NASA/CR—2003-212334

Advanced Propulsion Systems Study for General Aviation Aircraft

R. Mount
Rotary Power International, Inc., Wood-Ridge, New Jersey

July 2003

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National Aeronautics and
Space Administration

Glenn Research Center

July 2003

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Note that at the time of research, the NASA Lewis Research Center was undergoing a name change to the NASA John H. Glenn Research Center at Lewis Field. Both names may appear in this report.

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R. Mount
Rotary Power International, Inc.
Wood-Ridge, New Jersey 07075

ABSTRACT

This study defines a family of advanced technology Stratified Charge Rotary Engines (SCRE) appropriate for the enablement of the development of a new generation of general aviation aircraft. High commonality, affordability, and environmental compatibility are considerations influencing the family composition and ratings. The SCRE family is comprised of three engines in the 70 Series (40 $in.^3$ displacement per rotor), i.e. one, two, and four rotor and two engines in the 170 Series (105 $in.^3$ displacement per rotor), i.e., two and four rotor. The two rotor engines are considered the primary engines in each series. A wide power range is considered covering 125 to 2500 HP through growth and compounding/dual pac considerations. Mission requirements, TBO, FAA Certification, engine development cycles, and costs are examined. Comparisons to current and projected reciprocating and turbine engine configurations in the 125 to 1000 HP class are provided. Market impact, estimated sales, and U.S. job creation (R&D, manufacturing and infractures) are examined.

1.0 INTRODUCTION

This study investigates Stratified Charge Rotary Engines (SCRE's) as candidate advanced, intermittent combustion engines suitable for enablement of the development of a new generation of general aviation aircraft.

A family of SCRE engines is defined in providing high commonality, affordable and environmentally-superior candidate propulsion systems for addressing a wide general aviation power range, i.e., 125 to 2500 HP.

The family of SCRE's is comprised of two basic displacement power sections (70 Series, 40 cu.in. per rotor and 170 Series, 105 cu.in. per rotor) with variations in the number of high commonality rotor sections. For the 70 Series, variations of 1, 2 and 4 rotors are considered. For the 170 Series, variations of 2 and 4 rotors are considered.

Each of these five family members is then considered at two power levels (near term, i.e., 3 years and near term growth, i.e., 5 years) and with compounding of these basic or core units into Dual Pac configurations. The Dual Pac approach provides for twin engine redundancy and reliability while utilizing a single propeller shaft. The SCRE is particularly well suited to the Dual Pac approach for reasons of its simple, diametral shape similar to small turbines wherein Dual Pac arrangements are currently being certified.

A summary of the SCRE family of engines is provided in Figure 1.0-1. As noted, the twin rotor engines in each of the two Series are considered the primary engines.

The primary engines in the two series are examined as baseline engines for comparisons to current engines, a review of past and on-going NASA programs, definition of development plans through certification and production, and estimated sales, U.S. job creation, and market impact. Figure 1.0-2 outlines the generalized primary engines in the 70 Series (Model 2013R) and 170 Series (Model 2034R) identifying the "power section" (This is the core SCRE power unit and the primary variable in addressing a wide range of power requirements) and other portions of the overall engine package. These other portions include the reduction gearing, accessory gearbox and oil sump. Wide variation in these sections are possible depending upon the specific airframe (i.e., single or twin engines) and installation/application/performance requirements.

These variations are discussed in Section 4.1.8.1, 4.1.4 and 4.1.5 respectively.

Figure 1.0-3 outlines the family of SCRE's defined in this study and covering the very wide power range of 125 to 1250 HP. The family consists of three engines in the 70 Series, 40 cu.in. per rotor class and two engines in the 170 Series, 105 cu.in. per rotor class.

Figure 1.0-4 outlines four members of the SCRE family in compounded or Dual Pac arrangement. An extension of the power capability over the 680 to 2500 HP range is possible with these arrangements.

FAMILY OF STRATIFIED CHARGE ROTARY ENGINES

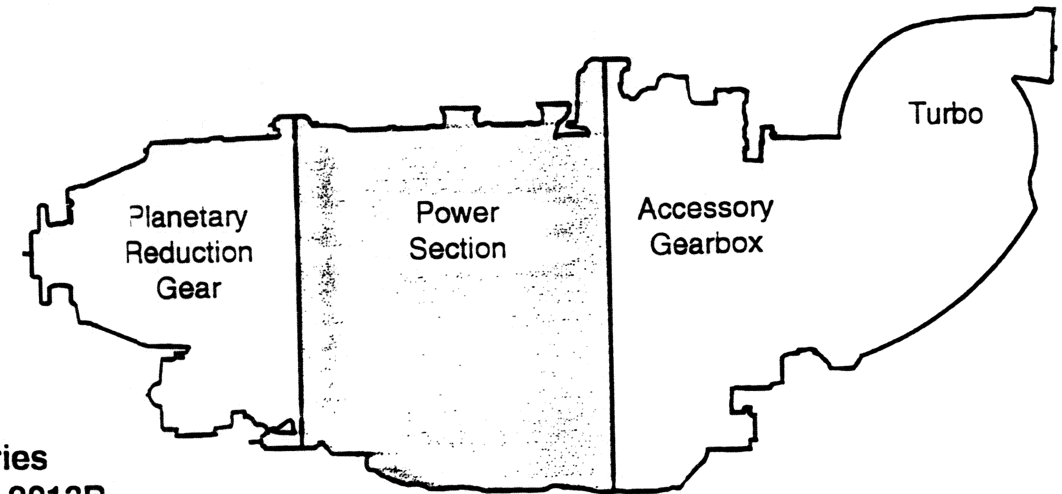
SCRE				HP RANGE		
Series	Displacement per Rotor	No. of Rotors	Model	Near Term	Near Term Growth	Compounding/ Dual Pac
	cu.in.			(3 years)	(5 years)	(5 years)
70	40	1	1007R	125	170	N/A
	40	2	2013R(prim.)	250	340	680
	40	4	4026R	500	680	1360
170	105	2	2034R(prim.)	425	625	1250
	105	4	4068R	850	1250	2500

FIG. 1.0-1

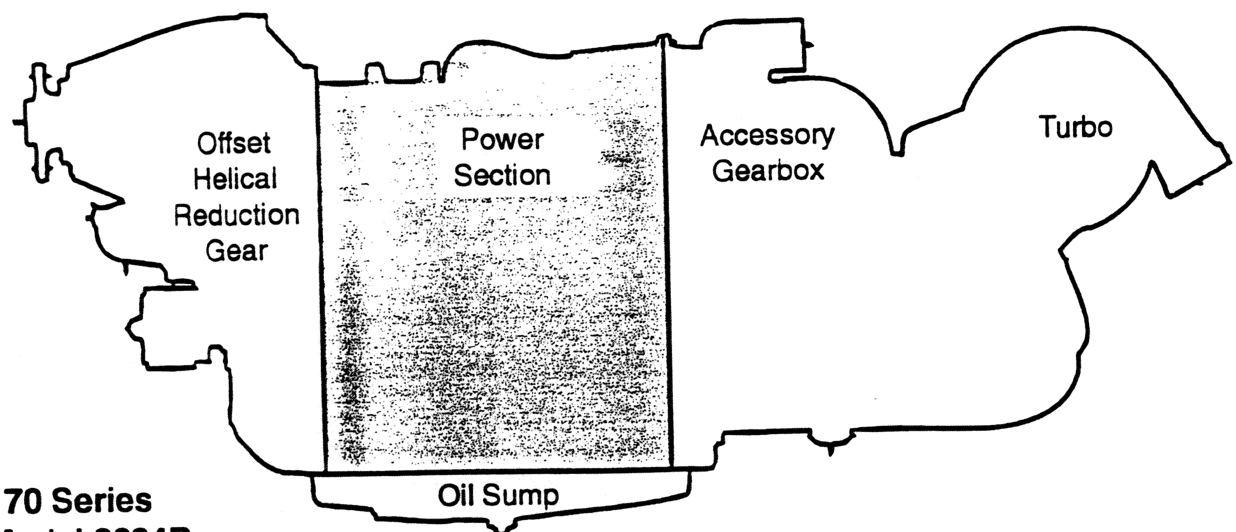
Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

