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Space Administration

REVOLUTIONARY OPPORTUNITIES FOR MATERIALS AND STRUCTURES STUDY

ADDENDUM

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ADDENDUM

ROMS (Revolutionary Opportunities for Materials and Structures Study)

3.0 INTRODUCTION

This addendum to the Revolutionary Opportunities for Materials and Structures (ROMS) Report, documents additions to the original Statement of Work (SOW) reported in Reference 1 (CR 179642) by modification No. 2, which added Tasks IIIA and IIIB. The primary purpose of these additional tasks was to conduct additional aircraft/engine sizing and mission analysis to obtain contributory aircraft performance data such as fuel burns and direct operating costs (DOC) for both the subsonic and supersonic engines.

3.1 DESCRIPTION OF ADDITIONAL TASKS

Tasks IIIA and IIIB increased the scope of the original Task III as is set forth in the following:

Task IIIA - Propulsion Evaluation, 1700-nmi subsonic mission:

- The purpose of this task was to determine the delta fuel burn and DOC based on the aircraft design range of 1700 nmi for the baseline and the advanced ROMS subsonic engine.

Task IIIB - Propulsion Evaluation, improved AST airplane:

- Establish a computer model baseline Mach 2.7, 5000 nmi, 290 PAX aircraft utilized in Task III and correlate this model with the NASA Langley model for the same aircraft
- Establish a 1984 technology baseline aircraft/engine model
- Install the ROMS 2010 engine to determine the engine influence on the baseline aircraft characteristics, fuel burn, and DOC
- Determine the effect on fuel burned and DOC of flying at the optimum cruise altitude as opposed to the fixed, initial altitude flown in Reference 1
- Modify the 1984 baseline aircraft structure and furnishing weights as directed by the NASA Project Manager to determine the influence of the aircraft technology on fuel burn and DOC
- Install the ROMS 2010 engine in the AST with improved structures and determine the net improvement in fuel burn and DOC
- Modify the 2010 technology model to incorporate laminar flow as directed by NASA PM and determine the impact on aircraft size, fuel burn, and DOC

- Modify the 2010 technology model for a two-engine configuration holding the same takeoff and landing characteristics as that of the four-engine configuration and, with the approval of the configuration by the NASA PM, calculate fuel burn and DOC for comparison with the four-engine configuration

- Compare the AST DOC results with those of a subsonic aircraft.

4.0 DISCUSSION OF EVALUATIONS

4.1 TASK IIIA - PROPULSION EVALUATION, 1700-nmi SUBSONIC MISSION

In Task III the screening and assessment of the subsonic propulsion technology and material ranking versus the fuel burn and DOC objectives were accomplished by using sensitivities calculated for the baseline configuration at 500 nmi. The purpose of Task IIIA was to calculate the similar sensitivities (sfc, engine weight, and nacelle drag) to those calculated in Task III, but for the 1700-nmi design range, and to develop delta fuel burn and DOC values to demonstrate the potential payoffs for the ROMS engine for the longer range design mission.

4.1.1 Sensitivities

The subsonic rubber fuel burn and DOC sensitivities for Task IIIA were calculated utilizing the same aircraft/engine model, mission profile (speed schedules, cruise altitude, and reserves), and computational technique as used in Task III. The aircraft utilization was reduced from 2200 to 970 trips per year due to the increase from a 500- to 1700-nmi mission. However, in terms of flight hours per year, the utilization increased from 3433 to 4055 hours.

The sensitivities of fuel burn and DOC to engine sfc, weight, and nacelle drag as a result of the longer range are shown in Tables 65 through 69 and in Figures 46 through 50. The DOC sensitivities are shown in carpet plot form to illustrate the impact of fuel price versus interest rates. Table 70 presents a summary of fuel burn and DOC sensitivity factors for the 1700-nmi mission. The DOC factors are based on zero percent interest and fuel cost of $1.00 and $2.00 per U.S. gallon. The sensitivities of engine sfc and weight and nacelle drag to fuel burn and DOC for the 1700-nmi design range are shown in Tables 65 through 69 and Figures 46 through 50. DOC sensitivities are shown in carpet plot form to illustrate the impact of fuel price versus interest rates. Table 70 summarizes these sensitivities for zero percent interest.

4.1.2 Payoffs

The ROMS 2010 engine potential payoffs, as measured by fuel burn and DOC improvements from the baseline 1984 engine, are shown in Table 71. Improvements for the 1700-nmi design range are compared with the payoffs for the 500-nmi mission reported in Reference 1. The fuel burn improvement for both the 500- and 1700-nmi missions was calculated at 13.4%. The identical results are

Table 65. NASA ROMS Study Task IIIA 1984 UDF™ Baseline Rubber Fuel Burn Derivatives (Percentage) for 1700-nmi Range (Climb SFC Improvements).

A/C AND ENGINE BASELINE SCALED DOWN FROM INITIAL INPUT BARE ENGINE WT OF 4100 LBS, SLS THRUST=22980 LBS USING DESIGN RANGE OF 1700 NM, WING LOADING = 105.33 LB/FT**2 AND A T/W TO OBTAIN R/C OF APPROX 300 FPM AT 39K' ALT.

ITEM	BASELINE FUEL BURN (LBS)	-5% SFC	-10% SFC	-15% SFC	-20% SFC
CLIMB	2704	-.44%	-.92%	-1.48%	-2.00
CRUISE	9479	-5.36%	-10.69%	-15.94%	-21.16
DESCENT	294	-.34%	-.68%	-1.36%	-1.70%
BLOCK FUEL	13271	-3.97%	-7.91%	-11.82	-15.70%
BLOCK FUEL (500 NM)	4808	-1.73%	-3.43%	-5.12%	-6.76%
ENGINE SCALE FACTOR	.881	0.876	0.872	0.868	0.8635
T/W	.311608	0.312	0.3124	.3129	0.3135
BARE ENGINE WEIGHT (LBS)	3552.6	3531.7	3510.9	3492.3	3473.5

NOTE: WS=105. 3 LB/SQ.FT. WAS HELD CONSTANT DURING RUBBERIZATION PROCESS. T/W WAS VARIED TO OBTAIN R/C OF APPROX 300 FPM @ 39K' ALT FOR DESIGN RANGE OF 1700 NM FOR EACH CASE.

Table 66. NASA ROMS Task IIIA 1984 UDF™ Baseline Rubber Fuel Burn Derivatives (Percentage) for 1700-nmi Range (Cruise SFC Improvements).

A/C AND ENGINE BASELINE SCALED DOWN FROM INITIAL INPUT BARE ENGINE WT OF 4100 LBS, SLS THRUST=22980 LBS USING DESIGN RANGE OF 1700 NM, WING LOADING = 105.33 LB/FT**2 AND A T/W TO OBTAIN R/C OF APPROX 300 FPM AT 39K' ALT.

ITEM	BASELINE FUEL BURN (LBS)	-5% SFC	-10% SFC	-15% SFC	-20% SFC
CLIMB	2704	-5.21%	-10.42%	-15.61%	-20.75%
CRUISE	9479	-.01%	0%	0%	-.01%
DESCENT	294	0%	0%	0%	0%
BLOCK FUEL	13271	-1.07%	-2.13%	-3.34%	-4.24%
BLOCK FUEL (500 NM)	4808	-2.52%	-5.03%	-7.53%	-10.02%
ENGINE SCALE FACTOR	.881	.881	.881	.881	.881
T/W	.311608	.31213	.3124	.312938	0.31345
BARE ENGINE WEIGHT (LBS)	3552.6	3551.8	3551.7	3551.5	3551

NOTE: WS=105.33 LB/SQ.FT. WAS HELD CONSTANT DURING RUBBERIZATION PROCESS. T/W WAS VARIED TO OBTAIN R/C OF APPROX 300 FPM @ 39K' ALT FOR DESIGN RANGE OF 1700 NM FOR EACH CASE.

Table 67. NASA ROMS Task IIIA Study, 1984 Baseline at 1700 nmi, Rubber Fuel Burn Derivatives (Percentage) for 1700-nmi Range (Overall SFC Improvements).

A/C AND ENGINE BASELINE SCALED DOWN FROM INITIAL INPUT BARE ENGINE WT OF 4100 LBS, SLS THRUST=22980 LBS USING DESIGN RANGE OF 1700 NM, WING LOADING = 105.33 LB/FT**2 AND A T/W TO OBTAIN R/C OF APPROX 300 FPM AT 39K' ALT.

ITEM	BASELINE FUEL BURN (LBS)	-5% SFC	-10% SFC	-15% SFC	-20% SFC
CLIMB	2704	-5.81%	-11.54%	-17.16%	-22.67%
CRUISE	9479	-5.39%	-10.73%	-16.05%	-21.29%
DESCENT	294	-5.44%	-10.88%	-16.33%	-21.77%
BLOCK FUEL	13271	-5.49%	-10.92%	-16.31%	-21.62%
BLOCK FUEL (500 NM)	4808	-5.43%	-10.82%	-16.18%	-21.44%
ENGINE SCALE FACTOR	.881	.876	0.871	.866	0.862
T/W	.311608	.31275	0.31394	0.3151	0.3163
BARE ENGINE WEIGHT (LBS)	3552.6	3530.3	3508.7	3486.2	3465.8

Table 68. NASA ROMS Task IIIA Study, 1984 Baseline at 1700 nmi, Rubber Fuel Burn Derivatives (Percentage) for 1700-nmi Range (Engine Weight Variation).

A/C AND ENGINE BASELINE SCALED DOWN FROM INITIAL INPUT BARE ENGINE WT OF 4100 LBS, SLS THRUST=22980 LBS USING DESIGN RANGE OF 1700 NM, WING LOADING = 105.33 LB/FT**2 AND A T/W TO OBTAIN R/C OF APPROX 300 FPM AT 39K' ALT.

ITEM	BASELINE FUEL BURN (LBS)	+10% ENG WT	-10% ENG WT	-15% ENG WT	-20% ENG WT
CLIMB	2704	+1.07%	-.85%	-1.29%	-1.74%
CRUISE	9479	+.66%	-.69%	-1.01%	-1.33%
DESCENT	294	+1.36%	-1.02%	-1.70%	-2.04%
BLOCK FUEL	13271	+.76%	-.75%	-1.10	-1.45%
BLOCK FUEL (500 NM) ♦	4808	+.79%	-.77%	-1.14%	-1.50%
ENGINE SCALE FACTOR	.881	0.887	0.874	0.871	0.868
T/W	.311608	0.3105	0.3125	0.313	0.3134
BARE ENGINE WEIGHT (LBS)	3552.6	3940.7	3169.2	2980.4	2793.5

NOTE: WS=105. 3 LB/SQ. FT. WAS HELD CONSTANT DURING RUBBERIZATION PROCESS TW WAS VARIED TO OBTAIN R/C OF APPROX 300 FPM @ 39K' ALT FOR DESIGN RANGE OF 1700 NM FOR EACH CASE.

Table 69. NASA ROMS Task IIIA Study, 1984 Baseline at 1700 nmi, Rubber Fuel Burn Derivatives (Percentage) for 1700-nmi Range (Nacelle Drag Variation).

A/C AND ENGINE BASELINE SCALED DOWN FROM INITIAL INPUT BARE ENGINE WT OF 4100 LBS, SLS THRUST=22980 LBS USING DESIGN RANGE OF 1700 NM, WING LOADING = 105.33 LB/FT**2 AND A T/W TO OBTAIN R/C OF APPROX 300 FPM AT 39K' ALT.

ITEM	BASELINE FUEL BURN (LBS)	+10% DRAG	-10% DRAG	-15% DRAG	-20% DRAG
CLIMB	2704	+.30%	-.15%	-.26%	-.37%
CRUISE	9479	+.33%	-.37%	-.55%	-.73%
DESCENT	294	0%	0%	0%	0%
BLOCK FUEL	13271	+.31%	-.32%	-.48%	-.64%
BLOCK FUEL (500 NM)	4808	+.29%	-.31%	-.46%	-.60%
ENGINE SCALE FACTOR	.881	.883	0.878	0.877	0.876
T/W	.311608	.3121	0.3109	0.3106	0.3103
BARE ENGINE WEIGHT (LBS)	3552.6	3563	3539.8	3534.2	3528.3

NOTE: WS=105. 3 LB/SQ. FT. WAS HELD CONSTANT DURING RUBBERIZATION PROCESS TW WAS VARIED TO OBTAIN R/C OF APPROX 300 FPM @ 39K' ALT FOR DESIGN RANGE OF 1700 NM FOR EACH CASE.

