NASA CR-144953A

ADDENDUM

TO

IDENTIFYING AND ANALYZING METHODS FOR REDUCING THE ENERGY CONSUMPTION OF HELICOPTERS

By

S. Jon Davis
Harold J. Rosenstein

Prepared under Contract No. NAS1-13624
By
Boeing Vertol Company
Philadelphia, Pennsylvania

for

National Aeronautics and
Space Administration

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LIST OF SYMBOLS AND ABBREVIATIONS

Btu	British thermal unit
b	rotor-blade number
c	rotor-blade chord, ft
C_P	rotor power coefficient, 550 hp/$\rho\pi R^2 V_{TIP}^3$
C_T	rotor thrust coefficient, $T/\rho\pi R^2 V_{TIP}^2$
DOC	direct operating cost, \$/seat-mile
EI	energy intensity, Btu/passenger-n mi
EW_{STR}/GW	structural empty-to-gross weight ratio
F_e	equivalent flat-plate drag area, ft^2
FM	helicopter rotor figure of merit, 0.707 $C_T^{3/2}/C_P$
HOEI	hover, one engine inoperative
HP	power, horsepower
KTAS	knots true airspeed
L/D_e	rotor lift-to-effective drag ratio
N MI	nautical miles
NRP	normal rated or maximum continuous power
R	rotor radius, ft
SFC	specific fuel consumption, lb fuel/hr/hp
T	thrust, lb
T/W	rotor thrust-to-gross weight ratio
V_{BR}	best-range cruising speed
V_{NRP}	normal-rated-power cruising speed
V_{TIP}	rotor tipspeed, ft/sec
W/A	helicopter rotor disk loading, lb/ft^2
ρ	atmospheric density, $slugs/ft^3$
σ	rotor solidity, $\frac{bc}{\pi R}$

1.0 INTRODUCTION

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 empty weight.

In the main body of this report, baseline helicopters incorporating today's technology were designed for a short range (200 n mi) and a very short-haul (100 n mi) mission scenario. Parametric analyses were then conducted to determine the impact of technology improvement.

Many of the parameters varied are interrelated. This addendum presents a summary of such interactions and adds some additional sensitivity values so that energy reduction and DOC as affected by the major technological factors or operational modes are clearly defined. Table 1 presents a summary of the technological improvements (and their associated EI reductions) to be addressed in the following paragraphs.

TABLE 1. SUMMARY OF PROJECTED TECHNOLOGICAL IMPROVEMENTS AND THEIR EFFECT ON ENERGY INTENSITY

Technological Area	Percent Improvement	Percent Reduction in Energy Intensity
Improved Engine SFC (conventional engines)	4.76% reduction	5.8%
Improved Engine SFC (regenerative engines)	14.3% reduction	16.6%
Reduced Parasite Drag	54% reduction	3.1%
Improved Cruise Efficiency (rotor L/D_e)	20% increase	6.5%
Improved Hover Efficiency (rotor figure of merit)	9.3% increase	9.2%
Reduced Structural Empty/Gross Weight	12.1% reduction	12.5%

2.0 MATCHED HELICOPTERS

In both CR-144953 and this addendum, reference is made to the matched helicopter. Such a matched helicopter is defined as a configuration having sufficient rotor solidity to allow its rotor limit and NRP cruising speeds to be equal. (It is worth noting that such matched vehicles exhibit minimum DOC values because of their ability to operate at NRP cruising speed.) Vehicles having less solidity are rotor-limited to a lower cruising speed.

The sizing of matched helicopters can introduce significant EI penalties. Accordingly, a more detailed discussion of the relative merits of matched versus unmatched helicopters is in order.

As an example, if the parasite-drag level of a given vehicle is reduced and the vehicle is resized with no accompanying change in solidity, the resulting helicopter will have the capability to fly at a higher cruising speed but will be limited to the rotor-limit cruising speed dictated by the solidity. Being limited to this cruising speed and operating at a reduced power required results in a reduced fuel-consumption rate. Therefore, this unmatched vehicle exhibits a significant reduction in EI compared to the original vehicle. However, since it is operating at a cruising speed less than its potential NRP cruising speed, it also exhibits an increased DOC (compared to the original vehicle).

If the original vehicle is again resized at a reduced parasite-drag level, and the rotor solidity is increased to allow operation at a higher cruising speed, several things occur:

1. The structural empty-weight fraction increases, reflecting the increased solidity
2. The increased structural empty weight causes an escalation in the gross weight.
3. Since the helicopter is not rotor-limited and can fly faster, the fuel consumption is increased.

The resulting matched helicopter thus exhibits less of an EI reduction relative to the original vehicle than the corresponding unmatched helicopter.

In summary, then, helicopters which are rotor-limited (i.e., unmatched) exhibit greater reductions in EI than those which are matched in such a way as to allow rotor-limit and NRP speeds to coincide. However, helicopters which cruise at speeds lower than NRP speed have higher DOC's than matched vehicles.

Since minimum-DOC operation is an important criterion for commercial helicopters, the study of CR-144953 emphasized the sizing of matched, minimum-DOC helicopters. The fact remains, however, that any choice between matched and unmatched helicopters must reflect a conscious choice between energy reduction and minimum-DOC operation.

3.0 RESULTS AND DISCUSSION

3.1 Presentation of Results

The type of graphic presentation used in this addendum for illustrating the interactions of Energy Intensity (EI) and Direct Operating Cost (DOC) with cruising speed is a vector representation. This allows a more complete display of the factors involved in EI or DOC reduction than bar charts or tables alone.

Figure 1 is a diagrammatic representation of such a typical EI vector diagram. Note that the vector's origin (point A) always corresponds to the EI value for the current technology (1975), compromise design-point helicopter. Note also that the end point of the vector (points B, C, or D) corresponds to the EI value of a resized helicopter incorporating either changes in technology level or design ground rules. Thus, the resulting vector illustrates both the magnitude and direction of the EI and cruising-speed changes obtained for such modifications in technology level or design ground rules. For example, vector AB illustrates a reduction in EI accompanied by an increase in cruising speed; vector AC illustrates a reduction in EI at a constant cruising speed; and vector AD represents a decrease in cruising speed at a constant EI level. It should be further noted that these EI-cruising speed vectors can be added together vectorially. This is illustrated in Figure 2, where vectors representing various technological modifications are added together to create a resultant vector incorporating all the individual technological changes.

3.2 Results

3.2.1 Effect of technological advances on matched aircraft. – Figure 2 presents in graphic form the effects of the following on Btu/passenger mile and DOC for matched aircraft.

Each vector represents the change (from the baseline value) in EI and cruising speed due to a given technological improvement.

