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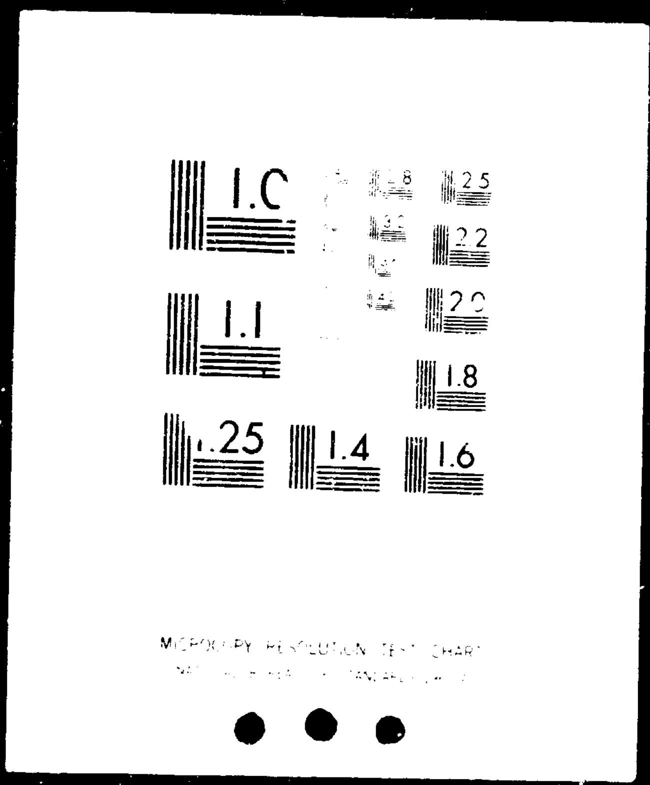

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FINAL REPORT

ADVANCED GENERAL AVIATION COMPARATIVE ENGINE/AIRFRAME INTEGRATION STUDY

by

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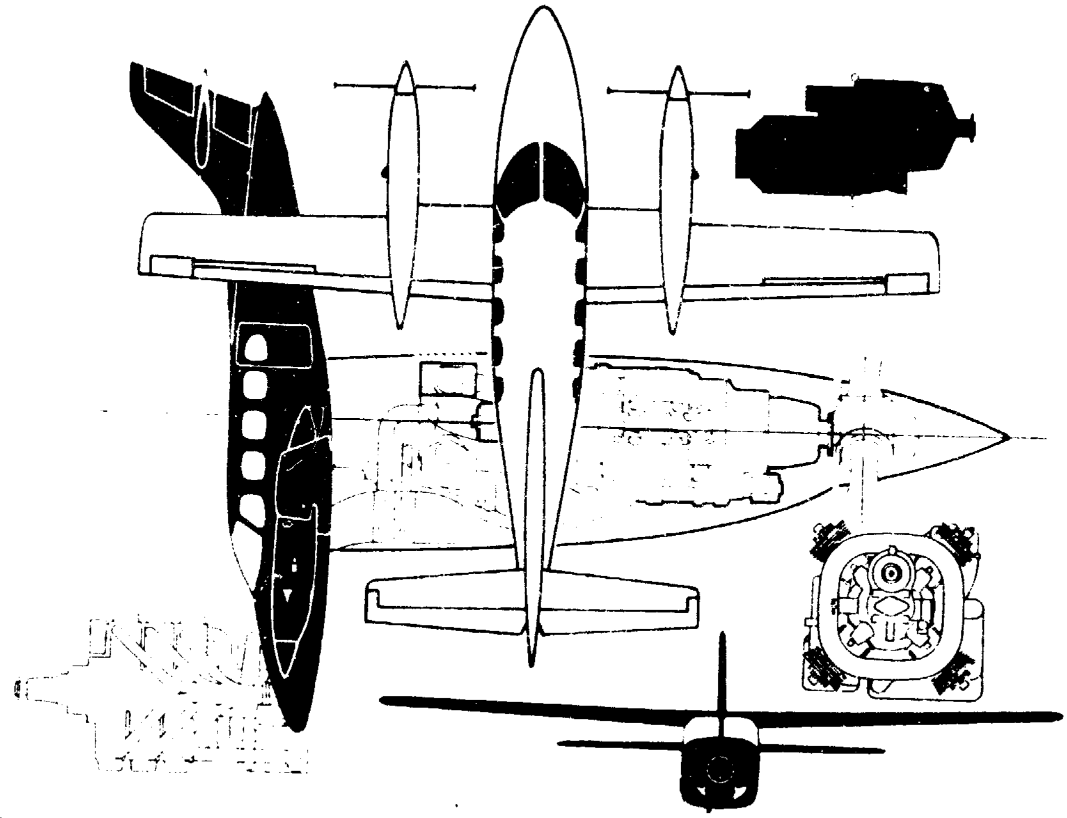

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FINAL REPORT

SEPTEMBER 1981

CONTRACT NAS 3-22221
CESSNA AIRCRAFT COMPANY
WICHITA, KANSAS

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FOREWORD

This report was prepared by the Pawnee Division of the Cessna Aircraft Company, Wichita, Kansas under contract NAS3-22221. The program was sponsored by NASA, Lewis Research Center; the NASA technical monitor was Dr. E. Willis.

The following Cessna personnel were principal contributors to the project; G. Huggins, D. Ellis, A. Mueller, C. Olson, J. Hembrey, and L. Engelbrecht.

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SUMMARY

The NASA Advanced Aviation Comparative Engine/Airframe Integration Study was initiated to help determine which of four promising concepts for new general aviation engines for the 1990's should be considered for further research funding. The engine concepts included one highly advanced version each of a rotary, diesel, spark ignition and turboprop powerplant; a conventional state-of-the-art piston engine was used as a baseline for comparison. In addition, advanced but lower risk alternatives were defined for the rotary and spark ignition engines. Late in the study, NASA revised the turboprop data to show significantly improved characteristics, defining a powerplant whose technological challenge is comparable to the other highly advanced engines. The original turboprop data is now viewed as representative of a lower risk and/or lower cost design.

Computer simulations were used to determine how the various characteristics of each engine interacted in the design process of pressurized singles and twins. Comparisons were made of how each engine performed relative to the others when integrated into an airframe and required to fly a transportation mission. The contemporary fleet of Cessna airplanes provided the data base for the study. However, design improvements expected to be available by 1990 were included to reflect the level of performance expected in that time frame.

Evaluation of the results placed heavy emphasis on low fuel consumption and direct operating cost and on high flight efficiency; acquisition cost, noise, multi-fuel capability and ease of installation were also considered but not weighted as heavily.

The results indicate that the highly advanced rotary engine offers the best all around performance and features for future general aviation aircraft. The diesel engine was the next most promising concept and was rated only slightly lower than the rotary. The other engines, though showing worthwhile advances relative to today's engines, did not appear as promising as these two powerplants. In particular the turboprop should be viewed primarily as a viable replacement for the baseline engine, offering market appeal rather than large improvements in efficiency or cost. A parametric analysis indicated that these results were essentially independent of the assumptions made in the study. It did show, however, the advisability of rematching the diesel turbocharger so that greater climb power is available.

The use of these rotary and diesel engines will lead to improved operating economics and freedom from our present dependence upon the availability of avgas. It is recommended that NASA fund research efforts which will provide enabling technology for both engines.

INTRODUCTION

General Aviation is a vital, integral part of the American transportation system (see Ref. 1) which reduces travel time relative to surface means, yet allows easy access to a vast number of destinations not served by scheduled air transportation. However, as uses and opportunities for small airplanes increase, rising fuel costs and spot unavailability of certain types of fuel are hampering their functional utilization. This is a trend which will almost certainly get worse. There is, therefore, an urgent need for more efficient engines capable of accepting the more readily available kerosene-based fuels, or better yet, having a wide tolerance for many fuel types. If the general aviation industry is to remain healthy and if the aircraft are to continue serving the public as they have, these engines must be developed in a timely way.

NASA, recognizing these needs, has funded seven recent studies examining four different powerplant concepts which fullfil the basic requirements for the new engine. These conceptual designs include advance spark ignition engines (Ref. 2), lightweight diesel engines (Ref. 3-4), stratified charge rotary engines (Ref. 5) and advanced small turboprop engines (Ref. 6-9).

Each of these engines exhibits, in varying degrees, the desirable characteristics of low specific fuel consumption, multi-fuel tolerance and reduced size and weight. However, the original studies do not permit a direct comparison of one engine against the others due to their having been conducted by different contractors using different guidelines. The present study was initiated to provide just such a comparison, starting with a common cruise design point and a consistent set of engine weight estimates.

METHODS AND DATA BASE

STUDY PHASE AND GUIDELINES

The study was divided into the following four major phases: Phase 1 was devoted to organization, gathering appropriate data, and modification of Cessna computer programs where necessary; Phase 2 covered the comparative evaluation of seven different engines in typical missions; Phase 3 explored variations in data, missions and configurations to show the influence of the assumptions made in Phases 1 and 2; in Phase 4 the technology plan recommendations were developed.

From the outset it was decided to base the bulk of the study on fairly conventional airframes, both in terms of structure and aerodynamics. This would make available an extensive and reliable data base and would, it was felt, provide the clearest picture of possible improvements due to the new engines themselves. The impact of an aerodynamically and structurally advanced airframe on the basic results is considered, however.

MISSION DEFINITION

Separate missions for pressurized single and twin engine airplanes were defined. These two typical transportation missions were derived by considering the capabilities of successful general aviation aircraft using the same class of engine (that is, 300 takeoff horsepower and up, which is the high end of the present day engine power spectrum), and then extrapolating them to generally more desirable levels just within the capability of the baseline powerplant.

The mission requirements selected are shown in Table I. In addition to the payload the airplanes were assumed to be equipped with optional equipment totalling 122kg (270lb) for the single and 204kg (450lb) for the twin.

The operational height was set at 25000 ft because cruise altitude has consistantly been increasing in recent designs (for better efficiency - see Ref. 10) and because the present FAA regulations tend to limit this growth to 25000 ft (see discussion below on altitude variation, under parametric studies).

The fuel volume and weight are based on 45 minutes reserve at normal cruise power. The minimum wing size must have sufficient volume to hold all of the fuel needed for the basic mission without requiring use of nacelle tanks.

TABLE I

MISSION DEFINITION AND MINIMUM PERFORMANCE LEVELS

	PRESSURIZED SINGLE-ENGINE		PRESSURIZED TWIN-ENGINE	
PAYLOAD-occupants -and baggage	544 kg	(1200 lbs)	635 kg	(1400 lbs)
RANGE @ MCP @ CRUISE SPEED	1296 km 370 km/hr	(700 NM) (200 KTS)	1482 km 417 km/hr	(800 NM) (225 KTS)
CRUISE ALTITUDE	7620 m	(25000 ft)	7620 m	(25000 ft)
RATE OF CLIMB AT CRUISE ALTITUDE	152 m/min	(500 ft/min)	152 m/min	(500 ft/min)
TIME TO CLIMB	30 min		30 min	
SINGLE ENGINE RATE OF CLIMB AT 5000 FT	---	---	76 m/min	(250 ft/min)
TAKEOFF DISTANCE AT SEA LEVEL	762 m	(2500 ft)	914 m	(3000 ft)
STALL SPEED	113 km/hr	(61 KTS)	139 km/hr	(75 KTS)
NOISE*	per FAR part 36		per FAR part 36	

*See discussion on page 18

The time-to-cruise-altitude requirement was set because experience indicates that cruise altitudes which take excessive time to reach are not often used. The rate of climb requirement was added to insure that reasonably quick increases in altitude could be made while operating in the 20000ft and above range.

ENGINE DATA

The characteristics of each engine were based almost entirely on data supplied by NASA, which in turn came from the feasibility studies defining the engines (Ref 2 through 9). Several of the engine feasibility studies considered both a near term or moderate technical risk engine and a longer term or high technical risk engine. In defining the engines NASA chose one high technology engine from each of the 4 engine types. In addition moderate risk advanced spark ignition and rotary engines were included. The latter are considered by NASA and the designers to be fall back designs should the more advanced engines prove to be unfeasible. A modern current technology spark ignition engine was also specified as a baseline for comparative purposes. These constituted the seven original powerplants analyzed. Late in the study, an eighth engine was added in the form of a revised version of the GATE with improvements of 10% in weight and specific fuel consumption. This was felt to better represent the philosophy of the GATE work, and provided a turboprop engine with a level of technology comporable to that of the highly advanced I.C. engines. The bulk of the GATE results shown in the report refer to the original turboprop engine; special reference is made to the revised engine where appropriate, and specific results are discussed on page 103.

All data were supplied for engines sized to 250 cruise horsepower at 25000 ft. For the turboprop this was taken to be 250 equivalent installed horsepower (i.e. SHP + $TV/550\eta_{prop}$ where T = residual jet thrust, V = velocity in feet per second and η_{prop} is an average propeller efficiency of 80%).

No systematic designation scheme was available to cover all the various engines. The baseline was given the mnemonic TSIO-550 which is standard for Teledyne Continental Motors. This stands for: turbosupercharged, injected, opposed with 550 cubic inch displacement. The advanced spark ignition engines (also by Teledyne Continental Motors) were designated GTSIO-420 for the advanced engine and GTSIO-420SC for the highly advanced engine. The code is the same as above with the added letters standing for gearing and statified charge. The diesel goes by the mnemonic GTDR-246 or geared, turbocharged, diesel, radial, with 246 cubic inch displacement. The rotaries are designated RC2-47 (advanced) and RC2-32 (highly advanced). The designation stands for rotary combustion, two rotors, with a displacement (the definition of which is peculiar to rotary engines) of 47 or 32 cubic inches per rotor. The turboprop goes by the acronym GATE, standing for General Aviation Turbine Engine which was the title of the set of studies defining this powerplant.

A summary chart showing the most pertinent data on engine characteristics is included as Table II. The complete NASA approved data package is shown on Table III. Other miscellaneous engine data are shown on Table IV and Figures 1 through 4.

As noted above and shown in Tables II and III, each engine excels in one or more characteristics. The rotaries and GATE have low RPM (good noise characteristics and propeller efficiency), the diesel and highly advanced spark ignition have the lowest SFC's, the rotaries and spark ignition have the highest climb power at altitude, while the GATE, rotaries and GTSIO-420SC are capable of using the widest spectrum of fuel types.

It should be noted, however, that the design philosophy of the turboprops stressed low initial cost rather than low fuel consumption.

AIRFRAME DATA BASE

The simulation requires data on drag, propeller characteristics, high lift devices, weight, pricing, operating expenses and noise. Each is dependent on airframe design and is discussed in detail below.

WEIGHT Airframe weight is broken into some 15 to 20 components (depending on model type) and each is estimated by an appropriate equation - usually a parametric fit to the present Cessna fleet. The equations, therefore, represent riveted and bonded aluminum structure. For this study the estimated weight for the major structural assemblies was reduced by 5% based on anticipated use of lighter materials, more extensive use of bonding, and better design and manufacturing practices.

DRAG The drag level of the single was based on the Cessna 210 which is one of the fastest aircraft in its class. The drag of the twin engine design was based on Cessna Models T303 and 421.

A parabolic polar representation for drag is used, with Cdo calculated from the equivalent skin friction coefficient (i.e. an emperically determined weighted average that accounts for skin friction, miscellaneous protruberances, etc) and the total wetted area. The induced drag coefficient Cdi is calculated from the equation:

TABLE II

SUMMARY ENGINE DATA CHART

TYPE	SPARK IGNITION			DIESEL	ROTARY		TURBOPROP
DESIGNATION	TSIO-550	GTSIO -420	GTSIO -420SC	GTDR-246	RC2-47	RC2-32	GATE
TECHNOLOGY LEVEL	CURRENT BASELINE	ADVANCED	HIGHLY ADVANCED	HIGHLY ADVANCED	ADVANCED	HIGHLY ADVANCED	HIGHLY ADVANCED
INSTALLED WEIGHT - Kg	320	275	239	221	221	178	177
- lbf	706	606	526	488	487	393	391
TAKEOFF POWER - KW	254	261	261	268	239	239	391*
BHP	340	350	350	360	320	320	525*
CRUISE POWER - KW	186	186	186	186	186	186	186*
BHP	250	250	250	250	250	250	250*
PROP RPM							
TAKEOFF	2700	2400	2400	2300	2400	2400	2000
CRUISE	2300	2150	2150	2300	2000	2000	2000
Cruise SFC g/KW-hr	271	218	201	196	226	216	292
lb/HP-hr	.446	.358	.331	.323	.371	.355	.480

*Installed ESHP

TABLE III

COMPLETE ENGINE DATA CHART

ENGINE TYPE	SPARK IGNITION			DIESEL	ROTARY		TURBINE
TECHNOLOGY	CURRENT TECHNOLOGY BASELINE TSIO 550	GTSIO 420	GTS 4 SC	1992 TECHNOLOGY	RC2 47	RC2-32	GATE DESIGN 3015
⚠1 ENGINE WEIGHT BASIC + ADDITIONAL	585 + 121 = 706	485 + 121 = 606	405 + 121 = 526	367 + 121 = 488	348 + 139 = 487	255 + 138 = 393	195 + 196 = 391
SCALING (BASIC WT)	$W_B \approx HP^{.810}$	$W_B \approx HP^{.810}$	$W_B \approx HP^{.810}$	SPECIFIC WEIGHT TO BE SCALED AS SHOWN IN ENCLOSURE 2	W_B = 92 + .8(TOHP)	W_B = 85.4 + .53(TOHP)	$W_B \approx HP_{GROSS}^{.72}$
DIMENSIONS (INCHES)	L = 50.62 W = 34.06 H = 20.02	L = 59.25 W = 33.375 H = 19.25	L = 59.25 W = 33.375 H = 19.25	L = 41.30 W = 24.00 H = 25.00	L = 52.0 W = 18.0 H = 17.0	L = 48.6 W = 16.0 H = 16.0	GEARBOX = 16.10 CASING = 12.10 L = 37.60 H = 19.0
SCALING	NONE	NONE	NONE	NONE	L = 44.8 + .0225(TOHP) W/H = NONE	L = 42.3 + .0197(TOHP) W/H = NONE	DIAM & H ≈ $HP_{GROSS}^{.36}$ L ≈ $HP_{GROSS}^{.27}$
⚠2 CG LOCATION	22.6 AFT 0.9 BELOW 0.65 RIGHT	32.6 AFT 0.56 BELOW 0.80 RIGHT	33.6 AFT 0.52 BELOW 0.90 RIGHT	15.7 AFT ON ℄ ON ℄	22.8 AFT ON ℄ ON ℄	22.7 AFT ON ℄ ON ℄	16.8 AFT 3.52 ABOVE ON ℄
⚠4 POWER (HP) (AT ISA CONDITIONS)	ALT / MCP / CRUISE 0 / 350 / 247 5K / 359 / 256 10K / 358 / 262 15K / 348 / [illegible] 20K / 327 / [illegible] 25K / 298 / 250 30K / 265 / 240 35K / 231 / 228 RPM / 2800 / 2300	ALT / MCP / CRUISE 0 / 350 / 229 5K / 367 / 242 10K / 374 / 251 15K / 366 / 256 20K / 351 / 256 25K / 323 / 250 30K / 290 / 240 35K / 252 / 228 RPM / 2400 / 2150	ALT / MCP / CRUISE 0 / 350 / 228 5K / 364 / 243 10K / 368 / 252 15K / 360 / 257 20K / 343 / 255 25K / 316 / 250 30K / 280 / 240 35K / 245 / 228 RPM / 2400 / 2150	ALT / MCP & CRUISE / ECONOMY CRUISE 0 TO 17K / 360 / 297 20K / 320 / 264 25K / 250 / 206 30K / 185 / 153 35K / 120 / 99 RPM / 2300 / 2300	ALT. / MCP / CRUISE 0 TO 21K / 320 / 250 25K / 275 / 250 30K / 227 / 208 35K / 190 / 176 RPM / 2400 / 2000	ALT / MCP / CRUISE 0 TO 21K / 320 / 250 25K / 275 / 250 30K / 227 / 208 35K / 190 / 176 RPM / 2400 / 2000	⚠3 GATE DATA (see tables below)
SFC (LB/HP HR)	0 TO 35K / 0.600 / 0.446	0 TO 35K / 0.486 / 0.358	0 TO 35K / 0.334 / 0.331	0 TO 17K / 0.313 / 0.290 20K / 0.317 / 0.293 25K / 0.323 / 0.299 30K / 0.33[illegible] / 0.305 35K / 0.336 / 0.311	0 TO 25K / 0.394 / 0.371 30K / 0.380 / 0.367 35K / 0.382 / 0.369	0 TO 25K / 0.372 / 0.355 30K / 0.370 / 0.354 35K / 0.378 / 0.357	
SCALING POWER	LINEAR	LINEAR	LINEAR	LINEAR	LINEAR	LINEAR	LINEAR
SCALING SFC	NONE	NONE	NONE	SCALE AS PER ENCLOSURE 2	NONE	NONE	SCALE AS PER ENCLOSURE 3
COOLING REQUIREMENT PERCENT SHP	100 %	77.6 %	79.3 %	70.3 %	58.5 %	61.1 %	3 % GROSS ESHP

GATE DATA FOR 250 INSTALLED CRUISE ESHP (25K, M=0.4, TIT=2260°F) ⚠3

TAKEOFF POWER AT SEA LEVEL ISA TIT=2710°F

KTAS	ISHP	FF	T
0	494	[illegible]	78
50	496	255	69
100	500	257	62
150	507	[illegible]	54
200	515	[illegible]	48

MAX CLIMB MAX CRUISE POWER TIT=2260°F

ALT → KTAS	SEA LEVEL ISHP	FF	T	10K ISHP	FF	T	18K ISHP	FF	T	25K ISHP	FF	T
0	301	[illegible]	64	264	[illegible]	58	227	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	303	[illegible]	58	269	[illegible]	52	232	[illegible]	48	190	[illegible]	44
100	307	[illegible]	52	274	[illegible]	47	237	[illegible]	43	196	[illegible]	39
150	313	[illegible]	46	280	[illegible]	42	243	[illegible]	39	203	[illegible]	[illegible]
200	322	[illegible]	41	289	[illegible]	38	253	[illegible]	[illegible]	213	[illegible]	[illegible]
250	334	[illegible]	37	300	[illegible]	34	265	140	[illegible]	225	[illegible]	[illegible]
300	349	[illegible]	34	315	[illegible]	32	278	[illegible]	[illegible]	240	[illegible]	[illegible]

REDUCED CRUISE POWER A TIT=2100°F

ALT → KTAS	SEA LEVEL ISHP	FF	T	10K ISHP	FF	T	18K ISHP	FF	T	25K ISHP	FF	T
0	232	[illegible]	59	209	[illegible]	[illegible]	[illegible]	112	49	[illegible]	[illegible]	44
50	235	[illegible]	53	[illegible]	[illegible]	47	190	112	44	163	95	40
100	238	[illegible]	47	218	[illegible]	[illegible]	194	[illegible]	39	165	[illegible]	35
150	243	[illegible]	41	[illegible]	[illegible]	37	[illegible]	[illegible]	35	[illegible]	[illegible]	31
200	250	[illegible]	36	[illegible]	136	35	[illegible]	[illegible]	31	174	[illegible]	28
250	260	[illegible]	32	[illegible]	[illegible]	29	213	121	27	182	103	25
300	276	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	225	129	[illegible]	[illegible]	107	22

REDUCED CRUISE POWER B TIT=2000°F

ALT → KTAS	SEA LEVEL	10K ISHP	FF	T	18K ISHP	FF	T	25K ISHP	FF	T
[illegible]		184	120	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
200		191	[illegible]	30	170	[illegible]	[illegible]	[illegible]	[illegible]	26
250		200	[illegible]	26	180	[illegible]	[illegible]	[illegible]	[illegible]	23
300		211	[illegible]	23	190	[illegible]	21	[illegible]	[illegible]	20

EXRAPOLATE LINEARLY TO 35K FT

⚠1 BASIC WEIGHT TO BE SCALED WITH POWER OUTPUT
ADDITIONAL WEIGHT IS CONSTANT (NOT SCALED)
ALL WEIGHTS ARE IN POUNDS

⚠2 CG LOCATION REFERENCED TO PROP FLANGE AND CRANKSHAFT ℄ (EXCEPT GATE)
GATE LATERAL AND VERTICAL POSITION REFERENCED TO PROPSHAFT ℄

⚠3 GATE DATA SCALED AS INDICATED ~ ISHP INSTALLED SHAFT HORSEPOWER - HP
FF FUEL FLOW - LB/HR T - EXHAUST THRUST - LBS

⚠4 CURRENT AND MODERATE RISK SPARK IGNITION ENGINES
EXPERIENCE A POWER LOSS OF ONE PERCENT PER 6°F RISE IN AMBIENT TEMPERATURE
OTHER IC ENGINES ARE NOT SENSITIVE TO TEMPERATURE VARIATION
GATE DATA IS BASED ON DENSITY ALTITUDE

TABLE IV
MISCELLANEOUS ENGINE DATA

a) Cooling drag data supplied by TCM for max cruise with cowl flaps closed

INSTALATION	ENGINE: TSIO-550	ENGINE: GTSIO-420	ENGINE: GTSIO-420SC
SINGLE	.0404 sqm (.435 sqft)	.0229 sqm (.247 sqft)	.0193 sqm (.208 sqft)
TWIN	.0321 sqm (.345 sqft)	.0182 sqm (.196 sqft)	.0153 sqm (.165 sqft)

b) Fuel Compatability

ENGINE	FUEL: AVGAS	DIESEL	JET FUELS	OTHERS
TSIO-550	X			
TSIO-420	X			
GTSIO-420SC	?	?	X	?
GTDR-246		X	X	
RC2-47, & -32	X	X	X	X
GATE		?	X	X

c) INSTALLATION WEIGHTS

DIESEL AND ALL SPARK IGNITION	kg	lb
BATTERY	10.4	23
PROPELLER	36.3	80
SPINNER	1.8	4
MOUNTING ISOLATORS	2.3	5
OVER-VOLTAGE RELAY	.5	1
PROP ATTACH HDWR.	1.8	4
EXHAUST PIPE	1.8	4
TOTAL	54.9	121

GATE	kg	lb
BATTERY	29.5	65
PROPELLER	36.3	80
SPINNER	1.8	4
STARTER/GEN	7.7	17
VACUUM PUMP	1.4	3
ACCESSORY DRIVE	.9	2
EXHAUST PIPE	2.3	5
OIL	3.6	8
ANTI-ICE	.9	2
ADDITIONAL	4.5	10
TOTAL	88.8	196

ROTARY	RC2-47 kg	RC2-47 lb	RC2-32 kg	RC2-32 lb
BATTERY	10.4	23	10.4	23
PROPELLER	36.3	80	36.3	80
SPINNER	1.8	4	1.8	4
MOUNTING ISOLATORS	2.3	5	1.8	4
VACUUM PUMP	.9	2	.9	2
PROP ATTACH HDWR.	1.8	4	1.8	4
STARTER SWITCH	.5	1	.5	1
GOVERNOR	1.4	3	1.4	3
ALTERNATOR	7.7	17	7.7	17
TOTAL	63.1	139	62.6	138

FIGURE 1

EFFECT OF ENGINE SCALING
ON SPECIFIC FUEL CONSUMPTION
GENERAL AVIATION TURBINE ENGINE

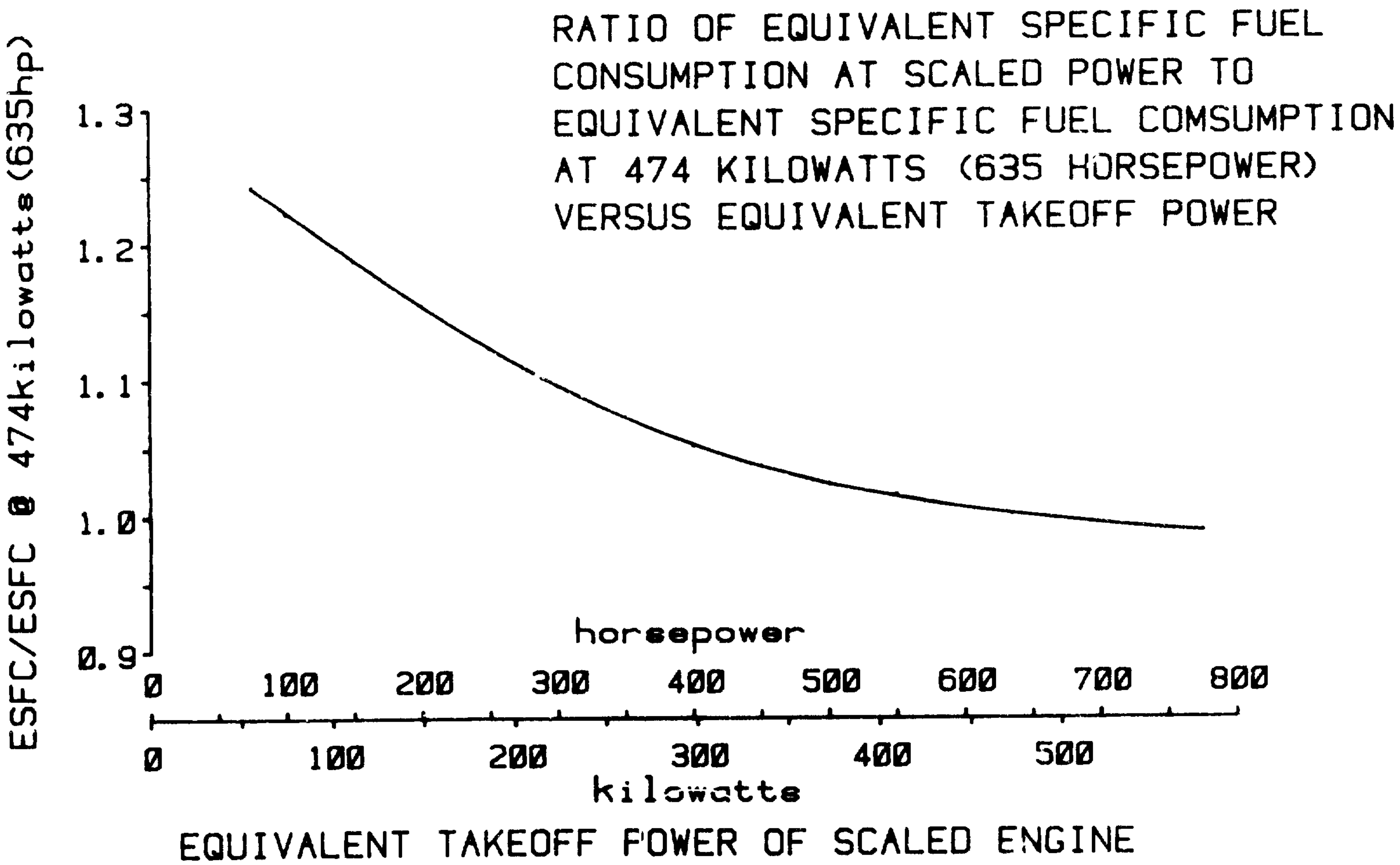


FIGURE 2

ADVANCED DIESEL ENGINE CHARACTERISTICS
EFFECT OF ALTITUDE ON ENGINE POWER
AND BRAKE SPECIFIC FUEL CONSUMPTION

FOR ENGINES RATED AT 268KW (360HP) TAKEOFF POWER
186KW (250HP) CRUISE POWER

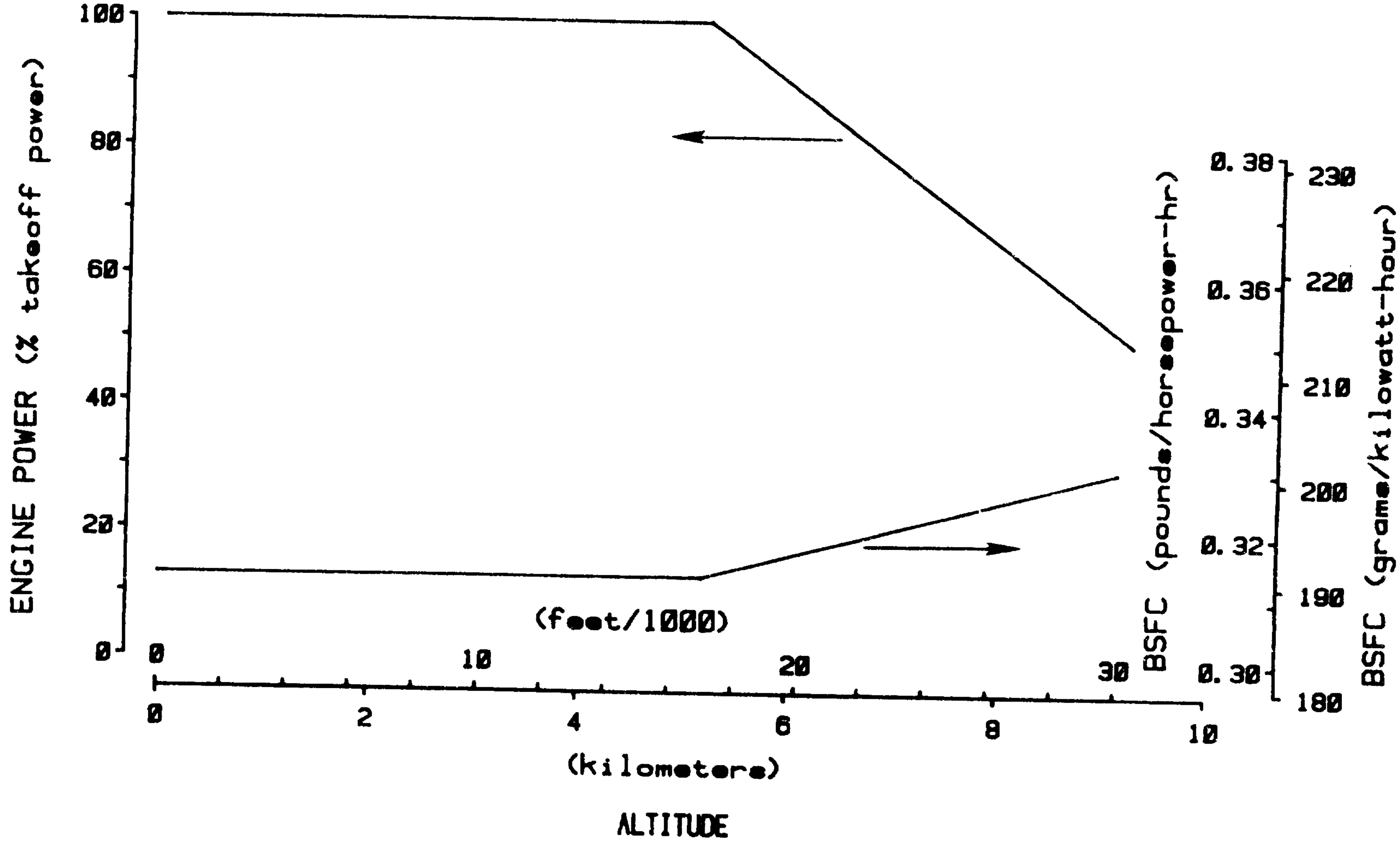
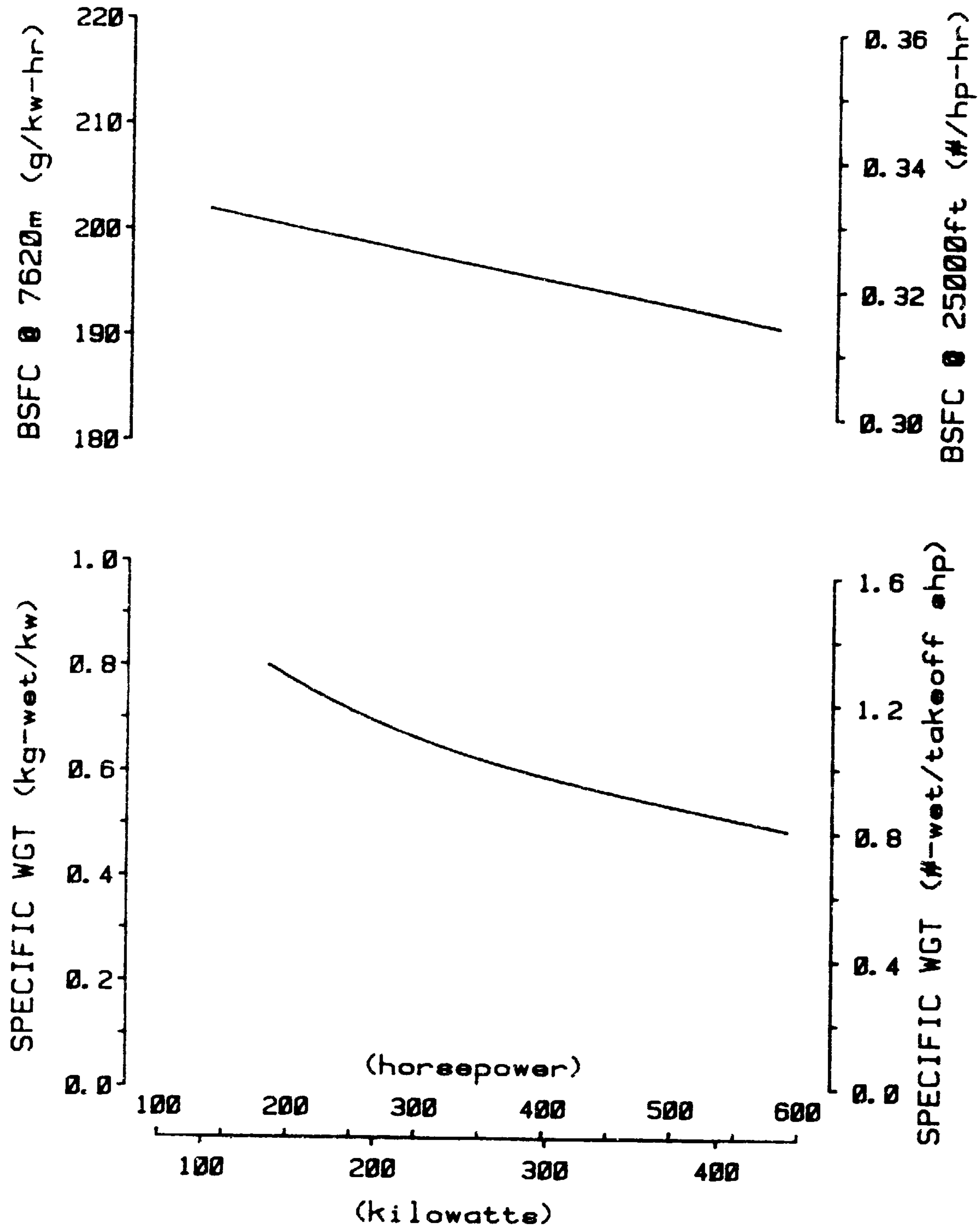


FIGURE 3

ADVANCED DIESEL ENGINE CHARACTERISTICS

EFFECT OF ENGINE SCALING ON
SPECIFIC WEIGHT AND BRAKE
SPECIFIC FUEL CONSUMPTION



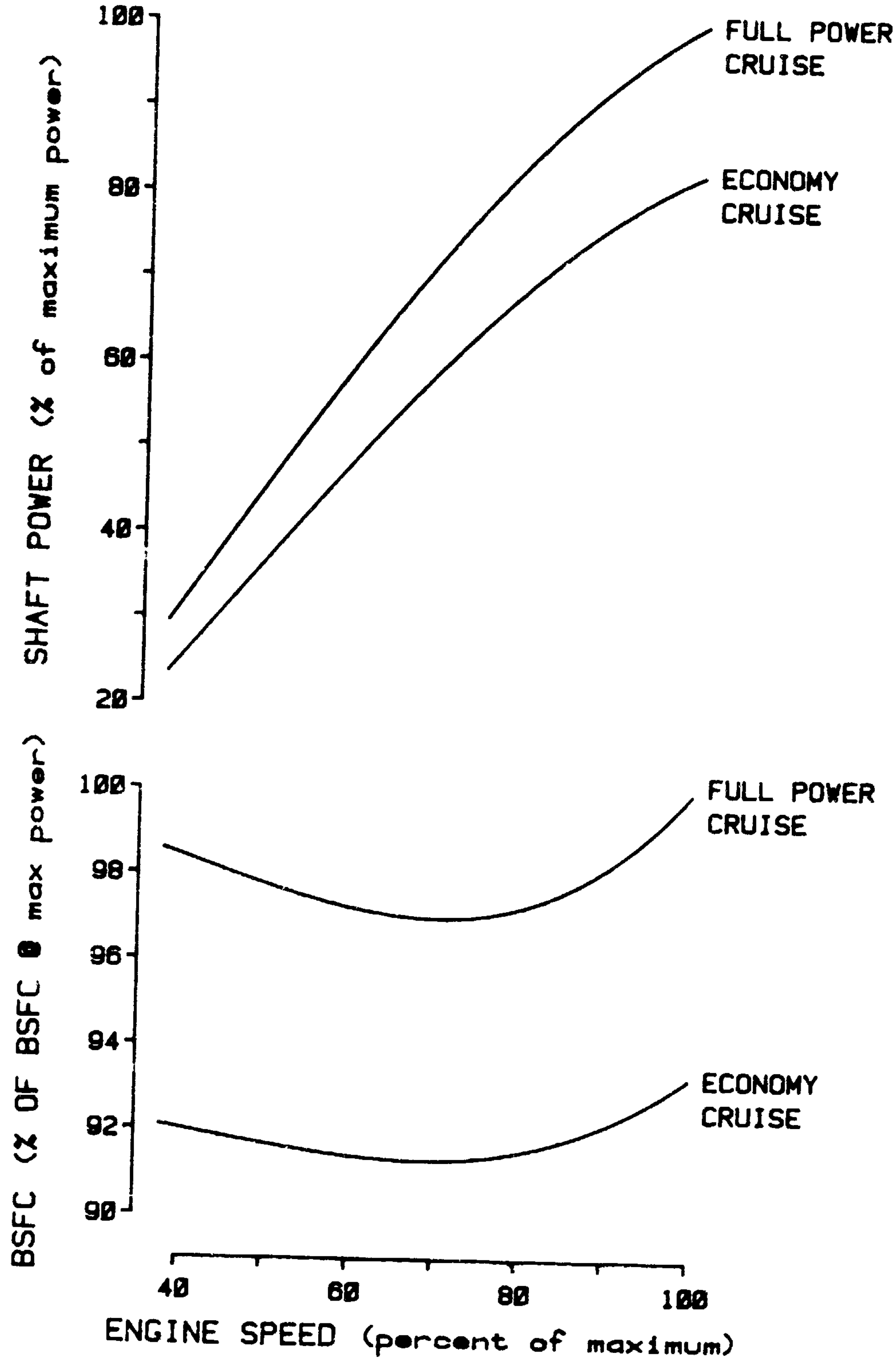
TAKEOFF POWER OF SCALED ENGINE

FIGURE 4

ADVANCED DIESEL ENGINE CHARACTERISTICS

EFFECT OF ENGINE SPEED ON POWER OUTPUT AND BRAKE SPECIFIC FUEL CONSUMPTION

ALL ALTITUDES



$$Cdi = (kCdo+.33/AR)C_L^2$$

where k is emperically determined by evaluating airplanes of a configuration similar to the one being sized. The values of skin friction coefficient and k used in this study are shown in Table V. Also shown are the increments for gear drag, flap drag and the fuselage wetted area for the different configurations (including nacelles for the twins); the sizing program determines the wetted areas of the wings and empennage and calculates the total.