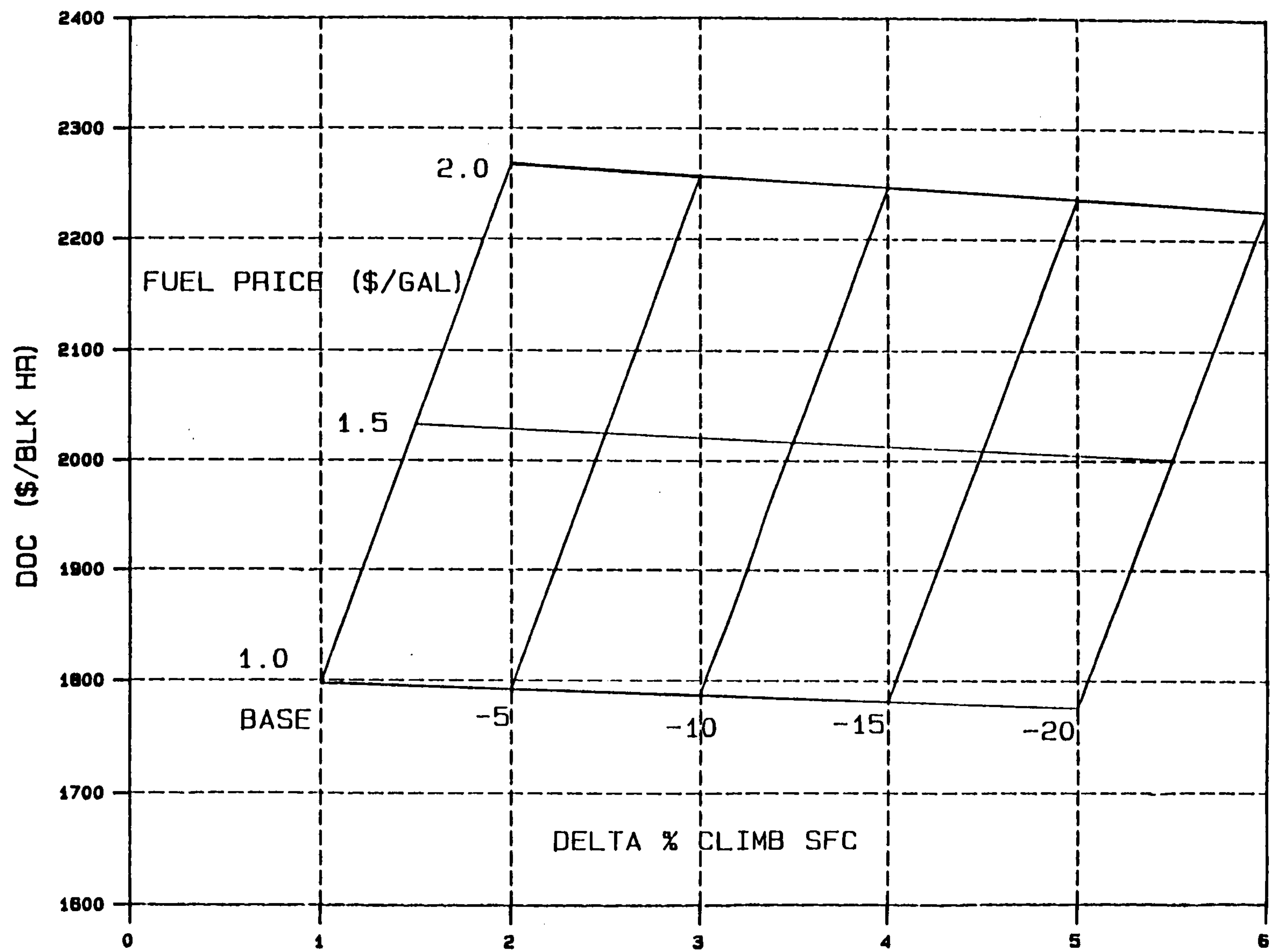


Figure 46. DOC Sensitivity to Climb SFC.

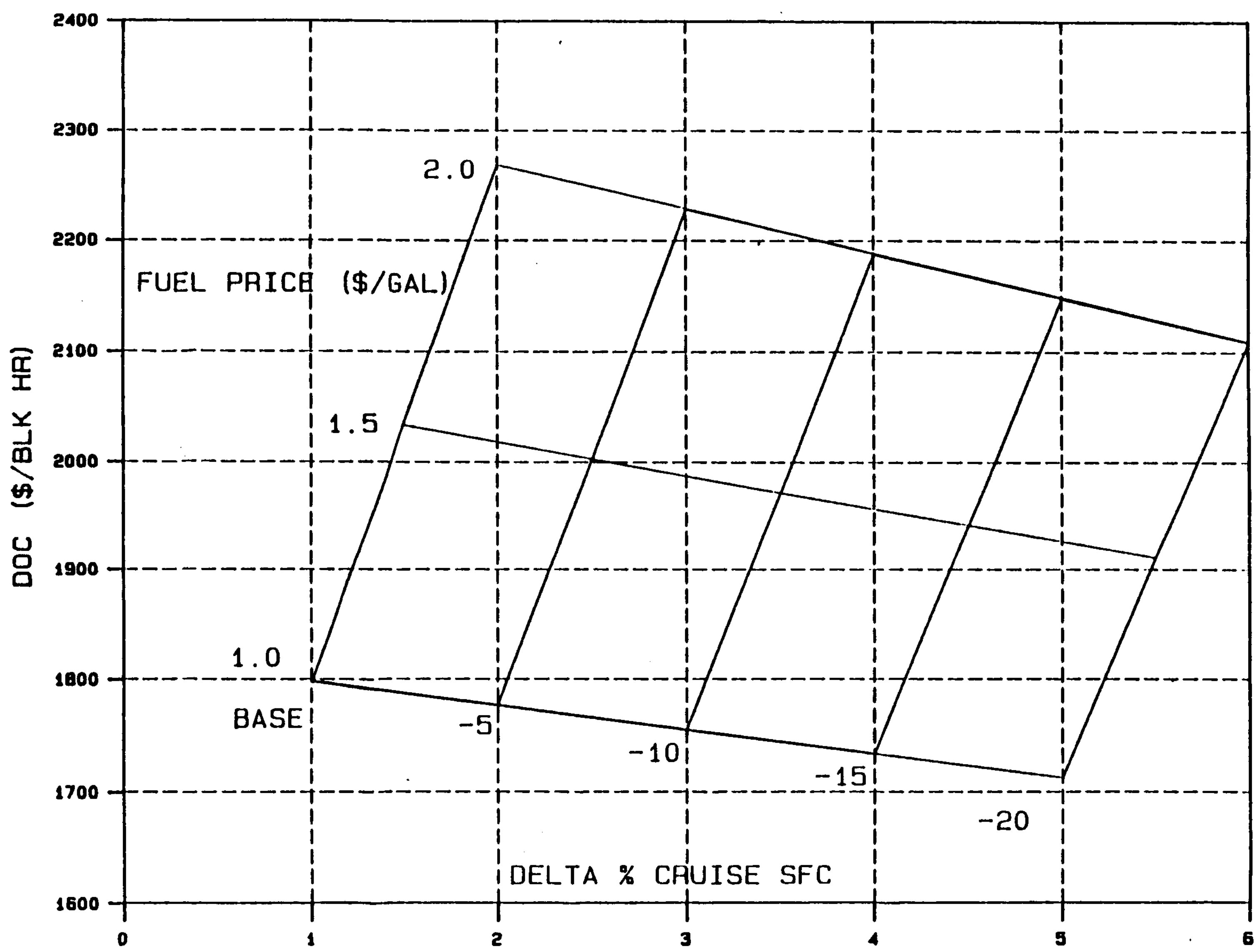


Figure 47. DOC Sensitivity to Cruise SFC.

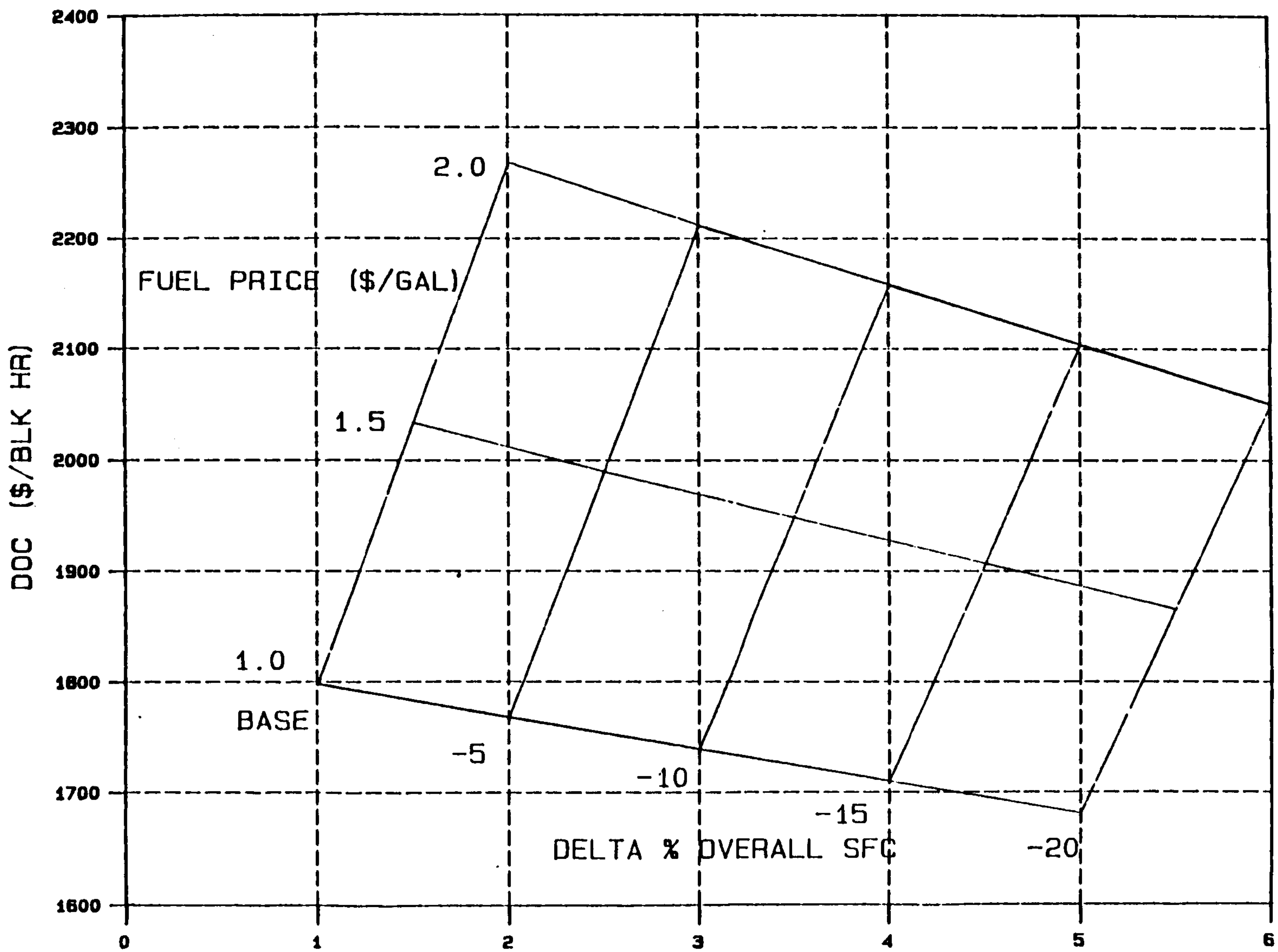


Figure 48. DOC Sensitivity to Overall SFC.