Primary Engines - Aft Mounted Turbos

Reduction Gear and Sump Options



70 Series
Model 2013R
Dry Sump

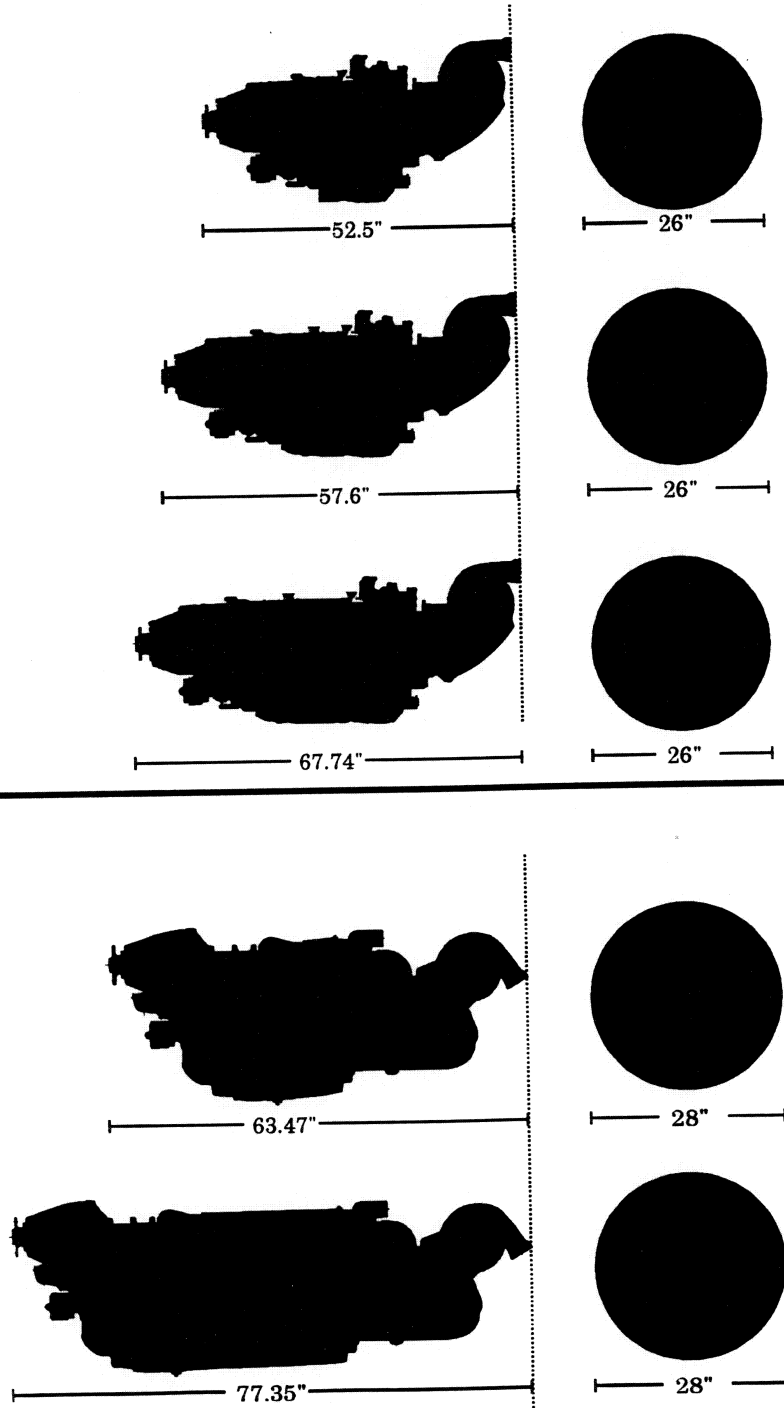


170 Series
Model 2034R
Integral Sump

FIG. 1.0-2

Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

125 to 1250 HP



	Engine Silhouette	Nacelle Dia Req'd	Take Off Power Near Term 3 yrs.	Take Off Power Growth 5 yrs.
70 Series				
Model 1007R	52.5"	26"	125	170
Model 2013R primary engine	57.6"	26"	250	340
Model 4026R	67.74"	26"	500	680
170 Series				
Model 2034R primary engine	63.47"	28"	425	625
Model 4068R	77.35"	28"	850	1250

FIG. 1.0-3

Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

Compounding / Dual PAC Considerations - 5 Years
680 to 2500 HP

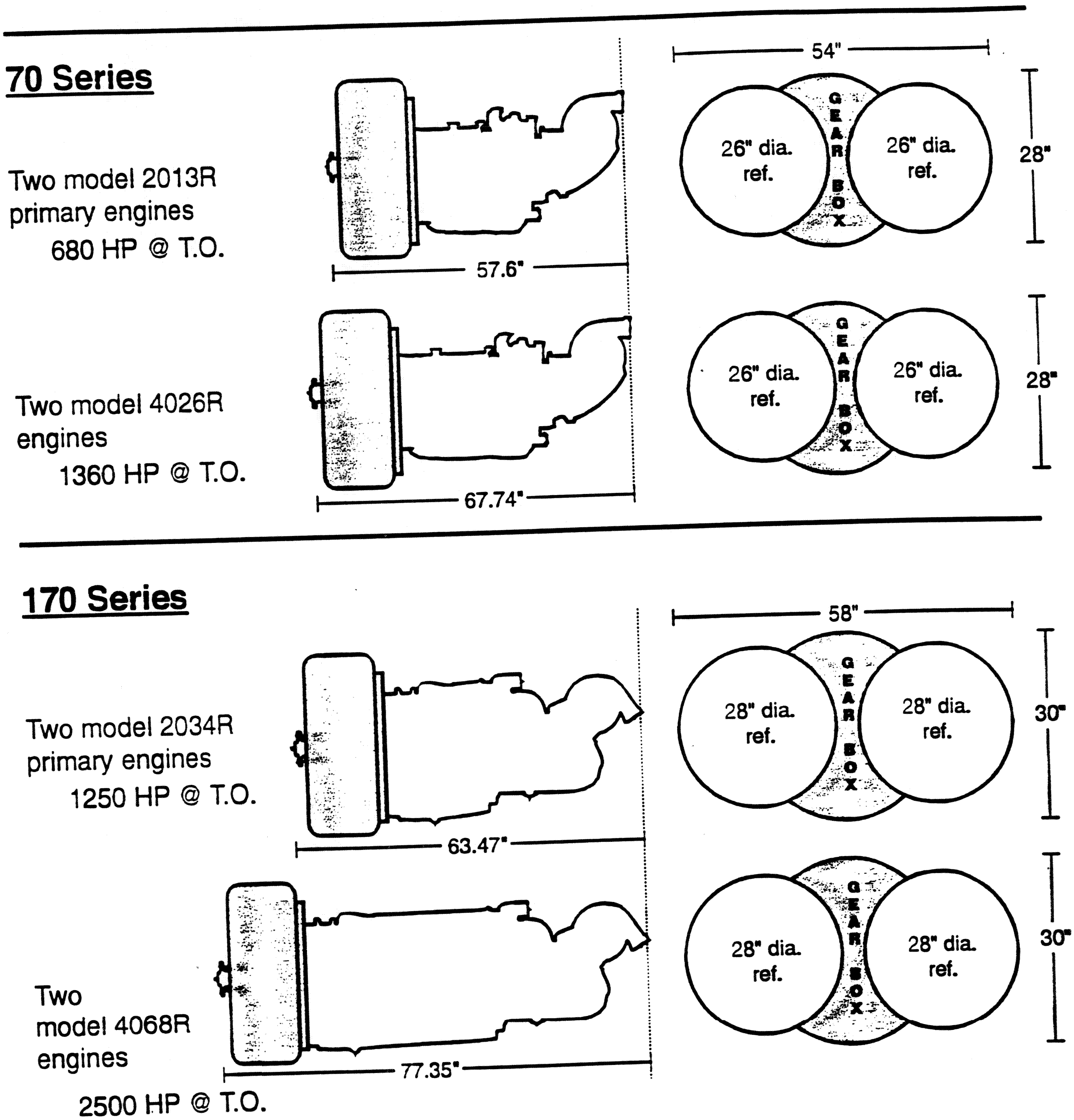


FIG. 1.0 - 4

2.0 EXECUTIVE SUMMARY

This study defines a family of advanced Stratified Charge Rotary Engines (SCRE's) appropriate to the enablement of the development of a new generation of general aviation aircraft. Figures 2.0-1 and 2.0-2 outline the basic SCRE system and combustion cycle respectively.

