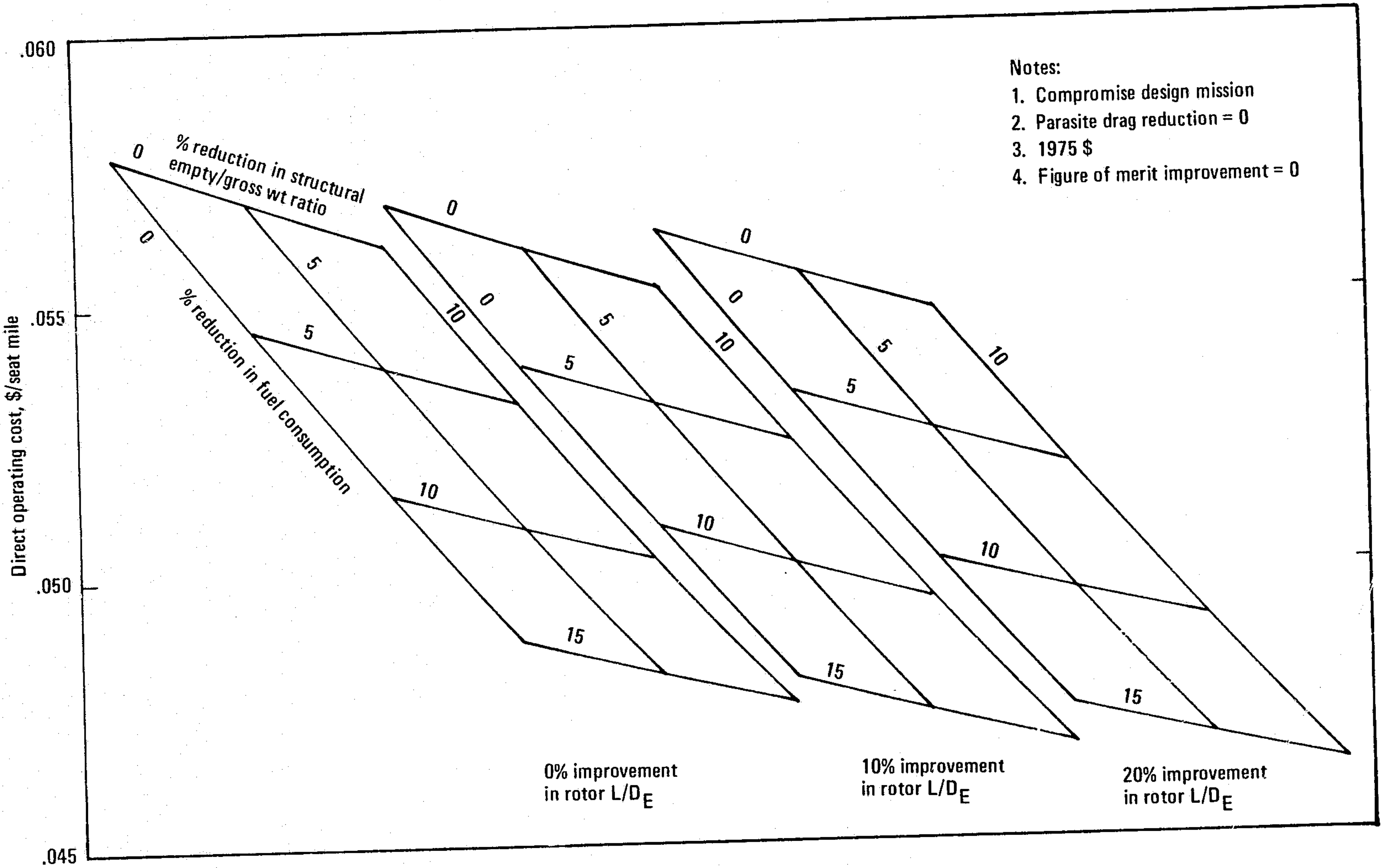


FIGURE B-25 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

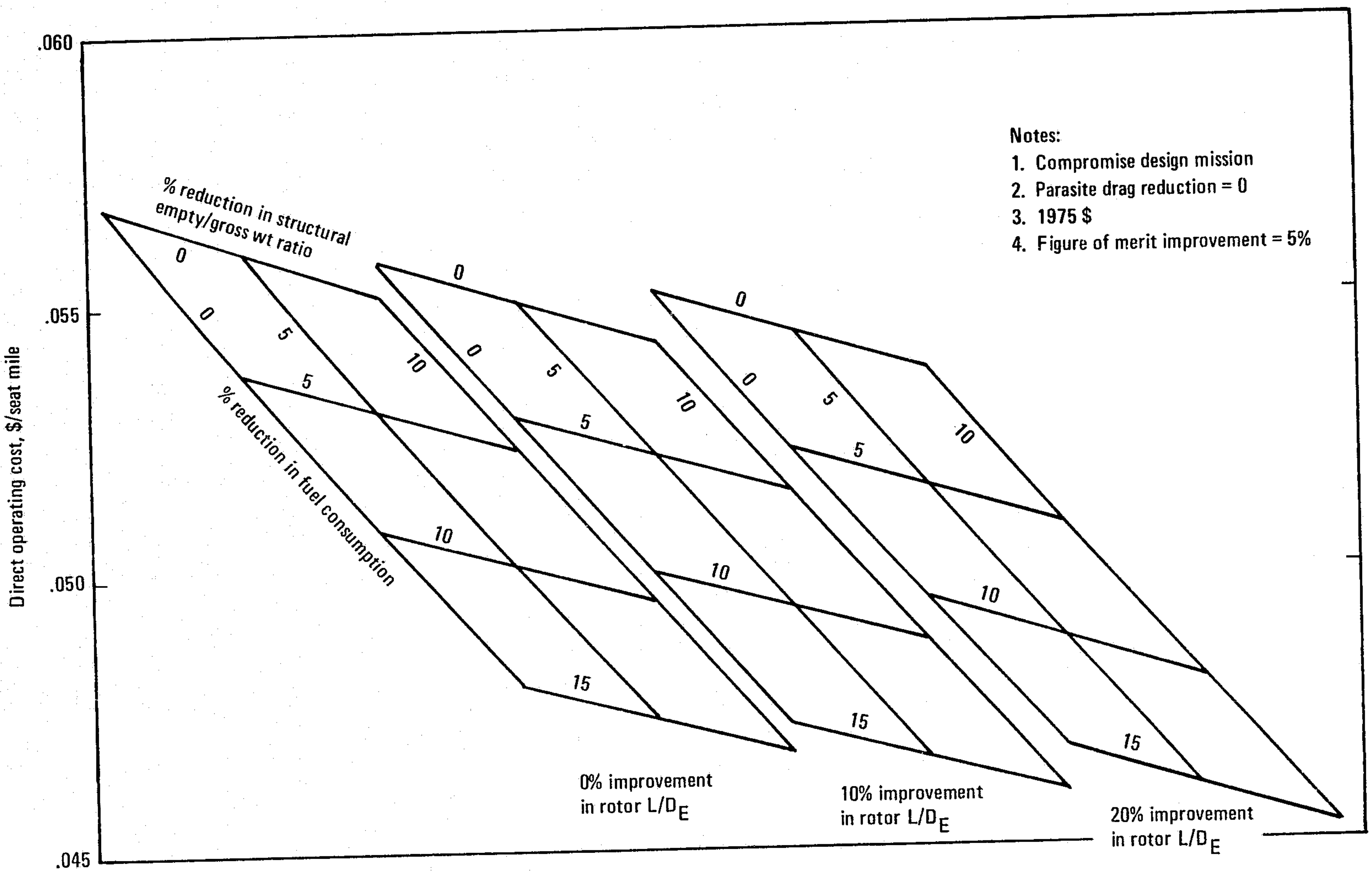


FIGURE B-26 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

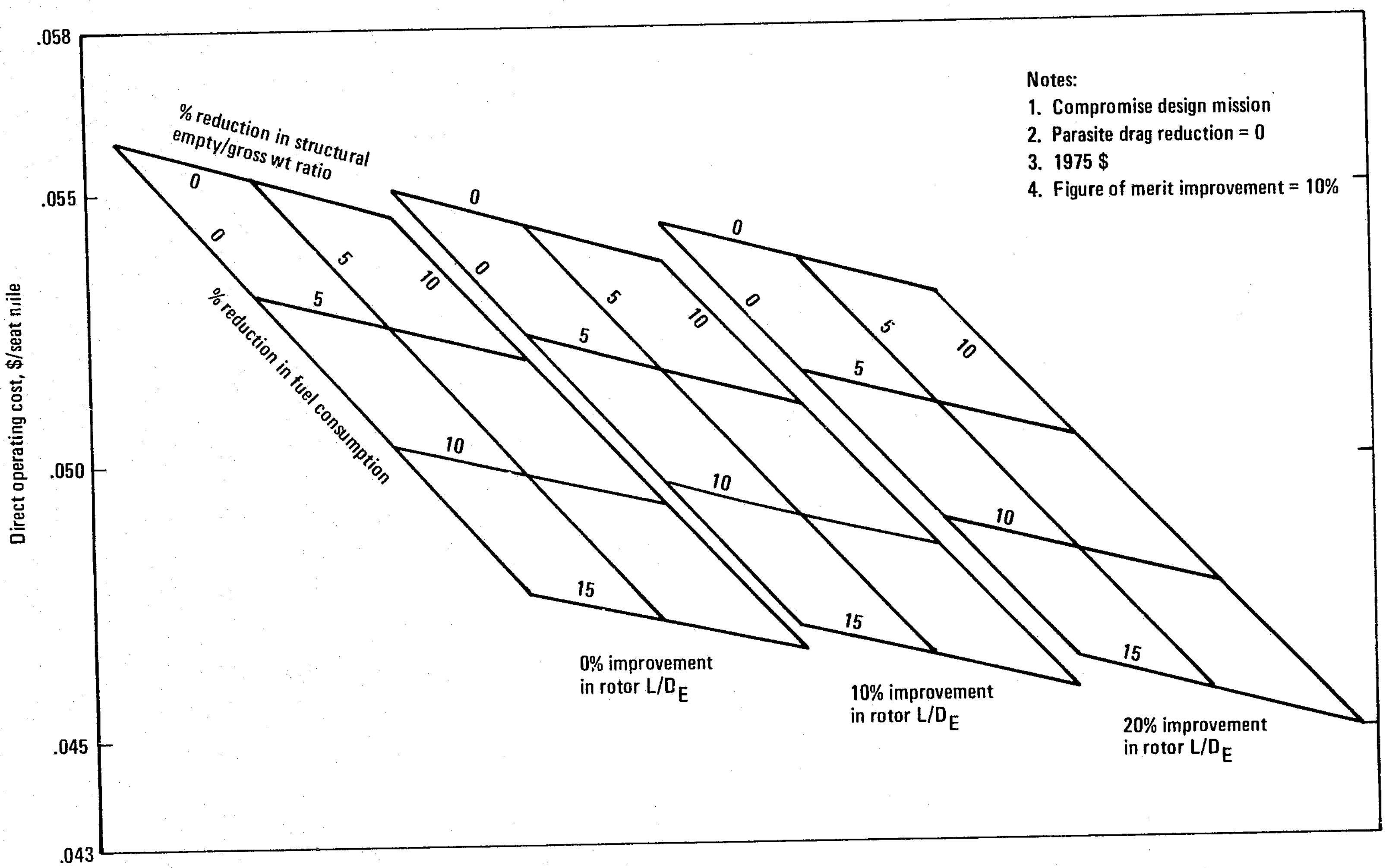


FIGURE B-27 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

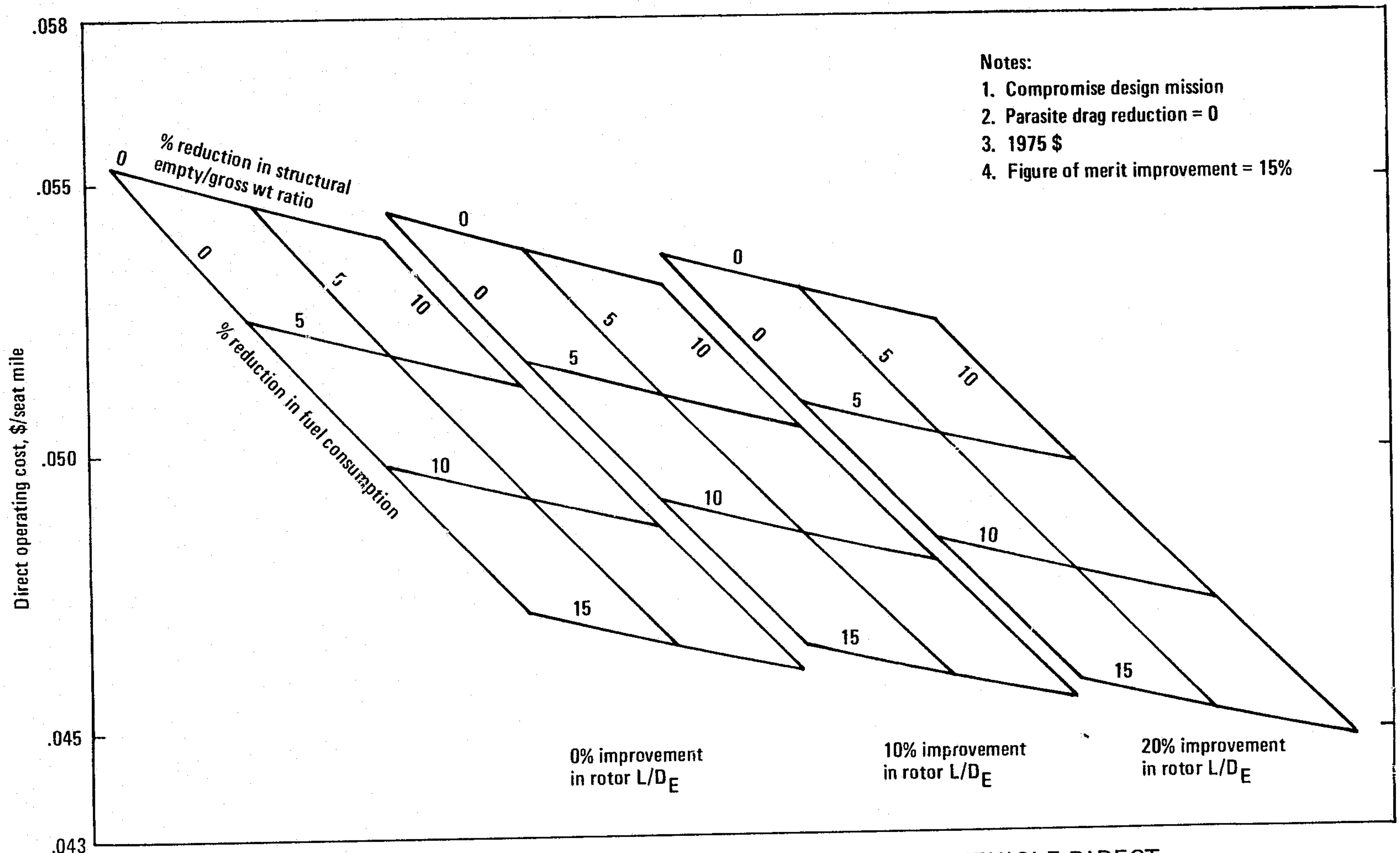


FIGURE B-28 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

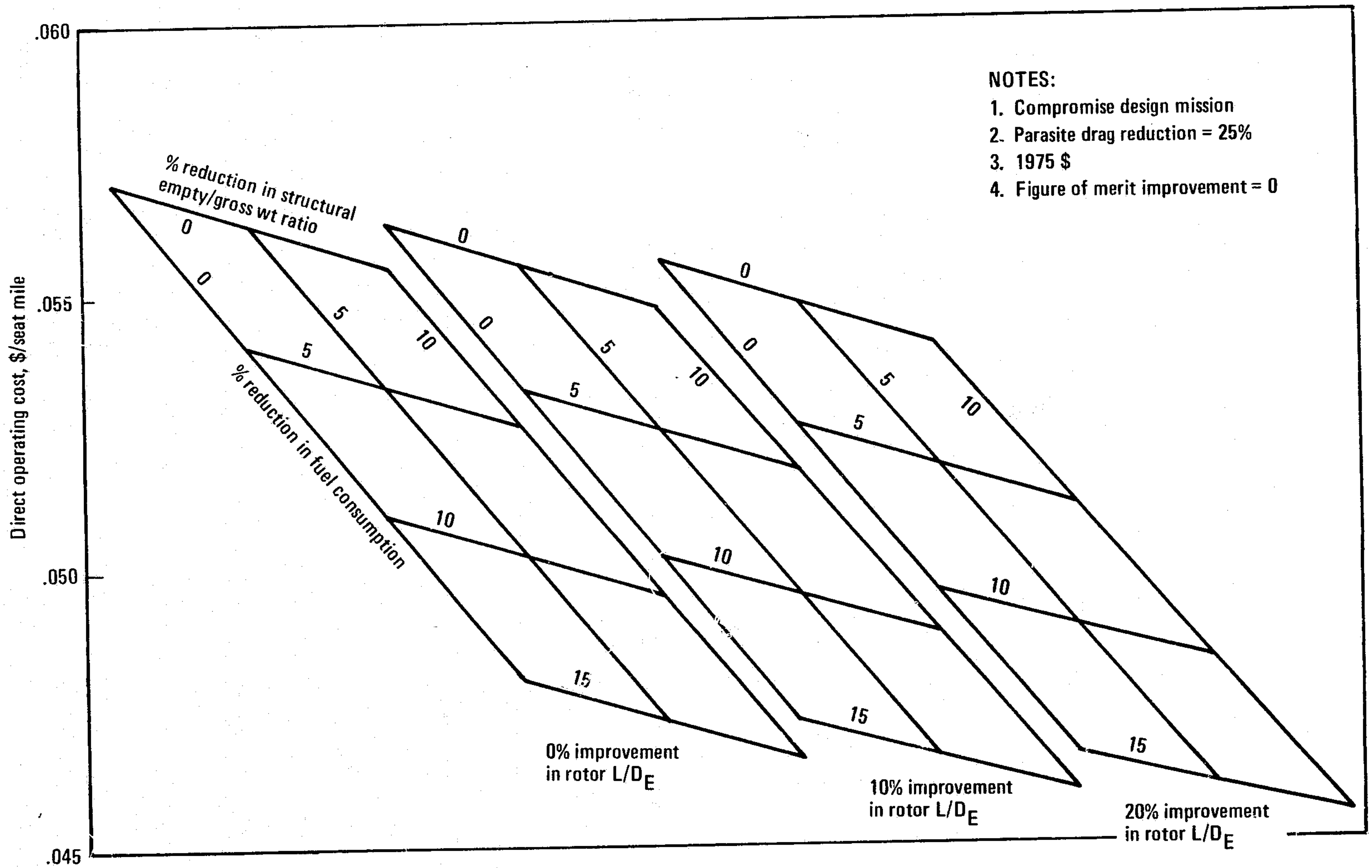


FIGURE B-29 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

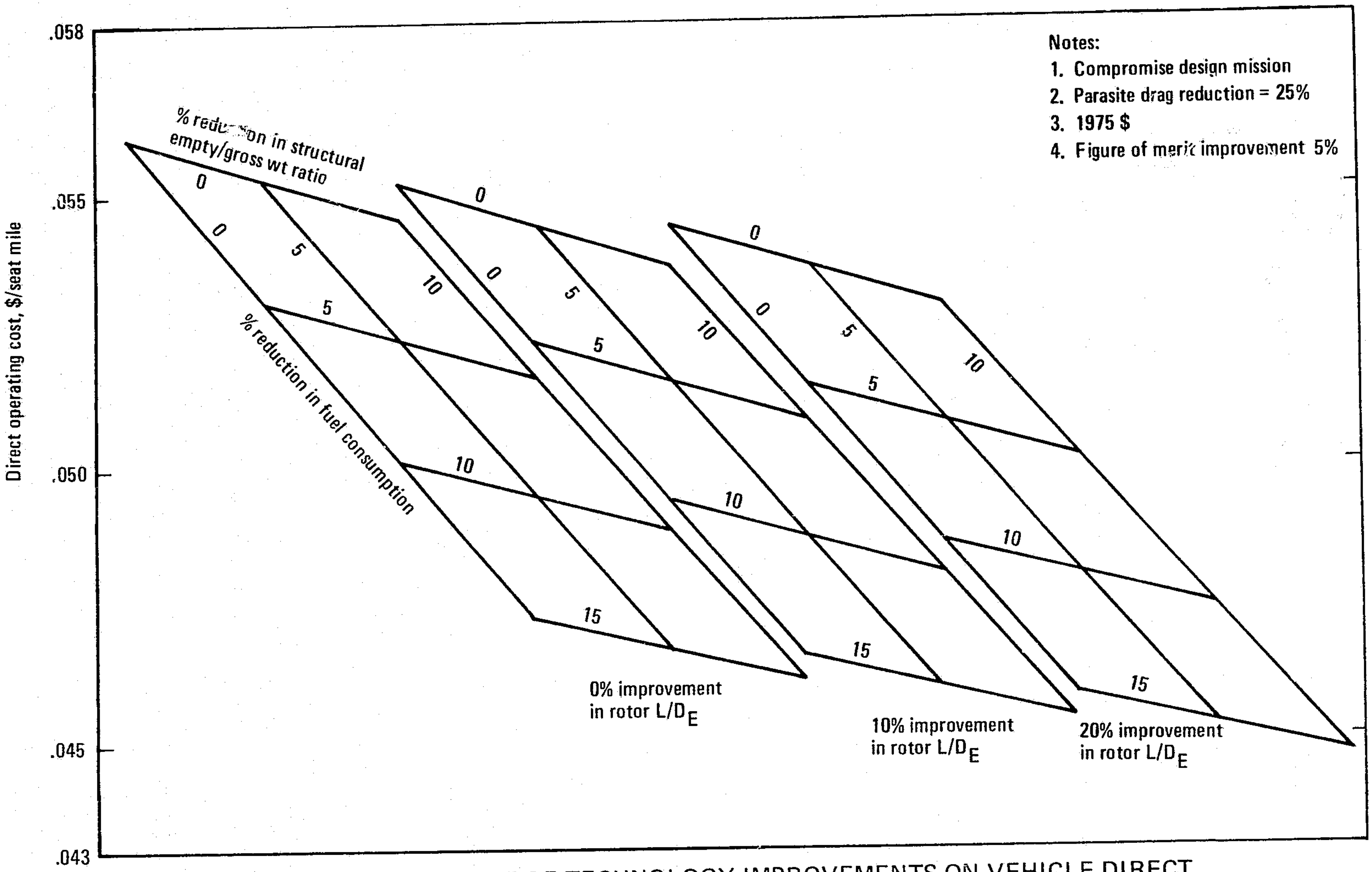


FIGURE B-30 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

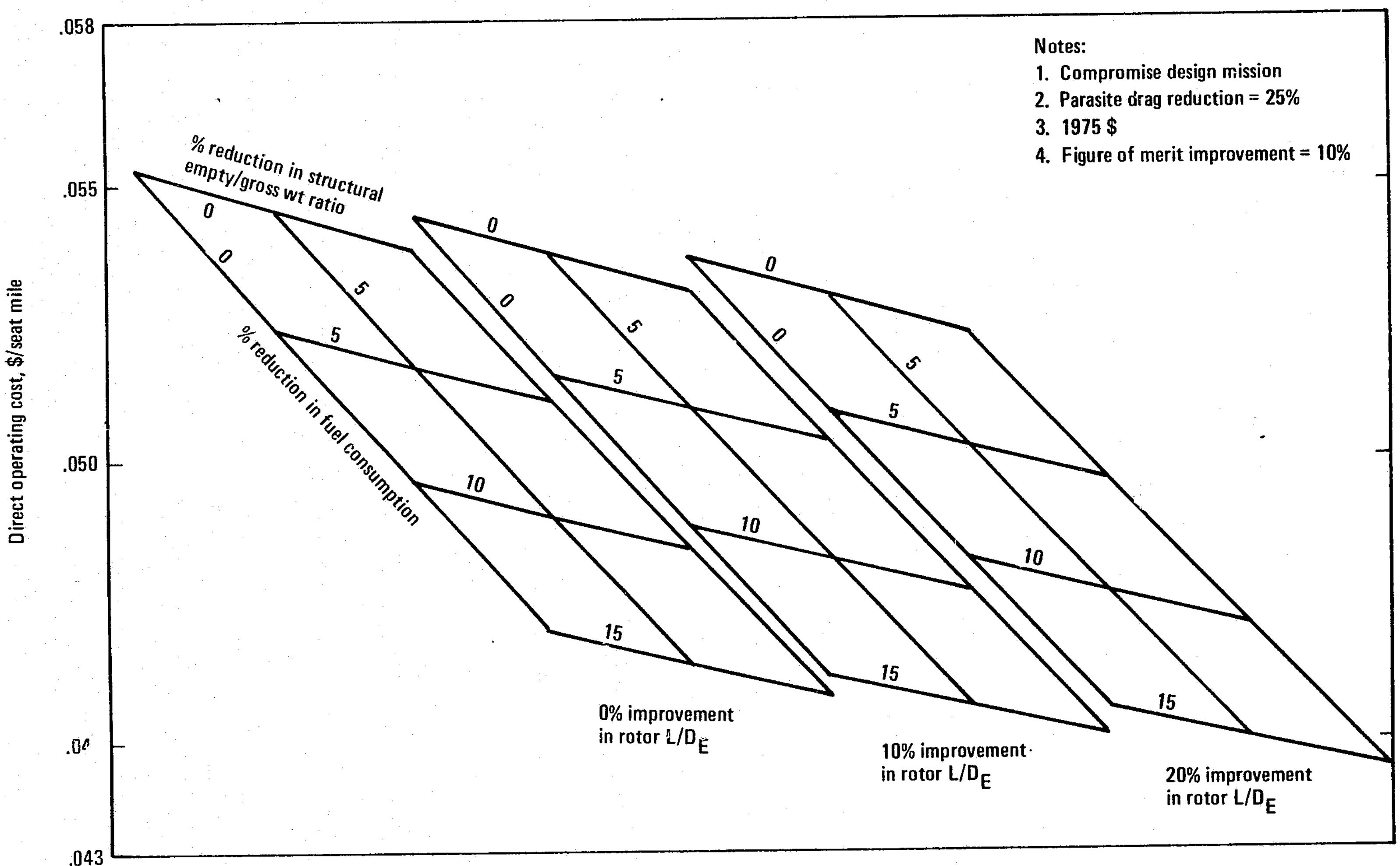


FIGURE B-31 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

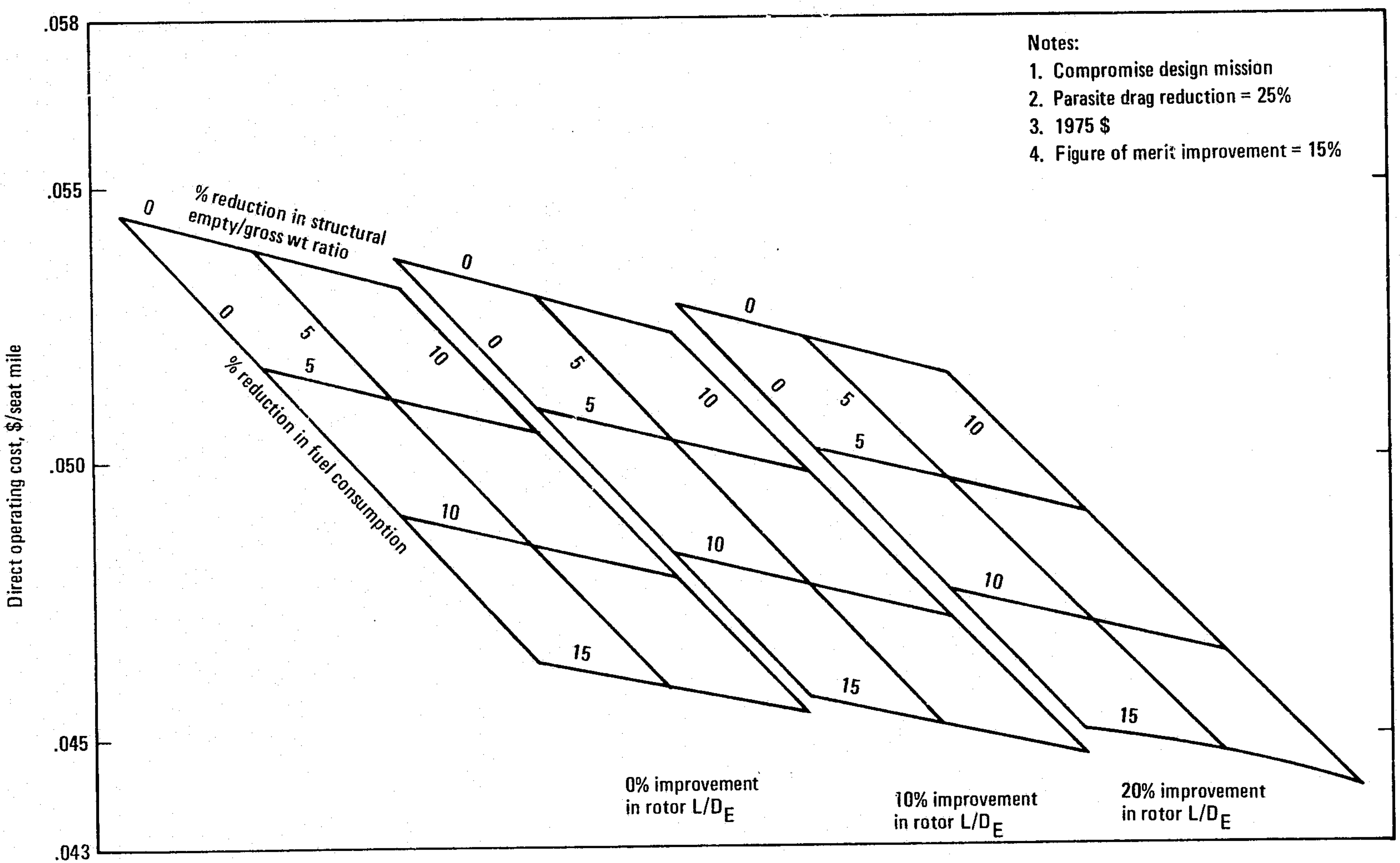


FIGURE B-32 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

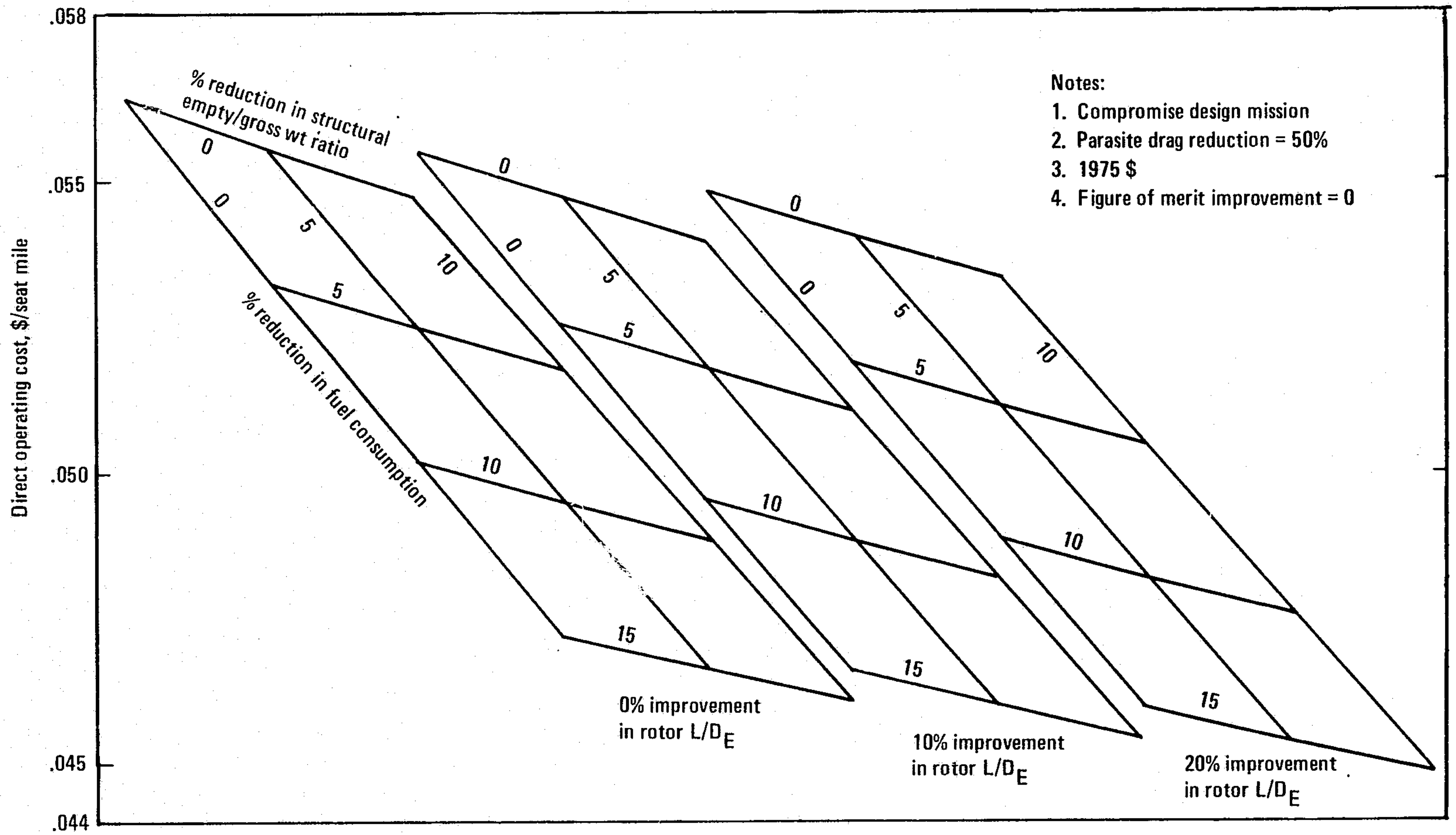


FIGURE B-33 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

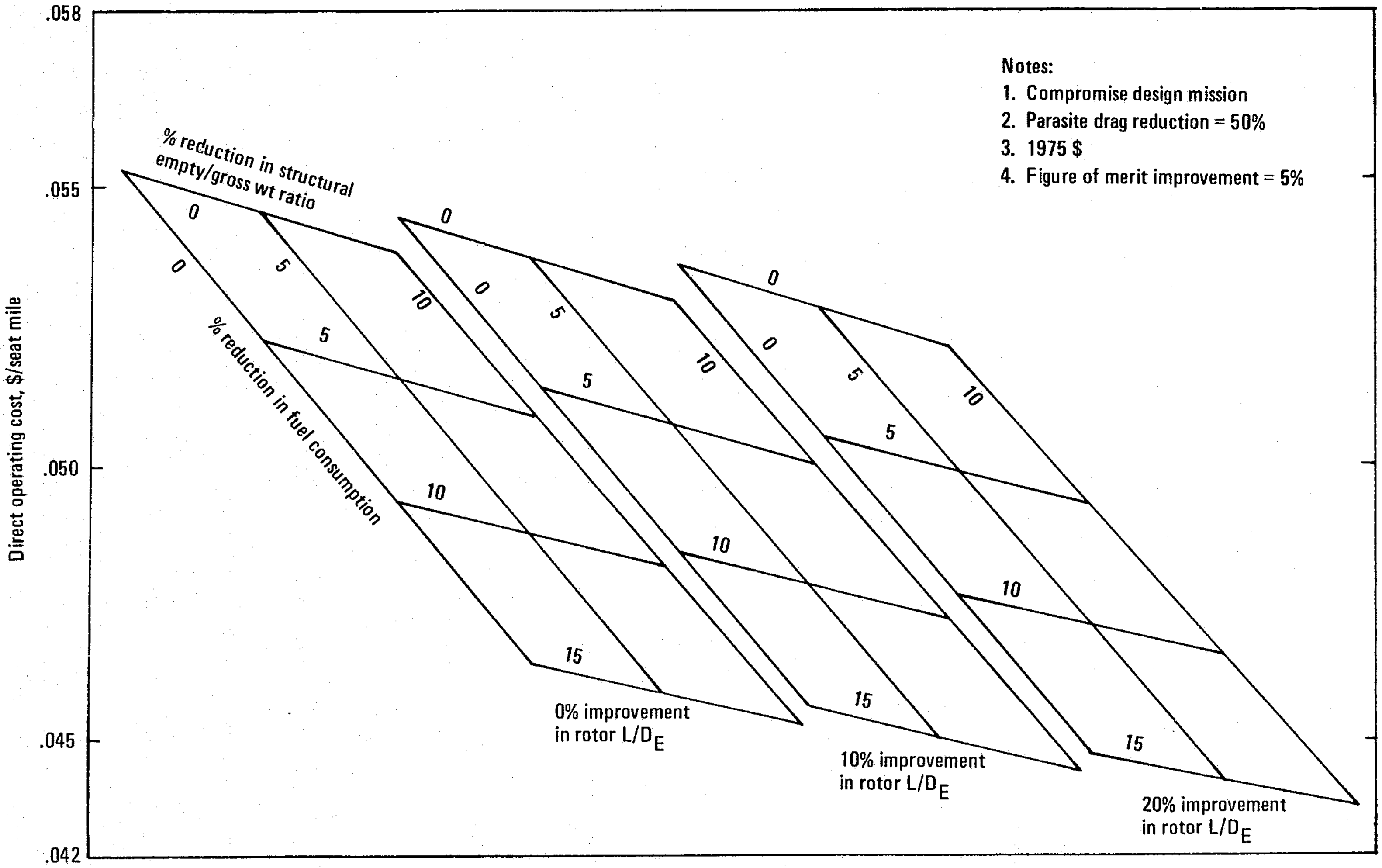


FIGURE B-34 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