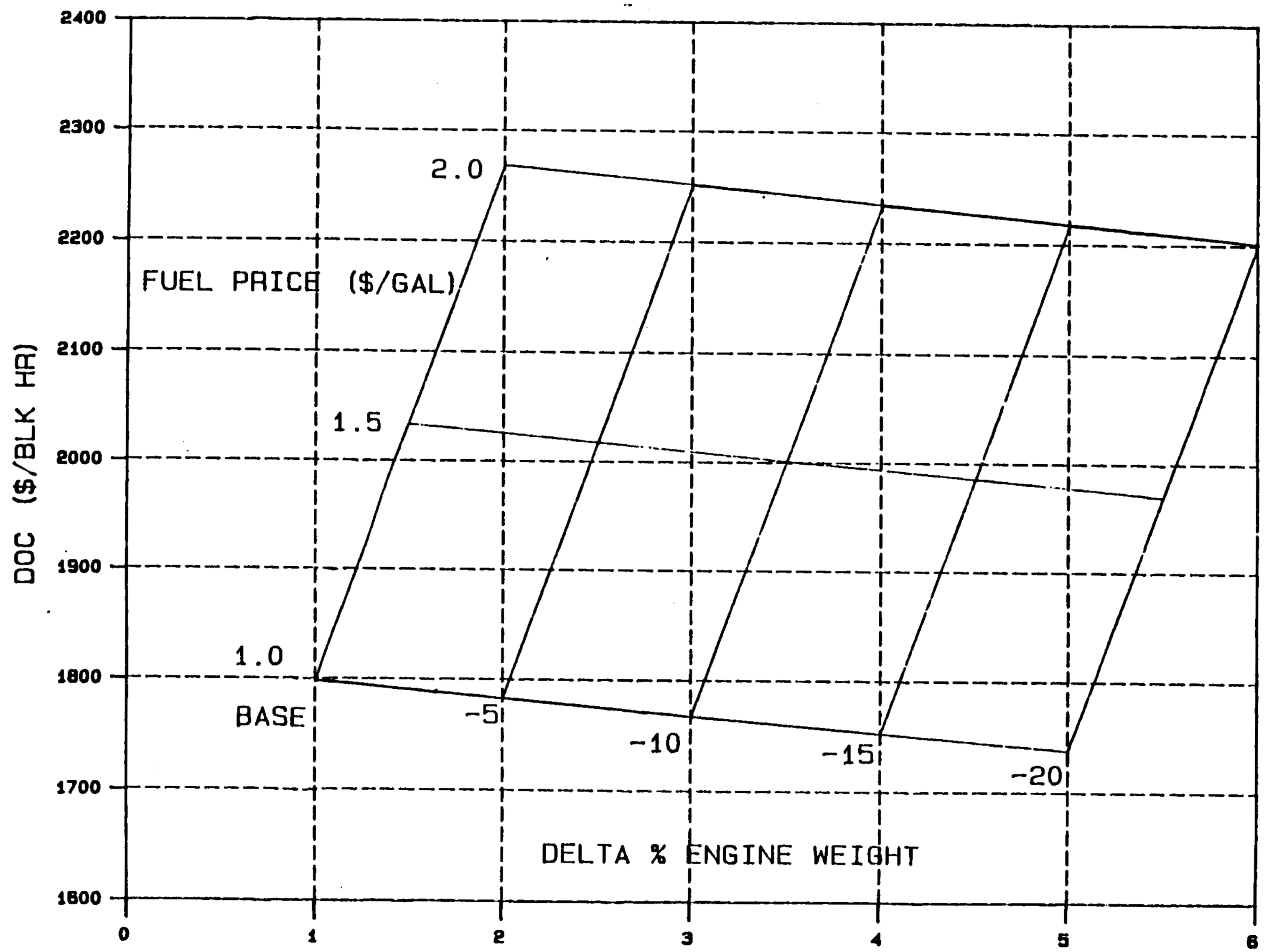


Figure 49. DOC Sensitivity to Engine Weight, 1700 nmi.

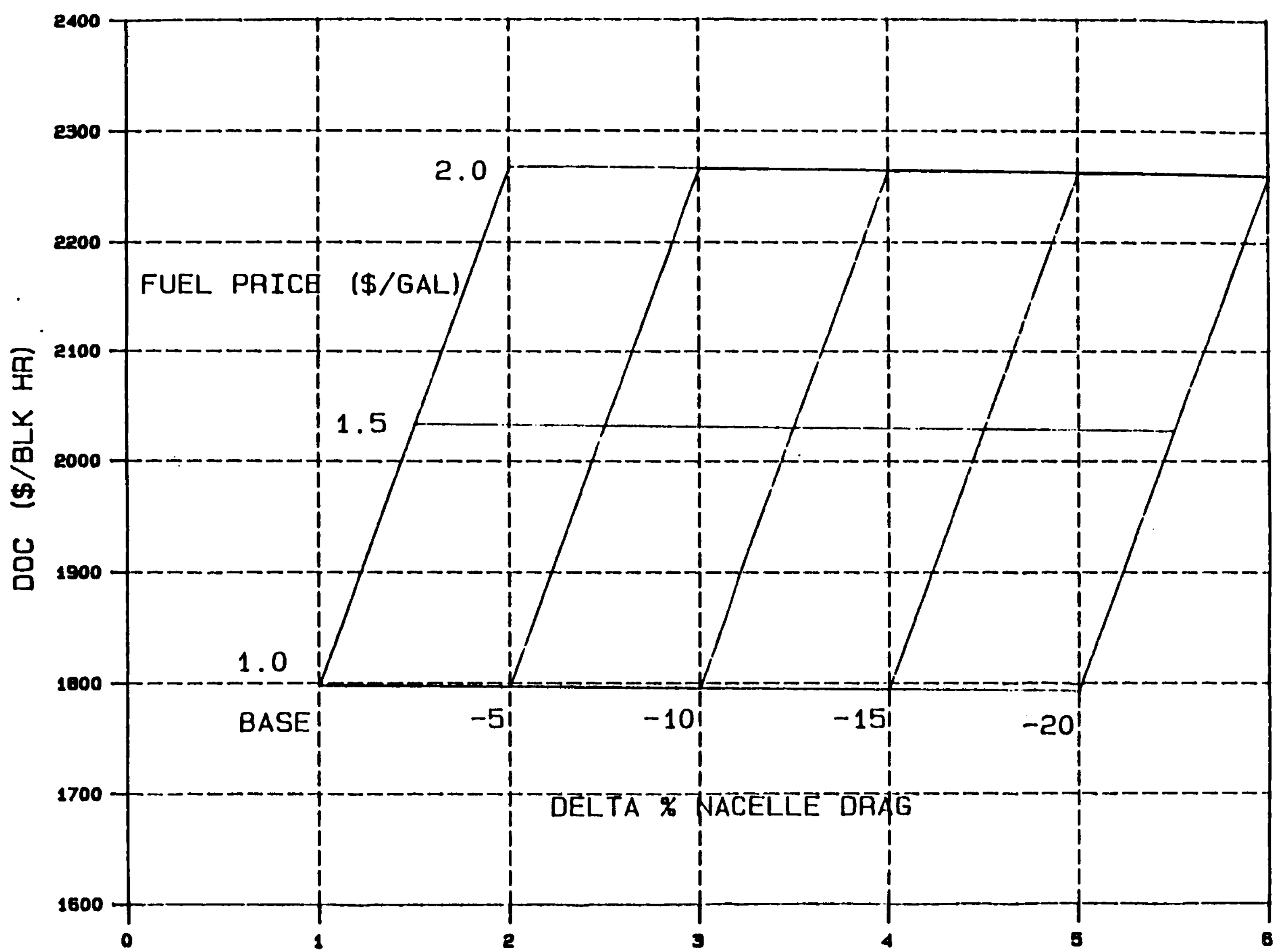


Figure 50. DOC Sensitivity to Nacelle Drag, 1700 nmi.

Table 70. Task IIIA - Subsonic Sensitivities at 1700 nmi.

Baseline

Fuel Burn (1700 nmi)	13,271 lb
Direct Operating Costs (DOC)	
Block Time	4.18 hours
Utilization	970 trips/year
$1.00/U.S. gallon	1689.60/block hour
$2.50/U.S. gallon	2395.60/block hour

Rubber Derivatives (Examples)

	Fuel Burn	DOC (0% Interest) $1.00*	DOC (0% Interest) $2.50*
SFC (Overall) - 10%	10.9% (0.891)	3.5% (0.965)	5.6% (0.744)
Engine Weight - 10%	0.8% (0.992)	1.6% (0.984)	1.3% (0.987)
Nacelle Drag - 10%	0.3% (0.997)	0.1% (0.999)	0.2% (0.998)

* Per U.S. Gallon

Table 71. Task IIIA - Subsonic ROMS Payoffs* at 1700 nmi.

	Fuel Burn, %	DOC, %†
500 nmi		
Revised Goal	-15	-5
ROMS Engine	-13.4	-4.9
1700 nmi		
ROMS Engine	-13.4	-5.4‡

* Using 0% Interest and $1.50/U.S. Gallon to Calculate Potential Improvements as in Task III

† 500-nmi Derivatives were Based on Resizing at 1700 nmi

‡ Changes in Fuel Burn and Utilization (hours/year)

due primarily to the fact that the fuel burn sensitivities for the 500-nmi range were based on an aircraft that was rubberized and sized at 1700 nmi and then flown at 500 nmi to determine delta fuel burns for engine weight, sfc, and nacelle drag changes. The DOC showed an improvement of 0.5% for the 1700-nmi design range versus the 500-nmi mission. The difference is primarily due to the change in utilization (trips per year) of aircraft which is not linear with range. To achieve the DOC improvement shown in Table 71 for both ranges with the ROMS engine, no change in engine acquisition or maintenance cost due to advanced materials was assumed.

4.2 TASK IIIB - EVALUATION OF IMPROVED AST AIRPLANE

An improved AST airplane was proposed to quantify the effect of aircraft technology on fuel burned and DOC for a supersonic transport powered by an advanced variable cycle engine (utilizing ROMS 2010 technology). The aircraft technology considered included reduced airframe weight (2010 technology) due to material improvements, laminar flow, and a twin-engine configuration. Task IIIB also determined the effect on fuel burn and DOC of cruising at optimum cruise altitude, as opposed to the fixed altitude considered in Reference 1. The study was accomplished by independently sizing the new vehicle one change at a time (that is, a 2010 engine in a 1984 airframe; then a 2010 engine in a 2010 airframe, etc.). A final comparison was made between the projected DOC of a 2010 supersonic transport and several subsonic transports.

Tasks III through IV of Reference 1 included a sensitivity study that was based on incremental sfc, engine weight and nacelle drag from the 1984 engine. Incremental data such as "deltas" provide first-order effects and can be most useful for screening purposes. Deltas provide an indication of the trend, but should only be used when a comprehensive sizing study is neither feasible nor available. Several sources of error may result from using incremental data to project trends:

- The basic engine cycle is usually different, resulting in a different thrust lapse, different specific thrust, and a change in the sfc relationship with power setting and altitude
- Mutual and unique airframe and engine size relationship is lost
- The performance criteria loses its relationship to the design mission.

Task IIIB evaluated the impact of new technology (that is, 1984 versus 2010) on aircraft size, fuel burn, and DOC using an analytical sizing routine rather than incremental sensitivities.

4.2.1 Background

Earlier studies (Reference 1) were sized at NASA Langley utilizing their computers and program. However during the interim, GE acquired the capability to perform supersonic sizing, and it was agreed that a satisfactory baseline correlation would provide continuity as well as allowing a savings in time and flexibility by performing the analysis in-house. Figure 51 is a flow diagram of Task IIIB, including the correlation between the NASA and GE code prior to the actual study. Results of this correlation are shown in Figure 52 and in Table 72 reflecting a takeoff gross weight (TOGW) variance of only 0.67%, and a total fuel burn within 0.44%. The mission was unchanged, as outlined in Figure 53, with the original requirements of 5000-nmi range, 290 passengers, Mach 2.7 cruise speed, and a takeoff distance of 9000 feet.

Table 72. Correlation of Supersonic Aircraft Models.