The primary foundation upon which the study is based is the combination of:

a) NASA Lewis Research Center's Research and Technology efforts over the past fifteen years with the SCRE as an advanced intermittent combustion engine candidate for general aviation needs of the mid 1990's and beyond (Figs 2.0-3a-c and 2.0-4, 70 Series Model 2013R Twin Rotor Engine and NASA Research Single Rotor Engine respectively).

b) Industry's parallel SCRE power section development for a wide variety of applications wherein a general advancement in SCRE technology and state-of-the art therein has been achieved. These parallel industry efforts have involved Curtiss-Wright Corporation, Deere & Co. and currently Rotary Power International, Inc. with a variety of SCRE's in displacements varying from as small as the 40 Series (0.407ℓ, 25 cu.in./rotor) to the 580 Series (5.8ℓ, 350 cu.in/rotor).

c) The twin rotor engines in the 70 Series and 170 Series size (depicted in Figures 2.0-3 and 2.0-5 respectively) which are considered as the "primary" or "baseline" engines for this study.

d) A list of publications which sequentially review technological progress with the SCRE's from 1982 to the 1995 timeframe, in NASA and industry supported efforts is provided in Section 7.0 - Bibliography and Section 8.0 Appendix.

The study and supporting analyses quantify the potential for the SCRE family to demonstrate improved environmental compatibility (reduced emissions and noise), reduced acquisition, maintenance, and operating costs, increased reliability and safety, and increased performance (reduced fuel consumption) and compares the SCRE potential with current engines (i.e., reciprocating spark ignition and small gas turbines). In this comparison it was necessary to consider both issues and actions involved with current engines in the reciprocating (spark ignition and diesel) and turbine engine categories. In terms of issues the spark ignition reciprocating engines, while firmly entrenched in the market remains Avgas dependent, Avgas availability is decreasing, the engine technology is to some degree outdated and growth is very limited. Modifications are being pursued to permit the usage of unleaded fuels in the lower HP range, i.e., 100-250 HP. Improved efficiencies through advanced, solid state ignition, controls and significant single level controls are being pursued and are supported by the NASA AGATE program. However, the basic issue of Avgas dependency remains. When considering domestic and foreign infrastructure factors it is necessary to note that Avgas fuel prices in Europe are 4 to 6 time Jet-A fuel prices.

Stratified Charge Ignition System

- Competitive fuel consumption
- Cold starting capability
- Broad operating range
- Independent from Cetane number