One of the most difficult problems is that of estimating engine cooling drag, which can be expected to vary widely over the range of engines considered. The heat rejection rate for each engine was known, but the associated pressure drop was not available for any of the powerplants. Without precise information on both values only rough estimates of drag are possible. Reference 11 gives some typical values which can be used to estimate cooling drag, but the range of possible values is so large that the data are all but useless for a comparison such as this. Reasonable estimates based on available data and experience were used in Phase 2 and a parametric drag variation was done in Phase 3 to determine the effects of different levels. The Phase 2 cooling drags used were:

ENGINE	DRAG LEVEL	REASON
Baseline	12% of total drag	Contemporary state of the art
Diesel and Adv S.I.	8% of total drag	Reduced heat rejection; improved state of the art
Rotaries	0% of total drag	Well designed liquid cooling system
GATE	0% of total drag	Turboprop

PROPELLERS The 1941 Hamilton Standard Propeller performance method is used in deriving the Cessna data base and is, therefore, the method used for estimating thrust in the sizing program.

A propeller configuration was chosen to match the mission requirements and the characteristics of each engine. Only one propeller optimization, however, was run for each engine/mission combination; i.e., the propeller choice was not part of the synergistic design process and, therefore, the propeller configuration may not represent the absolute optimum design though it will be very close. This optimization was constrained to keep propeller diameter to low enough values that the airplane could be certified under existing noise regulations. Diameter was also not allowed to exceed 90 inches to keep gear length and weight reasonable. This optimization process considered six climb points equally weighted with one cruise point to give good overall mission performance.

TABLE V

COMPONENTS USED IN ESTIMATING DRAG

CONFIGURATION	SINGLE ENGINE		TWIN ENGINE	
EQUIVALENT SKIN FRICTION COEF.	.0049		.0055	
k*	.30		.45	
	sqm	sqft	sqm	sqft
DRAG INCREMENT FOR TAKEOFF (FLAPS & GEAR)	.237	2.55	.307	3.30
FUSELAGE WETTED AREA FOR:				
BASELINE	26.66	287.0	55.57	598.2
RC2-47	27.36	294.5	52.55	565.6
RC2-32	27.36	294.5	52.55	565.6
GTDR-246	27.56	296.7	51.86	558.2
GTSIO-420	27.30	293.9	57.37	617.5
GTSIO-420GC	28.41	305.8	58.43	628.9
GATE	27.14	292.1	52.09	560.7

$$* \; C_{D_i} = \left(KC_{D_o} + \frac{.33}{A}\right) C_L^2$$

Use of constant speed, 3-bladed propellers with Clark-Y airfoils was assumed based on experience with this class of airplane.

The recently completed NASA study on General Aviation Propellers (GAP, see Ref. 15) indicates that significant gains are possible in propeller design. These gains are due to a combination of advances in aerodynamics and materials. In keeping with the general philosophy of conservatism only about one-half of the projected gains shown for these new propellers were incorporated into the study model. The gains used were:

Change in weight	20#	decrease
Change in efficiency	3%	increase
Change in noise	2dB(A)	decrease

WING TECHNOLOGY At the present time new laminar flow airfoils are being developed, but it is not certain that they will be in common use by 1990. The problems of maintaining the necessary manufacturing tolerances in conventional metal structures at a reasonable cost and of maintaining the necessary degree of cleanliness in day to day operations are obstacles to their adoption. Therefore, the use of turbulent boundary layer airfoils was assumed.

The flaps selected are conventional single slotted surfaces with moderate aft travel during deployment extending over 85% of the span. A trimmed maximum lift coefficient (with 30 degrees landing flaps) of 2.1 was assumed for the study and should be easily attainable. With the flaps occupying most of the wing span, slot lip spoilers and feeler ailerons are employed for lateral control.

ACQUISITION COST The total cost (in 1981 dollars) is estimated as the sum of airframe cost, powerplant cost, and the cost of optional equipment.

The airframe portion is estimated by a parametric fit to the 1981 Cessna fleet. This correlation relates price as an exponential function of dry empty weight (minus propulsion system and optional equipment weights), takeoff gross weight, maximum speed and wing area. The form of the equation and the exponents used are shown in Table VI.

The engine contribution to the selling price was estimated based on an arbitrary $100 per takeoff horsepower. This is slightly higher than today's average due to the necessary investment (using inflated dollars) in research and tooling to build a completely new powerplant. The $100/hp figure was also used for the turboprop but was applied to the gross (un-installed i.e. shaft plus accessory) equivalent horsepower for takeoff (sea level, standard day, zero airspeed).

TABLE VI

ACQUISITION COSTS

COST = Costs attributable to airframe + powerplant + optional equipment

AIRFRAME -- Parametric fit to Cessna's current fleet

$$\$ = a\, W_E^{\,b}\, V_{max}^{\,c}\, S_W^{\,d}\, W^e$$

$a = 7.268188 \times 10^{-4}$

$b = 1.06942$

$c = 1.056$

$d = .65289$

$e = .72723$

W_E = BEW - Optional Eq. - Powerplant

V_{max} = Maximum Speed in Knots

S_W = Wing Area (ft^2)

W = TAKEOFF GROSS WEIGHT (lbs)

POWERPLANT -- \$100/Takeoff Horsepower Rating (IC Engines)
\$100/Equivalent Uninstalled Takeoff Horsepower (Turboprop, Sea Level Std day, Zero Airspeed)

OPTIONAL EQUIPMENT -- Typical Values for Well Equipped Planes

\$48,000 Single Engine

\$82,000 Twin Engine

The cost values chosen for optional equipment are typical of well equipped IFR airplanes as they are ordered today. For the single engine model the value used was $48,000; for the twin it was $32,000.

DIRECT OPERATING COST The components considered in estimating DOC are: engine maintenance and overhaul, propeller overhaul, airframe and systems maintenance, cost of oil, fuel and insurance, depreciation, and reserves for avionics. A description of how these items are generated is included in Appendix I. For a study of hypothetical engines some of the terms such as engine maintenance and overhaul must be generalized even further; these are shown on Table VII.

The components of direct operating cost which relate to the engine were not available for the new powerplants (for example, overhaul cost). Fortunately, these are second order terms and even large errors have little effect on the total DOC. In lieu of better numbers the inputs to the DOC estimation routine, shown in Table VII, were based on an analysis of the current Cessna fleet. Turboprop values were generalized from data supplied by manufacturers of current generation turbine engines.

Note that depreciation (to zero residual in 7.5 years) is included in this estimate, making it an amortized direct operating cost. Five hundred hours annual utilization was assumed.

NOISE Noise is estimated by an equation based on a parametric fit to the present Cessna fleet. This relates noise primarily to propeller tip mach number, but also shows it to be a function of engine horsepower, number of blades, number of engines, rate of climb and a flag indicating whether the engine is normally aspirated or turbocharged. Again, in lieu of better information, this was used directly for all of the engines.

SIZING METHOD

If the engines are to be compared on an equitable basis, then each must be installed in the "best" airframe for that engine. "Best" in the context of this study meaning lowest mission fuel, lowest DOC and lowest acquisition cost, usually achieved by minimizing weight.

The computer logic that iterates on the design variables to determine the minimum (or best) aircraft configuration is called a sizing program. This one is designed to run on a Hewlett-Packard 9825A desk top computer system. The program structure is shown schematically on Figure 5. The input module prompts the user to supply all the numerical descriptions of the mission requirements, the engine, propeller and airframe characteristics, the economic

TABLE VII

DATA BASE

DIRECT OPERATING COST
BASED ON ANALYSIS OF CURRENT CESSNA FLEET

-ENGINE MAINTENANCE

$.225 \frac{\$/hr/eng}{BHP/eng}$ (IC)

$\frac{1}{2}$ PURCHASE PRICE IN 4000 HR TBO PERIOD (TURBOPROP)

-ENGINE OVERHAUL
PARAMETRIC FIT (IC)

$\frac{1}{2}$ PURCHASE PRICE IN 4000 HR TBO PERIOD (TURBOPROP)

-AIRFRAME/SYSTEM MAINTENANCE

PARAMETRIC FITS OF CURRENT FLEET

-PROPELLER OVERHAUL

TYPICAL CURRENT VALUES

-INSURANCE (HULL & LIABILITY)

1981 RATES

-FUEL COSTS

$1.70/GAL (BOTH AVGAS AND JET FUEL)

-OIL COSTS

$6.00/GAL

-DEPRECIATION

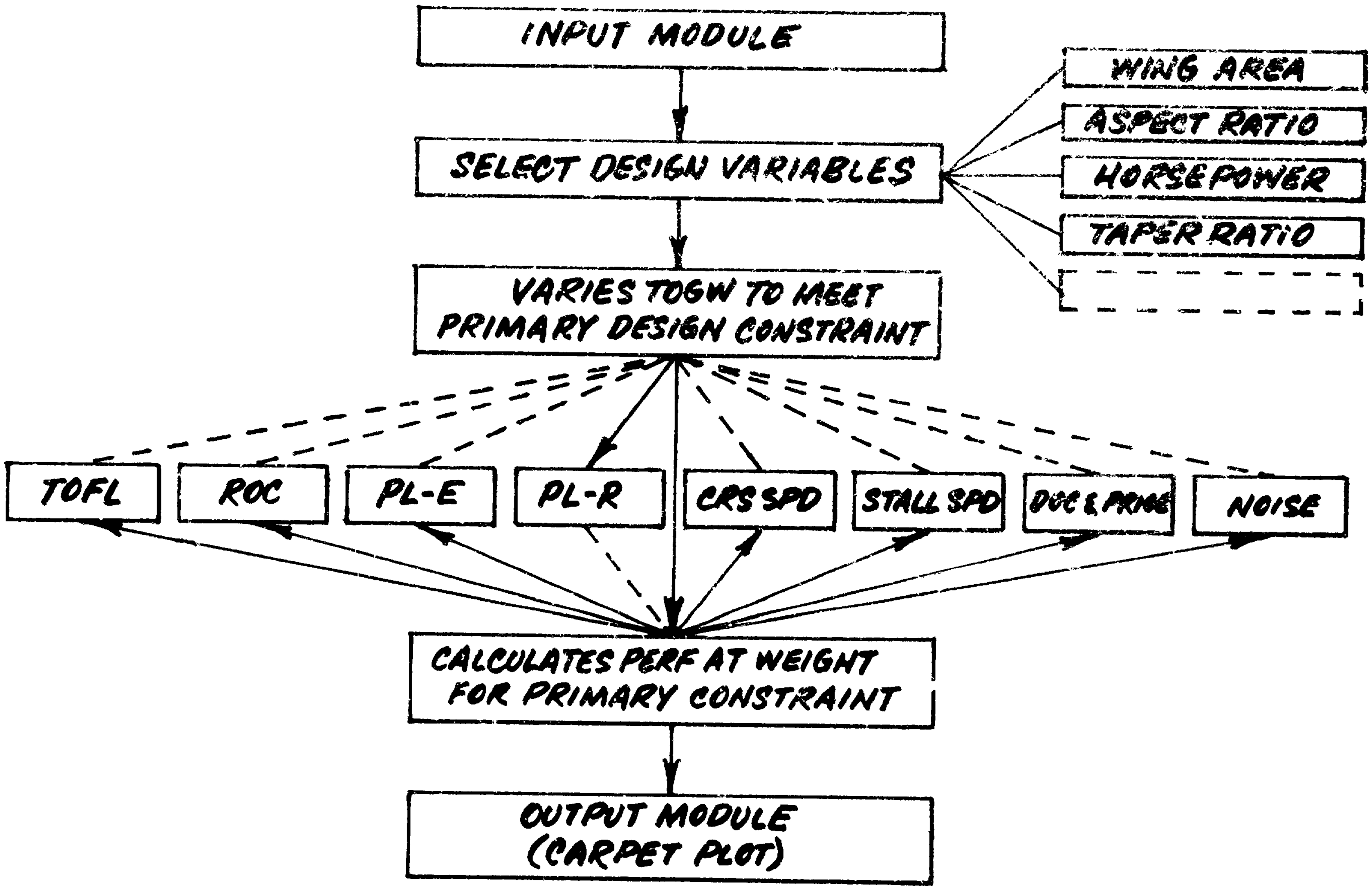
ZERO RESIDUAL IN 7.5 YEARS @ 500 HR/YR

-AVIONICS

10% OF AVIONICS COST EVERY 1000 HRS
(AVIONICS ACCOUNT FOR HALF THE OPTIONAL EQUIPMENT COSTS)

FIGURE 5

PROGRAM STRUCTURE



factors and the design characteristics to be varied as well as the range of variation.

The actual calculations then proceed automatically with a main routine sequentially changing the designated design variables. (The program works with any two factors - for example, wing area and aspect ratio - at the discretion of the analyst.) The program then varies takeoff gross weight (TOGW) to meet any of the design requirements chosen by the user. On the chart on Figure 5, a solid line is drawn showing payload-range as the selected requirement; dotted lines indicate that rate of climb, cruise speed, etc. could just as easily have been used. Once the TOGW is determined which allows the airplane to meet this primary design requirement, then that weight is used to calculate the other performance characteristics of the design. After the calculations are finished a separate module prints and automatically plots the results.

A typical output is shown on Figure 6. This is a carpet plot in which each point represents an airplane capable of carrying a 1200 pound payload 700 nautical miles. The weight is actually the independant variable used to drive the range to the selected value. Every airplane represented on this graph has a different set of performance characteristics, some better than the specified constraints and some worse.

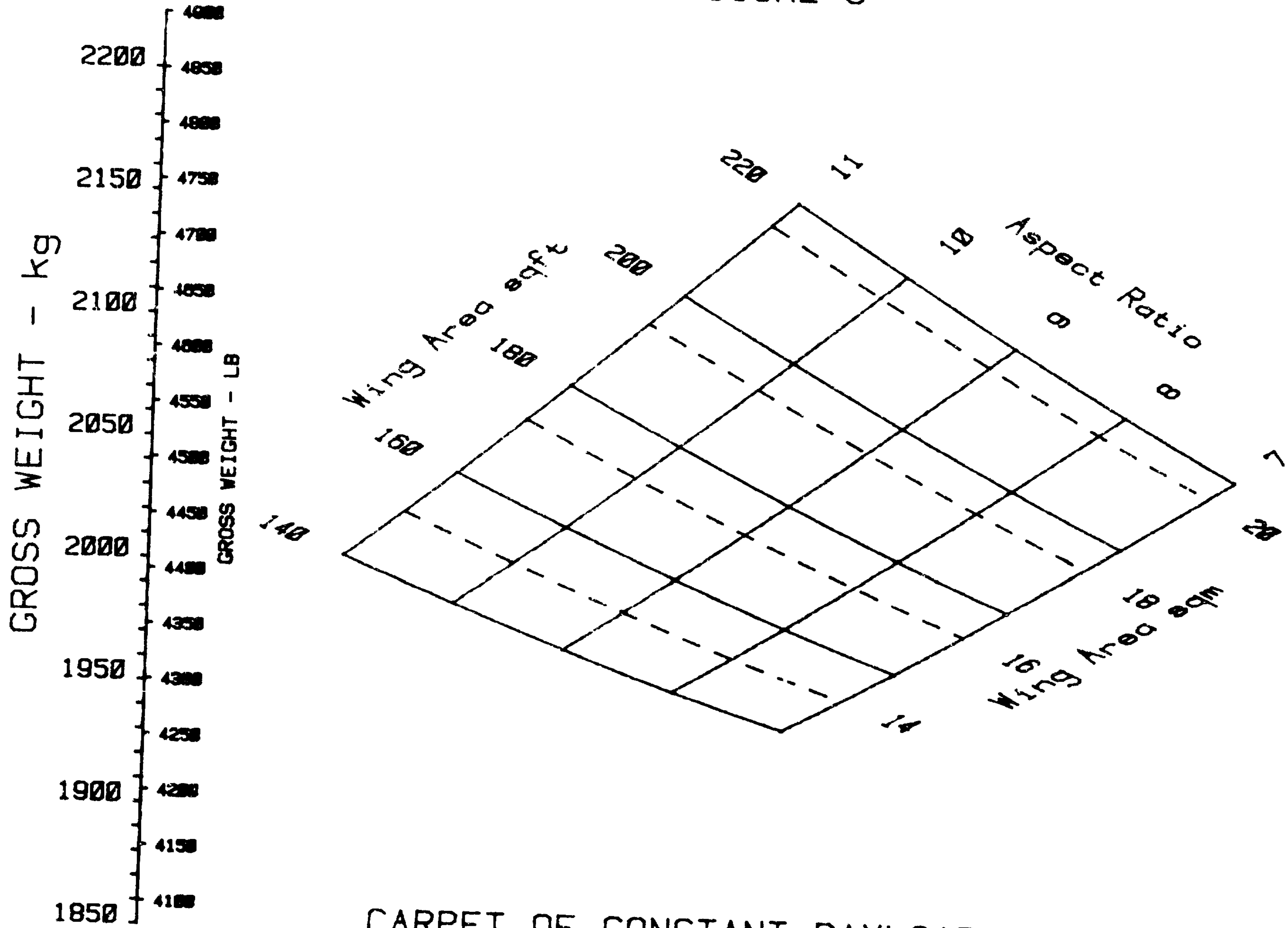
The program then plots overlays showing the boundaries where the remaining constraints are just met; an example is shown in Figure 7. The shaded region represents all airplanes that (1) are faster than the minimum cruise speed, (2) have a higher rate of climb than the minimum, and (3) have a stall speed lower than the maximum allowed. Note that although a maximum takeoff field length (TOFL) was specified it is not constraining in this example since all points in the shaded region exceed the requirement. The minimum weight point shown here occurs at a wing area of approximately 170 sq ft and an aspect ratio of around 8.5.

Actually, some 17 to 18 overlays are commonly used for each design to check such characteristics as fuel volume, acquisition cost, DOC, cruise efficiency, etc. The process makes all of the design choices visible and allows an easy tradeoff of one benefit against another.

EFFICIENT FLIGHT

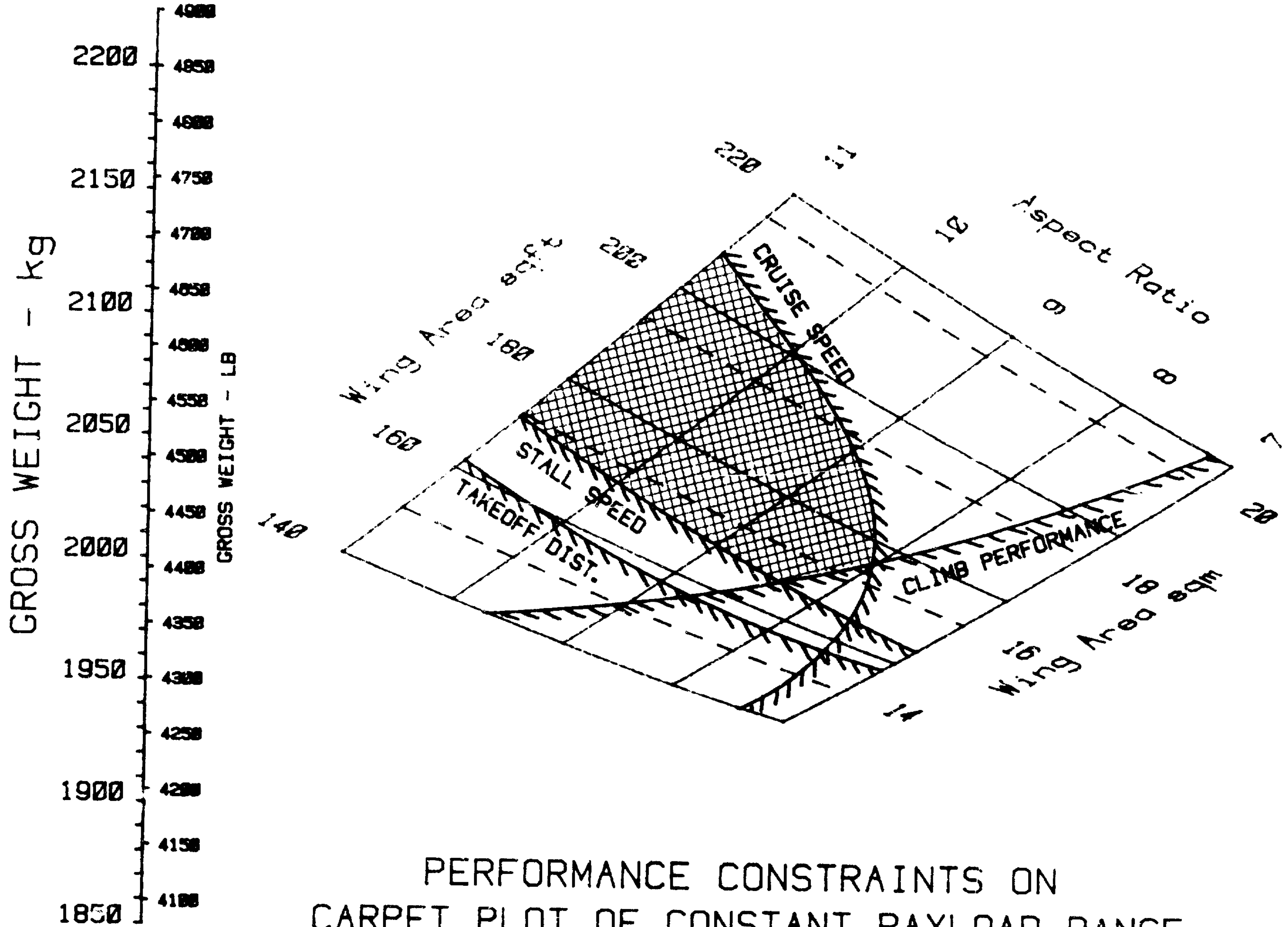
The aircraft speed that minimizes fuel consumption is the speed for maximum lift to drag ratio ($V_{L/D}$). For general aviation aircraft this usually corresponds to a power setting of around 45%; experience indicates that virtually no flights are made at this low speed. Reference 10 discusses this incompatability between common usage and best fuel speed and why it is impractical to

FIGURE 6



CARPET OF CONSTANT PAYLOAD RANGE

FIGURE 7



PERFORMANCE CONSTRAINTS ON
CARPET PLOT OF CONSTANT PAYLOAD RANGE

design an airframe to cruise at maximum L/D. Briefly summarized:

$$D/L = AV^2 + B/V^2 \text{ where:}$$

$A = \rho f/2W$ and $B = 2W/\rho b^2 \pi e$
ρ = density
f = equivalent flat plate area
W = Weight
b = wing span
e = span efficiency

High L/D is achieved by keeping the terms A and B small. Yet lowering the value of ρ (i.e., flying at higher altitudes) or raising the value of W to decrease A increases B and conversely. The same is true of the fictitous areas f and b^2 since they exist in some proportionality. Further:

$$L/D\max = \sqrt{(\pi e b^2/2f)} \text{ and } V_{L/D} = (\sqrt{2W/\rho}) / \sqrt[4]{(\pi e f b^2)}$$

which illustrates that a high value of L/D requires a low ratio of f to b^2 whereas a high value of $V_{L/D}$ requires a low product of f and b^2. Further, providing adequate power for climb means that there is an excess for cruise, making it all too easy to exceed $V_{L/D}$. If he isn't using all, or most of the power available, the pilot feels that he is wasting time.

Having reviewed this "designer's dilemma" Reference 10 goes on to introduce the concept of the "least wasteful way to waste fuel" which is the least increase in fuel per unit increase in speed above V for maximum L/D. This occurs at V* which is defined as $\sqrt[4]{3}(V_{L/D})$. On a typical trip, compared to flying at the speed for minimum fuel usage, flying at V*:

- is 32% faster
- reduces flight time by 24%
- uses only 16% more fuel

Flying at V* minimizes the power required to maintain kinetic energy in the face of energy dissipation due to drag, and minimizes the energy required to move a given weight a given distance at a given velocity.

The new engines considered in this study produce a given horsepower at a much lower weight and with a greatly reduced fuel consumption compared to current powerplants. This affects the sizing process in many ways. Consider again Figure 7: reanalysis with one of the advanced engines would lower the entire carpet to smaller weights and would also, on the new carpet, cause the cruise speed line to move up and to the right while the stall speed, climb and takeoff lines would move down. The resultant minimum moves to low values of wing area and aspect ratio.

Instinctively this does not seem right, in particular the large reduction in aspect ratio. And indeed it is not a good way to size the airplane because advantage is being taken of the engine's good performance to make the wing inefficiently small. The problem is to match the airframe's efficiency to the engine's characteristics. As shown above, it is impractical to design an airplane to cruise at $V_{L/D}$; it is practical, however, to size one to cruise at V* (or slightly higher at maximum cruise power so that reduced power settings still maintain speeds around V*). V* was, therefore, used as another constraint in this study to insure that efficient airframes were matched to each of the new engines. An alternative approach would be to constrain the cruising speed to that of the baseline, but this can also lead to choosing less efficient airframes. This is discussed in detail on page 97.

AIRFRAME DESIGN AND INSTALLATION CONCEPTS

BASELINE AIRFRAMES

SINGLE ENGINE The Cessna P210 is the basis for the single engine configuration chosen for the study (shown in Figure 8 with the baseline engine). The cabin area pressure vessel is little different in configuration from the P210 except for being stressed to the higher pressurization level required for cruise at 25000 ft while maintaining a 10000ft cabin altitude. The wing is redesigned for the new flap and roll control system and sized for the design mission of this study. The tail is resized as needed and uses higher aspect ratio surfaces than the P210. The engine compartment is changed, as necessary, to accommodate each engine.

TWIN ENGINE The twin engine baseline configuration for the study is shown on Figure 9. The design is seen to use a conventional, low wing layout with wing mounted engines. The wing configuration itself is the same as that of the single engine airplane except for the engine nacelles and is sized appropriately for each engine.

No installation drawings for the baseline engine were done since it is physically almost identical with the contemporary TSIO-520 which is in widespread use.

ROTARY-POWERED AIRFRAMES

SINGLE ENGINE The single engine design with the rotary engine is shown in Figure 10. For considerations of passenger comfort the size of the cabin compartment cannot be appreciably altered from the baseline. The wing cannot be moved very far fore or aft for both structural and aerodynamic reasons, so the lighter engine must be moved forward to keep the center of gravity in the correct position. This has the advantage of opening up a baggage compartment in front of the cabin which increases available baggage volume and provides an alternate loading area which makes center of gravity control easier. The wing area is smaller than for the baseline since the weight is considerably lower.

The engine installation drawing is shown in Figure 11 for the RC2-32 engine; the RC2-47 would be essentially the same. The small size of the engine allows it to fit easily into the cowl whose cross section is largely set by the cabin size. Accessibility should be very good relative to the baseline engine installation. The radiator, which should be large and thin for minimum cooling drag, fits comfortably within the cowl. There is also room to expand the cooling air to low speeds before entering the radiator, which is another requirement for low cooling drag. Induction

FIGURE 8

BASELINE SINGLE

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

GROSS WT, LB	4460
SPAN, FT	40.2
ASPECT RATIO	9.5

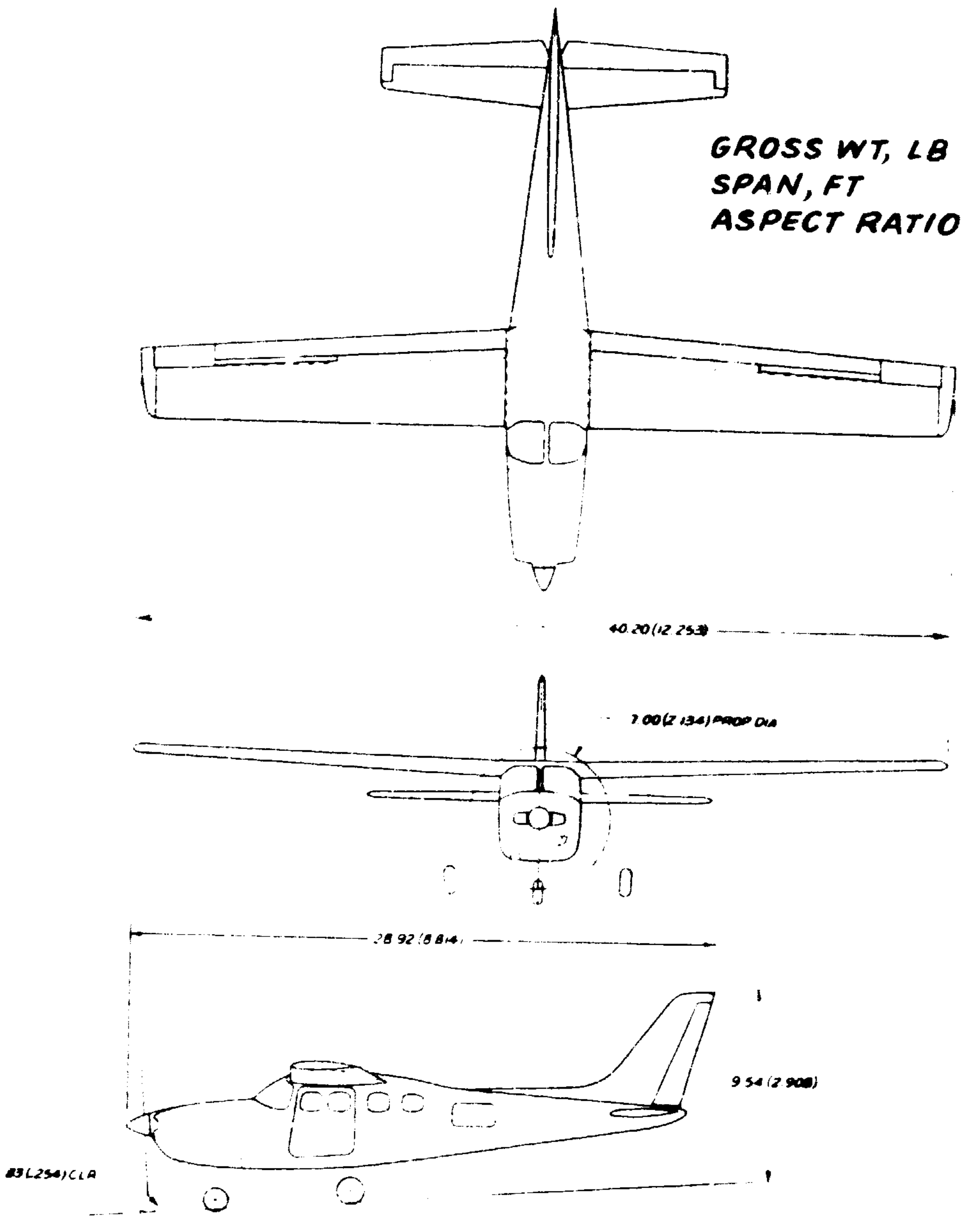


FIGURE 9
BASELINE TWIN
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

GROSS WT, LB	6850
SPAN, FT	44.5
ASPECT RATIO	11.0

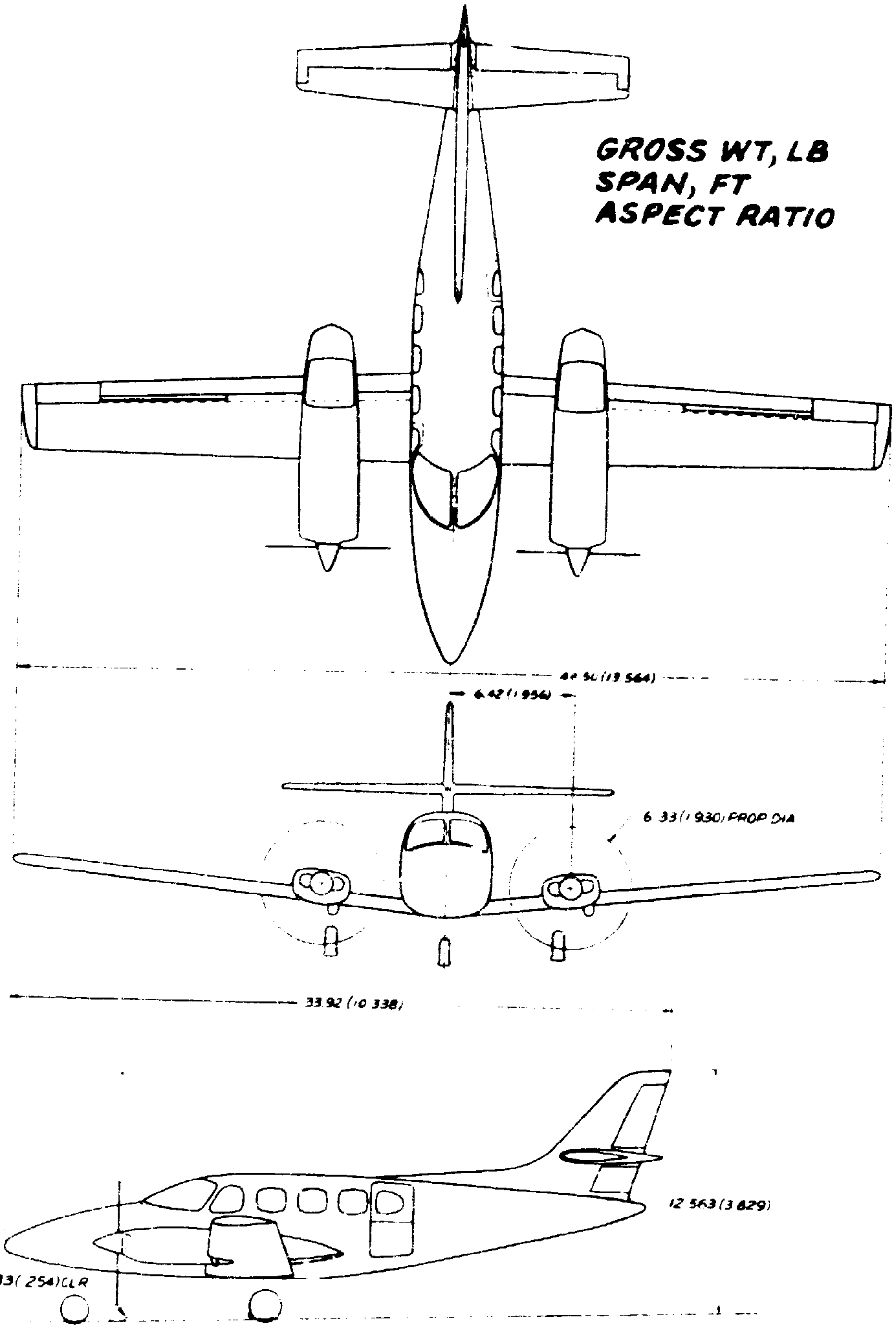


FIGURE 10
ROTARY SINGLE

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

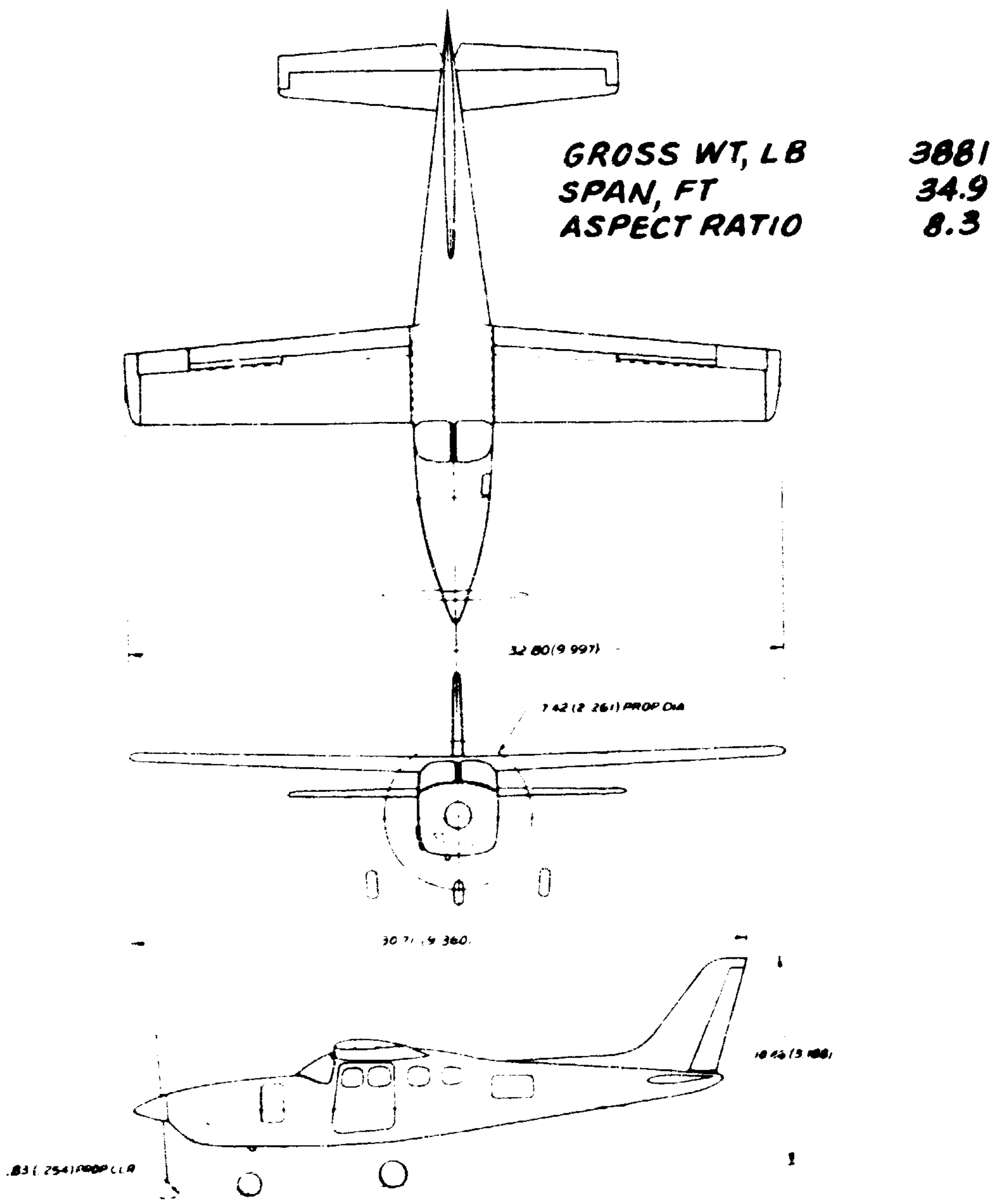
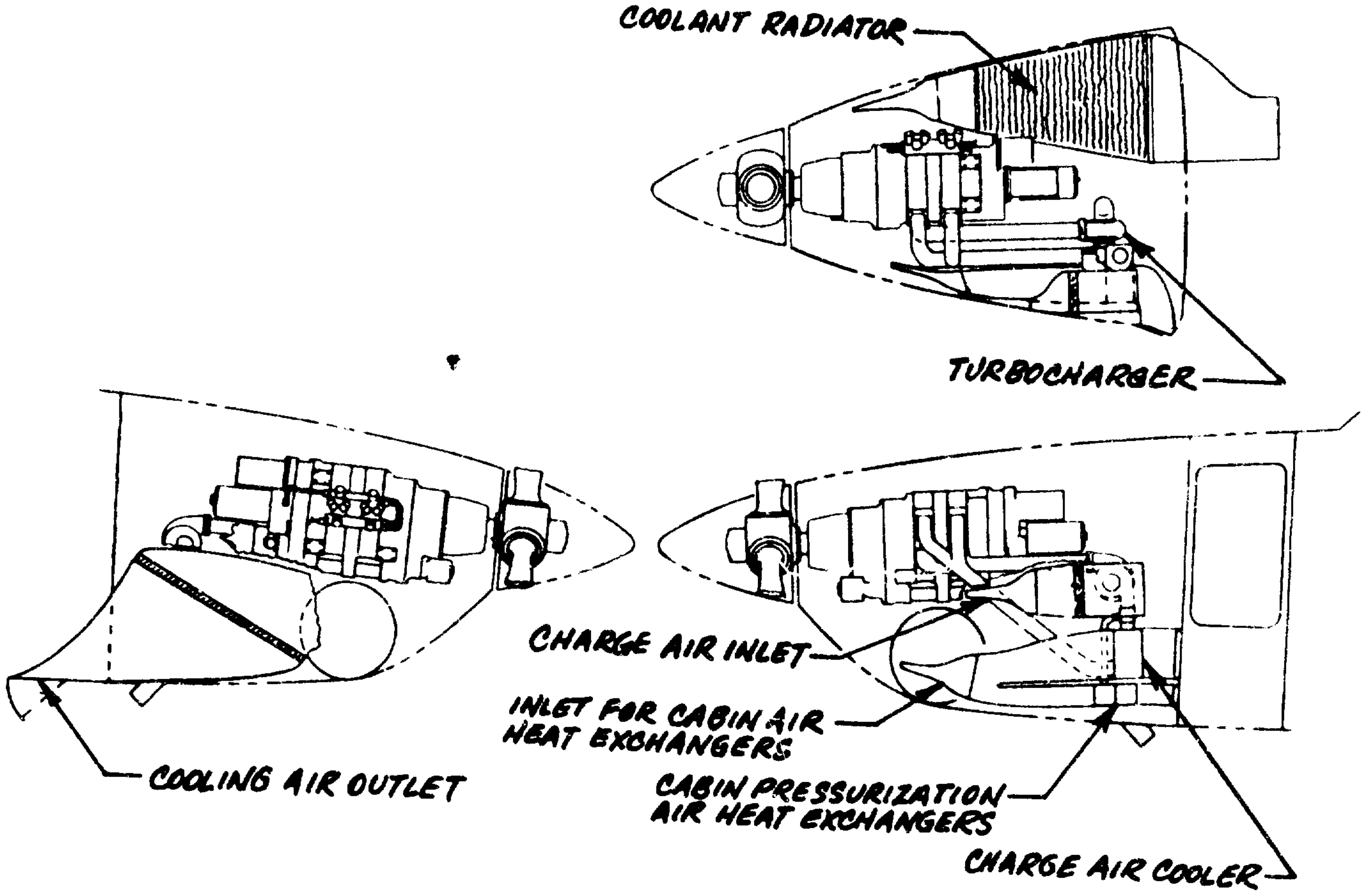


FIGURE 11

RC2-32 HIGHLY-ADVANCED ROTARY ENGINE SINGLE-ENGINE INSTALLATION CONCEPT



and cooling air are brought in through NACA flush scoops on the sides of the cowling.

Air is bled from the compressor for cabin pressurization. Provision must be made both to cool and to heat it depending on the outside conditions. For air cooled engines the pressurized air is passed through a heat exchanger that is either cooled by outside ram air or heated by air from a shroud around the exhaust pipe. A similar system is envisioned for the liquid cooled engine except that the ram air passes through an auxiliary radiator before flowing over the pressurized air heat exchanger. Temperature is controlled by the amount of coolant flowing through this auxiliary radiator. For cooling the cabin air no fluid is used, while for heating, the auxiliary radiator is fully functional and the heat is transferred back to the exchanger.

<u>TWIN ENGINE</u> The twin engine configuration using the rotary engines is shown in Figure 12. The radiators are housed in leading edge extensions on the inboard wing panels (similar to the installation on the British DeHavilland Mosquito of WW II). Although there might be slight weight penalties for this configuration, due to extra piping and coolant, it is felt that these would be offset by other advantages. Detailed examination of these factors was, however, beyond the scope of this study.

Again the radiators are kept large and thin with minimum flow velocities through them in order to reduce the cooling drag. They occupy the entire leading edge of the wing from the nacelle to the fuselage. Deice or antiice for the inboard wing sections will require careful development. Use of heat from the engine coolant to melt the ice will likely result in a runback of water which will refreeze on the wing and flaps. Pneumatic boots, however, will be difficult to locate without being affected by the heat and/or disturbing the flow into the radiator. It is possible that some combination of these two would work but more likely a completely new system will be required such as a glycol exuding leading edge.

The installation is shown on Figure 13. As can be seen the size of these engines allows the designer to produce extremely clean, thin nacelles with small cross sections and reduced wetted areas with a consequent reduction in drag. Further the destabilizing moment of the nacelle, which varies with the square of the width, is greatly reduced thus increasing stability or reducing the required tail size. Note that the spinners are the minimum size to accommodate the propeller hubs.