Parameter	1984* AST (NASA Code)	1984 AST (GE Code)
Airframe Technology Year	1984	1984
Engine Technology Year	1984	1984
Engine Cycle Source	Langley**	Langley**
Cruise Altitude Profile	Fixed	Fixed
Maximum Takeoff Gross Weight (MTOGW), lb	601,435	597,400
Operating Empty Weight (OEW), lb	233,810	222,205
Engine Corrected Air Flow, lb/s	599	592
Fuel Burn, lb	264,616	262,798
Total Fuel, lb	307,014	307,585
Propulsion Weight/Aircraft, lb	40,771	39,122
Dry Thrust (SLS/Standard Day)/Aircraft, lb	180,428	178,709

* Reference 1 - Baseline

** The GE 21/J11-B14a Cycle in Langley Model Included Higher Customer Off-Takes

The 9000-foot takeoff field length for the 1984 technology engine was based on a dry thrust to weight of 0.3 for all engine operating takeoff and, thus, suggested the potential use of the afterburner for emergency one-engine-inoperative condition. The 2010 ROMS technology nonafterburning engine size was based on a takeoff thrust to weight of 0.46 to handle the 9000-foot take-off field length with one engine inoperative. Figure 54 illustrates the aerodynamic planform which was unchanged with technology except for the absolute area of the lifting surfaces.

In transitioning from 1984 to 2010 airframe technology, under Task IIIB, the following changes were incorporated based on NASA Langley information: structure weight decreased by 15% and the furnishings by 10%. Changes due to

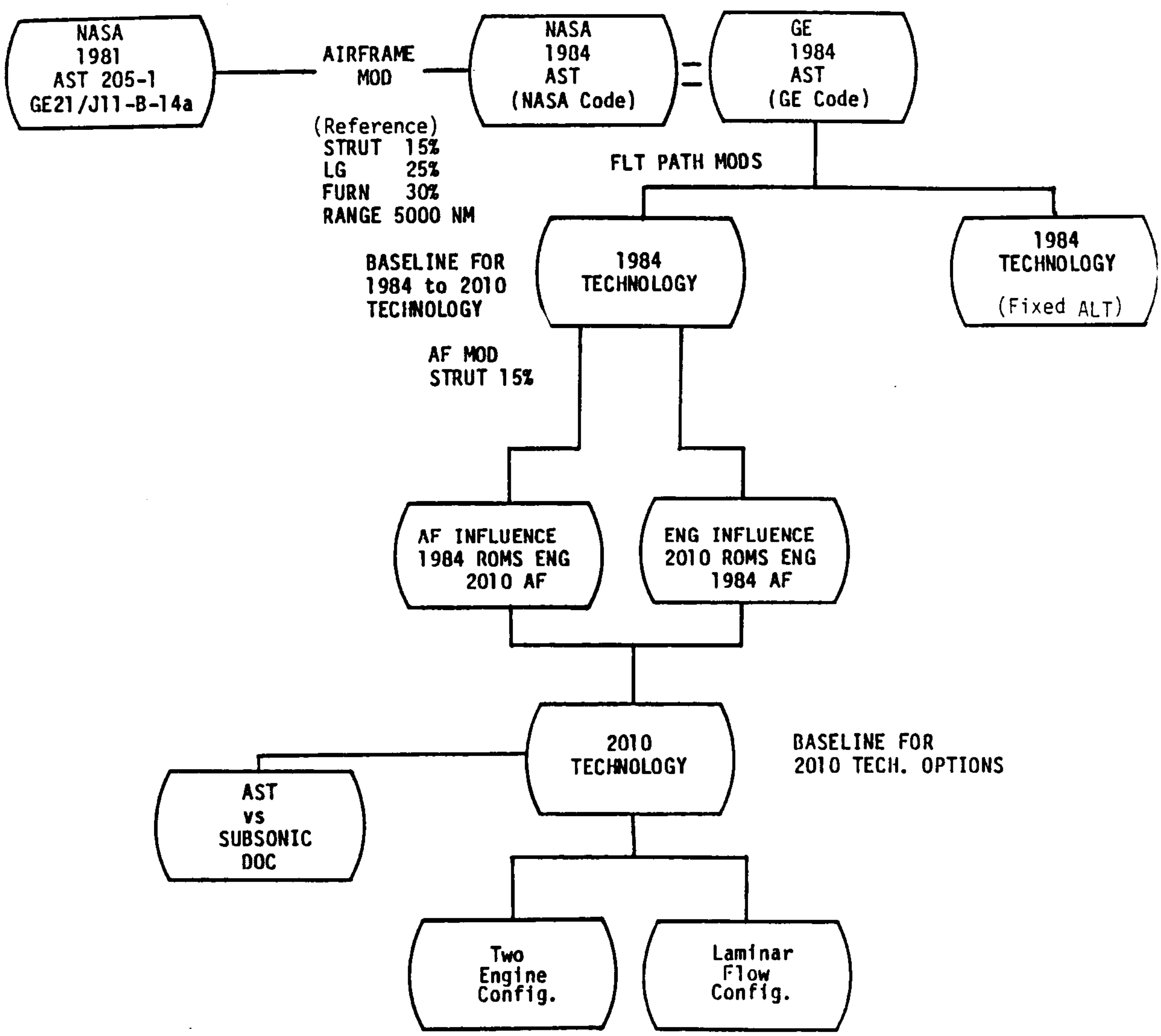
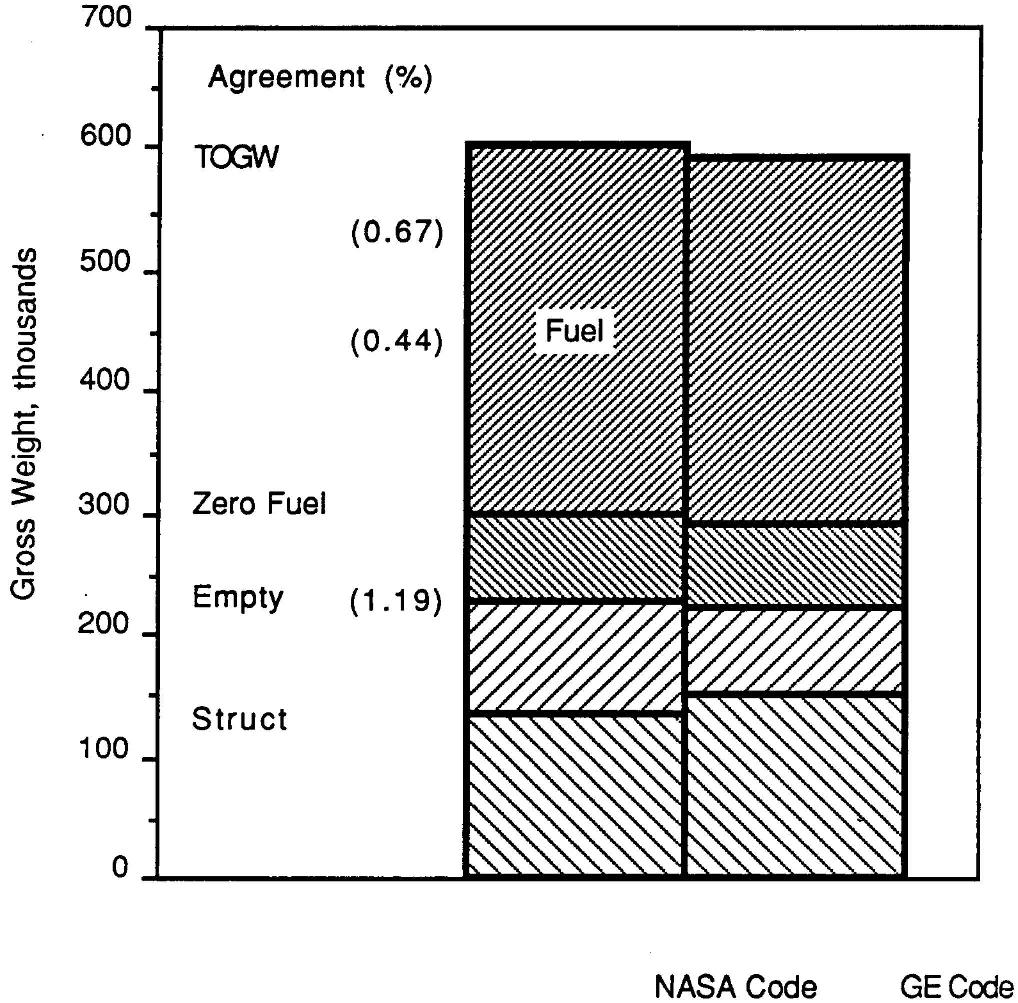


Figure 51. ROMS Task IIIB Flow Chart.



		NASA Code	GE Code
- Engine Airflow, lb/sec	(1.2)	599	592
- Average Cruise SR, nmi/lb	1.8	0.0221	0.0225

Figure 52. Correlation Comparison NASA to GE Sizing Code.

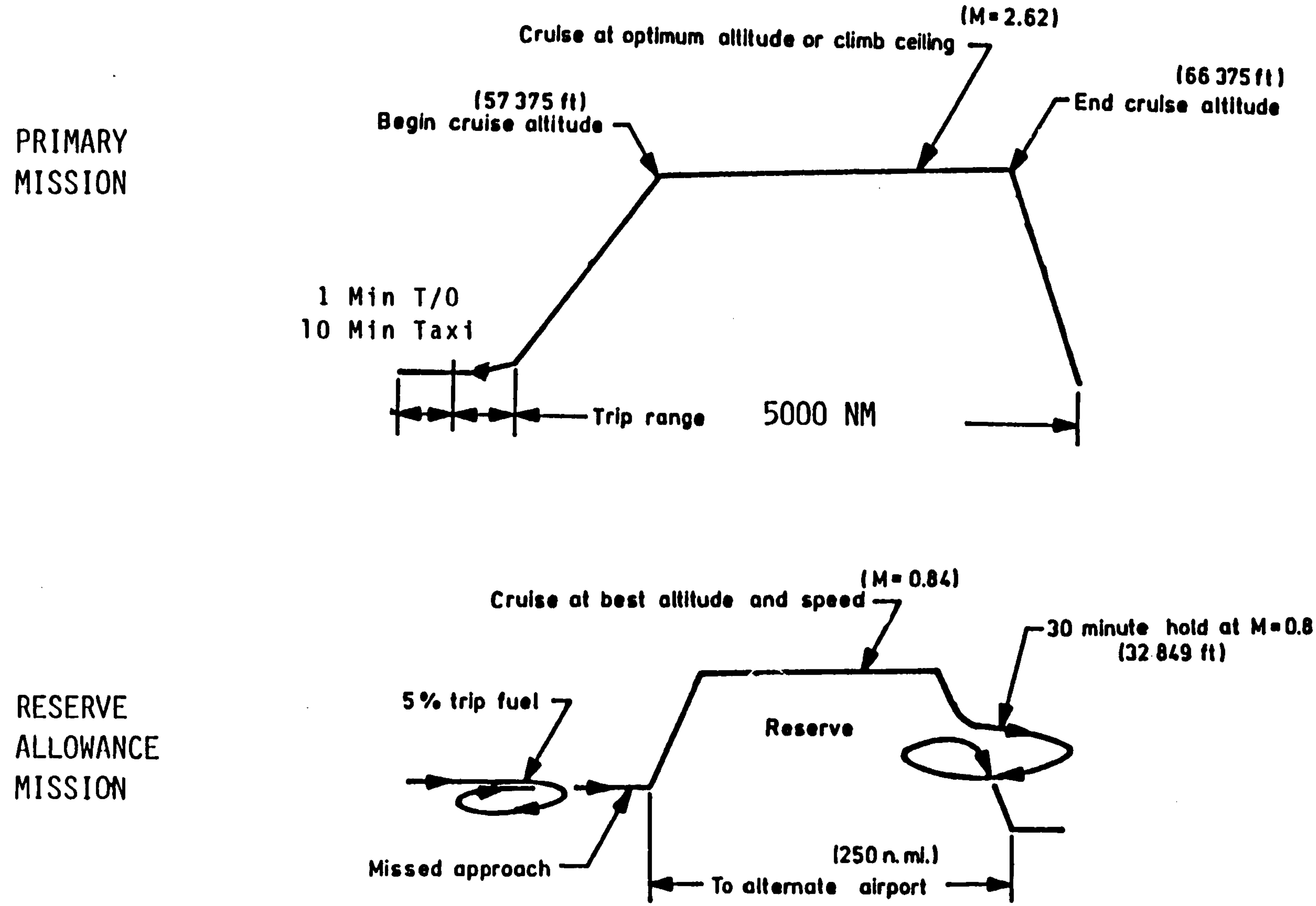


Figure 53. Supersonic Mission Profile.