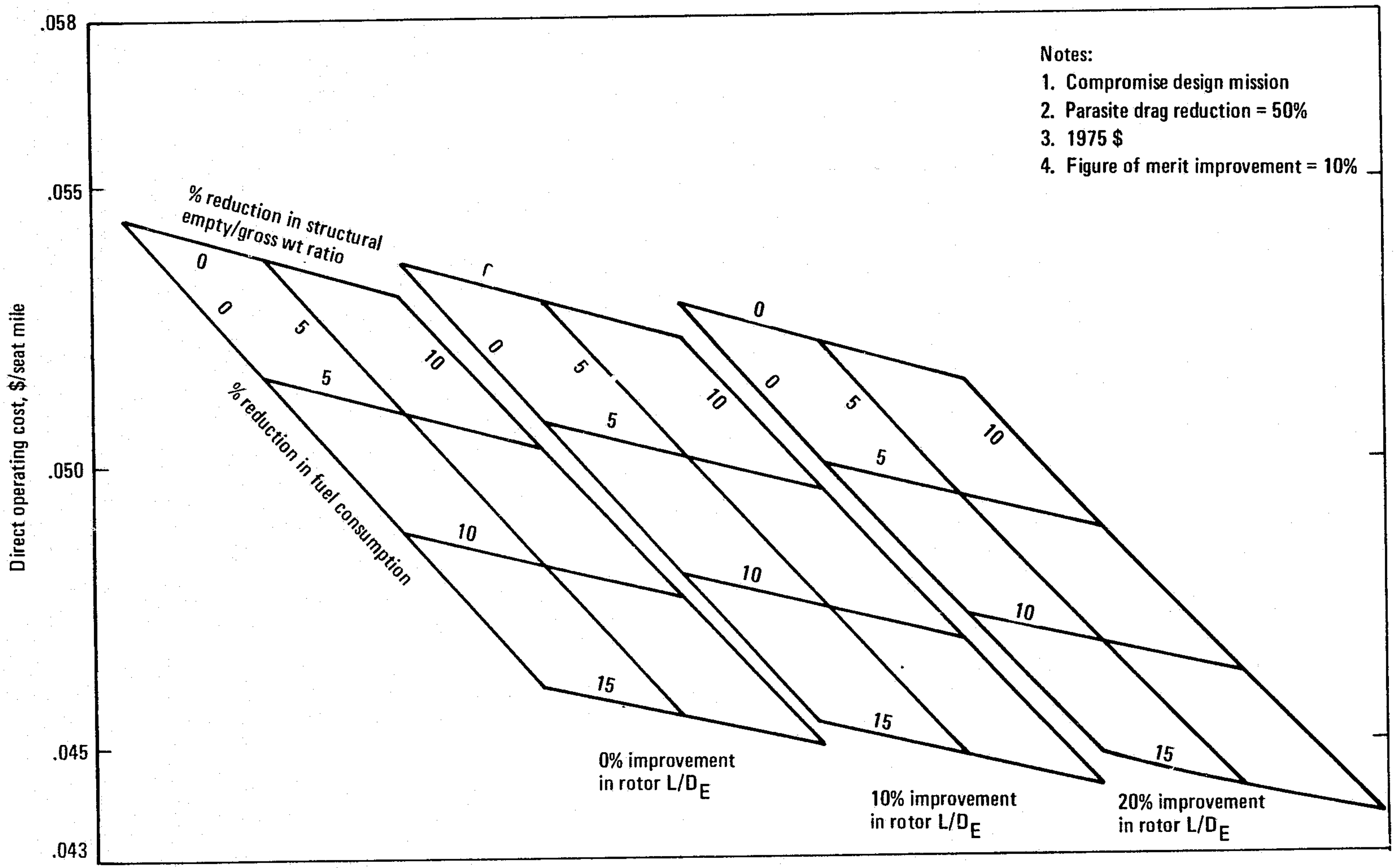


FIGURE B-35 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

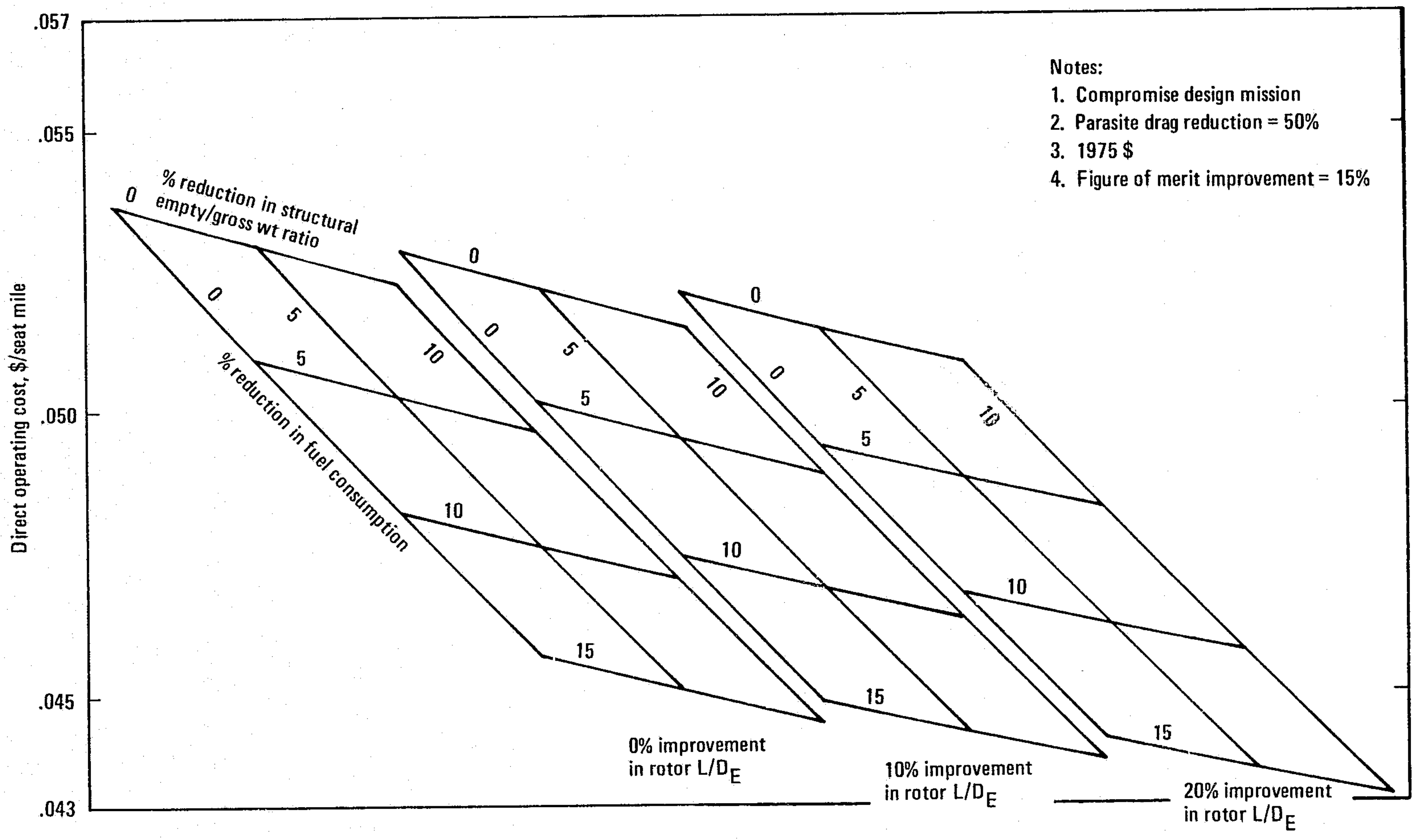


FIGURE B-36 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

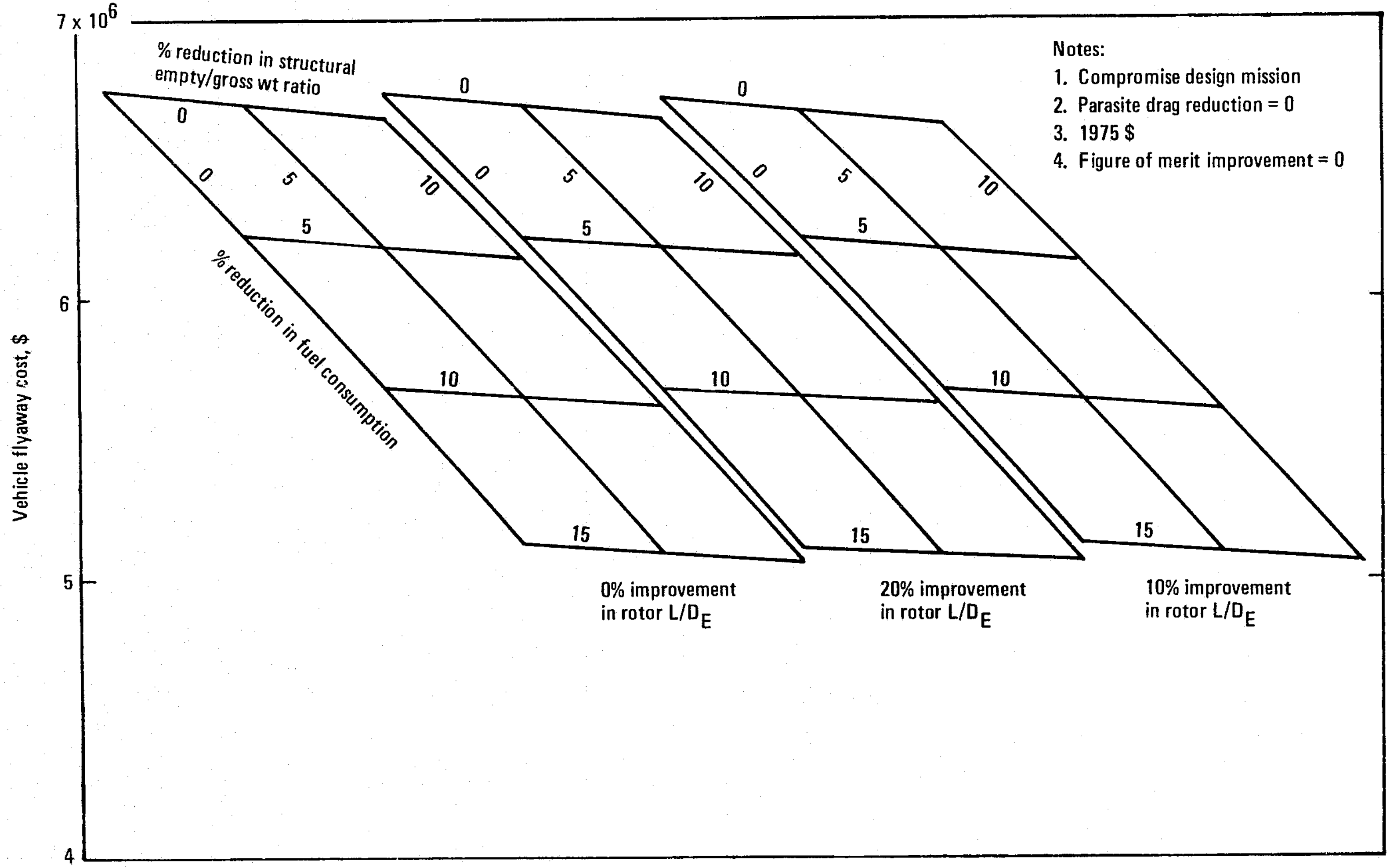


FIGURE B-37 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

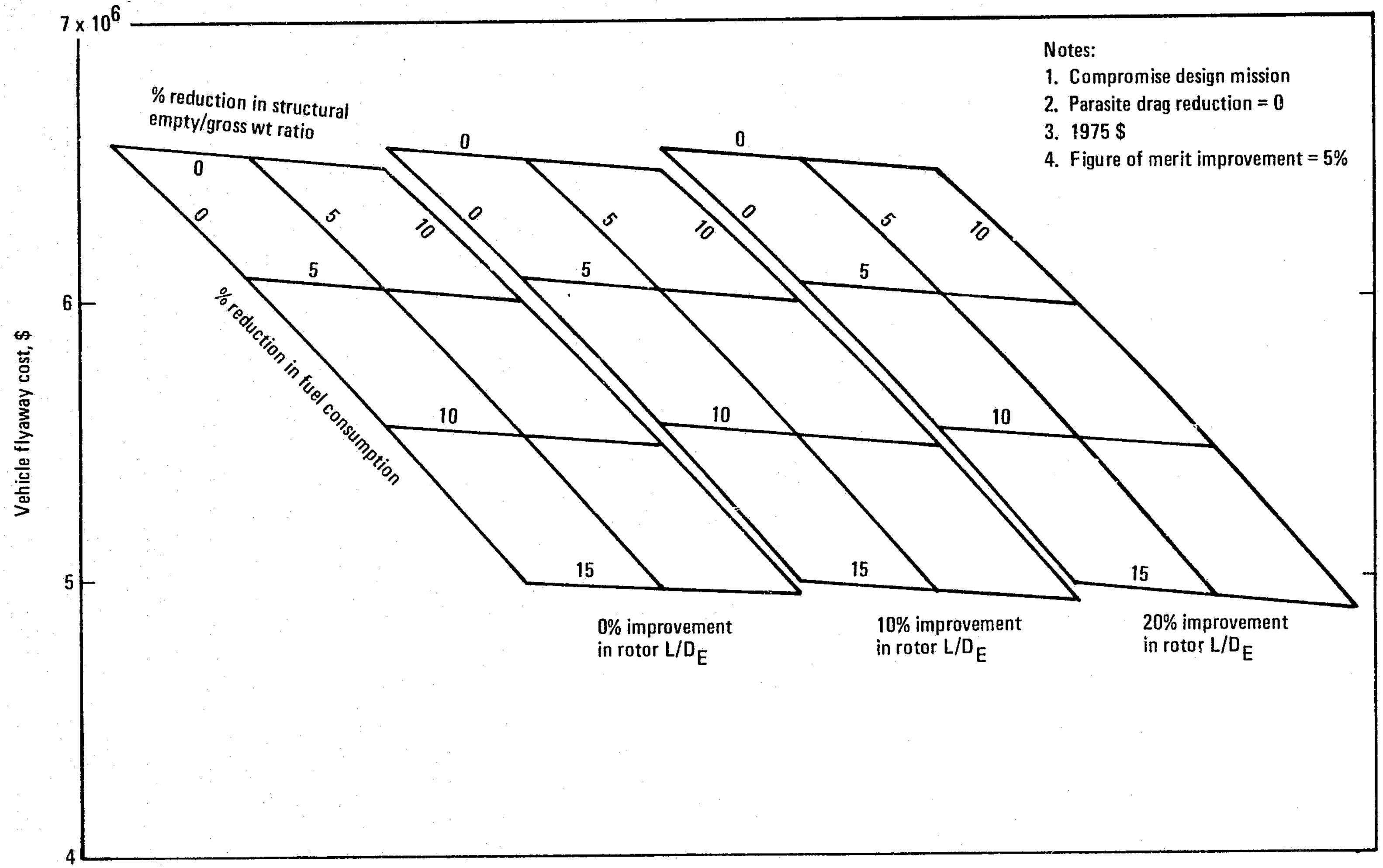


FIGURE B-38 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

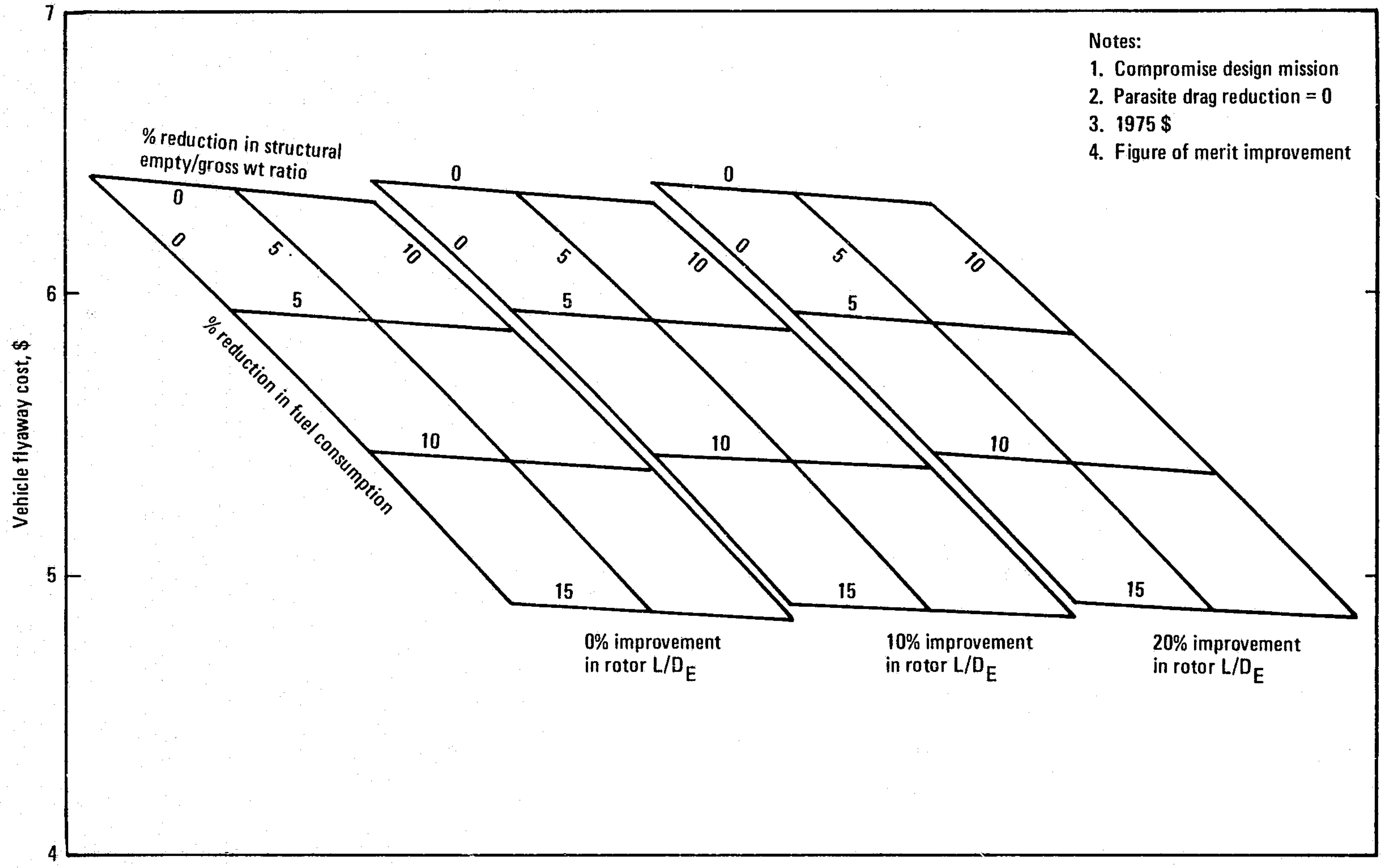


FIGURE B-39 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

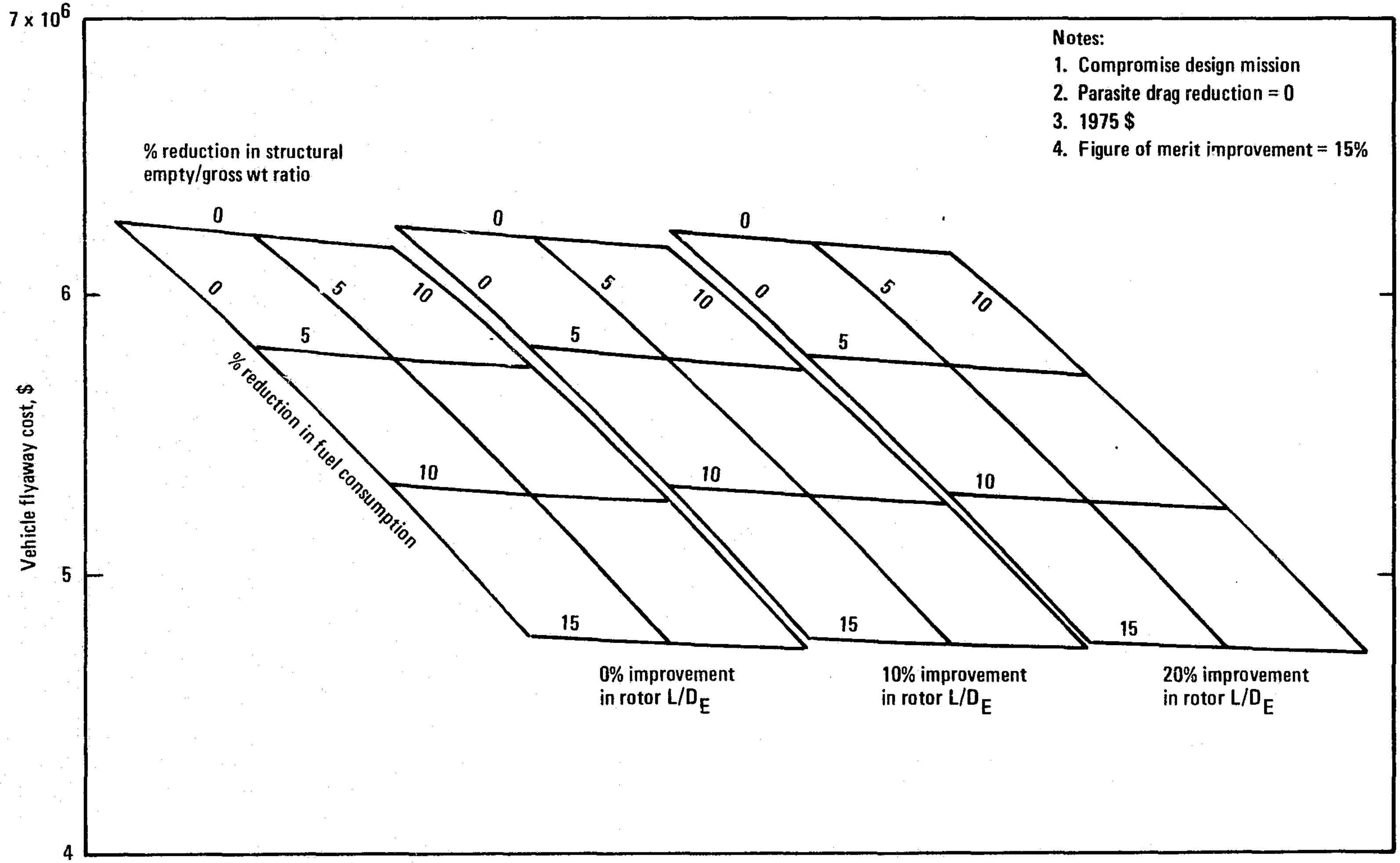


FIGURE B-40 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

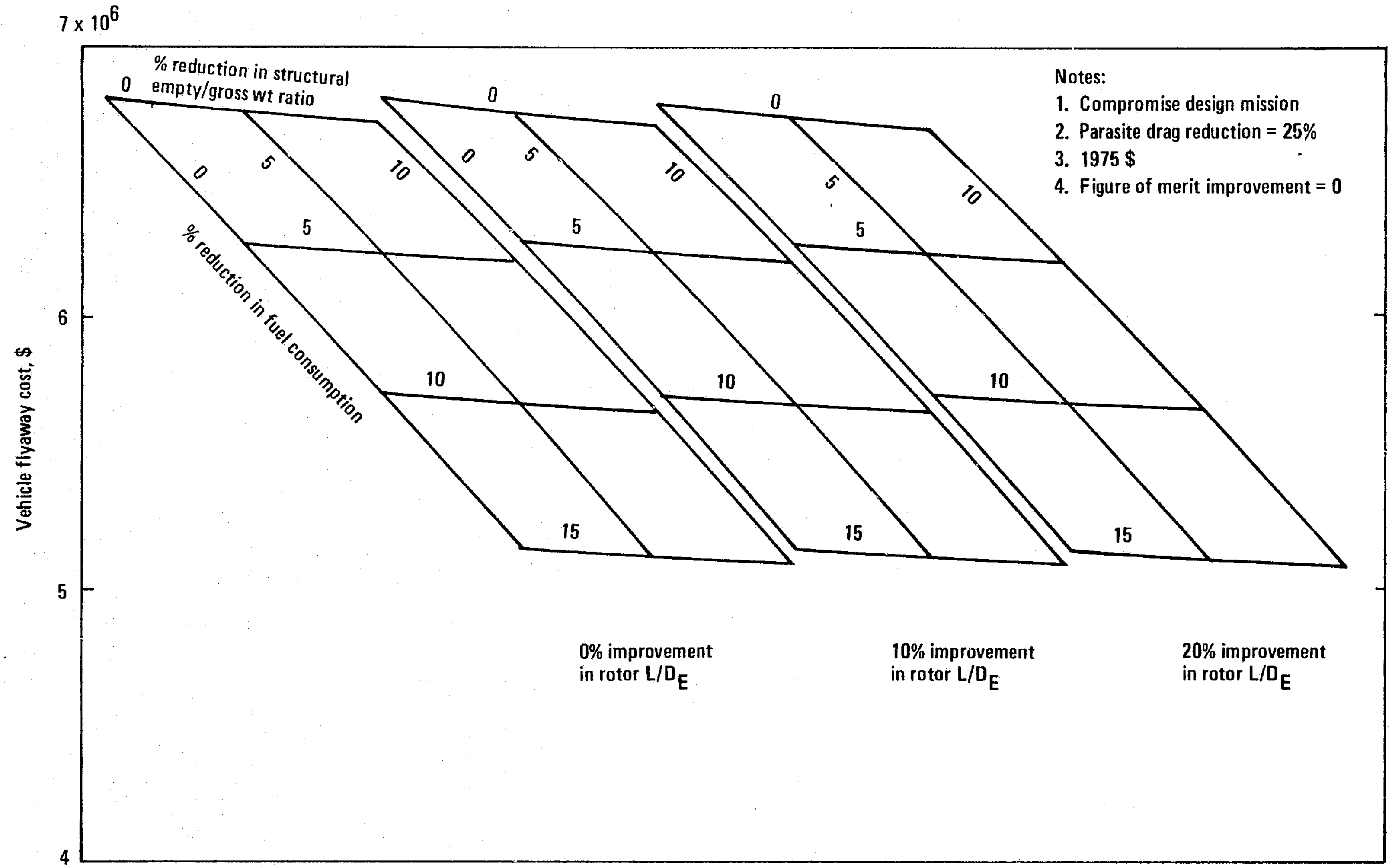


FIGURE B-41 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

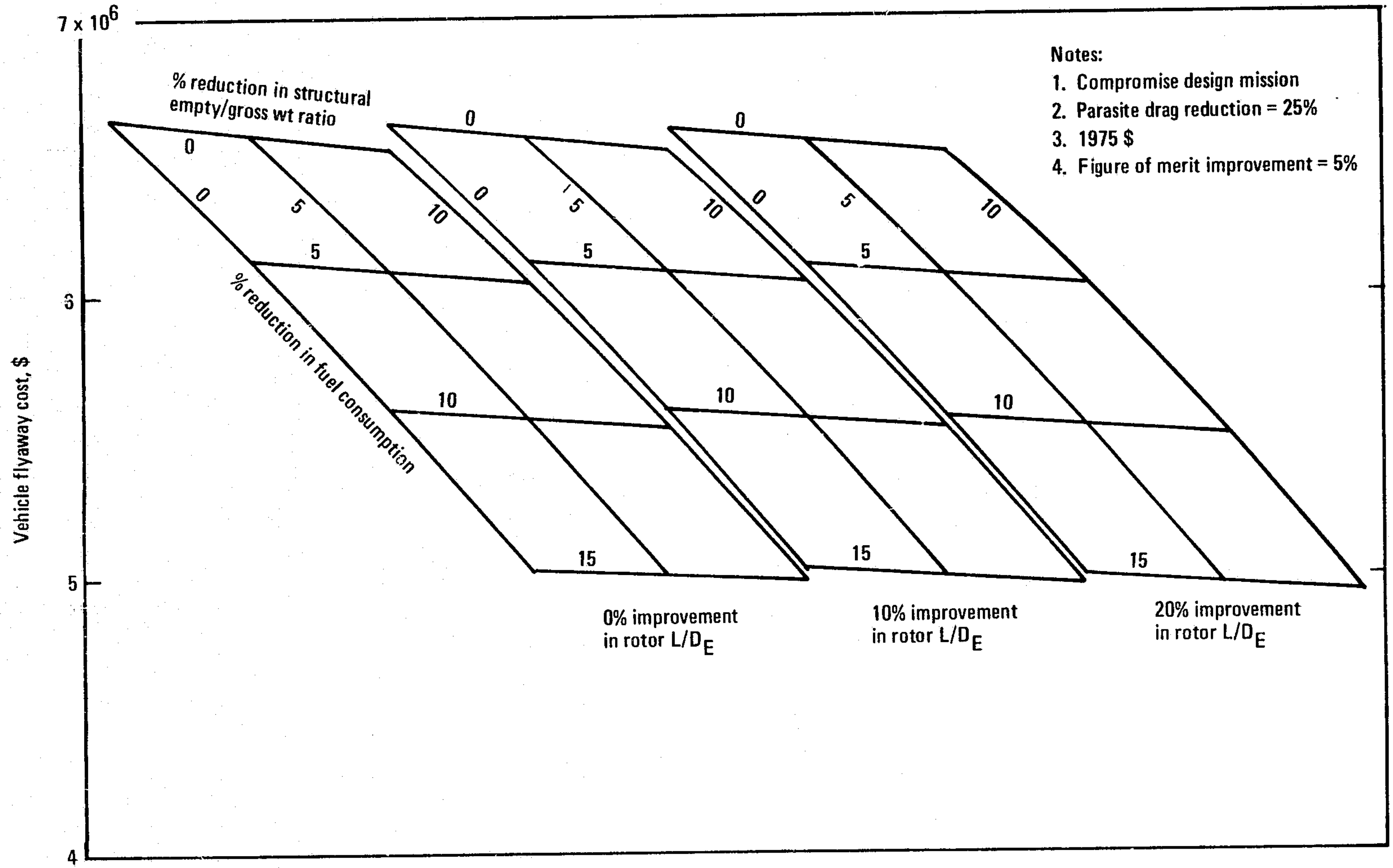
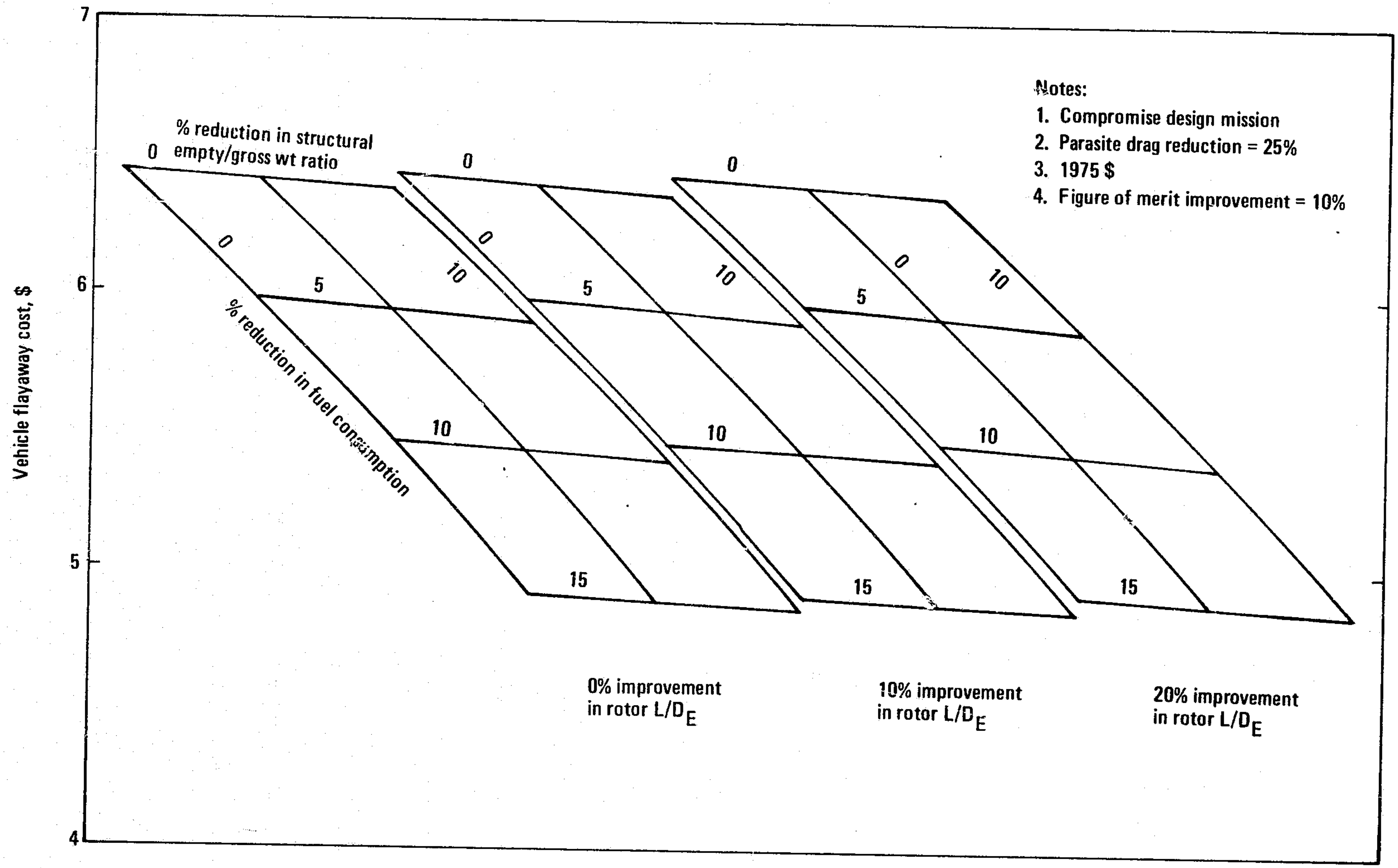


FIGURE B-42 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST



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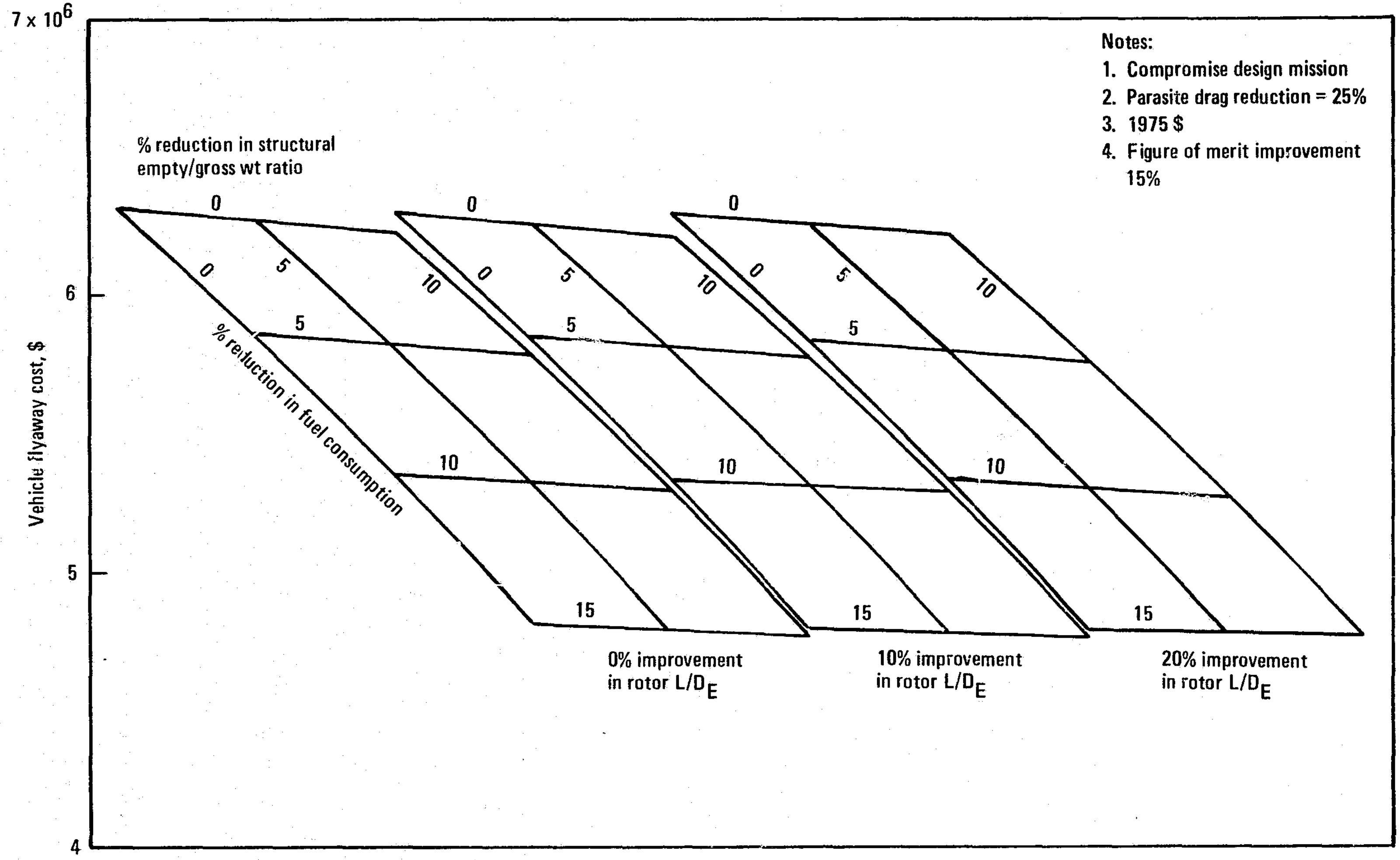

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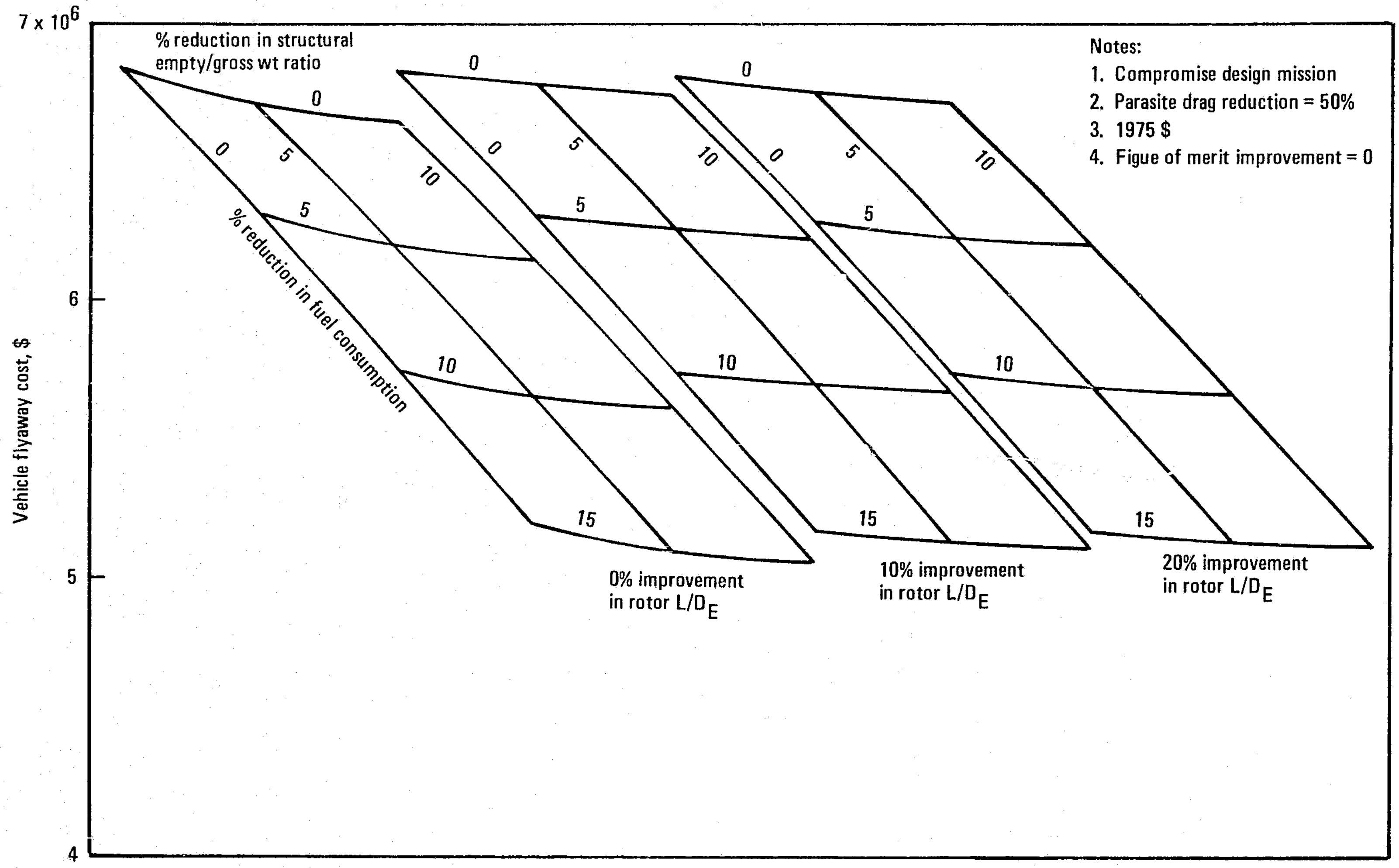