For clarity's sake, the vector for a 4.76-percent reduction in SFC has not been included. It has the same direction as the 14.3-percent SFC reduction vector, but a smaller magnitude.

Vector 1 represents a 14.3-percent reduction in engine SFC due to incorporation of regenerative-engine technology. Reduction in SFC results (because of the iterative nature of the sizing process) in a reduction in vehicle gross weight. Note, however, that this does not result in any change in vehicle cruising/rotor-limit speed.

Vector 2 represents a 54-percent reduction in vehicle parasite drag. Reduced parasite power required enables the helicopter to fly faster for the same amount of installed power. However, rotor solidity must be increased to allow the helicopter to fly faster without encountering the rotor limit. Thus, matching the helicopter NRP cruising and rotor-limit speeds

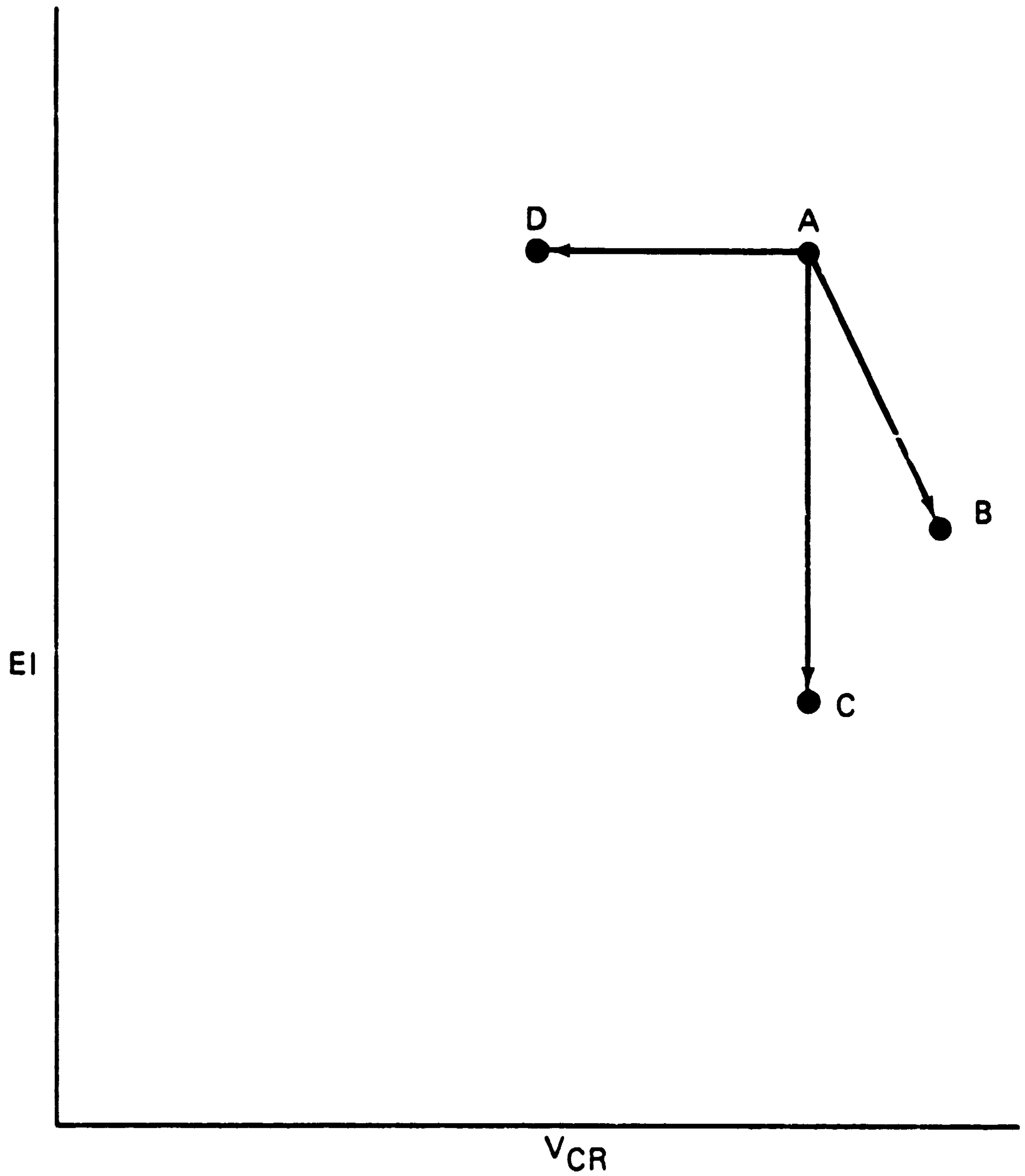


Figure 1. Typical EI vector diagram format

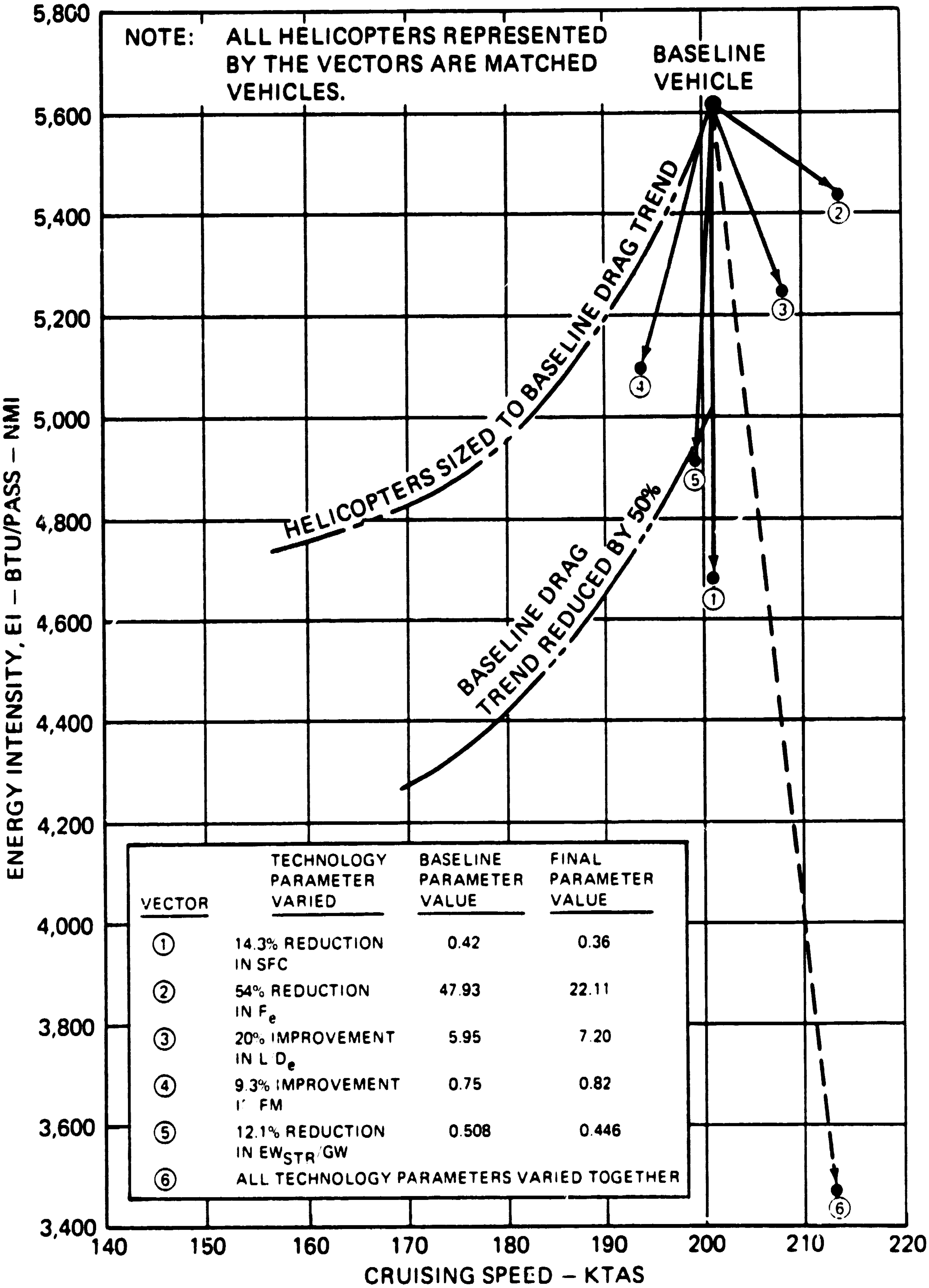


Figure 2. Effect of technological advances on the energy intensity of matched helicopters