The exhaust is ducted overboard on the outside of the nacelle to minimize cabin noise. There is insufficient room in the small nacelles to bend the exhaust pipe down and duct the exhaust out the bottom, and a vertical turbocharger installation is not recommended because of problems routing the induction air to the compressor face.

FIGURE 12
ROTARY TWIN

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

	RC2-47	RC2-32
GROSS WT, LB	5788	5454
SPAN, FT	38.1	35.0
ASPECT RATIO	9.8	8.45

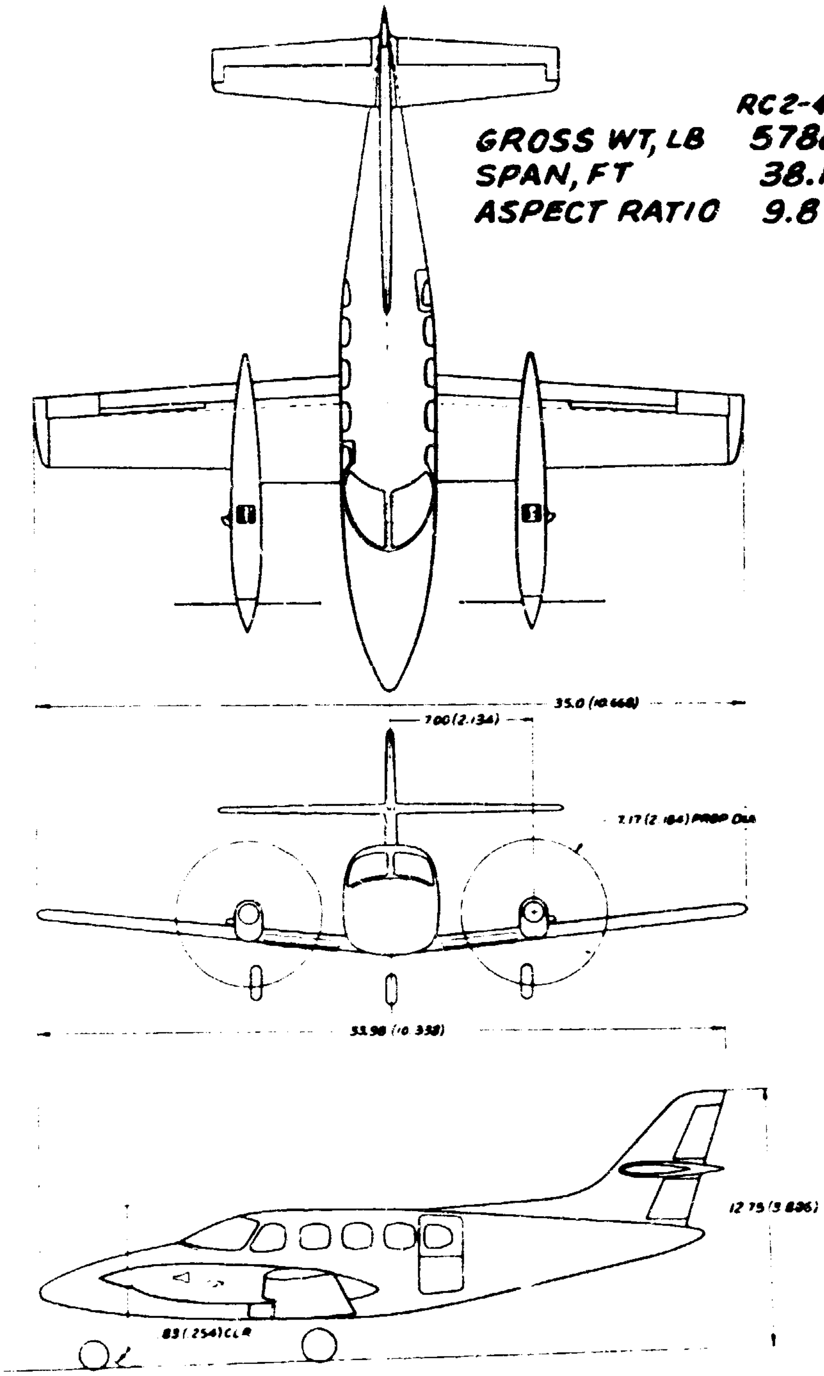
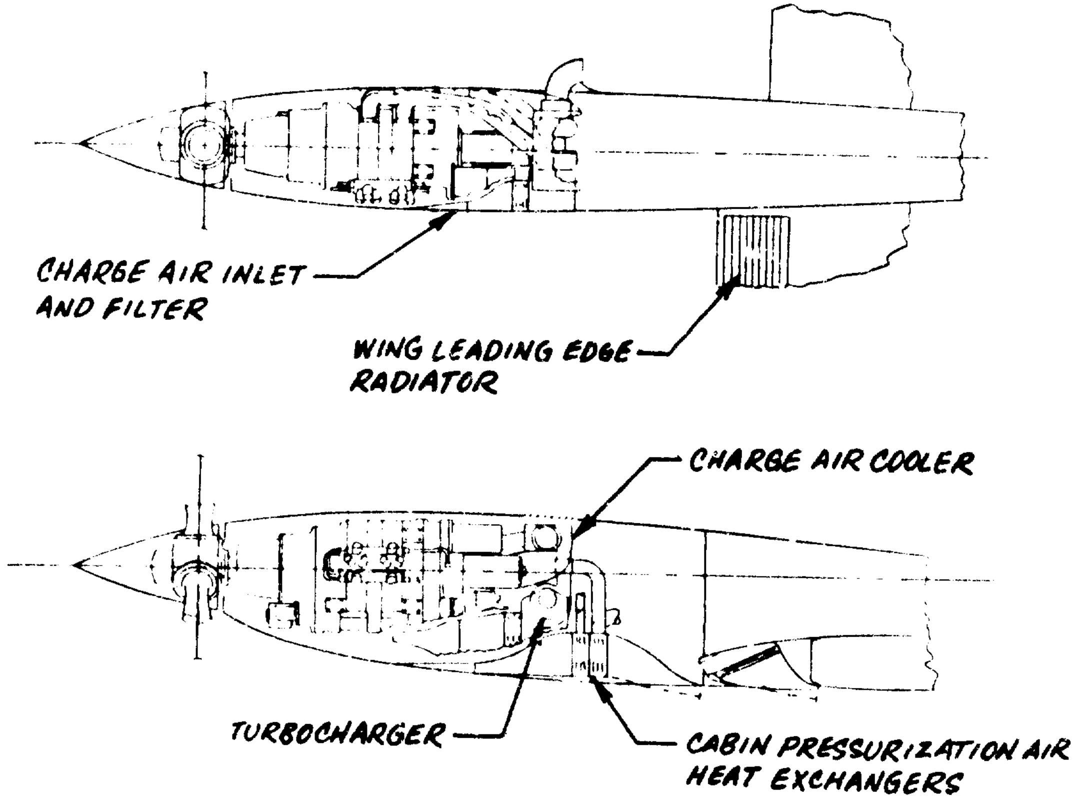


FIGURE 13

RC 2-32 HIGHLY-ADVANCED ROTARY ENGINE
TWIN-ENGINE INSTALLATION CONCEPT



DIESEL POWERED AIRFRAMES

SINGLE ENGINE The single engine airplane configured for the diesel is shown in Figure 14. Like the rotary, the light weight of this engine allows a baggage compartment to be added ahead of the cabin. The installation drawing is shown in Figure 15. The large frontal area of a radial presents no problem in the single since the cabin area dictates a large cross sectional area anyway. A propeller shaft extension was added for better cowling contours and an accompanying weight penalty of 3 pounds was added in the analysis.

The cabin air pressurization system employs a temperature regulation system identical to the rotary except that the auxiliary coolant radiator is replaced by an auxiliary oil radiator. (In either case should the system prove unworkable a system similar to that of an air cooled engine would probably be acceptable but would not have the simplicity of this design.)

TWIN ENGINE A similar engine installation was tried for the twin with the resultant 3-view shown in Figure 16. Compared to the baseline the nacelle shape is not bad. Compared to the rotary it is much less pleasing aesthetically, the wetted area is larger with a consequently greater drag and the large blockage area behind the propeller reduces its efficiency.

To offset these disadvantages the low profile engine configuration shown in Figure 17 was conceived. The power section is laid on its back so that the crankshaft rotates about a vertical axis with the output transferred 90 degrees through bevel gears to the propeller shaft. A 25 pound/engine weight penalty was added for this more complex gear box. This value is arbitrary and a careful design is expected to show that the new gear box is not much heavier than the one it replaces. The changes necessary to reverse the propeller rotation would be minimal.

The twin engine design utilizing this version of the diesel is shown on Figure 18. The nacelles are small and compact, shaped much like a cowling for a horizontally opposed engine. The installation itself is shown on Figure 19. This configuration will require careful attention to baffle design to provide cooling to all the cylinders. Again the spinner is the smallest that will enclose the propeller hub.

SPARK IGNITION POWERED AIRFRAMES

SINGLE ENGINE The single engine airframe adapted for the advance spark ignition engine is shown on Figure 20 and the engine installation is shown on Figure 21. These powerplants use a tuned

FIGURE 14

DIESEL SINGLE

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

GROSS WT, LB	3849
SPAN, FT	35.8
ASPECT RATIO	8.8

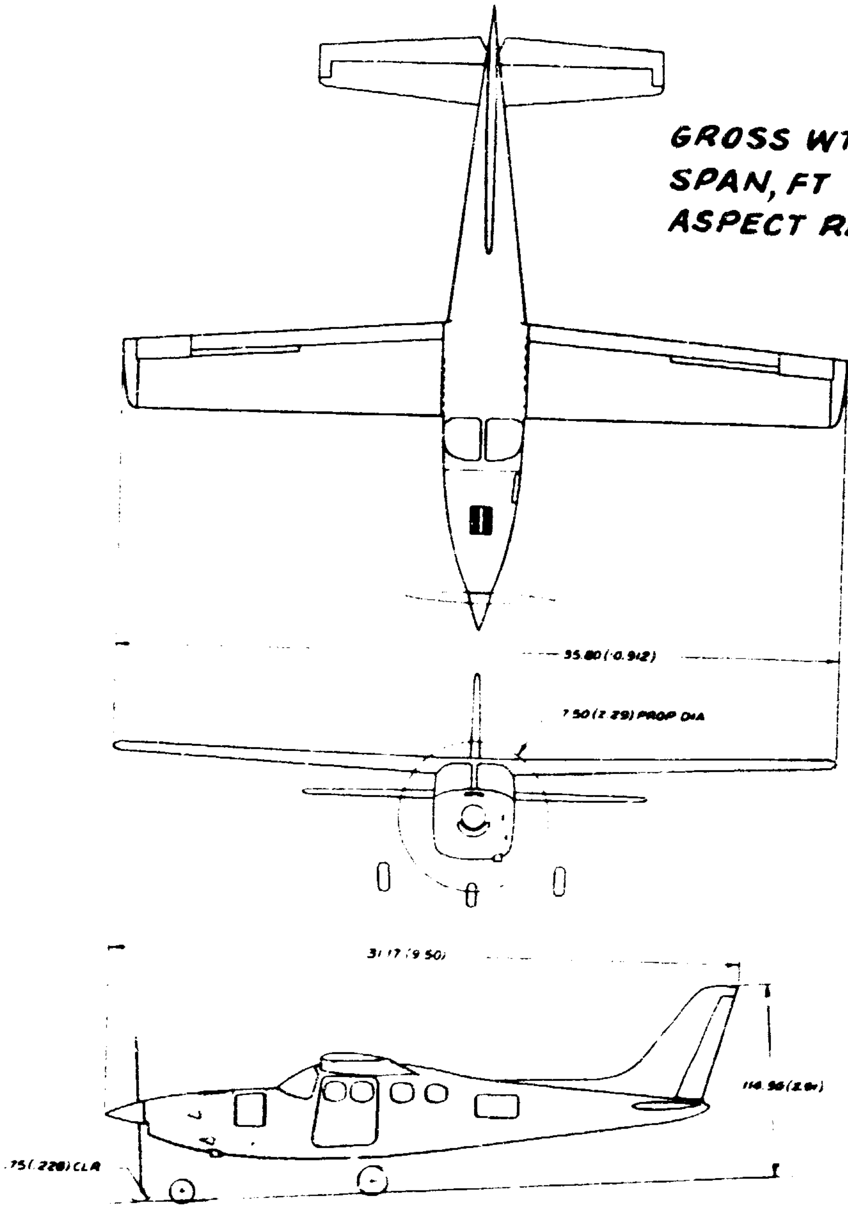


FIGURE 15

TDR-246 HIGHLY-ADVANCED DIESEL ENGINE SINGLE ENGINE INSTALLATION CONCEPT

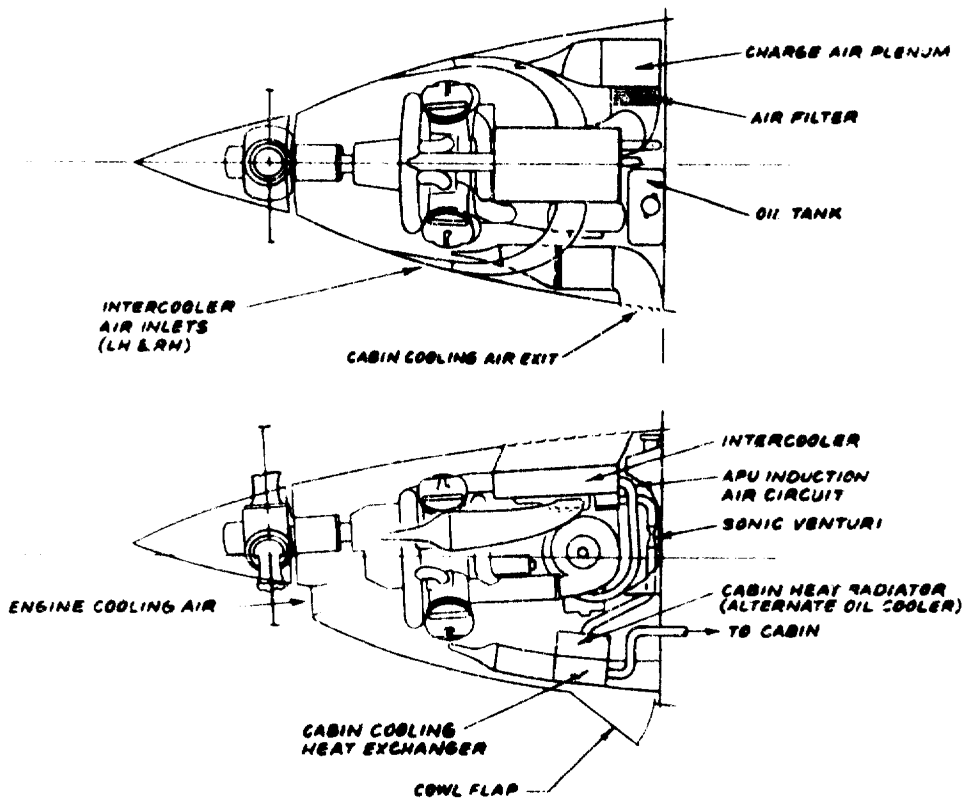


FIGURE 16
DIESEL TWIN (UPRIGHT MOUNTING)
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

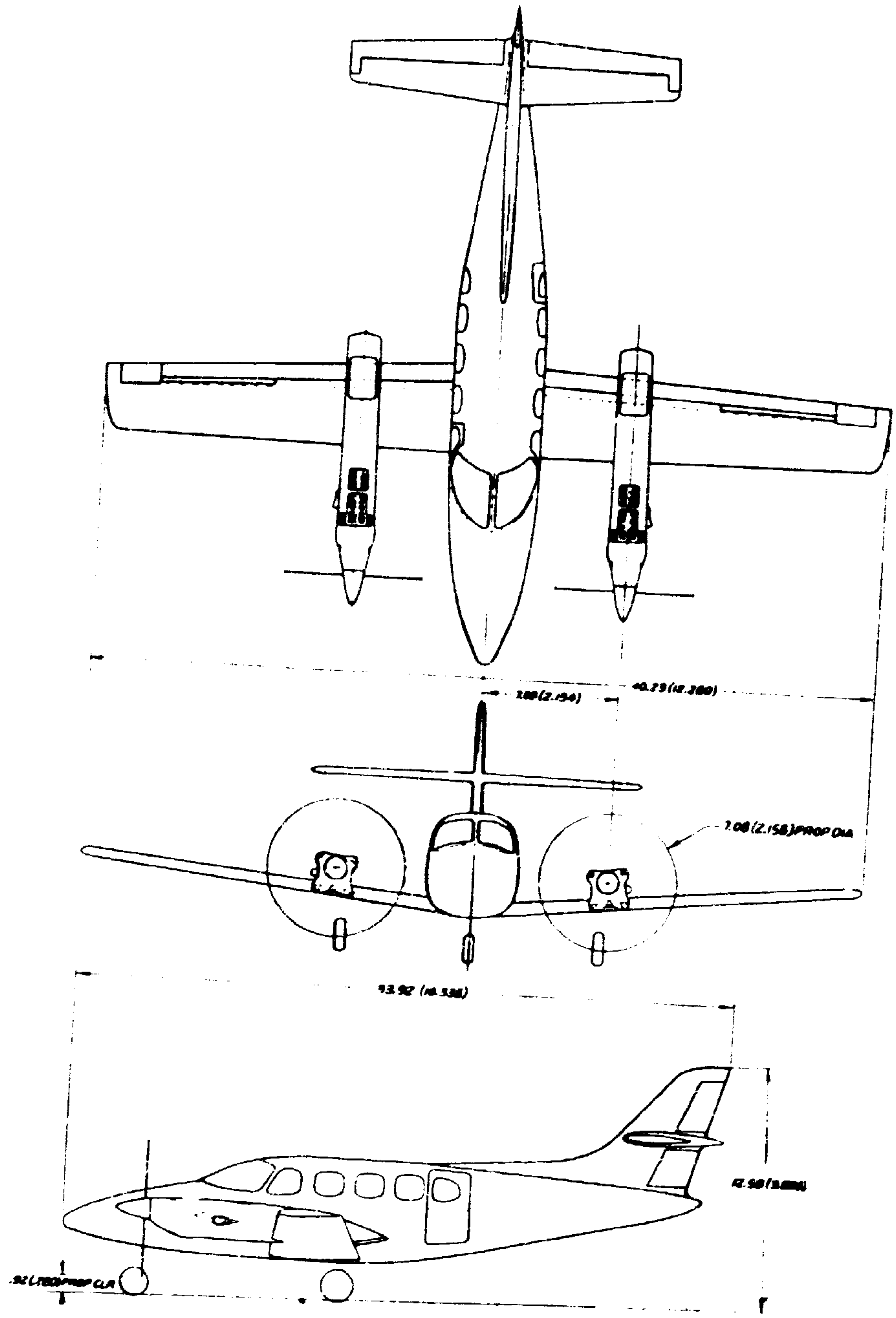


FIGURE 17

GTDR-246

LOW PROFILE CONFIGURATION

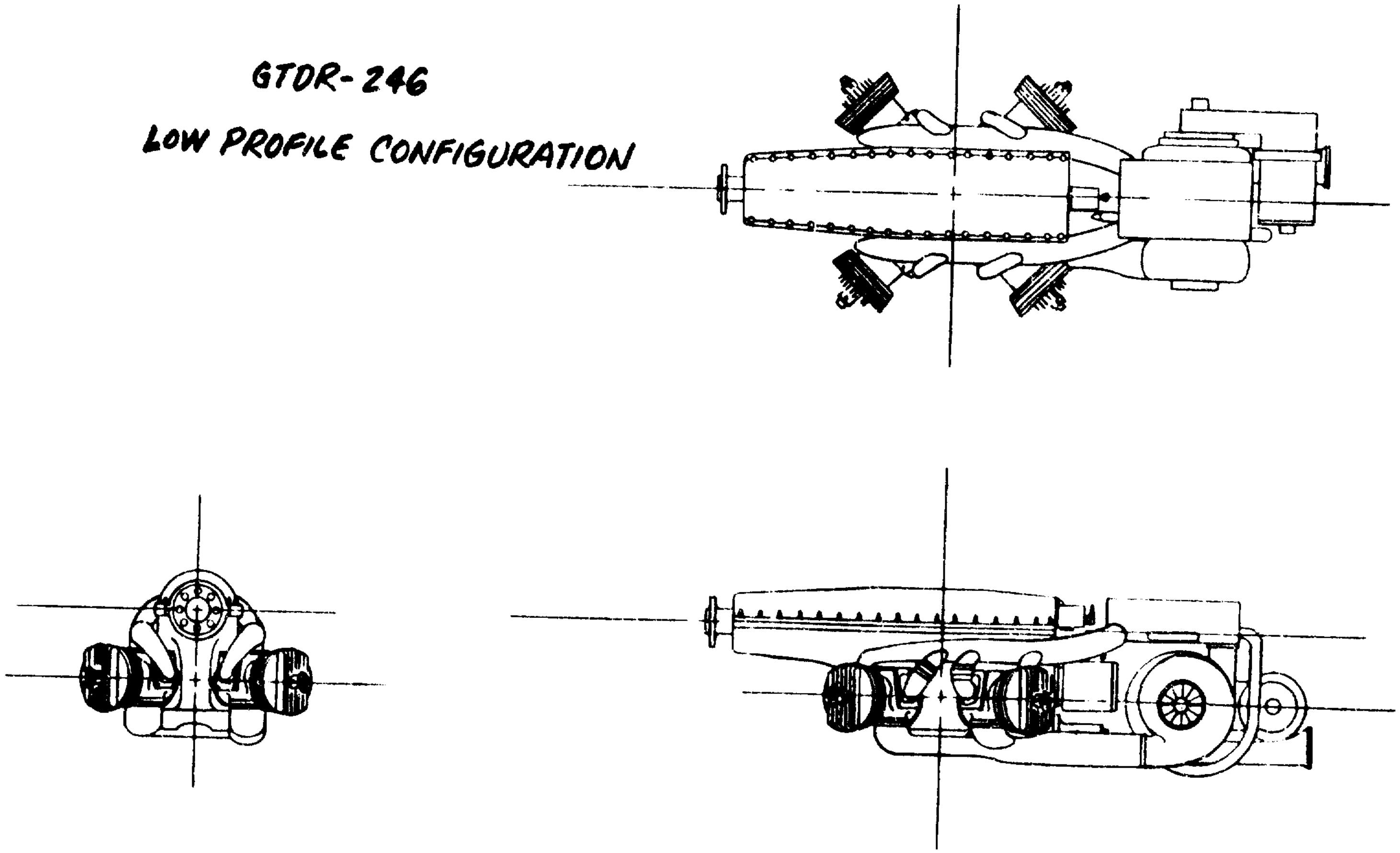


FIGURE 18

DIESEL TWIN

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

GROSS WT, LB	5753
SPAN, FT	39.1
ASPECT RATIO	10.6

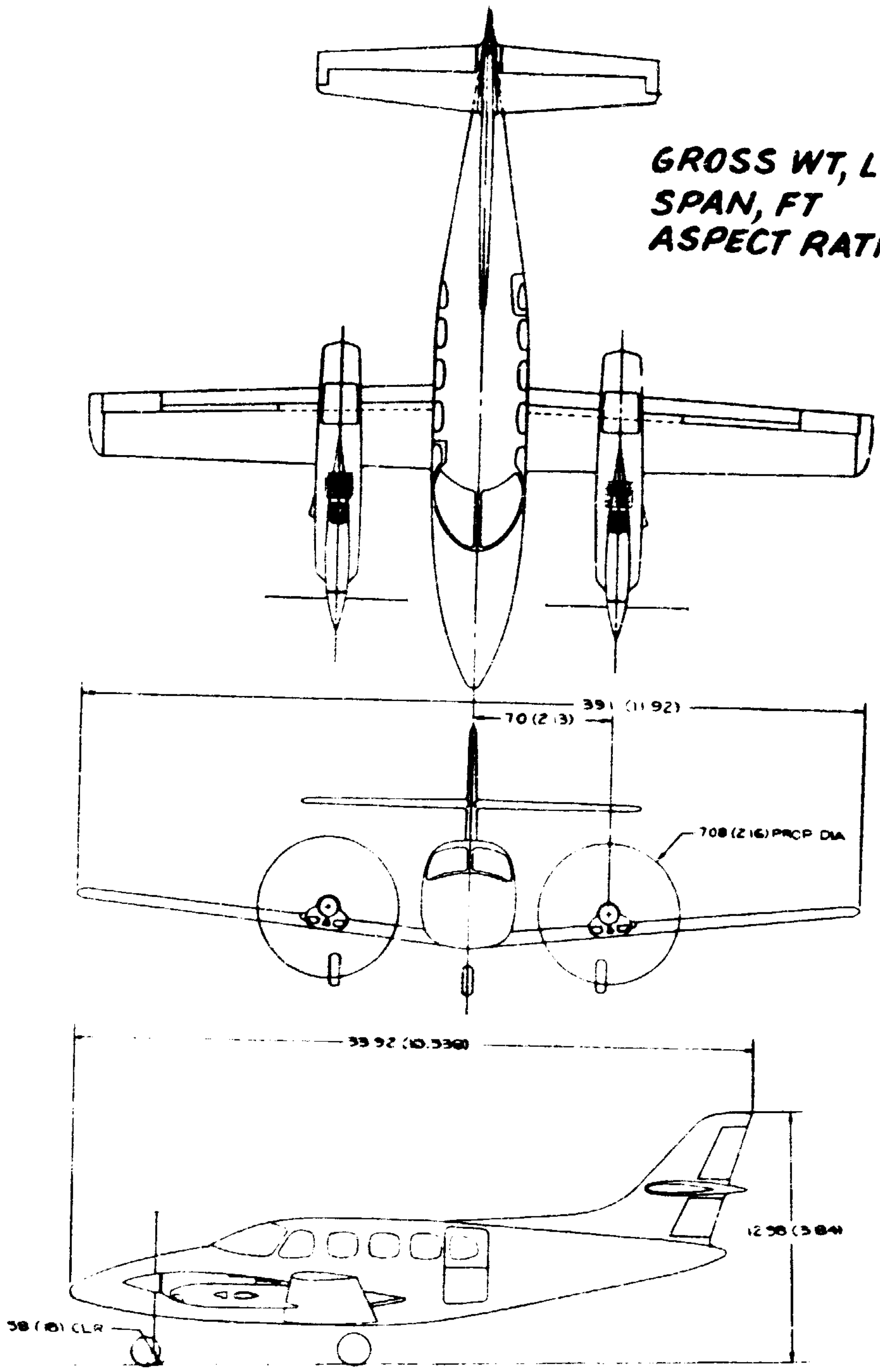


FIGURE 19

TDR-246 HIGHLY-ADVANCED DIESEL ENGINE TWIN-ENGINE INSTALLATION CONCEPT

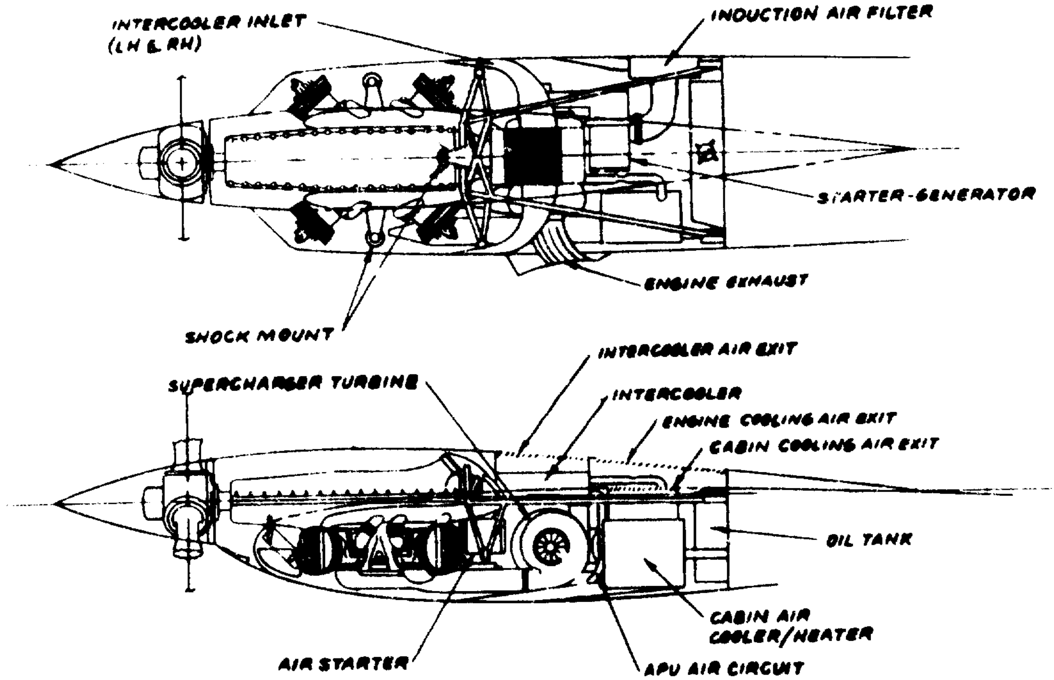


FIGURE 20
ADVANCED SPARK-IGNITION ENGINE
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

	GTSIO-420	GTSIO-420SC
GROSS WT, LB	4117	3888
SPAN, FT	37.8	35.3
ASPECT RATIO	9.15	8.55

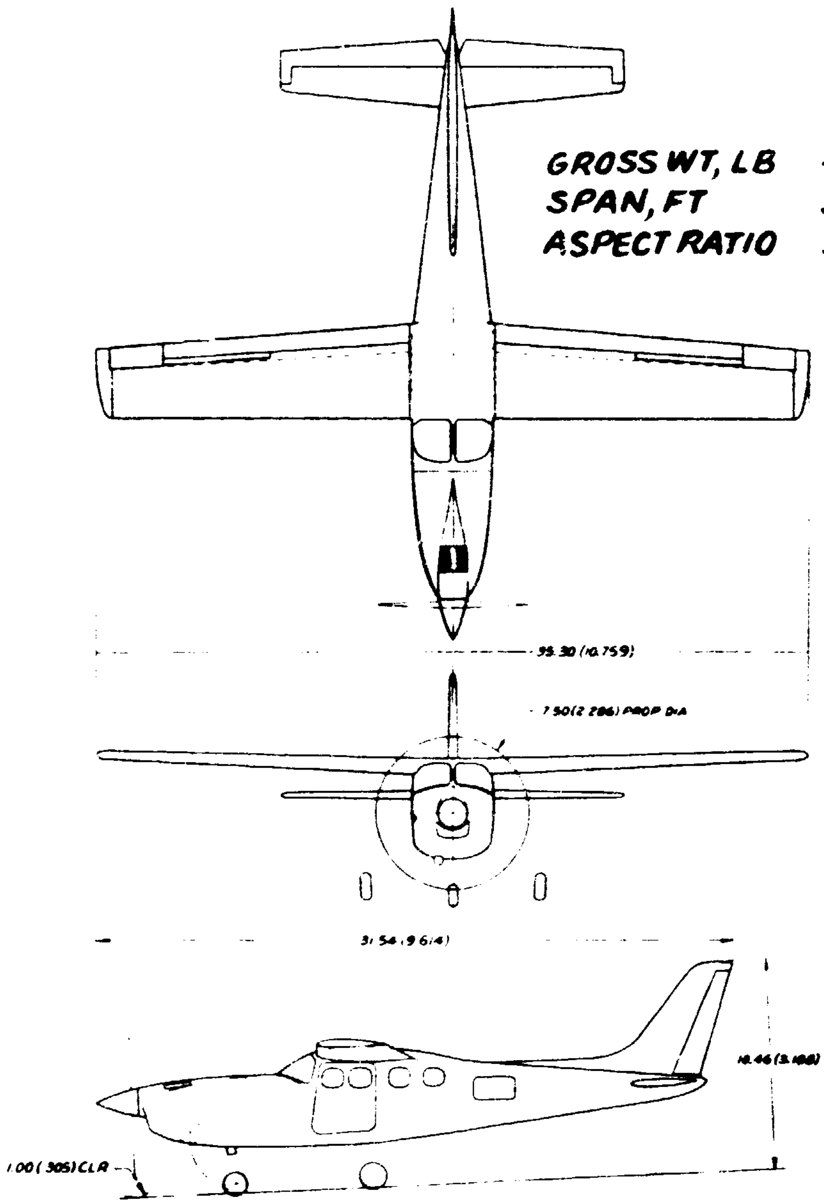
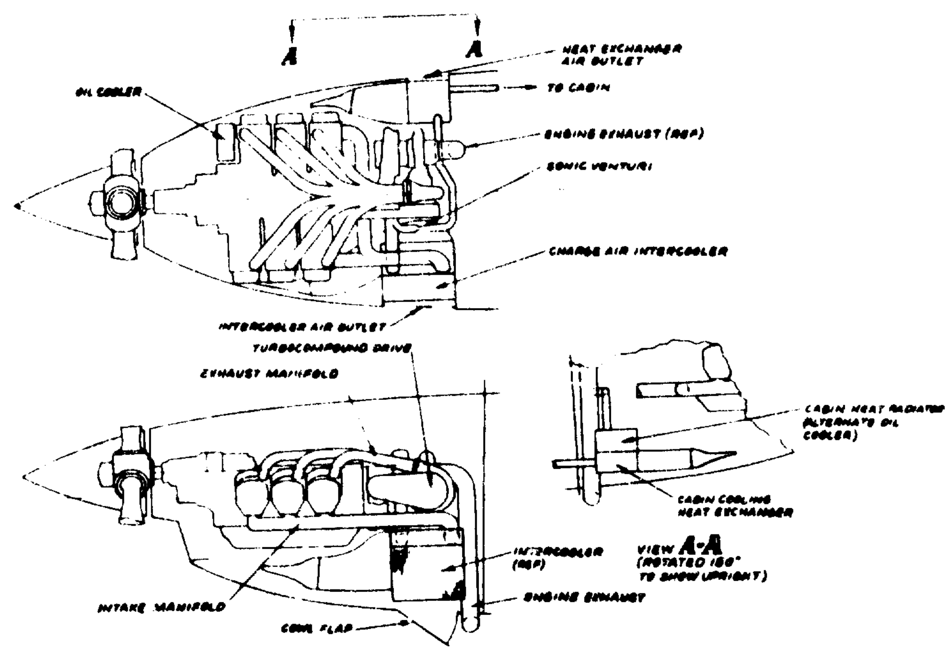


FIGURE 21

GTSIO-420SC HIGHLY-ADVANCED SPARK-IGNITION ENGINE SINGLE ENGINE INSTALLATION CONCEPT



exhaust system to improve turbocharger efficiency which makes the engines rather long. This limits the installation flexibility since the turbocharger cannot be relocated for the benefit of the airframe design. The length also precludes the installation of a nose baggage compartment.

Further the exhaust system, turbocompounding equipment and turbocharger are so located that it is unclear how accessories will be located at the back of the engine (as planned by TCM). Assuming that they are, maintenance may be difficult.

The overhead exhaust path requires an upflow cooling path. If the air is then ducted out through the top of the cowling, means must be provided to close the exit louvers in case of engine fire to prevent the blaze from coming through the cowling and destroying the windshield. If, on the other hand, the cooling air is ducted out the bottom through a cowl flap (as shown on Figure 21) then problems arise from heating of the accessories and turbocharger.

The engine designers envisioned cooling the oil by use of a finned sump. However the necessary ducting and baffling to get air to the sump and the required fin area on the sump are likely to be more complex and will weigh more than a conventional oil cooler. Therefore, Figure 21 shows a separate oil cooler.

Cabin air temperature can be controlled either by a conventional heat exchanger system or by a system similar to the diesel configuration.

<u>TWIN ENGINE</u> The twin engine spark ignition configuration and installation drawings are shown in Figures 22 and 23, respectively. Note here the relatively large nacelles. Also, whereas locating the accessories around the exhaust system was inconvenient on the single it is even more difficult in the compact nacelle of the twin.

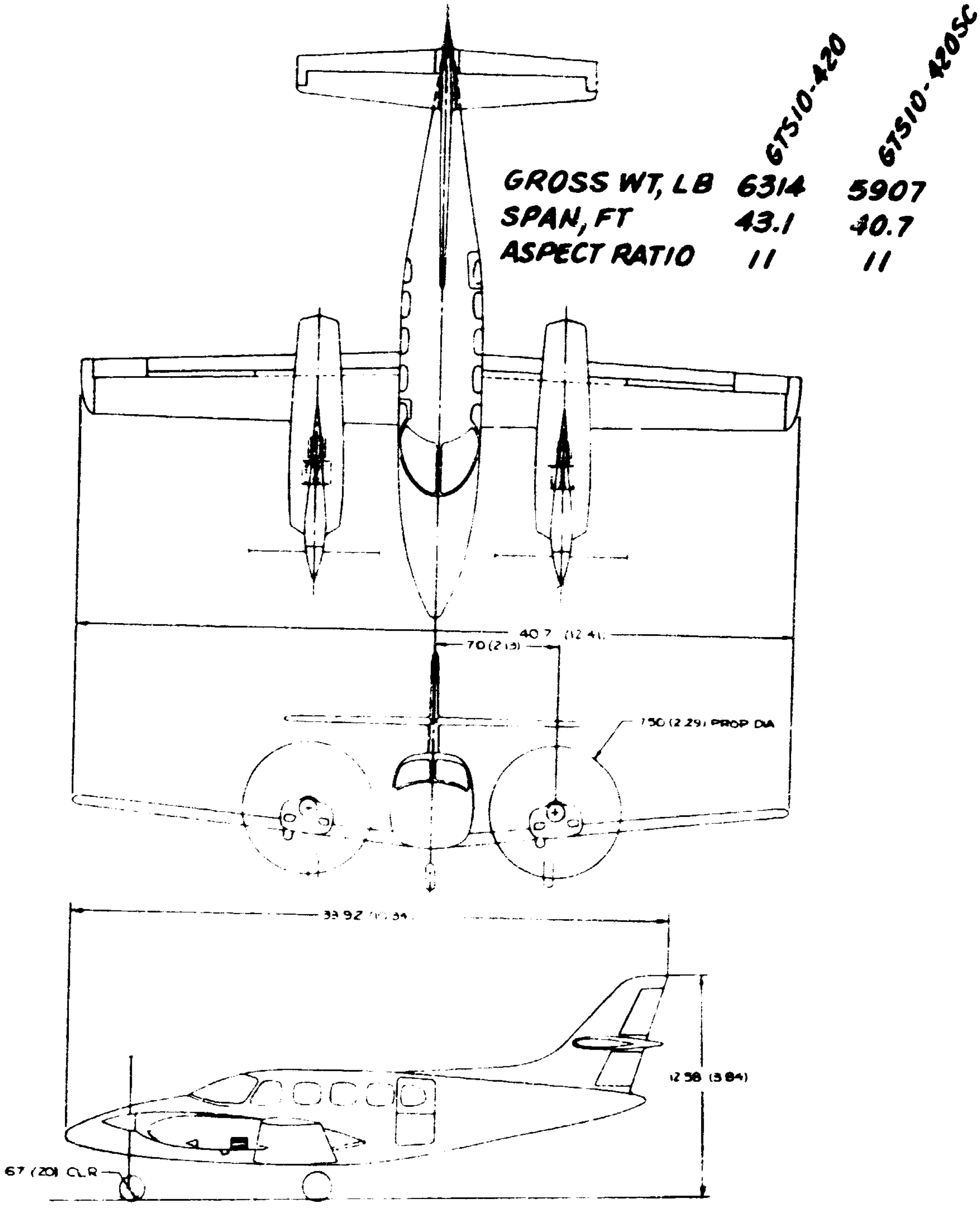
GATE POWERED AIRFRAMES

<u>SINGLE ENGINE</u> The GATE powered single is shown on Figure 24 and the installation drawings are on Figure 25.

The turboprop is very light which makes it possible to include a nose baggage compartment. The exhaust, however, is difficult to dump overboard. As shown, the exhaust ducting is rather long and takes a number of bends to reach the bottom of the airplane and yet allow room for the nose gear; it also intrudes somewhat into the nose baggage area. Leading the exhaust out the side is impractical because of possible intrusion of the exhaust products into the cabin through the door.