FIGURE B-45 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

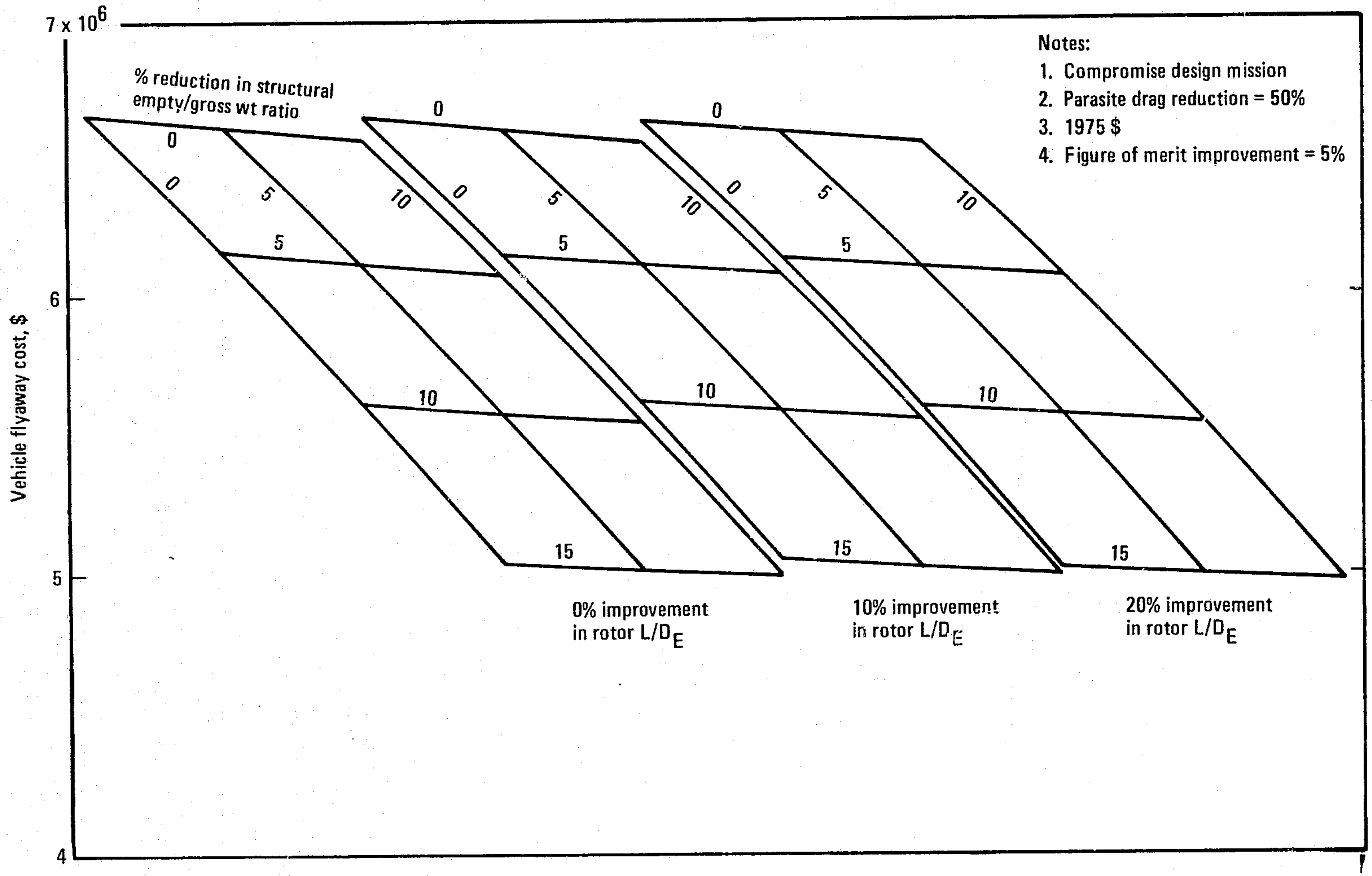


FIGURE B-46 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

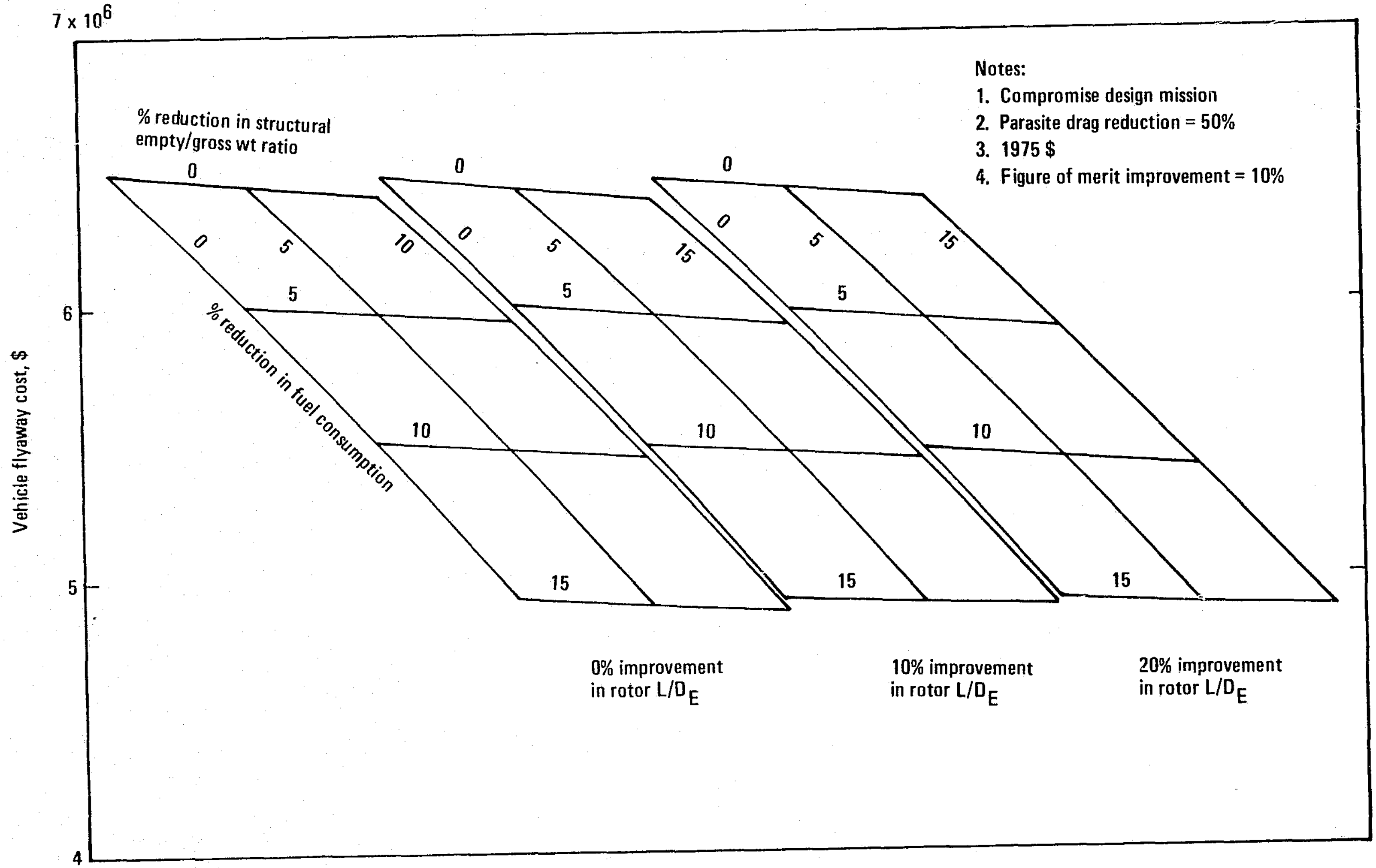


FIGURE B-47 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

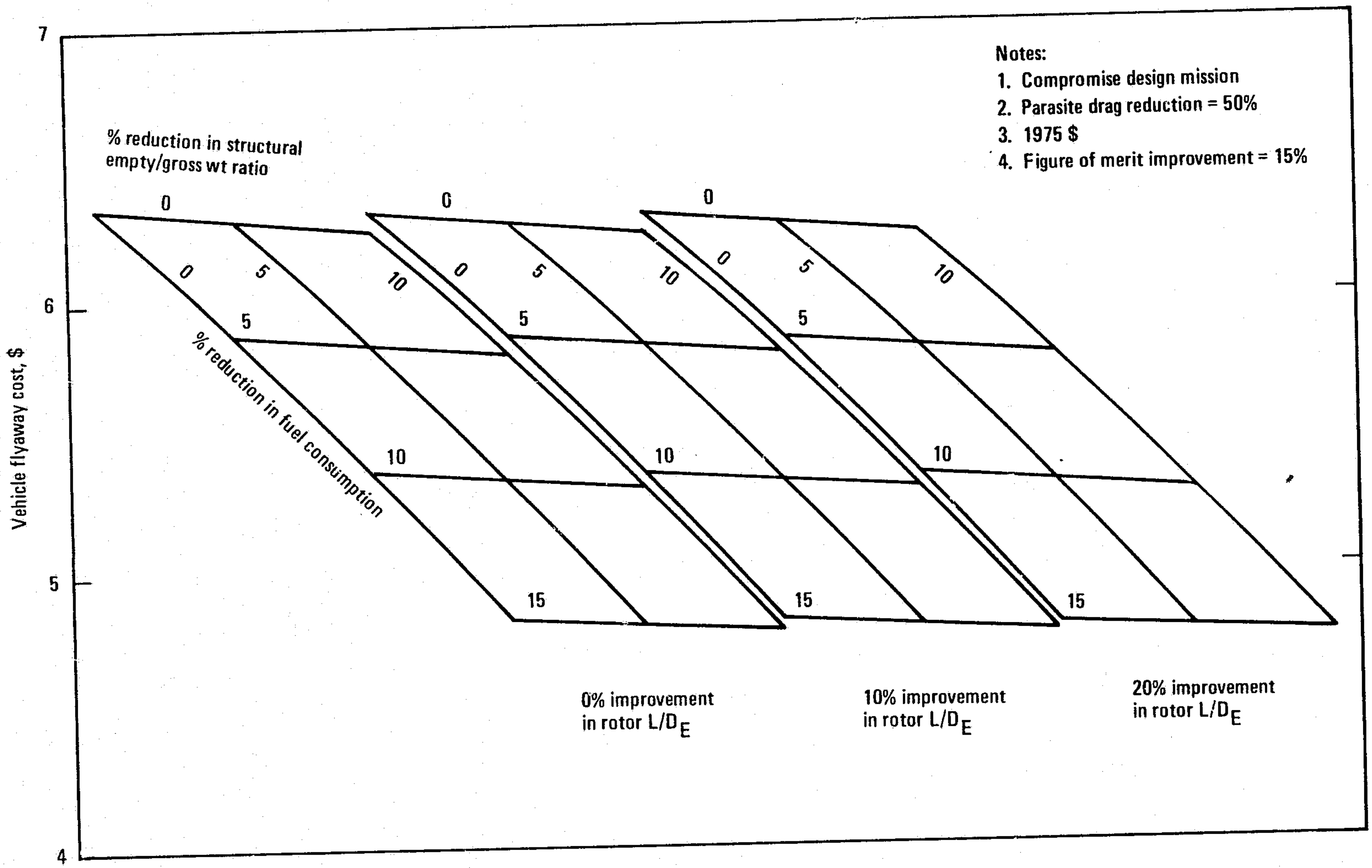


FIGURE B-48 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

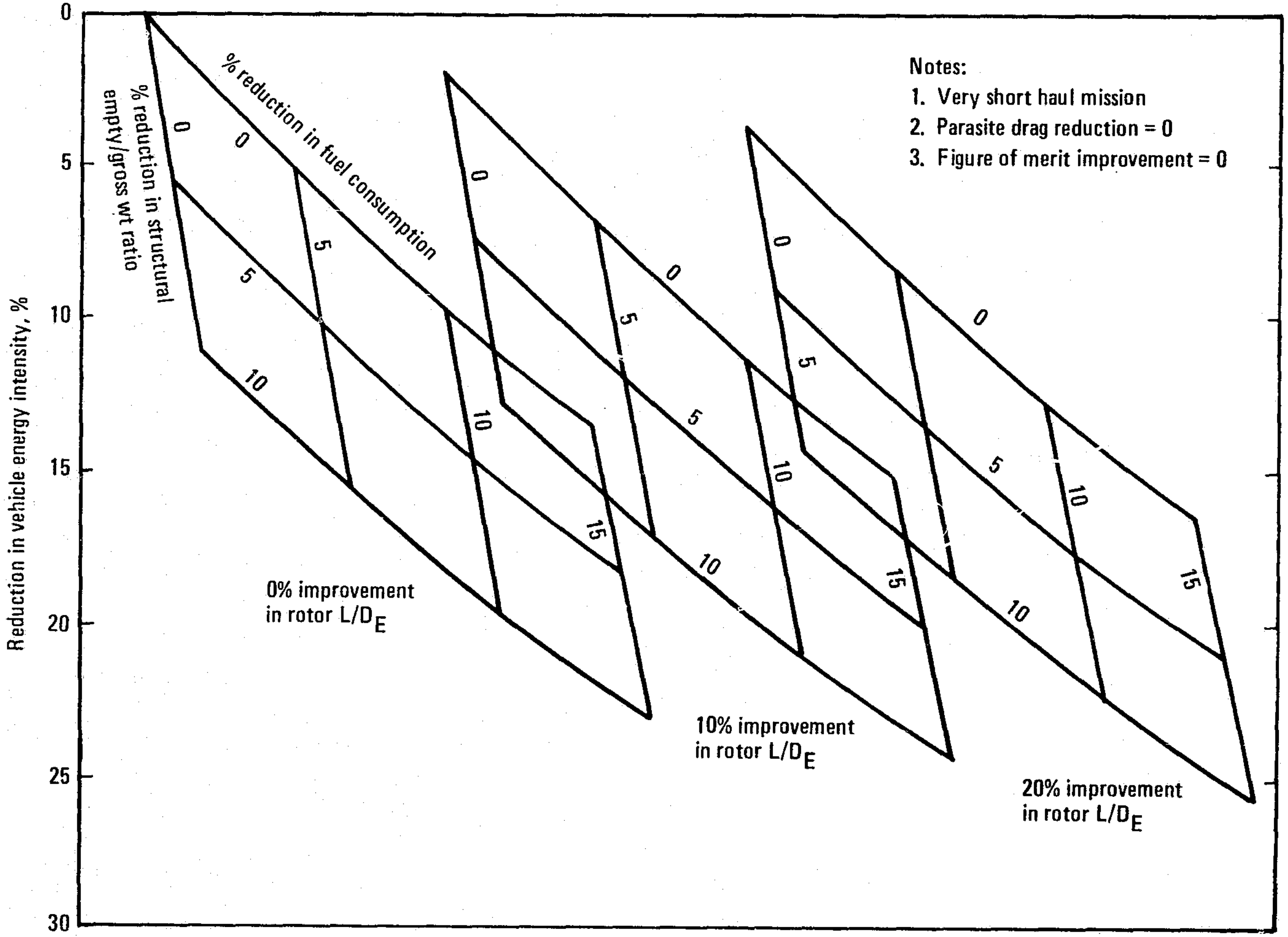


FIGURE B-49 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

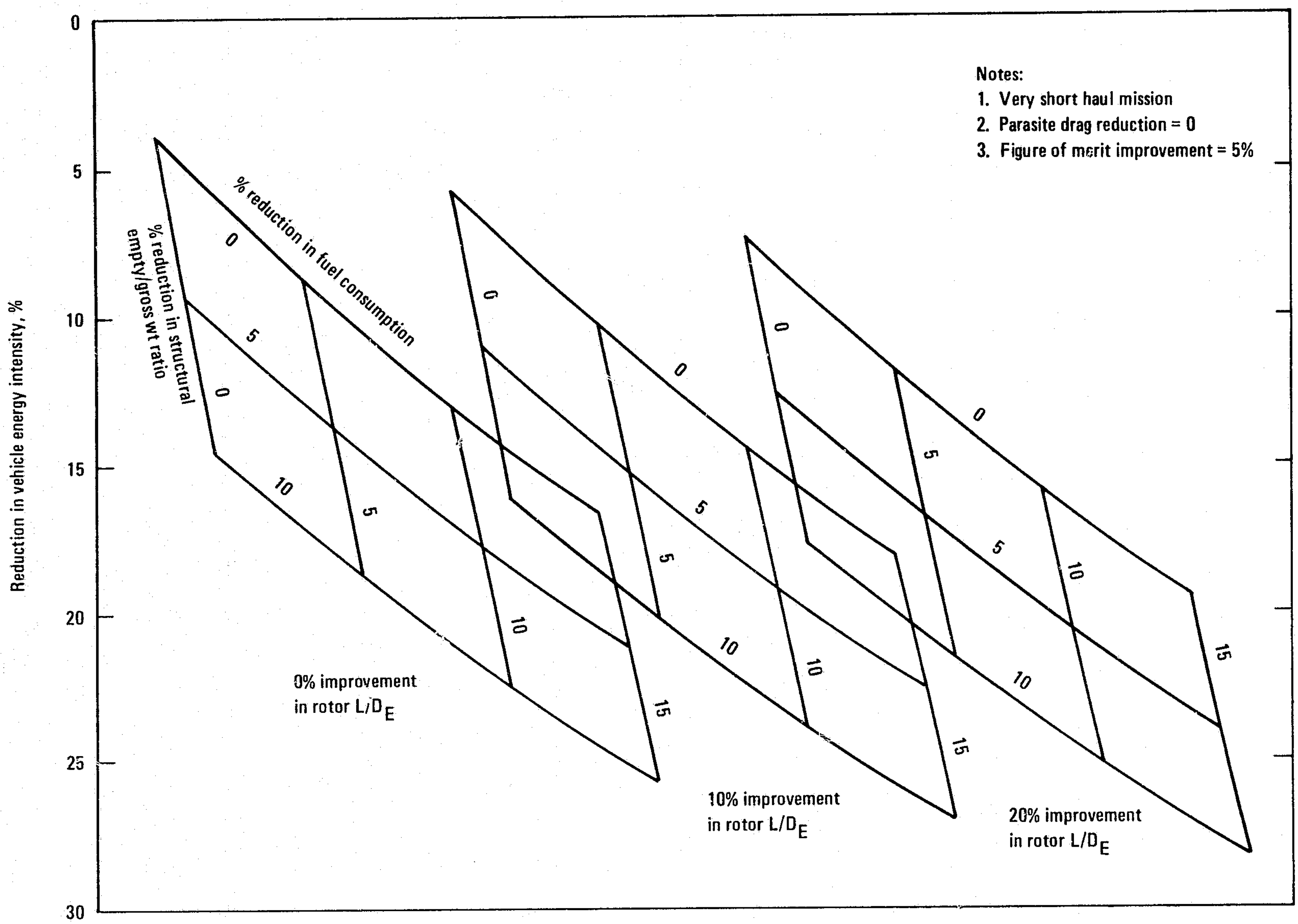


FIGURE B-50 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

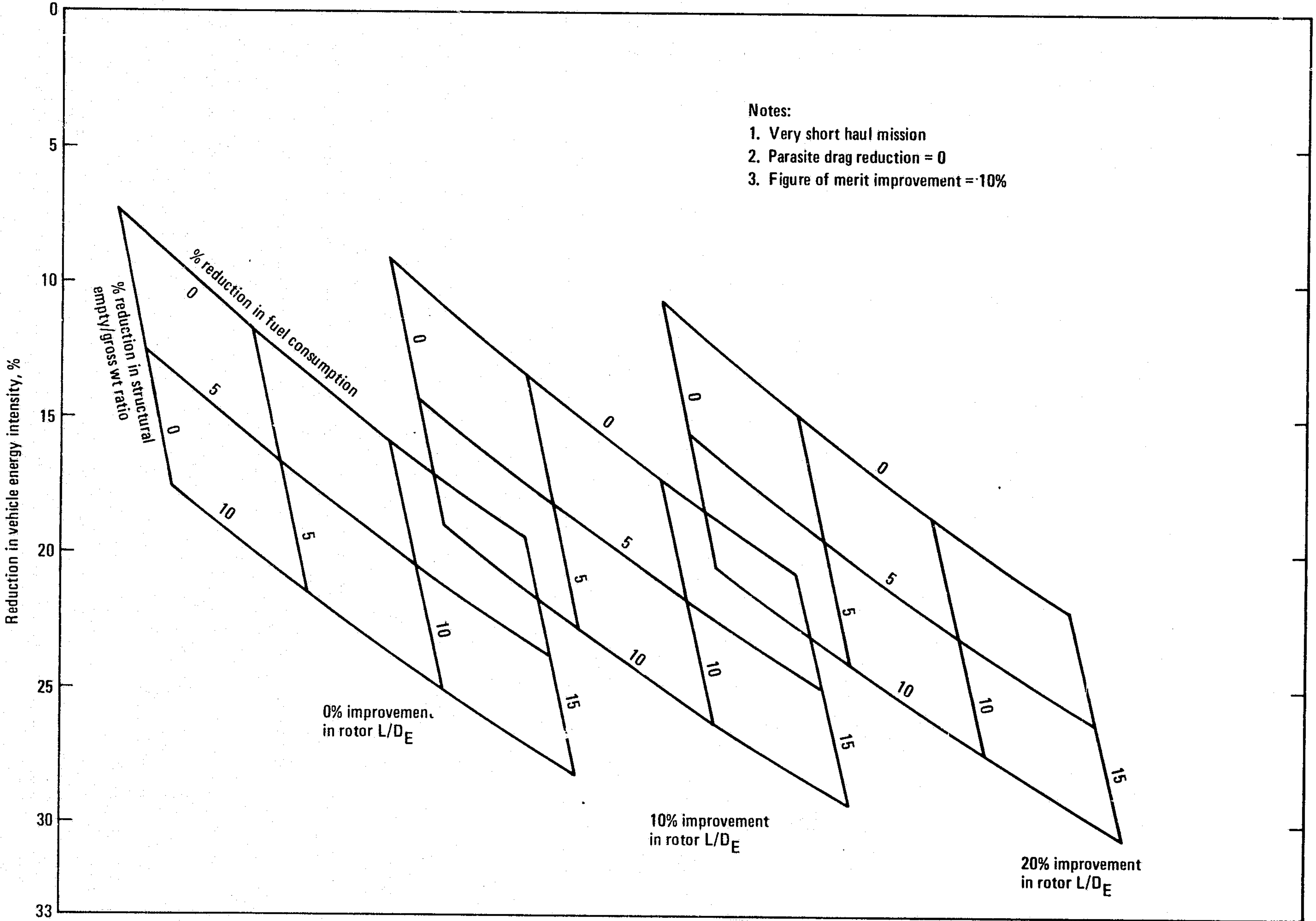


FIGURE B-51 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

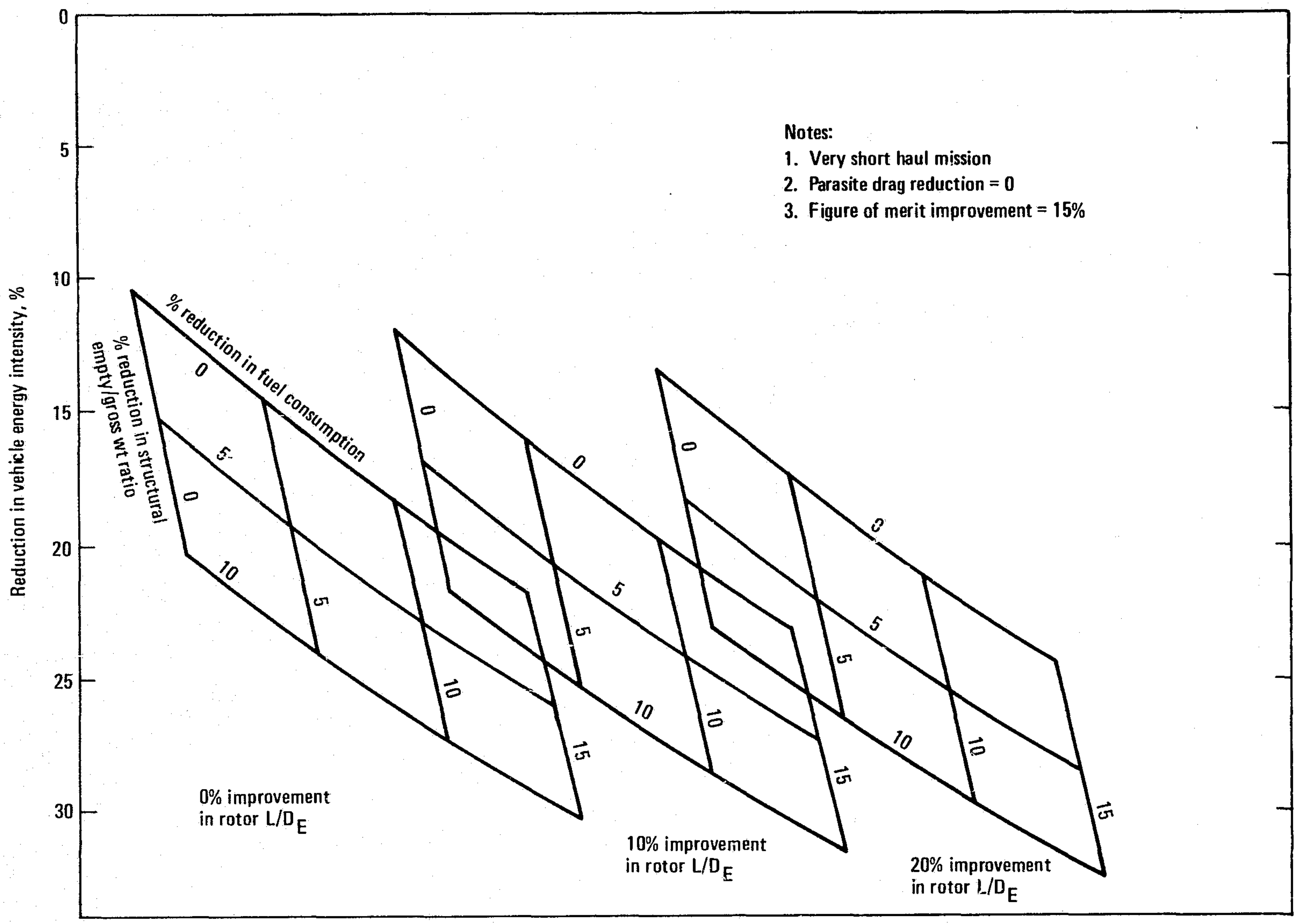


FIGURE B-52 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

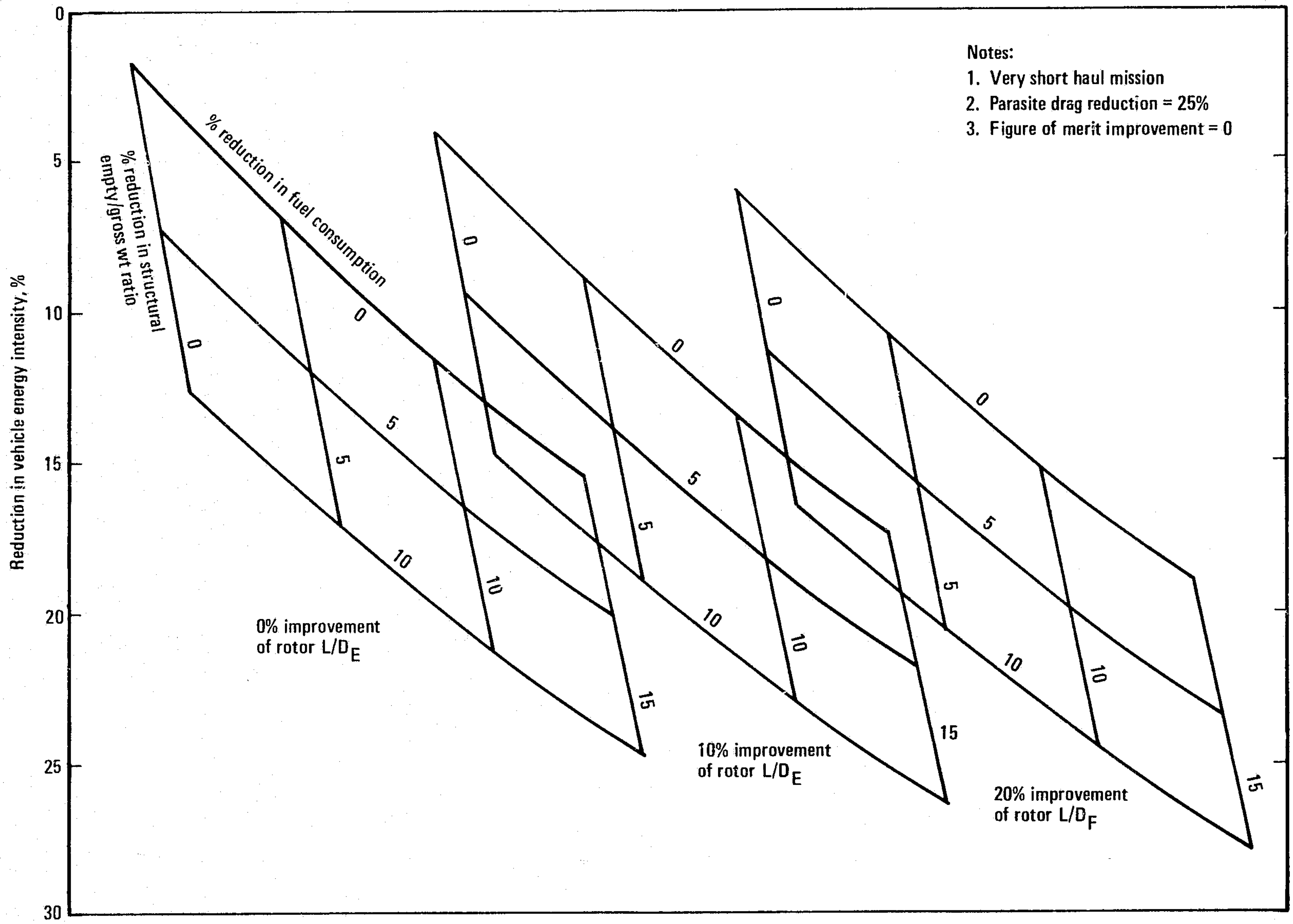


FIGURE B-53 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

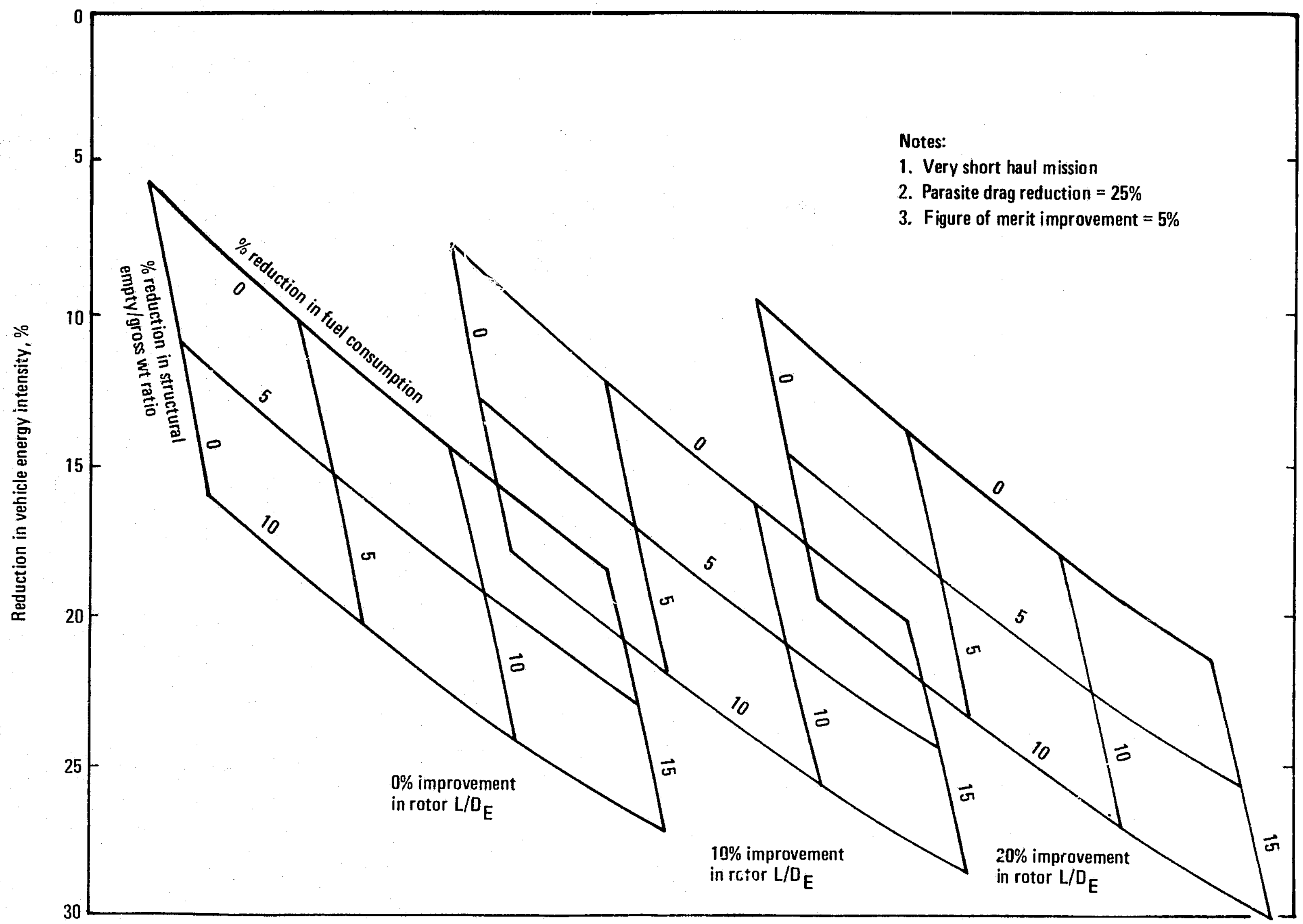


FIGURE B-54 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

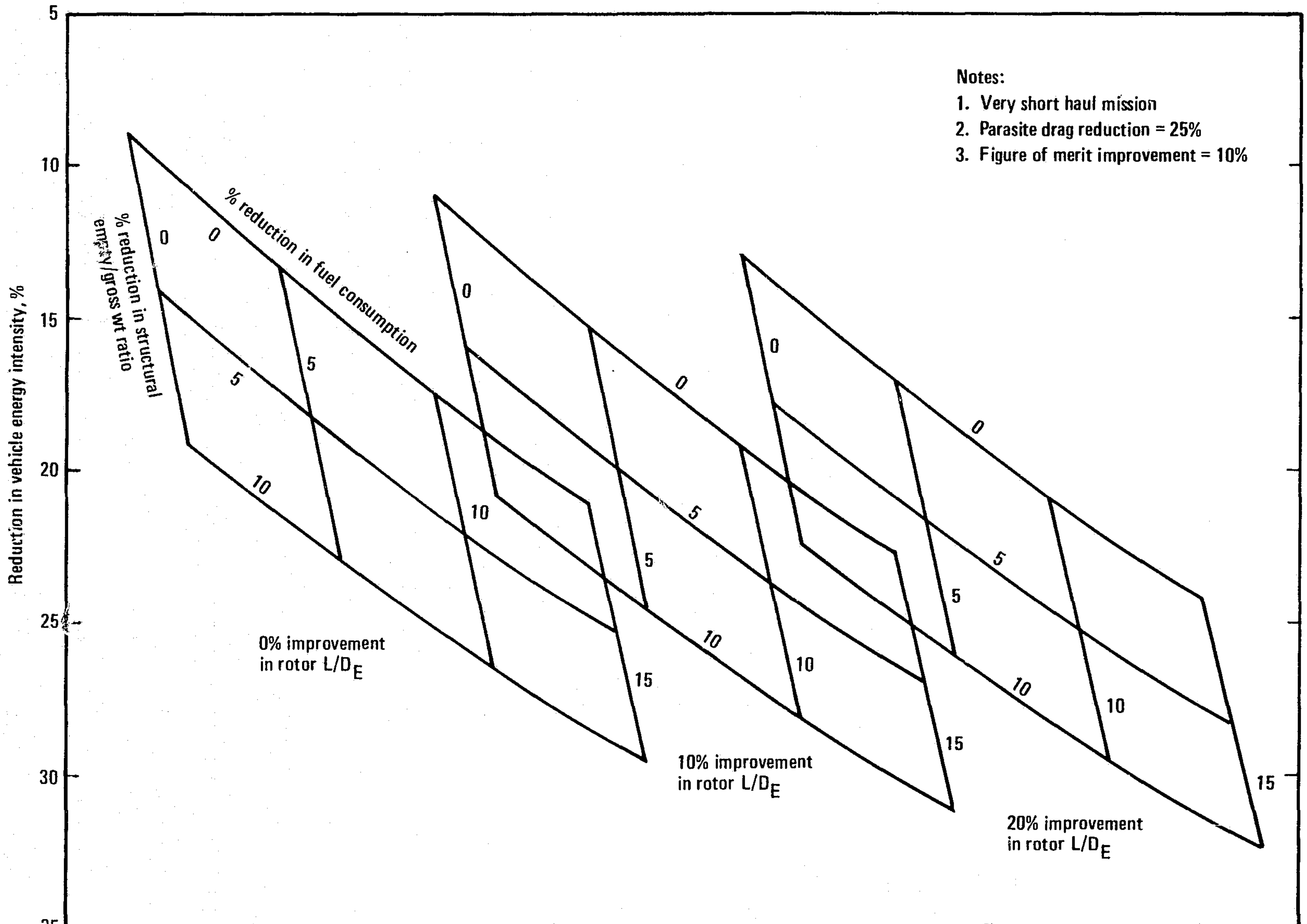


FIGURE B-55 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

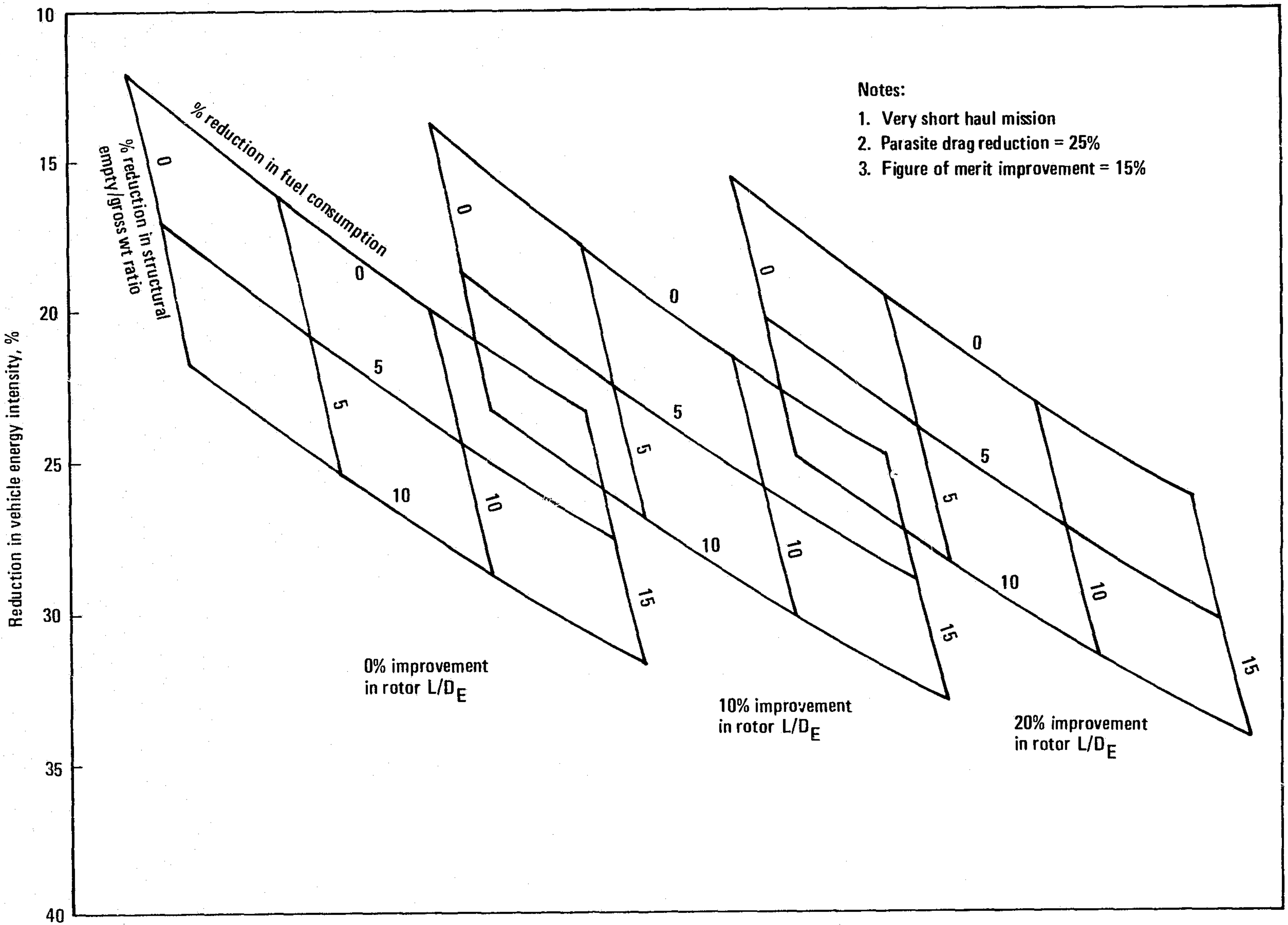


FIGURE B-56 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

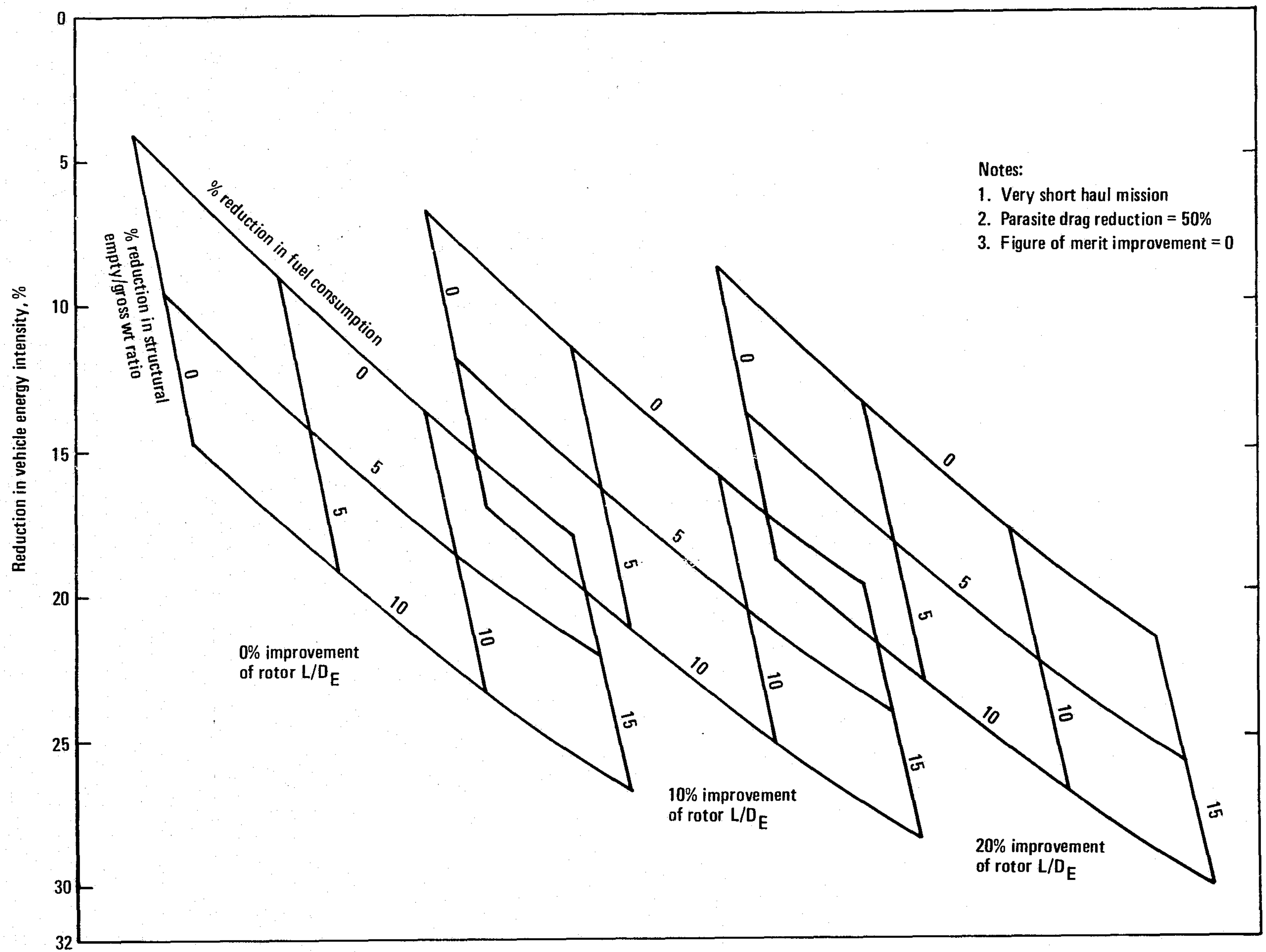


FIGURE B-57 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

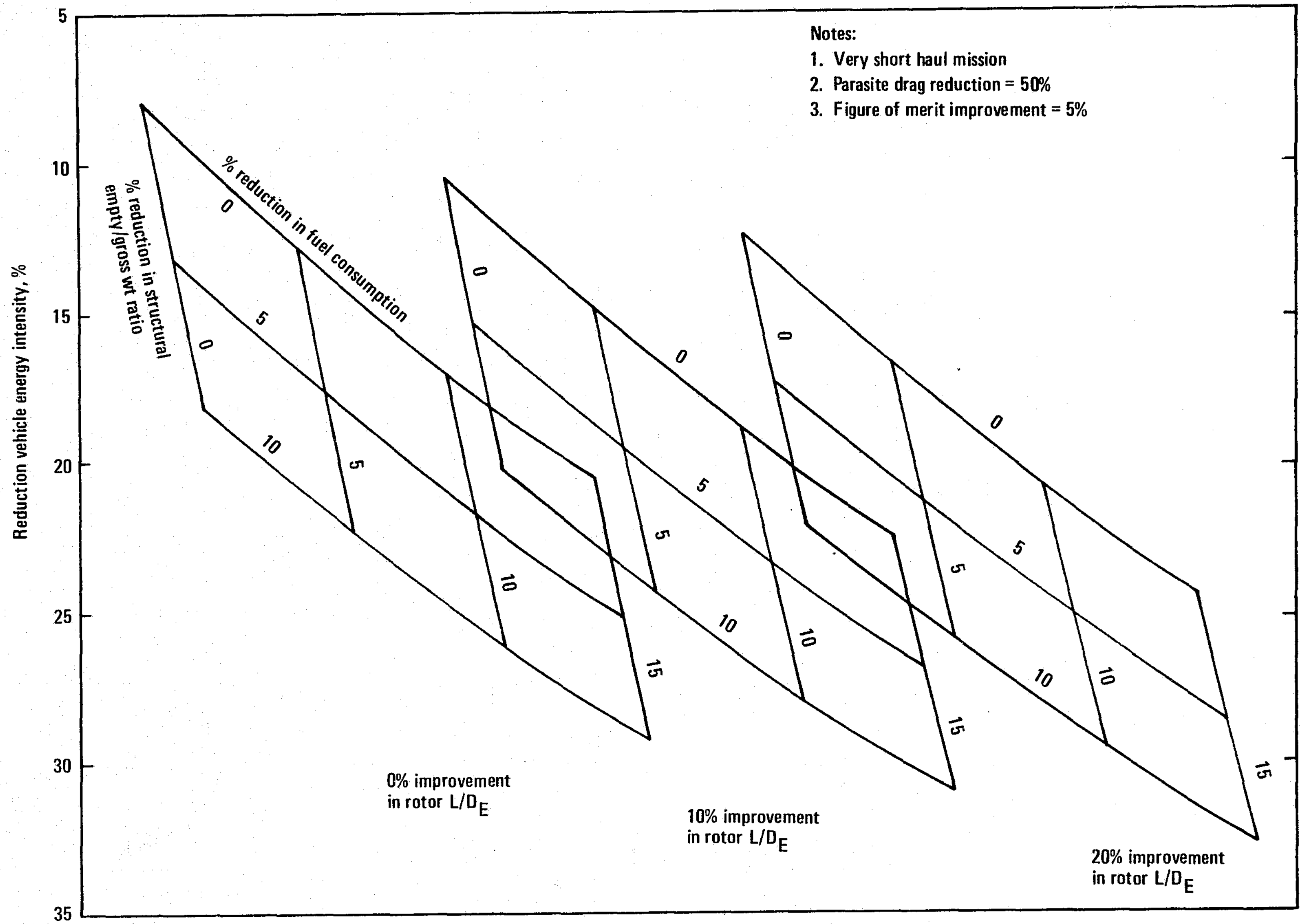


FIGURE B-58 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

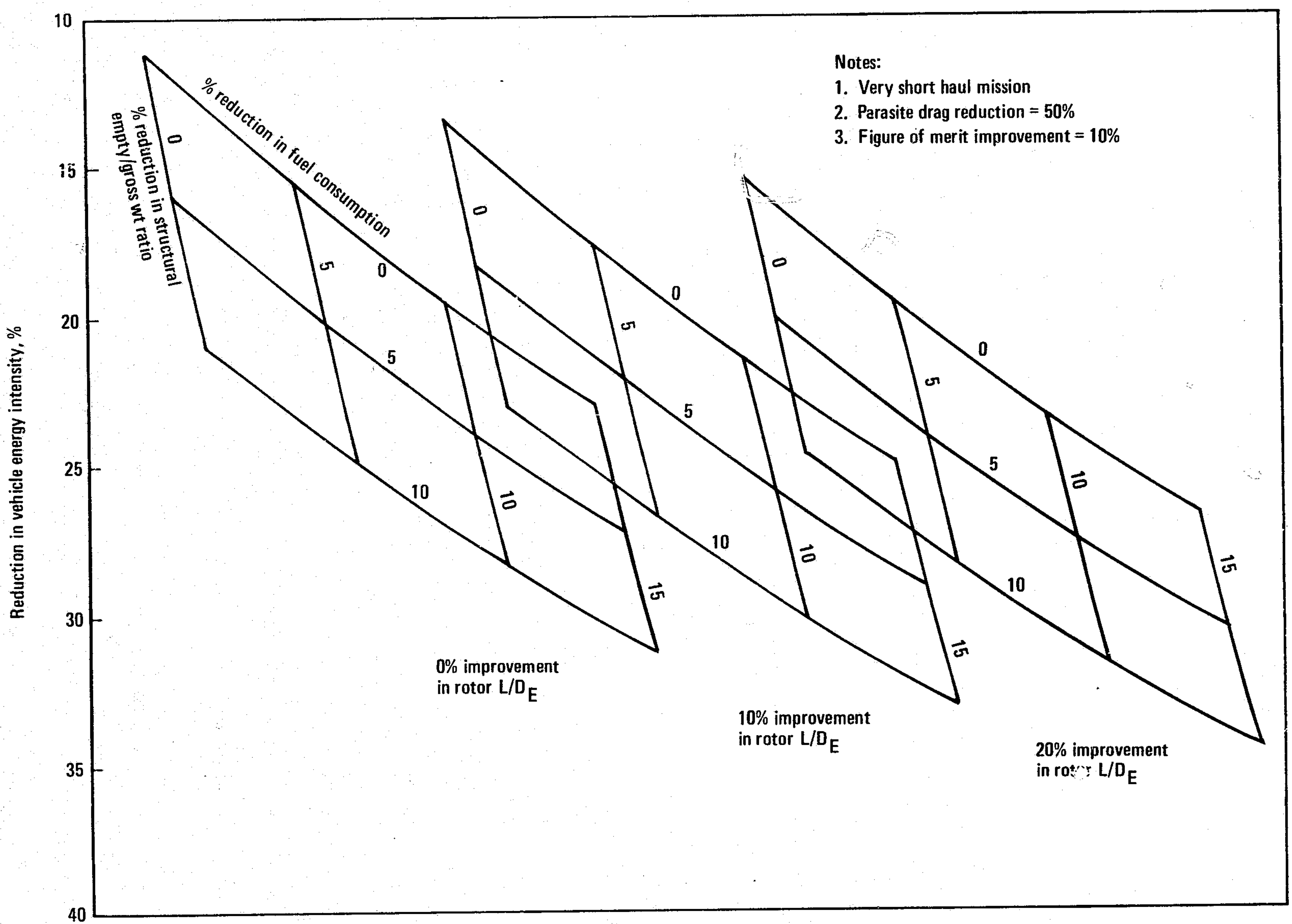


FIGURE B-59 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

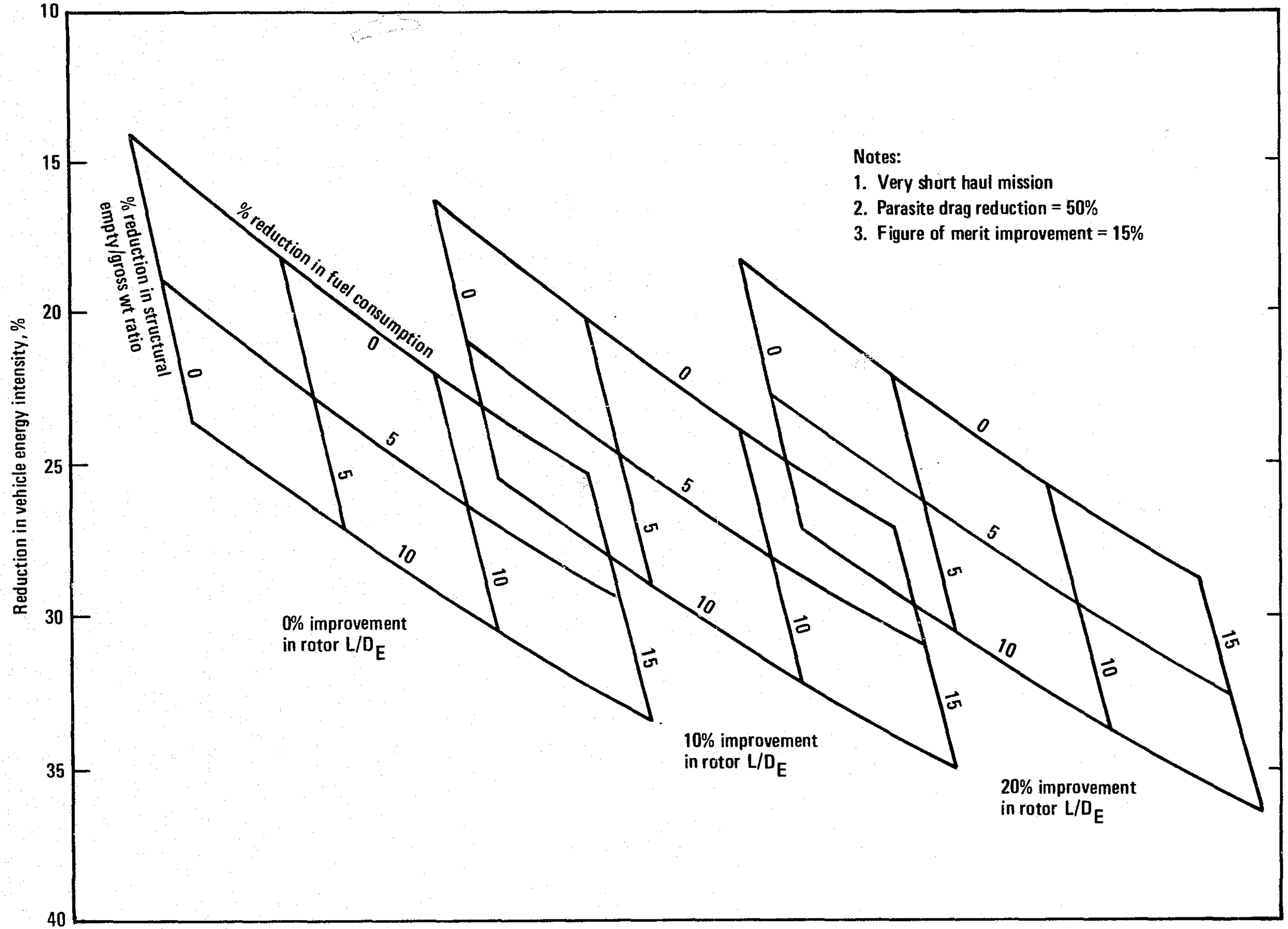


FIGURE B-60 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE ENERGY INTENSITY

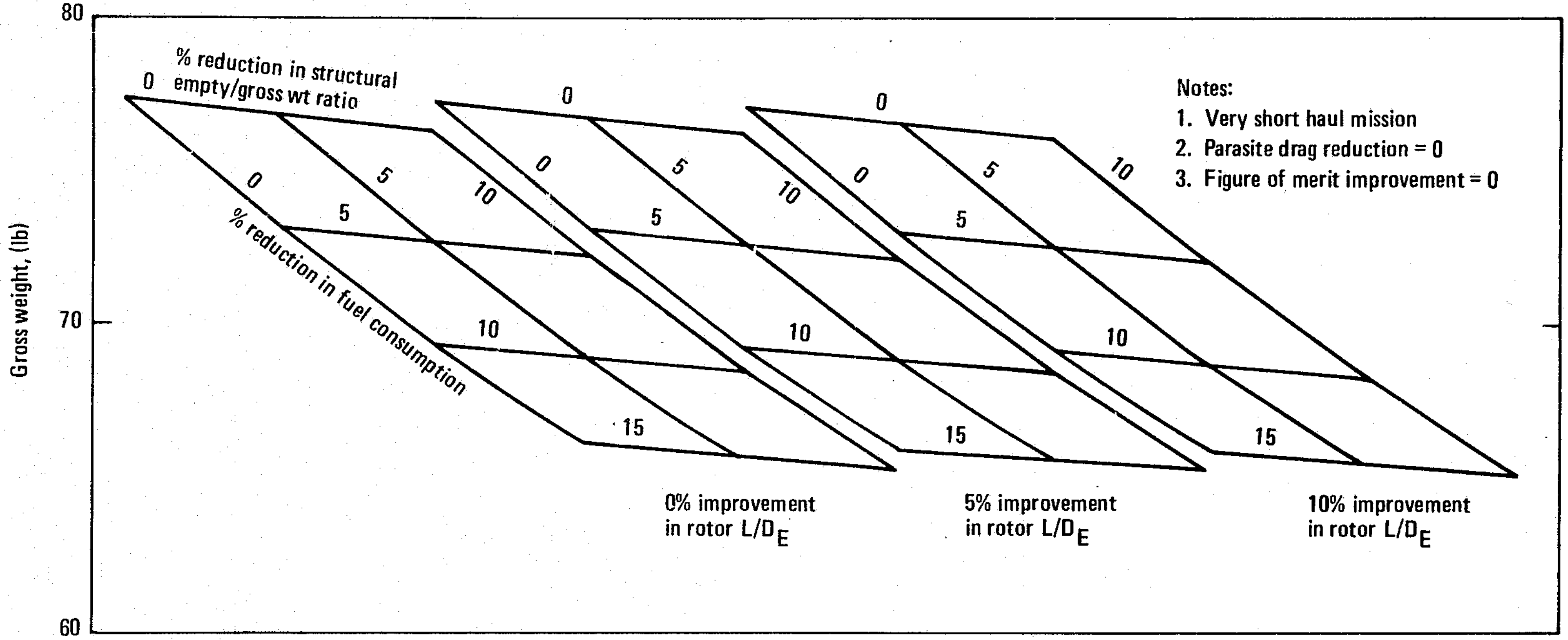
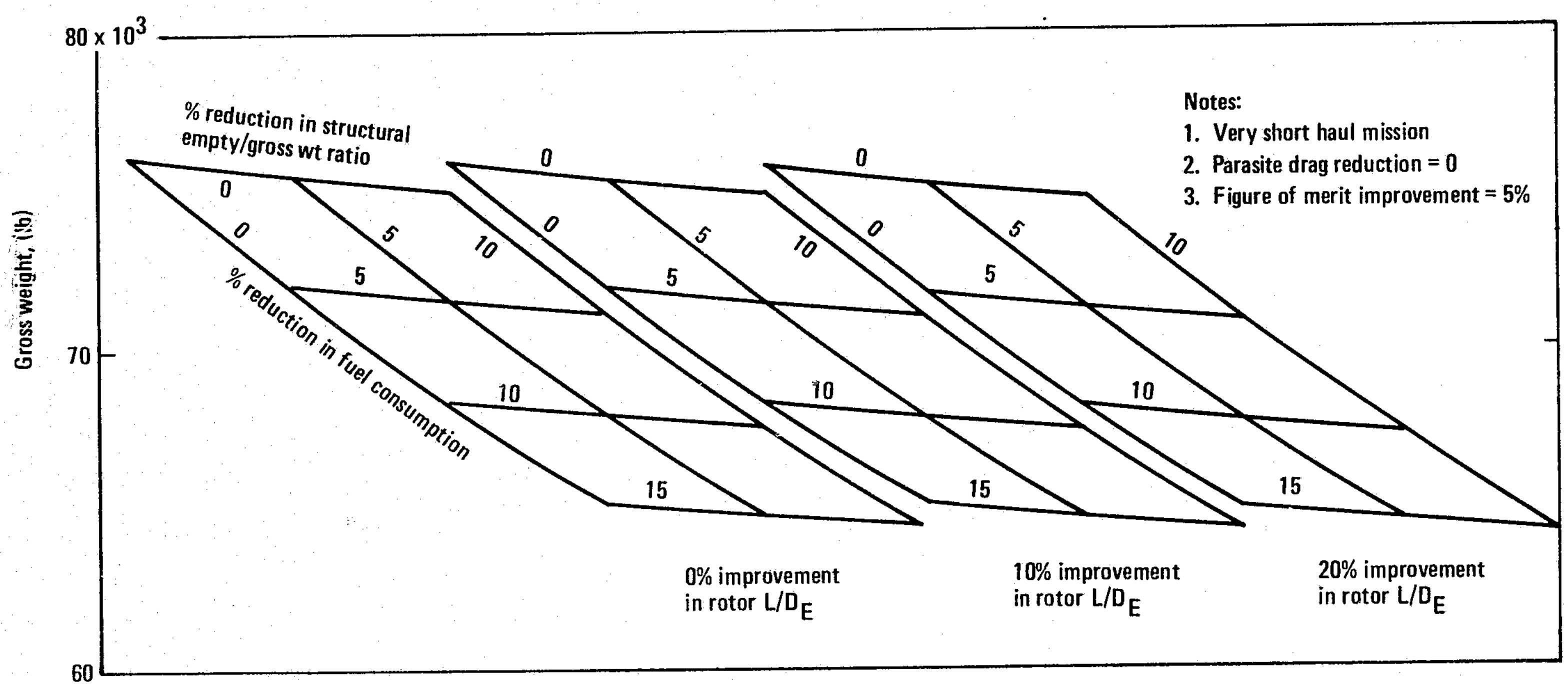


FIGURE B-61 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT



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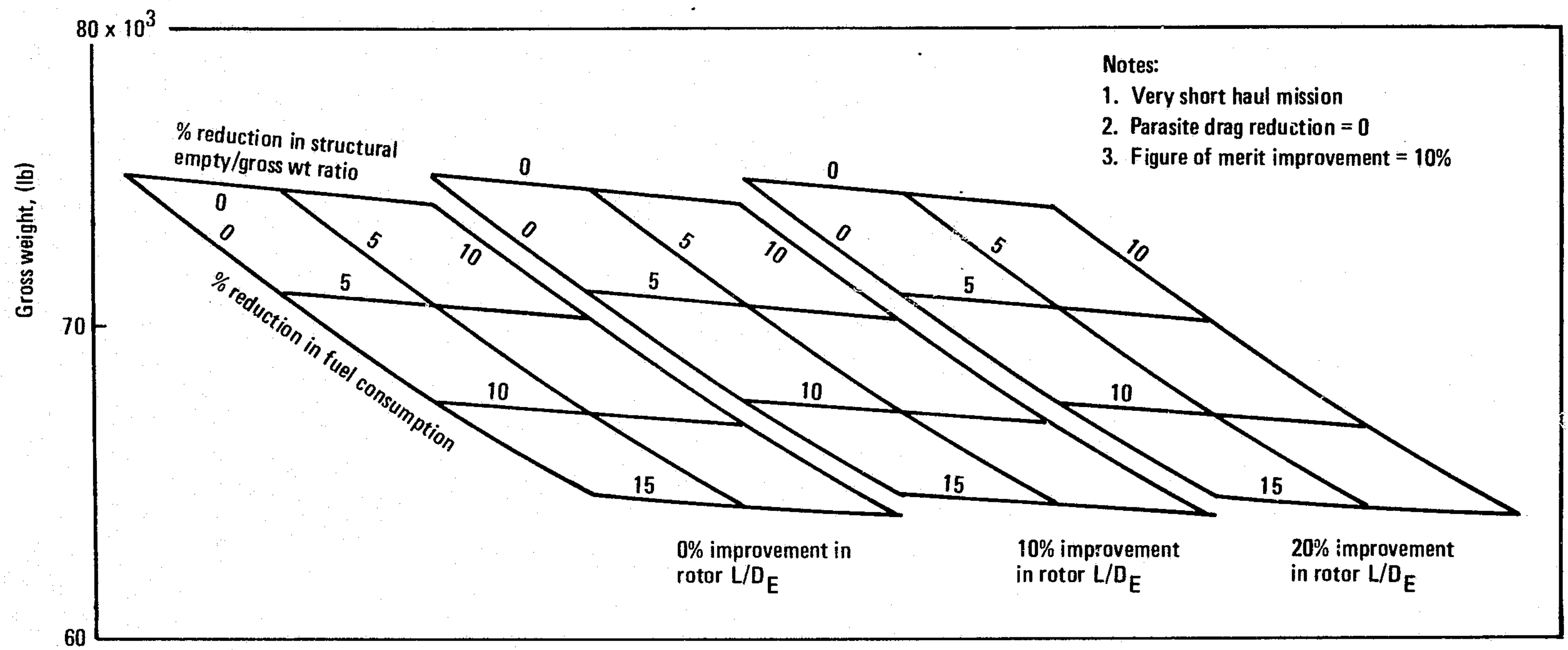