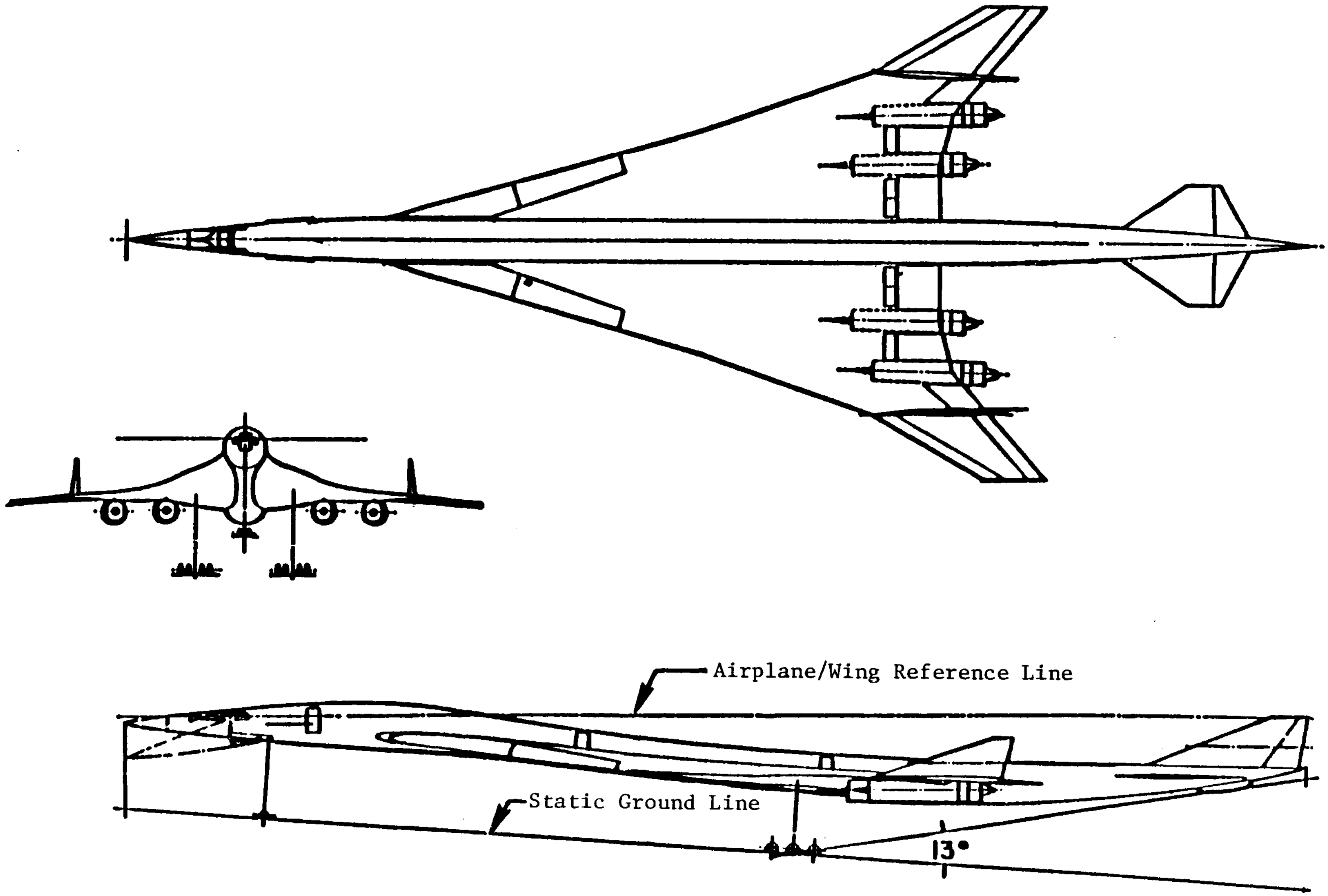


Figure 54. Supersonic Configuration.

laminar flow and the twin-engine configurations will be discussed in Paragraphs 4.2.3 and 4.2.4.

The direct operating cost analysis employed in Task IIIB to assess the DOC merits of the projected technology incorporated in the 2010 supersonic aircraft and the ROMS engine versus the 1984 baseline was the same methodology used in Task III. This methodology is based on a computerized version of the DOC formulas published by the Air Transport Association (ATA), as modified in 1978. Figure 55 identifies the elements included in the DOC calculations, two of which are depreciation and interest. The sum of these two elements represent what is termed "cost of ownership." The DOC value without ownership is known as "cash DOC;" This is useful in evaluating commercial aircraft systems because it eliminates the market place influences which are associated with establishing equipment prices. Both the DOC and cash DOC values were used in measuring the merits of the 2010 technology associated with Task IIIB.

4.2.2 Configuration Description

The flow chart depicted in Figure 51 is an overview of the Task IIIB configurations and the relationship of the configurations as used in determining the comparisons of ROMS technology. The Task IIIB 1984 technology baseline was established in two steps so that the effect of flying optimum altitude could be isolated.

The initial step consisted of a 5.5% sfc improvement which corrected for a high power extraction cycle penalty used in previous (Reference 1) analysis and correlation of computer codes. The second step consisted of initiating cruise at best cruise altitude rather than the 57,375 feet utilized in earlier analysis. The cycle improvement resulted in an 8.1% TOGW reduction (601,434 to 552,597 pounds), and the cruise altitude modification resulted in a TOGW of 530,956 pounds or an additional 3.9%.

Additional results for these two steps are presented in Tables 72 and 73. Figure 51 reveals that the 2010 technology was established independently for the engine and airframe plus the combined system. Results of these interim steps are listed in Table 73.

Figure 56 graphically depicts the incremental changes in TOGW and fuel burn, ending with the 2010 vehicle, which shows the combined technology impact due to the ROMS engine and the advanced airframe. With respect to TOGW, the engine change resulted in a 24.4% weight reduction; while structural advances in the airframe technology reduced the TOGW by 10.4%. The combined change from 1984 to 2010 was 31.4%. For a comparison of DOC and fuel burn, Figure 57 charts the data with respect to the ROMS Task IIIB 1984 engine and airframe technology baseline and demonstrates a 19.6% reduction in DOC (for example, $1.00/U.S. gallon and 3% interest) for the 2010 technology.

Stepping back, the engine technology of Reference 1 showed a fuel burn and DOC of 21.5% and 18.0%, respectively; whereas, Task IIIB analysis shows engine technology improvements of 29% and 20% when flown in the 1984 baseline aircraft at the fixed initial altitude of 57,375 feet. These improvements in

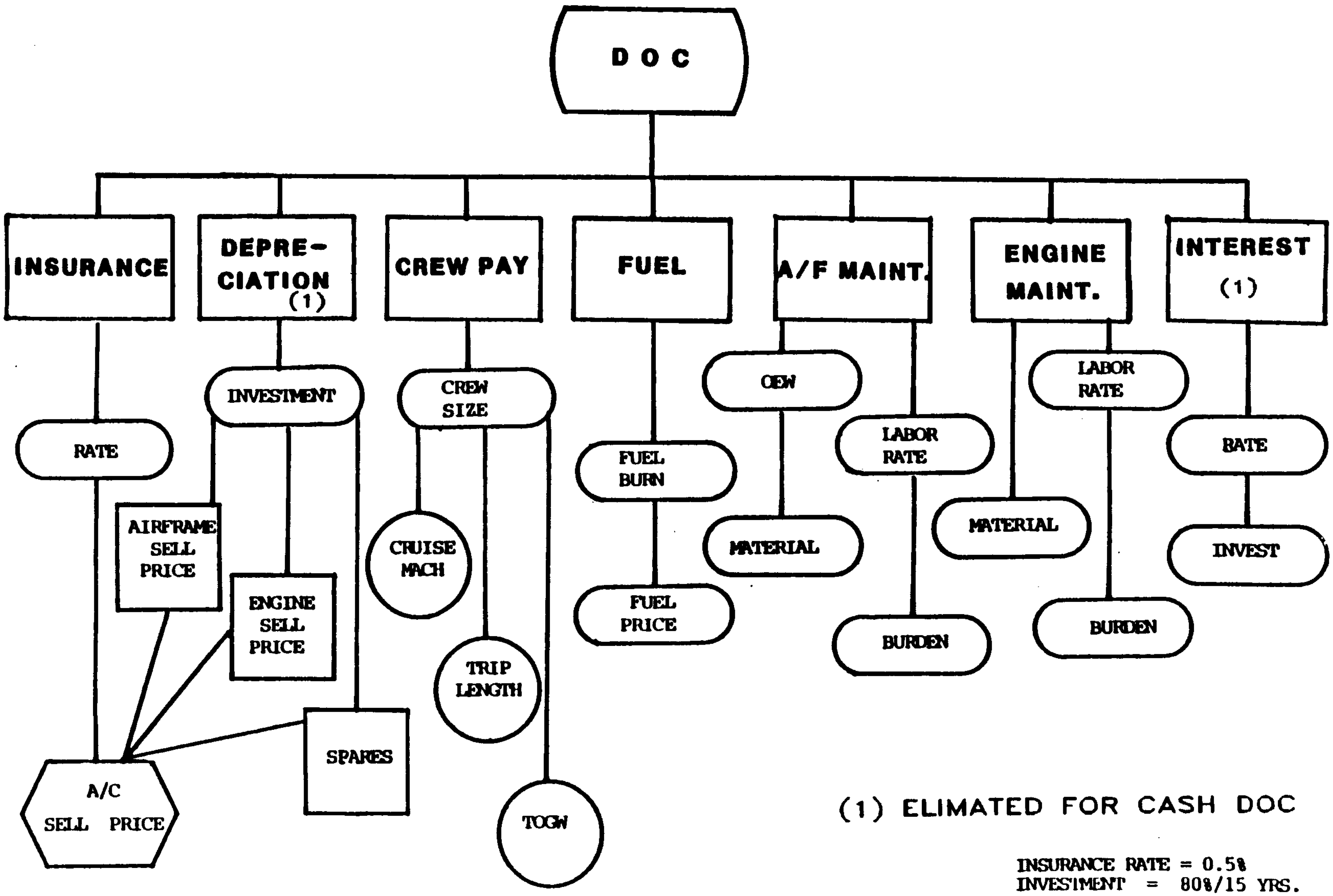
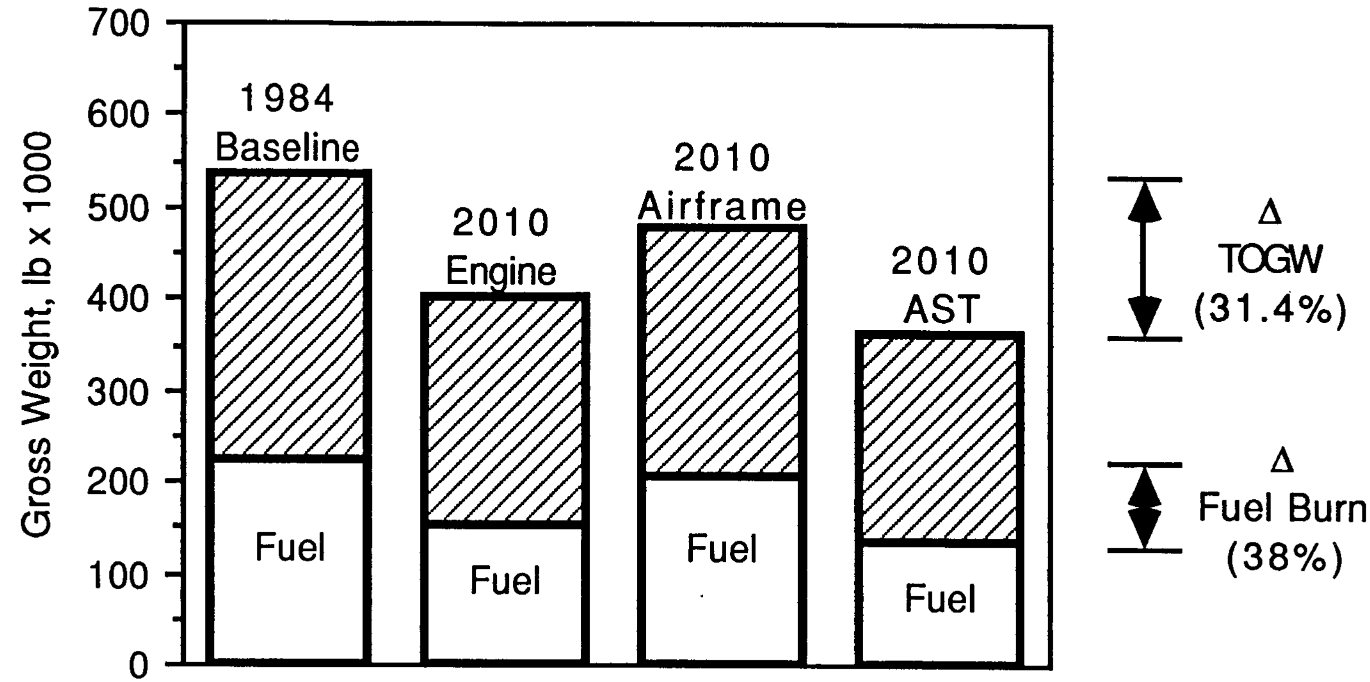


Figure 55. Direct Operating Cost Elements.