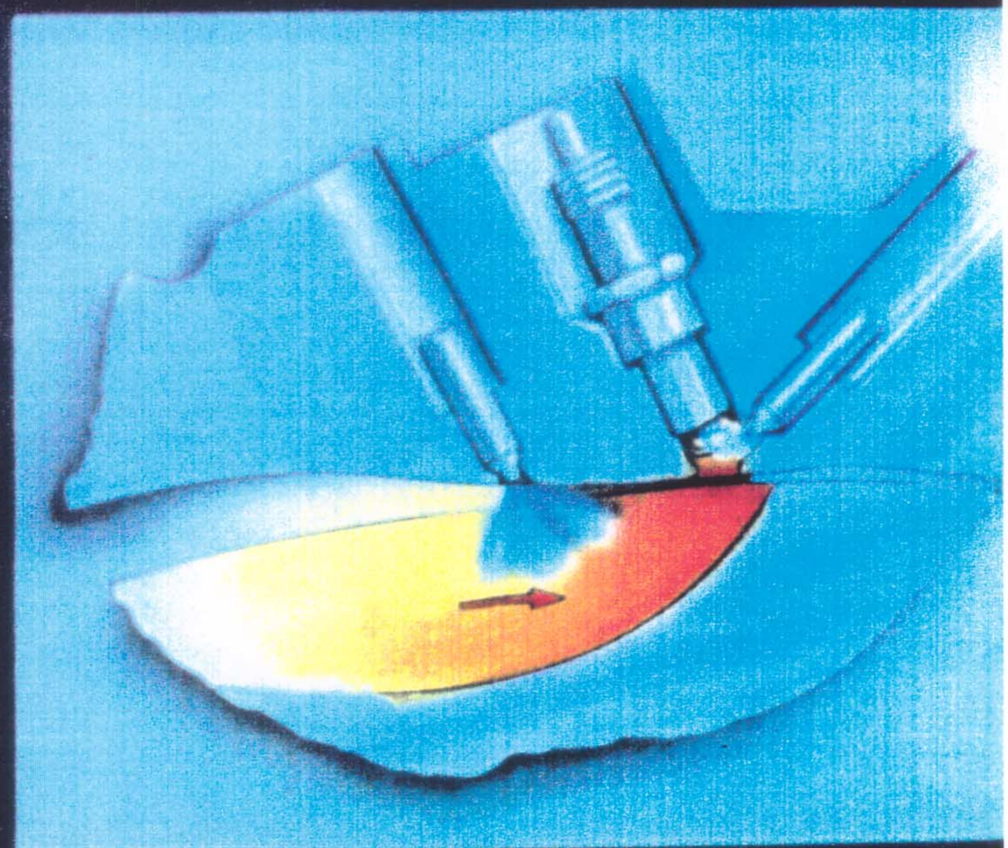


FIG. 2.0-1

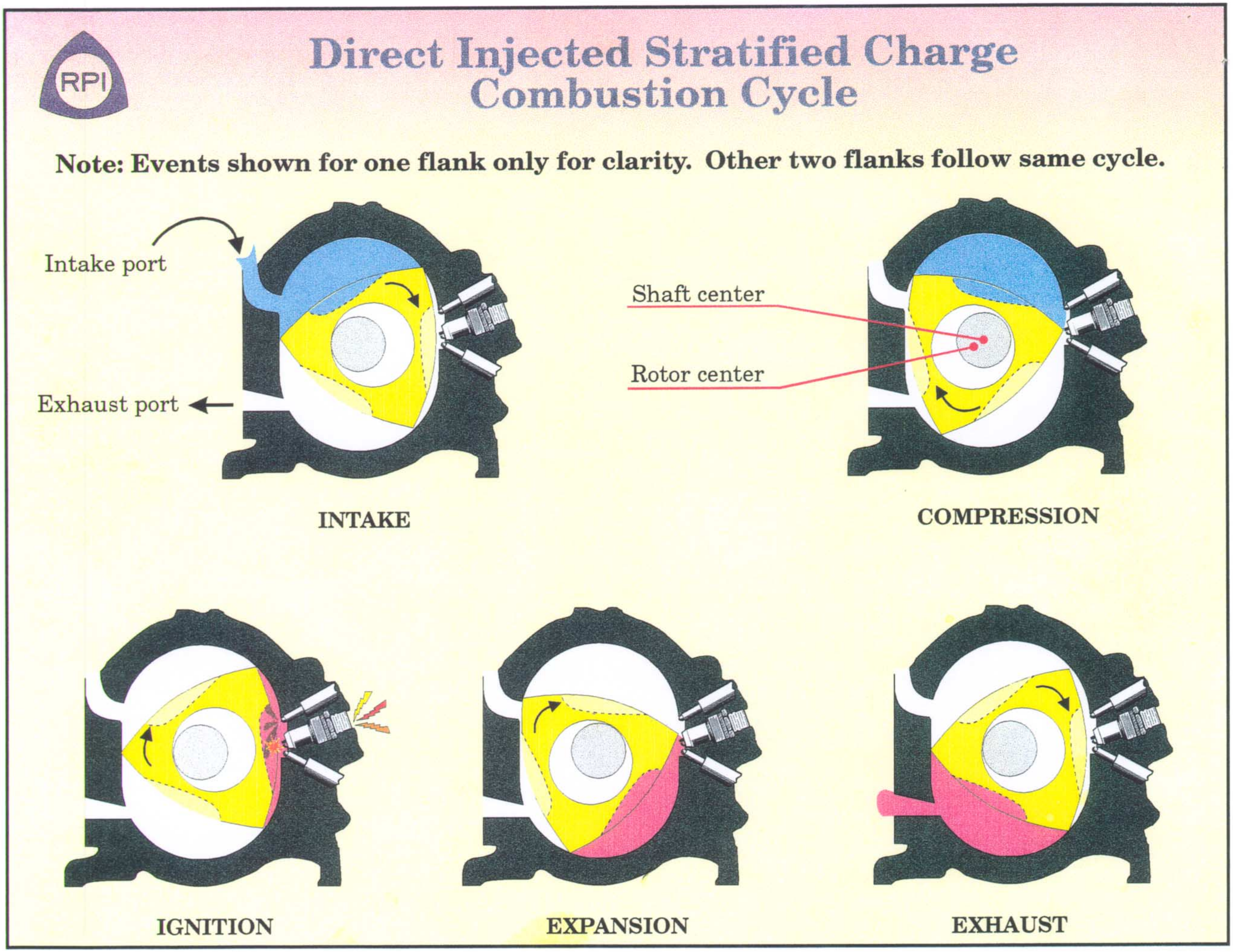

RPI
Direct Injected Stratified Charge
Combustion Cycle
Note: Events shown for one flank only for clarity. Other two flanks follow same cycle.
Intake port
Exhaust port
Shaft center
Rotor center
INTAKE
COMPRESSION
IGNITION
EXPANSION
EXHAUST

FIG. 2.0-2

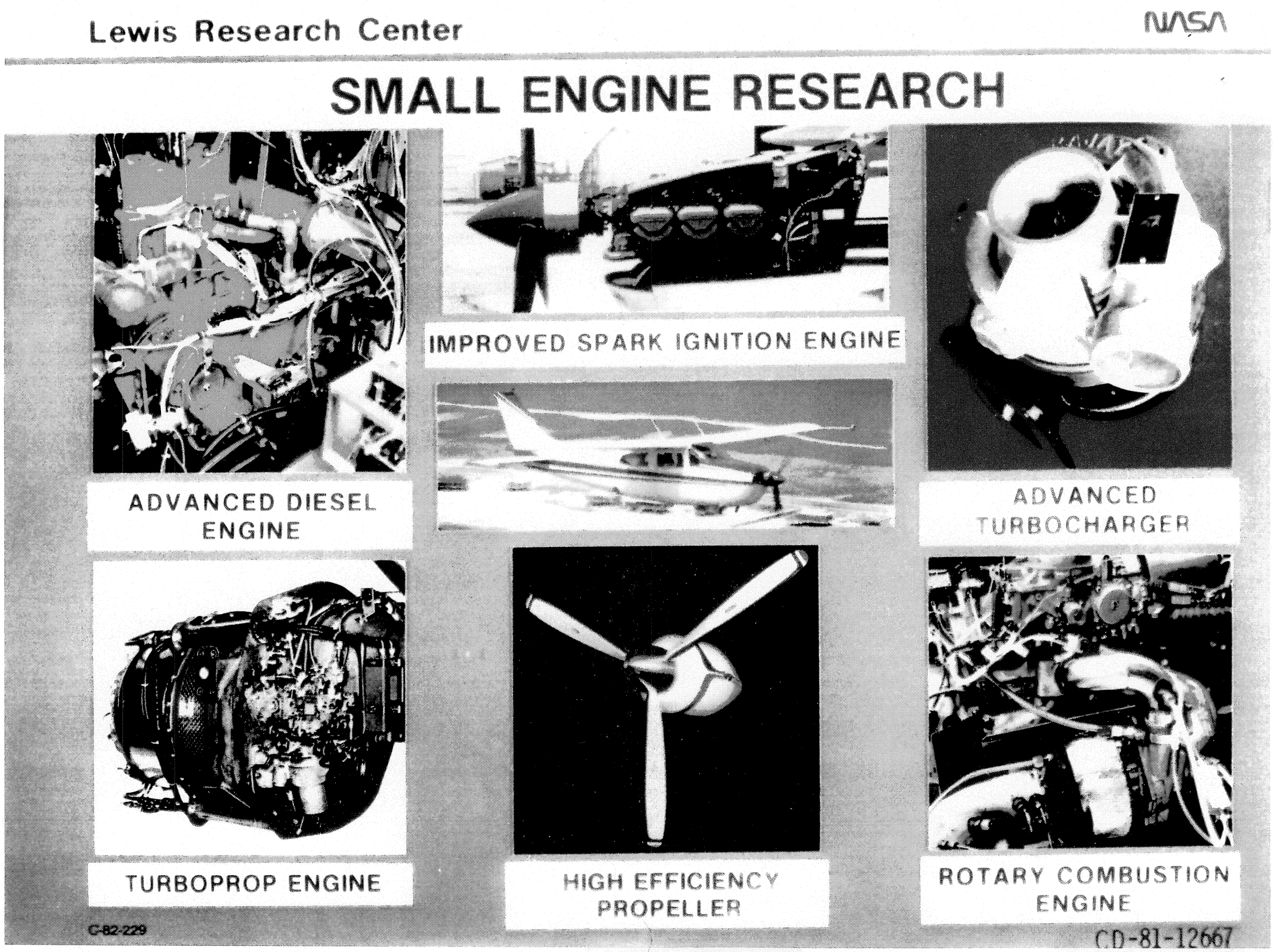
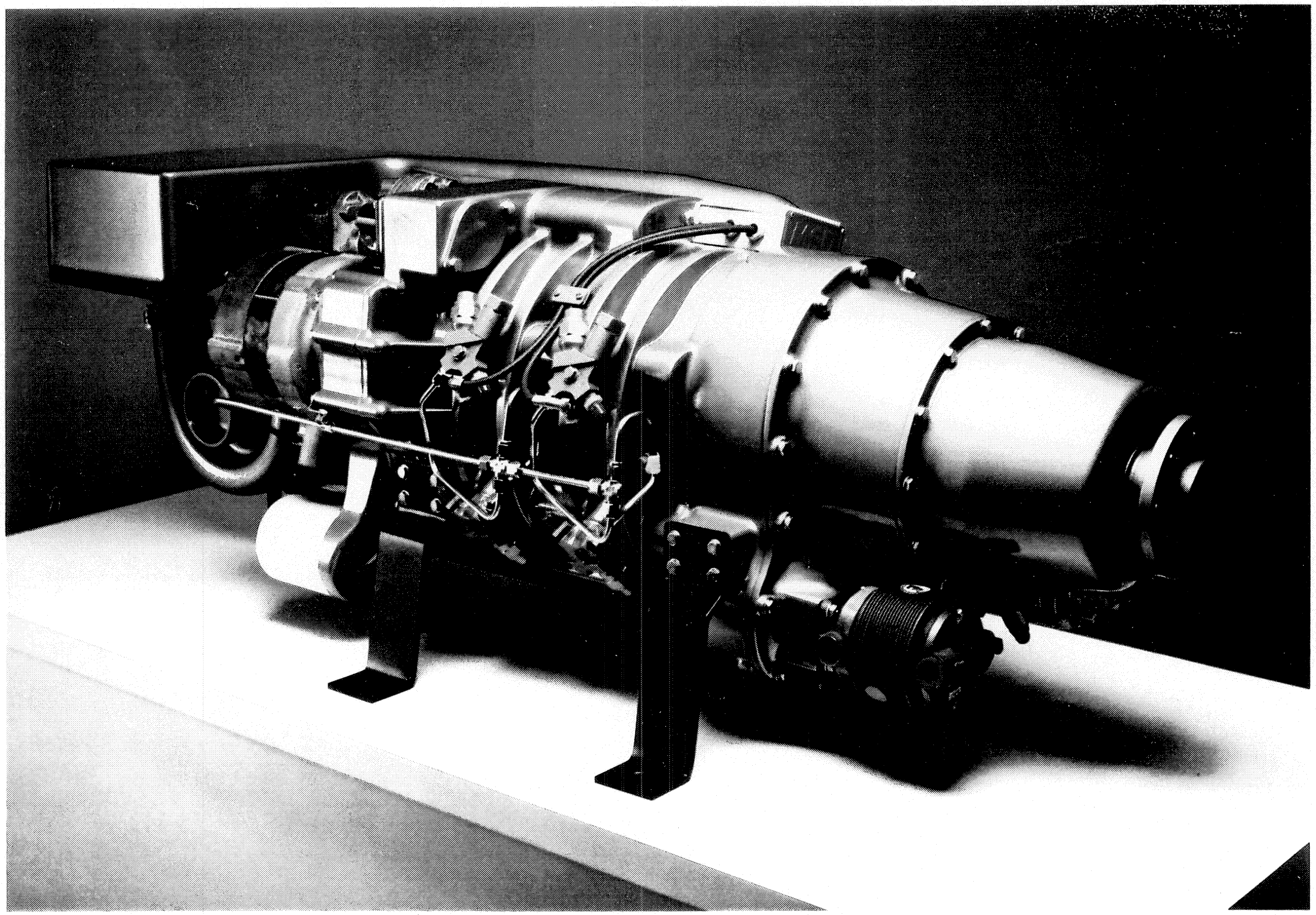