For heating the cabin air a system similar to that used on

FIGURE 22
ADVANCED SPARK IGNITION TWIN
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE



	6TSIO-420	6TSIO-420SC
GROSS WT, LB	6314	5907
SPAN, FT	43.1	40.7
ASPECT RATIO	11	11

FIGURE 23

GTSIO-420 SC HIGHLY-ADVANCED SPARK-IGNITION ENGINE
TWIN-ENGINE INSTALLATION CONCEPT

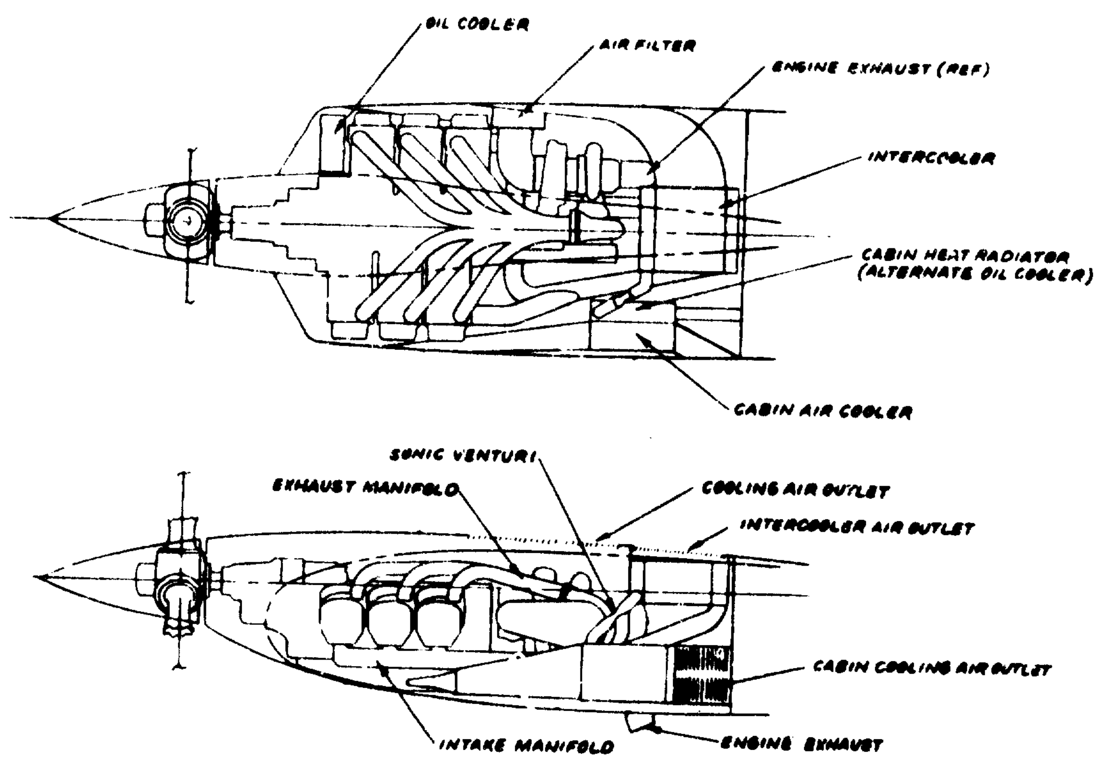


FIGURE 24
GATE SINGLE
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

GROSS WT, LB	3907
SPAN, FT	35.5
ASPECT RATIO	8.45

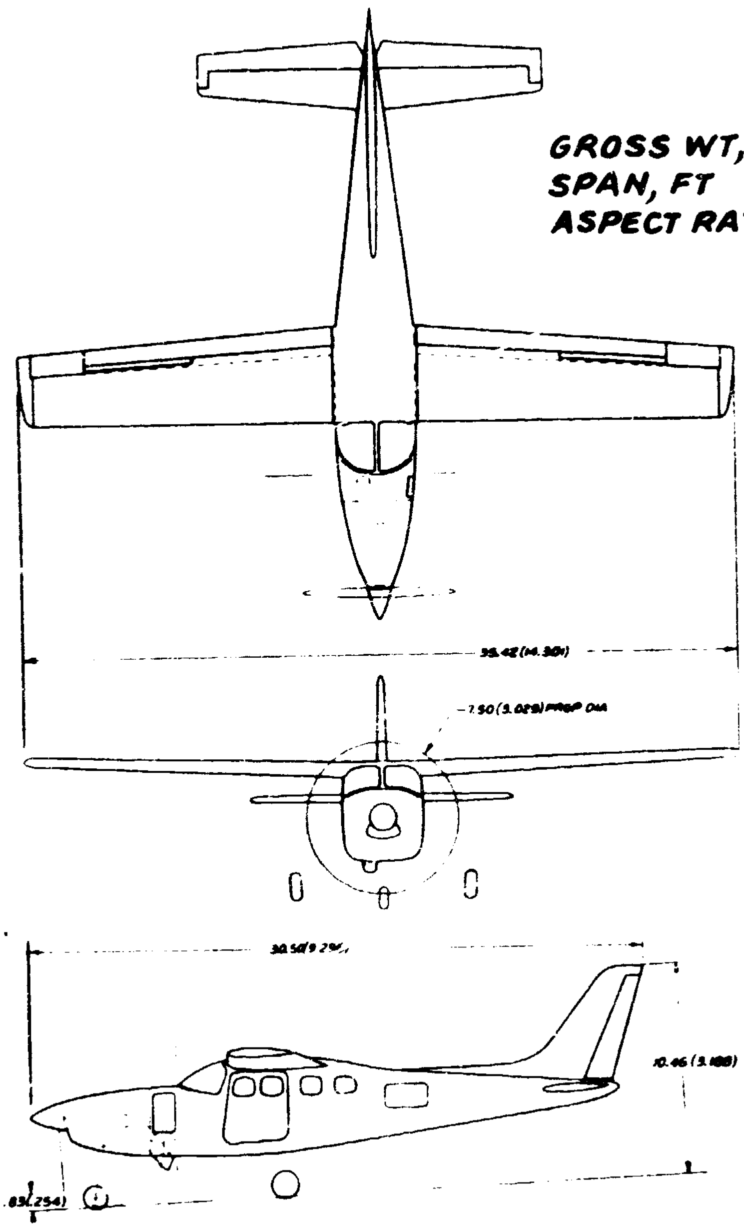
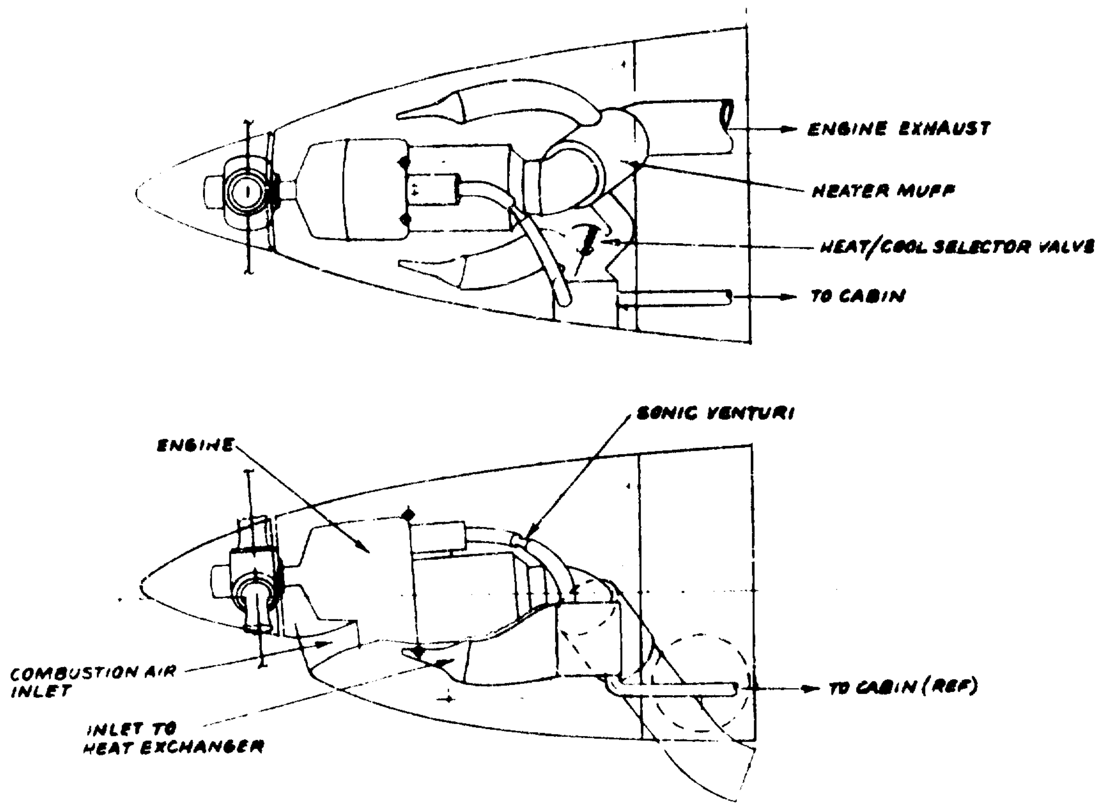


FIGURE 25

GATE HIGHLY-ADVANCED TURBOPROP ENGINE
SINGLE ENGINE INSTALLATION CONCEPT



conventional spark ignition engines is utilized, drawing hot ram air through a muff around the exhaust pipe.

Bleeding the compressor for cabin pressurization is impossible on this small turboprop because of unacceptable performance losses. Instead, a pump is mechanically driven through the accessory section to provide the required air.

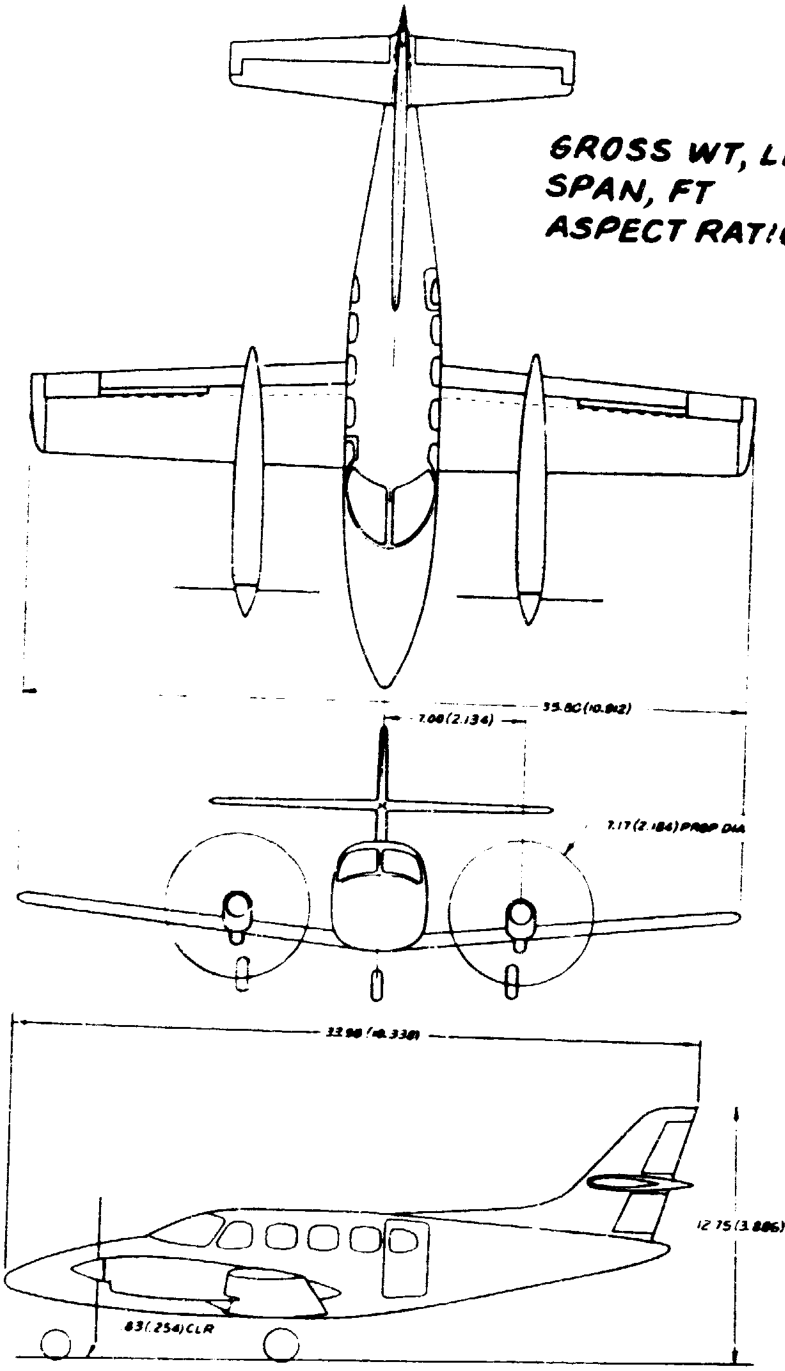
TWIN ENGINE The twin engine configuration and installation are shown on Figures 26 and 27. Maintaining the c.g. location in a favorable position with the light weight of this engine precludes short nacelles where the exhaust can be ducted out the rear. Therefore, short overboard exhausts are provided. This has the advantage of allowing baggage or fuel storage in the rear of the nacelles.

Again, this installation is typical of that which would be used with either the original or the revised GATE definition.

FIGURE 26

GATE TWIN

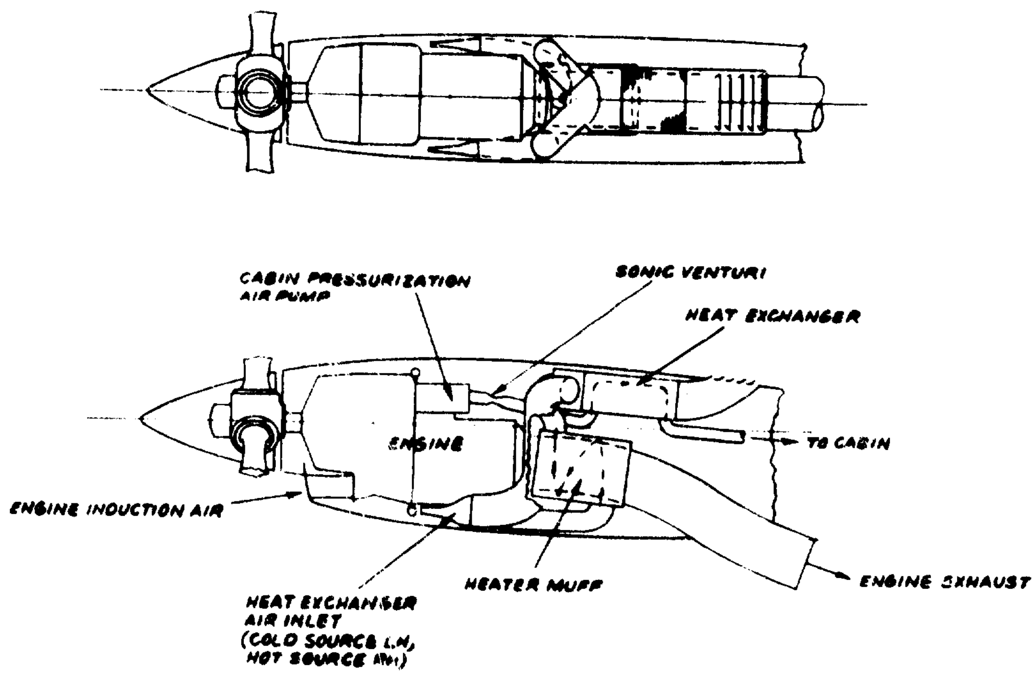
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE



GROSS WT, LB	5750
SPAN, FT	35.8
ASPECT RATIO	7.7

FIGURE 27

GATE HIGHLY-ADVANCED TURBOPROP ENGINE
TWIN-ENGINE INSTALLATION CONCEPT



RESULTS AND DISCUSSION

METHODS OF COMPARISON

The evaluation of the various engines is based on a comparison of the airframe/engine combination. Three methods are used to generate airframes for this comparison:

Method I. Fixed Airframe, Fixed Engine Size, Variable Mission

This method of comparison assumes that the airframe size and gross weight are fixed at the baseline values and the various engines are interchanged, and they are compared on their ability to produce the highest performance from that airframe. The advantage of this method is that it is representative of the first use to which any new engine is usually put, namely that of re-engining an existing airplane. The disadvantage is that it produces airplanes with considerable differences in range, payload, and speed and it is difficult to come to a consensus as to how these characteristics should be ranked in order to compare the results.

Method II. Fixed Engine Size, Fixed Mission, Variable Airframe

The second method of comparison allows the weight and wing geometry to change in order to most nearly match the entire vehicle performance to the requirements. This results in a more even handed comparison of the engines since each airframe is then the best configuration for that engine's characteristics. The disadvantage is that although the baseline engine is well sized, all of the new engines are somewhat oversized to do the given mission because of the smaller, lighter airframes which result. There is nothing to indicate that giving the engines the same cruise horsepower makes them "equal", whatever equal means in the context of this study. In any case, keeping a constant engine size does not show the true, maximum efficiency that the engines can deliver.

Method III. Fixed Mission, Variable Airframe and Engine

This analysis varies wing area and aspect ratio, gross weight and engine size concurrently to define the optimum design. This is probably the best means of comparing the engines because each engine is allowed to seek the lowest power level that will do the mission, considering its characteristics. The engines then are equal in terms of their ability to do a job rather than in terms of an arbitrary equality based on cruise horsepower. This precludes one engine having an advantage by any fortuitous matching of its rating and characteristics to the chosen mission. The only disadvantage of such a comparison is that it is much more time consuming than the first two methods.

EVALUATIONS

The results of the Phase 2 evaluation are discussed below and shown graphically on Figures 28 through 37 and 39 through 46. The results are also shown in tabular form in Appendix III.

Weight Method I, with the airframe fixed, has a constant gross weight and therefore no comparison is possible.

Using Method II, the variation in gross weight necessary to carry the required payload over the designated range is shown on Figure 28. All of the advanced engines show significant weight reductions relative to the baseline, with the exception of the GTSIO-420 (advanced spark ignition engine). Reductions of 12% to 17% are seen for the single engine designs (S.E.) and 14% to 20% for the twin engine designs (T.E.). This weight reduction is due to smaller engine weights, less fuel required, and structural weight savings resulting from lower gross weights and smaller, lower aspect ratio wings.

Allowing the engines to resize in the Method III type of analysis yields even larger reductions in total weight as shown in Figure 29. Once more excluding the GTSIO-420, the single engine weight reductions range from 15% to 19% and for the twins, from 18% to 23%. In each of these cases the highly advanced rotary (RC2-32) showed the largest potential for reducing the total aircraft weight. In general, here and throughout the comparisons, the twins show virtually the same trends as the singles.

Horsepower The horsepower reductions possible when resizing the engine and airframe (Method III) are shown on Figure 30. With the exception of the diesel and GATE on the single engine designs, the lighter weights and lower engine SFC's allow the engines to be resized downward to about 200 horsepower with the new engines needing approximately 50 less horsepower to do the same job as the current technology baseline engine. The diesel and GATE engines in the single engine airplanes cannot be reduced by the same amount because of their high lapse rate with altitude which reduces the climb performance at 25000 ft. On the twins, the extra power required to provide adequate single engine performance also provides good climb rates at altitude and, therefore, the high lapse rates are not as limiting.

Payload-Range For Method I, where weight was held constant at the value required for the baseline engine, use of the new engines resulted in significant increases in performance. The lighter weight of the powerplants meant that additional useful load became available relative to the baseline configurations. This weight advantage was arbitrarily divided equally between fuel and payload

FIGURE 28

TAKEOFF GROSS WEIGHT

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

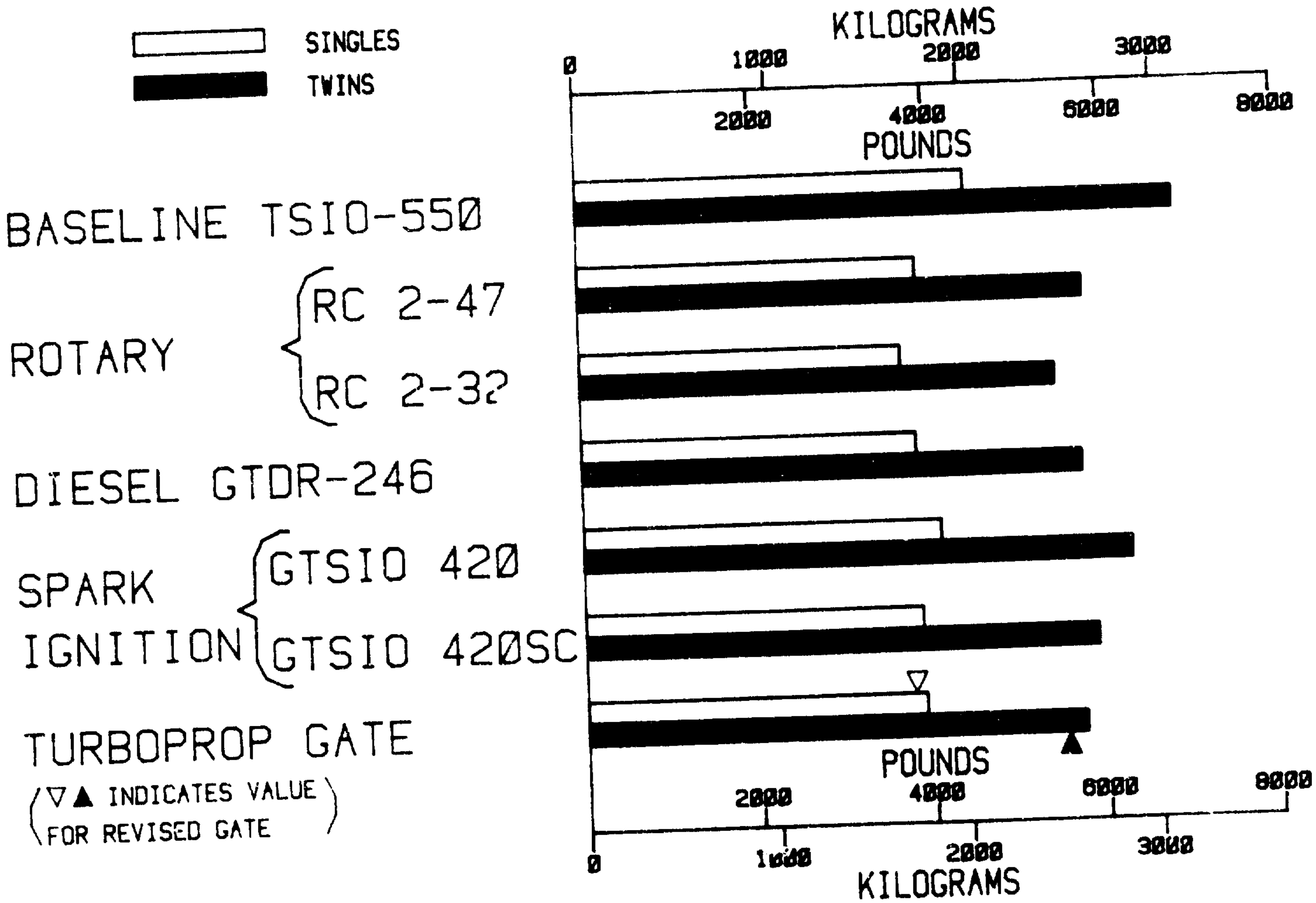


FIGURE 29

TAKEOFF GROSS WEIGHT

III. VARIABLE ENGINE AND AIRFRAME SIZE

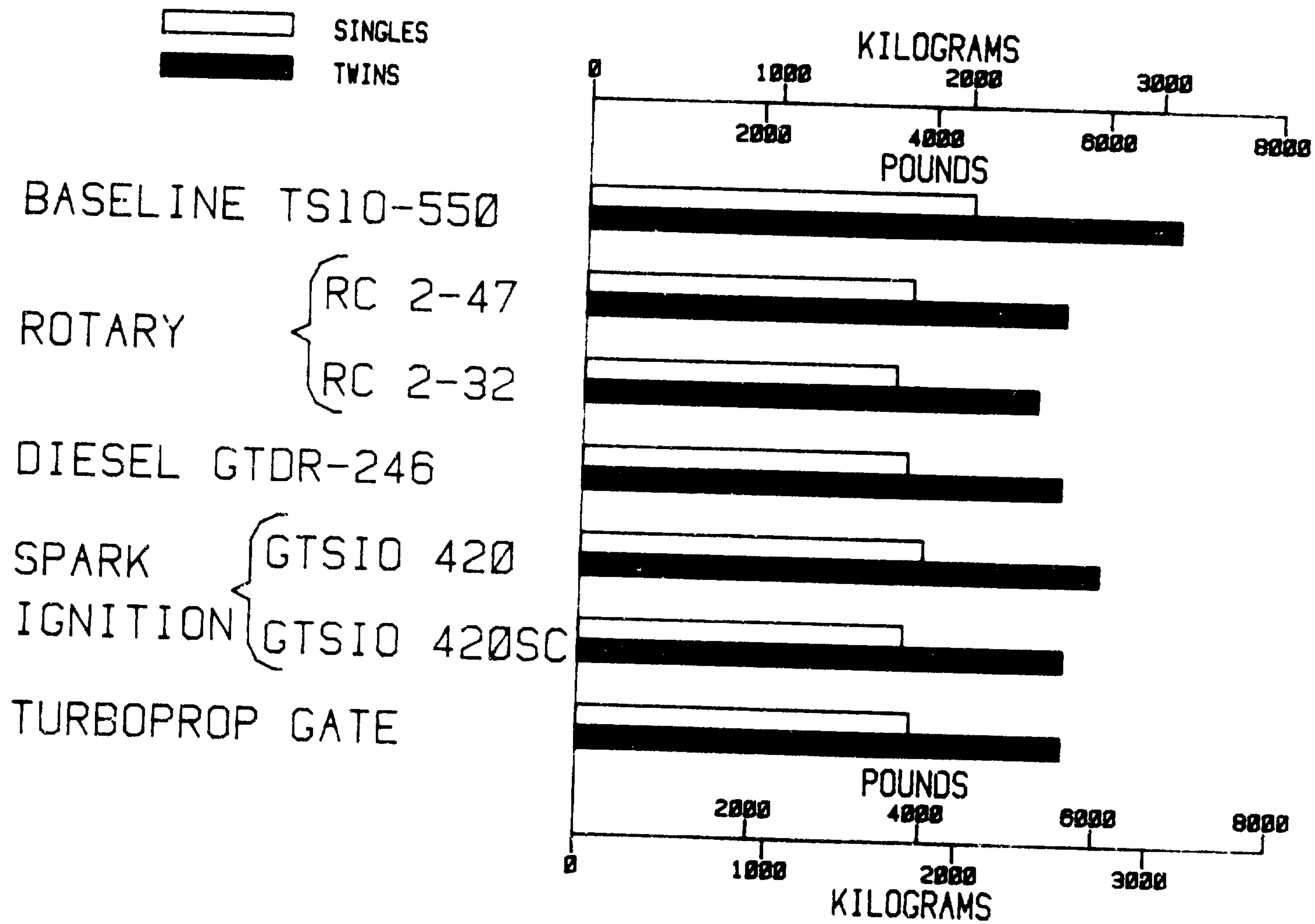
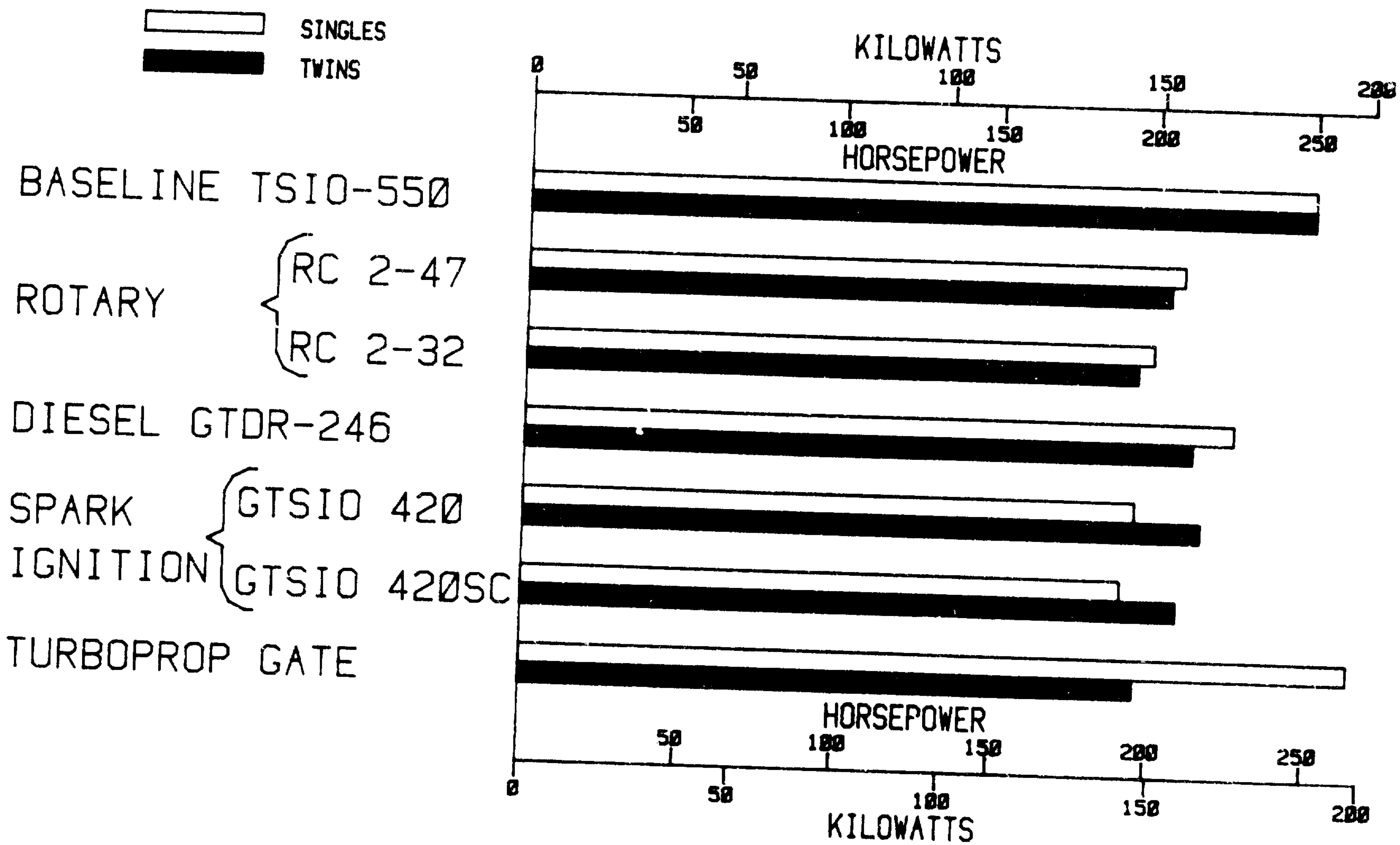


FIGURE 30

ENGINE POWER AT CRUISE

III. VARIABLE ENGINE AND AIRFRAME SIZE



except for the twins where only as much fuel was added as could be accommodated in the outboard wing panels without adding the weight and complexity of tanks in the nacelles (the singles, with no nacelles, had adequate volume for the added fuel).

The increases in range are shown in Figure 31 and the increases in payload in Figure 32. The low weight of the rotary and GATE permit the largest increases in payload varying from 13% for the singles to almost 40% for the twins. The range increases for the rotary are also large at 105% (S.E.) and 69% (T.E.). The high fuel consumption of the GATE, however, limits range increases to 45% (S.E.) and 20% (T.E.). Since the diesel engine weighs more than the rotary the net useful load (payload and fuel) gained is less; however, due to the low fuel consumption of this engine the increases in range are large - 102% (S.E.) and 81% (T.E.).

Mission Fuel The primary justification for undertaking the large investment in developing a new powerplant is to reduce fuel consumption. The mission fuel burned by each of the engines is shown in Figures 33 and 34 for Methods II and III, respectively. As can be seen, the original GATE shows very small reductions relative to the baseline engine. The moderate risk GTSIO-420 and the revised GATE show a somewhat greater reduction, but still have much less potential than the other four new I.C. engines. All four of these engines show similar savings of around 35% for Method II and 40% for Method III. The diesel powered twin burns the least fuel when compared on the basis of either Methods II or III. For Method II, the diesel powered single also shows the lowest fuel consumption. The GTSIO-420SC shows the lowest consumption for the singles according to Method III.

Direct Operating Cost The influence of the engines on direct operating cost (DOC) is shown on Figures 35 through 37. Method I type comparisons show only small changes in DOC between the various engines. This emphasizes the need to match the engine and airframe if the full benefits are to be realized. The GATE (both versions) and GTSIO-420 show only small decreases in DOC under Method II (Figure 36). The other four engines show substantial reductions of around \$20/hour (S.E.) and around \$40/hour (T.E) or savings of over 15% for each configuration. Under Method III (Figure 37), these same four engines show reductions of \$30/hour for singles and \$60 to \$70/hour for twins or savings of around 25%. This is a very substantial reduction-one which could have a major impact on the general aviation market.

Effect Of Assumed Fuel Cost On DOC One item addressed in the parametric evaluations was the effect of fuel cost on the direct operating cost. For the Phase II analysis a nominal value of \$1.70/gallon was used. This was typical of the price of avgas when the analysis was being run early in 1981. The same value was also used for jet fuel since recent data indicates that the difference

FIGURE 31

RANGE

I. FIXED ENGINE AND AIRFRAME SIZE

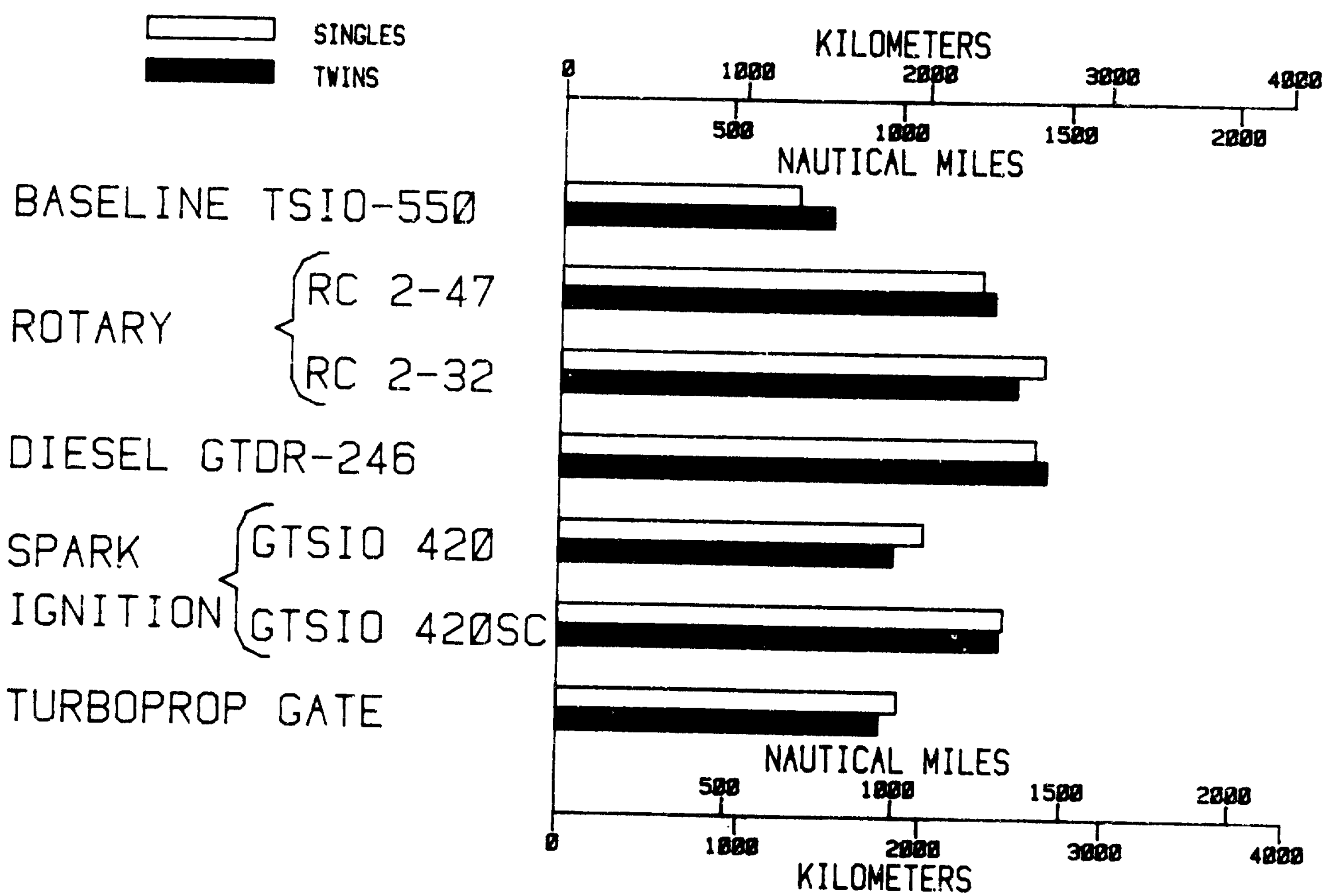


FIGURE 32

PAYLOAD

I. FIXED ENGINE AND AIRFRAME SIZE

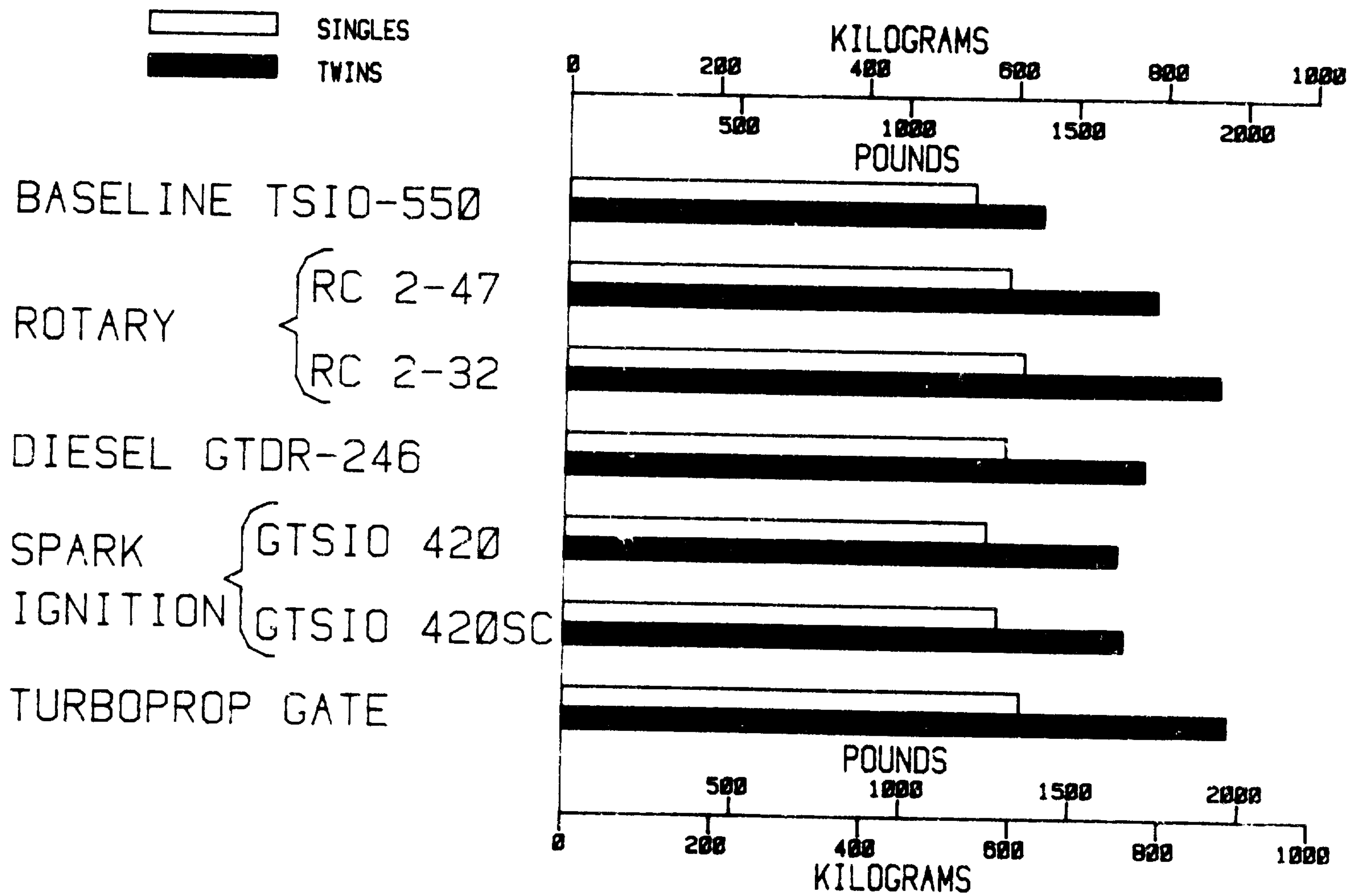


FIGURE 33
MISSION FUEL
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

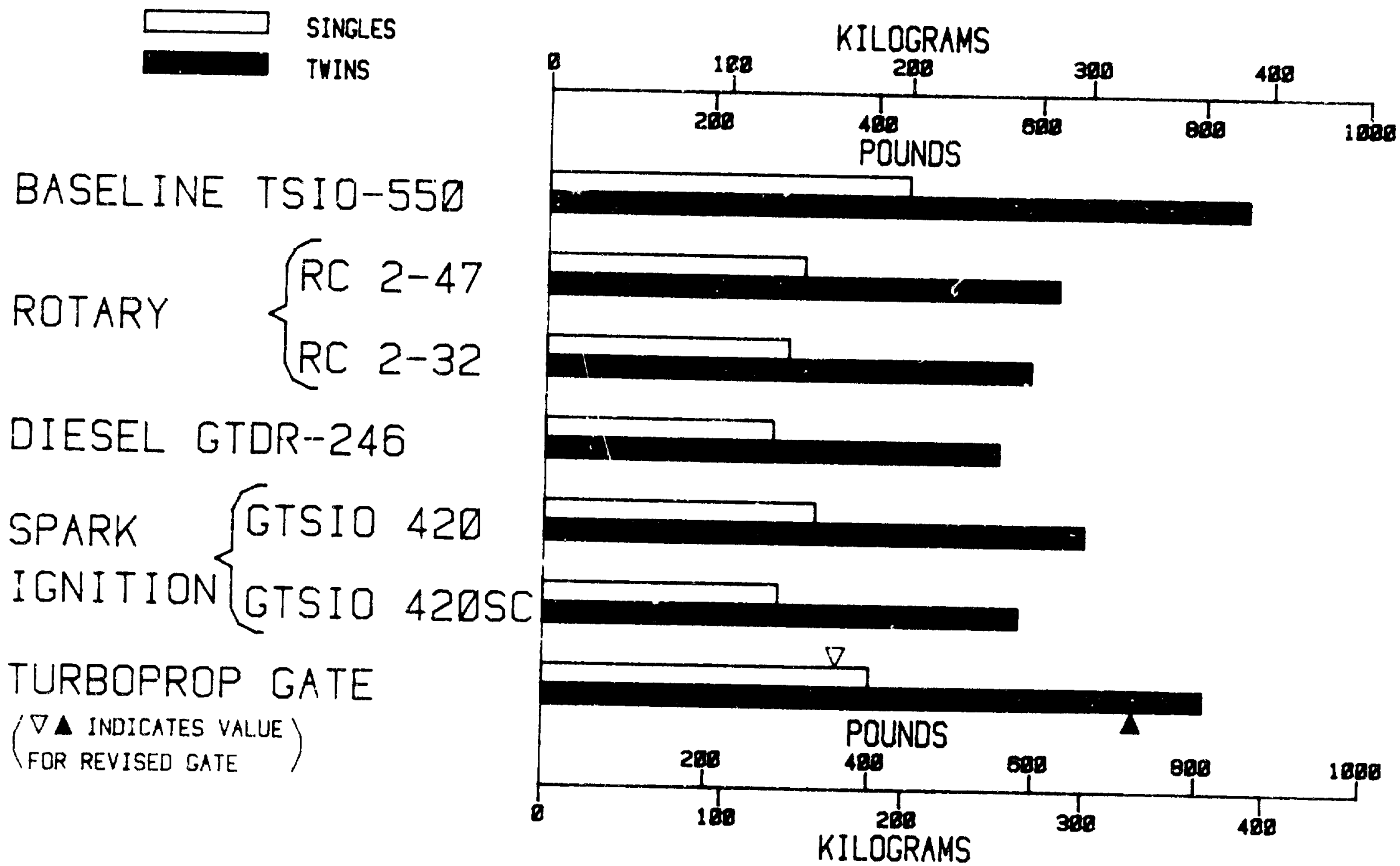


FIGURE 34
MISSION FUEL
III. VARIABLE ENGINE AND AIRFRAME SIZE

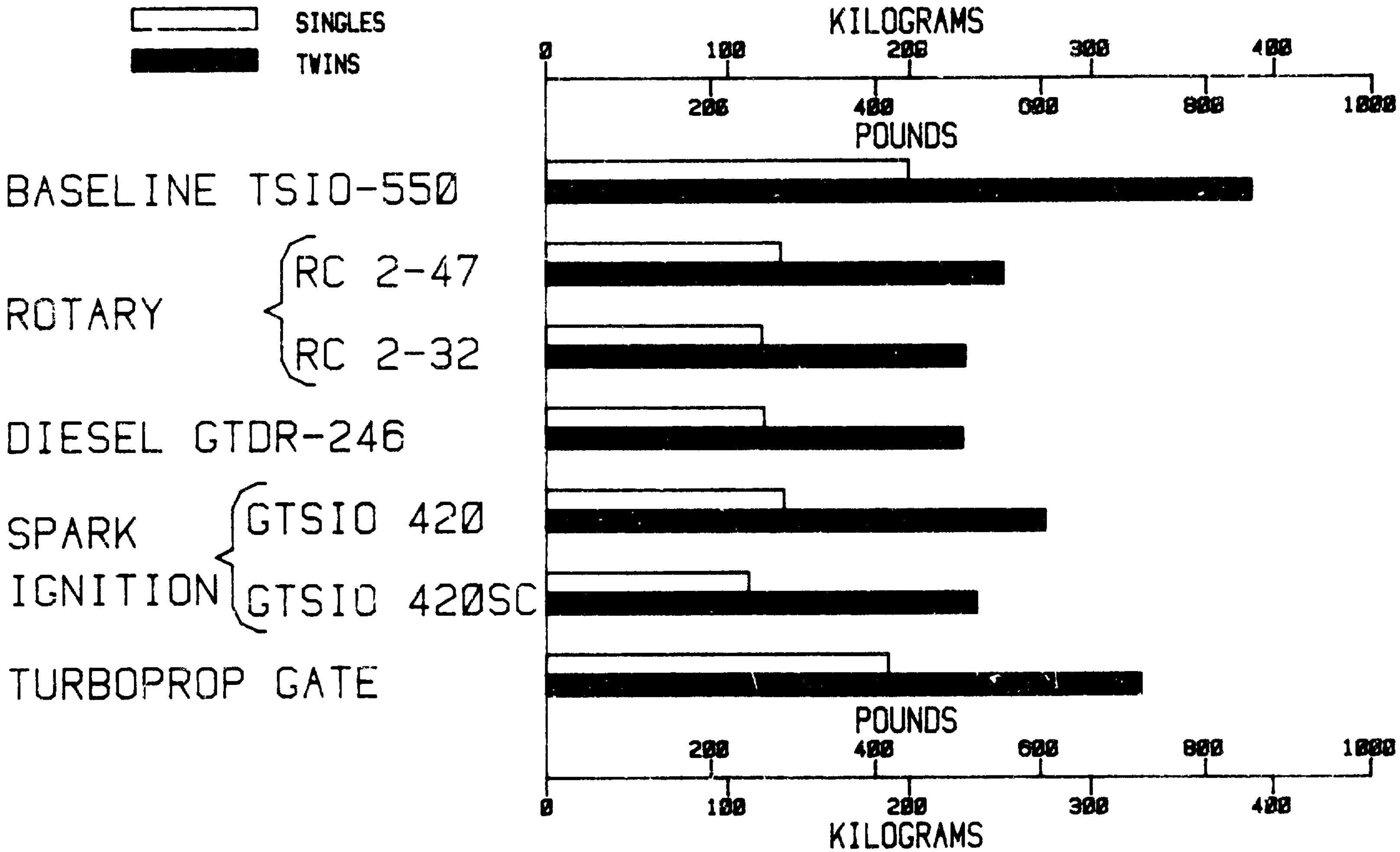


FIGURE 35

DIRECT OPERATING COST

I. FIXED ENGINE AND AIRFRAME SIZE

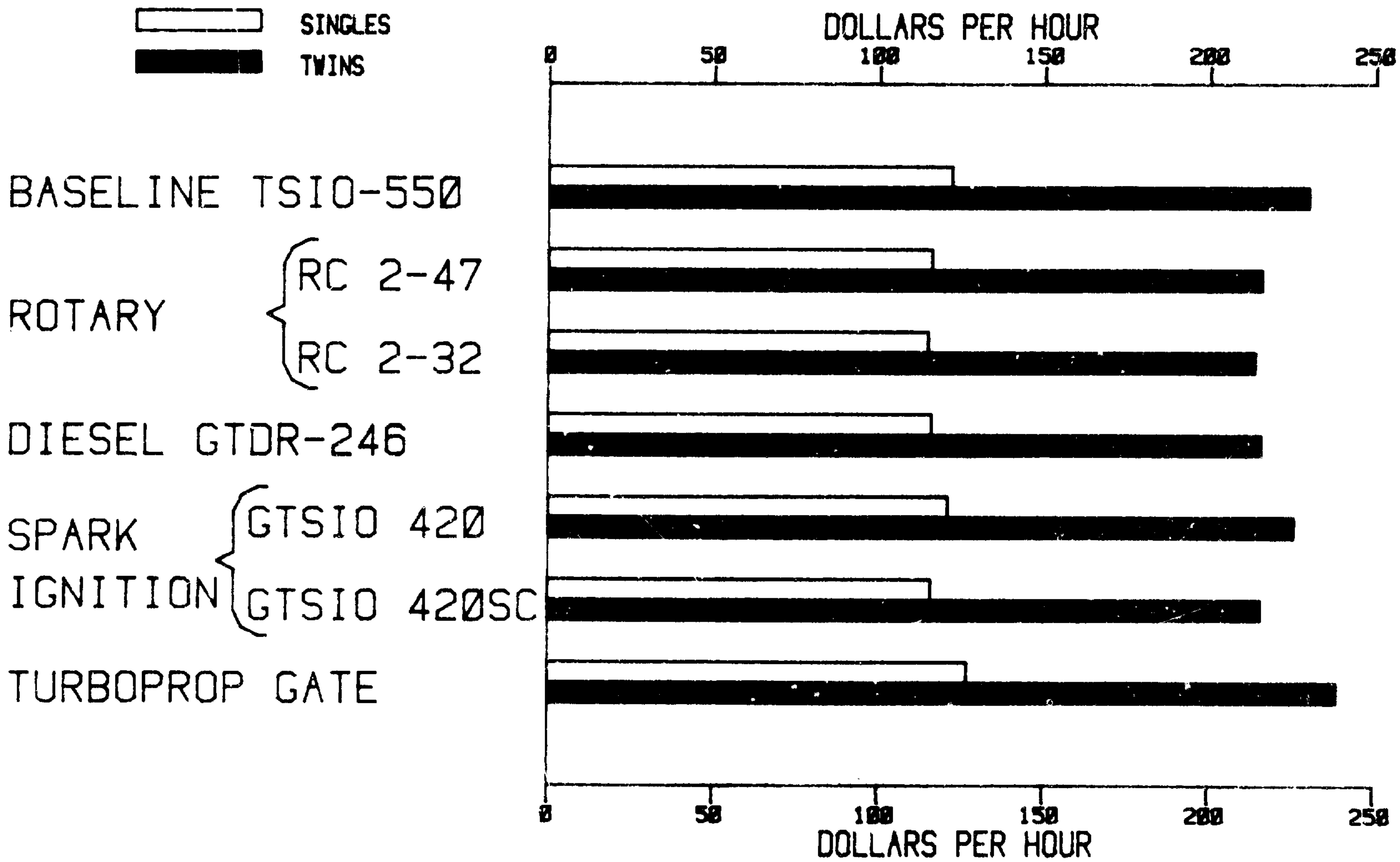


FIGURE 36
DIRECT OPERATING COST
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