results in an increase in cruising speed somewhat at the expense of EI. It is because of this matching that a large reduction in parasite drag (54 percent) does not reduce the EI in the amount that would be expected if no rotor limits were imposed. The EI reductions possible if these rotor limits are relaxed is discussed in Section 3.2.2.

Vector (3) represents a 20-percent increase in rotor L/D_e. As in the case of vector (2), reduced power required enables the helicopter to fly faster and thus dictates a solidity increase to achieve a matched vehicle.

Vector (4) represents a 9.3-percent improvement in figure of merit. The increased FM results in lower hover power requirements and thus lower installed power. This, in turn, results in an NRP cruising speed lower than the rotor-limit speed with the subsequent requirement to reduce the solidity to achieve a matched vehicle. Additionally, the reduced engine size results in lower fuel-consumption rates, and thus lowered EI.

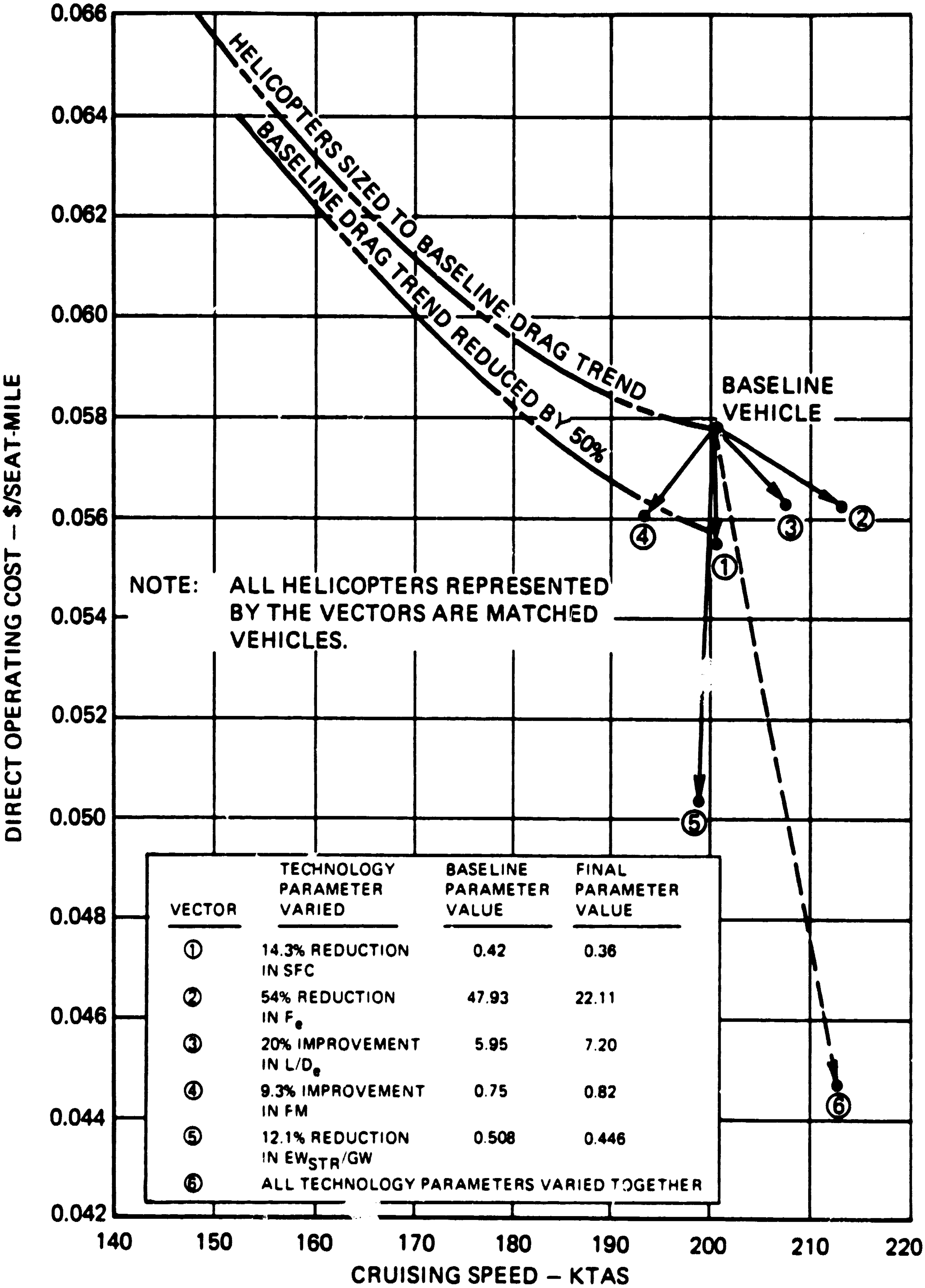
Vector (5) represents a 12.1-percent reduction in structural empty/gross-weight fraction. The considerable reduction in gross weight caused by the reduced empty weight results in a decreased hover power requirement and lower installed power. As in the case of vector (4), this results in lower fuel-consumption rates, and, therefore, a reduced EI.