Lewis Research Center
NASA
SMALL ENGINE RESEARCH
IMPROVED SPARK IGNITION ENGINE
ADVANCED DIESEL ENGINE
ADVANCED TURBOCHARGER
TURBOPROP ENGINE
HIGH EFFICIENCY PROPELLER
ROTARY COMBUSTION ENGINE
G-82-229
CD-81-12667

FIG. 2.0-3a



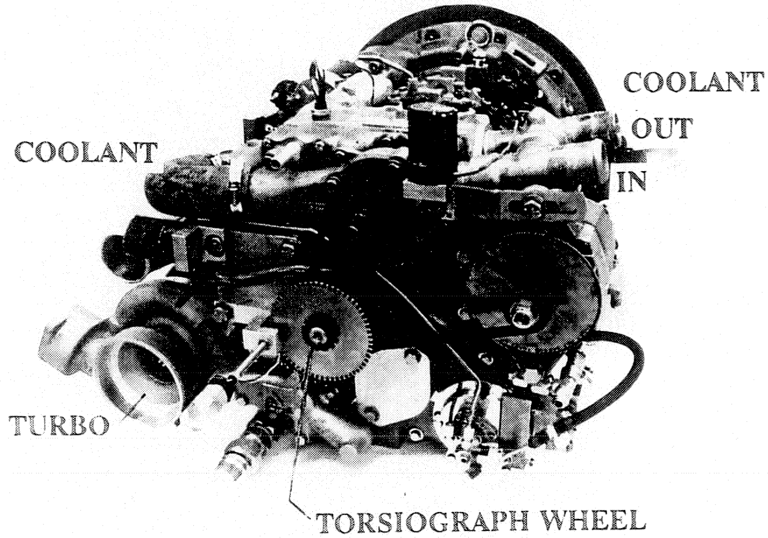
2013R AVIATION ENGINE
GENERAL ARRANGEMENT