FIGURE B-63 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

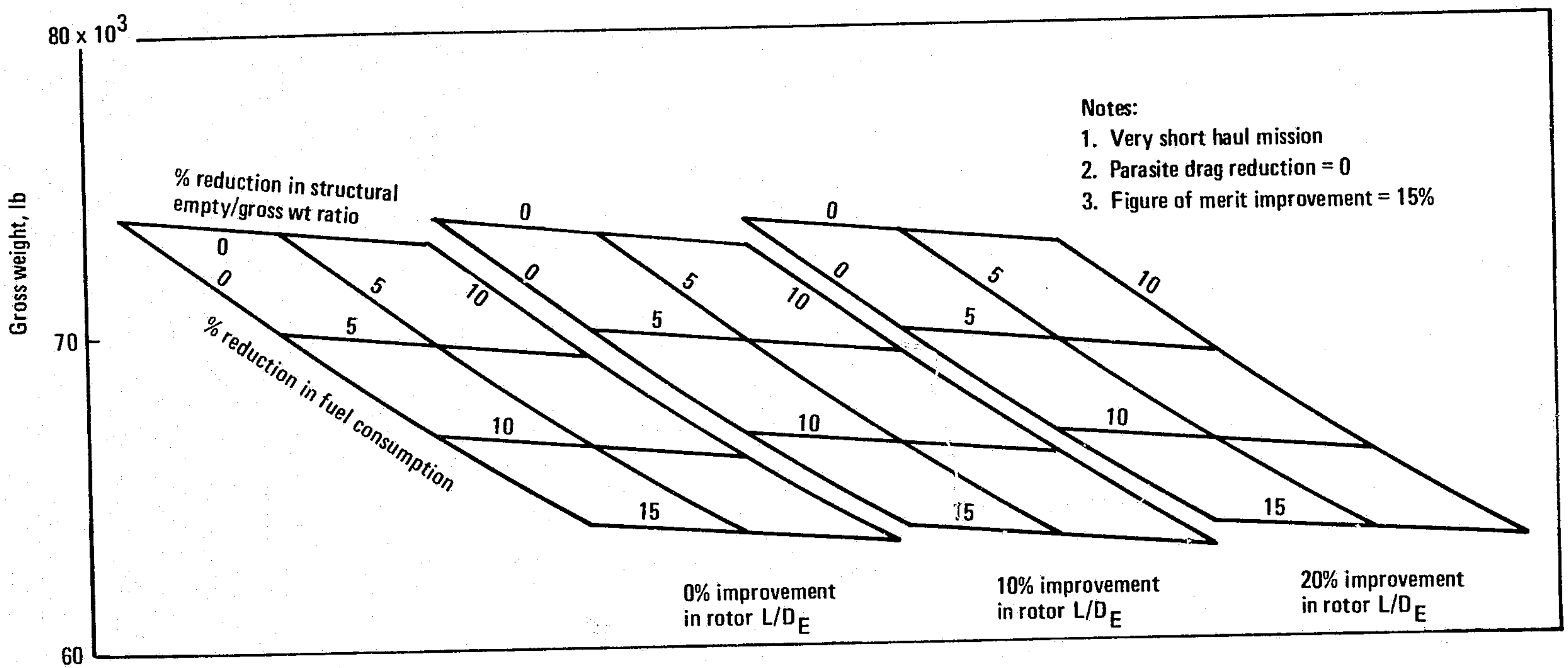

FIGURE B-64 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

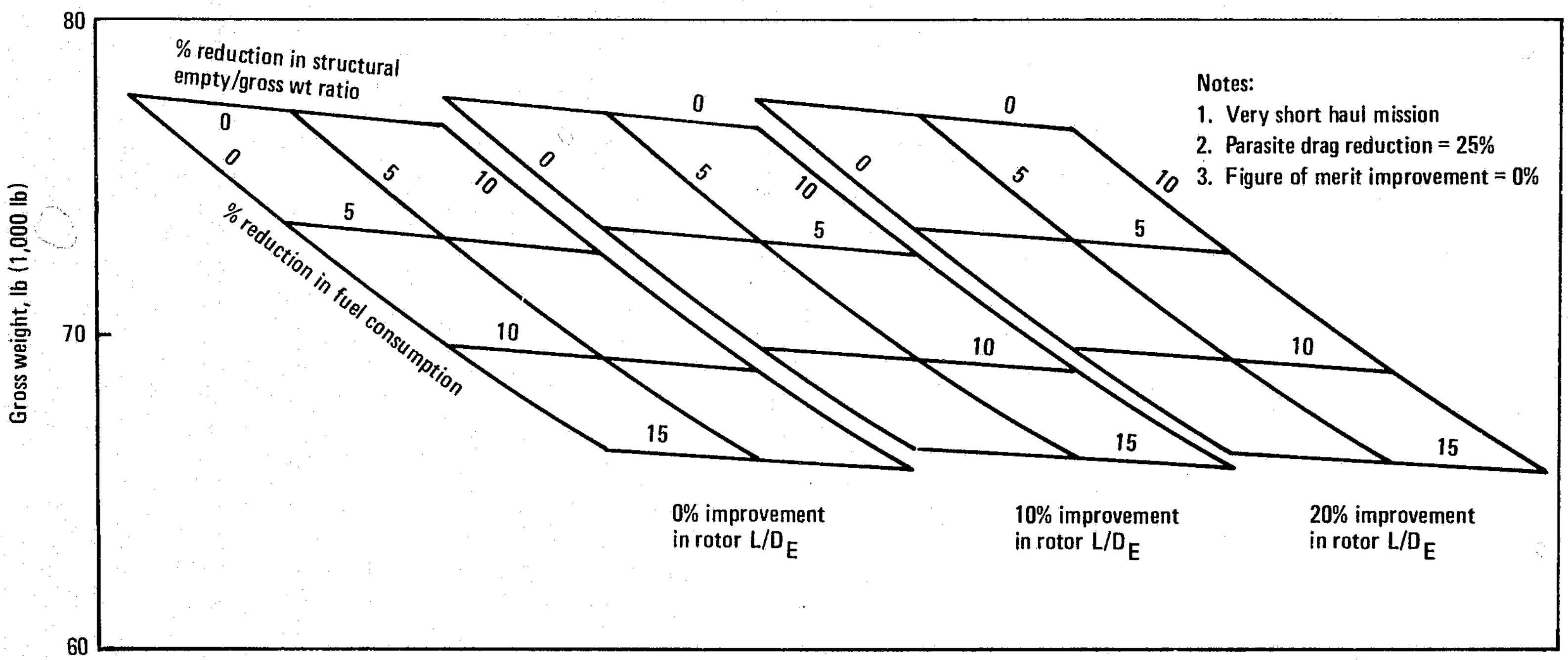

FIGURE B-65 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

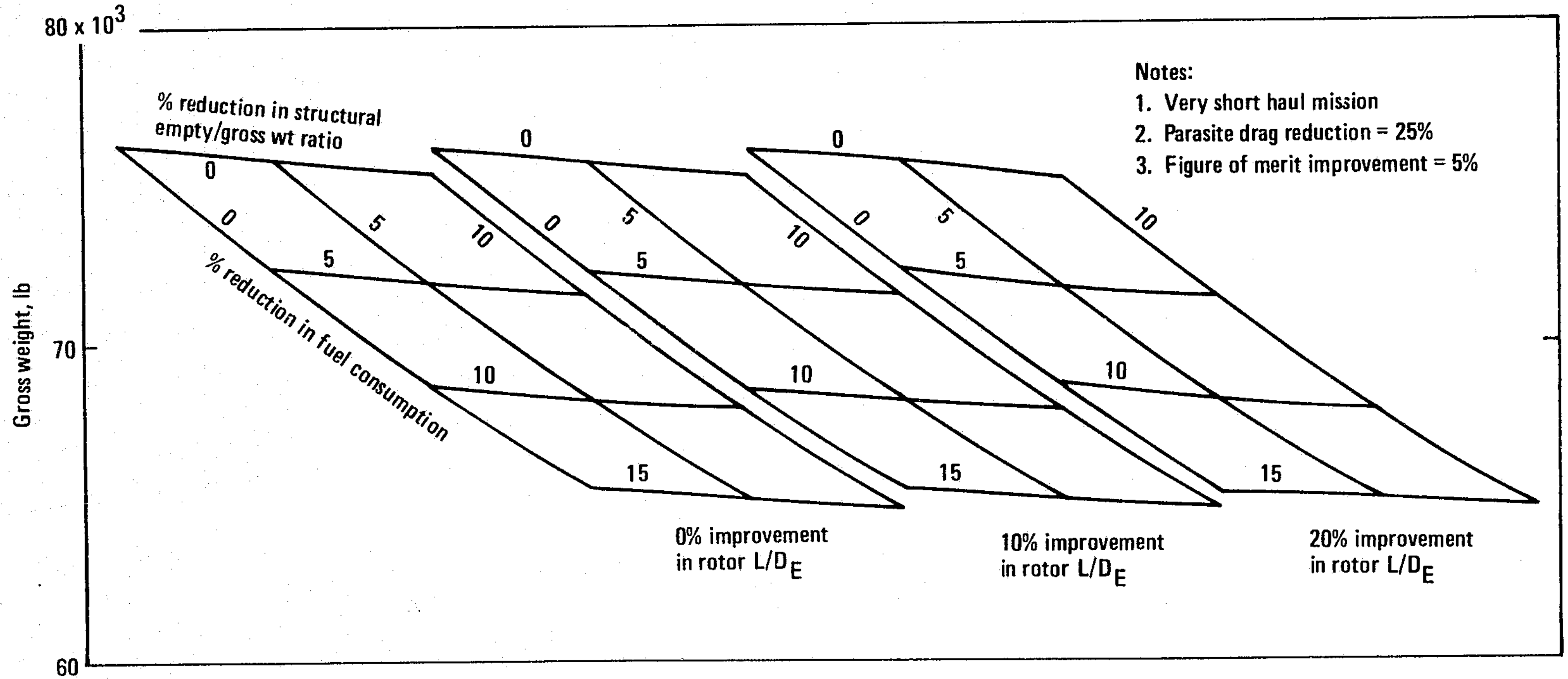

FIGURE B-66 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

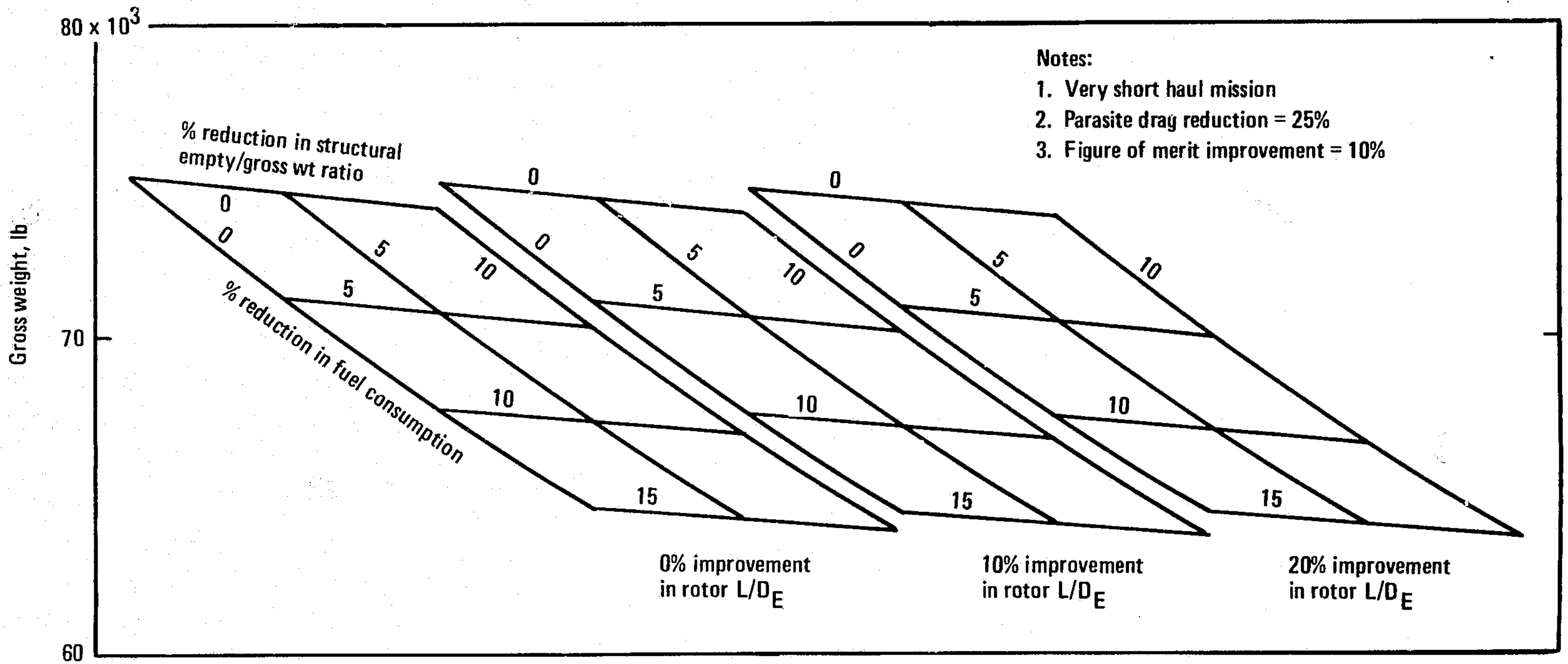

FIGURE B-67 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

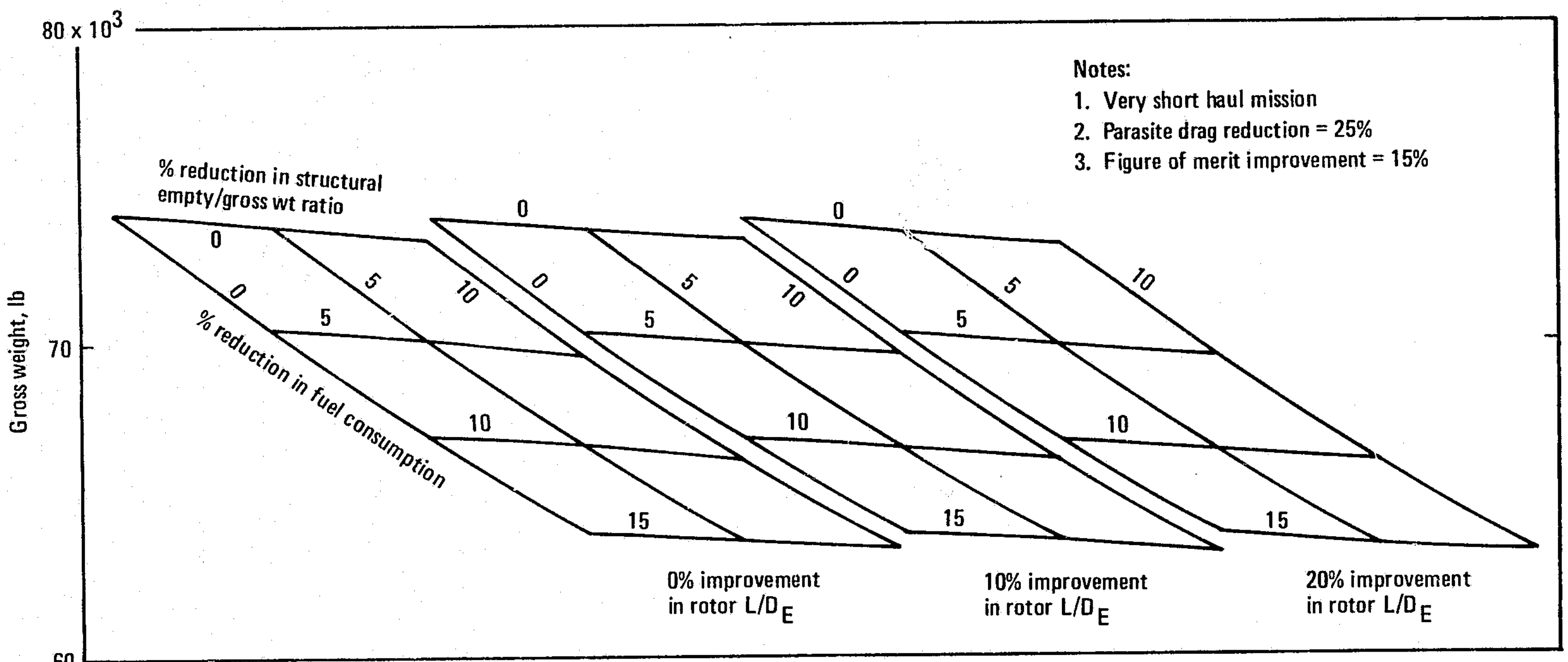

FIGURE B-68 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

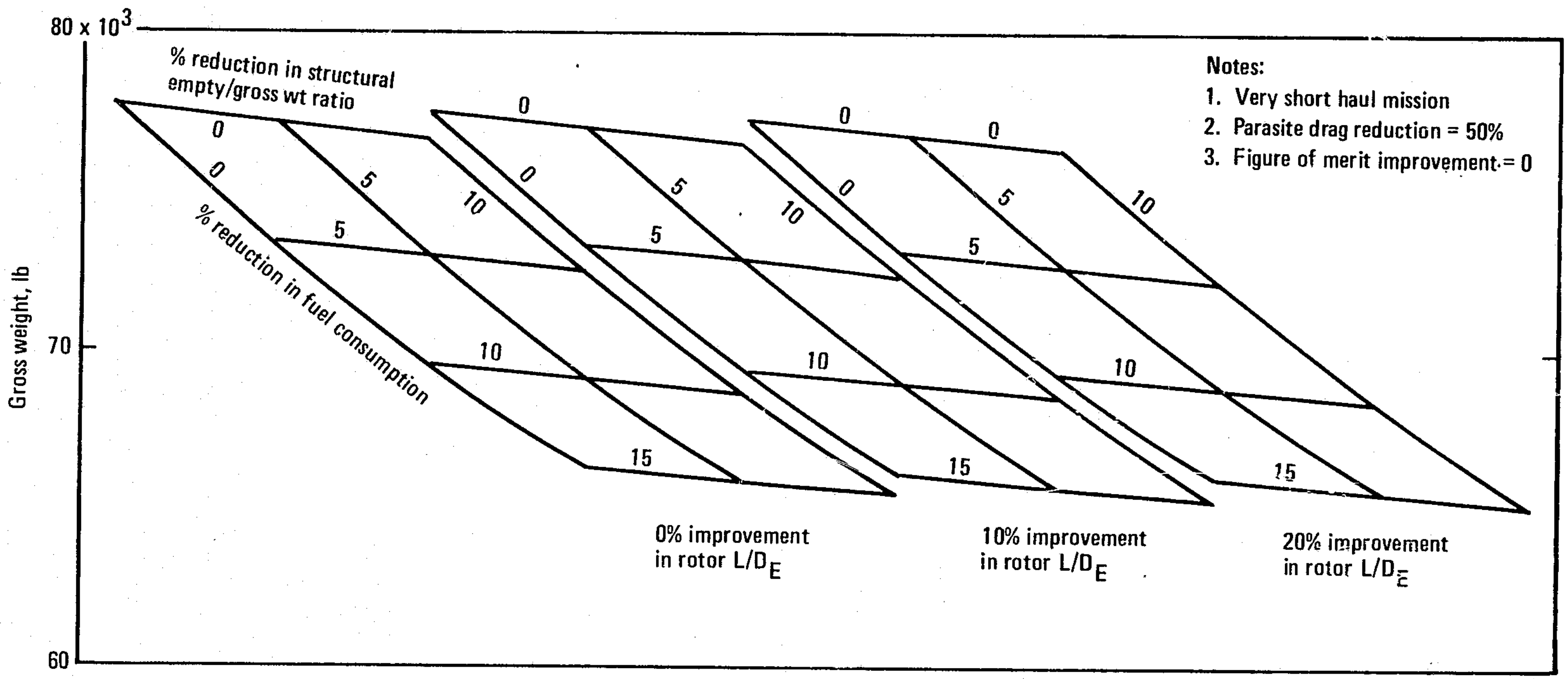

FIGURE B-69 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

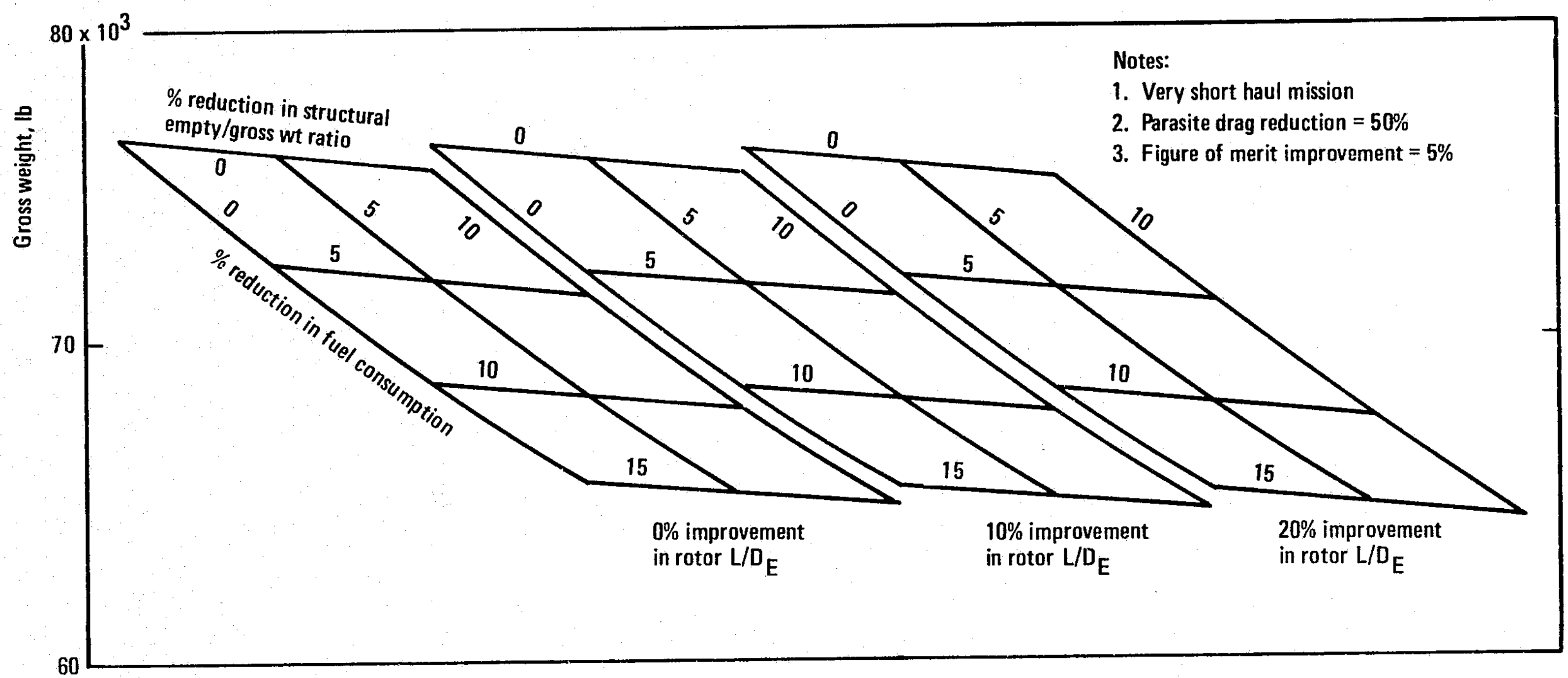

FIGURE B-70 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

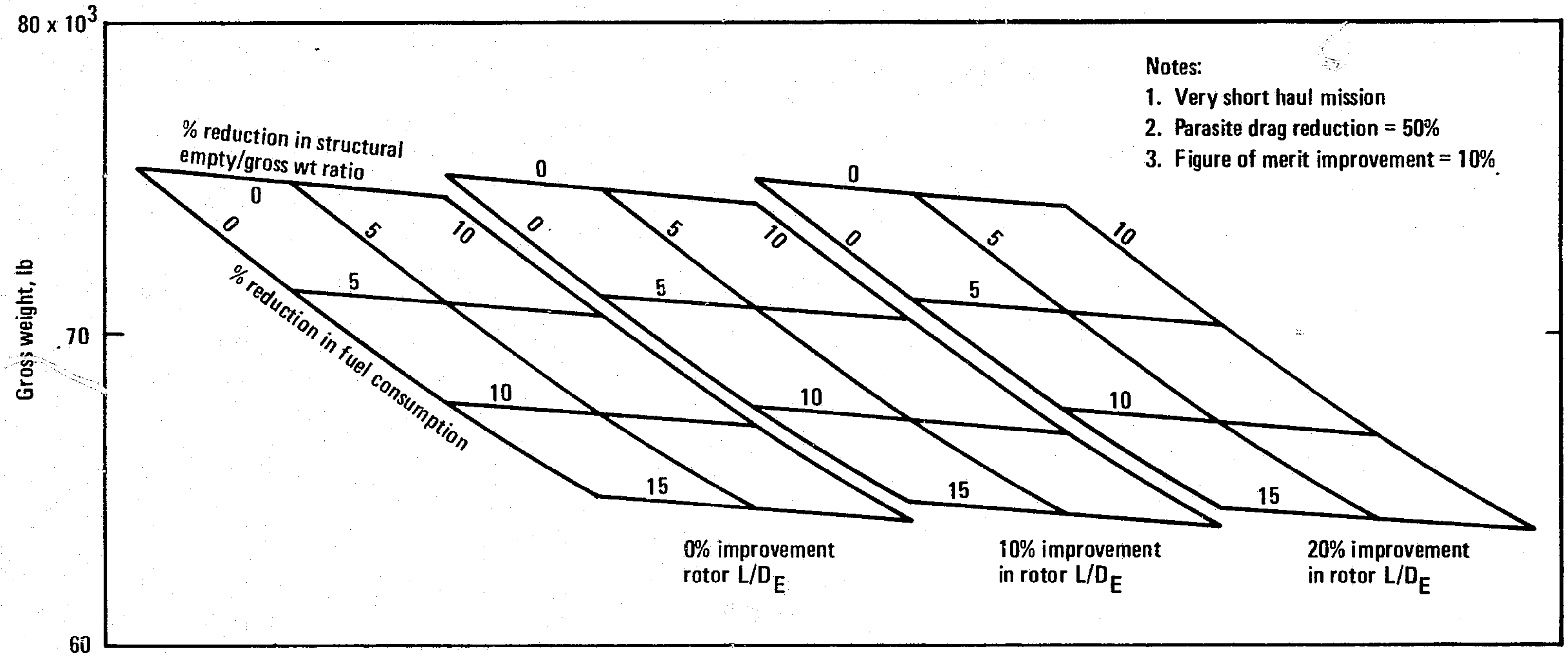

FIGURE B-71 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

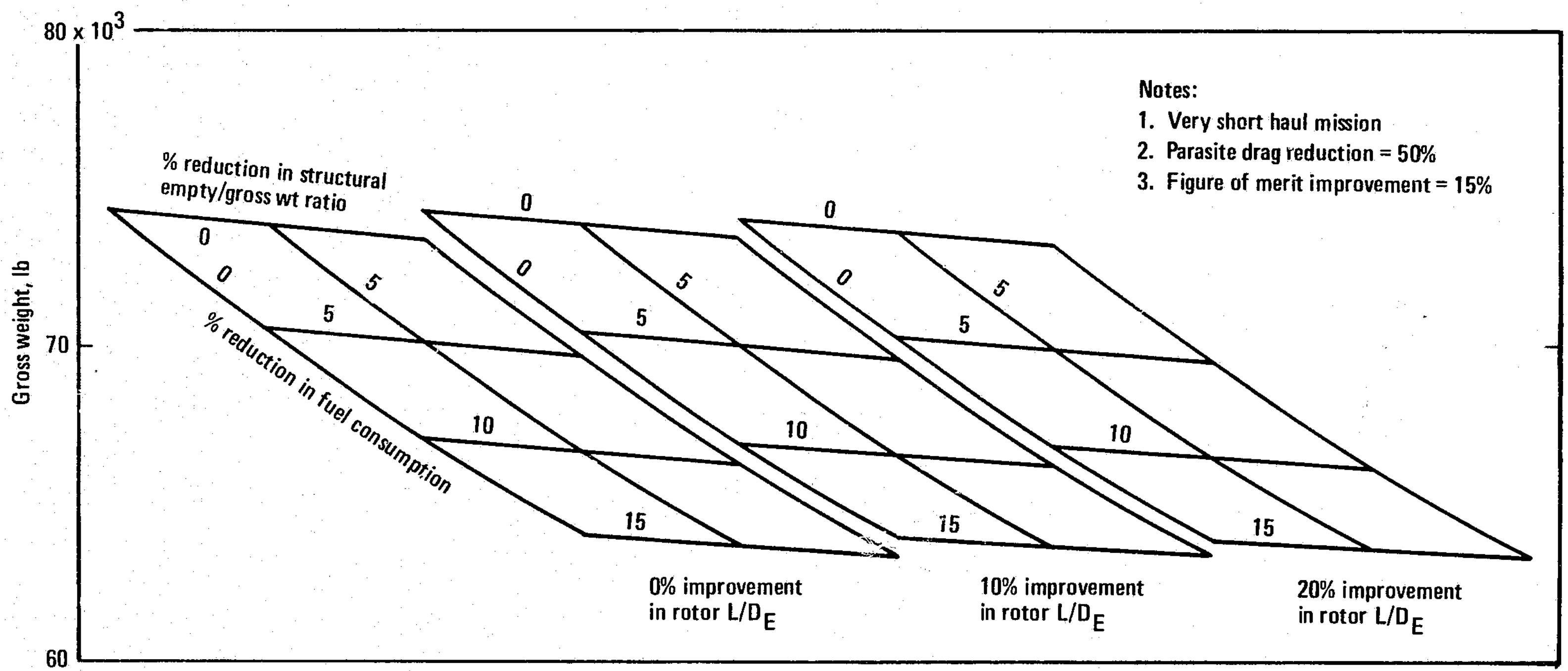

FIGURE B-72 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE GROSS WEIGHT

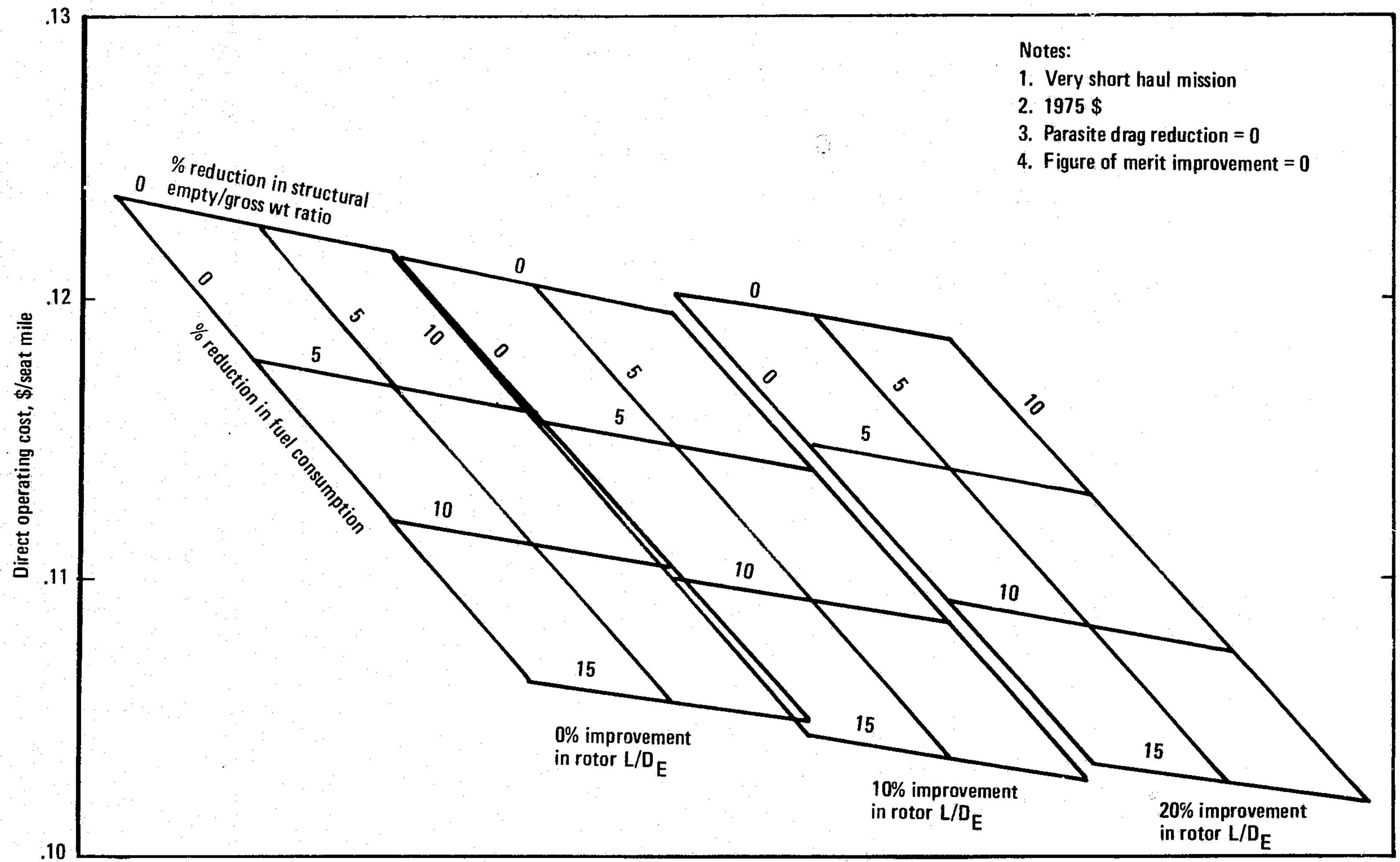

FIGURE B-73 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

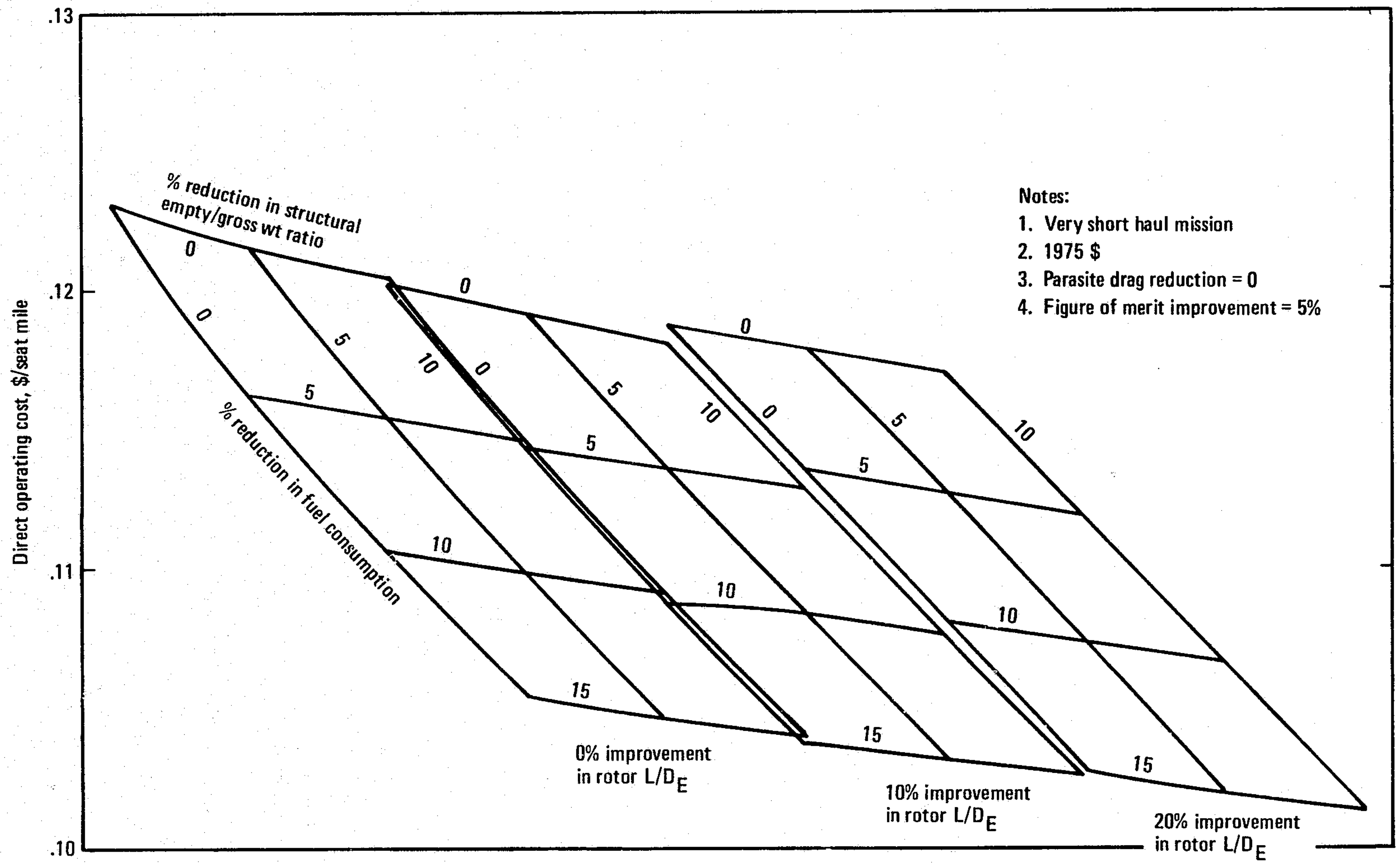