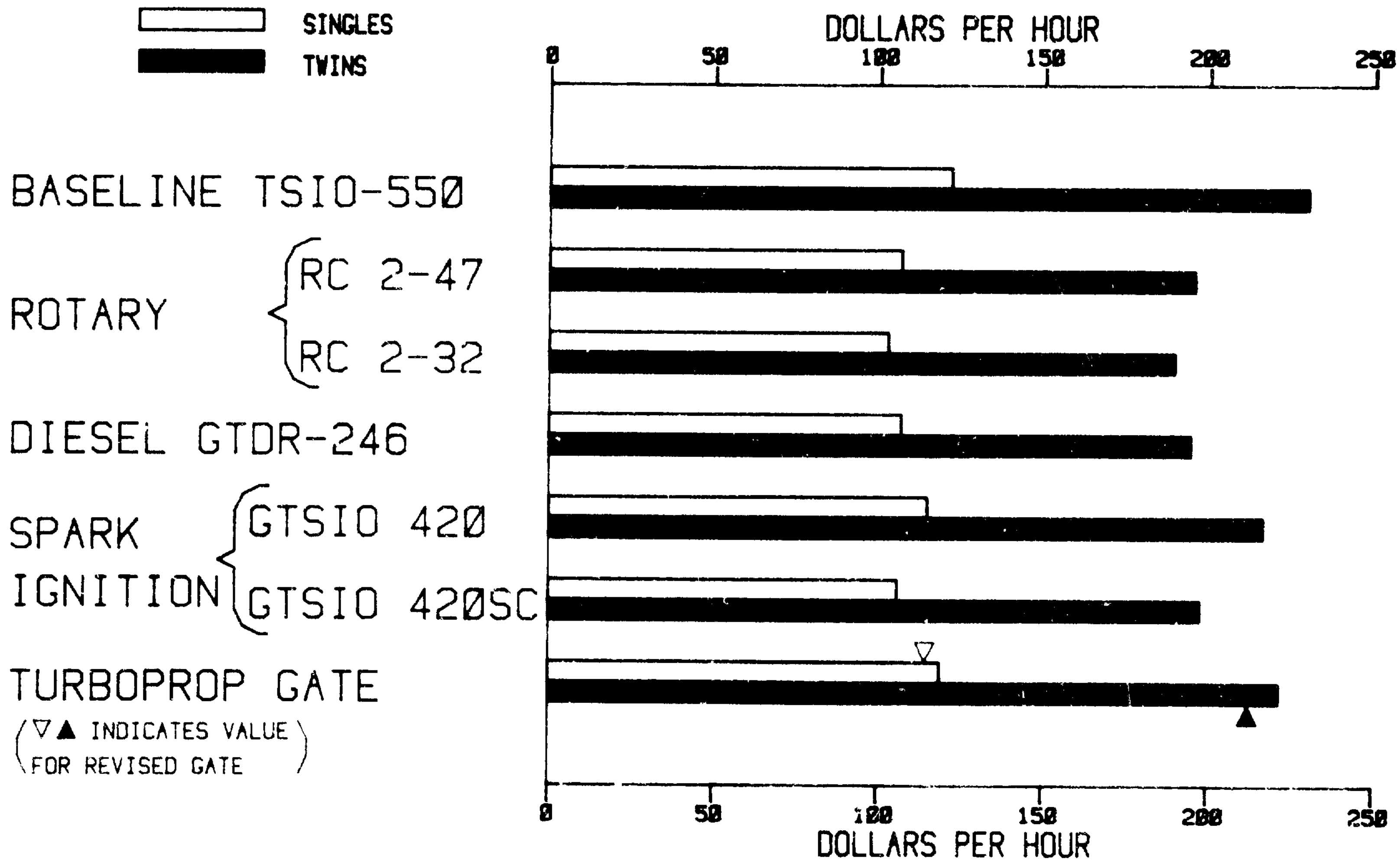
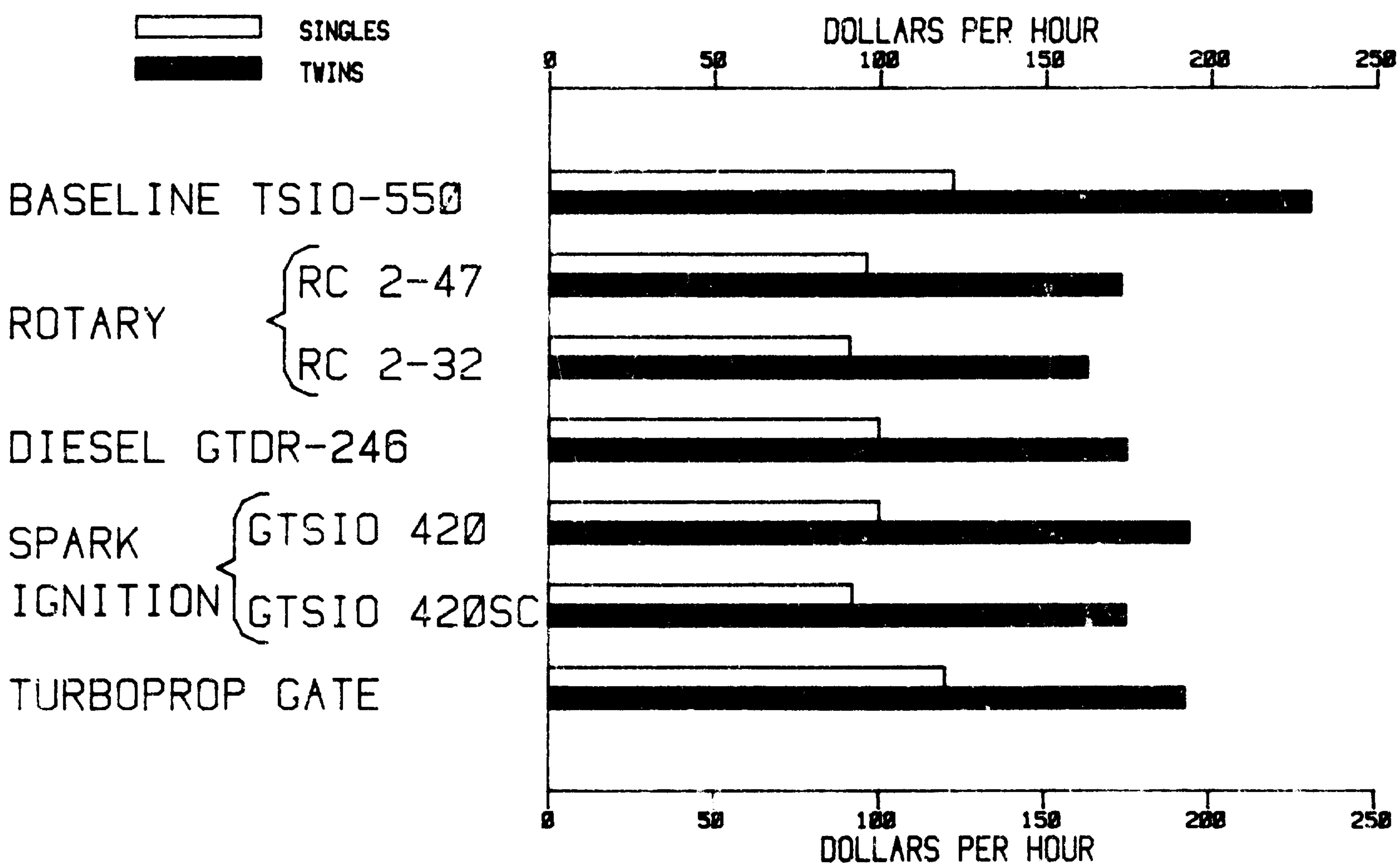


FIGURE 37
DIRECT OPERATING COST
III. VARIABLE ENGINE AND AIRFRAME SIZE



in price between these two fuels is narrowing and will eventually disappear, at least in this country. Variations in the price of fuel from $1/gallon to $4/gallon were analyzed for the highly advanced engines in the single engine configurations, with the results shown in Figure 38. The GATE (original definition) powered airplane has the highest DOC which grows larger with increasing fuel price. The revised GATE shows a lower level and slope but still remains consistently higher than the I.C. engines. The RC2-32 has the lowest DOC; as fuel prices increase this advantage decreases, but never completely disappears up to the maximum price studied. In effect, then, while fuel price has a major impact on DOC it does not significantly alter the relative rankings of the various engines.

Acquisition Cost The estimated purchase price of the various airplanes is shown in Figures 39 through 41 for Methods I through III, respectively. Comparisons based on Method I show slight increases for most of the advanced engines with only the GATE showing a significantly higher price. When the airframes are resized, however, as was done in Methods II and III, this picture changes. All except the GATE (both versions) and GTSIO-420 engines now show a large potential for reducing airplane price. The airplane using the RC2-32 has the largest estimated reduction in price at $30,000 for the single and $60,000 for the twin under Method II (or roughly a 15% decrease for both configurations). Corresponding numbers for Method III are $40,000 (S.E.) or a 20% decrease and $100,000 (T.E.) or a 25% decrease. As with DOC, decreases of this magnitude would have a major impact on the market.

Effect Of Engine Price On Acquisition Cost The acquisition costs derived under Phase 2 are heavily dependant on the engine price used. That price, however, is probably the most difficult characteristic to predict accurately.

The effect of changing engine price is shown on Table VIII for Methods II and III. The information is presented as the increment that would have to be added to the assumed engine price to bring the cost of the aircraft up to the level of the baseline powered airplane. And since acquisition cost is reflected in DOC through depreciation, the change in engine price required to eliminate the advantages in DOC shown by the new powerplants is also indicated.

For the intermittent combustion engines, the change in engine price required to match acquisition costs is large and to match DOC levels it is larger still. From this analysis it appears unlikely that the assumed engine price could be sufficiently in error to significantly effect the Phase 2 results.

Cruise Coefficient To further compare the engines a cruise coefficient was defined as:

FIGURE 38

EFFECT OF FUEL COST ON DIRECT OPERATING COST

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

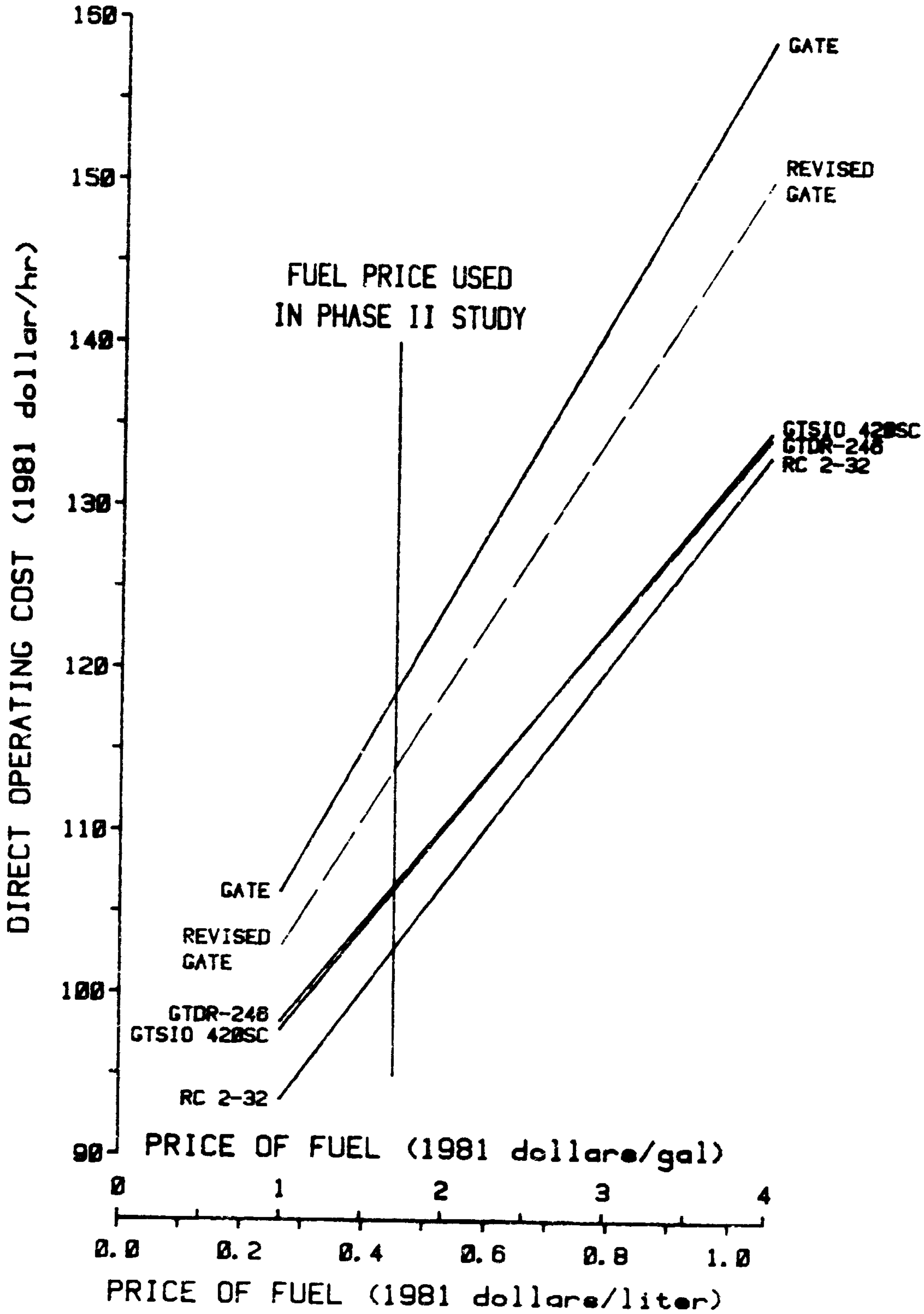


FIGURE 39

ACQUISITION COST

I. FIXED ENGINE AND AIRFRAME SIZE

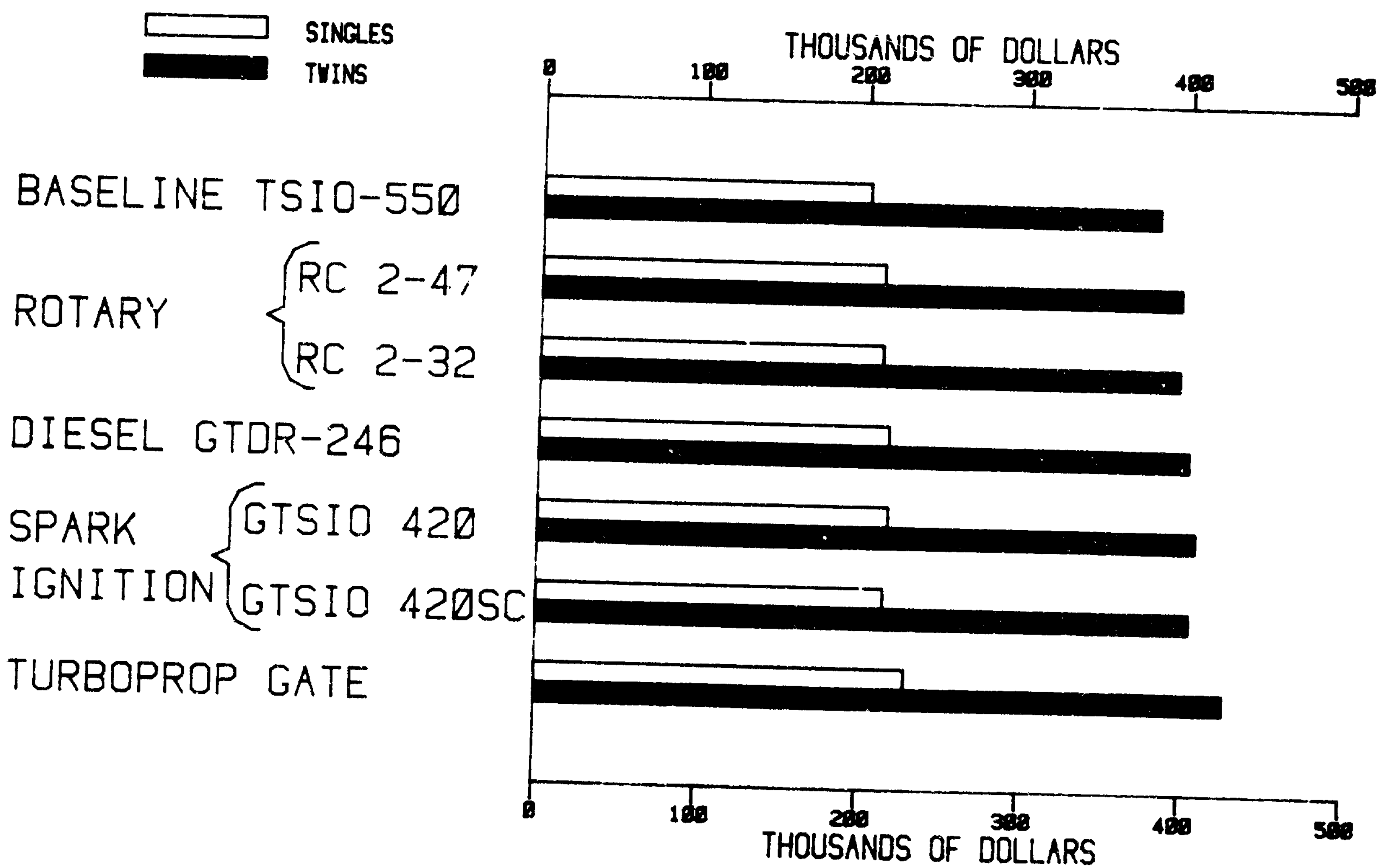


FIGURE 40

ACQUISITION COST

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

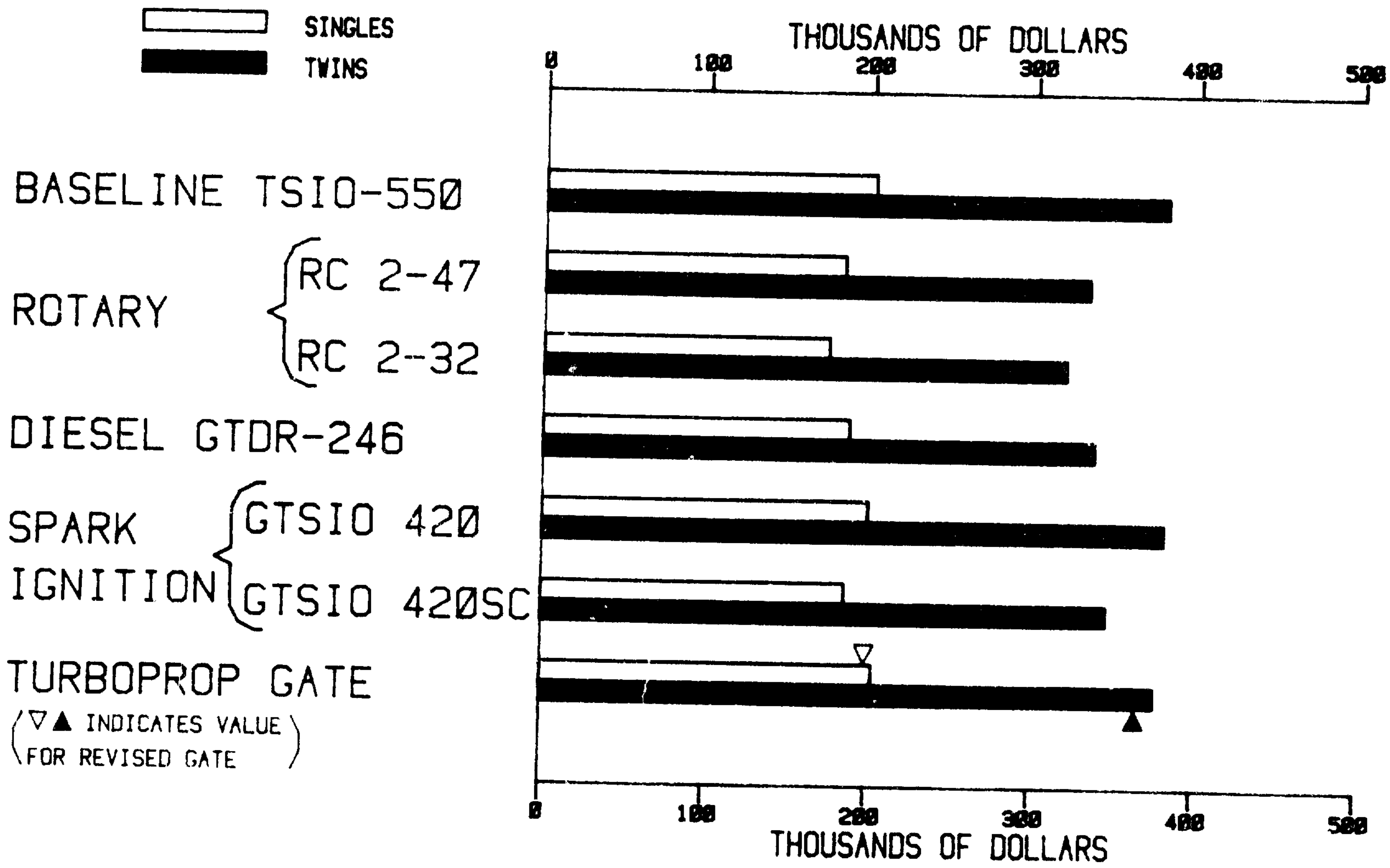


FIGURE 41
ACQUISITION COST
III. VARIABLE ENGINE AND AIRFRAME SIZE

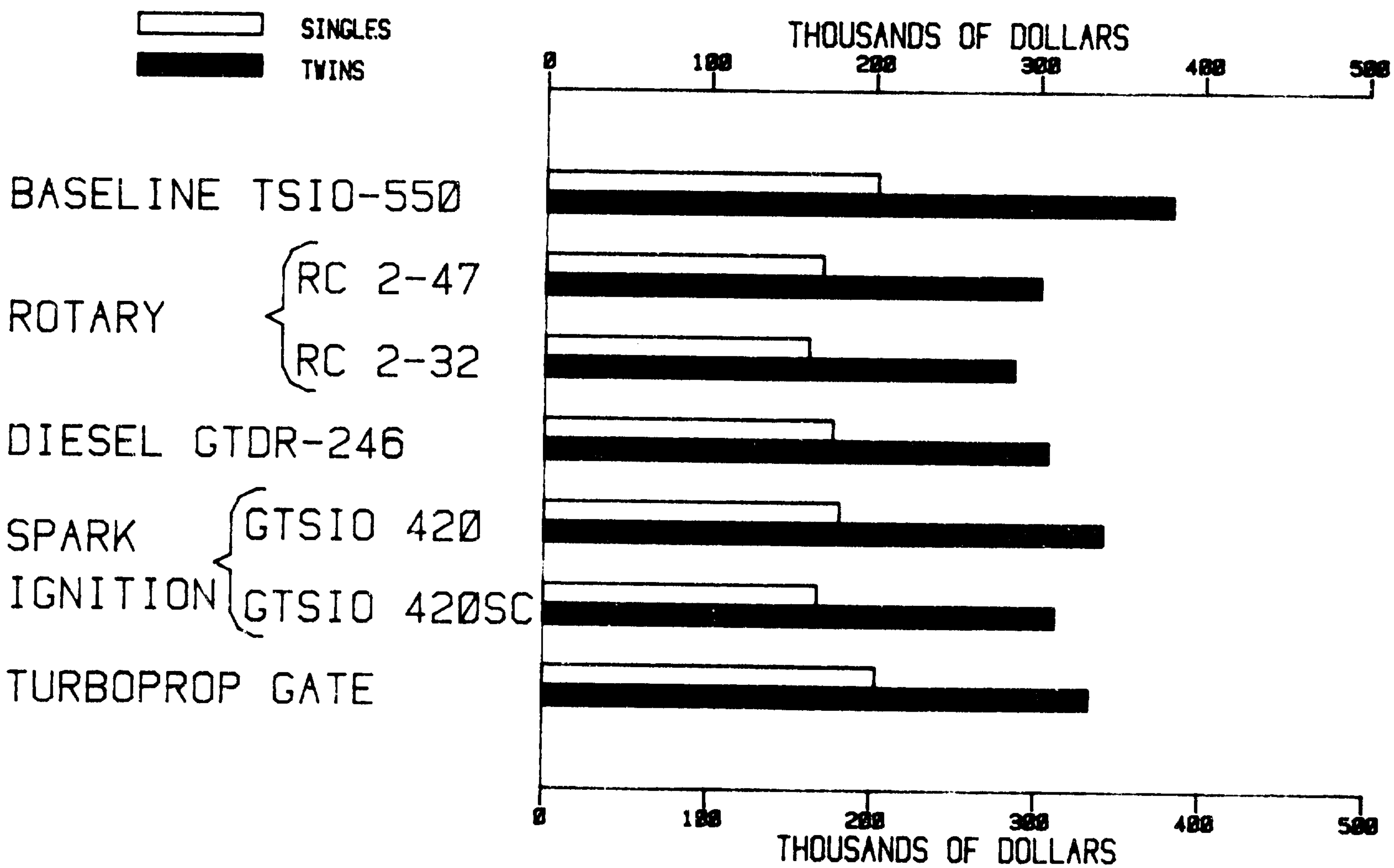


TABLE VIII

PHASE III

EFFECT OF ENGINE COST ON AIRCRAFT PRICE AND DOC

SHOWN: INCREMENT IN ENGINE COST REQUIRED TO MAKE ADVANCED AND BASELINE SINGLE ENGINE AIRPLANES COST THE SAME

BASIS OF COMPARISON	ENGINE	ACQUISITION COST		DIRECT OPERATION COST	
		ΔENGINE COST	% INCREASE	ΔENGINE COST	% INCREASE
II FIXED ENGINE VARIABLE AIRFRAME	RC2-32	27,000	84	64,620	202
	GTDR-246	14,000	39	51,562	143
	GTSIO-420SC	16,000	46	52,566	150
	GATE	-1,500	-3	11,719	22
III VARIABLE ENGINE AND AIRFRAME	RC2-32	41,000	160	102,739	402
	GTDR-246	25,900	80	75,334	232
	GTSIO-420SC	35,000	131	100,445	376
	GATE	-500	-1	5,357	9

$$C = \frac{\text{payload} \times V_{CRS} \times \text{Range}}{\text{Energy Consumed in cruise}}$$

and a relative cruise coefficient was defined as:

$$R = \frac{C(\text{for a specific configuration})}{C(\text{for the baseline configuration})}$$

This latter value may be thought of as an increase in efficiency in moving a given payload at a given speed over a given range.

Relative cruise coefficient is shown in Figure 42 as a percentage increase over the baseline value. For Method II, the RC2-32, GTSIO-420SC, and GTDR-246 have the highest values, around 55% to 60% better than the baseline with the diesel being slightly better than the others.

The same comparison is shown in Figure 43 for Method III. Here, the same three engines have an advantage over the baseline of 60% to 70%. In this case, the rotary has the highest value for the twin and the GTSIO-420SC for the single.

Evaluation Criteria A set of criteria was established early in the program to evaluate how each of the engines compared to the others. This evaluation scheme is outlined in Table IX. It reflects a point of view that a reduction in fuel consumption is the single most important characteristic for a new engine. The next most important characteristic is the potential to reduce direct operating cost, this factor being weighted only slightly lower than the first one. However, since fuel usage is also included in DOC the total weight given to reduced consumption is actually greater than the 10 point weighting factor would indicate. Acquisition cost, multifuel capability, flyover noise and installation factors are also included in the criteria.

The fuel compatability of the engines is shown on Table IVb. Some of the engines (e.g. GTDR-246) are shown as capable of burning diesel fuel. The high viscosity of diesel at low temperatures, however, creates a problem in maintaining a reliable fuel flow to the engine unless fuel heaters and insulation are provided. Therefore, no points were awarded for this capability.

The installation factor is the most subjective. No points are awarded if the engine is judged equivalent to the baseline. The GTSIO-420 and GTSIO-420SC were considered in this category though in some ways this may have been generous since the tuned exhaust system will probably make accessory location and accessibility more difficult than on present day engines. The GATE in the single engine airframe was also awarded zero points because of the difficulty in ducting the hot exhaust overboard.

FIGURE 42
INCREASE IN CRUISE COEFFICIENT
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

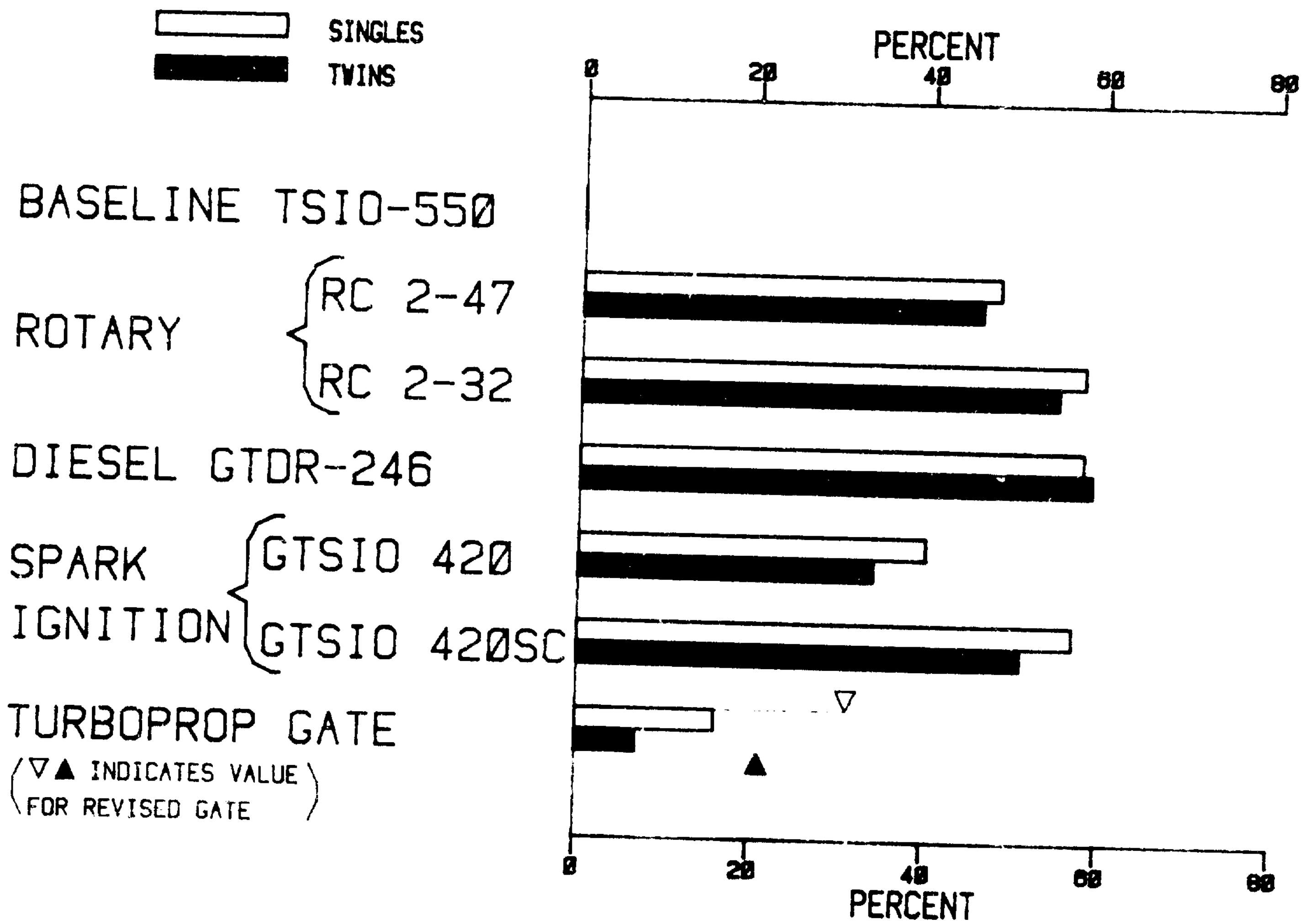


FIGURE 43

INCREASE IN CRUISE COEFFICIENT

III. VARIABLE ENGINE AND AIRFRAME SIZE

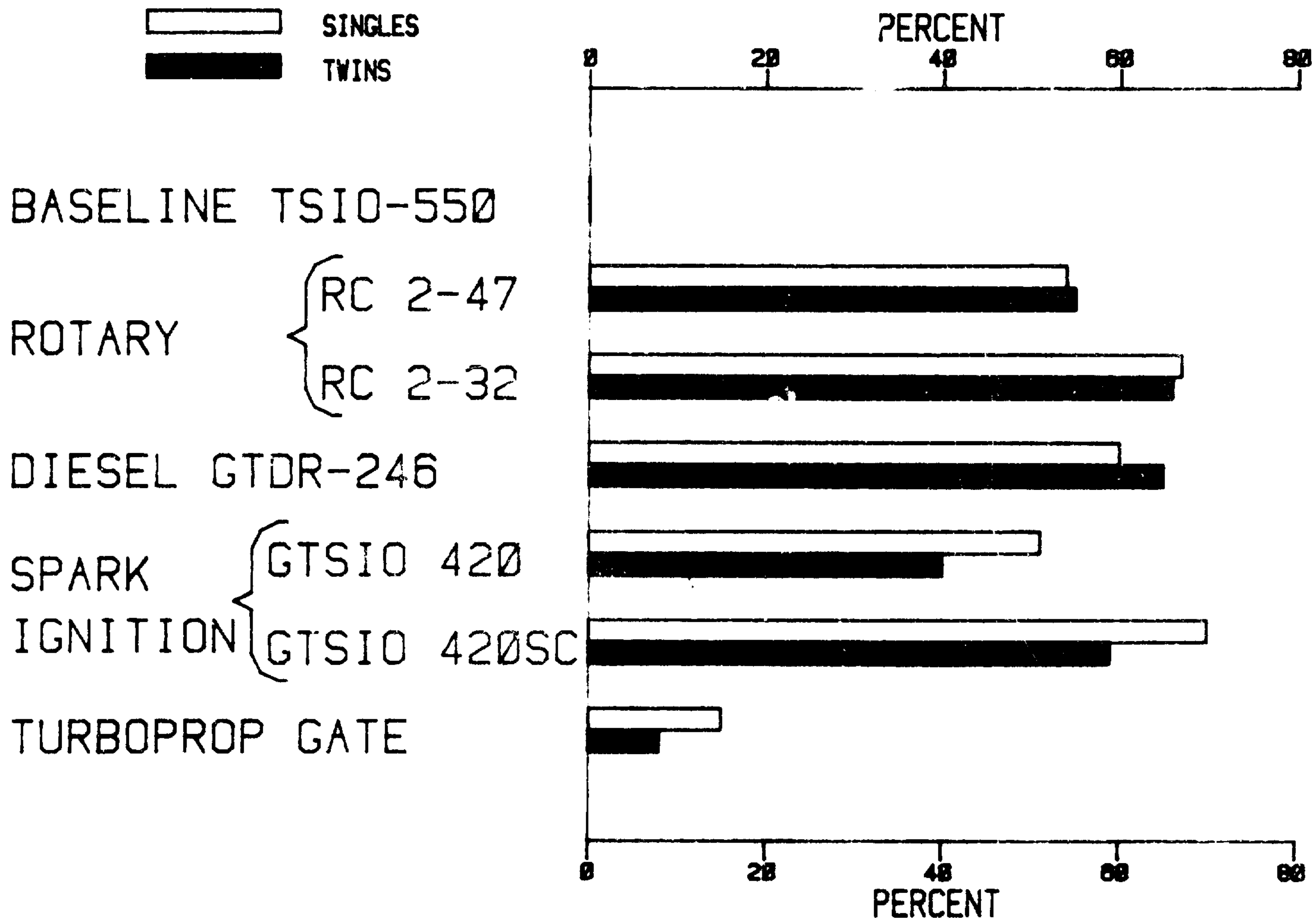


TABLE IX

EVALUATION SCHEME

	EVALUATION	WEIGHTING FACTOR
FUEL USAGE	10 POINTS FOR 25% LESS FUEL USED THAN BASELINE	10
DIRECT OPERATING COST	10 POINTS FOR 25% LOWER DOC	8
ACQUISITION COST	10 POINTS FOR 25% LOWER PURCHASE PRICE	6
MULTI-FUEL CAPABILITY	0 POINTS AVGAS ONLY 1 POINT JET FUEL ONLY 2 POINTS BOTH	5
FLYOVER NOISE	+1 QUIETER THAN BASELINE 0 SAME AS BASELINE ($\pm$2dBA)	10
INSTALLATION FACTOR	0 EQUIVALENT TO BASELINE 1 SOMEWHAT BETTER THAN BASELINE 2 MUCH BETTER THAN BASELINE	10

The diesel engine was awarded 10 points since a baggage area can be put in the nose of the single, and slender, low drag nacelles can be used on the twin. The GATE in the twin was also given 10 points because of the slender nacelles and relatively uncomplicated installation.

The rotaries were judged to be much better than the baseline and were awarded 20 points. With the light weight and small size of this engine a baggage compartment can be added in the nose of the single. On the twin the nacelles are slender. The liquid cooling gives complete control over the engine temperature in all flight regimes for maximum operating flexibility.

These evaluation criteria were applied to all engines for all three comparison methods and the results are shown in Figures 44 through 46 and in Tables AIII-VII and AIII-VIII. The absolute magnitudes of the numbers are virtually meaningless and only the relative rankings are of any importance. In general the RC2-47, RC2-32, GTDR-246 and GTSIO-420SC all have similar values for each method. The GATE (both versions) and GTSIO-420 ranked considerably lower. The RC2-32 was consistently the best with the diesel usually a close second.

PARAMETRIC EVALUATIONS

As noted above, the data from Phase II exhibited the same trends for both the singles and twins. Therefore, only the single engine airframes were carried forward into the parametric evaluations of Phase III. In the interest of time and available budget the baseline engine and the backup engine concepts (RC2-47 and GTSIO-420) were dropped from the analysis.

The parameteric evaluations involving fuel cost and engine price have already been discussed. Other variations in input data and mission definition were analyzed as follows:

Mission Definition The effects of selecting different missions (payload and range) are shown on Figures 47 and 48. The range was varied by plus or minus 200 NMi from the basic mission value of 700 NMi and the payload was varied by plus or minus 2 passengers (±400 pounds) from the basic mission value of 6 passengers. The comparison was by method II. In no case is there any crossover of the important parameters (evaluation criteria or fuel used) that would indicate that the original mission unfairly favored one engine over another.