FIG. 2.0-3b

ADVANCED ENGINE CONFIGURATION

NAS3-26920

MODEL 2013R 340 BHP/8000 RPM



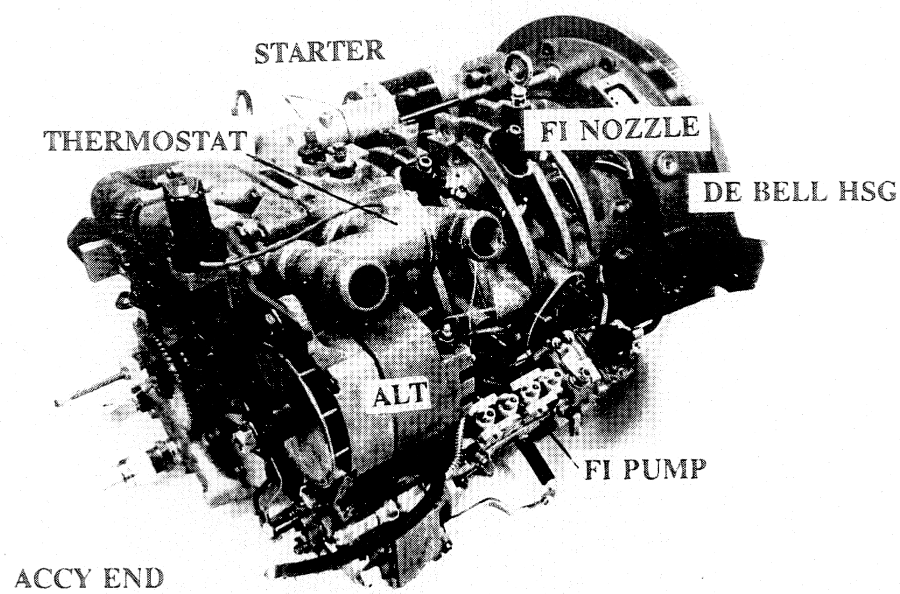
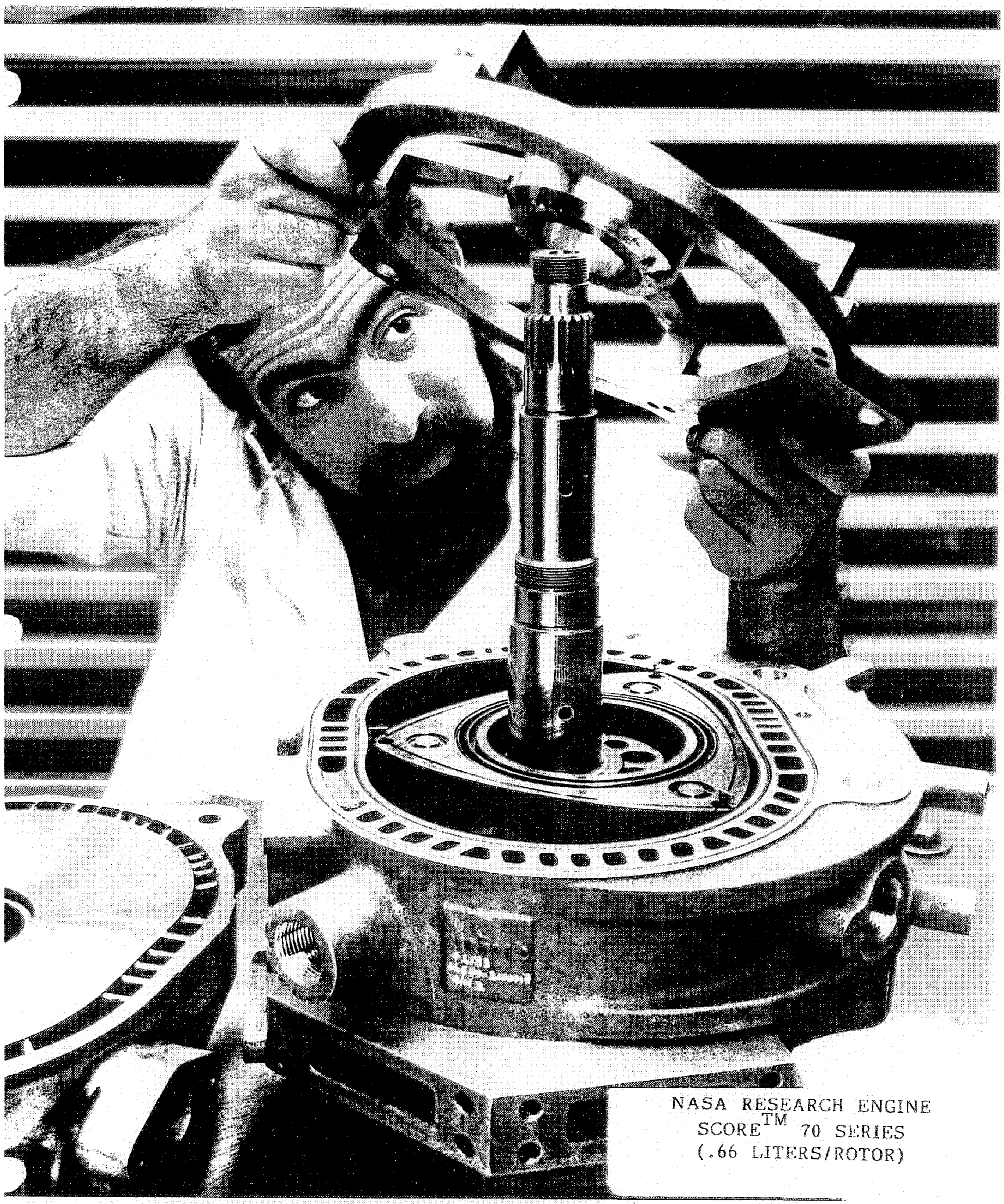
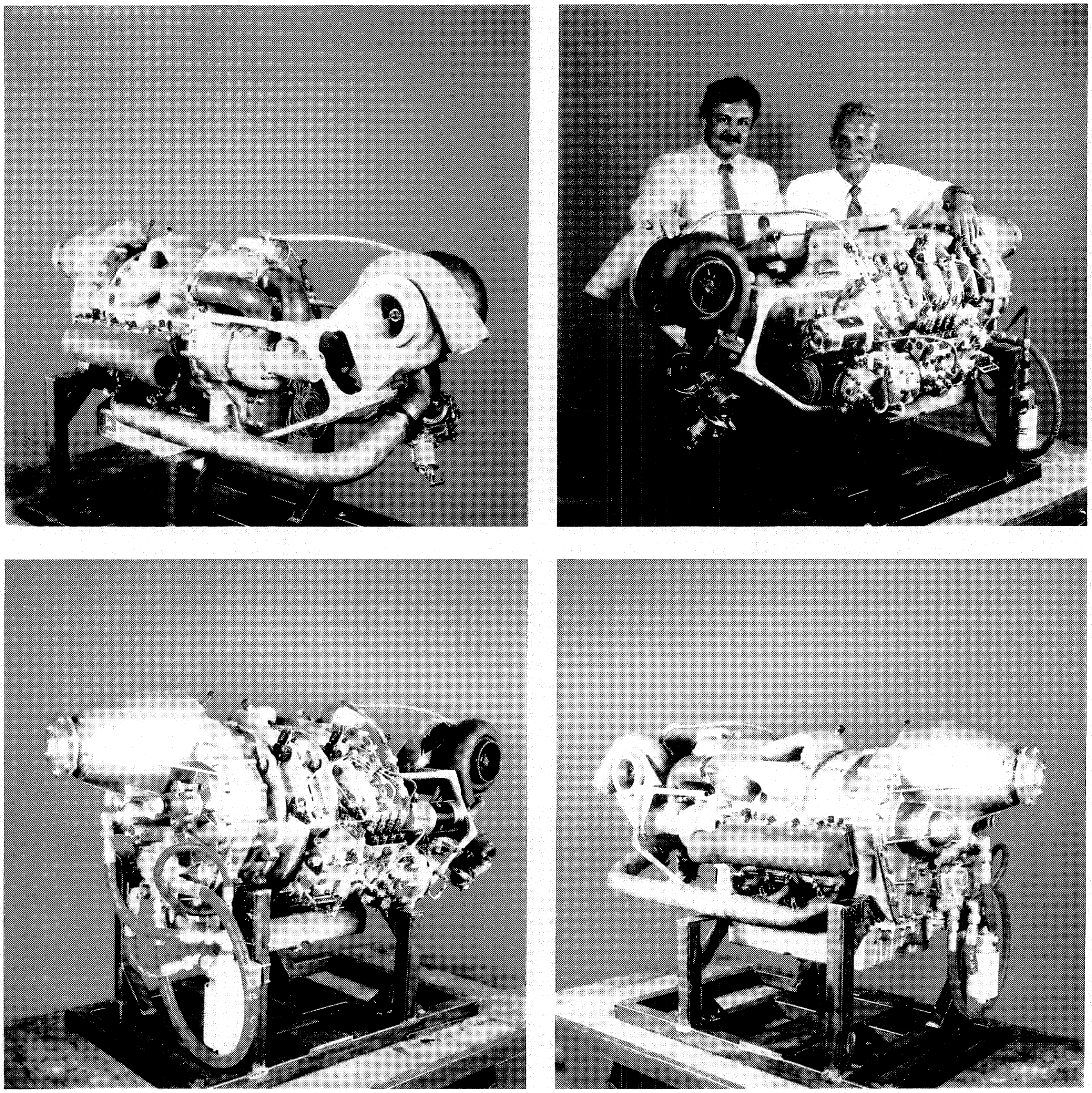


FIG. 2.0-3c



NASA RESEARCH ENGINE
SCORE^{TM} 70 SERIES
(.66 LITERS/ROTOR)

FIG. 2.0-4



170 SERIES
MODEL 2034R

FIG. 2.0-5

In the case of diesel reciprocating engine the very desirable high efficiency levels possible there remain tied to higher weight, higher noise and higher vibration levels. None of these are acceptable in modern aircraft requirements. Again, if one examines the domestic and foreign infrastructure, noise constraints on engine exhaust and propellers are predominant factors in acceptability of operation in many areas in Europe.

For the turbine engines the significant issues of high initial cost, high operating costs, high fuel consumption at low power and reduced power at altitude are inherent obstacles to wide acceptance in many categories of general aviation.

Figures 2.0-6 summarizes SCRE potential and significant technology differences vs Reciprocating Engines.

Figure 2.0-7 summarizes SCRE potential and significant technology differences vs Turbine Engine.

Figures 2.0-8 provides a Power Plant Comparative Analysis summarizing characteristics for the SCRE in comparison to piston and turbine engines by detail characteristic and in total.

Figure 2.0-9 presents a summary of features inherent in the SCRE and relates these features to advantages that might be noted by the aircraft operator.

A review of works, noted in Section 7.0 - Bibliography of this study will clearly show that a) NASA LeRC's early (Circa 1982) ranking of the SCRE as the leading candidate for an advanced aviation engine of the mid 1990's and beyond was valid and, b) the technology enablement efforts by industry (Curtiss-Wright Corporation, Deere & Co., and Rotary Power International, Inc.), under contracts to NASA LeRC, have demonstrated and verified the capabilities and advantages for SCRE vs. other candidate propulsion systems.

This study defines a high-commonality, affordable and environmentally-superior family of SCRE's appropriate to the enablement of the development of a new generation of general aviation aircraft and defines the timing and dollars required to make the SCRE family available to aircraft builders and the general aviation fleet.

Section 3.0 following, "Schedules and Costs for Development and FAA Certification", provides a time estimate (28 months) and a cost estimate ($9.5 Mil) for the Development and Engineering to advance either of the SCRE family primary engines (70 Series, Model 2013R or 170 Series, Model 2034R) from the current state-of-the-art to FAA certification, production and availability to the fleet. Added capital costs for flight test aircraft and conversion, development test cells and production equipment would amount to an additional $4 Mil required. Hence, with a program start in the last quarter of Government FY1996, i.e. July 1, 1996 and a total expenditure of $13.5 Mil the SCRE advanced general aviation propulsion system can be ready for field application in CY1998. While this is not a significantly high funding level, and the pay offs to the aviation community and to the engine producer on a long range basis are substantial, the up front waiting period of 5-6 years before any return on investment has been a significant stumbling block in transitioning this desirable, NASA fostered technology to general aviation.