Vector (6) represents a combination of all technological improvements considered. Note that the solidity requirement for the combination is dictated by the need for a rotor-limit/cruising speed match for vector (2).

Figure 3 presents the effect of the same technological improvements on direct operating cost. Superimposed on the vectors is the locus of points for a series of helicopters sized to operate at cruising speeds less than NRP speed. Note that the baseline vehicle is located at the minimum DOC speed and that operation at lower speeds results in an increase in DOC. Since minimum DOC is obtained when the helicopter is operated at NRP speed and each vector represents a vehicle sized to operate at V_{NRP}, it is logical to assume that each vector in itself represents a minimum-DOC-point vehicle.

Table 2 lists the dimensional, weight, power, drag, speed, energy, and cost characteristics of the vehicles defined by the technological improvement vectors plotted in Figures 2 and 3.

Figure 4 illustrates the helicopter sizing trends overlaid on Figures 2 and 3. The upper trend line is the locus of points of a series of helicopters sized to the baseline helicopter ground rules. All vehicles represented by this line have a main-rotor solidity of 0.100. Only the baseline vehicle uses this solidity fully, flying its mission at its NRP/rotor-limit cruising speed. All the other helicopters on this line fly at less than their NRP cruising speed. The lower trend line is the locus of points of a series of helicopters sized to baseline helicopter ground rules – but with a 50-percent parasite-drag reduction. Up to a cruising speed of 200.8 knots (the baseline vehicle rotor-limit/NRP speed), the rotor solidity is equal to 0.100. In the area between points A and B, progressive increases in rotor-limit speed are achieved by increasing rotor solidity until a match between rotor-limit and NRP cruising speeds is achieved at point B.



VECTOR	TECHNOLOGY PARAMETER VARIED	BASELINE PARAMETER VALUE	FINAL PARAMETER VALUE
①	14.3% REDUCTION IN SFC	0.42	0.36
②	54% REDUCTION IN F_e	47.93	22.11
③	20% IMPROVEMENT IN L/D_e	5.95	7.20
④	9.3% IMPROVEMENT IN FM	0.75	0.82
⑤	12.1% REDUCTION IN EW_{STR}/GW	0.508	0.446
⑥	ALL TECHNOLOGY PARAMETERS VARIED TOGETHER		

Figure 3. Effect of technological advances on the direct operating cost of matched helicopters.

TABLE 2. TECHNOLOGY IMPROVEMENT VECTORS SUMMARY

Technology Configuration	Vehicle Dimensional and Weight Characteristics						Vehicle Power and Drag Characteristics			Vehicle Speed, Energy, and Cost Characteristics			
	Gross Weight (lb)	Empty Weight (lb)	Mission Fuel ① (lb)	Rotor Diameter (ft)	Rotor Gap/Stagger Ratio	Rotor Solidity	Rotor Figure of Merit ②	Total Installed Power (shp)	Parasite-Drag Area (ft^2)	Cruising Speed ③ (ktas)	Energy Intensity (EI) (Btu/pass-n mi)	Percent Change in Energy Intensity, $\Delta EI/EI_{BASE}$	Direct Operating Cost ($/seat-mi)
Baseline	84,133	56,073	6,100	87.5	0.113	0.100	0.750	15,710	47.93	200.8	5,612	0	0.0578
Baseline With 4.76% SFC Reduction	83,237	55,635	5,754	87.0	0.114	0.100	0.750	15,545	47.68	200.8	5,287	5.8	0.0569
Baseline With 14.3% SFC Reduction	81,488	54,780	5,080	86.1	0.115	0.100	0.750	15,223	47.20	200.8	4,680	16.6	0.0555
Baseline With 54% F_e Reduction	84,631	56,877	5,907	87.7	0.113	0.106	0.743	15,957	22.11	213.2	5,438	3.1	0.05625
Baseline With 20% L/D_e Improvement	83,354	55,864	5,703	87.0	0.114	0.101	0.748	15,581	47.69	208	5,247	− 6.5	0.0563
Baseline With 9.3% FM Improvement	80,651	53,326	5,503	85.6	0.116	0.0975	0.822	13,747	46.96	193.4	5,096	9.2	0.0561
Baseline With 12.1% EW_{STR}/GW Reduction	72,971	45,910	5,335	81.5	0.122	0.100	0.750	13,657	44.75	198.9	4,911	12.5	0.0564
Advanced-Technology Helicopter - 4.76% SFC Reduction (All technology improvements combined)	70,058	44,398	4,260	79.8	0.124	0.106	0.812	12,139	20.18	213.2	3,909	30.35	0.0457
Advanced-Technology Helicopter 14.3% SFC Reduction (All technology improvements combined)	68,924	43,910	3,775	79.2	0.125	0.106	0.812	11,947	20.03	213.0	3,473	38.1	0.0447

NOTES ① Actual fuel consumed during mission, does not include reserves.