FIGURE B-74 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

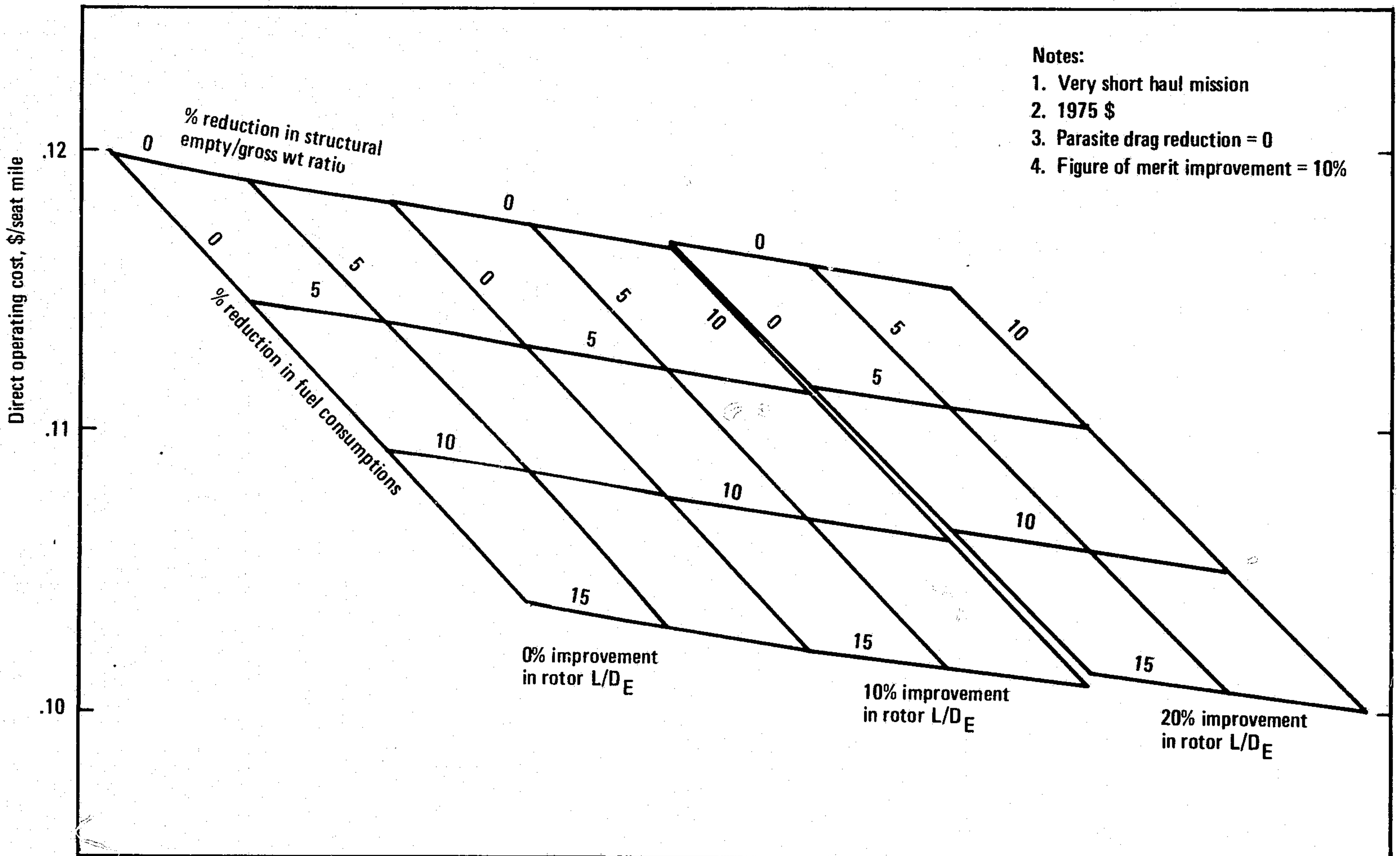

FIGURE B-75 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

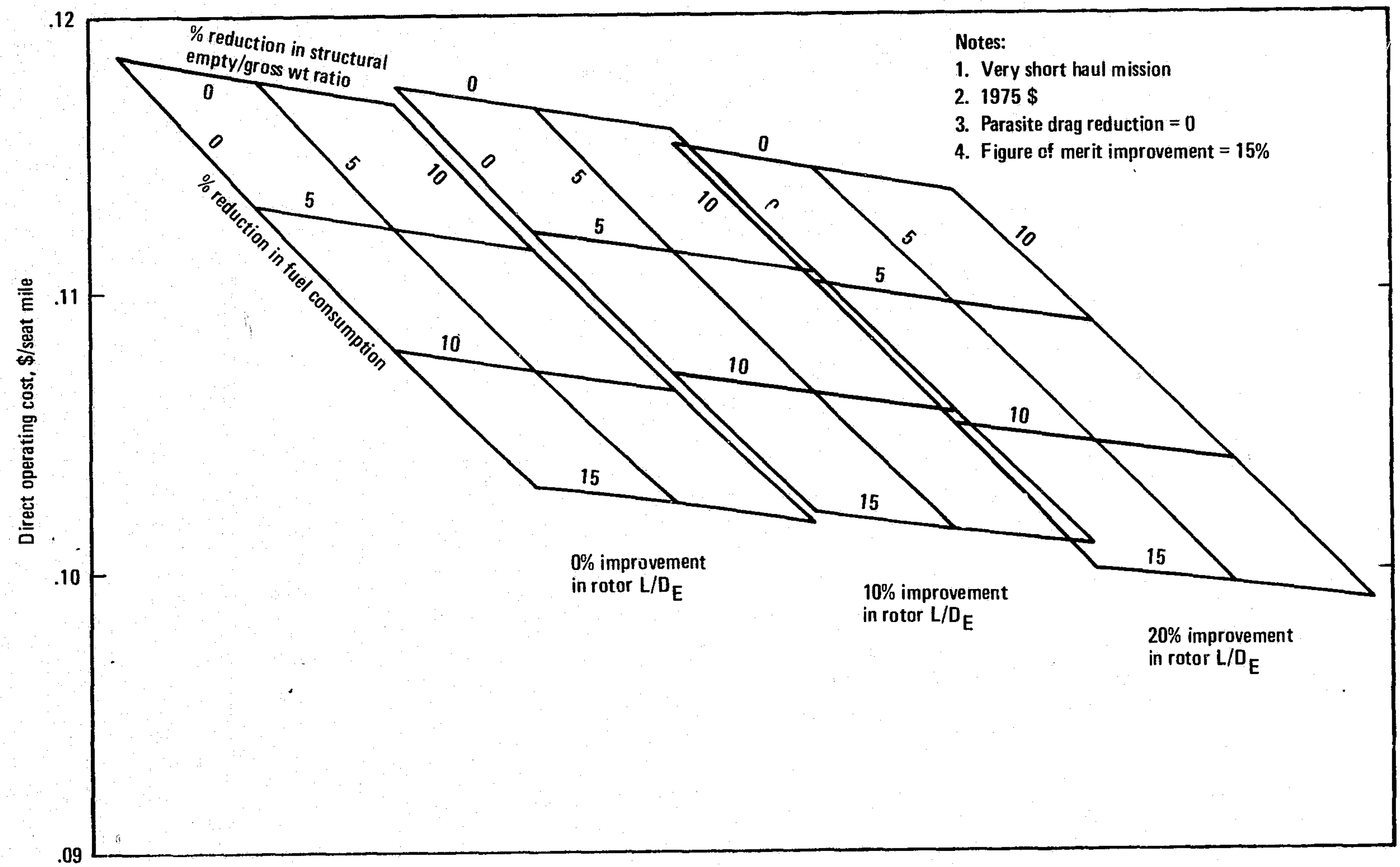

FIGURE B-76 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

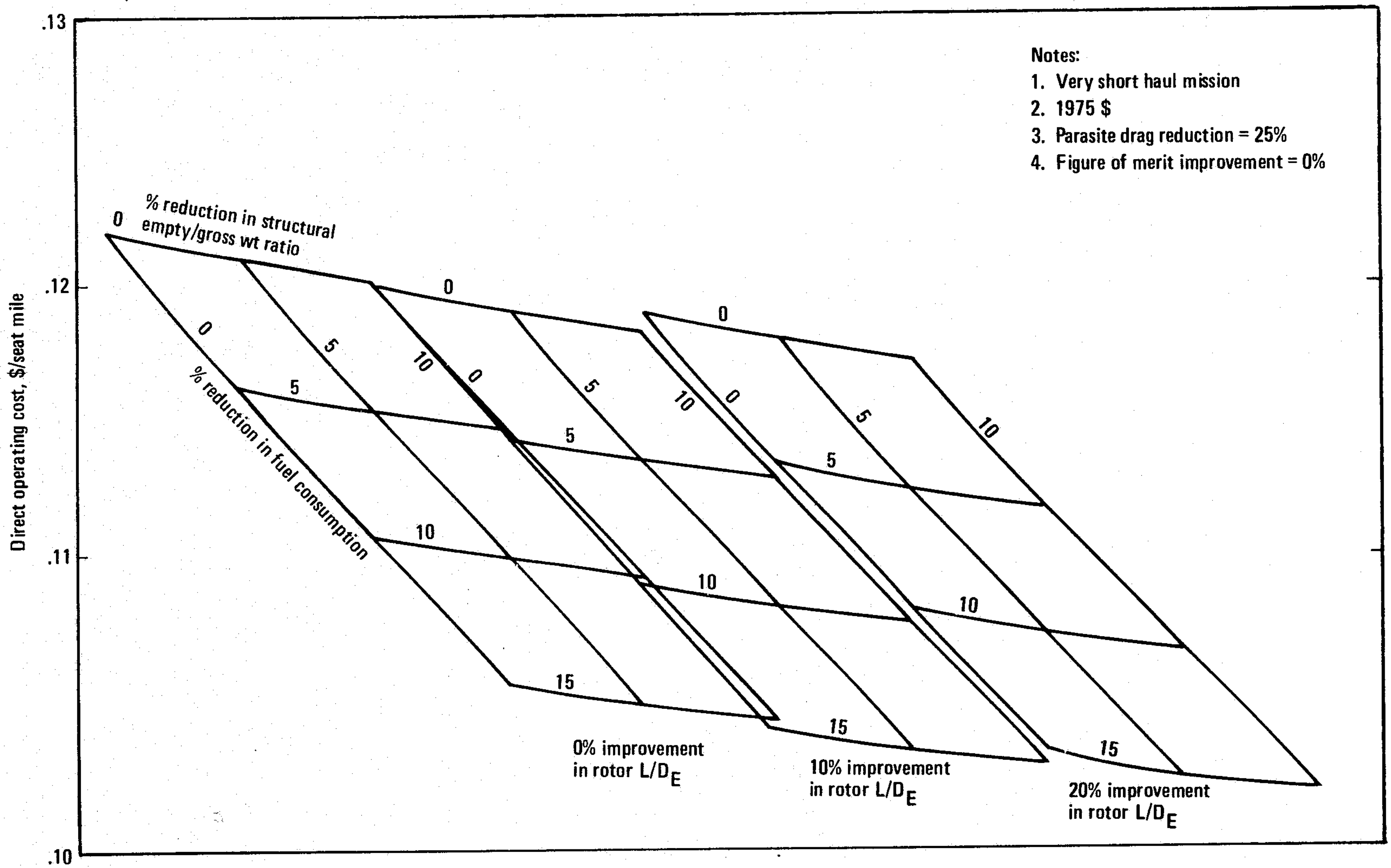

FIGURE B-77 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

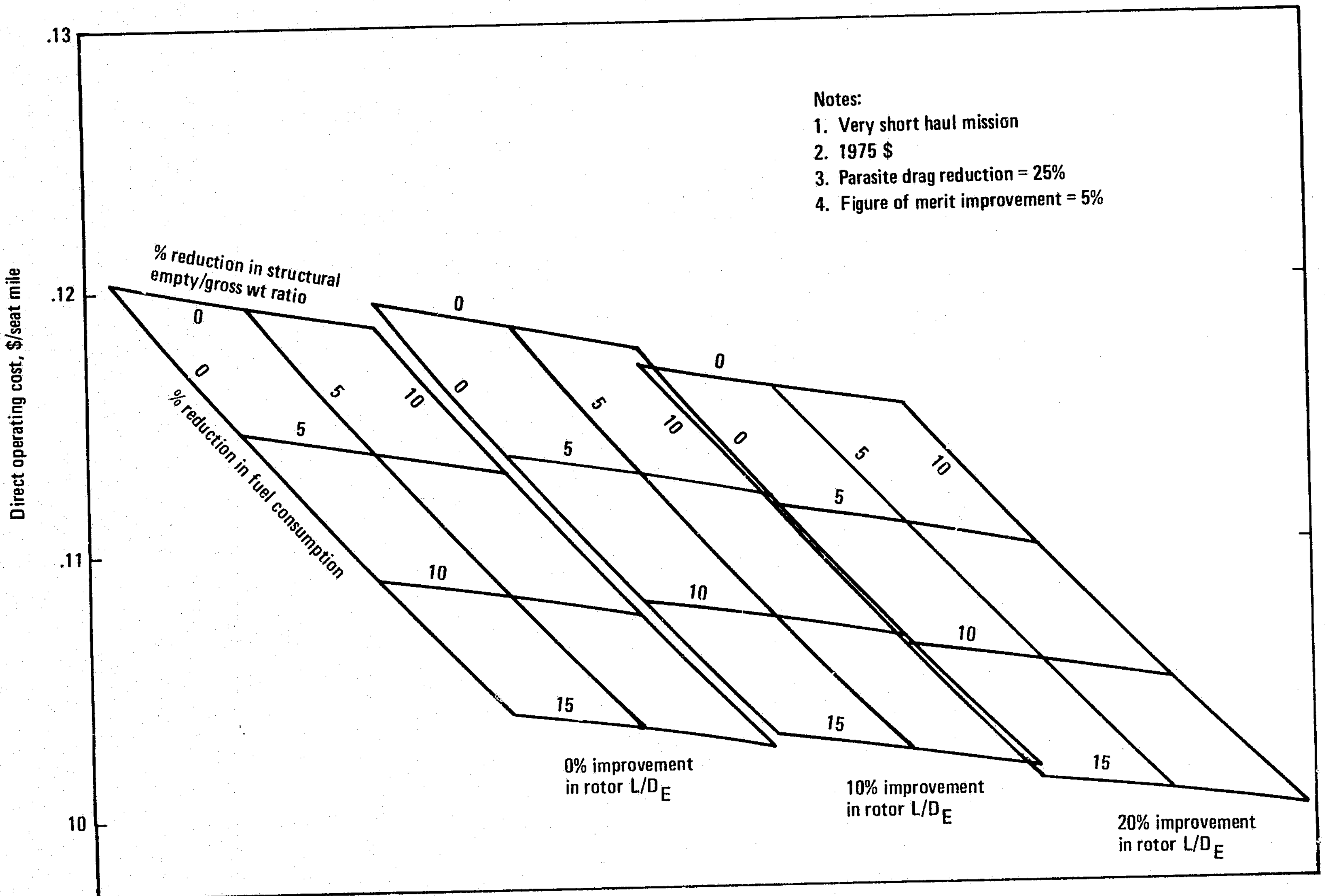

FIGURE B-78 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

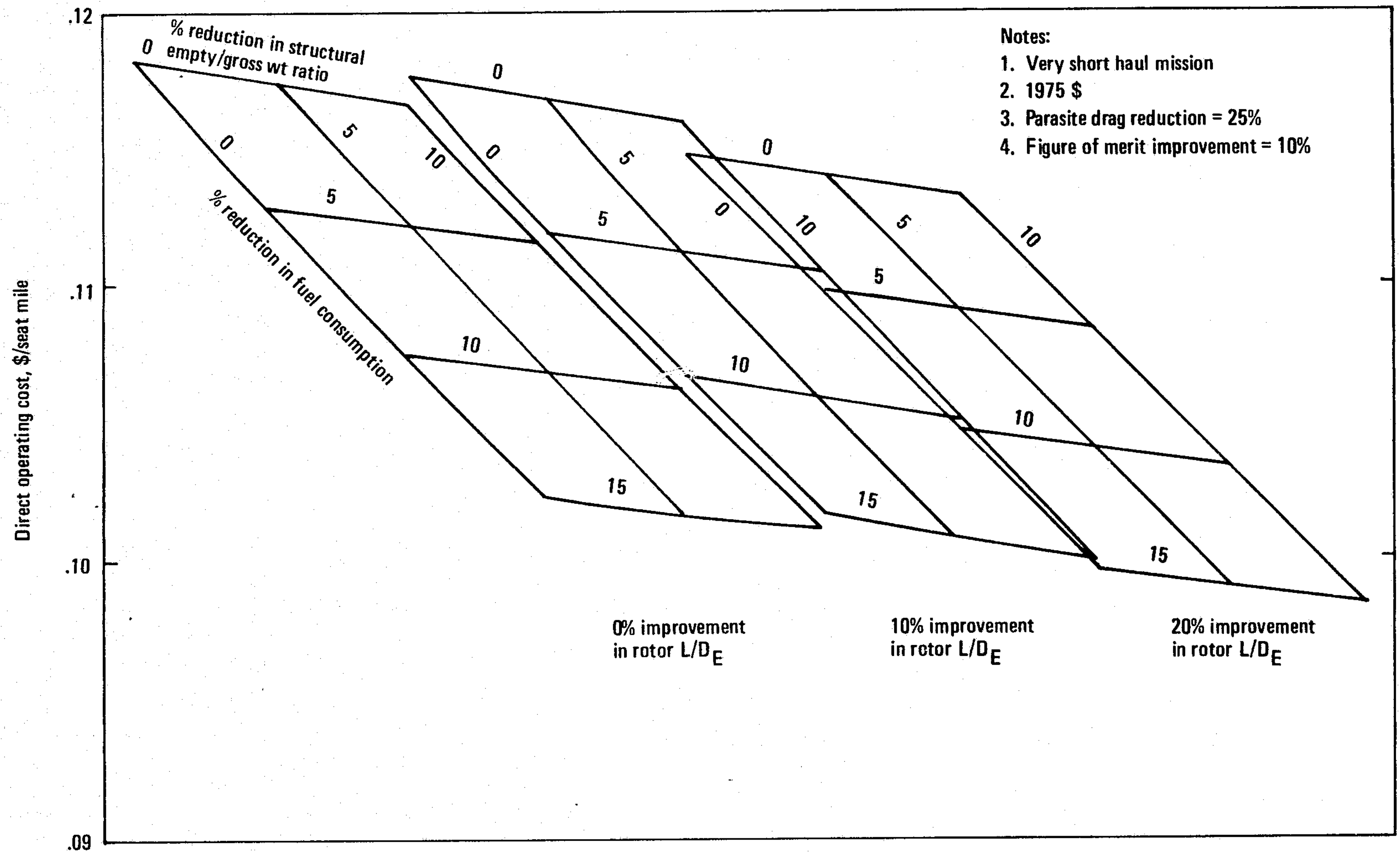

FIGURE B-79 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

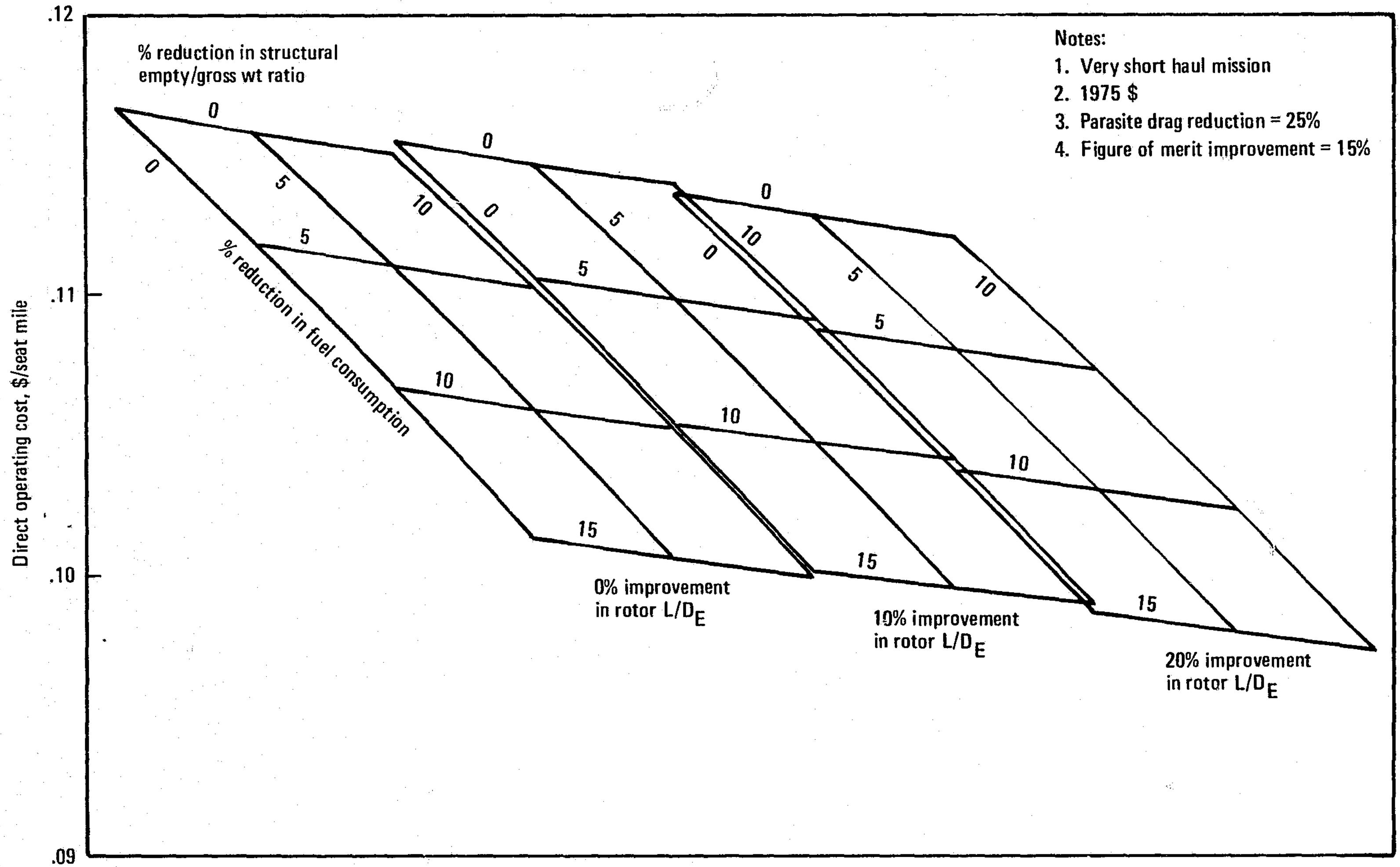

FIGURE B-80 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

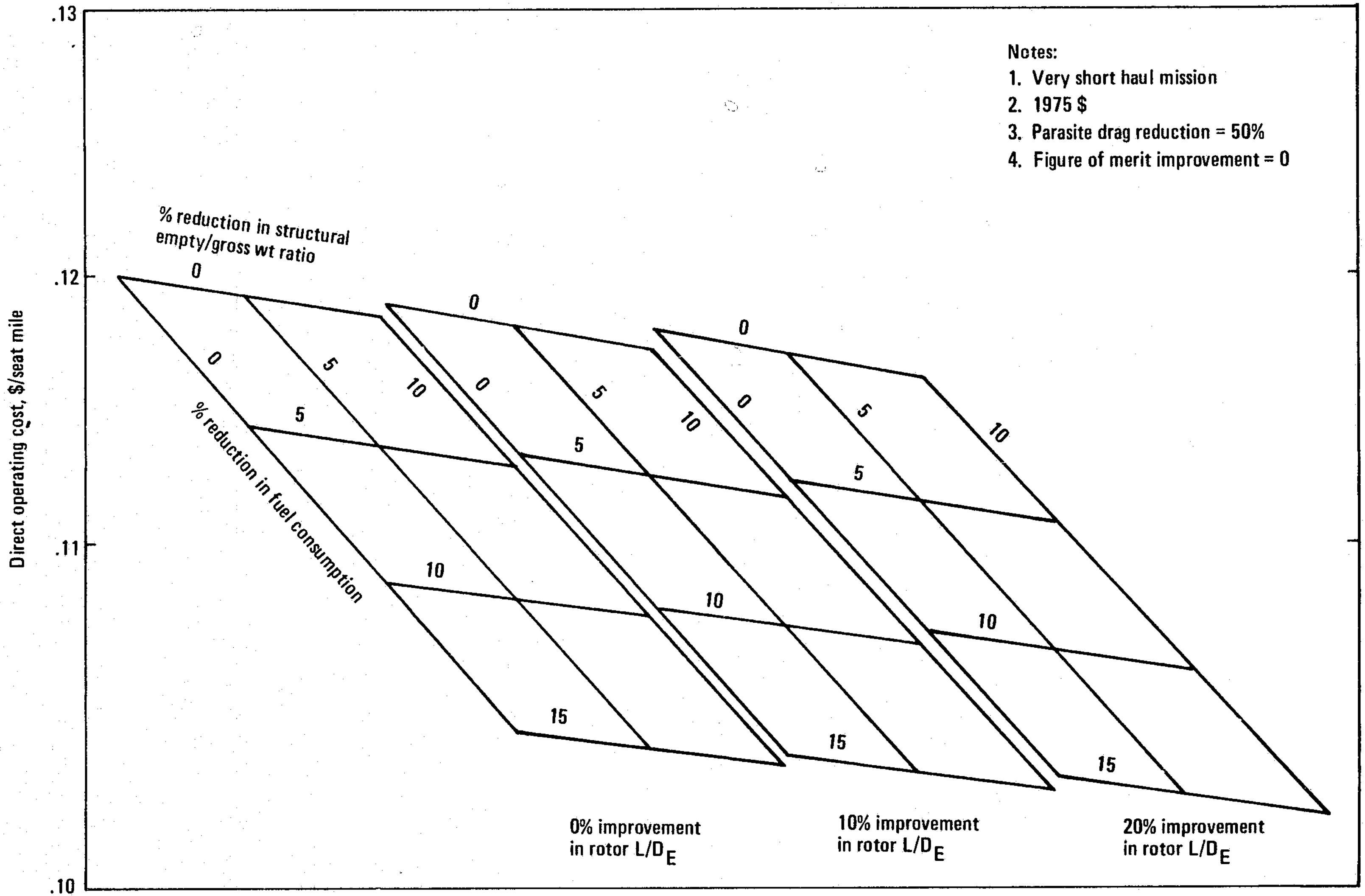

FIGURE B-81 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

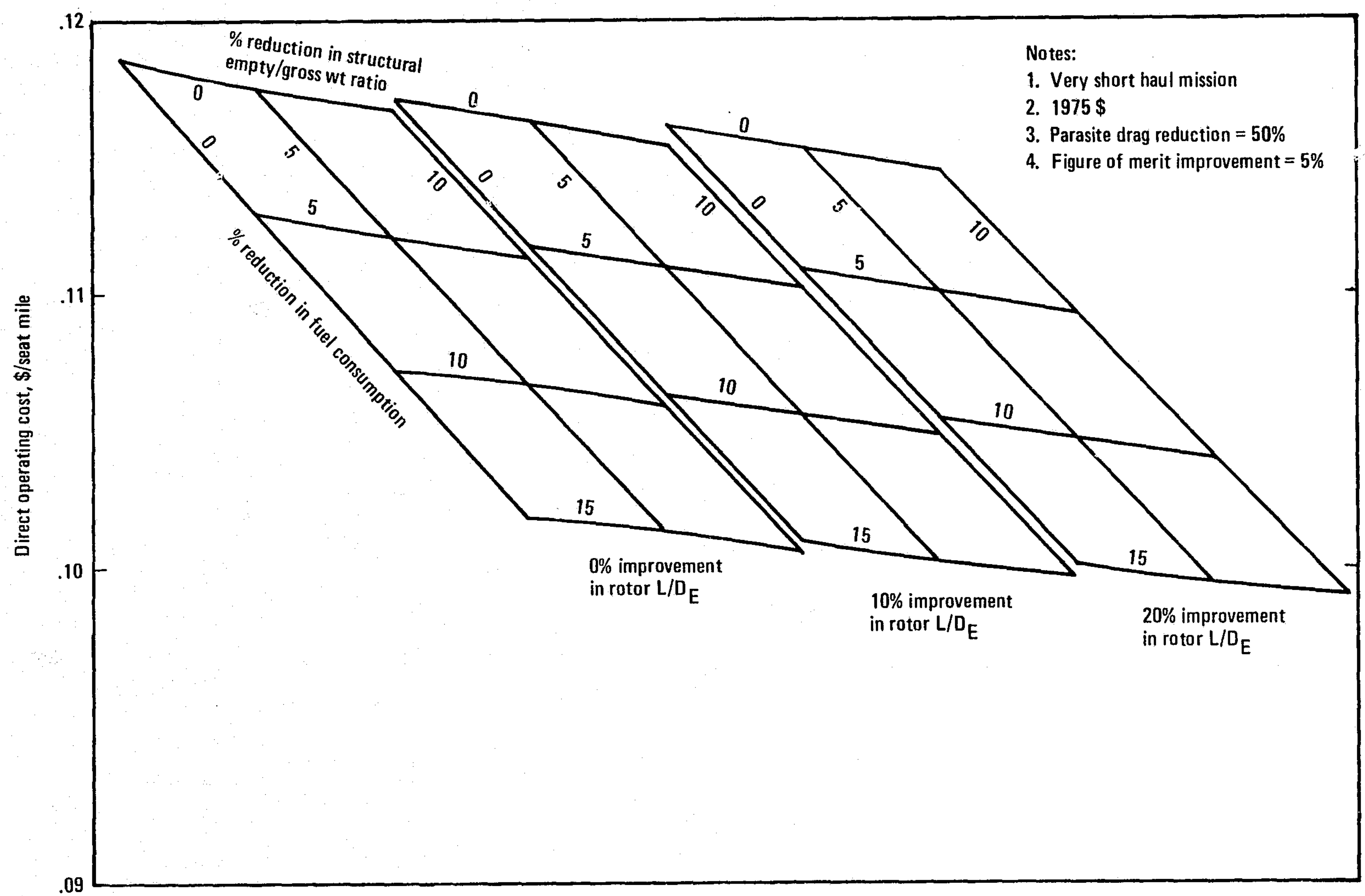

FIGURE B-82 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

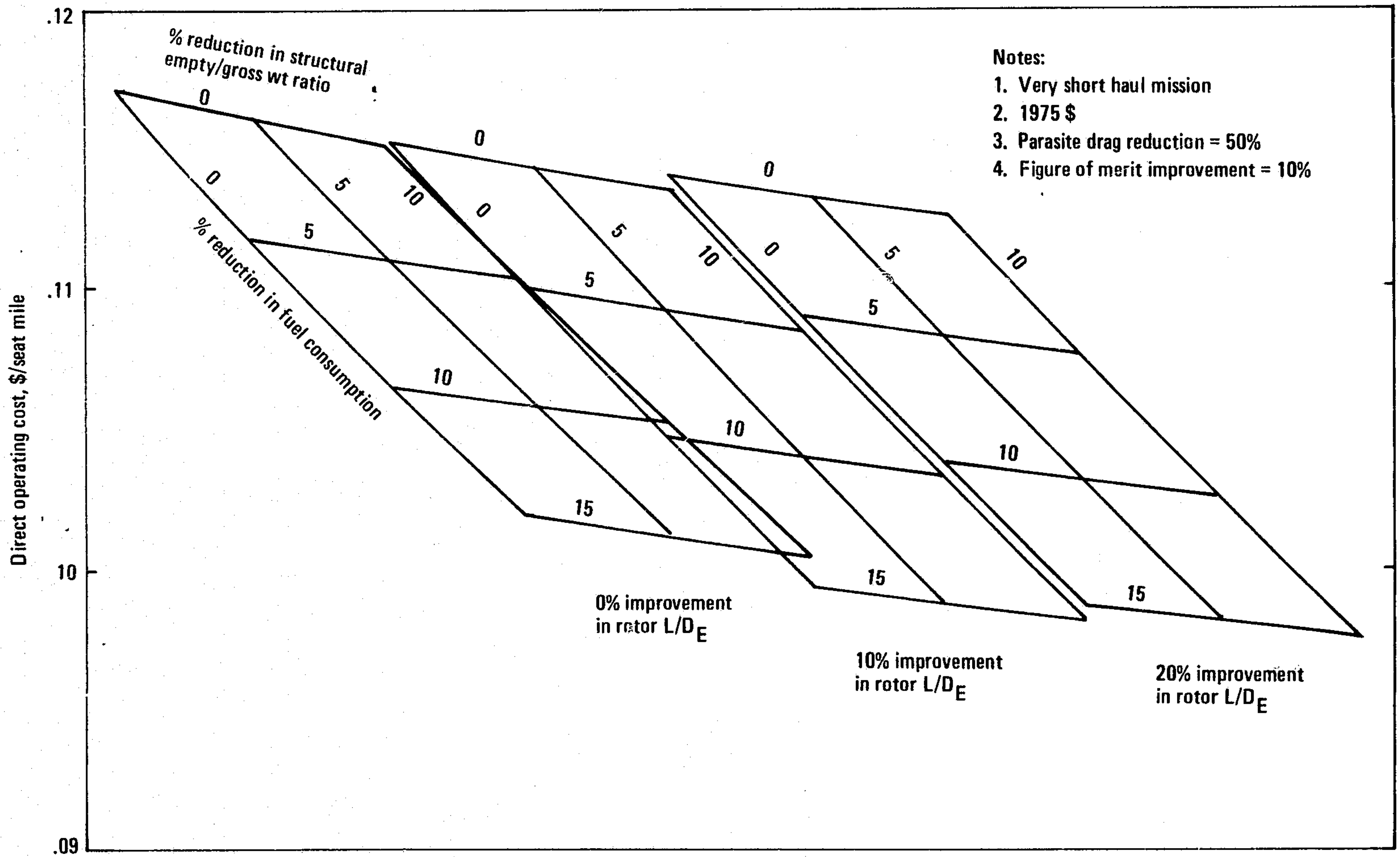

FIGURE B-83 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

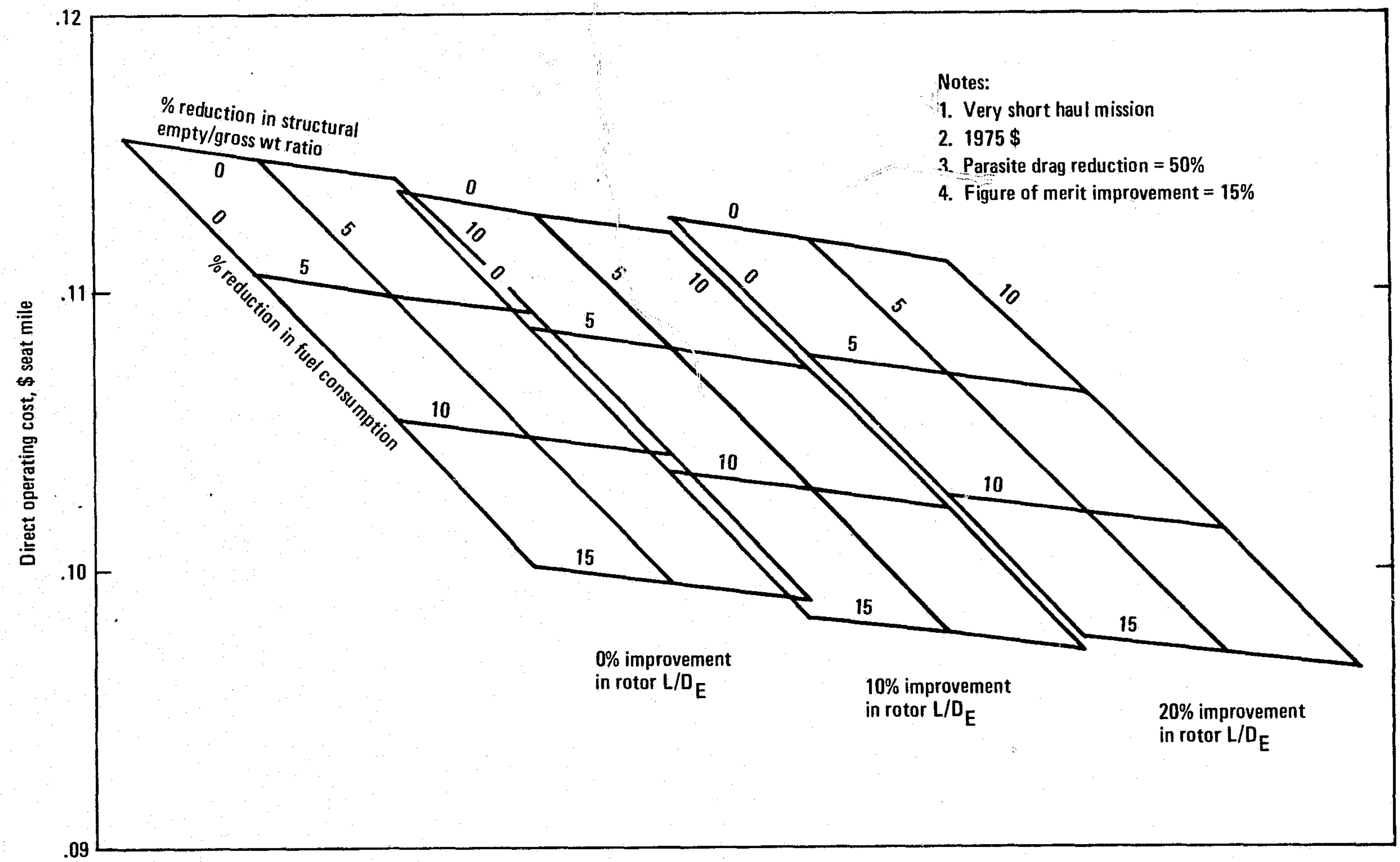

FIGURE B-84 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE DIRECT OPERATING COST