Table 73. ROMS Task IIIB - Tabulated Results.

Parameters	1984 Fixed Alt	1984 Baseline	Type of Technology: Engine	Type of Technology: Airframe	Type of Technology: Combined	Laminar Flow	Twin Engine
Airframe Technology Year	1984	1984	1984	2010	2010	2010	2010
Engine Technology Year	1984	1984	2010	1984	2010	2010	2010
Engine Cycle Source	GE	GE	GE	GE	GE	GE	GE
Cruise Altitude Profile	Fixed	Opt	Opt	Opt	Opt	Opt	Opt
Maximum Takeoff Gross Weight, lb	552,597	530,956	401,398	475,887	363,950	347,142	368,096
Operating Empty Weight, lb	209,045	202,705	160,119	168,242	136,471	139,896	140,288
Engine Corrected Air Flow lb/s	548	527	561	472	523	439	1,162
Fuel Burn, lb	235,772	221,629	149,419	202,514	137,378	117,778	137,500
Total Fuel, lb	275,742	260,342	172,821	238,102	158,934	138,573	159,265
Propulsion Weight/Aircraft, lb	35,851	34,282	19,682	30,324	18,231	14,969	22,262
Dry Thrust (SLS/Standard Day)/Aircraft, lb	165,227	158,824	185,309	142,378	173,048	145,182	191,996
Direct Operating Costs	Dollars per Block Hour						
Cost at $1/gallon	12,074	11,44	8,819	10,976	8,358	7,003	8,142
3% Interest and $1/gallon	14,507	13,899	11,542	13,492	11,175	10,434	10,869
0% Interest and $1.50/gallon	18,474	17,655	13,840	16,640	13,230	12,121	12,833
0% Interest and $1.00/gallon	14,064	13,509	11,045	12,852	10,660	9,918	10,261



(1) Reference Figure (54)

Figure 56. AST Technology Steps 1984 to 2010.

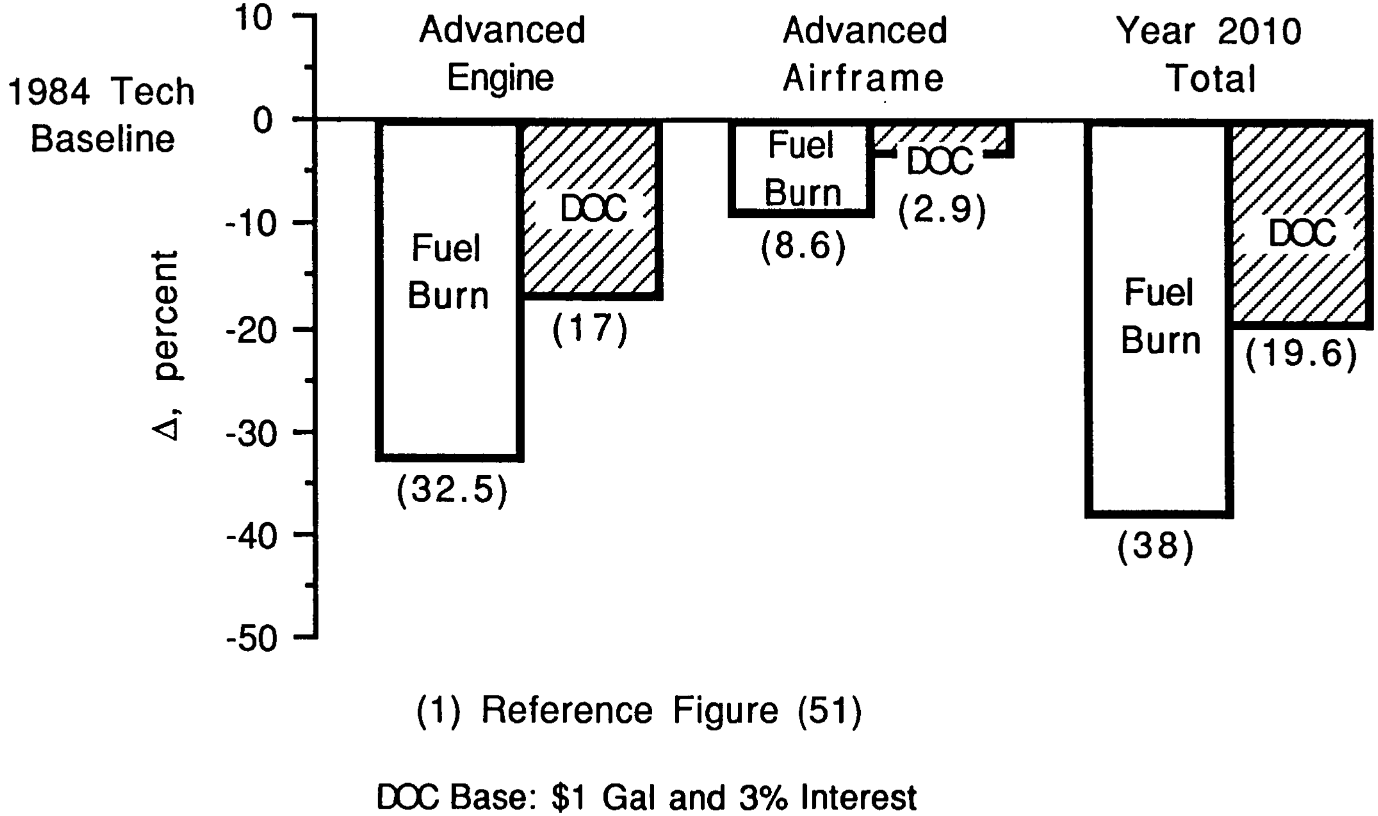


Figure 57. 1984 to 2010 Technology.

fuel burn and DOC result primarily from the fact that sensitivity factors were used to determine the delta improvement and, thus, did not reflect the better climb performance of the advanced ROMS engine or one-engine-inoperative take-off criteria. This improved climb performance results from the advanced ROMS engine operating at a higher combustion temperature. Consequently, it does not require an afterburner during climb as does the baseline engine flying at optimum cruise altitude and, rather than when flown at the fixed initial altitude of Reference 1, increases fuel burn and DOC improvements for the advanced ROMS engine to 32.5% and 17%, respectively (Figure 57).

The aerodynamic characteristics of the vehicle do not change; however, lower fuel requirements and lighter structure allow a reduction in wing area (Figure 58), with a cross-hatched 2010 period wing inside the 1984 outline. The corrected airflow, indicative of the engine size, was smaller by 0.8%, but as noted earlier, the overall maximum diameter was 20% smaller. The important parameter in a transport is the percentage of TOGW devoted to payload, such as 290 passengers/60,610 pounds); this percentage increases from 11.4% to 16.7% or a 46% change, a marked improvement in efficiency.

4.2.3 Technology Options, Laminar Flow

The potential for improving the aerodynamics of any configuration is implicit when discussing technology development programs. Basic research and testing have provided enough support to address the subject of supersonic laminar flow, so it was appropriate to investigate the payoff in this study. The investigation was cursory, with the defined scope maintained by setting very specific ground rules and criteria formulated as a consensus with NASA Langley. It was assumed that only the lifting surfaces would have systems to support boundary layer control (BLC) and, of that surface, only 85% would be affected. The system would be operated during cruise flight and inoperative during takeoff, climb, and descent. Also, there would be no lift or drag penalty with the system not operating. In other words, the coefficients used for the 2010 configuration would be used for all mission legs when the system was off. The latter assumption is optimistic but is offset by the restriction of the use of BLC to cruise only.

The literature is limited on supersonic laminar flow, but estimates on the system penalty in terms of weight or power requirements are nonexistent. The considerations that were addressed in proposing a system penalty were the affected surface area, plumbing weight from the APU to the active surfaces, the APU weight, APU fuel consumption, and the installation requirements for a supersonic inlet and exhaust.

A system weight of 10,000 pounds (approximately 3% of the TOGW) was used to size the vehicle with the results detailed in Table 73, Figures 59, and 60. Within these constraints, the laminar flow with a 10,000-pound system weight provided a 4.6% reduction in TOGW to 347,142 pounds. However, the operating empty weight (OEW) of the vehicle is indicative of the vehicle cost increased by 2.5%, as shown in Table 73. The improvement in cruise specific range due to BLC is 12.8%, which represents approximately 20,000 pounds of fuel saved.