Cooling Drag As discussed previously, cooling drag was impossible to estimate with any degree of precision. The actual values for any of these engines may, therefore, be different from those used in the Phase II analysis. Those values were chosen somewhat

FIGURE 44

EVALUATION CRITERIA

I. FIXED ENGINE AND AIRFRAME SIZE

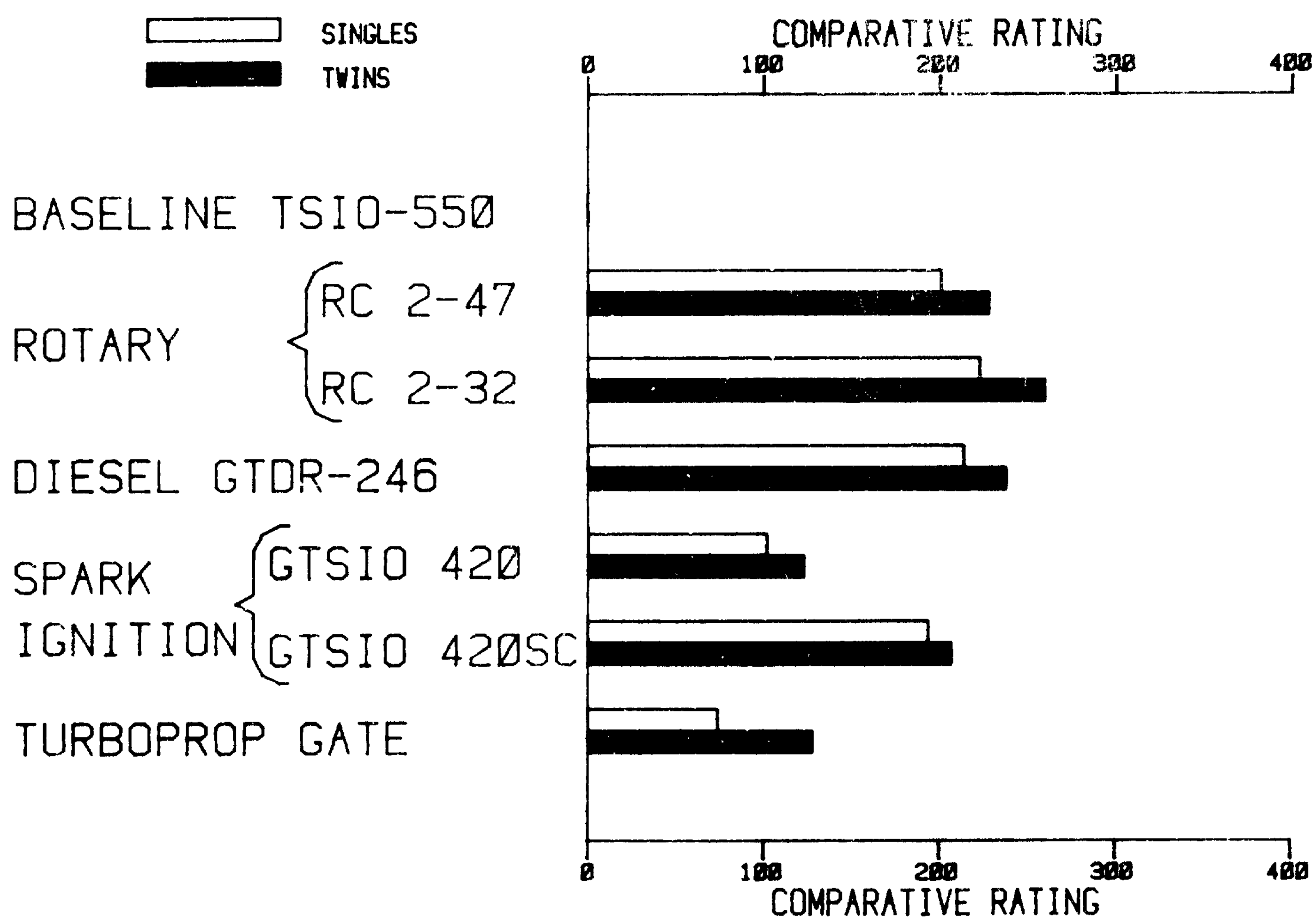


FIGURE 45

EVALUATION CRITERIA

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

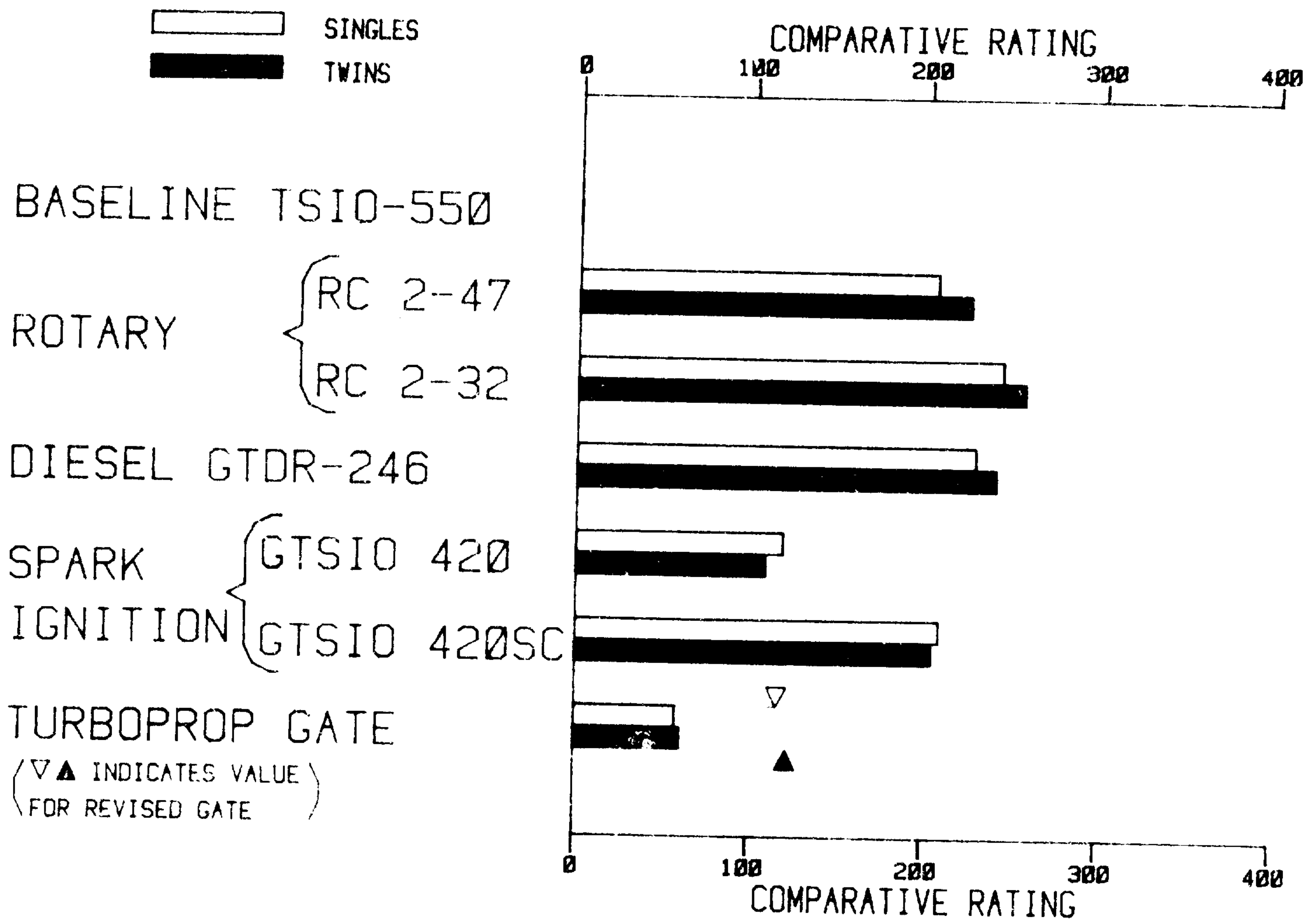


FIGURE 46

EVALUATION CRITERIA

III. VARIABLE ENGINE AND AIRFRAME SIZE

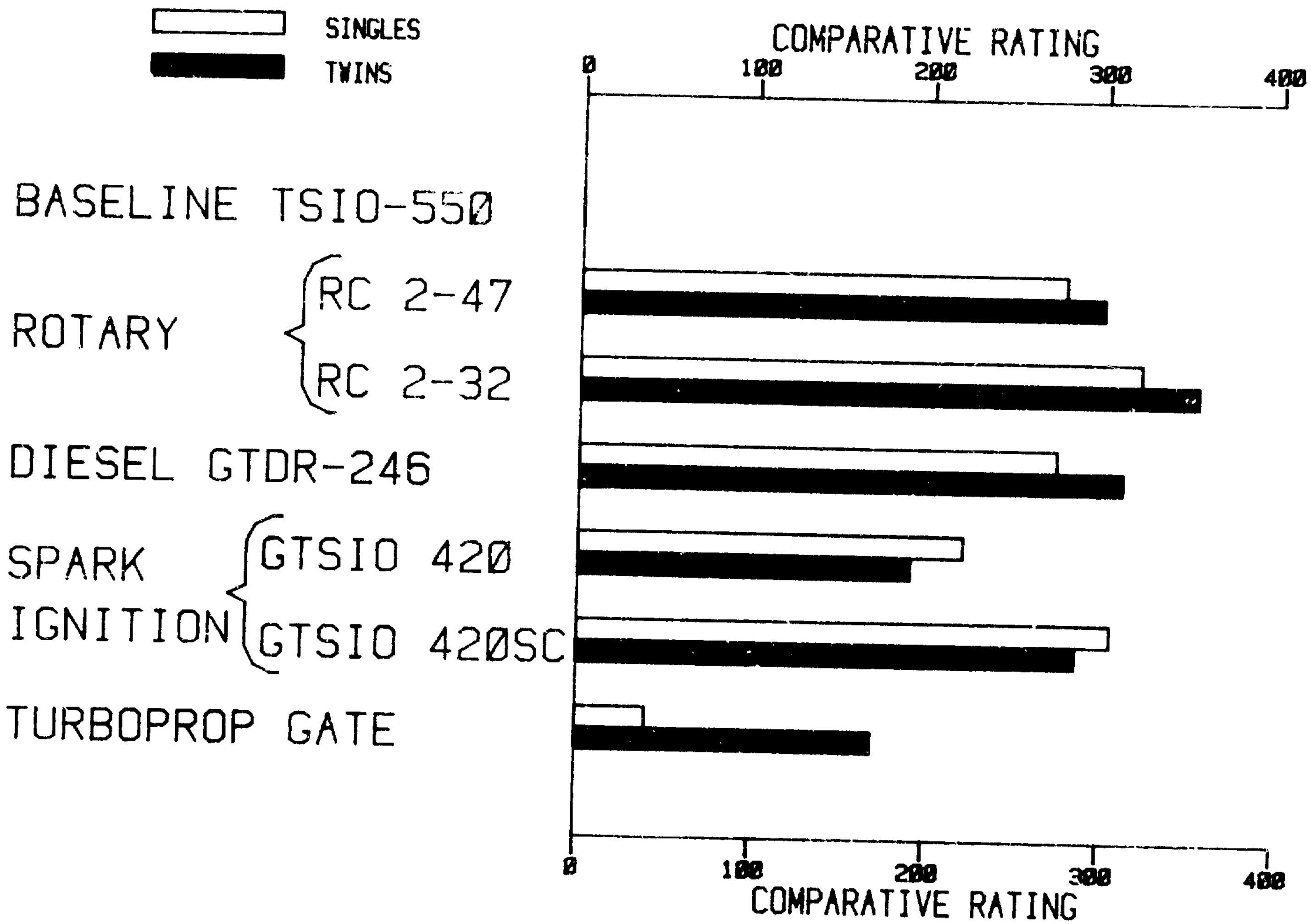


FIGURE 47

EFFECT OF VARYING MISSION PAYLOAD ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

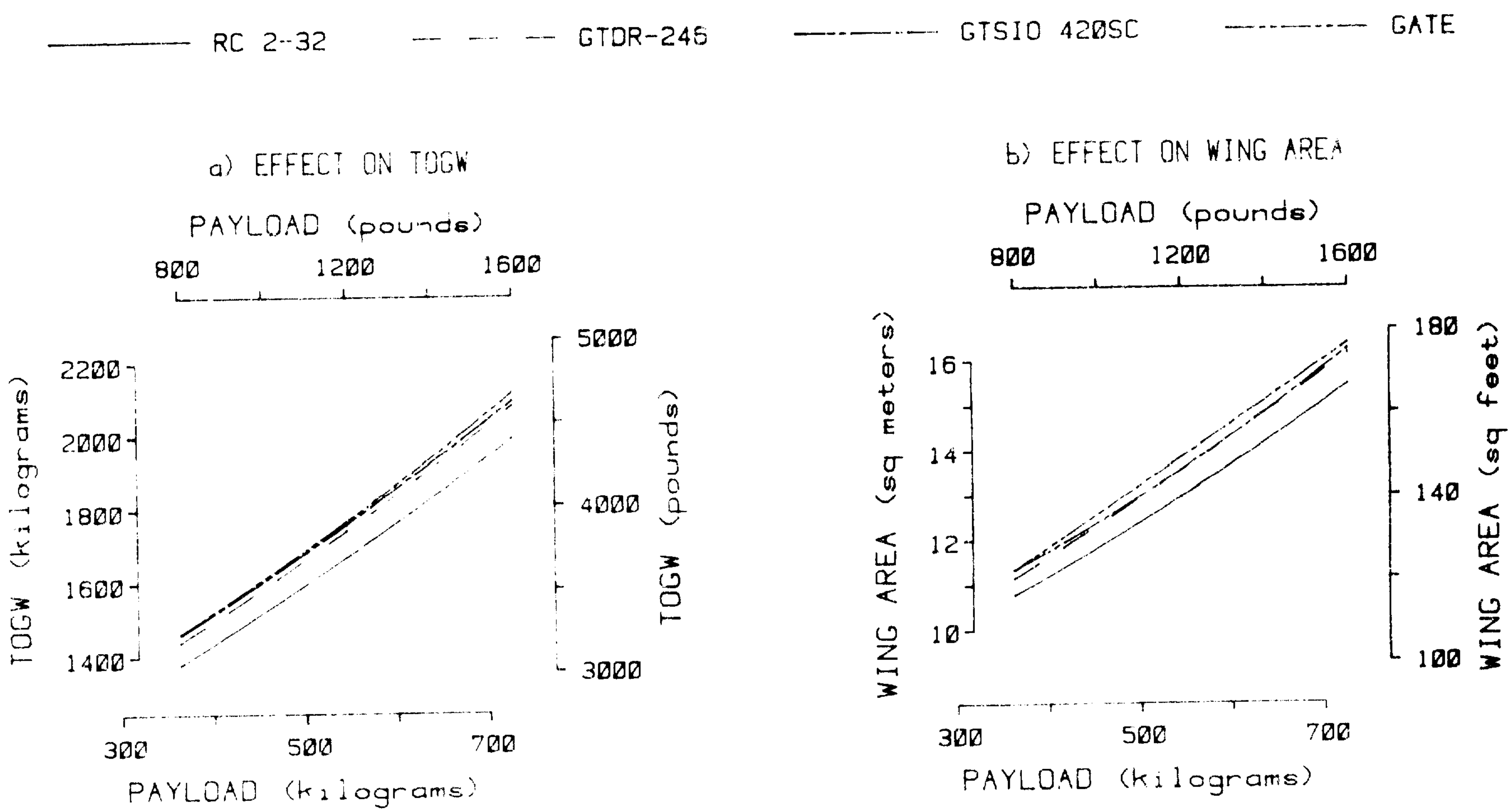


FIGURE 47 continued

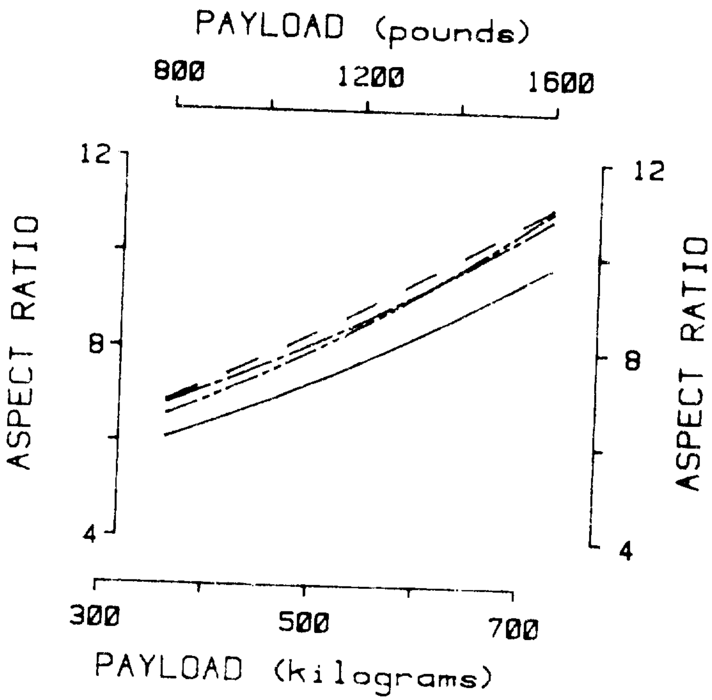
EFFECT OF VARYING MISSION PAYLOAD ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

——— RC 2-32 — — — GTDR-246 —·—·— GTSIO 420SC —··—··— GATE

c) EFFECT ON ASPECT RATIO



d) EFFECT ON WING SPAN

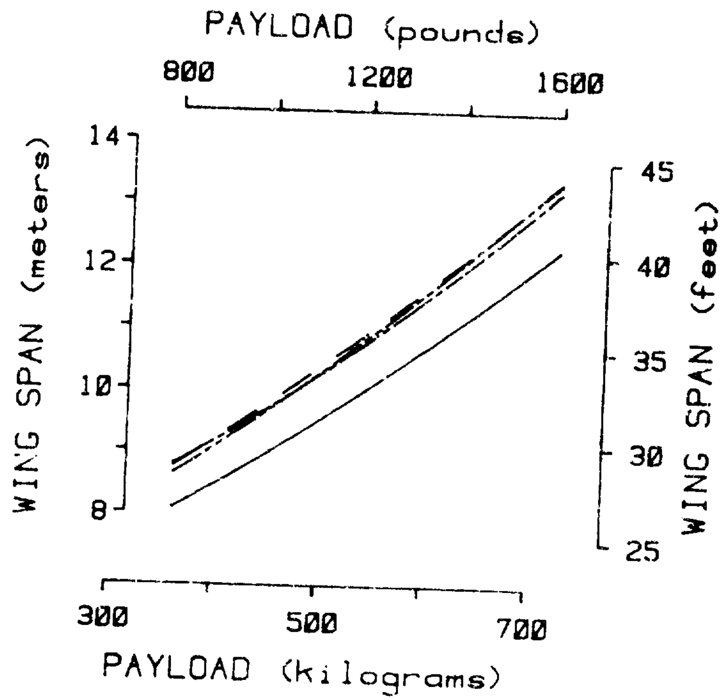


FIGURE 47 continued

EFFECT OF VARYING MISSION PAYLOAD ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

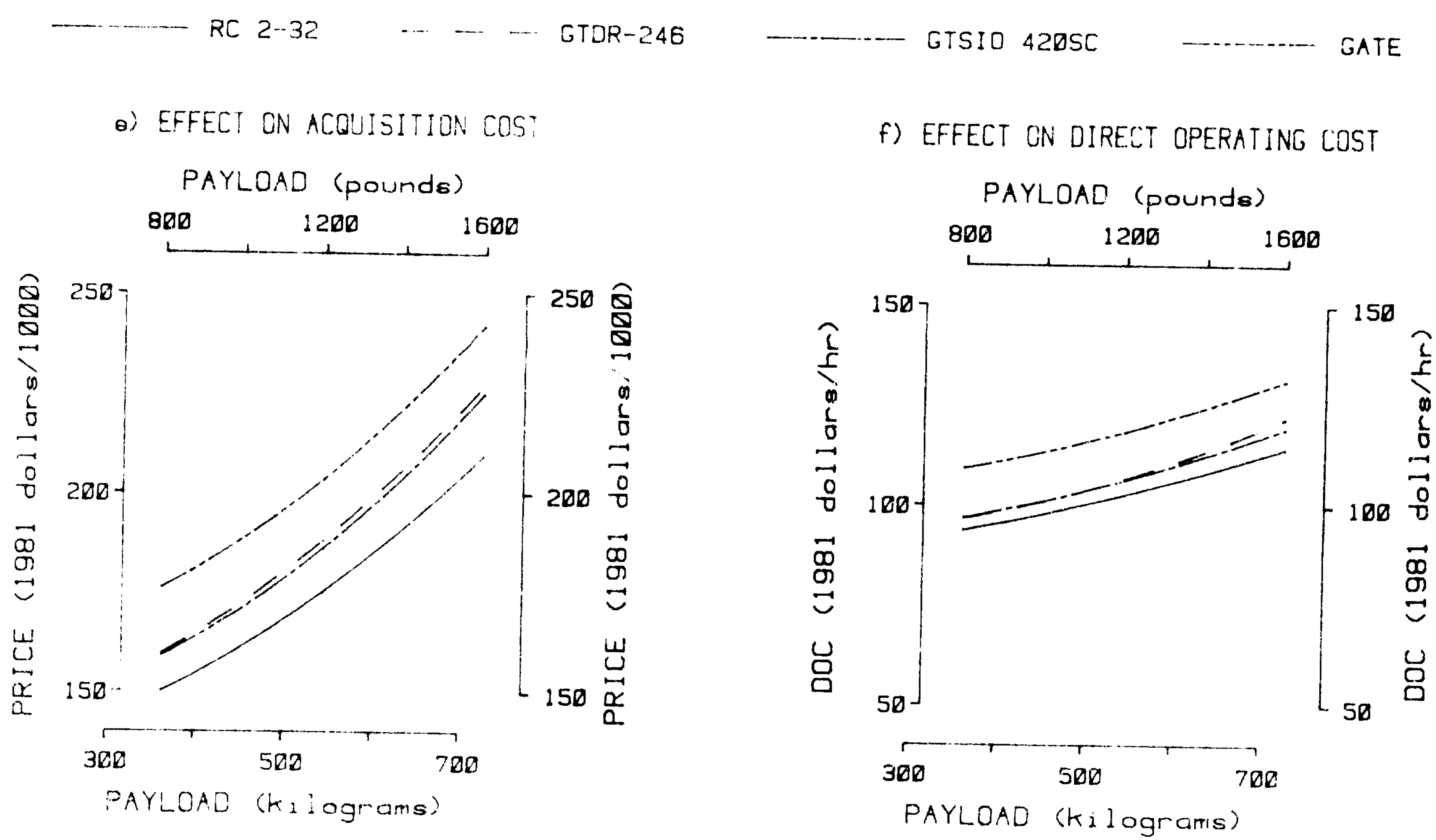


FIGURE 47 concluded

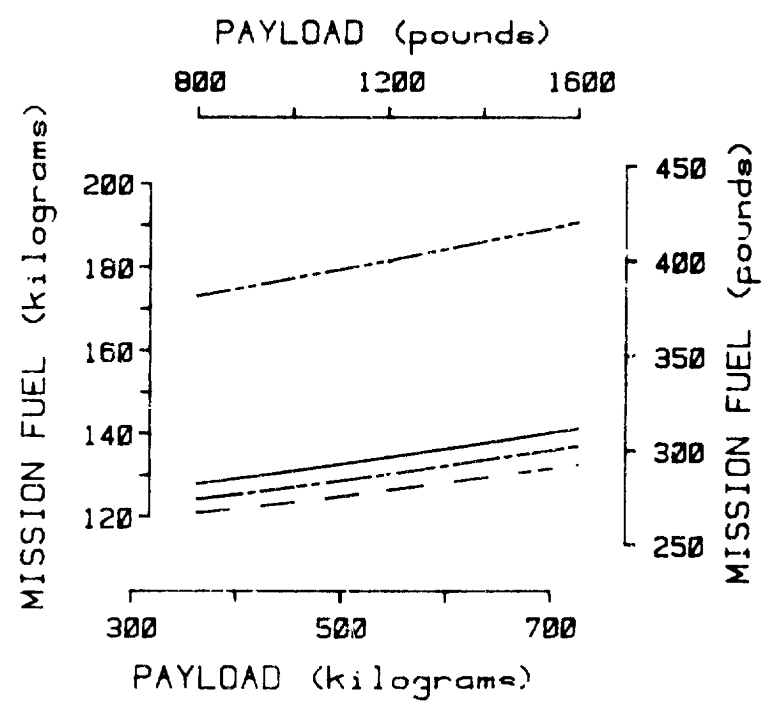
EFFECT OF VARYING MISSION PAYLOAD ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

——— RC 2-32 — — — GTDR-246 —·—·— GTSIO 420SC -·-·-·- GATE

g) EFFECT ON MISSION FUEL



h) EFFECT ON EVALUATION CRITERIA

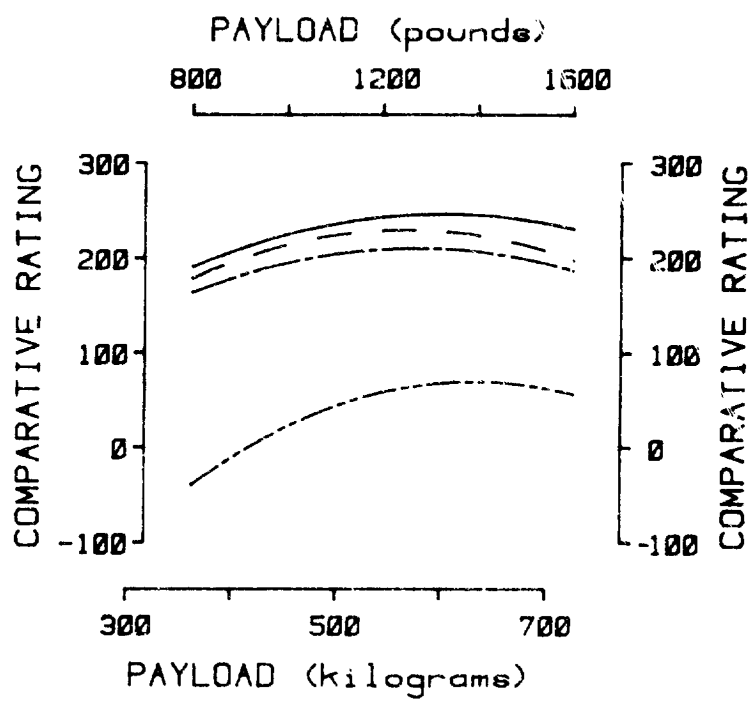


FIGURE 48

EFFECT OF VARYING MISSION RANGE ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

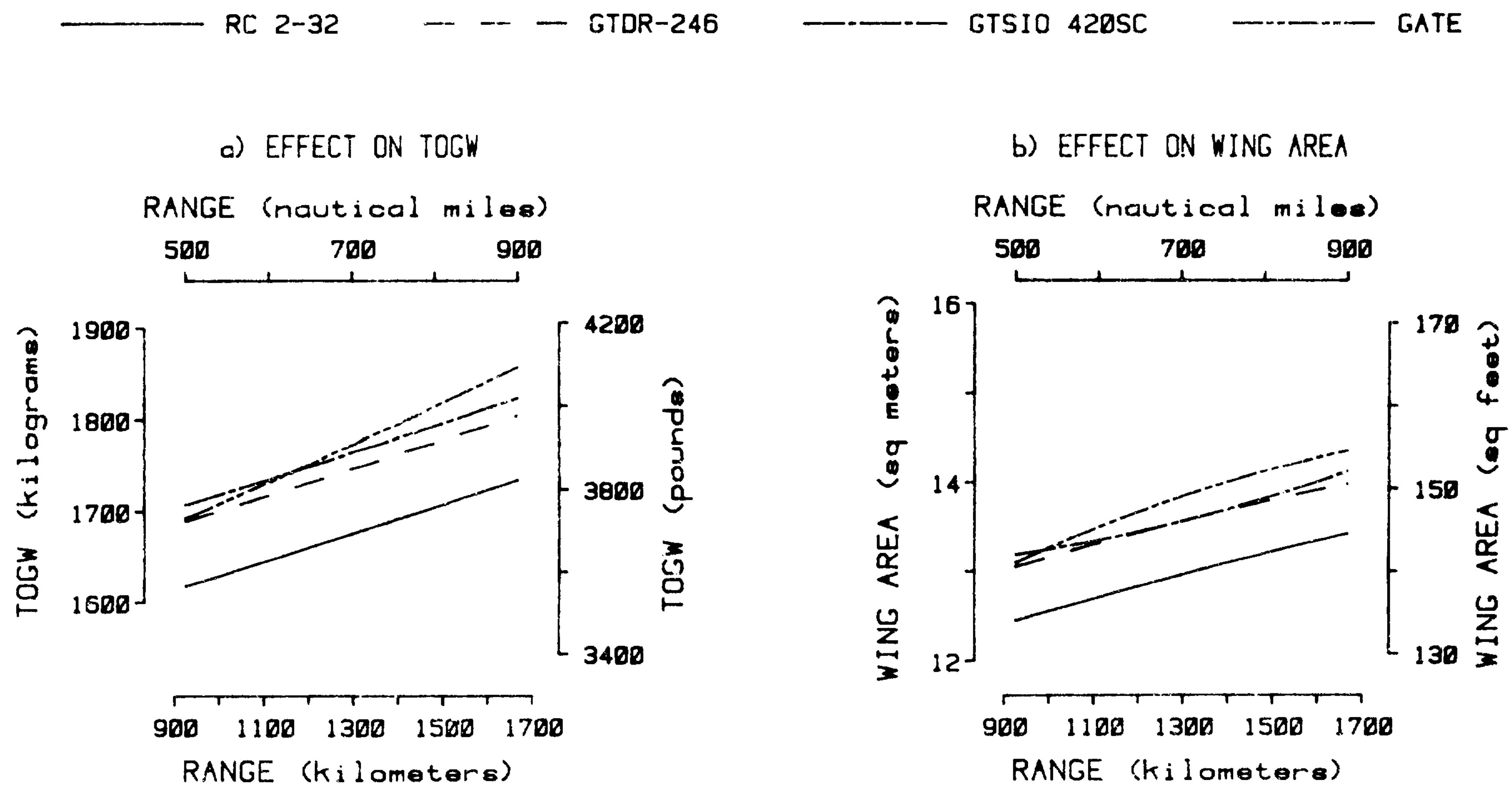
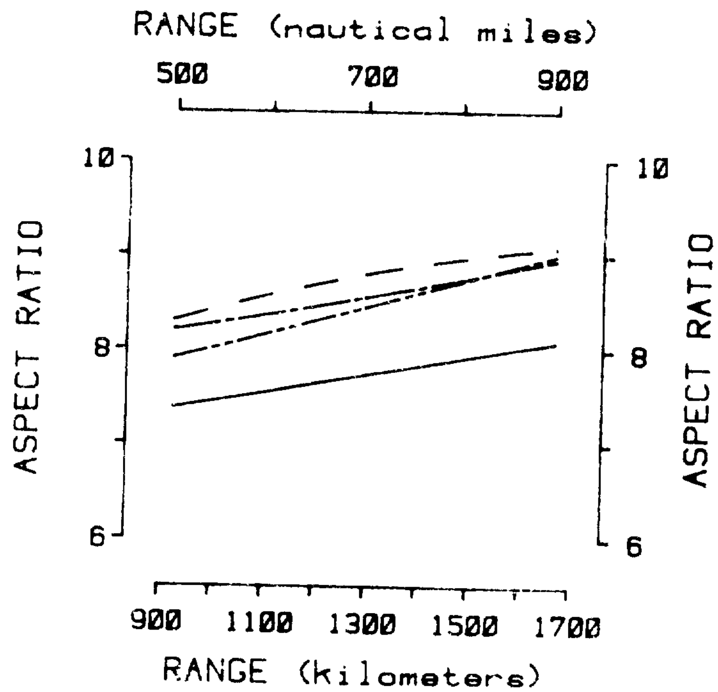


FIGURE 48 continued

EFFECT OF VARYING MISSION RANGE ON AIRCRAFT SIZING
II. FIXED ENGINE SIZE, VARIABLE AIRFRAME
SINGLE ENGINE CONFIGURATION

——— RC 2-32   — — — GTDR-246   —·—·— GTSIO 420SC   -·-·-·- GATE

c) EFFECT ON ASPECT RATIO



d) EFFECT ON WING SPAN

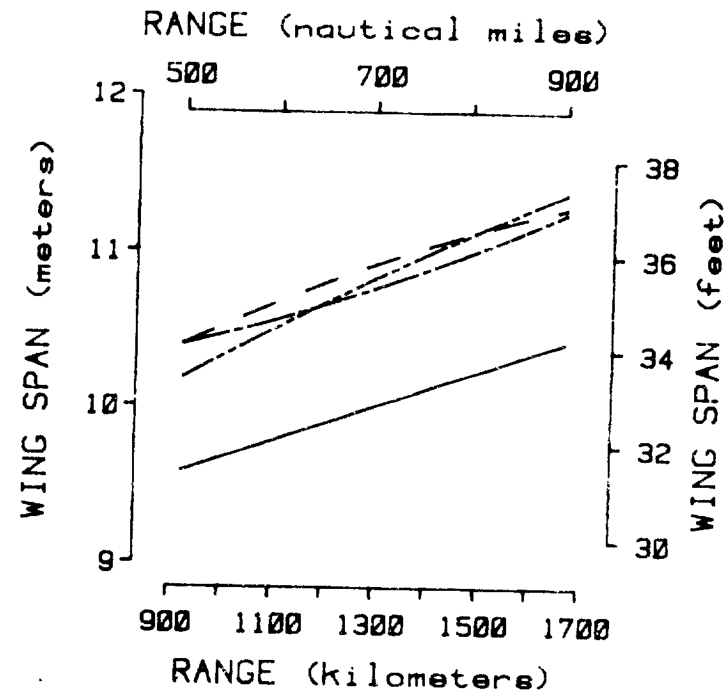


FIGURE 48 continued

EFFECT OF VARYING MISSION RANGE ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION

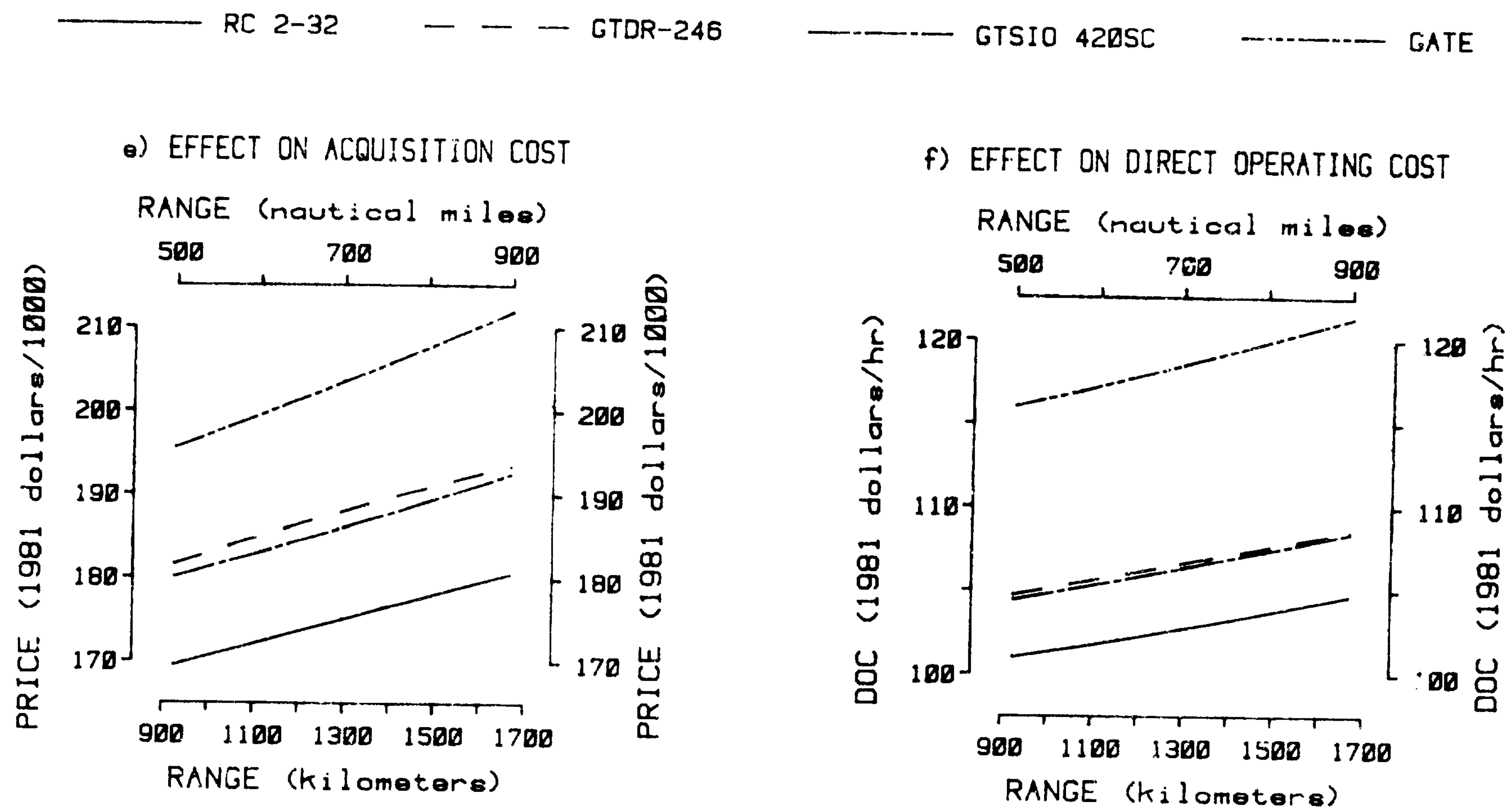
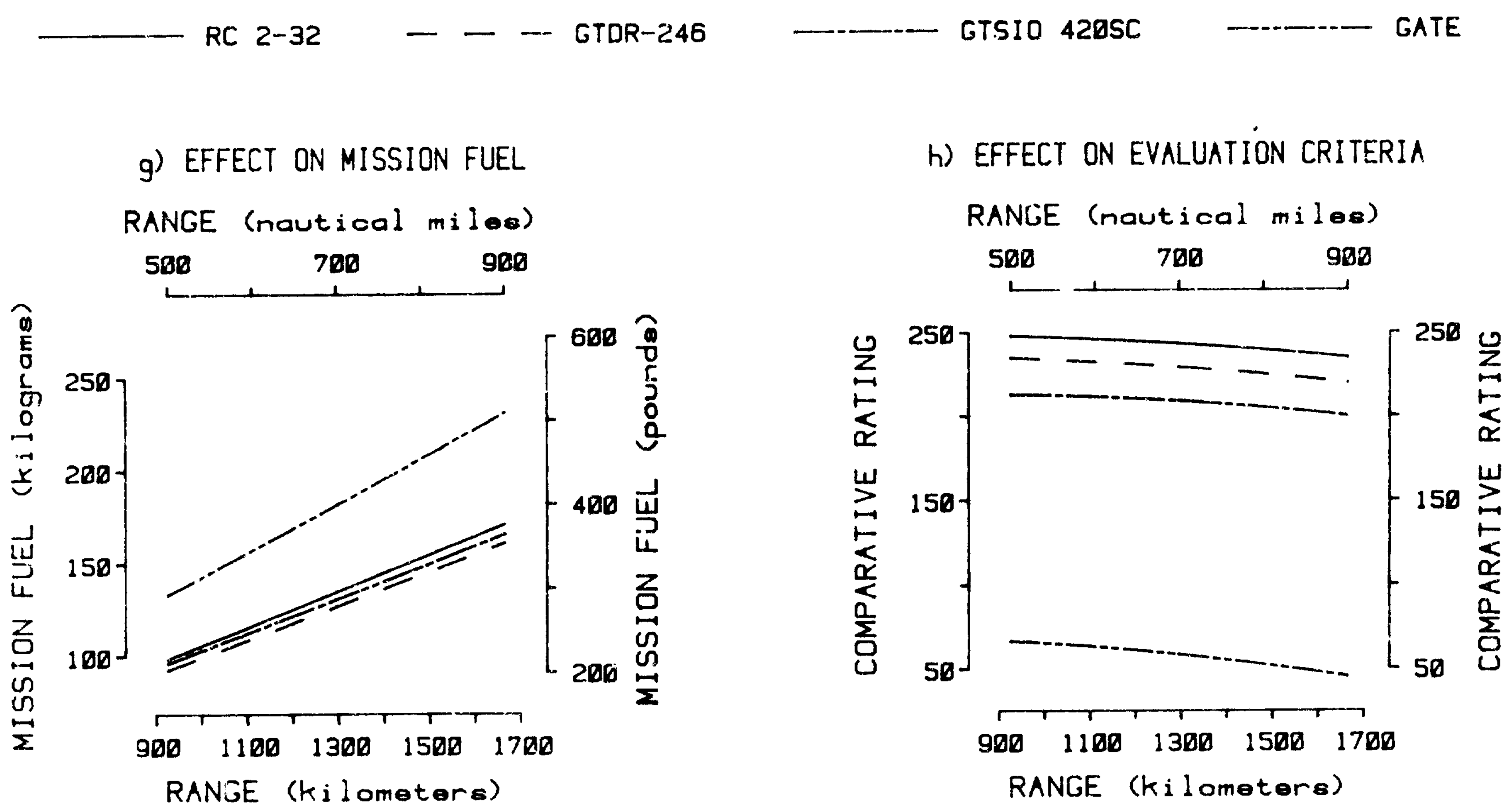


FIGURE 48 concluded

EFFECT OF VARYING MISSION RANGE ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

SINGLE ENGINE CONFIGURATION



optimistically; that is, it is unlikely that the cooling drag is less than estimated. On the other hand there is no reason to believe that any of the new engines would exhibit worse cooling drag than the baseline. This gives then, a reasonable approximation to the maximum and minimum cooling drags expected for each engine. Work on the Curtiss-Wright study (ref. 5) indicated that the variation in all aircraft characteristics with changes in cooling drag was linear over small ranges. Therefore, only 2 points need to be analyzed to define the trends.

The effects of variations in cooling drag are shown on Figure 49. Within this range of values the cooling drag has little effect on any aircraft characteristic except cruise speed and, in particular, the effect on DOC, acquisition cost and the evaluation criteria are minimal. This variable does not significantly alter the relative rankings between the 4 engines. The RC2-32, when evaluated with the highest reasonable drag level, still compares favorably with the others even when compared to the results for their best drag value. The conclusion is that had other values been chosen for cooling drag the results of the study would have been essentially the same.

<u>High Efficiency Inlet</u> NASA requested an investigation of the effects of using a high efficiency induction system inlet on the intermittent combustion engines. These are regularly used on the turbines but are seldom applied to conventional engines which often draw their induction air from the same plenum that supplies the cooling air flow.

The effect of inlet efficiency was already included in the GATE data. For the other engines the horsepower output varied only with altitude (that is, the pressure of the air entering the induction system was the static pressure).

A higher efficiency inlet on the rotary would not have helped at cruise since the engine was already capable of generating its maximum cruise rating with no pressure recovery. The small effect it might have had on climb where velocity is low was judged to be insignificant and not worth analyzing.