② Rotor figure of merit at SL, 90°F conditions

③ Cruising speed NRP cruising speed rotor-limit speed

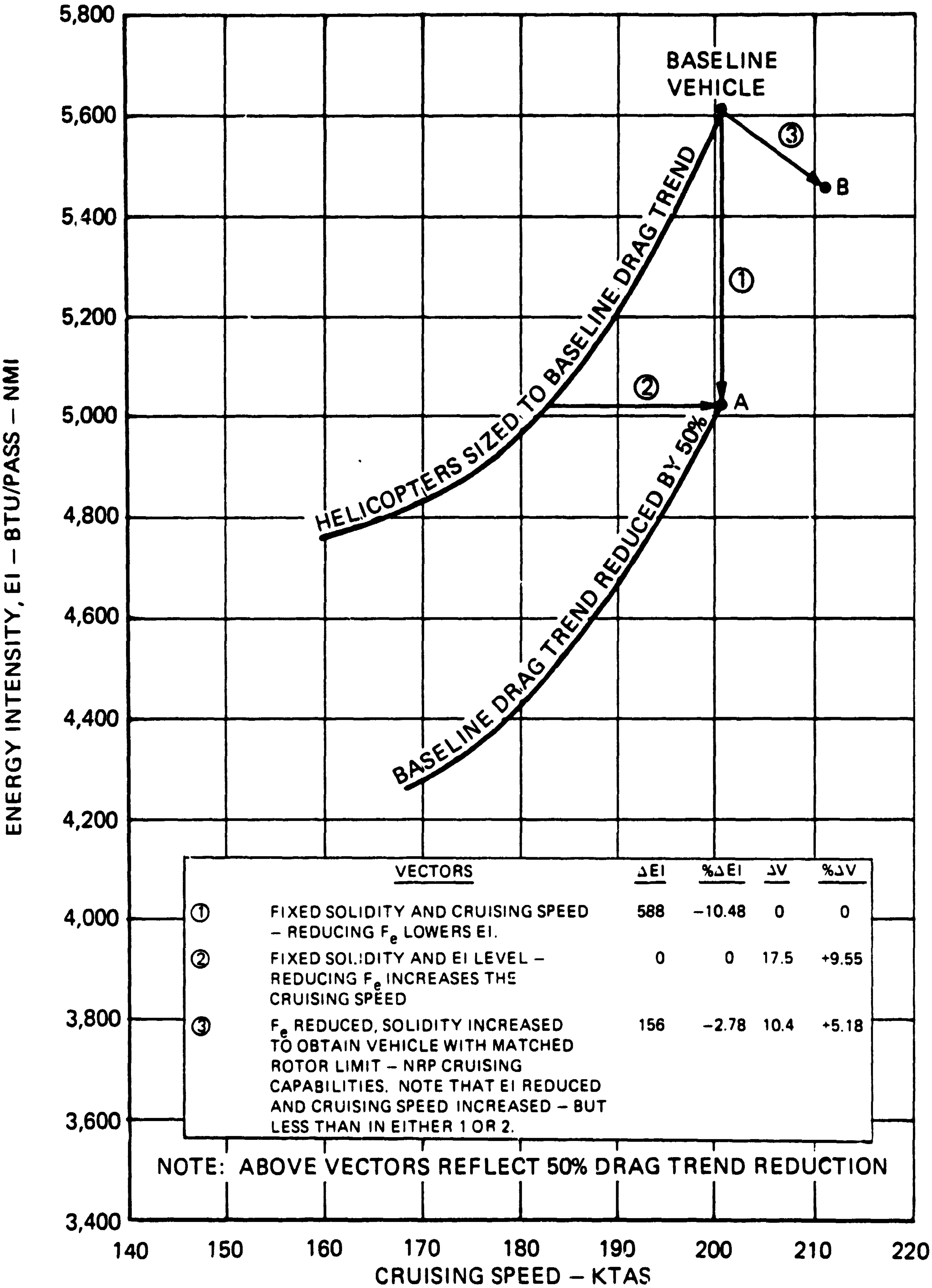


Figure 4. Effect of parasite-drag reduction and vehicle matching on energy intensity and cruising speed

Vectors ①, ②, and ③ depict three possible paths for employing parasite-drag reduction in the sizing of a helicopter.

Vector ① represents the result of applying a 50-percent parasite-drag reduction entirely to EI reduction. It is obtained simply by resizing the baseline helicopter with a 50-percent reduction in parasite drag and for operation at a fixed cruising speed of 200.8 knots.

Vector ② represents the result of applying a 50-percent parasite-drag reduction entirely to an increase in cruising speed. It is obtained by resizing a helicopter from the baseline drag trend line at a fixed level of EI and with a 50-percent reduction in parasite drag. Note that the resulting increased cruising speed corresponds to the baseline rotor-limit cruising speed of 200.8 knots.

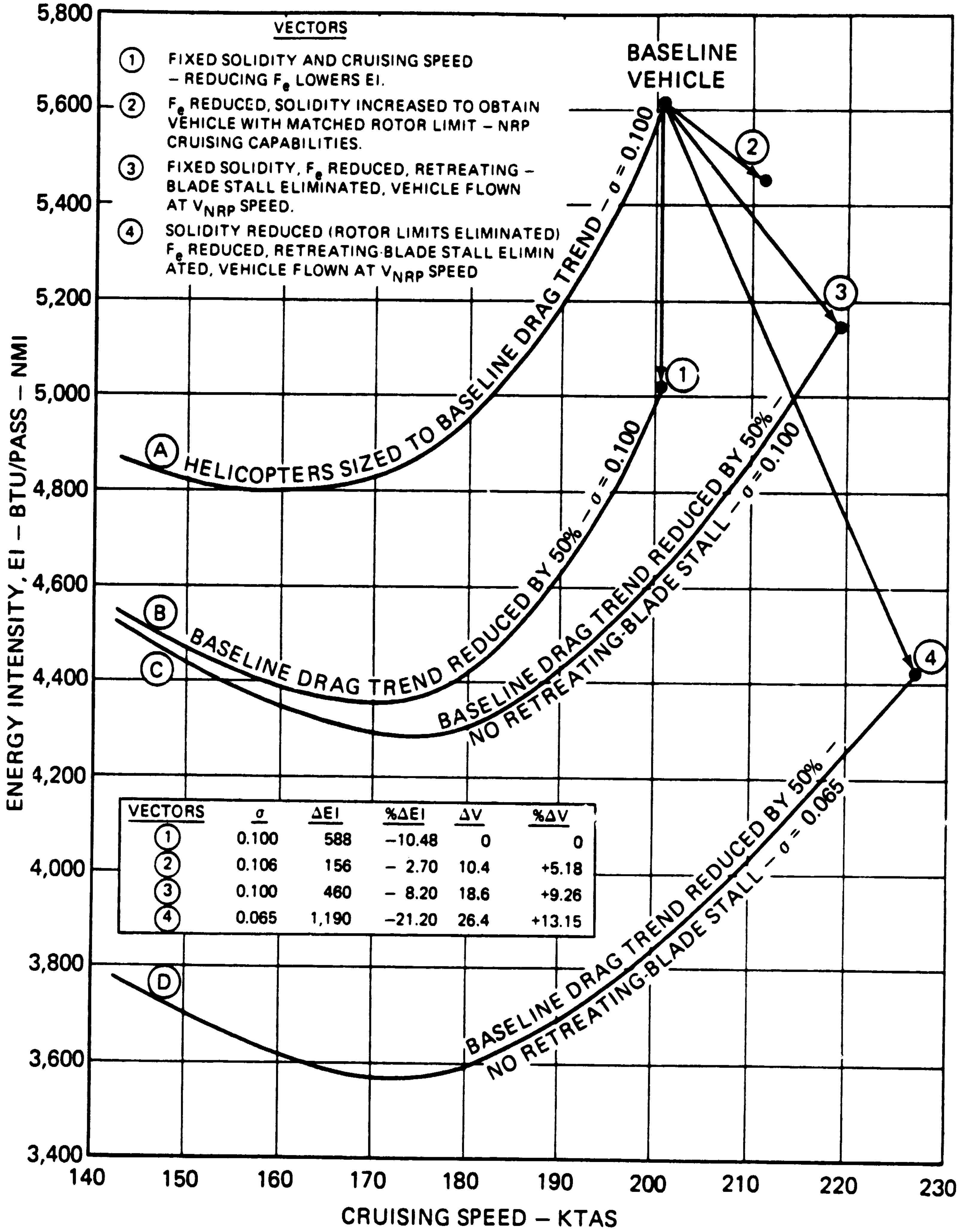
Vector ③ illustrates the result of reducing parasite drag by 50-percent and then increasing rotor solidity to allow full utilization of the potential cruising-speed increase (i.e., matching the rotor-limit and NRP cruising speeds). This is the sizing path followed in NASA CR-144953. Note that the resulting vector exhibits smaller changes in both EI and cruising speed than vectors ① or ②, respectively.