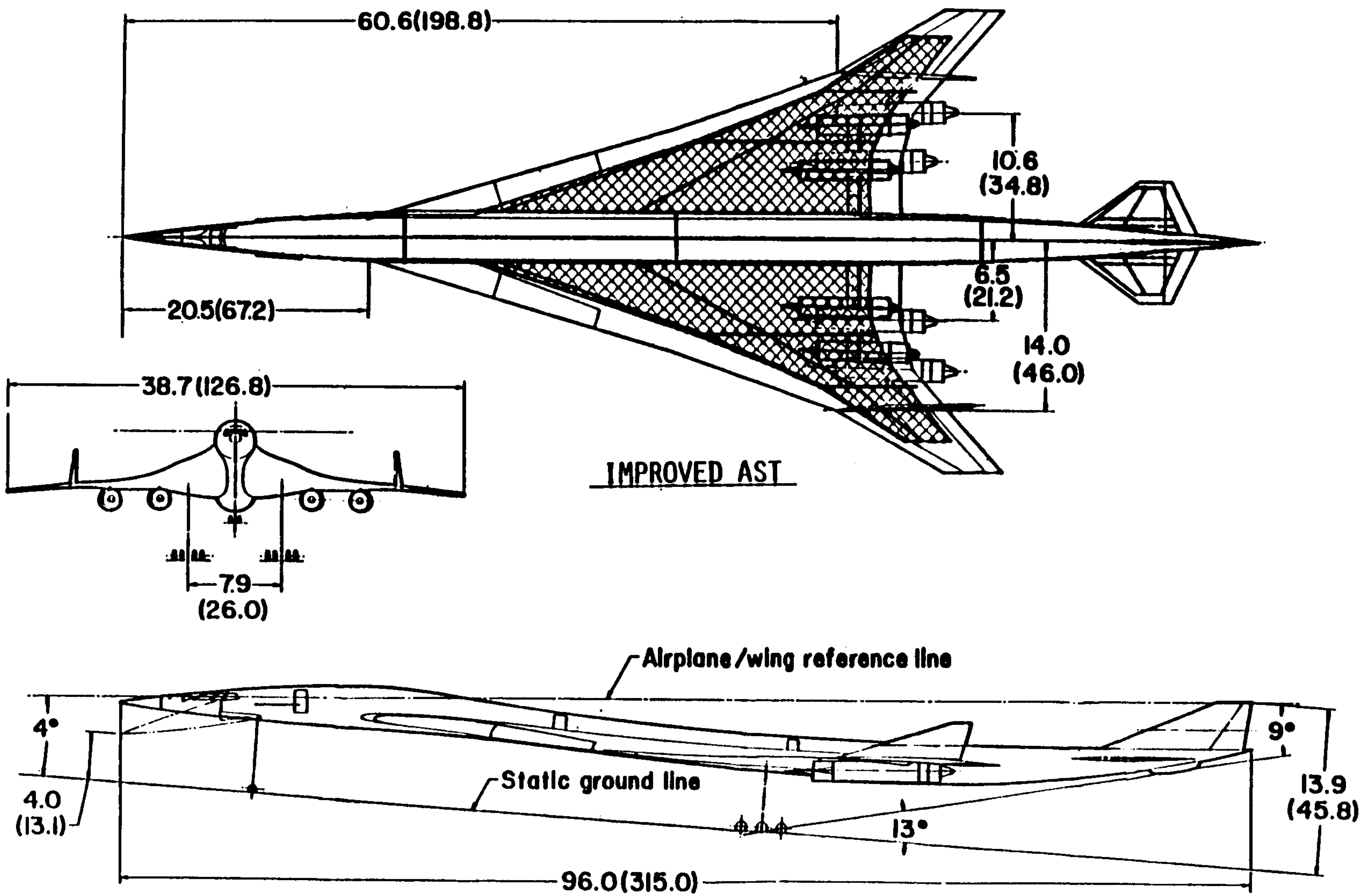
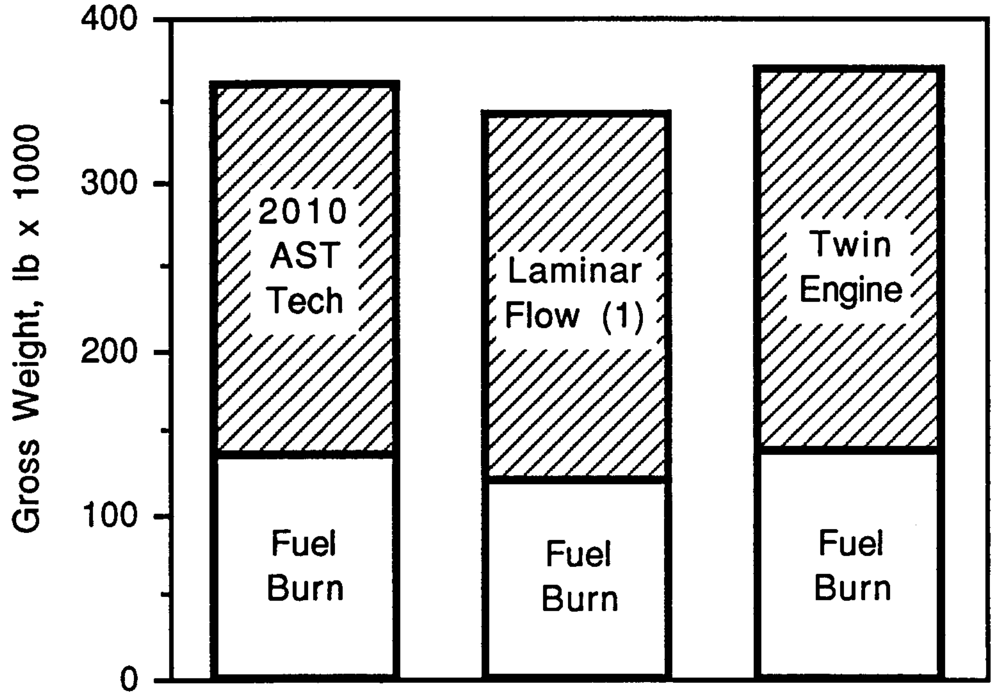


Figure 58. AST Wing Area Comparison.



(1) Includes 10,000 lb System Weight Penalty

Figure 59. AST 2010 Technology Options - TOGW and Fuel.

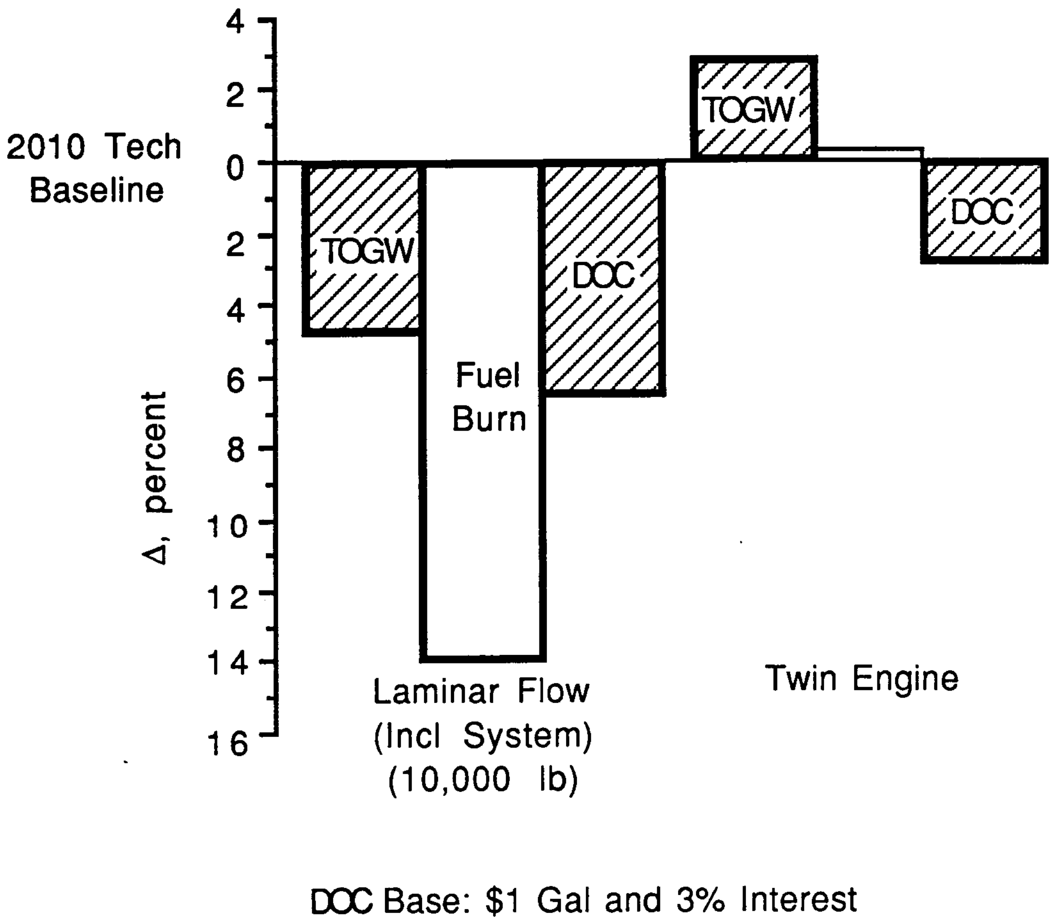


Figure 60. AST 2010 Technology Options - Fuel Burn and DOC.

The improvement in DOC is depicted in Figure 60 and amounts to a 6.5% savings when compared to the 2010 aircraft/engine.

4.2.4 Technology Options, Twin-Engine Configuration

The advent of clearance to fly twin-engine commercial aircraft, such as the Boeing 767, over the Atlantic prompted an interest in the potential of a lower-cost-twin vis-à-vis a four-engine vehicle in the supersonic regime. In analyzing a twin-engine configuration, the primary criteria assumed were: to meet the takeoff noise restrictions, fly the existing 5000-nmi mission, and maintain the high lift geometry of the baseline vehicle (that is, a takeoff wing loading of 68.7 psf).

The latter requirement is conservative since additional trailing edge is available with only two engines. A windmilling drag was assessed, acknowledging that the windmilling penalty is less than that for a frozen rotor. Geometrically, no reduction in the tail down line would be tolerated with respect to the lower center line of the engines. Data was run for takeoff considering both no throttle movement after engine loss and automatic maximum power on the remaining engine. The difference in procedure necessitates a 12% larger engine and an approximate 1% increase in TOGW. The takeoff noise level was met, assuming that the exhaust velocity did not exceed 2360 feet/second, which is substantially less than 100% capability.

The pertinent data for the most representative twin-engine configuration, allowing automatic power increased on the remaining engine, is found in Table 73. To meet the agreed-upon criteria, the twin-engine vehicle requires an increase in airflow size from 523 (per the 2010 baseline) to 1162 pounds per second. As noted in Figure 60, the twin represents a 3.0% savings in DOC, in spite of 1% growth in TOGW. A perspective of the twin-engine configuration and both a twin- and four-engine transport is shown in Figures 61 and 62; the latter emphasizes the relative engine size.

4.2.4.1 Subsonic/Supersonic Comparison

The 2010 supersonic commercial transport potential direct operating cost, as calculated in Task IIIB and presented in Table 73 and Figures 57 and 63, for the improved AST aircraft and the ROMS engine was compared with the DOC of several contemporary subsonic aircraft. Due to passenger capacity differences between the AST and comparable subsonic aircraft, DOC comparison with subsonic aircraft was based on the parameter of $/Seat/Trip instead of $/Trip as was used in the comparison of the 1984 baseline and 2010 supersonic aircraft.

Also the DOC comparison with the subsonic aircraft was calculated for DOC including amortization and interest and what has been termed cash DOC, which includes the same cost elements as DOC, except it excludes the cost of amortization and interest. The cash DOC provides a comparison of technology without including the price of equipment utilization. The aircraft price is usually driven by the market place competition and, therefore, is not always a measure of the cost of technology. In DOC comparison with the contemporary subsonic

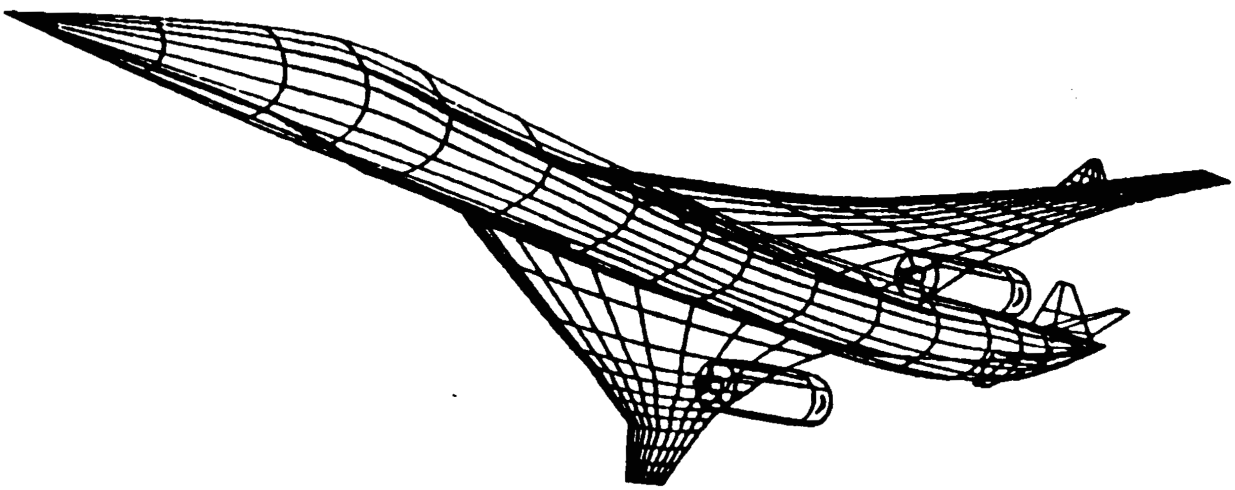


Figure 61. Twin Engine AST.