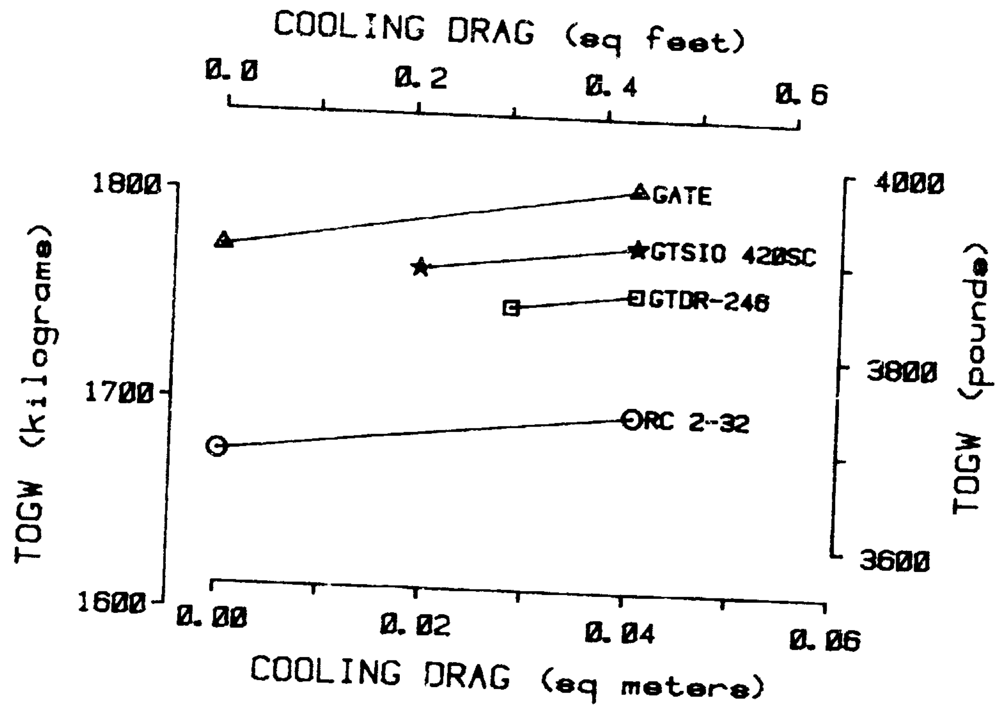
The diesel, however, has a high lapse rate above 17000 ft, losing 13.4 horsepower for every 1000 ft above the critical altitude. Assuming that an intake capable of 90 percent ram recovery would cause no changes in SFC, weight or drag (since the air must be supplied to the compressor anyway) the single engine diesel was reanalyzed. These assumptions probably represent the maximum benefits that could reasonably be realized even with careful development. The results are shown on Table X for both Method II and III. The benefits shown for this inlet are not negligible. For method II the evaluation criteria which had been 15 points less than the RC2-32's became 6 points better; for method III where

FIGURE 49

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

a) EFFECT ON TOGW



b) EFFECT ON WING AREA

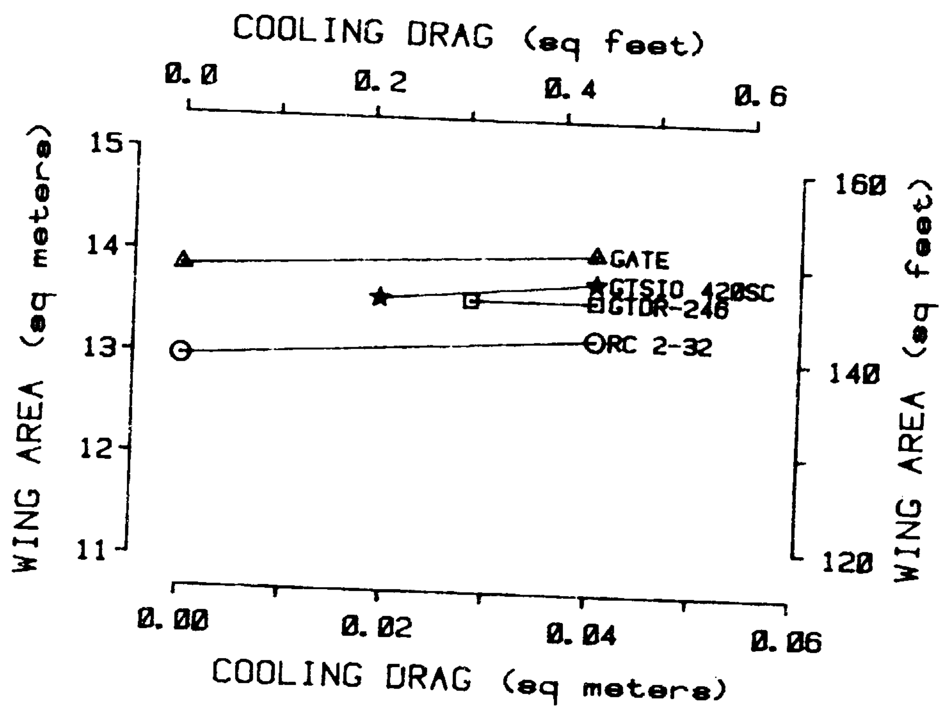
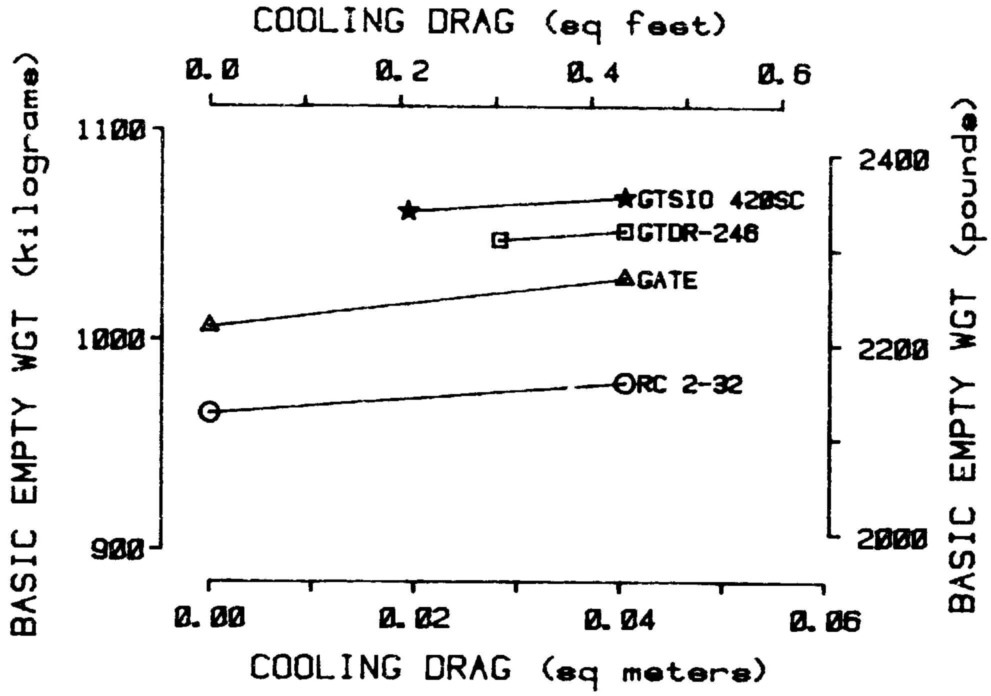


FIGURE 49 continued

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

c) EFFECT ON BASIC EMPTY WGT



d) EFFECT ON ASPECT RATIO

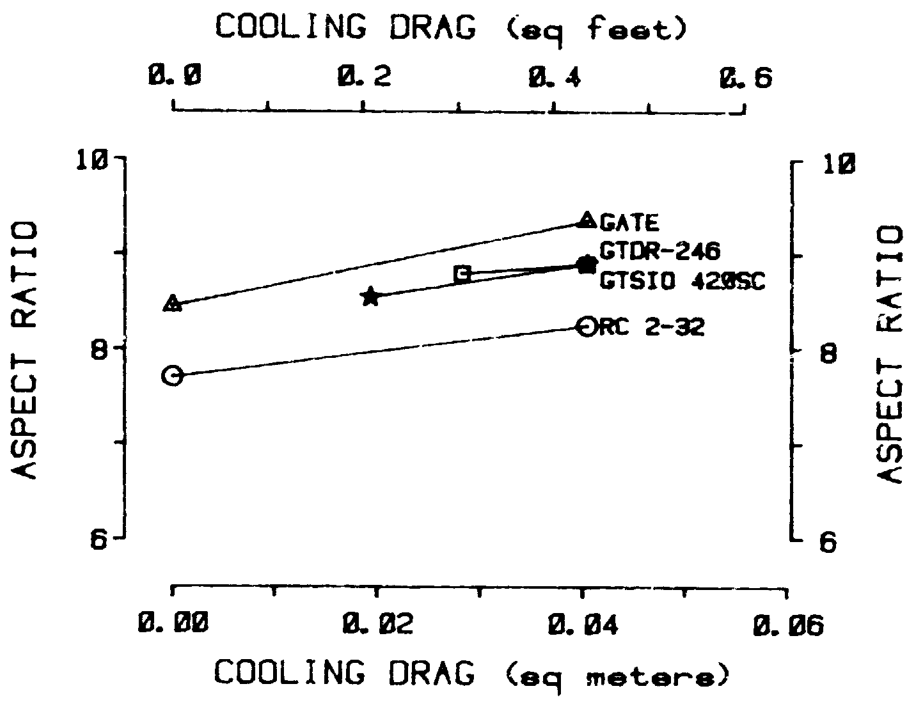
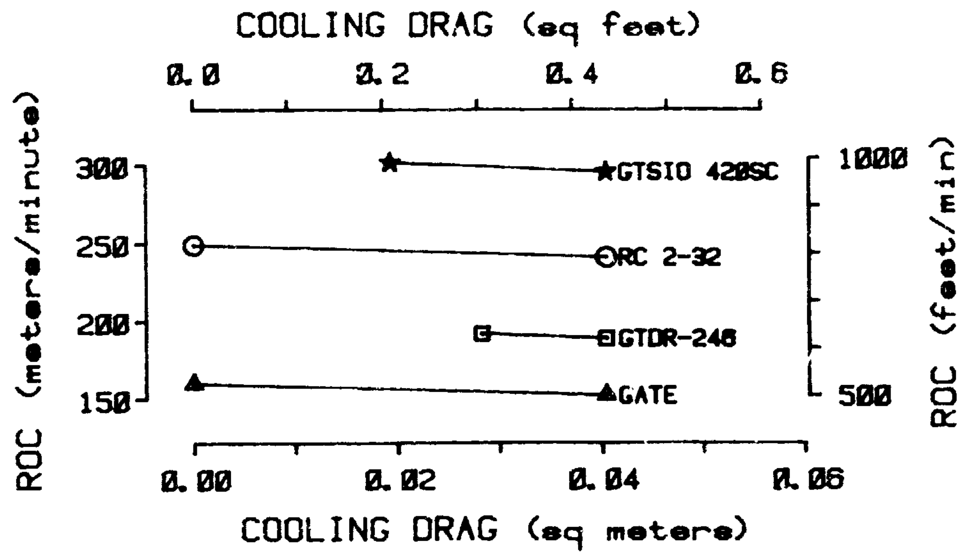


FIGURE 49 continued

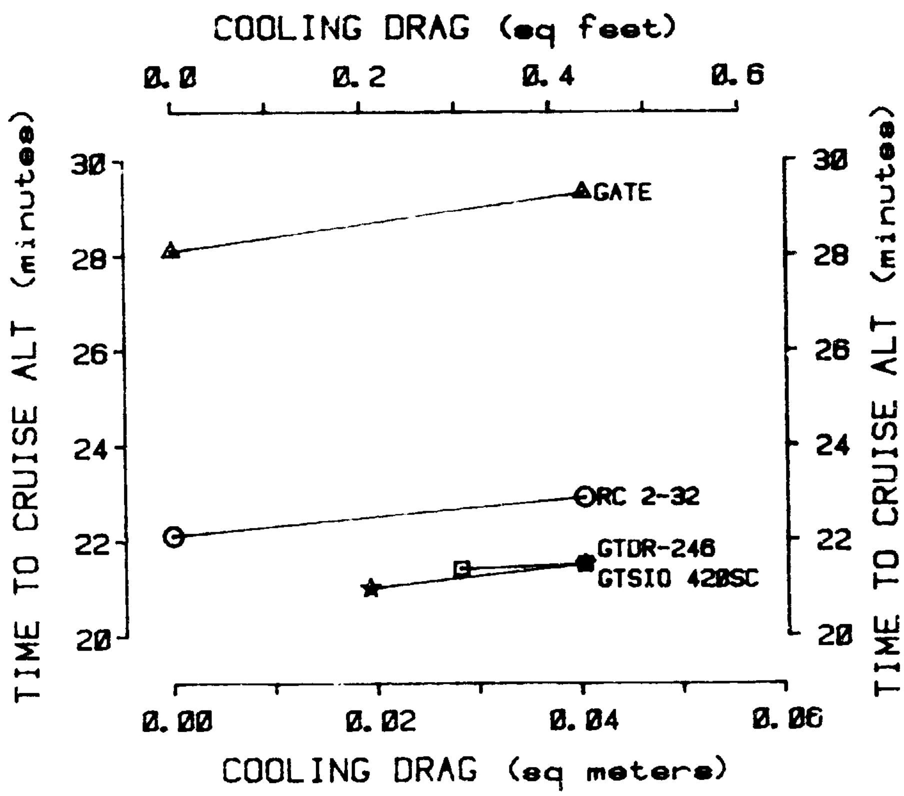
EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

e) EFFECT ON RATE OF CLIMB



f) EFFECT ON TIME TO CLIMB



2 OF 2

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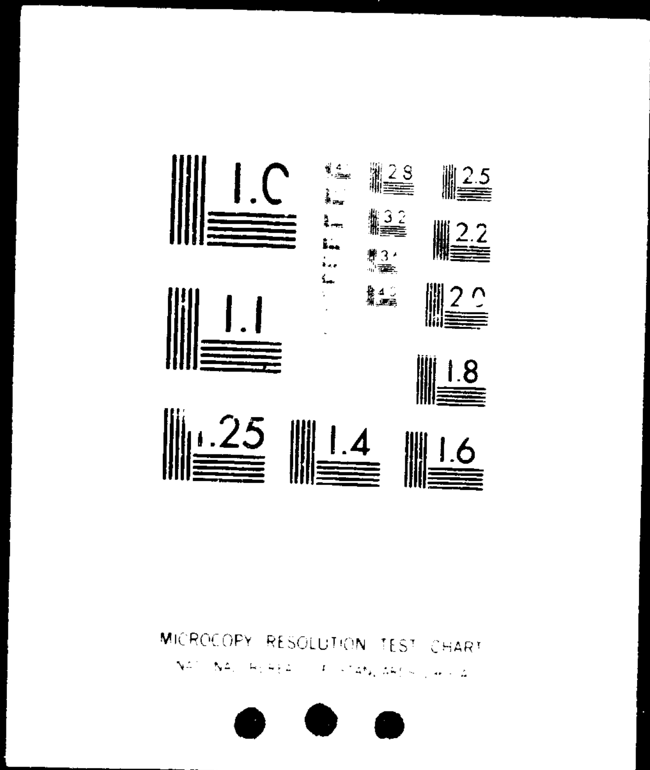
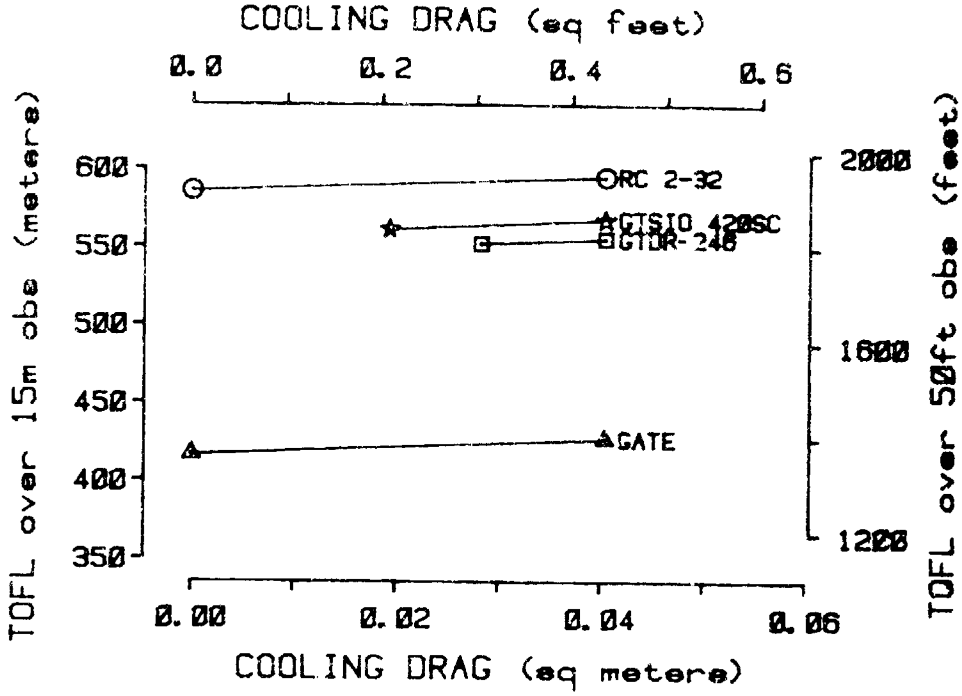


FIGURE 49 continued

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

g) EFFECT ON TAKEOFF DISTANCE



h) EFFECT ON CRUISE SPEED

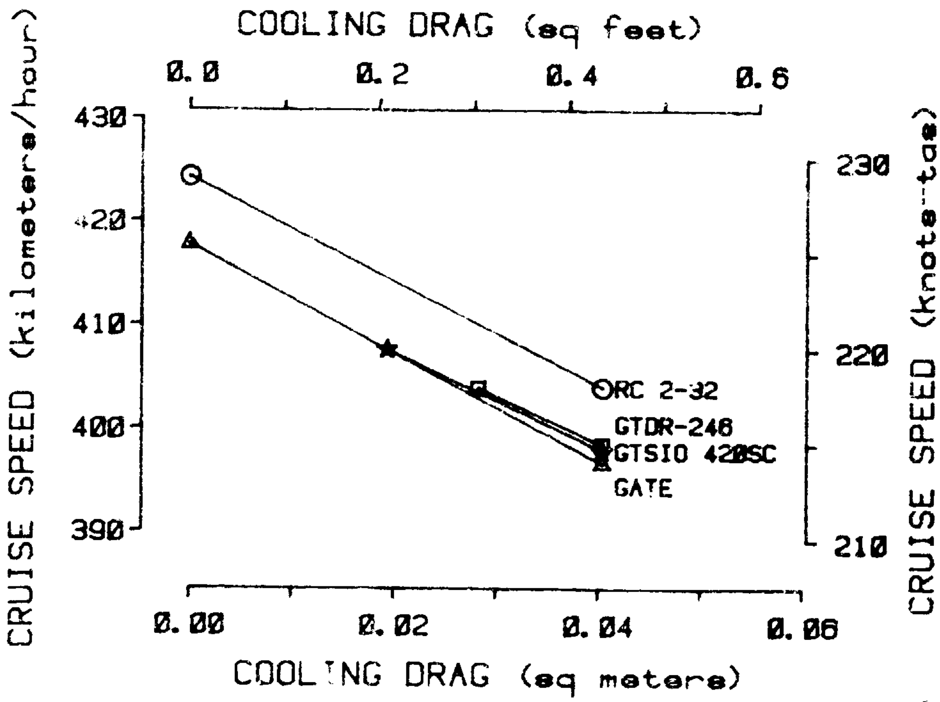
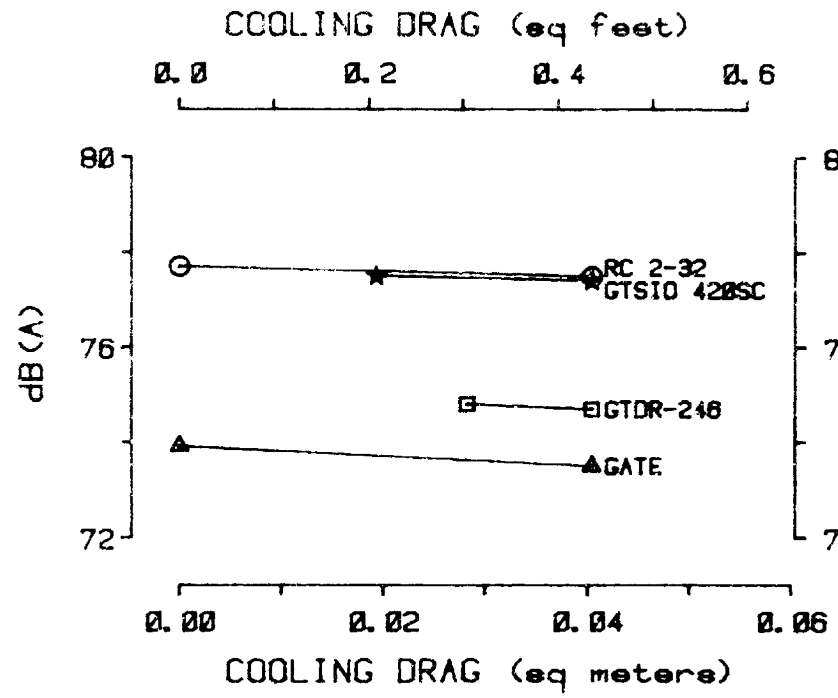


FIGURE 49 continued

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

i) EFFECT ON NOISE



j) EFFECT ON MISSION FUEL

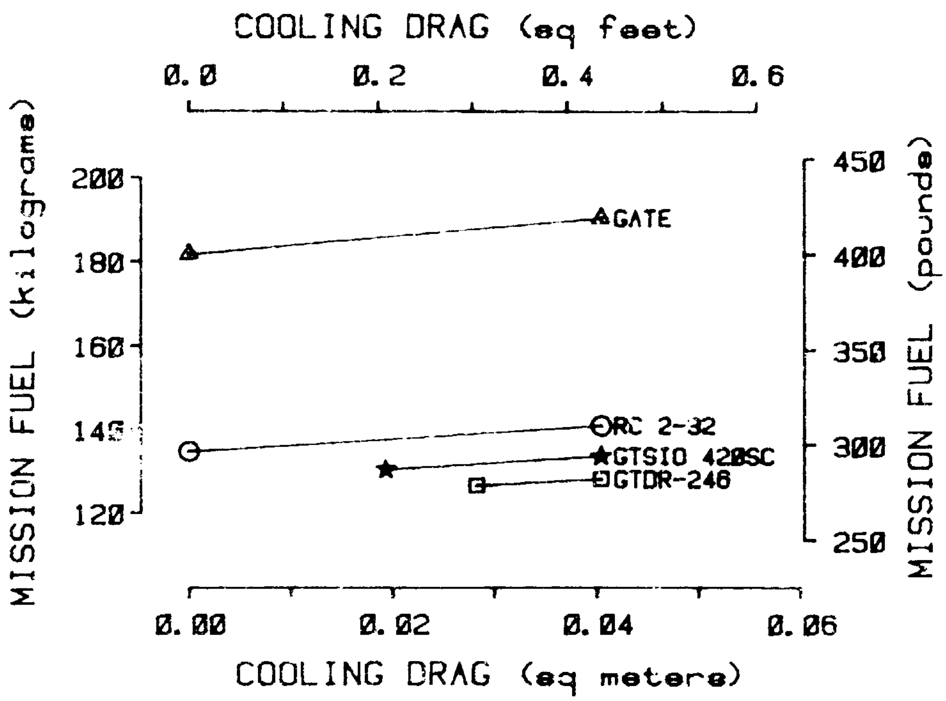
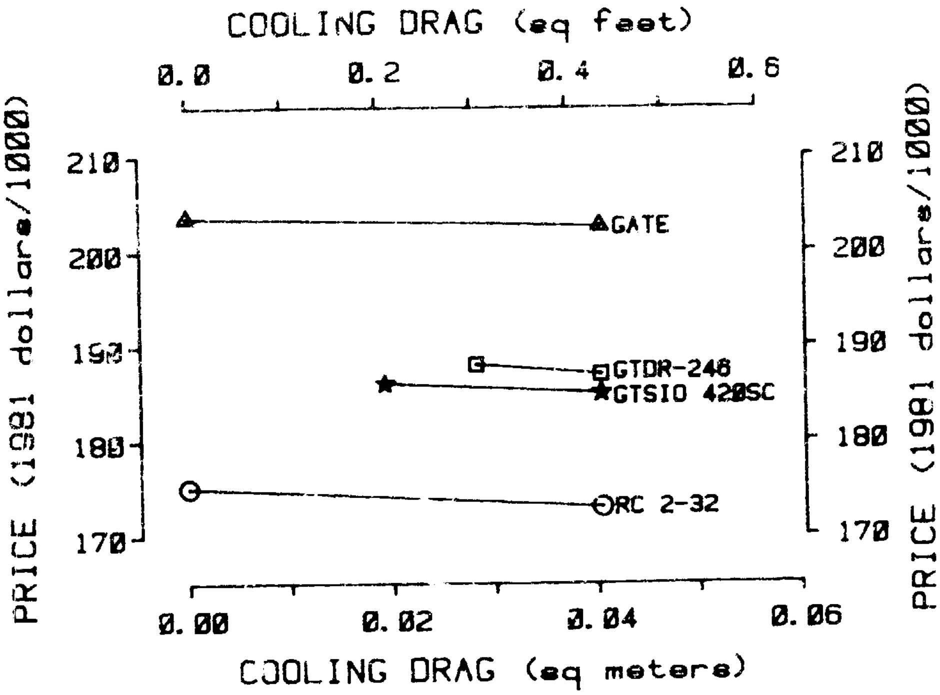


FIGURE 49 continued

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

k) EFFECT ON ACQUISITION COST



l) EFFECT ON DIRECT OPERATING COST

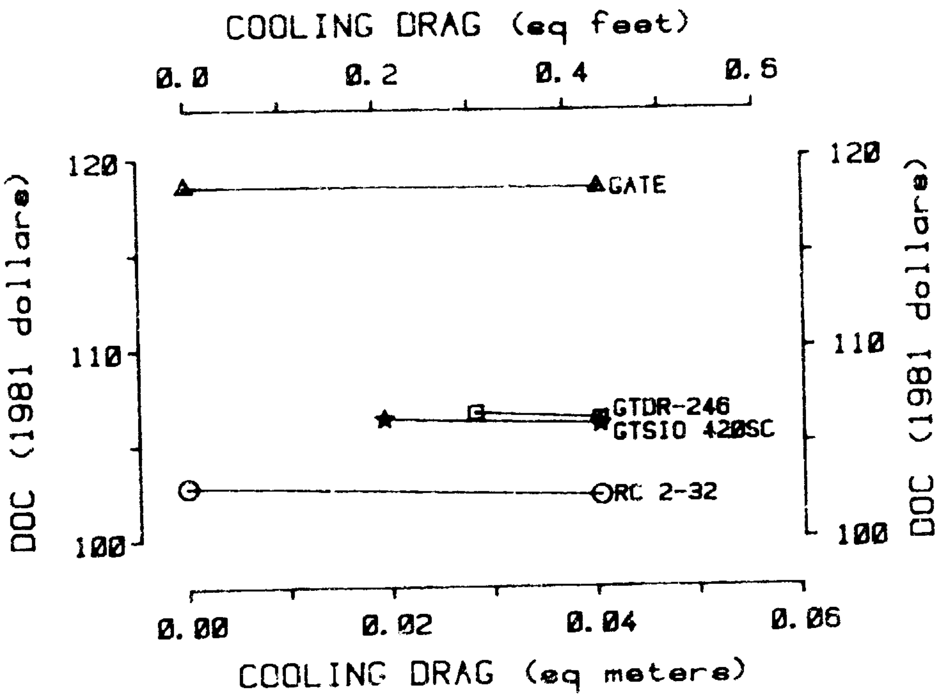
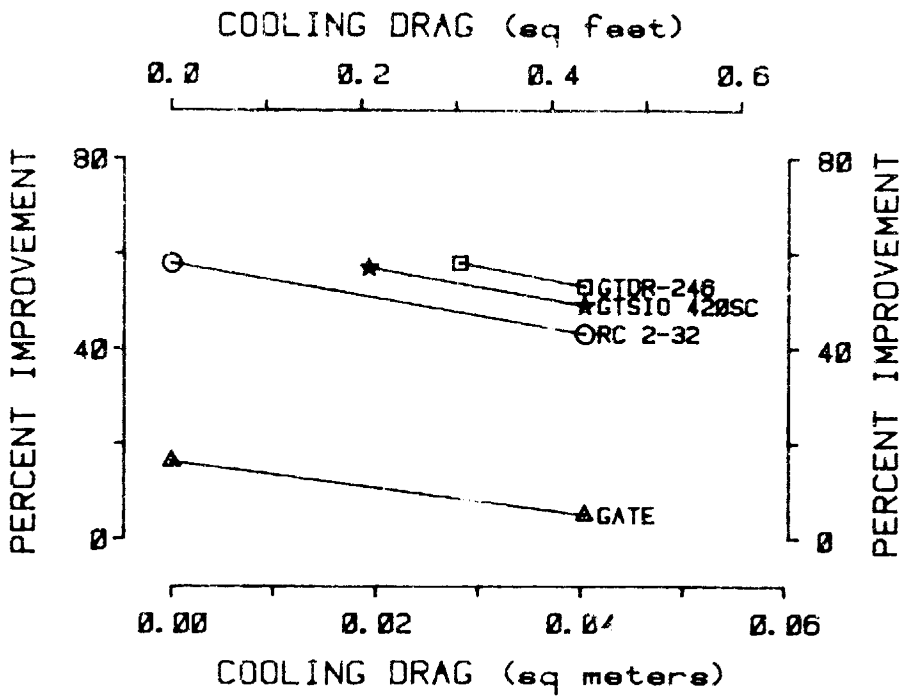


FIGURE 49 concluded

EFFECT OF COOLING DRAG ON AIRCRAFT SIZING

II. FIXED ENGINE SIZE, VARIABLE AIRFRAME

m) EFFECT ON CRUISE COEFFICIENT



n) EFFECT ON EVALUATION CRITERIA

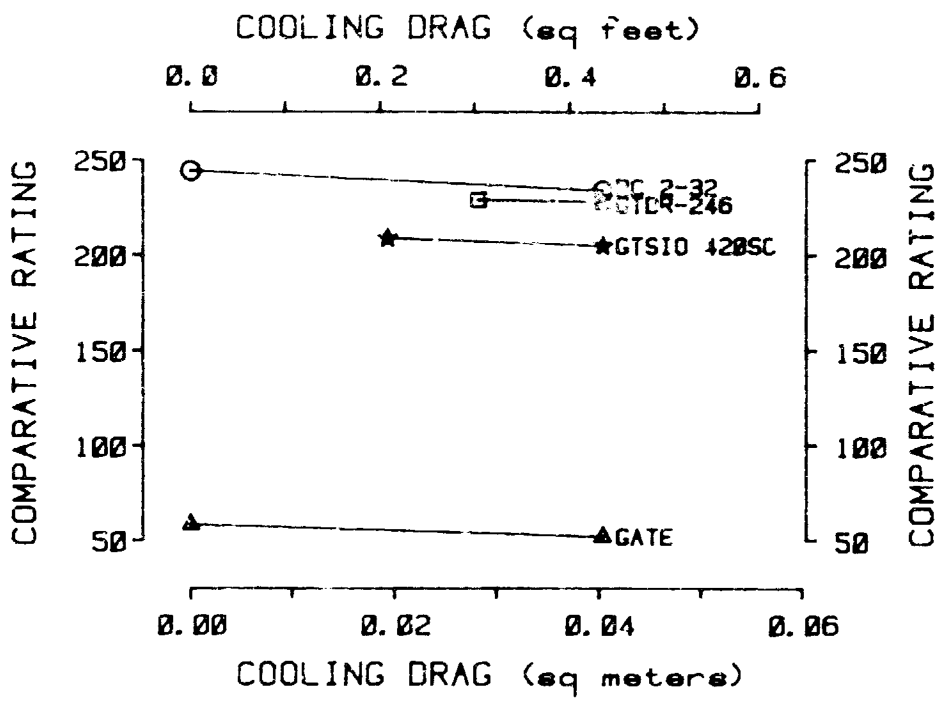


TABLE X
part 1
EFFECT OF HIGH EFFICIENCY INLET
TCM GTDR-246 DIESEL
SINGLE ENGINE

FIXED ENGINE, VARIABLE AIRFRAME

	STATIC PRESSURE TO ENGINE		HIGH EFFICIENCY INLET	
TAKEOFF POWER	268 kW	360 BHP	268 kW	360 BHP
CRUISE POWER	186 kW	250 BHP	186 kW	250 BHP
BASIC EMPTY WEIGHT	1043 kg	2310 lb	1018 kg	2245 lb
GROSS WEIGHT	1746 kg	3849 lb	1712 kg	3774 lb
WING AREA	13.6 sqm	146 sqft	13.2 sqm	142 sqft
WING SPAN	10.91 m	35.8 ft	9.81 m	32.2 ft
ASPECT RATIO	3.80	8.80	7.32	7.32
ROC AT CRUISE ALT	192 m/min	630 fpm	198 m/min	650 fpm
TIME TO CLIMB	21[illegible] min	21.4 min	20.8 min	20.8 min
TAKEOFF DISTANCE	552 m	1810 ft	549 m	1800 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	404 km/hr	218 KTS	417 km/hr	225 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	126.3 kg	278.5 lb	122.5 kg	270.0 lb
REQUIRED FUEL CAP	200 L	52.9 gal	195 L	51.6 gal
RELATIVE CRUISE EFF	1.58	1.58	1.55	1.55
V/V*	1.05	1.05	1.05	1.05
AVG CRUISE SPEED	407 km/hr	220 KTS	420 km/hr	227 KTS
MAXIMUM SPEED	436 km/hr	235.5 KTS	436 km/hr	235.5 KTS
PRICE	$188,000	$188,000	$181,500	$181,500
DOC	$106.6/hr	$106.6/hr	$104.6/hr	$104.6/hr
NOISE CHANGE	-4 dBA	-4 dBA	-4 dBA	-4 dBA
EVALUATION TOTAL	229*	229*	250	250
FUEL EFFICIENCY	8.24 km/L	16.84 NMPG	8.50 km/L	17.37 NMPG

* For comparison, the evaluation total on the RC2-32 was 244.

TABLE X
part 2
EFFECT OF HIGH EFFICIENCY INLET
TCM GTDR-246 DIESEL
SINGLE ENGINE

VARIABLE ENGINE AND AIRFRAME

	STATIC PRESSURE TO ENGINE		HIGH EFFICIENCY INLET	
TAKEOFF POWER	242 kW	325 BHP	238 kW	319 BHP
CRUISE POWER	168 kW	226 BHP	166 kW	222 BHP
BASIC EMPTY WEIGHT	1020 kg	2249 lb	993 kg	2190 lb
GROSS WEIGHT	1710 kg	3770 lb	1676 kg	3696 lb
WING AREA	13.2 sqm	142 sqft	13.0 sqm	140 sqft
WING SPAN	10.55 m	34.6 ft	9.81 m	32.2 ft
ASPECT RATIO	8.45	8.45	7.40	7.40
ROC AT CRUISE ALT	152 m/min	500 fpm	152 m/min	500 fpm
TIME TO CLIMB	24.6 min	24.6 min	25.4 min	25.4 min
TAKEOFF DISTANCE	619 m	2030 ft	629 m	2065 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	386 km/hr	208.5 KTS	397 km/hr	214.5 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	120.2 kg	265 lb	115.4 kg	254.5 lb
REQUIRED FUEL CAP	189 L	49.9 gal	182 L	48.1 gal
RELATIVE CRUISE EFF	1.60	1.60	1.58	1.58
V/V*	1.00	1.00	1.00	1.00
AVG CRUISE SPEED	390 km/hr	210.5 KTS	402 km/hr	217 KTS
MAXIMUM SPEED	420 km/hr	227 KTS	418 km/hr	225.5 KTS
PRICE	$176,100	$176,100	$169,400	$169,400
DOC	$99.5/hr	$99.5/hr	$96.8/hr	$96.8/hr
NOISE CHANGE	-4.5 dBA	-4.5 dBA	-4.5 dBA	-4.5 dBA
EVALUATION TOTAL	274*	274*	299	299
FUEL EFFICIENCY	8.66 km/L	17.70 NMPG	9.02 km/L	18.43 NMPG

* For comparison, the evaluation total on the RC2-32 was 322.

it had been 48 points less it moved to only 23 points behind. The fuel savings were 8.5 pounds (3 percent) for Method II and 10.5 pounds (4 percent) for Method III. These numbers indicate that, within the framework of the assumptions, the inlet could pay its way.

The major effect of the advanced inlet was an apparent increase in the engine's critical altitude. It could, therefore, just as easily be argued that the turbocharger design for the diesel should be changed. (For example, using the APU burner to increase turbine output above 17000 ft.) Its low critical altitude puts the diesel at somewhat of a disadvantage relative to the other I.C. engines mostly due to the airplane's comparatively poor climb performance at high altitude. Reasonable increases in climb rate could, in the synergistic design process, offset significant increases in fuel burned during the climb. A change such as this might produce results equal to or better than the advanced inlet. However, since no engine data were available on this configuration, no tradeoff analysis could be run.

The lapse rate of the advanced spark ignition engine is virtually zero until above 25000 ft where it is still only 1/6 that of the diesel. Therefore, a high efficiency inlet could not produce nearly as large a change for this engine as for the diesel and was consequently not analyzed.

Cruise Altitude Within the constraints of the engine's capabilities, increases in altitude usually bring increases in cruise efficiency. Because of this, turbocharged engines have been taking an increasingly larger share of the general aviation market. This trend has been accelerating in recent years as fuel costs continue to escalate.

For this reason the selected cruise altitude for the missions used in this study was 25000 ft, which is the next logical step above the 18000-23000 ft altitudes in common use today.

Lower altitudes than 25000 ft were not analyzed for all of the engines since future competitive aircraft will be capable of operating at this altitude and the aircraft of this study must also if they are to represent marketable products. The diesel's characteristics in particular seemed better matched perhaps to a lower altitude, but in Phase II it was analyzed at 25000 ft for the reason just stated.

The operation of small aircraft is effectively limited to 25000 ft primarily because of Federal Aviation Regulations (FAR's). Above that altitude the FAR's require fail-safe windshields and window panels (FAR-23.775e) and a supplemental oxygen dispensing unit (FAR-23.1447b). This, plus the higher pressurization differential (assuming that a 10000 ft cabin is maintained) adds an estimated 50 pounds to the basic empty weight of the airplane. Small increases in altitude above 25000 ft are not justified because of this weight penalty. The four advanced engines were, therefore, analyzed assuming a substantial increase in cruise altitude to 35000 ft. The diesel and GATE, however, had such high thrust lapse rates that no solution could be found without extrapolating the engine size to unreasonably large values far beyond the range of data supplied.

The rotary and advance spark ignition engines could be sized to this altitude and the results are shown on Table XI. Even at this altitude, however, the increased efficiency cannot compensate for the heavier empty weight and higher horsepower required. The evaluation criteria, in particular, are noticeably worse than for the 25000ft case.

It would be easy to conclude from these results that 25000 ft represents a reasonable maximum cruise altitude for general aviation. This would not, however, be correct. The correct conclusion is that the engine and turbocharger system must be matched to the cruise altitude intended for the aircraft. Simply scaling an engine to a larger size will not enable it to perform well at altitudes higher than where it was designed to operate.

With this in mind the baseline, RC2-32 and GTDR-246 were reanalyzed at a 17000 ft cruise altitude which corresponds to the diesel's critical altitude. This was done to see if the altitude choice had unfairly penalized the diesel. The results are shown on Table XII. Here the rotary and diesel are very evenly matched whereas at 25000 ft the rotary was clearly the superior powerplant. As pointed out above, marketing considerations make 17000 ft an impractical design altitude. The data in Figure XII merely demonstrate again the importance to a fair comparison of having all the engines designed for the same altitude. The diesel, which ran a close second to the rotary, would possibly have done better had its turbocharger been optimized for a higher altitude (see previous discussion under High Efficiency Inlet).

<u>Cruise at Constant Airspeed</u> There is an often quoted rule of thumb that says the horsepower required varies by the cube of the velocity. This indeed is a good approximation when considering the maximum speed where induced drag is low and parasite drag predominates. For general aviation aircraft flying at V*, however, induced drag is high enough that the horsepower required varies by the square, not the cube, of the velocity.

Even so, since the Cessna method of sizing usually defines airplanes with varying cruise speeds, it may still be asked why the airplanes shouldn't be compared when sized to the same cruise speed and, therefore, presumably are using the same cruise horsepower. This usually is not a good procedure, however. First, from the

TABLE XI
EFFECT OF SIZING FOR CRUISE AT 35000 FT
SINGLE ENGINE

ENGINE	RC 2-32		GTSIO-420SC	
TAKEOFF POWER	347 kW	465 BHP	313 kW	420 BHP
CRUISE POWER @25000´	283 kW	380 BHP	224 kW	300 BHP
CRUISE POWER @35000´	200 kW	268 BHP	204 kW	274 BHP
BASIC EMPTY WEIGHT	1146 kg	2527 lb	1217 kg	2683 lb
GROSS WEIGHT	1856 kg	4092 lb	1929 kg	4252 lb
WING AREA	14.3 sqm	154 sqft	15.0 sqm	161 sqft
WING SPAN	12.56 m	41.2 ft	12.83 m	42.1 ft
ASPECT RATIO	11.0	11.0	11.0	11.0
ROC AT 35000 FT	210 m/min	690 fpm	226 m/min	740 fpm
TIME TO CLIMB	23.2 min	23.2 min	26.5 min	26.5 min
TAKEOFF DISTANCE	415 m	1360 ft	479 m	1570 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	453 km/hr	244.5 KTS	446 km/hr	241 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	134.9 kg	297.5 lb	134.3 kg	296 lb
REQUIRED FUEL CAP	218 L	57.6 gal	217 L	57.3 gal
V/V*	1.00	1.00	1.00	1.00
AVG CRUISE SPEED	457 km/hr	247 KTS	450 km/hr	243 KTS
MAXIMUM SPEED	493 km/hr	266 KTS	452 km/hr	244 KTS
PRICE	$239,500	$239,500	$229,000	$229,000
DOC	$130.2/hr	$130.2/hr	$125.0/hr	$125.0/hr
NOISE CHANGE	-3.5 dBA	-3.5 dBA	-2.6 dBA	-2.6 dBA
EVALUATION TOTAL	103	103	111	111
FUEL EFFICIENCY	7.71 km/L	15.76 NMPG	7.75 km/L	15.84 NMPG

There was no solution for the GTDR-246 or the GATE within reasonable extrapolation of the engine size.

TABLE XII
EFFECT OF SIZING FOR CRUISE AT 17,000 FT
SINGLE ENGINE

ENGINE	BASELINE		RC2-32		GTDR-246	
TAKEOFF POWER	254 kW	340 BHP	205 kW	275 BHP	183 kW	245 BHP
CRUISE POWER @ 17000'	195 kW	262 BHP	160 kW	215 BHP	183 kW	245 BHP
BASIC EMPTY WEIGHT	1270 kg	2800 lb	916 kg	2020 lb	968 kg	2135 lb
GROSS WEIGHT	2060 kg	4542 lb	1616 kg	3562 lb	1670 kg	3682 lb
WING AREA	16.0 sqm	172 sqft	12.4 sqm	134 sqft	14.5 sqm	156 sqft
WING SPAN	12.95 m	42.5 ft	8.90 m	29.2 ft	9.94 m	32.6 ft
ASPECT RATIO	10.5	10.5	6.35	6.35	6.80	6.30
ROC AT 17000 FT	271 m/min	890 fpm	253 m/min	830 fpm	199 m/min	653 fpm
TIME TO CLIMB	20.0 min	20.0 min	19.3min	19.3 min	24.8 min	24.8 min
TAKEOFF DISTANCE	747 m	2450 ft	713 m	2340 ft	762 m	2500 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS	106 km/hr	57.5 KTS
CRUISE SPEED (INITIAL)	369 km/hr	199 KTS	369 km/hr	199KTS	369 km/hr	199 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	206 kg	455 lb	130 kg	286 lb	130 kg	287 lb
REQUIRED FUEL CAP	358 L	94.5gal	202L	53.4 gal	202 L	53.4 gal
V/V*	1.13	1.13	1.00	1.00	1.10	1.10
AVG CRUISE SPEED	372km/hr	201 KTS	372 km/hr	201 KTS	372 km/hr	201 KTS
PRICE	$209,000	$209,000	$158,000	$158,000	$157,000	$157,000
DOC	$125.5/hr	$125.5/hr	$92.2/hr	$92.2/hr	$91.3/hr	$91.3/hr
EVALUATION TOTAL	0	0	323*	323*	320*	320*
FUEL EFFICIENCY	4.5 km/L	9.2 NMPG	8.0 km/L	16.4 NMPG	8.0 km/L	16.3 NMPG

*RELATIVE TO BASELINE SIZED FOR 17000 FT CRUISE

Method II comparison it can be seen that equal cruise horsepower does not produce equal cruise speeds for the various engine/airframe combinations. Second, there are on the order of 8 specific constraints that each design must meet but only 4 major variables (gross weight, wing area, aspect ratio and engine size) which can be changed in order to match the airplane's performance to these constraints. That means that only 4, at most, can be satisfied and these are chosen so that the other constraints are exceeded. Trying to pick one constraint, cruise speed, and saying that it will be met whatever the cost to the others usually means choosing design parameters that increase the drag to artificially hold the speed of one configuration down to the value of another.