3.2.2 Effect of change in ground rules on energy intensity. – Figure 5 illustrates the effect on vehicle EI and cruising speeds of relaxing the basic rotor-limit and cruising-speed sizing ground rules of CR-144953. Lines Ⓐ and Ⓑ are the upper and lower trend lines referred to in Figure 4. Line Ⓒ is the locus of points of helicopters sized to the baseline helicopter ground rules – but with a 50-percent parasite-drag reduction, no rotor-limit speed restrictions, and with retreating-blade stall eliminated. Note that as the cruising speed decreases, lines Ⓑ and Ⓒ begin to converge, illustrating a corresponding reduction in retreating-blade stall effects. Line Ⓓ reflects, in addition to the assumptions of line Ⓒ, a reduction in rotor solidity from 0.100 to 0.065. This reduced solidity results in maximum FM being achieved at the vehicle hover/takeoff conditions. The fact that this lower rotor solidity can be tolerated at the vehicle cruising speeds is a reflection of the removal of rotor-limit constraints.

It can be seen that line Ⓓ represents the best EI reduction that might be achieved for the configuration and mission design ground rules. It should be emphasized, however, that this reduction depends on the following hypothesized assumptions:

1. Complete elimination of retreating-blade stall.
2. Either complete elimination of the rotor limits or the expansion of the limit boundaries sufficiently to allow the selection of rotor solidity based on maximizing hover performance only.

Vectors ① and ② refer to the two options available if parasite drag is reduced as presented in Figure 4. Vector ③ represents the application of a 50-percent F_e reduction and the elimination of retreating-blade stall and rotor limits to a baseline helicopter sized to cruise at NRP.



VECTORS	σ	ΔEI	%ΔEI	ΔV	%ΔV
1	0.100	588	−10.48	0	0
2	0.106	156	− 2.70	10.4	+5.18
3	0.100	460	− 8.20	18.6	+9.26
4	0.065	1,190	−21.20	26.4	+13.15

Figure 5. Effect of parasite-drag reduction, elimination of retreating-blade stall, and elimination of rotor limits on energy intensity and cruising speed

Vector 4 represents the vector 3 vehicle with rotor solidity reduced to maximize hover/takeoff performance.

Table 3 lists the dimensional, weight, power, drag, speed, and energy characteristics of the vehicles defined by the retreating-blade stall/rotor-limit vectors plotted in Figure 5.

Figure 6 is a vector representation of the effect on helicopter EI of hover-sizing and cruising-speed ground-rule change.

Vector 1 illustrates the effect of resizing the baseline helicopter to a two-engine configuration without any attempt to meet the hover OEI requirement. The resulting helicopter exhibits substantial reductions in EI and DOC relative to the baseline. This is due to both the smaller size of the engines and their operation at more optimum partial-power settings (with resultant fuel savings), and additionally to the iterative nature of the sizing process. Note also that this vehicle is a minimum-DOC vehicle since its cruising speed is at NRP.

The substantial reduction in EI and DOC realized by this vector underscores the importance of further investigation into means for meeting the HOEI requirement with a two-engined configuration without recourse to engine oversizing.

Vector 2 is the result of resizing the baseline helicopter to fly the design mission at 99 percent of best-range speed. Note that although the EI saving is over 13 percent, the DOC shows a marked increase. This is a result of resizing the helicopter at a cruising speed lower than V_{NRP}. This trend of increasing DOC with decreasing cruising speed is well illustrated by the trend lines shown in Figure 3.

Vector 3 is included for reference purposes and shows the effect of reducing parasite drag by 50 percent and resizing the resulting helicopter to operate at the baseline rotor-limit speed of 200.8 knots.

Figure 7 presents the effects of ground-rule changes on direct operating cost.

Table 4 lists the dimensional, weight, power, drag, speed, energy, and cost characteristics of the vehicles defined by the ground-rule change vectors plotted in Figures 6 and 7.

TABLE 3. RETREATING-BLADE STALL/ROTOR-LIMIT VECTORS SUMMARY

Vectors	Vehicle Dimensional and Weight Characteristics						Vehicle Power and Drag Characteristics				Vehicle Speed and Energy Characteristics		
	Gross Weight (lb)	Empty Weight (lb)	Mission Fuel (1) (lb)	Rotor Diameter (ft)	Rotor Gap/Stagger Ratio	Rotor Solidity	Rotor Operational Hover C_T/σ (2)	Rotor Figure of Merit (3)	Total Installed Power (shp)	Parasite-Drag Area (ft^2)	Cruising Spped (ktas)	Energy Intensity (EI) (Btu/pass-n mi)	Percent Change in Energy Intensity, $\Delta EI/EI_{BASE}$
Baseline	84,133	56,073	6,100	87.5	0.113	0.100	0.070	0.75	15,710	47.93	200.8 (4)	5,612	0
1. Baseline With 50% F_e Reduction	82,576	55,312	5,461	86.7	0.114	0.100	0.070	0.75	15,423	23.75	200.8 (5)	5,024	10.48
2. Baseline With 50% F_e Reduction and Matched Rotor-Limit Cruising Capabilities	84,702	56,912	5,930	87.8	0.113	0.106	0.066	0.743	15,970	24.04	211.2 (6)	5,456	2.7
3. Baseline With 50% (9) F_e Reduction, No Rotor Limits, No Retreating-Blade Stall	82,908	55,513	5,600	86.8	0.114	0.100	0.070	0.75	15,495	23.79	219.4 (7)	5,152	-8.2
4. Baseline With 50% (9) F_e Reduction, No Rotor Limits, No Retreating-Blade Stall	76,880	50,595	4,806	83.6	0.119	0.065	0.1076	0.787	13,719	22.95	227.2 (8)	4,422	-21.2

NOTES:

(1) Actual fuel consumed during mission, does not include reserves.