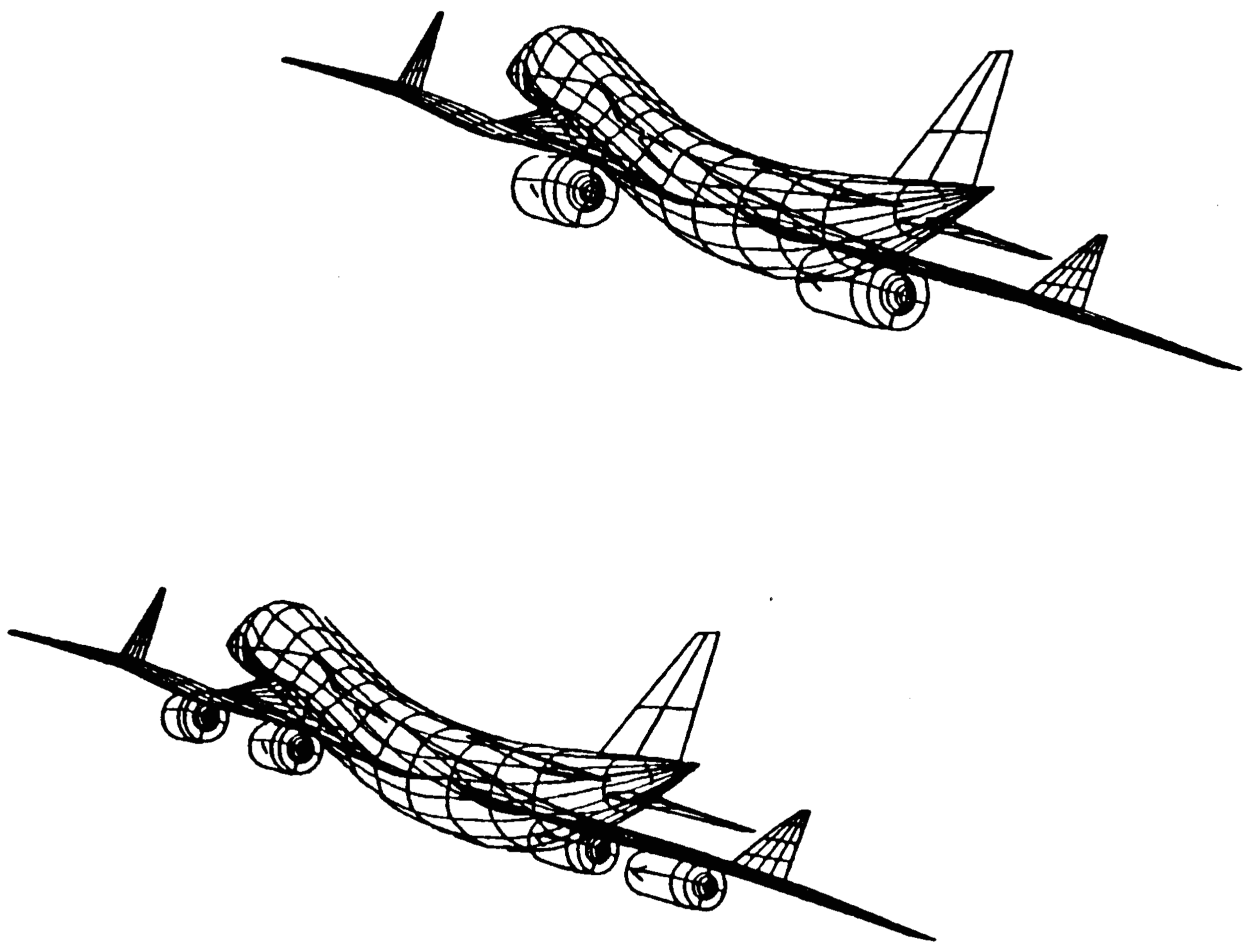


Figure 62. Twin- Versus Four-Engine Configuration (AST).

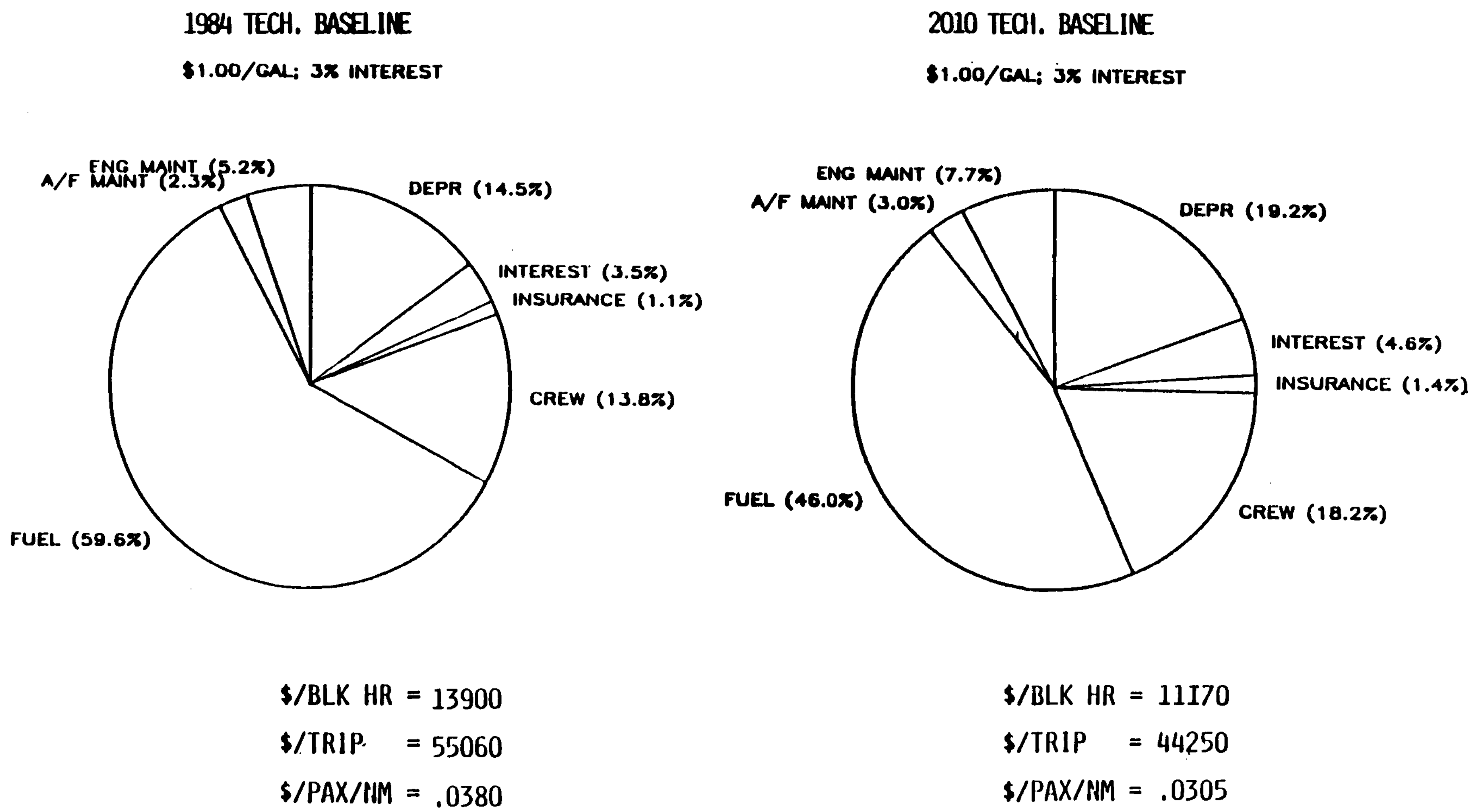


Figure 63. DOC Breakdown - 1984 Versus 2010.

aircraft, the hours of utilization per year were held constant for both the supersonic and subsonic aircraft. The assumption is not unrealistic since the 5000-nmi mission approximates the Los Angeles (LAX) to Tokyo (NRT) city pair, and the Mach 2.7 AST could make 4 trips per day within the airport curfew hours allowing a 2-hour turnaround.

Figure 64 provides the results of the cash DOC and DOC comparison for the advanced AST and subsonic aircraft. It is interesting to note that the cash DOC of the AST improves as the fuel price drops and is less than the subsonic aircraft at a fuel cost of $0.50 per gallon. This indicates that the AST fuel burn is a higher percentage of the cash DOC and, thus, has a greater impact on its operation when lower fuel prices are used.

5.0 SUMMARY

The scope and magnitude of Task IIIB did permit an analysis that was able to quantify the impact of technologies from 1984 to 2010 on an AST airframe and propulsion system improvements. The thrust to weight and thermal cycle improvements associated with the ROMS AST engine resulted in approximately a 4:1 advantage in fuel burn over that achieved by reductions in the airframe structure and furnishing weights. With respect to DOC, engine improvements were six times as effective as technology advances in airframe-associated weights. Compared to the four-engine aircraft, the twin-engine AST configuration shows the fuel burn to be line-to-line and a minimal DOC improvement. This small improvement in going from a four- to twin-engine configuration is primarily due to significant upsizing of the engine to meet one-engine-out takeoff. The laminar flow technology showed significant fuel burn and DOC payoff to be considered a viable supersonic aircraft technology.

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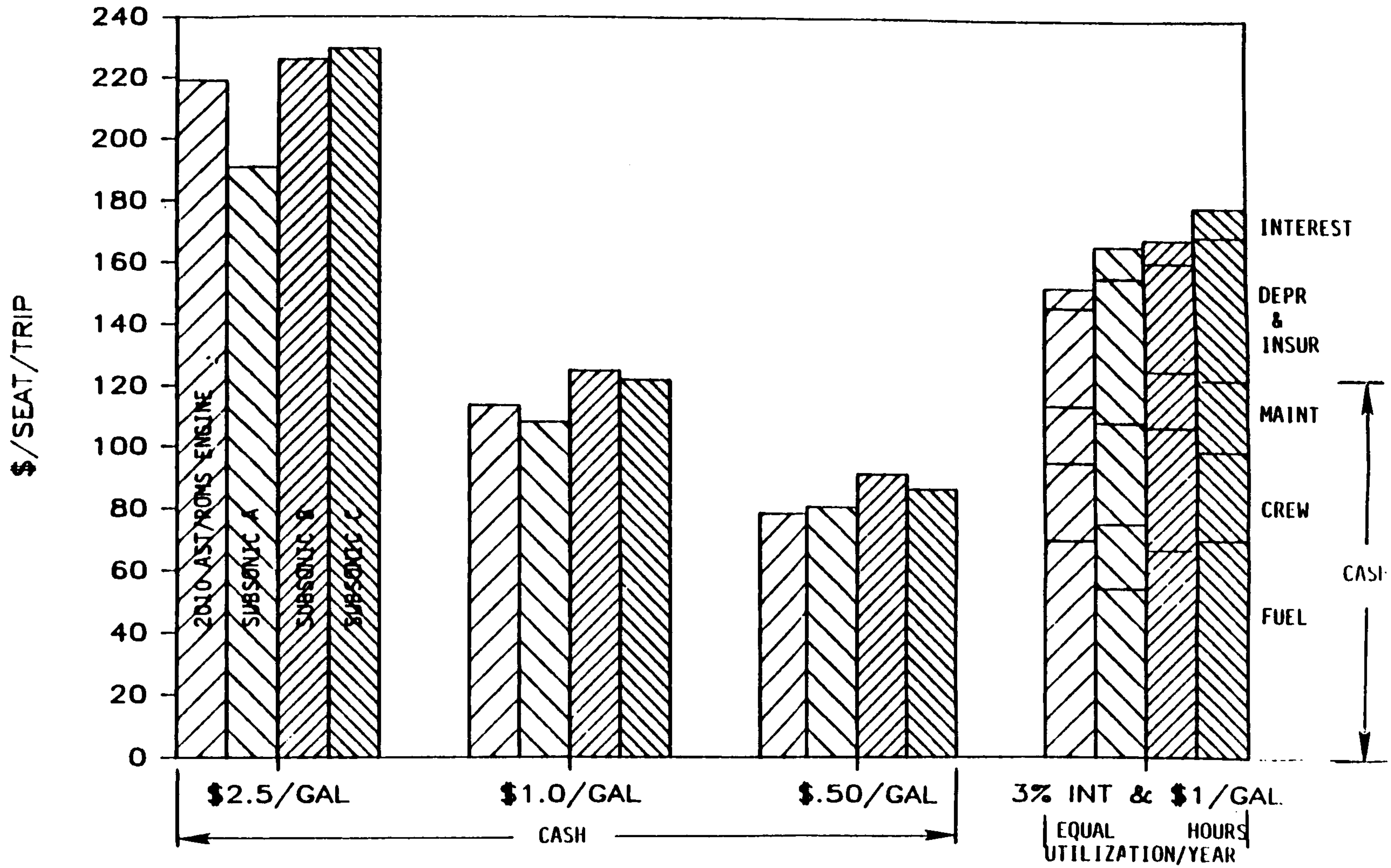
1. Schweiger, F.A., "Revolutionary Opportunities for Materials and Structures (ROMS) Study," NASA Contractor Report 179642.



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NOTE: 2010 AST is Four Engine Configuration w/o Laminar Flow

Figure 64. DOC Comparison, 5000 nmi.

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