SCRE VS. RECIPROCATING ENGINES

SCRE DOES NOT REQUIRE HIGH OCTANE, LEADED GASOLINE - RECIP DOES

SCRE CAN USE JET FUEL - RECIP CANNOT

- o LOWER COST FUEL- U.S. JET-A 1.815 $/GAL; AVGAS 2.40 $/GAL
  EUROPE JET-A COST $1.50/GAL;AVGAS $6.00 GAL
- o MORE READILY AVAILABLE
- o AVGAS NOT AVAILABLE IN MANY PARTS OF THE WORLD
- o ENVIRONMENTAL CONCERNS WILL SOON LIMIT OR ELIMINATE LEADED AVGAS

SCRE OFFERS DIESEL RANGE EFFICIENCIES AND LOW FUEL USAGE (LOWER THAN RECIP BY 2.5 TO 15% OVER MAX CRUISE AND T.O. RANGE)

- o LESS FUEL BURN/COST FOR GIVEN MISSION
- o EXTENDED RANGE MISSIONS

SCRE COSTS ARE COMPETITIVE WITH RECIPROCATING ENGINES

- o DETAILED COST STUDIES BY DEERE AND AVCO CONFIRMED SCRE COST 15% LOWER THAN RECIP COST IN HIGH VOLUME PRODUCTION i.e; > 2000 UNITS/YEAR.
- o RECIPROCATING AIRCRAFT ENGINES ARE EXPENSIVE. THEY ARE NOT SPIN-OFFS FROM HIGH VOLUME PRODUCTION LINES, I.E. AUTOMOTIVE
- o THE MARKET ACCEPTS THESE HIGH COSTS FOR HIGH POWER OUTPUT PER POUND, EFFICIENCY, RELIABILITY, CONFORMANCE TO FAA STANDARDS, SAFETY

SCRE HAS 40% FEWER PARTS THAN RECIP AND IS SIMPLE IN CONSTRUCTION OFFERING

- o RELIABILITY
- o EASE IN MAINTENANCE
- o HIGHER TIME BETWEEN OVERHAULS (TBO) i.e. 2500-3000 HOURS FOR SCRE VS 1600 - 2000 HOURS FOR RECIP

SCRE IS SMALLER AND LIGHTER THAN RECIP

- o CYLINDRICAL PACKAGING IS IDEAL FOR LOW DRAG, TWIN ENGINE AIRCRAFT NACELLE CONFIGURATION
- o SMALL DIAMETER PACKAGE PERMITS DUAL PAC (SOLOY) CONFIGURATIONS

SCRE OFFERS TURBINE LIKE SMOOTHNESS, LOW VIBRATION IN CONTRAST TO RECIPS

SCRE CAN RETROFIT INTO NUMEROUS EXISTING AIRCRAFT CURRENTLY POWERED BY RECIP AND TURBINE POWERPLANTS

- o PROVIDES MARKET EVEN UNDER CURRENTLY DEPRESSED CONDITIONS (WITH 11,000 ENGINES PER YEAR IN THE 250-450 HP CLASS REQUIRING OVERHAUL)

FIG. 2.0-6

SCRE VS. TURBINE ENGINES

SCRE SELLING PRICES CAN BE ABOUT 25% OF TURBINE ENGINE PRICES AT EQUIVALENT POWER LEVELS. AT 350-500 HP,

- o SCRE 60K
- o PT-6 300K

SCRE OFFERS LOWER FUEL CONSUMPTION (20-25% LOWER THAN TURBINE)

SCRE OFFERS FLAT RATING OF SEA LEVEL TAKE-0FF POWER TO HIGH ALTITUDES (20,000 FT.)

- o TURBINE EXPERIENCES SEVERE LAPSE IN POWER WITH ALTITUDE (NEEDS 75 TO 100% LARGER SIZE AT SEA LEVEL TO GIVE HP AT 20,000 FT.)

SCRE OFFERS LOWER OVERHAUL COSTS (20-25% OF TURBINE OVERHAUL COSTS)

- o TURBINE HOT SECTION REPLACEMENTS AND MAJOR OVERHAULS ARE VERY EXPENSIVE (PT6A-112 MAJOR OVERHAUL IS $90.000)

- o SCRE SERVICING CAN BE ACCOMPLISHED BY LESSER TRAINED PERSONNEL THAN REQUIRED BY TURBINE

FIG. 2.0-7

POWER PLANT COMPARATIVE ANALYSIS

CHARACTERISTIC	SCRE	PISTON	TURBINE
o REDUCED EMISSIONS AND NOISE			
UNBURNED HC	7	7	6
NOX	9	8	8
CO	8	6	8
EXHAUST NOISE	7	6	4
CASING NOISE	8	6	6
o INITIAL COSTS	8	9	1
o TOTAL LIFE CYCLE COSTS	8	6	6
o OPERATIONAL	9	6	9
o DURABILITY AND MAINTENANCE	8	4	9
o SAFETY AND RELIABILITY	8	5	9
o PERFORMANCE	9	6	7
o FUEL CONSUMPTION	6	5	3
o SIZE AND SHAPE	8	5	9
o COOLING	10	1	10
o MULTI-FUEL CAPABILITY	7	1	3
TOTALS	**120**	**81**	**98**

RATING 10 = HIGHEST OR BEST

1 = LOWEST OR WORST

FIG. 2.0-8

STRATIFIED CHARGE ROTARY ENGINES
FEATURES AND AIRCRAFT OPERATIONAL ADVANTAGES

FEATURES	AIRCRAFT OPERATIONAL ADVANTAGES
o STRATIFIED CHARGE	o LOW FUEL CONSUMPTION o MULTI FUEL CAPABILITIES
o LOW FUEL CONSUMPTION	o INCREASED RANGE AND ENDURANCE o INCREASED PAYLOAD o REDUCED DIRECT OPERATING COSTS
o JET-A FUEL	o LOWER COST o MORE READILY AVAILABLE o ENVIRONMENTALLY ACCEPTABLE (NO LEAD)
o LOW PARTS COUNT	o SIMPLICITY o IMPROVED SAFETY MARGIN o IMPROVED RELIABILITY o REDUCED SUPPORT COSTS
o RELIABILITY	o ENHANCED CUSTOMER CONFIDENCE o REDUCED MAINTENANCE COSTS o REDUCED OVERHAUL COSTS
o TURBOCHARGED-INTERCOOLED	o HIGH ALTITUDE PERFORMANCE
o POWER LAPSE RATE	o PROPORTIONAL TO DENSITY o BETTER AIRFRAME MATCH o INCREASED ALTITUDE CRUISE PERFORMANCE
o LIQUID COOLING	o STABLE TEMPERATURES o SIMPLIFIED OPERATING TECHNIQUES o LOWER DRAG VS. AIR COOLED o SAFE CABIN HEAT
o LOW VIBRATION LEVEL	o SIMILAR TO TURBINE
o PHYSICAL DIMENSIONS	o SMALL CROSS SECTION o CIRCULAR NACELLE o LOW PROFILE DRAG
o MODERN TECHNOLOGY	o CUSTOMER APPEAL

FIG. 2.0-9

In recognition of this, Rotary Power International, Inc. has promoted the formation of an industry consortium to accomplish the tasks on a cost sharing basis with NASA and has sought NASA Headquarters support for that approach. The industry consortium named Rotary Aircraft Engines Corporation (RAEC) would involve Rotary Power International, Inc. (SCRE Technology), Textron-Lycoming (Manufacturing, Sales, Service) and Lockheed-Martin (Manufacturing Support, Military/Government Sales - UAV's, APU's/GPU's) as shown in Fig. 2.0-10.

Figure 2.0-11 defines the inter-relationships that are being discussed.