(2) Hover C_T based on W/A = 7.0 psf, V_T = 705 fps, T/W = 1.1135, SL 90°F conditions.

(3) Rotor figure of merit at SL, 90°F conditions.

(4) Cruising speed = NRP cruising speed = rotor-limit speed.

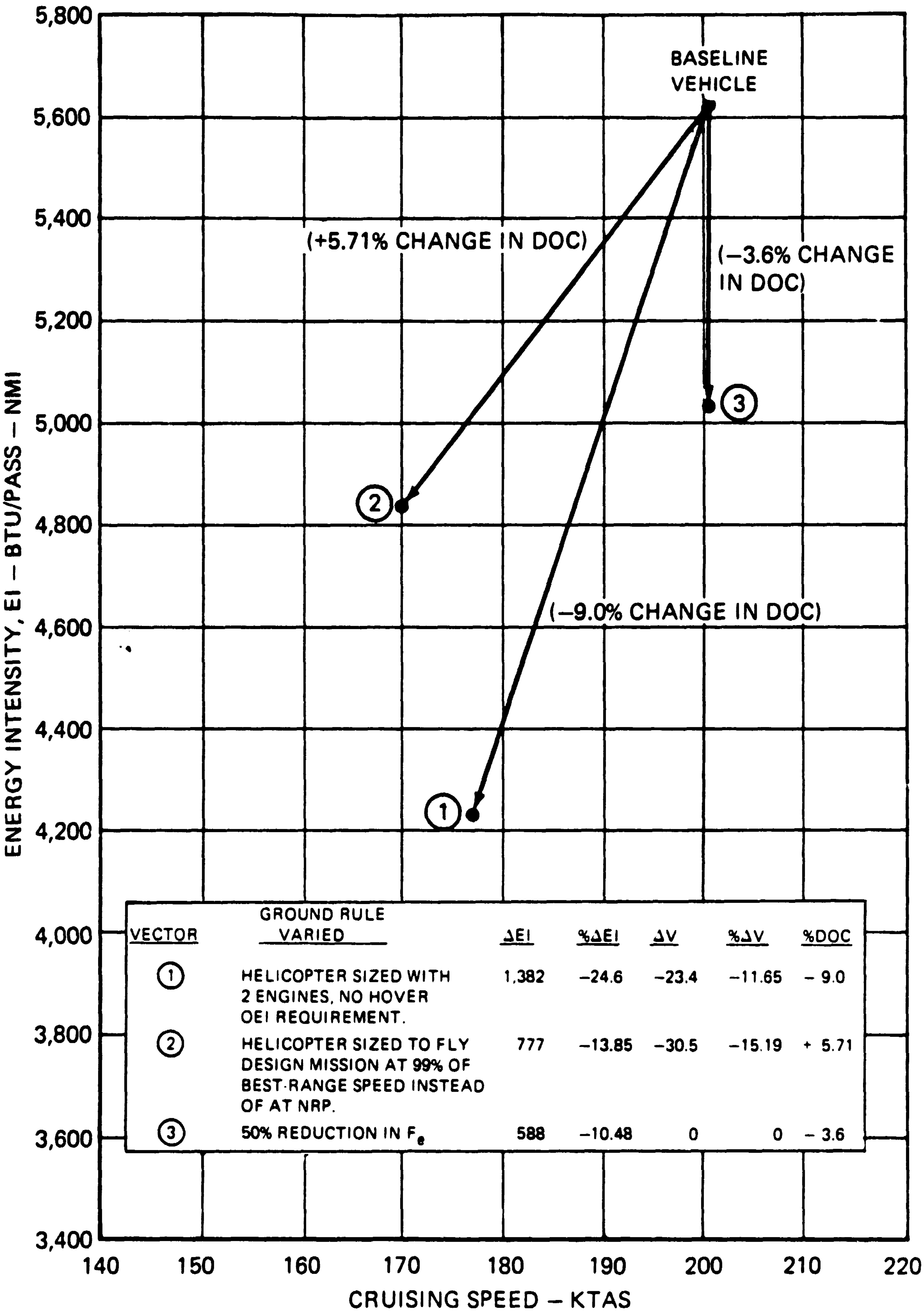
(5) Cruising speed = rotor-limit speed.

(6) Cruising speed = NRP cruising speed = rotor-limit speed.

(7) Cruising speed = NRP cruising speed.

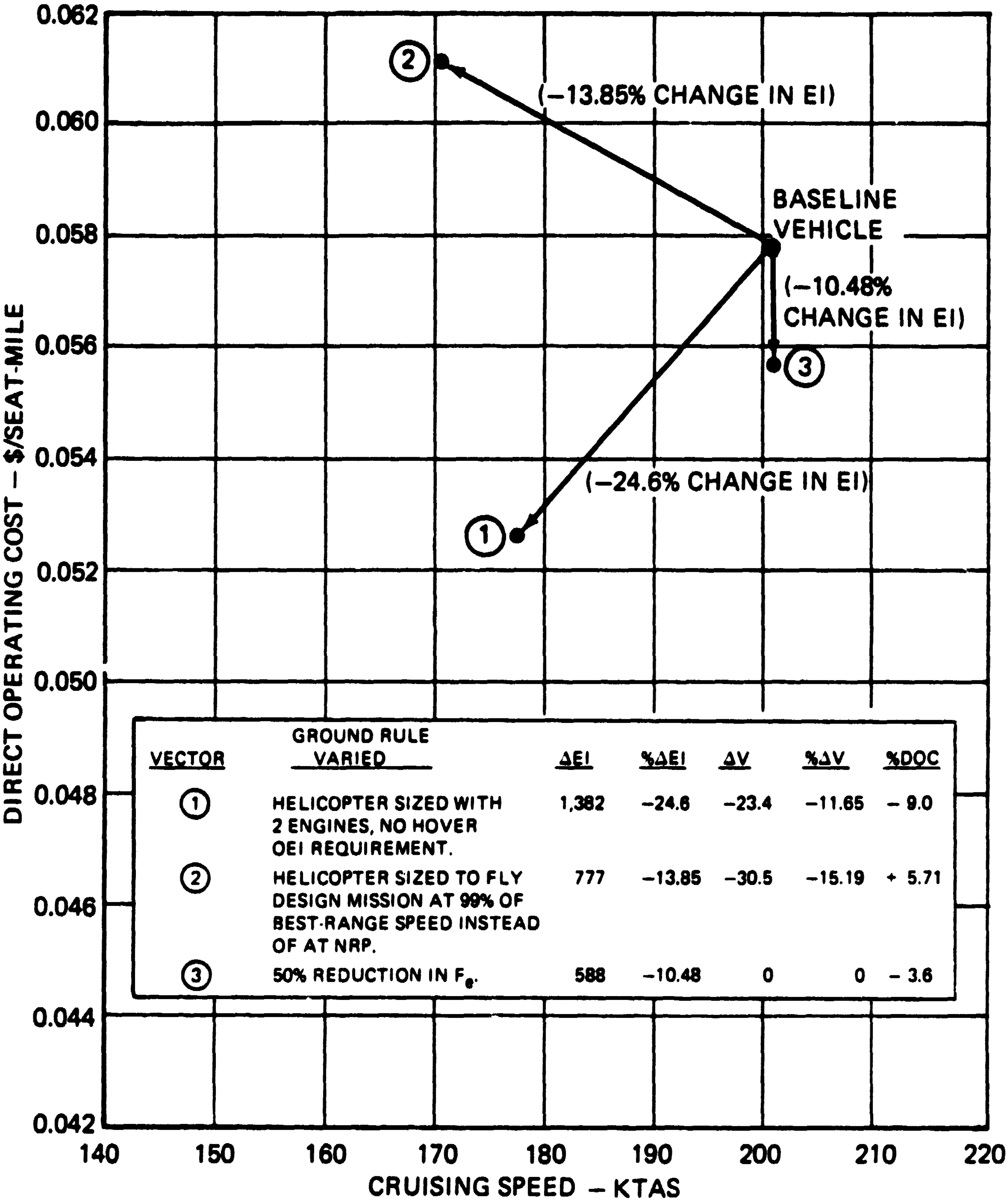
(8) Cruising speed = NRP cruising speed.