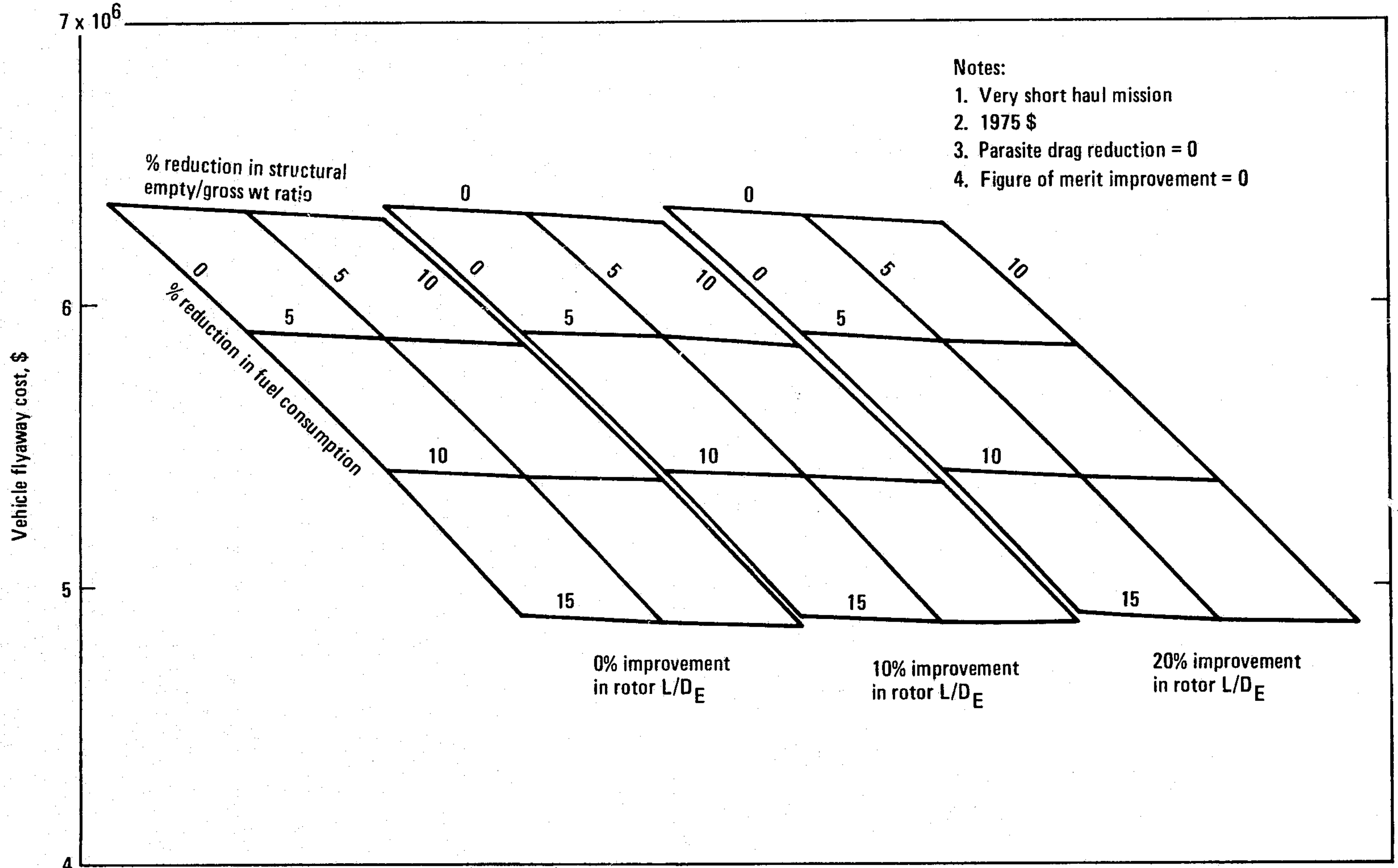

FIGURE B-85 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

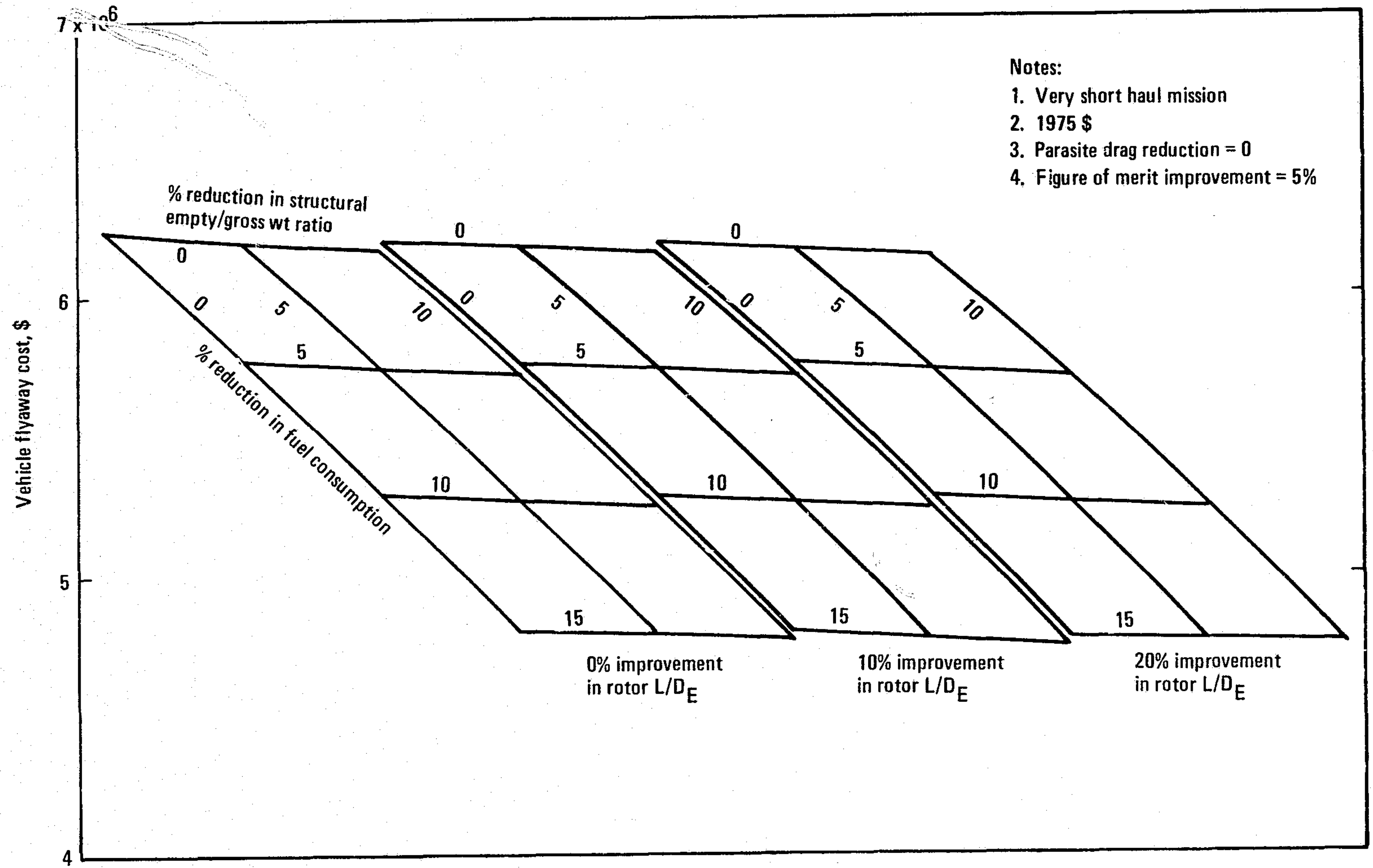

FIGURE B-86 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

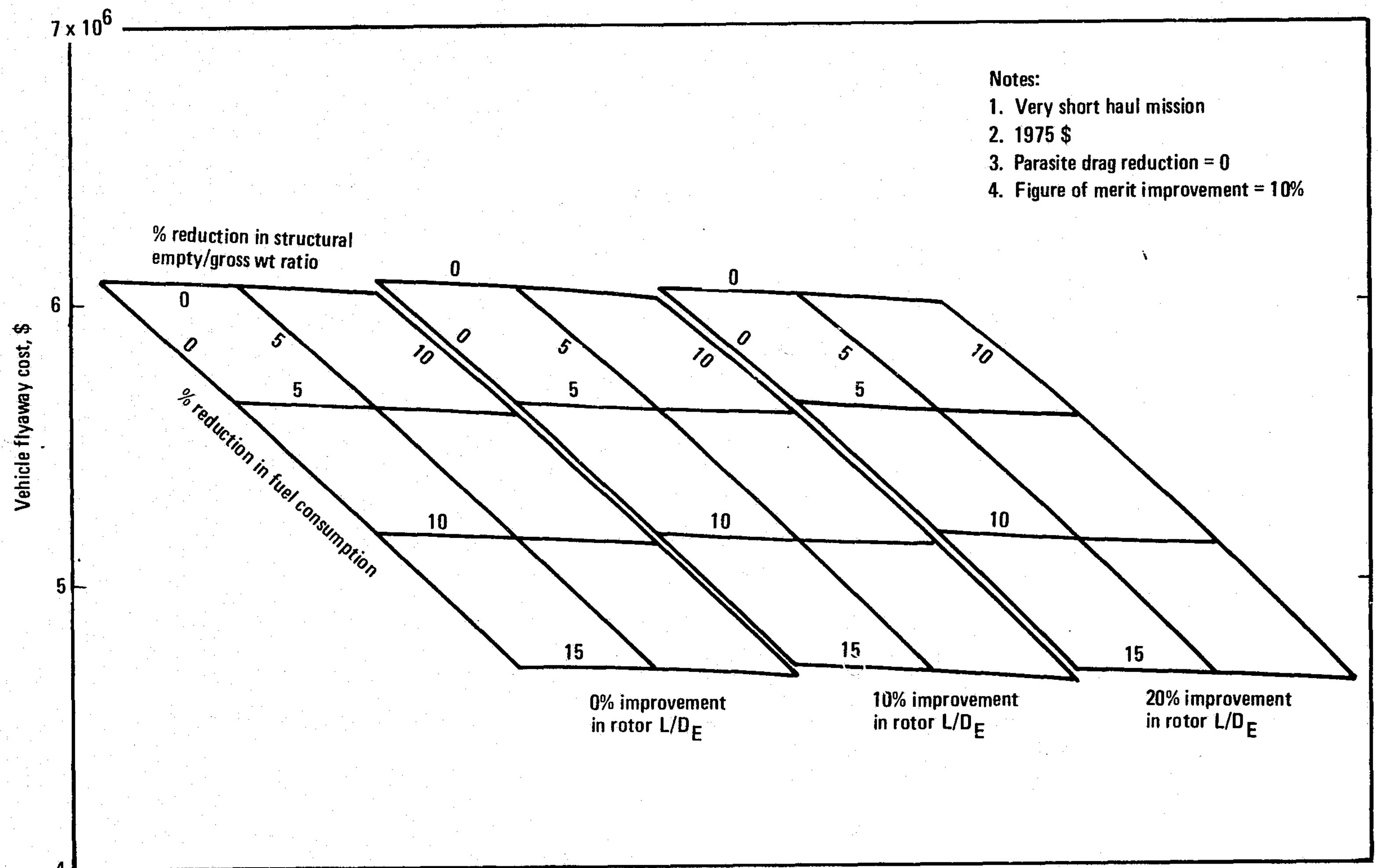

FIGURE B-87 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

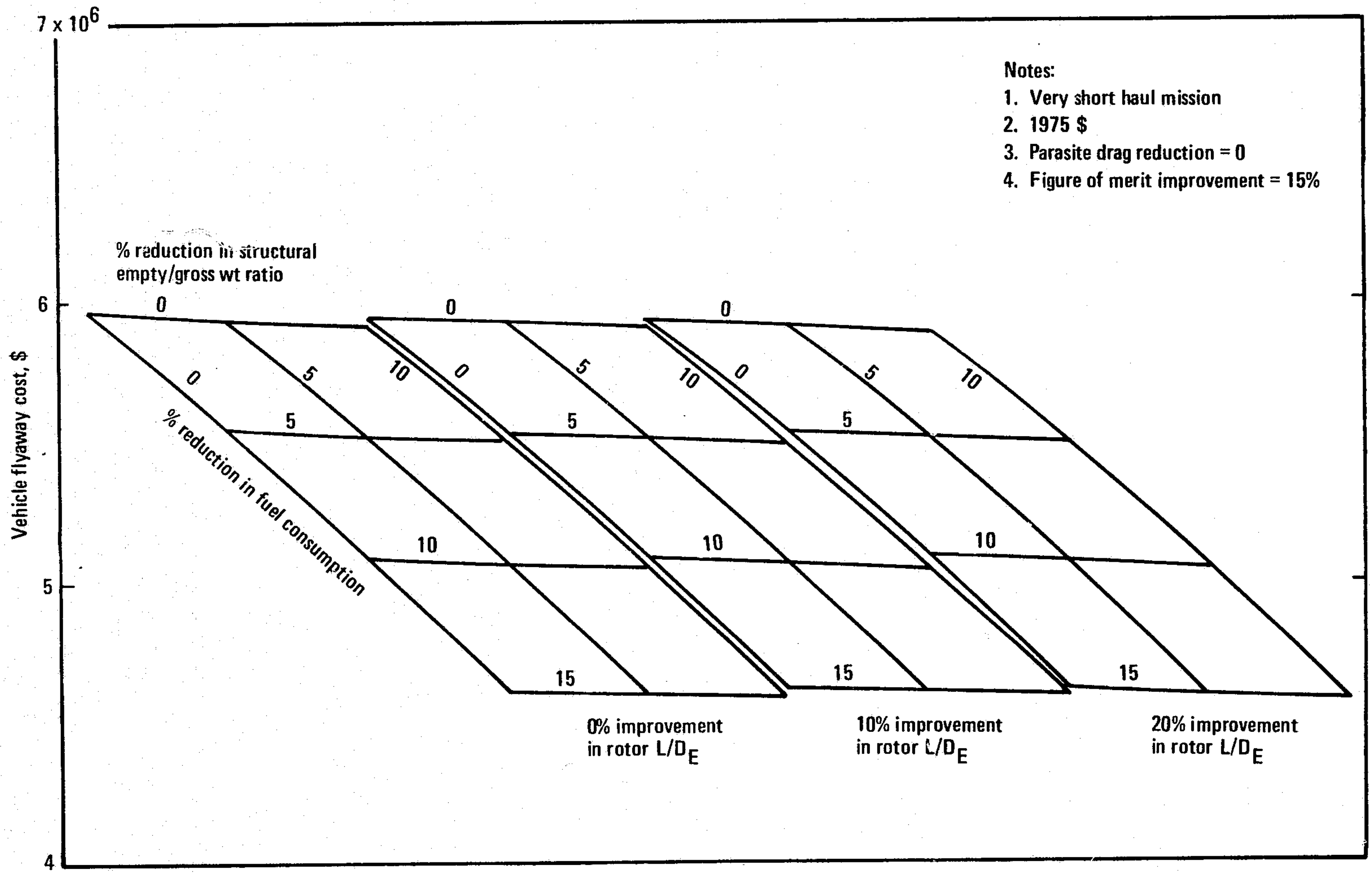

FIGURE B-88 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

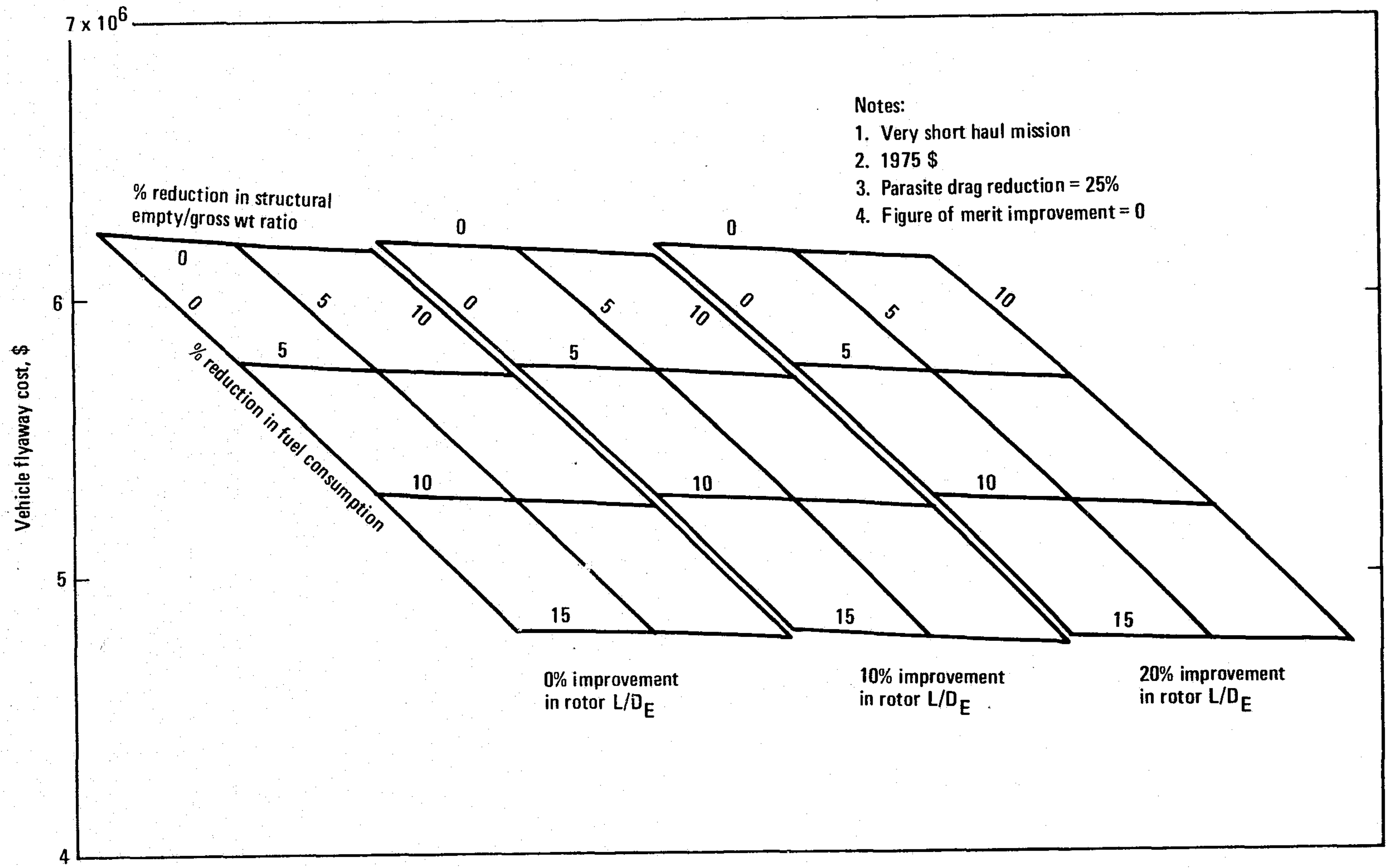

FIGURE B-89 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

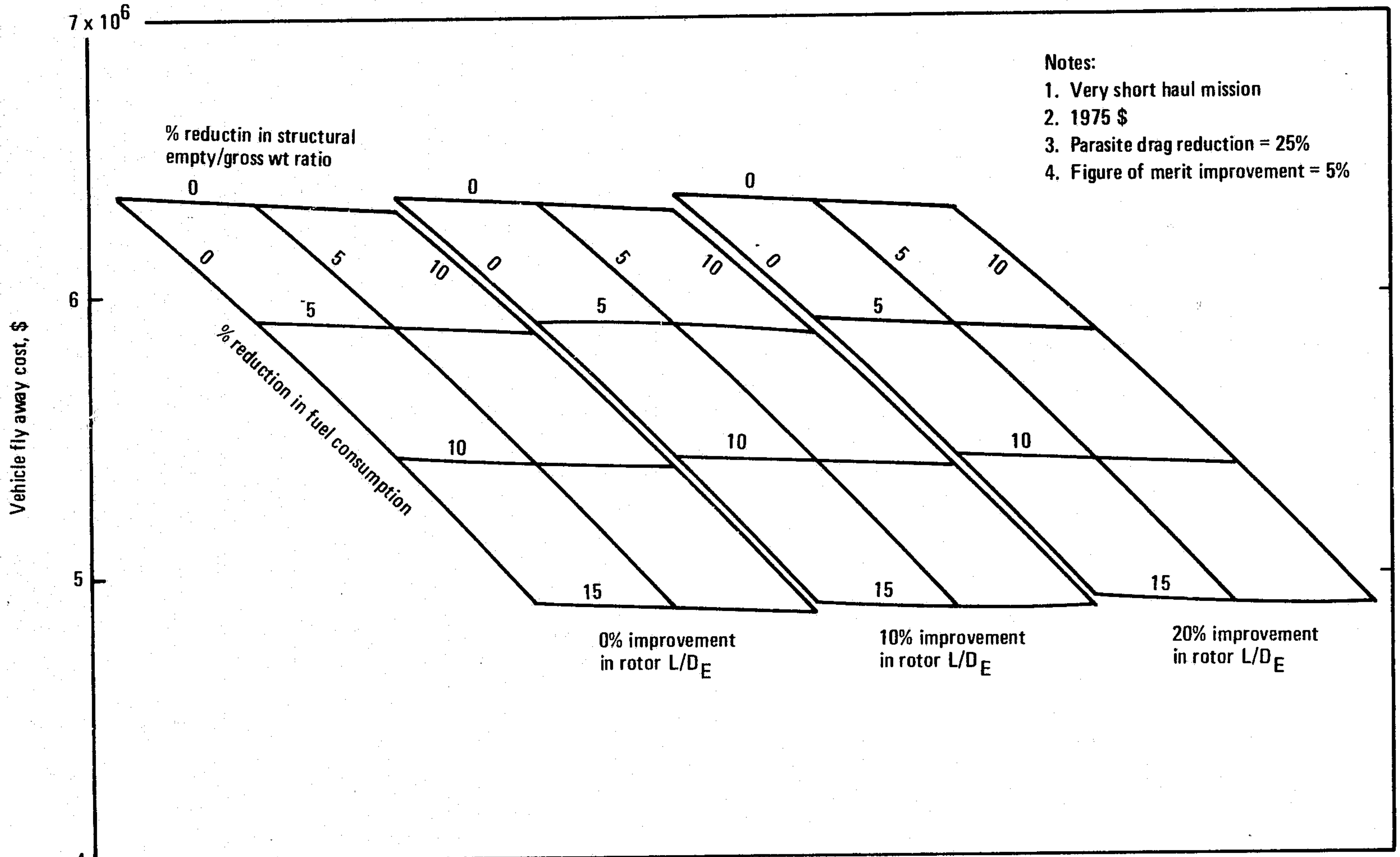

FIGURE B-90 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

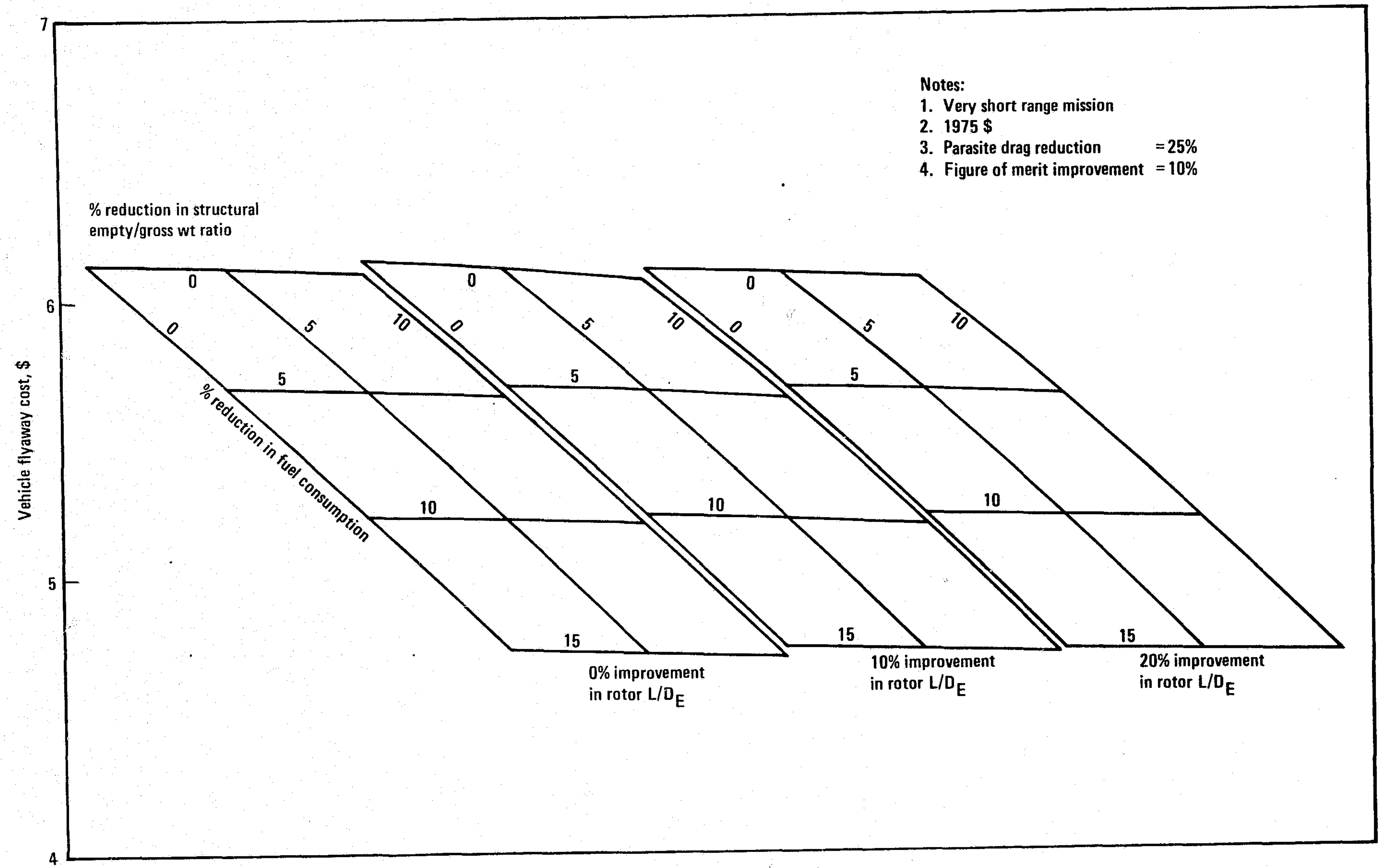

FIGURE B-91 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

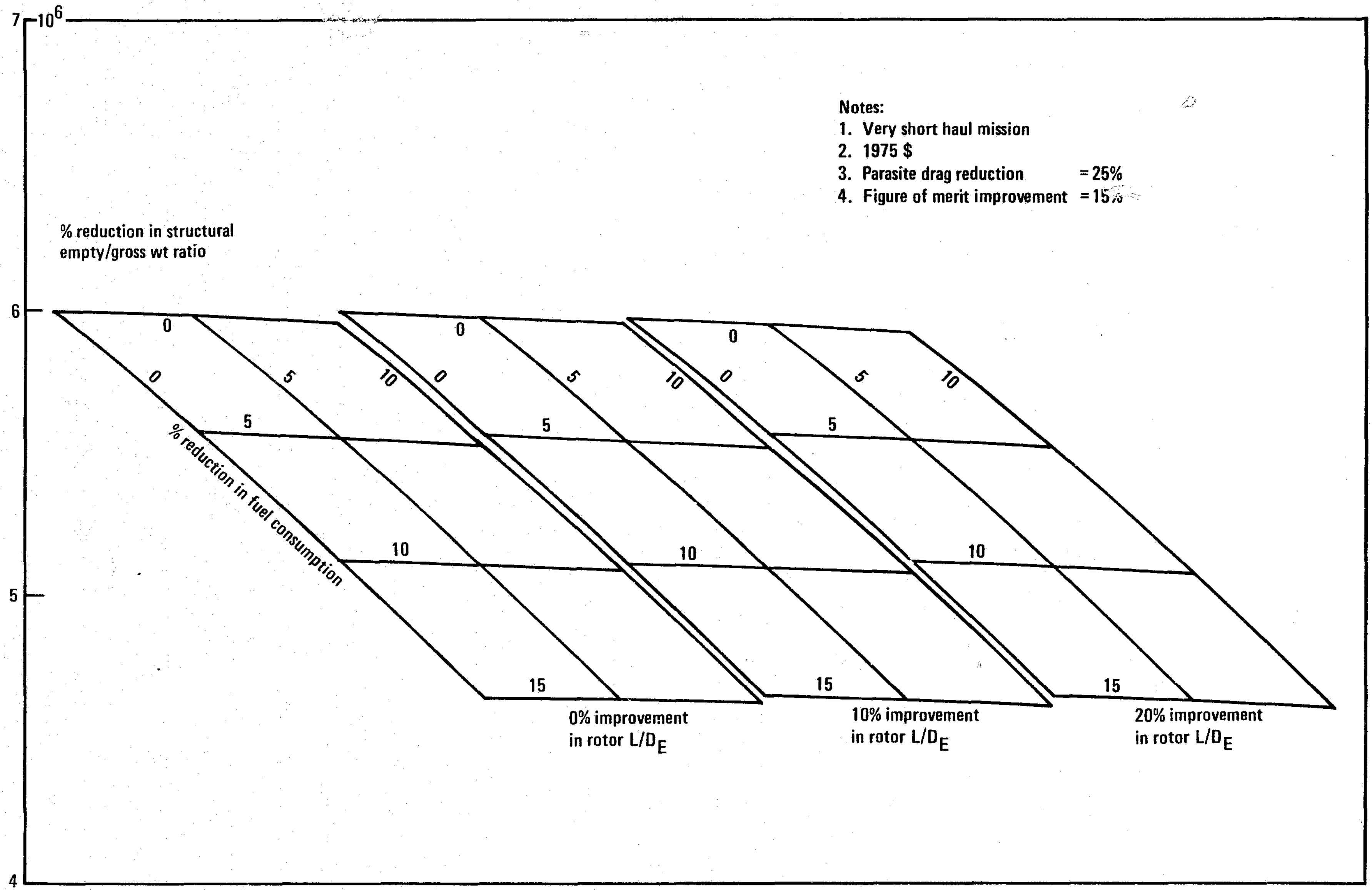

FIGURE B-92 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

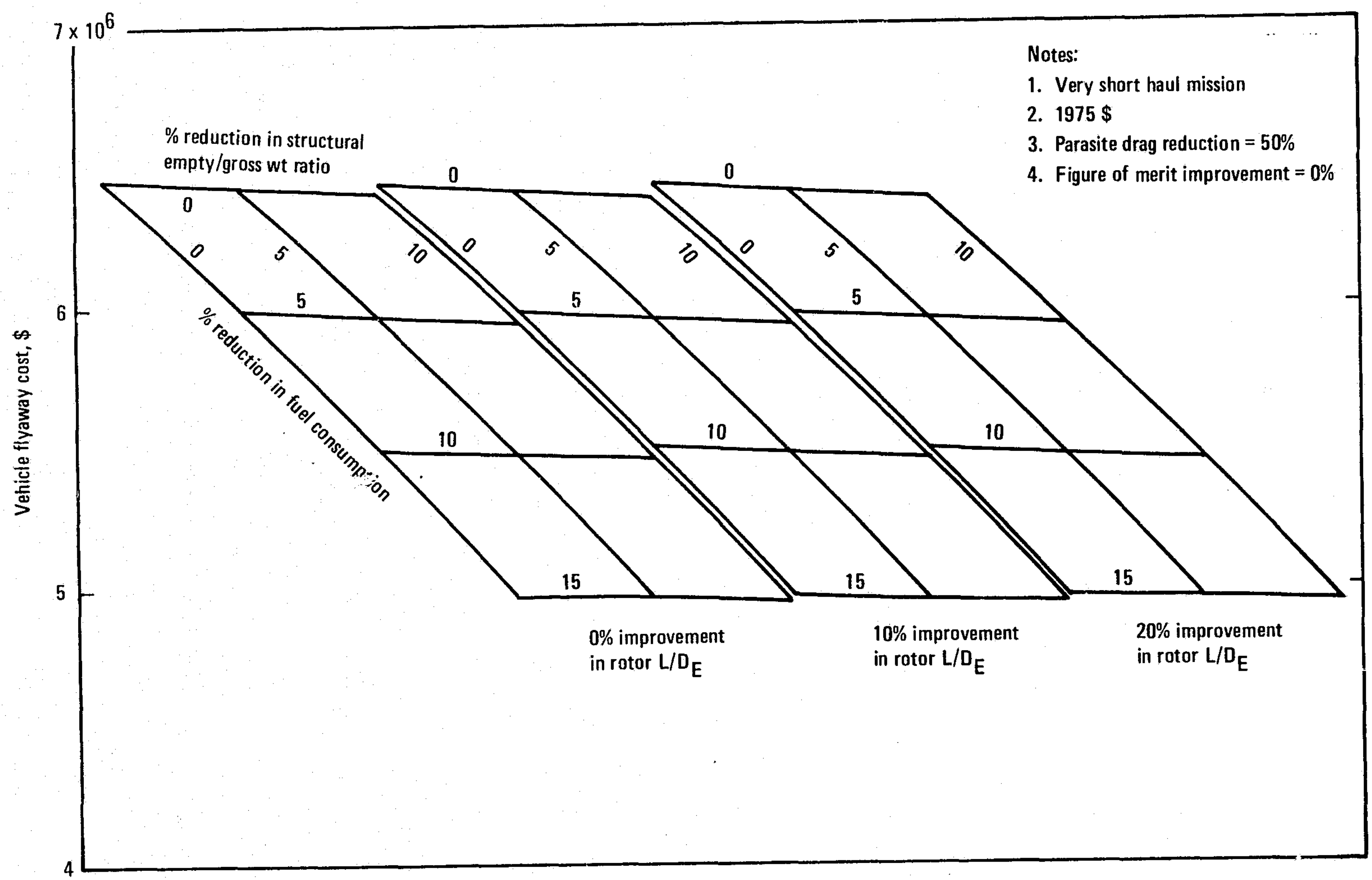

FIGURE B-93 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

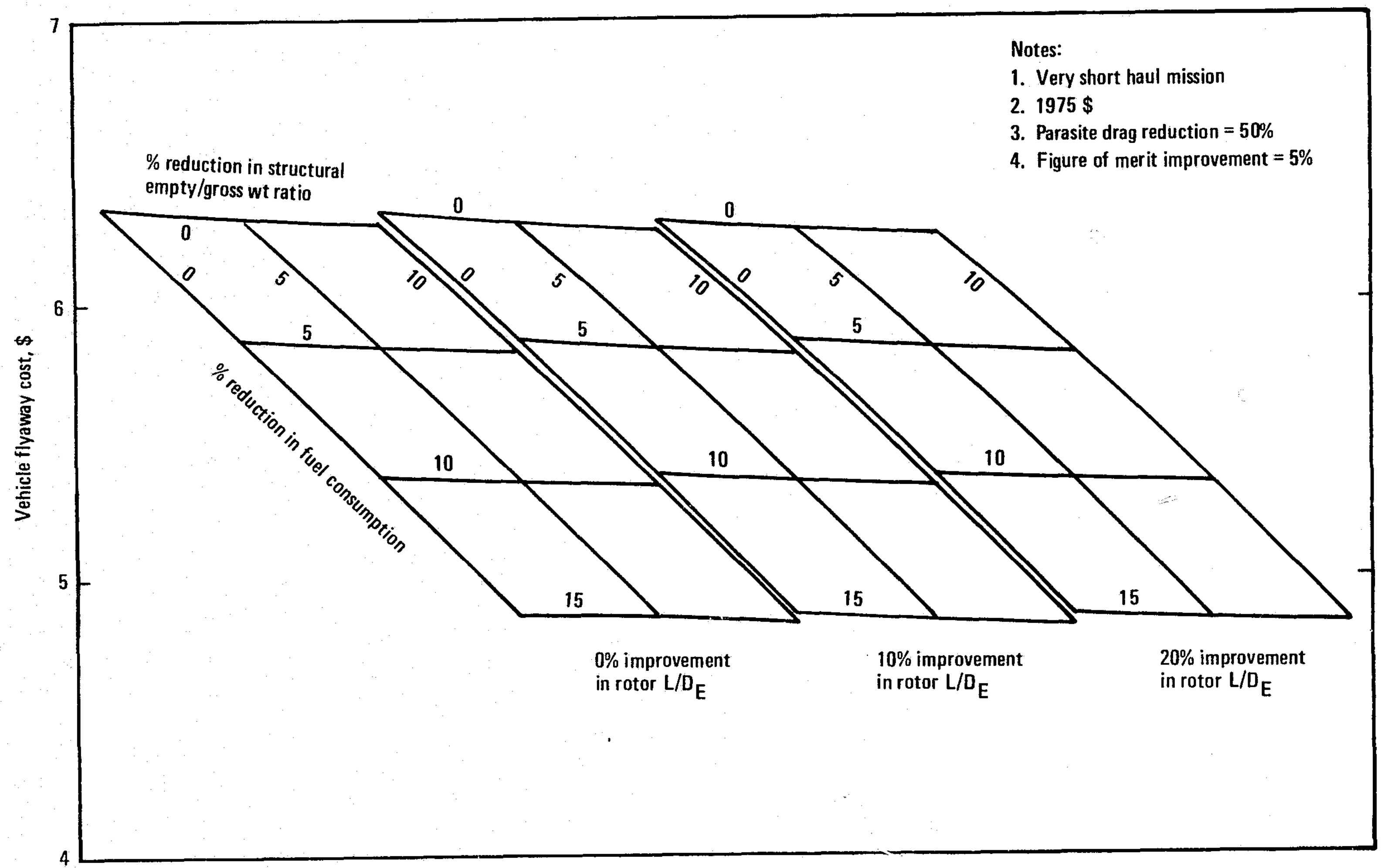

FIGURE B-94 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

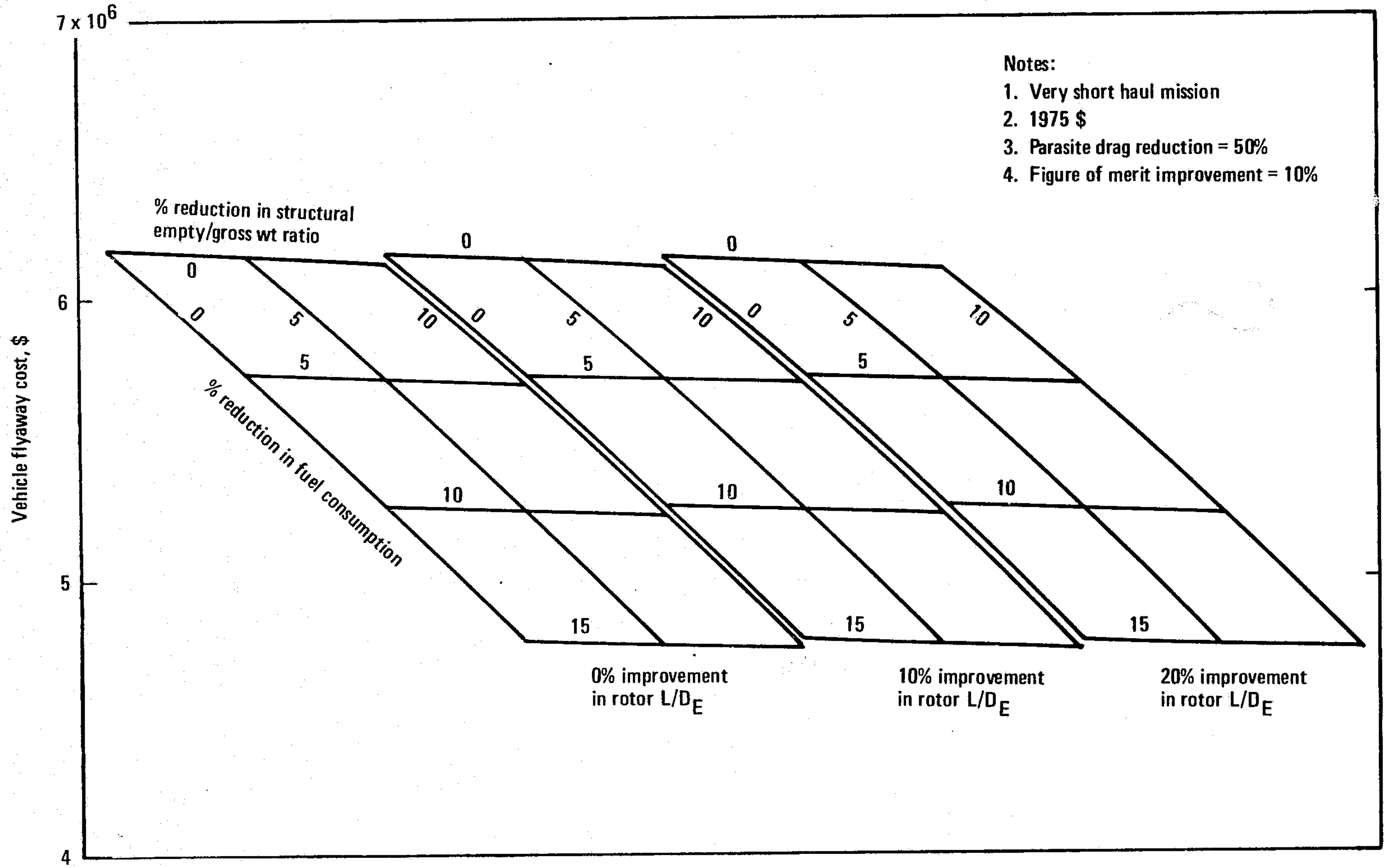

FIGURE B-95 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

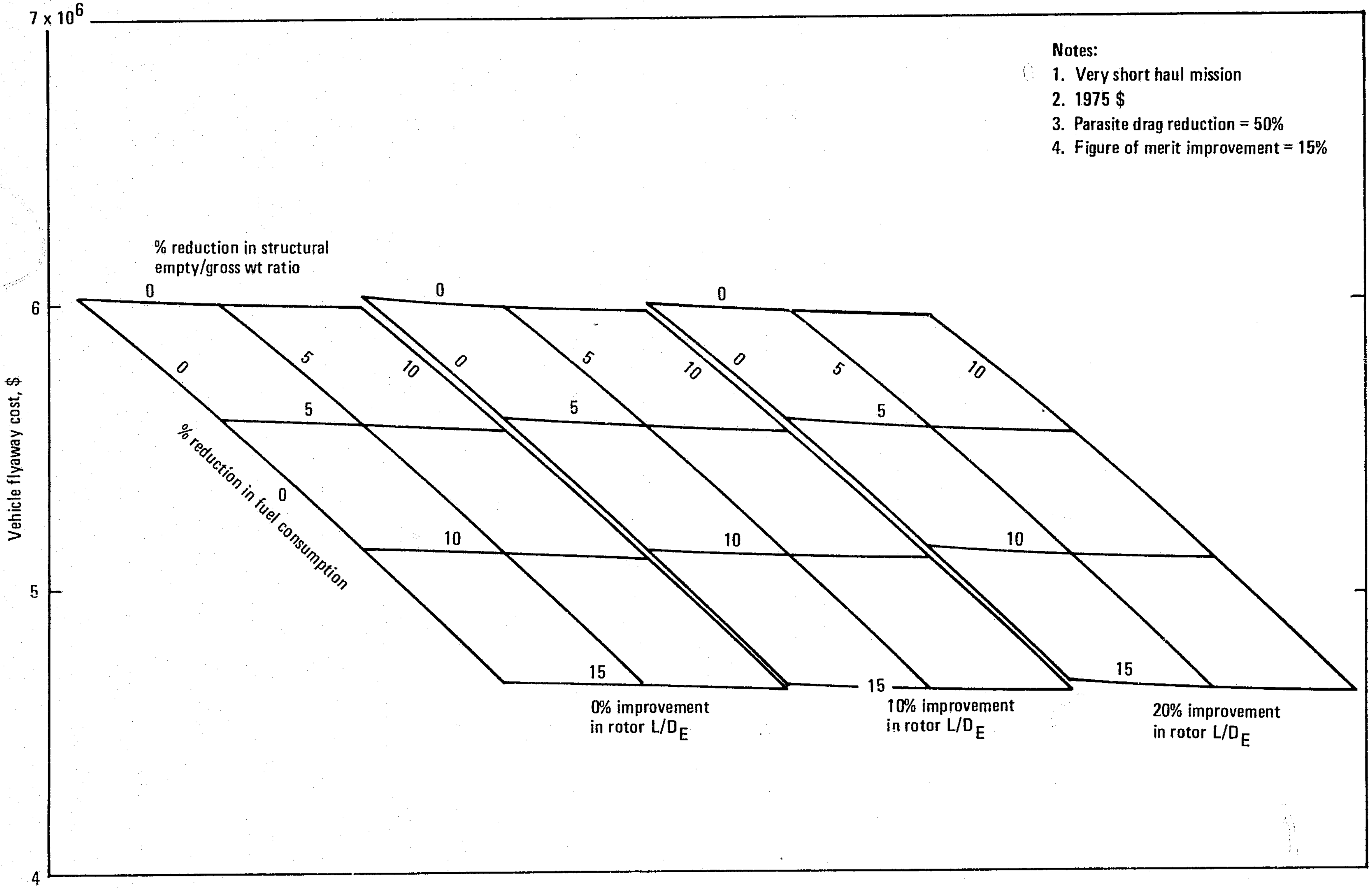

FIGURE B-96 EFFECT OF TECHNOLOGY IMPROVEMENTS ON VEHICLE FLYAWAY COST

APPENDIX C

HELICOPTER SIZING METHODOLOGY

The use of a computerized helicopter sizing program 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 such a computer program (called HESCOMP) for sizing helicopters.

The following description of HESCOMP shows the flexibility of the program as an analytical tool in the preliminary design process. Symbolically, the main input/output operations are shown in Figure C-1. A more detailed review of the program's capabilities is given in Reference 22.

The purpose of this program is to serve as a rapid computational tool, giving visibility to comparative design studies of helicopter systems. Program attributes include:

1. Capability to size a wide range of helicopter configurations for complex missions of up to 50 segments.
2. Input description of helicopter 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 helicopter dimensions, weights, propulsion system characteristics and performance.

This program has two primary independent applications and a third which is a combination of the first two. It may be used for the sizing of a specified vehicle to a given mission profile. Alternatively, it may be used for mission calculations for rotorcraft whose sizing details (gross weight, fuel available, engine power and fuel consumption, etc.) are known. As a combination of these two capabilities, the program may be used to first size a vehicle for a given mission and then calculate the off-design-point performance for other missions.

In the sizing mode, this program integrates the inputs from the main preliminary design areas of physical design (helicopter geometry) aerodynamics, weights, and propulsion utilizing size trend equations which reflect the variation of vehicle 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 geometry of the fuselage, the type of

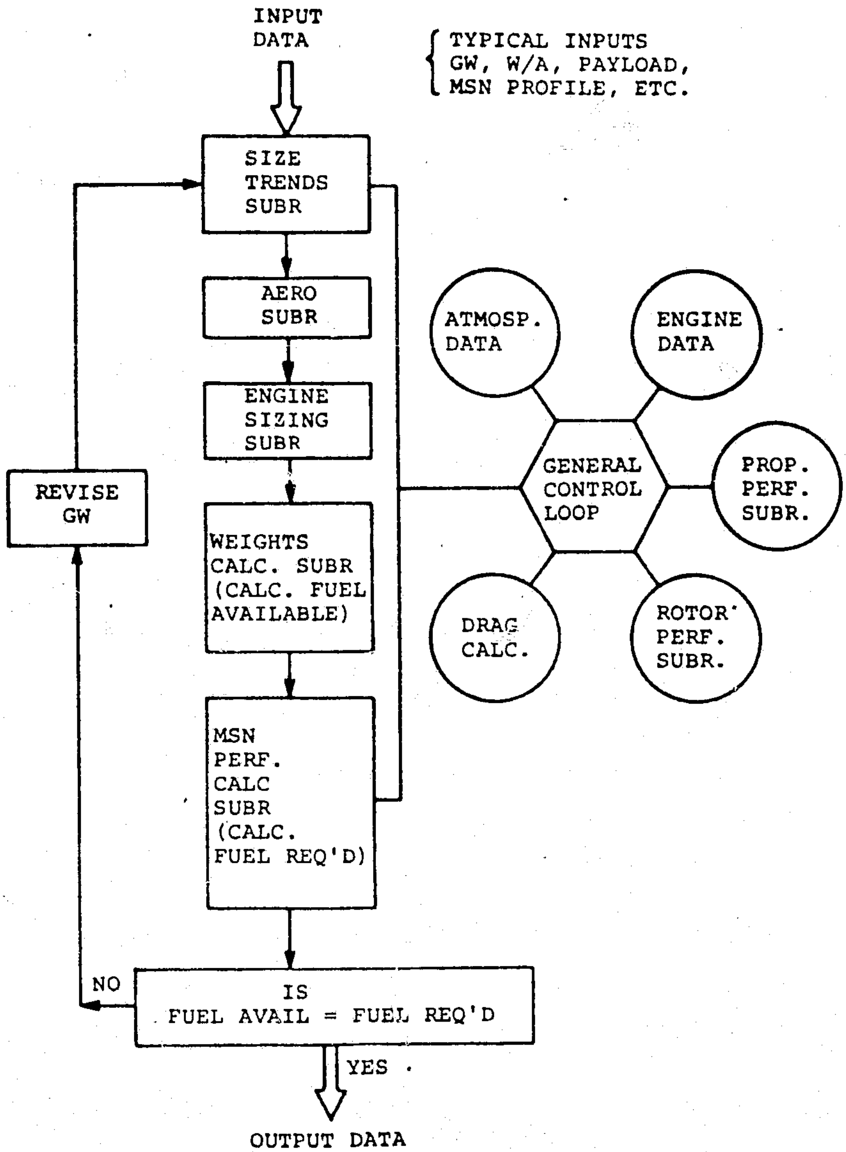

FIGURE C-1 SKETCH OF PROGRAM GEOMETRY

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propulsion system, a description of the misison profile, weights of fixed equipment, fixed9 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, nonlinear 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 this 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.

Helicopter 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 inputting only that item to be studied as a supplemental case. All other inputs will remain unaltered and the program will resize the helicopter.

Figure C-2 illustrates the output of a typical sizing case from this study.

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

THE FOLLOWING IS A CARD BY CARD REPRODUCTION OF THE INPUT DECK FOR THIS CASE

LOC. CORRESPONDS TO LOCATION NUMBER GIVEN ON INPUT SHEET
NUM STANDS FOR THE NUMBER OF SEQUENTIAL INPUT VALUES STARTING WITH LOC. (MAX. =5)
VAL EQUALS VALUE FOR VARIABLE CORRESPONDING TO LOC.
VAL1 VALUE CORRESPONDING TO LOC.+0001
VAL2 VALUE CORRESPONDING TO LOC.+0002
ETC.

NOTE : IN USING AUXILIARY ENGINES ; AUXILIARY ENGINE CYCLE INPUT LOCATIONS CAN BE CREATED BY PLACING A 66666 CARD IN FRONT AND BEHIND A STANDARD ENGINE CYCLE

LOC.	NUM	VAL	VAL1	VAL2	VAL3	VAL4
1201	5	.00000	.00000	1.0000	2.0000	1.0000
1206	1	.00000				
1222	3	1.1150	1.2070	1.0000		
1301	3	2.5100	.15200	.00000		
1305	2	1665.0	1740.0			
1307	3	2500.0	2580.0	2660.0		
1310	1	8.0000				
1311	5	1625.0	1800.0	2100.0	2400.0	2650.0
1316	3	2900.0	3150.0	3400.0		
1319	1	3.0000				
1320	3	.00000	.20000	.40000		
1326	3	.00000	.00000	.00000		
1332	3	.14830	.15040	.16060		
1338	3	.40650	.42280	.44920		
1344	3	.72560	.75490	.79670		
1350	3	.98980	1.0260	1.0800		
1356	3	1.2400	1.2910	1.3520		
1362	3	1.4590	1.5320	1.5970		
1368	3	1.6500	1.7420	1.8130		
1374	1	8.0000				
1375	5	1625.0	1800.0	2100.0	2400.0	2650.0
1380	3	2900.0	3150.0	3400.0		
1383	1	3.0000				
1384	3	.00000	.20000	.40000		
1390	3	.48800E-01	.48800E-01	.48800E-01		
1396	3	.10160	.10160	.10160		
1402	3	.19960	.19960	.20520		
1408	3	.31660	.31740	.32880		
1414	3	.41160	.41420	.42980		
1420	3	.49790	.50400	.52430		
1426	3	.56910	.59750	.62190		
1432	3	.61580	.66460	.71130		
1438	1	8.0000				
1439	5	1625.0	1800.0	2100.0	2400.0	2650.0
1444	3	2900.0	3150.0	3400.0		
1447	1	3.0000				
1448	3	.00000	.20000	.40000		
1454	3	.65400	.65400	.65400		
1460	3	.75000	.74900	.74800		
1466	3	.85600	.85600	.85400		

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE

1472	3	.93800	.93700	.93600		
1478	3	.99800	.99700	.99500		
1484	3	1.0540	1.0530	1.0520		
1490	3	1.1080	1.1060	1.1050		
1496	3	1.1580	1.1570	1.1560		
1502	1	8.0000				
1503	5	1625.0	1800.0	2100.0	2400.0	2650.0
1508	3	2900.0	3150.0	3400.0		
1511	1	3.0000				
1512	3	.00000	.20000	.40000		
1518	3	.35500	.36560	.37160		
1524	3	.52190	.52660	.53370		
1530	3	.75030	.75380	.76210		
1536	3	.90650	.91000	.91590		
1542	3	.99840	1.0020	1.0120		
1548	3	1.0710	1.0790	1.0920		
1554	3	1.1390	1.1500	1.1660		
1560	3	1.2010	1.2180	1.2330		
1601	2	4.2000	-9.0000			
1603	5	.99500E-02	.28000E-01	.26200	.27600	2.4500
1608	1	.86500				
1609	5	.90000E-02	2.8200	.90000E-01	1.1700	.12400E-02
1614	2	.75600	.78300			
1616	1	10.000				
1617	5	.00000	.40000E-02	.70000E-02	.90000E-02	.10000E-01
1622	5	.11000E-01	.11500E-01	.12000E-01	.15500E-01	.22000E-01
1627	5	1.0180	1.0850	1.1540	1.2330	1.2790
1632	5	1.3140	1.3270	1.3370	1.3640	1.3970
1637	1	1.0000				
1	5	1.0000	1.0000	2.0000	1.0000	2.0000
6	4	1.0000	4.0000	1.0000	1.0000	
12	2	1.0000	.00000			
18	1	.00000				
20	5	2.0000	1.0000	1.0000	45000.	.00000
25	5	.00300	.00000	.00000	.34700	230.00
30	5	225.00	3.5000	1.0000	.00000	1.0000
35	5	1.0300	2.0000	3.0000	3.0000	4.0000
40	5	5.0000	4.0000	5.0000	4.0000	5.0000
45	5	2.0000	1.0000	9.0000	40.000	60.000
50	1	100.00				
99	1	1.0000				
120	1	.13830				
122	5	12.920	12.920	1.3932	1.7028	48.170
127	1	.00000				
132	1	.00000				
142	4	.00000	.00000	.00000	.00000	
152	5	.41700	.63500	.18800	.33500	1.8500
157	5	.30000	.33300	.62500	.52500	11.700
171	3	4.2300	2.0000	7.0000		
176	5	4.0000	-12.000	.25000	.12000	.15000
181	5	705.00	.13600	1.0635	219.00	1000.0
186	5	.00300	.76900E-01	1.2500	1.2500	1.0000
191	2	1.5350	.00000			
193	2	.87000	.87000			
217	1	2.5100				
219	3	3.0000	.00000	1.0000		
223	2	.97000	150.00			
227	5	.00000	1.1135	31.000	.82713	1.0000
232	2	1.0900	.00000			
238	1	.82713				
312	2	1269.0	.48140			
316	1	.00000				

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

327	1	1.0000				
330	1	.00000				
2502	3	13356.	1943.0	18000.		
2605	3	.00000	.00000	400.00		
2608	5	1.0000	.00000	.00000	.00000	.00000
2613	5	25.000	20.000	30.000	.30000	.00000
2618	4	150.00	.00000	.00000	.00000	
2622	5	125.00	2.8000	.40000E-01	.80000	.00000
2627	5	1.0000	.00000	.00000	.00000	.00000
2632	5	.00000	.00000	.00000	.00000	.00000
2637	5	44.000	1.0000	61.000	.29000	1.0000
2642	5	1.0000	1.0000	1.0000	1.0000	250.00
2647	5	5.0000	.00000	.00000	.00000	.69000E-01
2652	2	.44000	.00000			
2654	5	1.0000	1.0000	1.0000	1.0000	1.0000
2659	5	1.0000	1.0000	1.0000	1.0000	1.0000
2664	5	1.0000	1.0000	1.0000	1.0000	1.0000
2669	5	1.0000	1.0000	1.0000	1.0000	1.0000