There is another option, however, which is to compare the airplanes when cruising at the same speed at reduced throttle settings. There was sufficient part throttle data to do the analysis for the diesel and RC2-32 engines which were also the most interesting. These were analyzed while operating at so called "economy cruise" ratings, or throttle settings that allowed an efficient matching of the cruise airspeeds to that of the baseline single. The results are shown on Table XIII. Note that the takeoff gross weight, acquisition cost and DOC are virtually unchanged, while the evaluation criteria, relative cruise coefficient and mission fuel are nominally better. The effect is to make already dramatic improvements slightly better. It does not change the relative rankings of the engines nor does it make the large performance improvements of these engines, relative to today's powerplants, significantly more obvious.

Advanced Airframe As outlined in the section on assumptions, the study was modeled using aerodynamics, materials and missions for the 1990 airplanes which were logical progressions from the aircraft of today. There are, however, many active research and development programs which could radically alter that picture in the next decade. These possibilities are discussed below along with estimates of how much each would change the characteristics of a new airplane if the technology matured sufficiently to allow their use.

Composites Materials: Here the problem is not in material characteristics, which are in many ways already demonstrably better than aluminum, but in the costs associated with using them. Reference 14 suggests potential weight savings of at least 25 percent in major components (wings, fuselage, etc.) and 12 percent in the landing gear. These values are somewhat conservative compared to other estimates.

Propeller: The propeller characteristics used up to this point in the analysis took advantage of only about one half of the potential gains indicated by the NASA GAP study (Ref. 15). The full gains used here are a 6 percent improvement in propeller efficiency (i.e., $\eta_{prop_{new}} - \eta_{prop_{old}} = .06$), a 40 pound decrease in weight and a

TABLE XIII
part 1
EFFECT OF OPERATING AT REDUCED POWER
SINGLE ENGINE RC2-32

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE AND CRUISE SPEED

THROTTLE SETTING	MAXIMUM CRUISE		ECONOMY CRUISE	
TAKEOFF POWER	239 kW	320 BHP	239 kW	320 BHP
CRUISE POWER @25000'	186 kW	250 BHP	154 kW	206 BHP
BASIC EMPTY WEIGHT	965 kg	2127 lb	995 kg	2194 lb
GROSS WEIGHT	1674 kg	3691 lb	1676 kg	3696 lb
WING AREA	13.0 sqm	139.5 sqft	13.0 sqm	140 sqft
WING SPAN	10.00 m	32.8 ft	11.28 m	37.0 ft
ASPECT RATIO	7.73	7.73	9.80	9.80
ROC AT 25000 FT	249 m/min	816 fpm	290 m/min	950 fpm
TIME TO CLIMB	22.1 min	22.1 min	20.2 min	20.2 min
TAKEOFF DISTANCE	585 m	1920 ft	563 m	1847 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	424 km/hr	229 KTS	382 km/hr	206 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	134 kg	296 lb	114.5 kg	252.5 lb
REQUIRED FUEL CAP	214 L	56.5 gal	199 L	52.7 gal
V/V*	1.05	1.05	1.00	1.00
AVG CRUISE SPEED	423 km/hr	231 KTS	384 km/hr	207.5 KTS
MAXIMUM SPEED	439 km/hr	237 KTS	443 km/hr	239 KTS
PRICE	$175,000	$175,000	$180,000	$180,000
DOC	$102.7/hr	$102.7/hr	$104.5/hr	$104.5/hr
NOISE CHANGE	-1.0 dBA	-1.0 dBA	-2.0 dBA	-2.0 dBA
EVALUATION TOTAL	244	244	272	272
FUEL EFFICIENCY	7.73 km/L	15.80 NMPG	9.10 km/L	18.60 NMPG

TABLE XIII
part 2
EFFECT OF OPERATING AT REDUCED POWER
SINGLE ENGINE GTDR-246

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE AND CRUISE SPEED

THROTTLE SETTING	MAXIMUM CRUISE		ECONOMY CRUISE	
TAKEOFF POWER	268 kW	360 BHP	268 kW	360 BHP
CRUISE POWER @25000′	186 kW	250 BHP	154 kW	206 BHP
BASIC EMPTY WEIGHT	1048 kg	2310 lb	1048 kg	2311 lb
GROSS WEIGHT	1746 kg	3849 lb	1726 kg	3807 lb
WING AREA	13.6 sqm	146 sqft	13.4 sqm	144.5 sqft
WING SPAN	10.91 m	35.8 ft	11.06 m	36.3 ft
ASPECT RATIO	8.80	8.80	9.10	9.10
ROC AT 25000 FT	192 m/min	630 fpm	200 m/min	656 fpm
TIME TO CLIMB	21.4 min	21.4 min	20.9 min	20.9 min
TAKEOFF DISTANCE	552 m	1810 ft	547 m	1793 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	404 km/hr	218 KTS	382 km/hr	206 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	126.3 kg	278.5 lb	111.6 kg	246 lb
REQUIRED FUEL CAP	200 L	52.9 gal	176 L	46.6 gal
V/V*	1.05	1.05	1.00	1.00
AVG CRUISE SPEED	407 km/hr	220 KTS	385 km/hr	208 KTS
MAXIMUM SPEED	436 km/hr	235.5 KTS	447 km/hr	236 KTS
PRICE	$188,000	$188,000	$187,000	$187,000
DOC	$106.6/hr	$106.6/hr	$106.4/hr	$106.4/hr
NOISE CHANGE	-4.0 dBA	-4.0 dBA	-4.0 dBA	-4.0 dBA
EVALUATION TOTAL	229	229	260	260
FUEL EFFICIENCY	8.22 km/L	16.80 NMPG	9.35 km/L	19.10 NMPG

4 dB(A) improvement in noise.

Accessories: An arbitrary weight reduction of 20 percent, due mostly to improved electronics and materials, has been assumed for the advanced airframes.

Laminar Flow Airfoils: Reference 16 indicates that a potential reduction in wing profile drag of 40 percent is reasonable if laminar flow is achieved over large areas of the surface. Assuming that the wing profile drag is approximately 1/3 of the total airframe value, then a savings of approximately 13 percent is possible.

Lift Coefficient: A trimmed maximum lift coefficient of 2.5 is assumed for this advanced airframe analysis and should be reasonably easy to obtain with the large span flaps.

Analysis: The improvements discussed above are in no way conservative but neither are any unreasonably optimistic. With adequate research funding they probably can be realized. The results of reanalyzing the single engine airframe powered by the baseline and RC2-32 engines and with these more optimistic assumptions are shown on Table XIV. Note that the price per pound of airframe was not changed despite the use of advanced materials, thus assuming a major reduction in the cost of manufacturing composite structures.

For the baseline single these improvements due to aerodynamics and materials show greater potential (as judged by the evaluation criteria) than the GTSIO-420 moderate risk, advanced spark ignition engine does. The improvements coupled with the RC2-32 show a potential savings in fuel (compared to the baseliine) of 39 percent versus 33 percent for that engine without them.

REVISED GATE After work on Phase 2 had been virtually completed, NASA, in conjunction with Teledyne-CAE, discovered that an inadvertent error had been made when the Teledyne GATE engine was scaled to the higher design point altitude required for the present study. The result was an SFC and an engine weight which were almost exactly 10 percent too high. Therefore, the analysis was redone using Method II with the two indicated factors reduced by 10 percent.

The results, shown in Table XV and overplotted on Figures 28,33,36,38,40,42,45, indicate a very significant improvement but still do not compare favorably with the rotary and diesel powered machines. Note, however, that even these revised data are still based on a low-initial-cost design philosophy which was prevalent at the time that NASA initiated the GATE studies. An approach that strives specifically for low fuel consumption might well be more competitive with the other engine types.

TABLE XIV

part 1

EFFECT OF ADVANCED AIRFRAME

SINGLE ENGINE TSIO -550

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

AIRFRAME DESIGN	CONSERVATIVE		OPTIMISTIC	
TAKEOFF POWER	254 kW	340 BHP	254 kW	340 BHP
CRUISE POWER @25000'	186 kW	250 BHP	186 kW	250 BHP
BASIC EMPTY WEIGHT	1241 kg	2736 lb	1021 kg	2252 lb
GROSS WEIGHT	2023 kg	4460 lb	1780 kg	3924 lb
WING AREA	15.9 sqm	170 sqft	11.6 sqm	125 sqft
WING SPAN	12.25 m	40.2 ft	11.16 m	36.6 ft
ASPECT RATIO	9.50	9.50	10.70	10.70
ROC AT 25000 FT	198 m/min	650 fpm	259 m/min	850 fpm
TIME TO CLIMB	28.4 min	28.4 min	22.4 min	22.4 min
TAKEOFF DISTANCE	683 m	2240 ft	686 m	2250 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	382 km/hr	206 KTS	426 km/hr	230 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	200 kg	440 lb	177 kg	390 lb
REQUIRED FUEL CAP	344 L	91.0 gal	314 L	83.0 gal
V/V*	1.00	1.00	1.05	1.05
AVG CRUISE SPEED	387 km/hr	209 KTS	431 km/hr	232.5 KTS
PRICE	$202,000	$202,000	$158,500	$158,500
DOC	$122.0/hr	$122.0/hr	$108.0/hr	$108.0/hr
NOISE CHANGE	0.0 dBA	0.0 dBA	-1.0 dBA	-1.0 dBA
EVALUATION TOTAL	0	0	134	134
FUEL EFFICIENCY	4.70 km/L	9.60 NMPG	5.28 km/L	10.80 NMPG

TABLE XIV
part 2
EFFECT OF ADVANCED AIRFRAME
SINGLE ENGINE RC2-32

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

AIRFRAME DESIGN	CONSERVATIVE		OPTIMISTIC	
TAKEOFF POWER	239 kW	320 BHP	239 kW	320 BHP
CRUISE POWER @25000'	186 kW	250 BHP	186 kW	250 BHP
BASIC EMPTY WEIGHT	965 kg	2127 lb	782 kg	1725 lb
GROSS WEIGHT	1674 kg	3691 lb	1479 kg	3260 lb
WING AREA	13.0 sqm	139.5 sqft	9.60 sqm	103 sqft
WING SPAN	10.00 m	32.8 ft	8.50 m	27.9 ft
ASPECT RATIO	7.73	7.73	7.55	7.55
ROC AT 25000 FT	249 m/min	816 fpm	293 m/min	960 fpm
TIME TO CLIMB	22.1 min	22.1 min	18.6 min	18.6 min
TAKEOFF DISTANCE	585 m	1920 ft	585 m	1920 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	424 km/hr	229 KTS	465 km/hr	251 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	134 kg	296 lb	122 kg	269 lb
REQUIRED FUEL CAP	214 L	56.5 gal	199 L	52.5 gal
V/V*	1.05	1.05	1.05	1.05
AVG CRUISE SPEED	428 km/hr	231 KTS	419 km/hr	253 KTS
PRICE	$175,000	$175,000	$141,000	$141,000
DOC	$102.7/hr	$102.7/hr	$92.0/hr	$92.0/hr
NOISE CHANGE	-1.0 dBA	-1.0 dBA	-3.5 dBA	-3.5 dBA
EVALUATION TOTAL	244	244	364	346
FUEL EFFICIENCY	7.73 km/L	15.80 NMPG	8.51 km/L	17.40 NMPG

TABLE XV
part 1
EFFECT OF 10% IMPROVEMENT IN GATE ENGINE

SINGLE ENGINE

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

ENGINE	BASIC ENGINE		-10% WEIGHT & SFC	
TAKEOFF POWER	391 kW	525 BHP	391 kW	525 BHP
CRUISE POWER @25000'	186 kW	250 BHP	186 kW	250 BHP
BASIC EMPTY WEIGHT	1006 kg	2218 lb	975 kg	2150 lb
GROSS WEIGHT	1772 kg	3907 lb	1719 kg	3790 lb
WING AREA	13.8 sqm	149 sqft	13.4 sqm	144 sqft
WING SPAN	10.82 m	35.5 ft	10.42 m	34.2 ft
ASPECT RATIO	8.45	8.45	8.10	8.10
ROC AT 25000 FT	160 m/min	524 fpm	267 m/min	545 fpm
TIME TO CLIMB	28.1 min	28.1 min	27.0 min	27.0 min
TAKEOFF DISTANCE	416 m	1365 ft	405 m	1330 ft
STALL SPEED	113 km/hr	61 KTS	113 km/hr	61 KTS
CRUISE SPEED (INITIAL)	418 km/hr	225.6 KTS	420 km/hr	227 KTS
PAYLOAD	544 kg	1200 lb	544 kg	1200 lb
RANGE	1296 km	700 NM	1296 km	700 NM
MISSION FUEL	181 kg	400 lb	162 kg	358 lb
REQUIRED FUEL CAP	291 L	77.0 gal	263 L	69.4 gal
V/ V*	1.05	1.05	1.05	1.05
AVG CRUISE SPEED	423 km/hr	228.5 KTS	424 km/hr	229 KTS
RELATIVE CRUISE EFF	1.16	1.16	1.31	1.31
PRICE	$203,000	$203,000	$198,000	$198,000
DOC	$118.5/hr	$118.5/hr	$114.0/hr	$114.0/hr
NOISE CHANGE	-5.0 dBA	-5.0 dBA	-5.0 dBA	-5.0 dBA
EVALUATION TOTAL	58	58	116	116
FUEL EFFICIENCY	5.72 km/L	11.70 NMPG	6.41 km/L	13.10 NMPG

TABLE XV
part 2
EFFECT OF 10% IMPROVEMENT IN GATE ENGINE

TWIN ENGINE

METHOD II FIXED ENGINE, VARIABLE AIRFRAME, FIXED PAYLOAD-RANGE

ENGINE	BASIC ENGINE		-10% WEIGHT & SFC	
TAKEOFF POWER	391 kW	525 BHP	391 kW	525 BHP
CRUISE POWER @25000'	186 kW	250 BHP	186 kW	250 BHP
BASIC EMPTY WEIGHT	1524 kg	3360 lb	1477 kg	3257 lb
GROSS WEIGHT	2608 kg	5750 lb	2514 kg	5542 lb
WING AREA	15.4 sqm	166 sqft	14.6 sqm	157 sqft
WING SPAN	10.91 m	35.8 ft	10.64 m	34.9 ft
ASPECT RATIO	7.70	7.70	7.75	7.75
ROC AT 25000 FT	238 m/min	780 fpm	247 m/min	810 fpm
SEROC @ 5000 ft	119 m/min	390 fpm	123 m/min	405 fpm
TIME TO CLIMB	18.6 min	18.6 min	17.9 min	17.9 min
TAKEOFF DISTANCE	383 m	1255 ft	375 m	1230 ft
STALL SPEED	130 km/hr	70 KTS	131 km/hr	70.5 KTS
CRUISE SPEED (INITIAL)	464 km/hr	250.7 KTS	469 km/hr	253 KTS
PAYLOAD	635 kg	1400 lb	635 kg	1400 lb
RANGE	1482 km	800 NM	1482 km	800 NM
MISSION FUEL	367 kg	808.5 lb	328 kg	723 lb
REQUIRED FUEL CAP	587 L	155.0 gal	528 L	139.5 gal
V/V*	1.05	1.05	1.05	1.05
AVG CRUISE SPEED	471 km/hr	254.5 KTS	474 km/hr	256 KTS
RELATIVE CRUISE EFF	1.07	1.07	1.21	1.21
PRICE	$377,000	$377,000	$365,000	$365,000
DOC	$222.0/hr	$222.0/hr	$212.0/hr	$212.0/hr
NOISE CHANGE	-3.0 dBA	-3.0 dBA	-4.0 dBA	-4.0 dBA
EVALUATION TOTAL	61	61	122	122
FUEL EFFICIENCY	3.23 km/L	6.60 NMPG	3.62 km/L	7.40 NMPG

CONCLUSIONS

* The advanced and highly-advanced internal combustion engines all offer the potential for substantially improved airplanes in all respects - performance, fuel burn, and cost - compared to the baseline, particularly if the airframe is resized to take advantage of the powerplant characteristics.

* The turboprop (either version) might be viewed as a viable replacement for the baseline engine, offering market appeal, but no major improvement in efficiency or cost.

* Results for singles and twins show the same trends, regardless of the method of comparison.

* Parametric studies show that the results are relatively insensitive to the assumptions (drag level, weights, costs, etc.) made and the missions chosen.

* Advanced materials and aerodynamic features can provide very worthwhile improvements in performance, fuel burn, and cost. Used in combination with the advanced engines, the gains become very large.

* On the basis of the evaluation criteria the engines in the study rank as follows:

	ENGINE	STRONG POINTS	WEAK POINTS
1)	RC2-32 Rotary	Low fuel burn, low DOC, small size, low weight, multi-fuel capability	Cooling system maintenance
2)	GTDR-246 Diesel	Low fuel burn, low wgt	Less multifuel capability
3) Tie	RC2-47 Rot	Same factors as RC2-32	Lower overall performance than 1) or 2)
	GTSIO 420SC Spark Ign	Low fuel burn, low wgt	Mechanical complexity
4)	GTSIO 420 Spark Ign	None, compared to other engines	Relatively heavy, poor economics
5)	GATE Turboprop	Low weight "turbine image"	High fuel consumption, high power lapse rate, high cost

TECHNICAL PROGRAM RECOMMENDATIONS

PREFERRED ENGINE CANDIDATE

Although all of the I.C. engines studied show substantial improvements over the baseline, the highly advanced rotary and diesel engines are clearly the preferred candidates for development by virtue of their very high ranking according to the evaluation criteria. If added importance is assigned to the ability to operate on the widest possible range of fuels, the rotary will have a definite edge.

TECHNOLOGY PROGRAM

It is recommended that a program be established by NASA which will focus on enabling technologies for both the rotary and diesel engines, paced to allow building of the "highly advanced" versions by 1990. Midway in this period, it would be highly desirable to have flightworthy experimental engines available for testing by an airframe manufacturer in order to assess installation factors, systems integration, vibration, performance, and certification potential. These interim "moderately advanced" engines might themselves be candidates for production, depending on their performance and market conditions; at any rate, the experience gained should be valuable in assessing and directing the overall program.

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APPENDIX I

DIRECT OPERATION COSTS FOR GENERAL AVIATION AIRCRAFT
1981 Estimate

1) ENGINE PERIODIC MAINTENANCE

Use past experience (i.e. similar engine/airframe combination) or engine manufacturer's estimate.

otherwise use:

$$\frac{\text{Number of labor hours for 100 hour inspection x labor rate}}{100}$$

then double this answer to account for parts.

labor rate early 1981 ran $20/hour S/E
$25/hour M/E
$30/hour Turboprops

Turboprops must be considered under a different formula. Instead of being inspected every hundred hours, they undergo a series of Hot Section Inspections during the overhaul period. These are usually of considerably greater time than 100 hours. For some engines the work scheduled for each HSI is different as the time from last overhaul increases.

$$\frac{\text{(cost of labor + cost of parts) for HSI's + misc.}}{\text{TBO}}$$

(filters, igniters + labor not included in HSI)

2) RESERVES FOR ENGINE OVERHAUL

The assumption (conservative) is made that every other overhaul will require, instead of an overhaul, a remanufactured engine. Therefore:

$$\frac{\text{(overhaul cost + cost of remanufactured engine)/2}}{\text{TBO}}$$

For Turboprops:

$$\frac{\text{overhaul cost (labor + parts) + additional allowances}}{\text{TBO}}$$

Additional allowances includes an allowance for premature removal of the engine (1/5 to 1/2 of overhaul cost) and engine accessories (starter generator etc.) and engine components (Turbines, nozzles, etc.).

3) PROPELLER OVERHAUL

Propeller		DOC ($/hr)
Fixed Pitch		.11
S/E Controllable	LSE	.43
	HPSE	.60
	Centurion class	.82
M/E Controllable (per propeller)		.90

4) AIRFRAME MAINTENANCE

This number is based on a parametric fit of the available data.

DOC 1.472 + .000534 TOGW - .000373 BHP (Total)
+2.774 (Twins only) + 1.878 (if pressurized)

5) INSURANCE (HULL + LIABILITY)

See tables A IV-1 and A IV-2

6) Fuel cost

$$DOC = \frac{price}{gal} \times \frac{gal}{hour}$$ ($1.70/US gal used for all fuels)

7) OIL COST

$$DOC = \frac{price}{gal} \times GPH \text{ used}$$ ($6/gal approximates oil + filter)

or alternately use

$$DOC = \frac{actual\ price}{gal} \times GPH \text{ used*} + \frac{cost\ of\ filter}{\#hrs\ between\ filter\ change}$$

*Include oil consumed and oil lost during oil changes.

8) DEPRECIATION

$$= \frac{Total\ equipped\ airplane\ price}{7.5 \times utilization\ rate\ /\ year}$$

Depreciated to zero residual in 7.5 years

9) RESERVES FOR AVIONICS

$$\frac{10\%\ of\ total\ avionic\ package\ (standard + optional)}{1000\ hrs}$$

10) RESERVES FOR SYSTEMS MAINTENANCE

DOC -.513 + .000803 TOGW + 1.109 (if pressurized)

Again this is a parametric fit of available data.

TABLE A IV-1

Pleasure & Business Rates For Well-Qualified Pilots:

Hull Value	Single Engine Rate	Multi-Engine rate
$15,000 - 24,999	3.00%	
25000 - 39,999	2.75	
40,000 - 59,999	2.50	
60,000 - 99,999	2.00	
100,000 - 149,000	1.75	
150,000 - 200,000	1.60	
150,000 - 299,999		1.75%
300,000 - 499,999		1.50
500,000 - 750,000		1.35
750,000 - 1 Mil.		1.10
1 Mil - 1.5 Mil.		1.00

TABLE A IV-2

Legal Liability Limit of $5,000,000 combined single limit

Seats	Annual Premium
4	$ 575
5	675
6	725
7	825
8	975
9	1,075
10	1,175
11	1,250

APPENDIX II

MISCELLANEOUS DATA USED IN STUDY

Cabin Pressurization	Adequate for 10,000 ft cabin at cruise altitude
Reserve Fuel	The gross weight was calculated assuming adequate fuel for the mission plus 45 minutes reserve at cruise power
Maximum Landing Weight For Twins	95% of Gross Weight
Shaft Horsepower	All engine power ratings supplied by NASA were assumed to be installed values; i.e., the power available to the propeller after all accessory drive requirments were met
Fuel For Starting Runup, Taxi, and Takeoff	The total fuel for these functions was estimated to be equivalent to .085 hours at takeoff power
Drag Due To Engine Out	A value of Cd = .0035 was used based on T303 data. This assumes inoperative engine propeller feathered and a bank angle of 5 degrees into the good engine
Aspect Ratio	Values greater than 11 were not used. Primarily this was felt to be the maximum value to which the data base could be accurately extrapolated.
Takeoff Characteristics	Climb velocity at 50 feet/Vs = 1.2 Rolling Friction Coefficient = .02 Maximum Lift Coefficient = 1.6
Fuel Characteristics	see below
Airplane Usage	500 Hours/Year

Fuel Characteristics:

	ρ	Heat val	Cost
Avgas	6.0#/g	18720BTU/#	$1.70/g
Jet Fuel	6.7#/g	18400BTU/#	$1.70/g

APPENDIX III

TABULATED DATA

The results of the Phase 2 study, shown graphically in Figures 28 through 37 and 39 through 46, are tabulated herein. Included also is a table showing the values of each component of the evaluation criteria analysis for all engines for the three methods of comparison both for single and twin engine configurations.

TABLE AIII-I

AIRPLANE COMPARISONS

SINGLE ENGINE
FIXED ENGINE & AIRFRAME SIZE
VARIABLE MISSION & PERFORMANCE

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	239	239	268	261	261	391
POWER	BHP	340	320	320	360	350	350	525
CRUISE	kW	186	186	186	186	186	186	186
POWER	BHP	250	250	250	250	250	250	250
EMPTY WEIGHT	kg	1241	1148	1105	1152	1201	1170	1105
	lb	2736	2531	2437	2539	2648	2579	2436
GROSS WEIGHT	kg	2023	2023	2023	2023	2023	2023	2023
	lb	4460	4460	4460	4460	4460	4460	4460
WING AREA	sqm	15.8	15.8	15.8	15.8	15.8	15.8	15.8
	sqft	170	170	170	170	170	170	170
WING SPAN	m	12.3	12.3	12.3	12.3	12.3	12.3	12.3
	ft	40.2	40.2	40.2	40.2	40.2	40.2	40.2
ASPECT RATIO		9.5	9.5	9.5	9.5	9.5	9.5	9.5
ROC	m/min	198	198	198	150	264	251	130
AT 25000′	fpm	650	650	650	493	866	822	427
CLIMB TIME	min	28.4	27.5	27.5	25.9	24.4	25.0	33.4
TAKEOFF	m	683	705	705	643	643	644	475
DISTANCE	ft	2240	2313	2312	2110	2110	2113	1558
STALL	km/hr	113	113	113	113	113	113	113
SPEED	KTS	61	61	61	61	61	61	61
CRUISE	km/hr	382	407	407	389	396	394	404
SPEED	KTS	206	220	220	210	214	213	218
PAYLOAD	kg	544	592	613	590	565	581	613
	lb	1200	1305	1352	1301	1246	1281	1352
RANGE	km	1296	2309	2658	2615	2004	2450	1876
	NM	700	1247	1435	1412	1082	1323	1013
MISSION FUEL	kg	200	252	274	254	226	244	264
	lb	440	555	605	560	499	538	583
TRANS	Mg km/L	25.3	43.5	47.5	48.8	36.0	47.1	35.1
EFF	ton NMPG	5.7	9.8	10.7	11.0	8.1	10.6	7.9
RELATIVE EFF		1.00	1.51	1.64	1.59	1.40	1.57	1.23
V/V*		1.00	1.04	1.04	1.02	1.03	1.03	1.03
NOISE	dBA	0.0	0.0	0.0	-3.0	0.0	0.0	-4.0
PRICE	$1000	202	212	212	217	217	215	229
DOC	$/hr	122	116	115	116	121	116	127
EVAL TOTAL		---	201	223	214	102	194	74

TABLE AIII-II

AIRPLANE COMPARISONS

TWIN ENGINE
FIXED ENGINE & AIRFRAME SIZE
VARIABLE MISSION & PERFORMANCE

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	239	239	268	261	261	391
POWER	BHP	340	320	320	360	350	350	525
CRUISE	dW	186	186	186	186	186	186	186
POWER	BHP	250	250	250	250	250	250	250
EMPTY WEIGHT	kg	2008	1796	1710	1818	1932	1866	1688
	lb	4428	3959	3770	4007	4260	411[illegible]	3722
GROSS WEIGHT	kg	3107	3107	3107	3107	3107	3107	3107
	lb	6850	6850	6850	6850	6850	6850	6850
WING AREA	sqm	16.7	16.7	16.7	16.7	16.7	16.7	16.7
	sqft	180	180	180	180	180	180	180
WING SPAN	m	13.6	13.6	13.6	13.6	13.6	13.6	13.6
	ft	44.5	44.5	44.5	44.5	44.5	44.5	44.5
ASPECT RATIO		11.0	11.0	11.0	11.0	11.0	11.0	11.0
ROC	m/min	312	311	311	251	397	381	195
AT 25000'	fpm	1025	1019	1019	825	1301	1250	641
CLIMB TIME	min	18.7	18.2	18.2	17.6	17.1	17.2	22.5
SEROC	M/MIN	105	92	92	137	129	125	96
at 5000 ft	fmp	243	301	301	451	423	410	314
TAKEOFF	m	713	735	735	638	676	676	489
DISTANCE	ft	2338	2410	2410	2093	2217	2218	1605
STALL	km/hr	135	135	135	135	135	135	135
SPEED	KTS	73	73	73	73	73	73	73
CRUISE	km/hr	423	450	450	437	433	433	456
SPEED	KTS	229	243	243	236	234	234	246
PAYLOAD	kg	635	790	876	776	741	751	891
	lb	1400	1741	1931	1711	1634	1656	1965
RANGE	km	1482	2367	2605	2676	1839	2428	1776
	NM	800	1283	1353	1445	996	1311	959
MISSION FUEL	kg	388	459	461	459	373	434	446
	lb	355	1011	1017	1011	822	957	983
TRANS	Mg km/L	17.3	32.8	38.2	36.4	26.2	33.7	28.4
EFF	ton NMPG	3.9	7.4	8.6	8.2	5.9	7.6	6.4
RELATIVE EFF		1.00	1.71	1.99	1.82	1.52	1.69	1.45
V/V*		1.00	1.03	1.03	1.02	1.02	1.02	1.04
NOISE	dBA	0.0	-1.0	-1.0	-4.0	-0.5	-0.5	-2.0
PRICE	$1000	381.5	396	396	403	408	405	427
DOC	$/hr	230	216	214	216	226	216	239
EVAL TOTAL		---	228	260	238	123	207	128

TABLE AIII-III

AIRPLANE COMPARISONS

SINGLE ENGINE
FIXED ENGINE & PAYLOAD RANGE
VARIABLE AIRFRAME

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	239	239	268	261	261	391
POWER	BHP	340	320	320	360	350	350	525
CRUISE	kW	186	186	186	186	186	186	186
POWER	BHP	250	250	250	250	250	250	250
EMPTY WEIGHT	kg	1241	1042	965	1048	1143	1061	1006
	lb	2736	2297	2127	2310	2520	2340	2218
GROSS WEIGHT	kg	2023	1760	1674	1746	1867	1764	1772
	lb	4460	3881	3691	3849	4117	3888	3907
WING AREA	sqm	15.8	13.7	13.0	13.6	14.5	13.6	13.8
	sqft	170	147	140	146	156	146	149
WING SPAN	m	12.3	10.6	10.0	10.9	11.5	10.8	10.8
	ft	40.2	34.9	32.8	35.8	37.8	35.3	35.5
ASPECT RATIO		9.5	8.3	7.7	8.8	9.2	8.6	8.5
ROC	m/min	198	236	249	192	297	302	160
AT 25000′	fpm	650	775	816	630	974	990	524
CLIMB TIME	min	28.4	23.3	22.1	21.4	22.0	21.0	28.1
TAKEOFF	m	683	616	585	552	591	561	416
DISTANCE	ft	2240	2020	1920	1810	1940	1840	1365
STALL	km/hr	113	113	113	113	113	113	113
SPEED	KTS	61	61	61	61	61	61	61
CRUISE	km/hr	382	420	424	404	406	407	419
SPEED	KTS	206	227	229	218	219	220	226
PAYLOAD	kg	544	544	544	544	544	544	544
	lb	1200	1200	1200	1200	1200	1200	1200
RANGE	km	1296	1296	1296	1296	1296	1296	1296
	NM	700	700	700	700	700	700	700
MISSION FUEL	kg	200	142	134	127	150	130	181
	lb	440	314	296	279	331	287	400
CRUISE	km/L	4.7	7.3	7.7	8.2	6.2	8.0	5.7
MILEAGE	NMPG	9.6	14.9	15.8	16.8	12.7	16.3	11.7
RELATIVE EFF		1.00	1.48	1.58	1.58	1.40	1.57	1.16
V/V*		1.00	1.05	1.05	1.05	1.05	1.05	1.05
NOISE	dBA	0.0	-1.0	-1.0	-4.0	-1.0	-1.5	-5.0
PRICE	$1000	202	184	175	188	200	186	203.5
DOC	$/hr	122	107	103	107	115	106	119
EVAL TOTAL		---	206	244	229	119	209	58

TABLE AIII-IV

AIRPLANE COMPARISONS

TWIN ENGINE
FIXED ENGINE & PAYLOAD RANGE
VARIABLE AIRFRAME

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	239	239	268	261	261	391
POWER	BHP	340	320	320	360	350	350	525
CRUISE	kW	186	186	186	186	186	186	186
POWER	BHP	250	250	250	250	250	250	250
EMPTY WEIGHT	kg	2008	1644	1509	1669	1868	1725	1524
	lb	4428	3625	3327	3680	4118	3802	3360
GROSS WEIGHT	kg	3107	2625	2474	2610	2864	2679	2608
	lb	6850	5788	5454	5753	6314	5907	5750
WING AREA	sqm	16.7	13.7	13.5	13.4	15.7	14.0	15.4
	sqft	180	148	145	144	169	151	166
WING SPAN	m	13.6	11.6	10.7	11.9	13.1	12.4	10.9
	ft	44.5	38.1	35.0	39.1	43.1	40.7	35.8
ASPECT RATIO		11.0	9.8	8.5	10.6	11.0	11.0	7.7
ROC	m/min	312	384	408	324	451	469	238
AT 25000′	fpm	1025	1260	1340	1062	1480	1540	780
CLIMB TIME	min	18.7	14.9	14.0	14.3	15.3	14.2	18.5
SEROC	m/min	105	122	130	183	158	166	119
at 5000 ft	fmp	343	400	425	600	520	545	390
TAKEOFF	m	713	637	573	565	607	600	383
DISTANCE	ft	2338	2090	1880	1855	1990	1970	1255
STALL	km/hr	135	137	135	140	135	137	130
SPEED	KTS	73	74	73	75	73	74	70
CRUISE	km/hr	424	465	467	452	441	446	465
SPEED	KTS	229	251	252	244	238	241	251
PAYLOAD	kg	635	635	635	635	635	635	635
	lb	1400	1400	1400	1400	1400	1400	1400
RANGE	km	1481	1481	1481	1481	1481	1481	1481
	NM	800	800	800	800	800	800	800
MISSION FUEL	kg	337	283	269	252	300	264	367
	lb	855	625	592	555	661	581	809
CRUISE	km/L	2.7	4.2	4.5	4.7	3.6	4.5	3.2
MILEAGE	NMPG	5.6	8.6	9.1	9.7	7.3	9.2	6.6
RELATIVE EFF		1.00	1.46	1.55	1.59	1.34	1.51	1.07
V/V*		1.00	1.05	1.05	1.05	1.05	1.05	1.05
NOISE	dBA	0.0	-2.0	-3.0	-4.0	-1.5	-2.0	-3.0
PRICE	$1000	381.5	334	320.5	338.5	382	347	377
DOC	$/hr	230	196	190	195	217	198	222
EVAL TOTAL		---	225	257	241	109	205	61

TABLE AIII-V

AIRPLANE COMPARISONS

SINGLE ENGINE
FIXED PAYLOAD RANGE
VARIABLE ENGINE & AIRFRAME

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	200	191	242	204	199	411
POWER	BHP	340	268	256	325	273	267	551
CRUISE	kW	186	156	149	169	145	142	197
POWER	BHP	250	209	200	225	195	191	264
EMPTY WEIGHT	kg	1241	1012	955	1020	1099	1029	981
	lb	2736	2230	2105	2249	2422	2258	2162
GROSS WEIGHT	kg	2023	1715	1641	1710	1799	1707	1752
	lb	4460	3782	3618	3770	3967	3764	3864
WING AREA	sqm	15.[illegible]	13.4	12.7	13.2	13.9	13.2	13.6
	sqft	170	144	137	142	150	142	146
WING SPAN	m	12.3	10.6	10.7	10.6	12.3	11.7	9.3
	ft	40.2	34.6	35.1	34.6	40.2	38.5	30.6
ASPECT RATIO		9.5	8.4	9.0	8.5	10.8	10.5	6.8
ROC	m/min	198	173	174	152	209	210	152
AT 25000′	fpm	650	568	570	500	686	690	500
CLIMB TIME	min	28.4	30.0	30.0	24.6	29.0	28.7	28.2
TAKEOFF	m	683	733	722	619	756	738	405
DISTANCE	ft	2240	2405	2370	2030	2480	2420	1330
STALL	km/hr	113	113	113	113	113	113	113
SPEED	KTS	61	61	61	61	61	61	61
CRUISE	km/hr	382	393	391	387	370	370	422
SPEED	KTS	206	212	211	209	200	200	228
PAYLOAD	kg	544	544	544	544	544	544	544
	lb	1200	1200	1200	1200	1200	1200	1200
RANGE	km	1296	1296	1296	1296	1296	1296	1296
	NM	700	700	700	700	700	700	700
MISSION FUEL	kg	200	129	119	120	131	112	189
	lb	440	285	262	265	289	246	416
CRUISE	km/L	4.7	8.1	8.8	8.7	7.1	9.3	5.5
MILEAGE	NMPG	9.6	16.5	17.9	17.7	14.5	19.1	11.3
RELATIVE EFF		1.00	1.54	1.67	1.60	1.51	1.70	1.15
V/V*		1.00	1.00	1.00	1.00	1.00	1.00	1.00
NOISE	dBA	0.0	-1.0	-1.0	-4.5	0.0	-0.5	-5.0
PRICE	$1000	202	169	161	176	180	167	203
DOC	$/hr	122	96	91	100	100	92	120
EVAL TOTAL		---	278	322	274	221	306	40

TABLE AIII-VI

AIRPLANE COMPARISONS

TWIN ENGINE
FIXED PAYLOAD RANGE
VARIABLE ENGINE & AIRFRAME

ENGINE		TSIO -550	RC2-47	RC2-32	GTDR -246	GTSIO -420	GTSIO -420SC	GATE
TAKEOFF	kW	254	195	186	228	225	218	309
POWER	BHP	340	262	250	306	302	293	415
CRUISE	kW	186	153	145	159	161	156	146
POWER	BHP	250	205	195	213	216	209	196
EMPTY WEIGHT	kg	2009	1591	1470	1606	1765	1632	1517
	lb	4428	3485	3240	3540	3892	3597	3344
GROSS WEIGHT	kg	3107	2519	2381	2517	2727	2549	2547
	lb	6850	5553	5250	5550	6013	5620	5615
WING AREA	sqm	16.7	13.3	12.8	12.9	14.8	13.7	14.6
	sqft	180	143	138	139	159	147	157
WING SPAN	m	13.6	12.1	11.9	11.9	12.7	12.3	12.7
	ft	44.5	39.6	39.0	39.1	41.8	40.2	41.6
ASPECT RATIO		..0	11.0	11.0	11.0	11.0	11.0	11.0
ROC	m/min	312	285	291	239	367	364	162
AT 25000'	fpm	1025	935	955	785	1205	1195	530
CLIMB TIME	min	18.7	19.1	18.8	17.8	18.3	18.2	25.5
SEROC	m/min	105	76	76	130	112	112	76
at 5000 ft	fmp	343	250	250	425	367	367	250
TAKEOFF	m	713	768	739	658	698	681	479
DISTANCE	ft	2338	2520	2425	2160	2290	2235	1570
STALL	km/hr	135	135	135	139	135	135	131
SPEED	KTS	73	73	73	75	73	73	71
CRUISE	km/hr	424	432	428	424	419	417	420
SPEED	KTS	229	233	231	229	226	225	227
PAYLOAD	kg	635	635	635	635	635	635	635
	lb	1400	1400	1400	1400	1400	1400	1400
RANGE	km	1482	1482	1482	1482	1482	1482	1482
	NM	800	800	800	800	800	800	800
MISSION FUEL	kg	388	252	231	230	275	237	328
	lb	855	555	509	506	606	523	723
CRUISE	km/L	2.7	4.7	5.1	5.2	3.9	5.0	3.6
MILEAGE	NMPG	5.6	9.7	10.5	10.6	7.9	10.3	7.4
RELATIVE EFF		1.00	1.55	1.66	1.65	1.40	1.59	1.08
V/V*		1.00	1.00	1.00	1.00	1.00	1.00	1.003
NOISE	dBA	0.0	-1.0	-2.5	-5.0	-1.0	-1.0	-3.0
PRICE	$1000	381.5	301.5	286	307	341	312	333
DOC	$/hr	230	173	163	175	194	175	193
EVAL TOTAL		---	300	355	312	191	286	170

TABLE AIII-VII
RESULTS OF EVALUATION CRITERIA

SINGLE ENGINE

ENGINE	FUEL BURNED	DOC	PRICE	MULTI-FUEL	NOISE	INSTL	TOTAL
I - FIXED ENGINE AND AIRFRAME SIZE, VARIABLE MISSION							
RC2-47	167*	16	-12	10	0	20	201
RC2-32	187*	18	-12	10	0	20	223
GTDR-246	191*	16	-18	5	10	10	214
GTSIO-420	117*	3	-18	0	0	0	102
GTSIO-420SC	183*	16	-15	10	0	0	194
GATE	109*	-18	-32	5	10	0	74
II - FIXED ENGINE SIZE AND MISSION, VARIABLE AIRFRAME							
RC2-47	115	40	21	10	0	20	206
RC2-32	131	51	32	10	0	20	244
GTDR-246	147	40	17	5	10	10	229
GTSIO-420	99	18	2	0	0	0	119
GTSIO-420SC	139	41	19	10	0	0	209
GATE	36	9	-2	5	10	0	58
III - FIXED MISSION, VARIABLE ENGINE AND AIRFRAME SIZE							
RC2-47	141	58	39	10	0	20	278
RC2-32	162	81	49	10	0	20	322
GTDR-246	159	59	31	5	10	10	274
GTSIO-420	137	58	26	0	0	0	221
GTSIO-420SC	176	79	41	10	0	0	306
GATE	22	4	-1	5	10	0	40

TABLE AIII-VIII
RESULTS OF EVALUATION CRITERIA

TWIN ENGINE

ENGINE	FUEL BURNED	DOC	PRICE	MULTI-FUEL	NOISE	INSTL	TOTAL
I - FIXED ENGINE AND AIRFRAME SIZE, VARIABLE MISSION							
RC2-47	188*	19	-9	10	0	20	228
RC2-32	217*	22	-9	10	0	20	260
GTDR-246	208*	19	-14	5	10	10	238
GTSIO-420	134*	6	-17	0	0	0	123
GTSIO-420SC	193*	19	-15	10	0	0	207
GATE	155*	-13	-29	5	0	10	128
II - FIXED ENGINE SIZE AND MISSION, VARIABLE AIRFRAME							
RC2-47	108	47	30	10	10	20	225
RC2-32	123	56	38	10	10	20	257
GTDR-246	140	49	27	5	10	10	241
GTSIO-420	91	18	0	0	0	0	109
GTSIO-420SC	128	45	22	10	0	0	205
GATE	22	11	3	5	10	10	61
III - FIXED MISSION, VARIABLE ENGINE AND AIRFRAME SIZE							
RC2-47	140	30	50	10	0	20	300
RC2-32	162	93	60	10	10	20	355
GTDR-246	163	77	47	5	10	10	312
GTSIO-420	116	50	25	0	0	0	191
GTSIO-420SC	155	77	44	10	0	0	286
GATE	62	52	31	5	10	10	170

END

DATE

FILMED

JUN 25 1982