(9) It cannot be emphasized too strongly that vectors 3 and 4 are the result of the assumption that retreating-blade stall and rotor limits can somehow be eliminated. Vector 4 utilizes this latter assumption fully by reducing rotor solidity (to optimize hover efficiency) to a value well below that dictated by an NRP-rotor-limit cruising-speed match.



VECTOR	GROUND RULE VARIED	ΔEI	%ΔEI	ΔV	%ΔV	%DOC
1	HELICOPTER SIZED WITH 2 ENGINES, NO HOVER OEI REQUIREMENT.	1,382	−24.6	−23.4	−11.65	− 9.0
2	HELICOPTER SIZED TO FLY DESIGN MISSION AT 99% OF BEST-RANGE SPEED INSTEAD OF AT NRP.	777	−13.85	−30.5	−15.19	+ 5.71
3	50% REDUCTION IN F_e	588	−10.48	0	0	− 3.6

Figure 6. Effect of ground-rule changes on helicopter energy intensity



VECTOR	GROUND RULE VARIED	ΔEI	%ΔEI	ΔV	%ΔV	%DOC
1	HELICOPTER SIZED WITH 2 ENGINES, NO HOVER OEI REQUIREMENT.	1,382	−24.6	−23.4	−11.65	− 9.0
2	HELICOPTER SIZED TO FLY DESIGN MISSION AT 99% OF BEST-RANGE SPEED INSTEAD OF AT NRP.	777	−13.85	−30.5	−15.19	+ 5.71
3	50% REDUCTION IN F_e.	588	−10.48	0	0	− 3.6

Figure 7. Effect of ground-rule changes on helicopter direct operating cost

TABLE 4. GROUND-RULE CHANGE VECTORS SUMMARY

Ground Rules	Vehicle Dimensional and Weight Characteristics						Vehicle Power and Drag Characteristics			Vehicle Speed, Energy, and Cost Characteristics			
	Gross Weight (lb)	Empty Weight (lb)	Mission Fuel (1) (lb)	Rotor Diameter (ft)	Rotor Gap/Stagger Ratio	Rotor Solidity	Rotor Figure of Merit (2)	Total Installed Power (shp)	Parasite-Drag Area (ft^2)	Cruising Speed (ktas)	Energy Intensity (EI) (Btu/pass-n mi)	Percent Change in Energy Intensity, $\Delta EI/EI_{BASE}$	Direct Operating Cost ($/seat-mi)
Baseline	84,133	56,073	6,100	87.5	0.113	0.100	0.750	15,710	47.93	200.8 (3)	5,612	0	0.0578
Baseline – 2 Engines – No Hover OEI Rqmt	75,513	49,306	4,598	82.9	0.120	0.100	0.750	10,535	45.50	177.4 (4)	4,230	–24.6	0.0526
Baseline – Mission Flown at 99% V_{BR} Instead of V_{NRP}	82,428	55,240	5,255	86.6	0.115	0.100	0.750	15,396	47.46	170.3 (5)	4,835	–13.85	0.0611
Baseline 50% F_e Reduction	82,576	55,312	5,461	86.7	0.114	0.100	0.750	15,423	23.75	200.8 (6)	5,024	–10.48	0.0557

NOTES:
(1) Actual fuel consumed during mission; does not include reserves.
(2) Rotor figure of merit at SL, 90°F conditions.
(3) Cruising speed = NRP cruising speed = rotor-limit speed.
(4) Cruising speed = NRP cruising speed.
(5) Cruising speed = 99% best-range speed.
(6) Cruising speed = rotor-limit speed.

4.0 CONCLUDING REMARKS

The conclusions arrived at in this addendum can be summarized as follows:

1. Unmatched helicopters exhibit greater reductions in energy intensity than matched configurations. However, matched helicopters are always minimum-direct-operating-cost vehicles. Therefore, the choice between matched and unmatched helicopters must reflect a conscious decision between the goals of maximum-energy-intensity reduction and minimum-direct-operating-cost operation.

2. The manner in which a parasite-drag reduction is applied in the resizing of a helicopter is important in determining the level of EI reduction obtained. Thus, the relatively small EI reduction noted for the matched vehicle of CR-144953, which was resized with a 54-percent reduction in parasite drag, was due to that aircraft's utilization of its reduced parasite power in increasing design cruising speed rather than operating at a fixed cruising speed and reduced fuel (energy) consumption.

3. Substantial reductions in EI could be obtained if a satisfactory way could be found to increase rotor efficiency by simultaneously performing the contradictory tasks of reducing retreating-blade stall and reducing solidity requirements (through the expansion of rotor forward-flight operating limits).

4. Substantial reductions in both EI and DOC could be realized if a means could be found for meeting the HOEI requirement with a two-engine configuration without recourse to engine oversizing.