347	5	3.0000	7.0000	.00000	.50000	1.0000
354	5	.00000	.30000	.34000	.40000	.50000
359	2	.60000	1.0000			
361	5	.11200	.97000E-01	.90000E-01	.81000E-01	.60000E-01
366	2	.52000E-01	.52000E-01			
368	5	.11200	.97000E-01	.90000E-01	.81000E-01	.60000E-01
373	2	.52000E-01	.52000E-01			
375	5	.11200	.97000E-01	.90000E-01	.81000E-01	.60000E-01
380	2	.52000E-01	.52000E-01			
401	2	.00000	.00000			
411	2	.16700	.16700			
441	2	.82713	.82713			
461	2	1.0000	1.0000			
481	2	.00000	.00000			
511	2	.00000	.00000			
521	2	1.0400	1.0400			
531	2	.16700E-01	.16700E-01			
541	2	.82713	.82713			
551	2	.33300E-01	.33300E-01			
571	2	2.0000	2.0000			
581	2	100.00	100.00			
591	2	.00000	.00000			
621	2	250.00	250.00			
631	2	2.0000	2.0000			
641	2	700.00	2000.0			
651	2	.82713	.82713			
721	4	1.0000	1.0000	2.0000	4.0000	
733	1	100.00				
741	4	.00000	.00000	.00000	.00000	
771	4	10.000	2.0000	1.0000	10.000	
781	4	2.0000	2.0000	2.0000	2.0000	
791	4	175.00	196.00	200.00	250.00	
801	4	.82713	.82713	.82713	.82713	
871	3	2.0000	2.0000	2.0000		
881	3	100.00	100.00	100.00		
891	3	.00000	.00000	3.0000		
911	3	.00000	.00000	.00000		
921	3	100.00	100.00	100.00		
941	3	1200.0	700.00	.00000		
951	3	500.00	500.00	500.00		
961	3	175.00	196.00	200.00		
971	3	.82713	.82713	.82713		
1031	1	.00000				
1061	1	.11110				

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

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1071	1	.82713				
1081	1	.33330				
1181	1	2000.0				
1191	1	.00000				
1201	5	.00000	.00000	1.0000	2.0000	1.0000
1206	1	.00000				
1222	3	1.1150	1.2070	1.0000		

```
WG =  .450000E 05  WFA =  .502391E 49  WFR =  .765020E 45
WG =  .450000E 05  WFA = -.120417E 05  WFR =  .455905E 04
WG =  .687154E 05  WFA =  .210967E 03  WFR =  .675138E 04
```

FIGURE C-2   OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

HESCOMP
HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM B-91

TANDEM ROTOR
PURE HELICOPTER

SIZE DATA THIS RUN CONVERGED IN 3 ITERATIONS

GROSS WEIGHT = 84133. LB

FUSELAGE

LF	LENGTH	88.2 FT.
LC	CABIN LENGTH	48.2 FT.
DELTAX1	FWD. ROTOR LOCATION	.8 FT.
DELTAX2	AFT ROTOR LOCATION	.4 FT.
WF	WIDTH	12.9 FT.
G/S	ROTOR GAP/STAGGER RATIO	.113
(O/L/D)	ROTOR OVERLAP/DIAMETER RATIO	.000
SF	WETTED AREA	3564.8 SQ. FT.

WING

- NO WING USED

FORWARD ROTOR PYLON

AR	ASPECT RATIO	.188
SFP	WETTED AREA	47.6 SQ. FT.
FAFP	FRONTAL AREA	9.5 SQ. FT.
HP1	HEIGHT	1.9 FT.
CBARFP	MEAN CHORD	9.8 FT.
LAMBDA FP	TAPER RATIO	.335
(T/C)R	ROOT THICKNESS/CHORD	.417
(T/C)T	TIP THICKNESS/CHORD	.835

AFT ROTOR PYLON

AR	ASPECT RATIO	.625
SAP	WETTED AREA	479.3 SQ. FT.
HP2	HEIGHT	11.7 FT.
CBARAP	MEAN CHORD	18.7 FT.
LAMBDA AP	TAPER RATIO	.525
(T/C)R	ROOT THICKNESS/CHORD	.300
(T/C)T	TIP THICKNESS/CHORD	.333

PRIMARY ENGINE NACELLE

LN	LENGTH	.0 FT.
DN	MEAN DIAMETER	0. FT.
SN	WETTED AREA(TOTAL FOR ALL ENGINES)	.0 SQ. FT.

AUXILIARY INDEPENDENT ENGINE NACELLE

-NO AUXILIARY INDEPENDENT ENGINE USED

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

PROPELLER(AUXILIARY PROPULSION)

- NO PROPELLER USED

MAIN ROTOR

DMR	DIAMETER	87.5	FT.
SIGMR	SOLIDITY	.100	
WG/A	DISC LOADING	7.0	LB/SQ. FT.
CT/SIGMA	THRUST COEFF./SOLIDITY	.077	
NR	NO. OF ROTORS	2.	
NO. BLADES	NO. OF BLADES/ROTOR	4.	
THETA	BLADE TWIST	-12.000	DEG.
XC	BLADE CUTOUT/RADIUS RATIO	.250	
VTIP	TIP SPEED	704.	FT./SEC.

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

```
W E I G H T S   D A T A     IN LBS

          MLF            MANEUVER LOAD FACTOR                          3.500
          ULF            ULTIMATE LOAD FACTOR                          5.250

      PROPULSION GROUP
              WPRG       TOTAL MAIN ROTOR GROUP                        10190.
          K12 WPRB           MAIN ROTOR BLADE (PER ROTOR)                      3199.
          K13 WPH            MAIN ROTOR HUB (PER ROTOR)                        1896.
              WBF            BLADE FOLDING(PER ROTOR)                             0.
          K15 WAR        AUXILIARY PROPULSION ROTOR GROUP                  0.
              WDS        DRIVE SYSTEM                                   9791.
          K16 WPDS           MAIN ROTOR DRIVE SYSTEM                           9791.
          K20 WTRDS          TAIL ROTOR DRIVE SYSTEM                              0.
          K17 WADS           AUXILIARY PROPULSION DRIVE SYSTEM                    0.
          K18 WEP        PRIMARY ENGINES                                2388.
          K19 WEA        AUXILARY ENGINES                                  0.
              WPEI       PRIMARY ENGINE INSTALLATION                    1051.
              WAEI       AUXILIARY ENGINE INSTALLATION                     0.
              WFS        FUEL SYSTEM                                     560.
          DELTA WP       PROPULSION GROUP WEIGHT INCREMENT                 0.
                WP   TOTAL PROPULSION GROUP WEIGHT                                         23980.

      STRUCTURES GROUP
          K8  WW         WING                                              0.
              WTG        TAIL GROUP                                        0.
          K9  WHT            HOR. TAIL                                            0.
          K14 WTR            TAIL ROTOR                                           0.
          K6  WB         FUSELAGE                                      10774.
          K7  WLG        LANDING GEAR                                   3365.
              WNG            NOSE GEAR                                          673.
              WMG            MAIN GEAR                                         2692.
              WTES       TOTAL ENGINE SECTION                              0.
              WPES           PRIMARY ENGINE SECTION                               0.
              WAES           AUXILIARY ENGINE SECTION                             0.
          DELTA WST      STRUCTURE WEIGHT INCREMENT                      400.
                WST  TOTAL STRUCTURE WEIGHT                                                14539.

      FLIGHT CONTROLS GROUP
              WPFC       PRIMARY FLIGHT CONTROLS                        4198.
              WCC            COCKPIT CONTROLS                                   160.
          K1  WRC            MAIN ROTOR CONTROLS                               2430.
          K2  WSC            MAIN ROTOR SYSTEMS CONTROLS                       1459.
          K3  WFW            FIXED WING CONTROLS                                  0.
              WTM            TILT MECHANISM                                       0.
              WSAS           SAS                                                150.
              WAFC       AUXILIARY FLIGHT CONTROLS                         0.
          K4  WRCA           AUX. PROPULSION ROTOR CONTROLS                       0.
          K5  WSCA           AUX. PROPULSION ROTOR SYS. CONTROLS                  0.
              WMC            MISCELLANEOUS CONTROLS                               0.
          DELTA WFC      CONTROL WEIGHT INCREMENT                          0.
```

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

WFC	TOTAL CONTROL WEIGHT	4198.
WFE	WEIGHT OF FIXED EQUIPMENT	13356.
WE	WEIGHT EMPTY	56073.
WFUL	FIXED USEFUL LOAD	1943.
OWE	OPERATING WEIGHT EMPTY	58016.
WPL	PAYLOAD	18000.
(WF)A	FUEL	8117.
WG	GROSS WEIGHT	84133.

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

```
                         H E S C O M P
HELICOPTER SIZING & PERFORMANCE COMPUTER PROGRAM    8-91

     R O T O R   D A T A

          ROTOR CYCLE NO.     4.2000

          MAIN ROTOR SOLIDITY SIZED BY MANUEVER CONDITIONS
          H =      1000.0 FT. , TEMP =       55.4 DEG. , V =       219.0 KT.
          ROTOR MANUEVER G'S =  1.250 , CT/SIGMA =  .077
```

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

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

P R O P U L S I O N   D A T A
        PRIMARY PROPULSION CYCLE NO.     2.510
                TURBOSHAFT ENGINE

                 3.  ENGINES

           BHP*P           MAX. STANDARD S.L. STATIC H.P.          15710.     H.P.

           ENGINE SIZED FOR TAKEOFF AT T/W =1.11
           H =     0. FT, TEMPERATURE = 90.00 DEG.F.,
            1.000 ENGINES INOPERATIVE, AND      .00 FT/MIN VERTICAL RATE OF CLIMB.

           NO CRUISE CONDITION SPECIFIED.

               MAIN ROTOR DRIVE SYSTEM RATING          15710.     H.P.

        XMSN SIZED AT 100. PERCENT OF TOTAL PRIMARY ENGINE INSTALLED POWER
        (MAX. STANDARD S.L. STATIC H.P.)
```

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

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

A E R O D Y N A M I C S D A T A

FE	TOTAL EFFECTIVE FLATPLATE AREA	47.926	SQFT
SWET	TOTAL WETTED AREA	4092.	SQFT
CBARF	MEAN SKIN FRICTION COEFF.	.011713	

D R A G B R E A K D O W N IN SQFT

FEW	WING FE	.000
FEF	FUSELAGE FE	47.926
FEFP	FORWARD(MAIN) ROTOR PYLON FE	.000
FEAP	AFT ROTOR PYLON FE	.000
FEMRH	MAIN ROTOR HUB(S) FE	.000
FETRH	TAIL ROTOR HUB FE	.000
FEVT	VERTICAL TAIL FE	.000
FEHT	HORIZONTAL TAIL FE	.000
FEN	PRIMARY ENGINE NACELLE FE	.000
FENI	AUX. INDEPENDENT CRUISE ENG. NAC. FE	.000
FENS	AUX. INDPENDENT CRUISE ENG. STRUT FE	.000
DELTA FE	INCREMENTAL FE	.000

A E R O D Y N A M I C C O E F F .

A5		47.92624
A6		.00000
A7		.00000
A8		.00000
A9		.00000
E	WING LIFT EFFICIENCY FACTOR	.00000
EVT	VERTICAL TAIL LIFT EFFICIENCY FACTOR	.00000

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

MISSION PERFORMANCE DATA

TAXI FOR .167 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)
.000	.00	.0	84133.	0.	.0	1665.0	T	.000	952.	----	----	----	
.167	.00	158.9	83974.	0.	.0	1665.0	T	.000	952.	----	----	----	

TAKEOFF, HOVER, OR LAND AT T/W = 1.040 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
M.ROTOR VTIP	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	VRC RHP	PRIM.ENG FUEL FLOW (LBS/HR)	AUX.ENG FUEL FLOW (LBS/HR)	ROTLIM CODE			DELDCM	FMI	CPPRO	CPIND	CDO
.167	.00	158.9	83974.	0.	.0	2264.6	P	.563	4150.	1.040	.737	8829.	.0062	.062
703.8	8418.	----	----	0.	4150.		A			.0000	.737	.00009	.00038	.0092
.184	.00	228.3	83905.	0.	.0	2264.1	P	.562	4147.	1.040	.737	8819.	.0062	.062
703.8	8409.	----	----	0.	4147.		A			.0000	.737	.00009	.00038	.0092
.200	.00	297.1	83836.	0.	.0	2263.5	P	.562	4144.	1.040	.737	8810.	.0062	.062
703.8	8400.	----	----	0.	4144.		A			.0000	.737	.00009	.00038	.0092

CLIMB TO 700. FT. WITH CONSTANT EAS 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)
M.ROTOR VTIP (FPS)	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG FUEL FLOW (LBS/HR)	BHP AUX	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST	
CPPRO	CPIND.	CPPAR	CPNUD	CDO	DELCDS	DELCDM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN	

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

.200	.00	297.1	83836.	0.	100.0	2500.0	T	.854	100.0	.240	.060	-1.1	14.5	13392.	2614.
703.8	5212.	----	----	----	5586.	----	----	.000	----	----	----	----		----	
.000108	.000138	.000028	.000014	.00916	.00001	.00015	.000115	A	----	----	----	----	----	----	
.202	.16	306.0	83827.	250.	100.4	2500.0	T	.850	100.0	.241	.060	-1.1	14.3	13335.	2594.
703.8	5217.	----	----	----	5557.	----	----	.000	----	----	----	----		----	
.000109	.000140	.000028	.000014	.00917	.00001	.00016	.000116	A	----	----	----	----	----	----	
.204	.32	314.9	83818.	500.	100.7	2500.0	T	.847	100.0	.242	.060	-1.1	14.1	13278.	2573.
703.8	5222.	----	----	----	5528.	----	----	.000	----	----	----	----		----	
.000109	.000141	.000028	.000014	.00918	.00001	.00017	.000116	A	----	----	----	----	----	----	
.205	.45	322.1	83811.	700.	101.0	2500.0	T	.844	100.0	.242	.061	-1.1	14.0	13233.	2557.
703.8	5226.	----	----	----	5505.	----	----	.000	----	----	----	----		----	
.000109	.000143	.000028	.000014	.00920	.00001	.00018	.000117	A	----	----	----	----	----	----	

CLIMB TO 2000. FT. WITH CONSTANT EAS 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)
H.ROTOR VTIP (FPS)	H.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG. FUEL FLOW (LBS/HR)	BHP AUX	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST	
CPPRO	CPIND	CPPAR	CPNUD	CD0	DELCD0	DELCDM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN	
.205	.45	322.1	83811.	700.	101.0	2500.0	T	.844	100.0	.242	.061	-1.1	14.0	13233.	2557.
703.8	5226.	----	----	----	5505.	----	----	.000	----	----	----	----		----	
.000109	.000143	.000028	.000014	.00920	.00001	.00018	.000117	A	----	----	----	----	----	----	
.206	.62	331.1	83802.	950.	101.4	2500.0	T	.840	100.0	.243	.06[illegible]	-1.1	13.9	13175.	2536.
703.8	5232.	----	----	----	5476.	----	----	.000	----	----	----	----		----	
.000110	.000144	.000029	.000014	.00921	.00001	.00020	.000118	A	----	----	----	----	----	----	
.208	.78	340.1	83793.	1200.	101.8	2500.0	T	.837	100.0	.244	.062	-1.1	13.7	13118.	2515.
703.8	5237.	----	----	----	5447.	----	----	.000	----	----	----	----		----	
.000110	.000146	.000029	.000015	.00923	.00001	.00022	.000119	A	----	----	----	----	----	----	
.210	.95	349.1	83784.	1450.	102.2	2500.0	T	.834	100.0	.245	.062	-1.1	13.5	13060.	2494.
703.8	5244.	----	----	----	5418.	----	----	.000	----	----	----	----		----	
.000110	.000147	.000029	.000015	.00925	.00002	.00023	.000120	A	----	----	----	----	----	----	
.211	1.12	358.1	83775.	1700.	102.5	2500.0	T	.834	100.0	.246	.063	-1.1	13.4	13002.	2473.
703.8	5250.	----	----	----	5389.	----	----	.000	----	----	----	----		----	
.000111	.000149	.000030	.000015	.00927	.00002	.00025	.000121	A	----	----	----	----	----	----	
.213	1.30	367.2	83766.	1950.	102.9	2500.0	T	.835	100.0	.247	.063	-1.1	13.2	12945.	2452.
703.8	5257.	----	----	----	5360.	----	----	.000	----	----	----	----		----	
.000111	.000151	.000030	.000015	.00929	.00002	.00027	.000121	A	----	----	----	----	----	----	
.213	1.33	369.0	83764.	2000.	103.0	2500.0	T	.835	100.0	.247	.063	-1.1	13.2	12933.	2448.
703.8	5258.	----	----	----	5355.	----	----	.000	----	----	----	----		----	
.000111	.000151	.000030	.000016	.00930	.00002	.00027	.000122	A	----	----	----	----	----	----	

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

CRUISE AT 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. PEHF	EAS (KTS)	MU	CT PRIME OVER SIGMA	ALPHA D/L (DEG)	SPEC. RANGE (NMPP)	BHP
M.ROTOR VTIP (FPS)	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG FUEL FLOW (LBS/HR)	BHP AUX.	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST
CPPRO	CPIND	CPPAR	CPNUD	CDO	DELCDS	DELCOM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN

WARNING : ROTOR LIMIT HAS BEEN EXCEEDED. FORWARD FLIGHT SPEED HAS BEEN REDUCED ACCORDINGLY. CHECK ALL VALUES OF TAS,MU,CT'/SIGMA & CXR IN THIS PERFORMANCE LEG.

.213	1.33	369.0	83764.	2000.	200.8	2500.0	T	.865	194.9	.481	.063	-4.2	.03648	13592.
703.8	13040.	----	----	----	5502.	----	----	.000	----	----	----	----		----
.000437	.000079	.000223	.000026	.02252	.00322	.01030	.000462	E	----	----	----	----	----	----
.263	11.33	643.1	83490.	2000.	200.5	2500.0	T	.855	194.7	.481	.063	-4.2	.03675	13512.
703.8	12961.	----	----	----	5456.	----	----	.000	----	----	----	----		----
.000423	.000078	.000222	.000026	.02237	.00314	.01023	.000461	A	----	----	----	----	----	----
.313	21.33	915.2	83218.	2000.	200.7	2500.0	T	.855	194.9	.481	.063	-4.2	.03679	13520.
703.8	12969.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000434	.000078	.000222	.000026	.02237	.00312	.01025	.000462	A	----	----	----	----	----	----
.363	31.33	1187.1	82946.	2000.	200.7	2500.0	T	.855	194.9	.481	.062	-4.3	.03678	13485.
703.8	12935.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000432	.000077	.000222	.000026	.02230	.00308	.01022	.000462	A	----	----	----	----	----	----
.413	41.33	1458.9	82674.	2000.	200.9	2500.0	T	.855	195.1	.482	.062	-4.3	.03682	13491.
703.8	12941.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000433	.000076	.000223	.000024	.02230	.00306	.01024	.000463	A	----	----	----	----	----	----
.463	51.33	1730.5	82402.	2000.	200.9	2500.0	T	.855	195.1	.482	.062	-4.3	.03682	13461.
703.8	12912.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000431	.000076	.000223	.000026	.02224	.00301	.01022	.000463	A	----	----	----	----	----	----
.512	61.33	2002.1	82131.	2000.	201.1	2500.0	T	.855	195.3	.482	.062	-4.3	.03685	13467.
703.8	12917.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000432	.000075	.000224	.000026	.02223	.00299	.01024	.000464	A	----	----	----	----	----	----
.562	71.33	2273.5	81859.	2000.	201.1	2500.0	T	.855	195.3	.482	.062	-4.3	.03686	13441.
703.8	12893.	----	----	----	5457.	----	----	.000	----	----	----	----		----
.000431	.000075	.000224	.000026	.02218	.00295	.01023	.000464	A	----	----	----	----	----	----
.612	81.33	2544.8	81588.	2000.	201.3	2500.0	T	.855	195.5	.483	.061	-4.3	.03689	13446.
703.8	12897.	----	----	----	5458.	----	----	.000	----	----	----	----		----
.000431	.000074	.000224	.000025	.02218	.00293	.01025	.000465	A	----	----	----	----	----	----
.661	91.33	2815.9	81317.	2000.	201.4	2500.0	T	.855	195.5	.483	.061	-4.4	.03690	13426.
703.8	12877.	----	----	----	5458.	----	----	.000	----	----	----	----		----
.000430	.000074	.000225	.000025	.02213	.00289	.01024	.000465	A	----	----	----	----	----	----
.711	101.33	3086.9	81046.	2000.	201.6	2500.0	T	.855	195.7	.483	.061	-4.4	.03693	13430.

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

```
 703.8     12871.     ----      ----     ----    5458.     ----     ----    .000   ----   ----   ----   ----            ----
 .000431  .000073   .000225   .000025   .02212   .00287   .01025  .000466   A     ----   ----   ----   ----    ----    ----

 .761     111.33    3357.7    80775.    2000.    201.6    2500.0     T      .855  195.8   .484   .061   -4.4   .03694  13413.
 703.8     12866.     ----      ----     ----    5458.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000073   .000225   .000025   .02209   .00284   .01025  .000466   A     ----   ----   ----   ----    ----    ----

 .810     121.33    3628.3    80504.    2000.    201.8    2500.0     T      .855  195.9   .484   .061   -4.4   .03697  13417.
 703.8     12869.     ----      ----     ----    5455.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000072   .000226   .000025   .02208   .00281   .01026  .000467   A     ----   ----   ----   ----    ----    ----

 .860     131.33    3898.8    80234.    2000.    201.9    2500.0     T      .856  196.0   .484   .060   -4.4   .03699  13400.
 703.8     12853.     ----      ----     ----    5458.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000072   .000226   .000025   .02207   .00278   .01026  .000467   A     ----   ----   ----   ----    ----    ----

 .909     141.33    4169.2    79963.    2000.    202.0    2500.0     T      .856  196.2   .485   .060   -4.5   .03701  13403.
 703.8     12855.     ----      ----     ----    5459.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000071   .000227   .000025   .02203   .00276   .01027  .000468   A     ----   ----   ----   ----    ----    ----

 .959     151.33    4439.3    79693.    2000.    202.2    2500.0     T      .856  196.3   .485   .060   -4.5   .03704  13397.
 703.8     12850.     ----      ----     ----    5459.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000071   .000227   .000025   .02201   .00273   .01028  .000469   A     ----   ----   ----   ----    ----    ----

 1.008    161.33    4709.3    79423.    2000.    202.3    2500.0     T      .856  196.5   .485   .060   -4.5   .03706  13396.
 703.8     12843.     ----      ----     ----    5453.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000070   .000228   .000025   .02199   .00270   .01029  .000469   A     ----   ----   ----   ----    ----    ----

 1.058    171.33    4979.2    79153.    2000.    202.5    2500.0     T      .856  196.6   .486   .060   -4.5   .03709  13397.
 703.8     12850.     ----      ----     ----    5459.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000070   .000228   .000025   .02198   .00268   .01030  .000470   A     ----   ----   ----   ----    ----    ----

 1.062    172.26    5004.1    79126.    2000.    202.5    2500.0     T      .856  196.6   .486   .060   -4.5   .03709  13398.
 703.8     12850.     ----      ----     ----    5459.     ----     ----    .000   ----   ----   ----   ----            ----
 .000430  .000070   .000228   .000025   .02198   .00268   .01030  .000470   A     ----   ----   ----   ----    ----    ----

      DESCEND TO H =  1200. FT. ,R =   175.00 N.MI. AT CONSTANT EAS

                                                         PRIM.    PRIM.    PRIM.                 CT PRIME
                     FUEL                    PRES.       TURB.    ENG.     ENG.                  OVER    ALPHA
 TIME     RANGE      USED      WEIGHT        ALT.   TAS  TEMP.    CODE     PEHF     EAS    MU    SIGMA    D/L    GAMMA   BHP    R/S
 (HRS)    (N.M.)     (LBS)     (LBS.)        (FT)  (KTS) (R)                        (KTS)                 (DEG)  (DEG)          (FPM)

                                                                                           AUX.   AUX.   AUX.           AUX.
 M.ROTOR  M.ROTOR  T.ROTOR   T.ROTOR  PROP   PRIM.ENG   BHP     ETAP             AUX. ENG. TURB.  ENG.   ENG.        ENG. BHP
 VTIP     RHP      VTIP      RHP      VTIP   FUEL FLOW  AUX     PROP   TAUX/T  FUEL FLOW  TEMP.  CODE   PEHF        OR THRUST
 (FPS)             (FPS)              (FPS)  (LBS/HR)                         (LBS/HR)

 CPPRO    CPIND    CPPAR     CPNUD    CDO    DELCDS.   DELCDM    CXR    ROTLIM    J      CP     CT     CLW     CDW    RN
                                                                         CODE

 1.052    172.26    5004.1    79128.    2000.    103.0    1993.5     P      .261  100.0   .247   .060    1.5   -2.7   4039.  500.
 703.8      3773.     ----      ----     ----    2470.     ----     ----    .000   ----   ----   ----   ----           ----
 .000111  .000135  -.000039   .000015   .00925   .00000   .00024 -.000158   A     ----   ----   ----   ----    ----   ----

 1.066    172.60    5012.4    79120.    1900.    103.0    1992.4     P      .259  100.0   .247   .060    1.6   -2.7   4020.  500.
 703.8      3754.     ----      ----     ----    2434.     ----     ----    .000   ----   ----   ----   ----           ----
 .000111  .000135  -.000040   .000015   .00925   .00000   .00024 -.000162   A     ----   ----   ----   ----    ----   ----

 1.069    172.94    5020.7    79112.    1800.    103.0    1992.3     P      .259  100.0   .247   .060    1.6   -2.7   4019.  500.
```

FIGURE C-2   OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

703.8	3753.	----	----	----	2484.	----	----	.000	----	----	----	----		----	
.000111	.000135	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.072	173.29	5029.0	79103.	1700.	103.0	1992.3	P	.259	100.0	.247	.060	1.6	-2.7	4019.	500.
703.8	3753.	----	----	----	2484.	----	----	.000	----	----	----	----		----	
.000111	.000135	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.076	173.62	5037.3	79095.	1600.	103.0	1992.3	P	.259	100.0	.247	.060	1.6	-2.7	4018.	500.
703.8	3752.	----	----	----	2484.	----	----	.000	----	----	----	----		----	
.000111	.000134	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.079	173.97	5045.5	79087.	1500.	103.0	1992.3	P	.259	100.0	.247	.060	1.6	-2.7	4018.	500.
703.8	3752.	----	----	----	2484.	----	----	.000	----	----	----	----		----	
.000111	.000134	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.082	174.31	5053.8	79078.	1400.	103.0	1992.3	P	.259	100.0	.247	.060	1.6	-2.7	4018.	500.
703.8	3752.	----	----	----	2484.	----	----	.000	----	----	----	----		----	
.000111	.000134	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.086	174.66	5062.1	79070.	1300.	103.0	1992.2	P	.259	100.0	.247	.060	1.6	-2.7	4017.	500.
703.8	3751.	----	----	----	2483.	----	----	.000	----	----	----	----		----	
.000111	.000134	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	
1.089	175.00	5070.4	79062.	1200.	103.0	1992.2	P	.259	100.0	.247	.060	1.6	-2.7	4017.	500.
703.8	3751.	----	----	----	2483.	----	----	.000	----	----	----	----		----	
.000111	.000134	-.000040	.000015	.00925	.00000	.00024	-.000162	A	----	----	----	----	----	----	

CRUISE AT 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. PEHF	EAS (KTS)	MU	CT PRIME OVER SIGMA	ALPHA D/L (DEG)	SPEC. RANGE (NMPP)	BHP
M.ROTOR VTIP (FPS)	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG FUEL FLOW (LBS/HR)	BHP AUX	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST
CPPRO	CPIND	CPPAR	CPNUD	CDB	DELCDS	DELCDM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN
1.089	175.00	5070.4	79062.	1200.	204.1	2500.0	T	.868	200.5	.489	.058	-4.7	.03674	13689.
703.8	13133.	----	----	----	5555.	----	----	.000	----	----	----	----		----
.000427	.000066	.000234	.000024	.02167	.00256	.01012	.000478	A	----	----	----	----	----	----
1.099	177.00	5124.8	79007.	1200.	204.3	2500.0	T	.869	200.7	.490	.058	-4.7	.03677	13722.
703.8	13165.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000429	.000066	.000234	.000024	.02172	.00257	.01015	.000479	A	----	----	----	----	----	----
1.109	179.00	5179.2	78953.	1200.	204.3	2500.0	T	.869	200.7	.490	.058	-4.7	.03678	13721.
703.6	13164.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000429	.000065	.000235	.000024	.02172	.00256	.01015	.000479	A	----	----	----	----	----	----
1.118	181.00	5233.6	78898.	1200.	204.3	2500.0	T	.869	200.8	.490	.058	-4.7	.03678	13720.
703.6	13163.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000429	.000065	.000235	.000024	.02171	.00256	.01015	.000479	A	----	----	----	----	----	----
1.128	183.00	5287.9	78844.	1200.	204.4	2500.0	T	.869	200.8	.490	.058	-4.7	.03678	13719.

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

703.8	13162.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000429	.000065	.000235	.000024	.02171	.00255	.01016	.000479	A	----	----	----	----	----	----
1.138	185.00	5342.3	78790.	1200.	204.4	2500.0	T	.869	200.8	.490	.058	-4.7	.03679	13718.
703.8	13161.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000429	.000065	.000235	.000024	.02170	.00255	.01016	.000479	A	----	----	----	----	----	----
1.148	187.00	5396.7	78735.	1200.	204.6	2500.0	T	.869	201.0	.491	.058	-4.8	.03682	13756.
703.8	13197.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000430	.000065	.000236	.000024	.02176	.00256	.01020	.000480	A	----	----	----	----	----	----
1.157	189.00	5451.0	78681.	1200.	204.6	2500.0	T	.869	201.0	.491	.058	-4.8	.03683	13754.
703.8	13196.	----	----	----	5556.	----	----	.000	----	----	----	----		----
.000430	.000065	.000236	.000024	.02175	.00255	.01020	.000480	A	----	----	----	----	----	----
1.167	191.00	5505.3	78627.	1200.	204.1	2500.0	T	.868	200.5	.489	.058	-4.7	.03673	13628.
703.8	13074.	----	----	----	5555.	----	----	.000	----	----	----	----		----
.000425	.000065	.000234	.000024	.02156	.00249	.01007	.000477	A	----	----	----	----	----	----
1.177	193.00	5559.8	78572.	1200.	204.1	2500.0	T	.868	200.5	.489	.058	-4.7	.03674	13628.
703.8	13074.	----	----	----	5555.	----	----	.000	----	----	----	----		----
.000425	.000065	.000234	.000024	.02156	.00249	.01007	.000478	A	----	----	----	----	----	----
1.183	194.31	5595.3	78537.	1200.	204.1	2500.0	T	.868	200.5	.489	.058	-4.8	.03674	13628.
703.8	13074.	----	----	----	5555.	----	----	.000	----	----	----	----		----
.000425	.000065	.000234	.000024	.02156	.00248	.01007	.000478	A	----	----	----	----	----	----

DESCEND TO H = 700. FT. ,R = 196.00 N.MI. AT CONSTANT EAS

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)
H.ROTOR VTIP (FPS)	H.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG FUEL FLOW (LBS/HR)	BHP AUX	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST	
CPPRO	CPIND	CPPAR	CPNUD	CDE	DELCDS	DELCDM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN	
1.183	194.31	5595.3	78537.	1200.	101.8	1993.7	P	.255	100.0	.244	.058	1.6	-2.8	3992.	500.
703.8	3727.	----	----	----	2515.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000038	.000014	.00919	.00000	.00019	-.000156	A	----	----	----	----	----	----	
1.187	194.64	5603.7	78528.	1100.	101.8	1992.7	P	.254	100.0	.244	.058	1.6	-2.8	3974.	500.
703.8	3710.	----	----	----	2509.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000039	.000014	.00919	.00000	.00019	-.000160	A	----	----	----	----	----	----	
1.190	194.98	5612.1	78520.	1000.	101.8	1992.6	P	.254	100.0	.244	.058	1.6	-2.8	3974.	500.
703.8	3709.	----	----	----	2509.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000039	.000014	.00919	.00000	.00019	-.000160	A	----	----	----	----	----	----	
1.193	195.32	5620.4	78511.	900.	101.8	1992.5	P	.253	100.0	.244	.058	1.6	-2.8	3973.	500.
703.8	3709.	----	----	----	2509.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000039	.000014	.00919	.00000	.00019	-.000160	A	----	----	----	----	----	----	
1.197	195.66	5628.8	78503.	800.	101.8	1992.6	P	.253	100.0	.244	.058	1.6	-2.8	3973.	500.

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

703.8	3708.	----	----	----	2509.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000139	.000014	.00919	.00000	.00019	-.000160	A	----	----	----	----	----	----	
1.200	196.00	5437.1	76495.	700.	101.8	1992.6	P	.253	100.0	.244	.058	1.6	-2.0	3973.	500.
703.8	3708.	----	----	----	2509.	----	----	.000	----	----	----	----		----	
.000109	.000128	-.000039	.000014	.00919	.00000	.00019	-.000160	A	----	----	----	----	----	----	

CRUISE AT 100.0 KNOTS TAS, LIMITED BY NORMAL ENGINE RATING

TIME (HRS) M.ROTOR VTIP (FPS) CPPRO	RANGE (N.M.) M.ROTOR RHP CPIND	FUEL USED (LBS) T.ROTOR VTIP (FPS) CPPAR	WEIGHT (LBS.) T.ROTOR RHP CPNUD	PRES. ALT. (FT) PROP VTIP (FPS) CD0	TAS (KTS) PRIM-ENG FUEL FLOW (LBS/HR) DELCDS	PRIM. TURB. TEMP. (R) BHP AUX DELCDM	PRIM. ENG. CODE ETAP PROP CXR	PRIM. ENG. PEHF TAUX/T ROTLIM CODE	EAS (KTS) AUX. ENG. FUEL FLOW (LBS/HR) J	MU AUX. TURB. TEMP. CP	CT PRIME OVER SIGMA AUX. ENG. CODE CT	ALPHA D/L (DEG) AUX. ENG. PEHF CLW	SPEC. RANGE (NMPP) CDW	BHP AUX. ENG. BHP OR THRUST RN
1.200	196.00	5637.1	78495.	700.	100.0	2062.0	P	.331	99.0	.240	.057	-1.2	.03460	5185.
703.8	4883.	----	----	----	2890.	----	----	.000	----	----	----	----		----
.000108	.000127	.000028	.000013	.00915	.00000	.00015	.000115	A	----	----	----	----	----	----
1.210	197.00	5666.0	78466.	700.	100.0	2061.9	P	.331	99.0	.240	.057	-1.2	.03461	5183.
703.8	4882.	----	----	----	2889.	----	----	.000	----	----	----	----		----
.000108	.000126	.000028	.000013	.00915	.00000	.00015	.000115	A	----	----	----	----	----	----
1.220	198.00	5694.9	78437.	700.	100.0	2061.8	P	.330	99.0	.240	.057	-1.2	.03462	5181.
703.8	4880.	----	----	----	2889.	----	----	.000	----	----	----	----		----
.000108	.000126	.000028	.000013	.00915	.00000	.00015	.000115	A	----	----	----	----	----	----
1.230	199.00	5723.8	78408.	700.	100.0	2061.7	P	.330	99.0	.240	.057	-1.2	.03462	5179.
703.8	4878.	----	----	----	2888.	----	----	.000	----	----	----	----		----
.000108	.000126	.000028	.000013	.00915	.00000	.00015	.000115	A	----	----	----	----	----	----
1.240	200.00	5752.7	78379.	700.	100.0	2061.6	P	.330	99.0	.240	.057	-1.2	.03463	5177.
703.8	4876.	----	----	----	2888.	----	----	.000	----	----	----	----		----
.000108	.000126	.000028	.000013	.00915	.00000	.00015	.000115	A	----	----	----	----	----	----

DESCEND TO H = 0. FT. AT CONSTANT EAS (SPIRAL DESCENT PATH - NO RANGE CREDIT)

TIME (HRS) M.ROTOR VTIP (FPS) CPPRO	RANGE (N.M.) M.ROTOR RHP CPIND	FUEL USED (LBS) T.ROTOR VTIP (FPS) CPPAR	WEIGHT (LBS.) T.ROTOR RHP CPNUD	PRES. ALT. (FT) PROP VTIP (FPS) CD0	TAS (KTS) PRIM-ENG FUEL FLOW (LBS/HR) DELCDS	PRIM. TURB. TEMP. (R) BHP AUX DELCDM	PRIM. ENG. CODE ETAP PROP CXR	PRIM. ENG. PEHF TAUX/T ROTLIM CODE	EAS (KTS) AUX. ENG. FUEL FLOW (LBS/HR) J	MU AUX. TURB. TEMP. CP	CT PRIME OVER SIGMA AUX. ENG. CODE CT	ALPHA D/L (DEG) AUX. ENG. PEHF CLW	GAMMA (DEG) CDW	BHP AUX. ENG. BHP OR THRUST RN	R/S (FPM)

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

1.240	200.00	5752.7	78379.	700.	101.0	1994.6	P	.254	100.0	.242	.057	1.6	-2.8	3975.	500.
703.8	3711.	----	----	----	2534.	----	----	.000	----	----	----	----		----	
.000109	.000125	-.000038	.000013	.00916	.00000	.00016	-.000155	A	----	----	----	----	----	----	
1.243	200.34	5761.1	78370.	600.	101.0	1993.7	P	.252	100.0	.242	.057	1.6	-2.8	3958.	500.
703.8	3694.	----	----	----	2529.	----	----	.000	----	----	----	----		----	
.000109	.000125	-.000039	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.247	200.67	5769.6	78362.	500.	101.0	1993.6	P	.252	100.0	.242	.057	1.6	-2.8	3958.	500.
703.8	3693.	----	----	----	2529.	----	----	.300	----	----	----	----		----	
.000109	.000125	-.000039	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.250	201.01	5778.0	78354.	400.	101.0	1993.6	P	.252	100.0	.242	.057	1.6	-2.8	3957.	500.
703.8	3693.	----	----	----	2529.	----	----	.000	----	----	----	----		----	
.000109	.000125	-.000039	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.253	201.35	5786.4	78345.	300.	101.0	1993.6	P	.252	100.0	.242	.057	1.6	-2.8	3957.	500.
703.8	3693.	----	----	----	2529.	----	----	.000	----	----	----	----		----	
.000109	.000125	-.000039	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.257	201.68	5794.9	78337.	200.	101.0	1993.6	P	.252	100.0	.242	.057	1.6	-2.8	3957.	500.
703.8	3692.	----	----	----	2529.	----	----	.000	----	----	----	----		----	
.000109	.000124	-.000038	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.260	202.02	5803.3	78323.	100.	101.0	1993.5	P	.252	100.0	.242	.057	1.6	-2.8	3956.	500.
703.8	3692.	----	----	----	2528.	----	----	.000	----	----	----	----		----	
.000109	.000124	-.000038	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	
1.263	202.35	5811.7	78320.	0.	101.0	1993.5	P	.252	100.0	.242	.057	1.6	-2.8	3956.	500.
703.8	3692.	----	----	----	2528.	----	----	.000	----	----	----	----		----	
.000109	.000124	-.000038	.000013	.00916	.00000	.00016	-.000159	A	----	----	----	----	----	----	

TAKEOFF, HOVER, OR LAND AT T/W = 1.040 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
M.ROTOR VTIP	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	VRC RHP	PRIM.ENG FUEL FLOW (LBS/HR)	AUX.ENG FUEL FLOW (LBS/HR)	ROTLIM CODE			DELDCM	FMI	CPPRO	CPIND	CDO
1.263	200.00	5811.7	78320.	0.	.0	2223.9	P	.515	3901.	1.040	.728	8070.	.0058	.058
703.8	7682.	----	----	0.	3901.	----	A			.0000	.728	.00009	.00034	.0092
1.280	200.00	5876.9	78255.	0.	.0	2223.4	P	.514	3898.	1.040	.728	8061.	.0058	.058
703.8	7674.	----	----	0.	3898.	----	A			.0000	.728	.00009	.00034	.0092
1.297	200.00	5941.6	78190.	0.	.0	2223.0	P	.514	3895.	1.040	.727	8053.	.0057	.058
703.8	7666.	----	----	0.	3895.	----	A			.0000	.727	.00009	.00034	.0092

TAXI FOR .167 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)
1.297	200.00	5941.6	78190.	0.	.0	1665.0	T	.000	952.	----	----	----	----

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

1.464 200.00 6100.5 78031. 0. .0 1665.0 T .000 952. ---- ---- ---- ----

TRANSFER ALTITUDE TO 2000. FT.

TIME (HRS)	RANGE (N.M.)	FUEL USED (LBS)	WEIGHT (LBS.)	PRES. ALT. (FT)
1.464	200.00	6100.5	78031.	0.
1.464	200.00	6100.5	78031.	2000.

CRUISE AT SPEED FOR 99 PER CENT BEST RANGE WITH HEADWIND OF .0 KNOTS

FOR RESERVEFUEL

TIME (HRS) / M.ROTOR VTIP (FPS) / CPPRO	RANGE (N.M.) / M.ROTOR RHP / CPIND	FUEL USED (LBS) / T.ROTOR VTIP (FPS) / CPPAR	WEIGHT (LBS.) / T.ROTOR RHP / CPNUD	PRES. ALT. (FT) / PROP VTIP (FPS) / CD0	TAS (KTS) / PRIM.ENG FUEL FLOW (LBS/HR) / DELCDS	PRIM. TURB. TEMP. (R) / BHP AUX / DELCDM	PRIM. ENG. CODE / ETAP PROP / CXR	PRIM. ENG. PEHF / TAUX/T / ROTLIM CODE	EAS (KTS) / AUX. ENG. FUEL FLOW (LBS/HR) / J	MU / AUX. TURB. TEMP. / CP	CT PRIME OVER SIGMA / AUX. ENG. CODE / CT	ALPHA D/L (DEG) / AUX. ENG. PEHF / CLW	SPEC. RANGE (NMPP) / / CDW	BHP / AUX. ENG. BHP OR THRUST / RN
1.464	200.00	6100.5	78031.	2000.	171.2	2237.5	P	.555	166.2	.411	.059	-3.3	.04409	8696.
703.8	8290.	----	----	----	3885.	----	----	.000	----	----	----	----		----
.000239	.000080	.000138	.000029	.01436	.00069	.00468	.000336	A	----	----	----	----	----	----
1.522	210.00	6327.3	77804.	2000.	171.2	2236.6	P	.554	166.2	.411	.059	-3.3	.04415	8680.
703.8	8274.	----	----	----	3880.	----	----	.000	----	----	----	----		----
.000239	.000079	.000138	.000029	.01434	.00068	.00467	.000336	A	----	----	----	----	----	----
1.581	220.00	6553.8	77578.	2000.	171.2	2235.7	P	.553	166.2	.411	.058	-3.3	.04421	8664.
703.8	8259.	----	----	----	3875.	----	----	.000	----	----	----	----		----
.000238	.000079	.000138	.000029	.01432	.00066	.00465	.000336	A	----	----	----	----	----	----
1.639	230.00	6780.0	77351.	2000.	171.2	2234.8	P	.552	166.2	.411	.058	-3.3	.04427	8648.
703.8	8243.	----	----	----	3870.	----	----	.000	----	----	----	----		----
.000238	.000078	.000138	.000028	.01430	.00065	.00464	.000336	A	----	----	----	----	----	----
1.697	240.00	7005.9	77125.	2000.	171.2	2234.0	P	.551	166.2	.411	.058	-3.3	.04433	8632.
703.8	8227.	----	----	----	3865.	----	----	.000	----	----	----	----		----
.000238	.000078	.000133	.000028	.01428	.00064	.00463	.000336	A	----	----	----	----	----	----
1.756	250.00	7231.5	76900.	2000.	171.2	2233.1	P	.550	166.2	.411	.058	-3.3	.04438	8616.
703.8	8212.	----	----	----	3860.	----	----	.000	----	----	----	----		----
.000237	.000078	.000138	.000028	.01425	.00063	.00462	.000336	A	----	----	----	----	----	----

LOITER FOR .333 HRS. FOR RESERVE FUEL

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)	TOTAL FUEL FLOW (LBS/HR)	BHP

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

M.ROTOR VTIP (FPS)	M.ROTOR RHP	T.ROTOR VTIP (FPS)	T.ROTOR RHP	PROP VTIP (FPS)	PRIM.ENG FUEL FLOW (LBS/HR)	BHP AUX	ETAP PROP	TAUX/T	AUX. ENG. FUEL FLOW (LBS/HR)	AUX. TURB. TEMP.	AUX. ENG. CODE	AUX. ENG. PEHF		AUX. ENG. BHP OR THRUST
CPPRO	CPIND	CPPAR	CPNUD	CDO	DELCDS	DELCDM	CXR	ROTLIM CODE	J	CP	CT	CLW	CDW	RN
1.464	250.00	7231.5	78031.	2000.	93.2	2057.1	P	.332	90.5	.223	.059	-1.0	2813.	5120.
703.8	4821.	----	----	----	2813.	----	----	.000	----	----	----	----		----
.000105	.000144	.000022	.000011	.00911	.00000	.00011	.000100	A	----	----	----	----	----	----
1.575	250.00	7544.0	77718.	2000.	93.2	2055.9	P	.330	90.5	.223	.059	-1.0	2807.	5099.
703.8	4801.	----	----	----	2807.	----	----	.000	----	----	----	----		----
.000105	.000143	.000022	.000011	.00911	.00000	.00011	.000100	A	----	----	----	----	----	----
1.686	250.00	7855.9	77406.	2000.	93.2	2054.6	P	.329	90.5	.223	.058	-1.0	2801.	5078.
703.8	4780.	----	----	----	2801.	----	----	.000	----	----	----	----		----
.000105	.000142	.000022	.000011	.00911	.00000	.00011	.000100	A	----	----	----	----	----	----
1.797	250.00	8167.0	77095.	2000.	93.2	2053.4	P	.327	90.5	.223	.058	-1.0	2794.	5057.
703.8	4760.	----	----	----	2794.	----	----	.000	----	----	----	----		----
.000105	.000141	.000022	.000011	.00911	.00000	.00011	.000100	A	----	----	----	----	----	----

MISSION FUEL REQUIRED = 6100.28
RESERVE FUEL REQUIRED = 2066.75
TOTAL FUEL REQUIRED = 8167.03

****

END OF SUCCESSFUL CASE

****

FIGURE C-2 OUTPUT OF A TYPICAL HESCOMP SIZING CASE (CONTINUED)

APPENDIX D

HELICOPTER COSTING METHODOLOGY

FLYAWAY COSTS

The airframe cost of the current technology baseline helicopter is calculated using a value of $100.00 per pound of airframe. The airframe weight is arrived at as follows:
Airframe = Empty Weight - ($W_R + W_{DR} + W_{EN} + W_{AV}$)

Where:

W_R = Weight of Rotors

W_{DR} = Weight of Drive System

W_{EN} = Weight of Engines

W_{AV} = Weight of Avionics

It should be noted that in the equations used for calculating airframe maintenance costs, which use airframe weight, the weight of the avionics systems was included in the airframe since the AIA methodology does not make provision for calculating avionics maintenance cost as a separate item. Other major systems costs were calcualted as shown below:

Helicopter Dynamic System Cost = \$90 ($W_{DR} + W_R$)

Engine Cost = E_N (\$550HP 0.785)

where:

E_N = Number of Engines

HP = Static SHP at SL/STD for 1 engine

Avionics Cost/vehicle = $300,000

OPERATING COSTS

Direct operating costs were developed using the Aerospace Industries Association's (AIA) "Standard Method of Estimating Direct Operating Costs of Turbine Powered VTOL Transport Aircraft" dated 1968modified as follows:

Crew Costs

$$\$/FH = \frac{.067 \text{ Gross Weight}}{1000} + 185$$

Engine Maintenance Costs

Labor ($/FH) - 0.65 (AIA Costs)

Material ($/FH) = 0.65 (AIA Costs

Maintenance Burden

$$\$/FH = 1.5\,(DL_{AF} + DL_{EN} + DL_{DS})$$

Where:

DL_{AF} = Direct Labor Costs for Airframe Maintenance

DL_{EN} = Direct Labor Costs for Engine Maintenance

DL_{DS} = Direct Labor Costs for Dynamic System Maintenance

The selected utilization, 3000 flight hours per year, reasonably represents the values corresponding to block times for 100 to 200 n mi average flight distances as read from the AIA utilization curve.

Table D-1 lists the other factors used in calculating the direct operating costs. Table D-2 shows the variations in airframe and dynamic system prices per pound due to the application of advanced materials technology.

The preceding methodology has been incorporated into a samll computer program which accepts input data directly from the HESCOMP computer program described in Appendix C. Figure D-1 illustrates the output of this cost program for the sizing case illustrated in Figure C-2, Appendix C.

TABLE D-1 GROUND RULES FOR CURRENT TECHNOLOGY COST CALCULATIONS

ITEM	
YEAR DOLLARS	1975
AVIONICS PRICE, \$/ACFT	300,000
AIRFRAME PRICE, \$/LB	100
DYNAMIC SYSTEM PRICE, \$/LB	90
ENGINE PRICE, \$/RATED SHP	280 $(HP^{.785})$
CREW COSTS, \$/HR	$\frac{0.067\ GW}{1000} + 185$
FUEL, \$/U.S. GAL	0.25
OIL, \$/LB	1.43
NONREVENUE FACTOR, %	2
LABOR RATE, \$/HR	8.60
AIRFRAME LABOR, MH/FH	1.0 X AIA FORMULA
AIRFRAME MATERIAL, \$/FH	1.0 X AIA FORMULA
ENGINE LABOR, MH/FH	0.65 X AIA FORMULA
ENGINE MATERIAL, \$/FH	0.65 X AIA FORMULA
ENGINE TBO, HR	4500
DYNAMIC SYSTEM LABOR, MH/FH	1.0 X AIA FORMULA
DYNAMIC SYSTEM MATERIAL, \$/FH	1.0 X AIA FORMULA
DYNAMIC SYSTEM TBO, HR	4500
MAINTENANCE BURDEN	150% DIRECT LABOR
DEPRECIATION PERIOD, YR	12
SPARES - %	
AIRFRAME	8
ENGINES	40
DYNAMIC SYSTEM	20
UTILIZATION, FLT HR/YR	3000

TABLE D-2 VARIATION IN AIRFRAME AND DYNAMIC SYSTEM PRICES/POUND DUE TO THE USE OF ADVANCED MATERIALS

STRUCTURAL WE/GW REDUCTION	0%	5%	10%	15%
AIRFRAME COST ($/LB)	100	99.37	97.32	93.15
DYNAMIC SYSTEM COST ($/LB)	90	89.71	88.74	86.89

CASE NO. TECHNOLOGY IMPROVEMENT STUDY-COMP DSN PT(100/6)- EWR=0,LDEI=0,FER=

SHORT HAUL MISSION; BLOCK DISTANCE 230.31 S. MI.

GROSS WEIGHT (LB)	84133.	TOTAL COST	6754787.	AVAILABLE SEATS	100.
WEIGHT EMPTY (LB)	56073.	$/LB FOR AIRFRAME	100.	UTILIZATION (HR/YR)	3000.00
WEIGHT OF AIRFRAME (LB)	32858.	COST OF AIRFRAME	3285814.	BLOCK SPEED (ST. MPH)	157.34
WEIGHT OF DYNAMIC SYS (LB	19981.	COST OF DYNAMIC SYS	1798309.	BLOCK SPEED (KMPH)	253.22
WEIGHT OF AVIONICS (LB)	846.	COST OF AVIONICS	300000.	BLOCK FUEL (LB)	6100.28
ENGINE RATING (SHP)	5237.	COST PER ENGINE	456888.	NUMBER OF ENGINES	3.

	COST PER AIR MILE	COST PER SEAT MILE	COST PER AIR KM	COST PER SEAT KM
FLYING OPERATIONS				
FLIGHT CREW	1.207547	.012075	.750370	.007504
FUEL AND OIL	1.011488	.010115	.628539	.006285
HULL INSURANCE	.286201	.002862	.177845	.001778
TOTAL FLYING OPERATIONS	2.505236	.025052	1.556753	.015568
DIRECT MAINTENANCE - FLIGHT EQUIP.				
AIRFRAME - LABOR	.223185	.002232	.138687	.001387
MATERIAL	.138668	.001387	.086169	.000862
ENGINES - LABOR	.099676	.000997	.061939	.000619
MATERIAL	.186625	.001866	.115969	.001160
DYNAMIC SYSTEM - LABOR	.209513	.002095	.130191	.001302
MATERIAL	.215096	.002151	.133660	.001337
TOTAL DIRECT MAINTENANCE	1.072761	.010728	.666612	.006666
MAINTENANCE BURDEN	.798560	.007986	.496225	.004962
TOTAL MAINTENANCE	1.871321	.018713	1.162837	.011628
DEPRECIATION - FLIGHT EQUIP.	1.399198	.013992	.869461	.008695
TOTAL DIRECT COST INCL MAINT BURD	5.775754	.057758	3.589051	.035891

FIGURE D-1 OUTPUT OF COST PROGRAM FOR HESCOMP CASE SHOWN IN FIGURE C-2