ADVANCED GENERAL AVIATION PROPULSION SYSTEM
Stratified Charge Rotary Engine

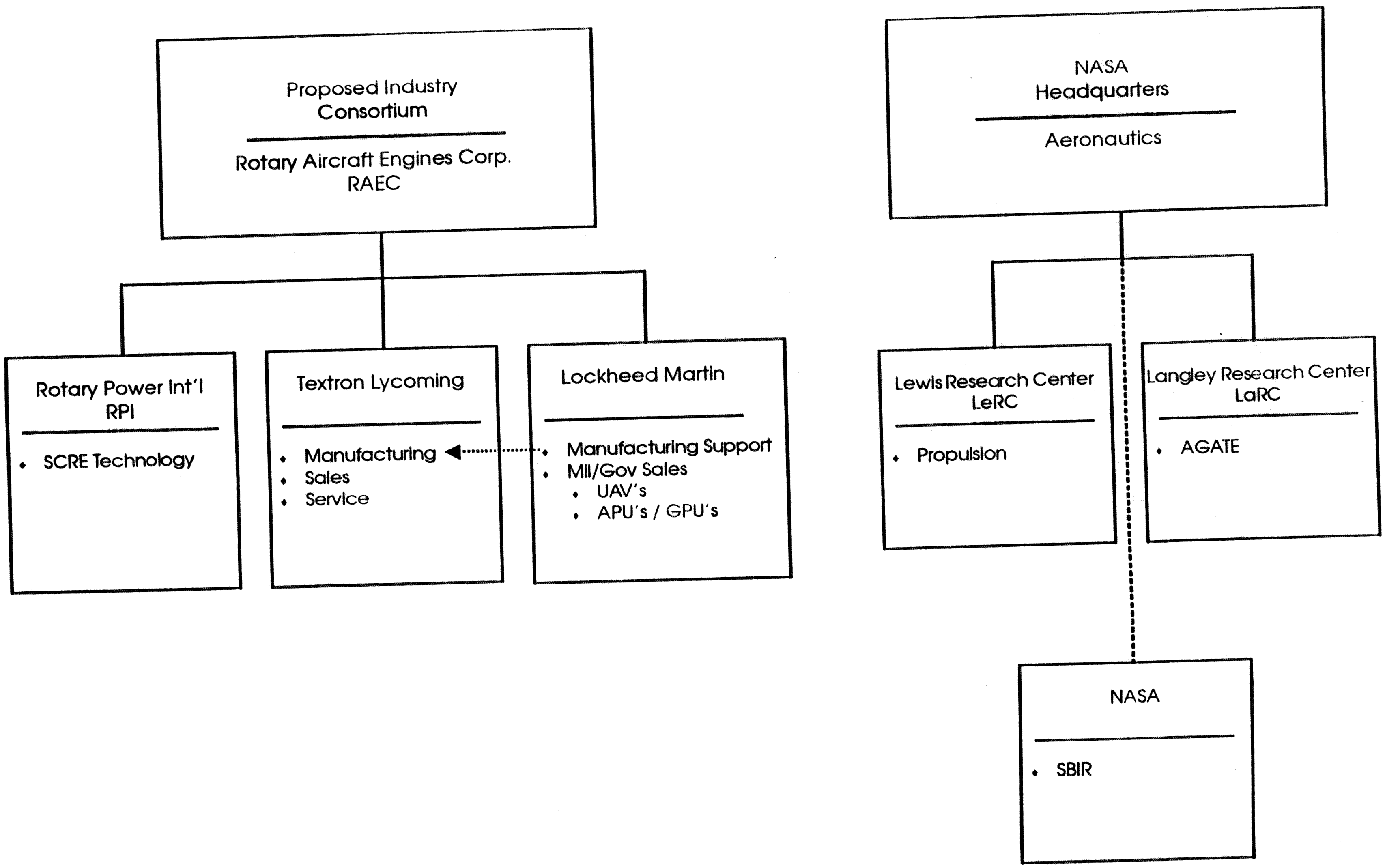


FIG. 2-0-10

RAEC Industry Consortium - Proposed

Inter-Relationships
RPI - Lockheed Martin - Textron Lycoming

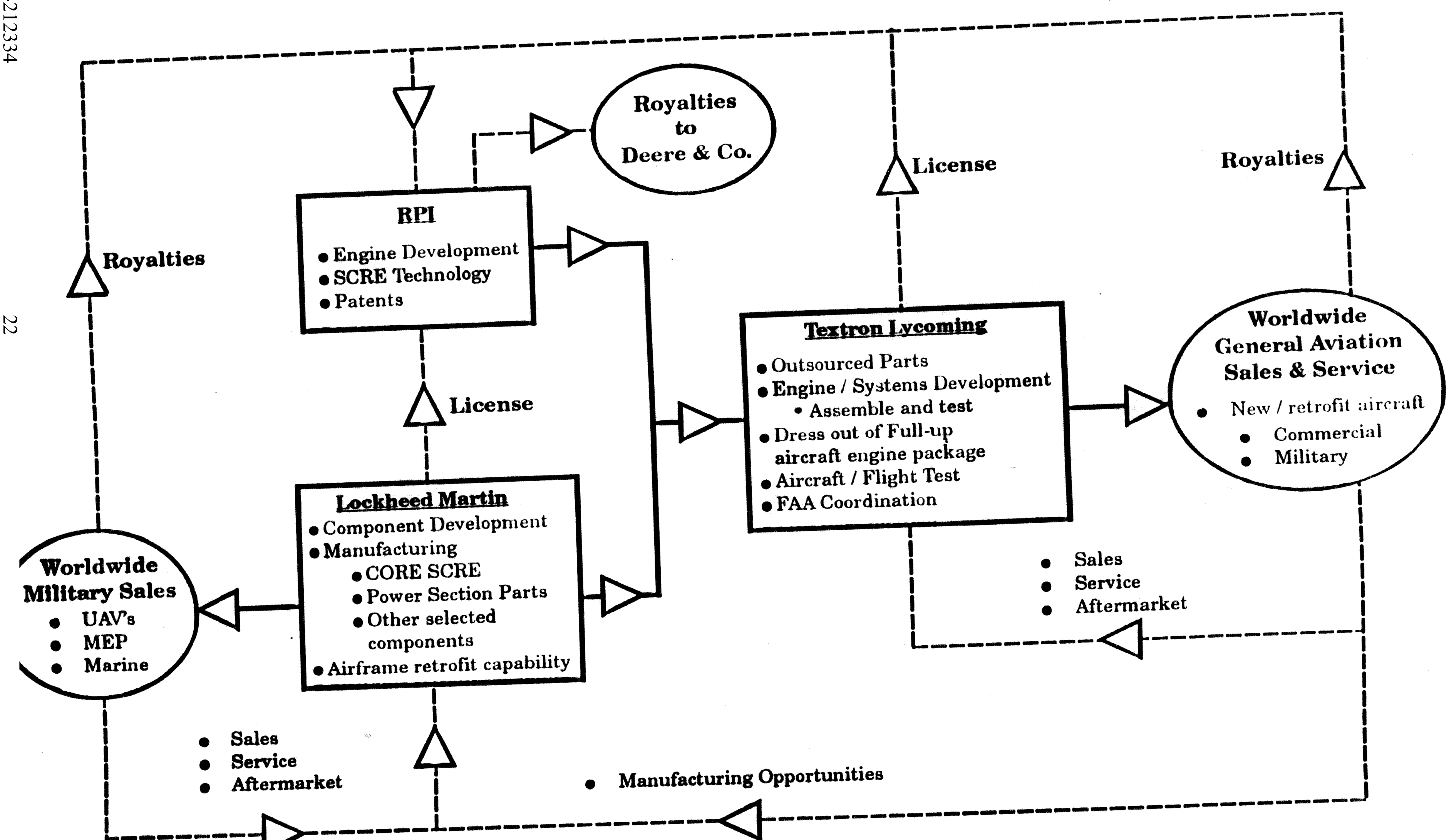


FIG. 2.0-11

3.0 SCHEDULE AND COSTS FOR DEVELOPMENT AND FAA CERTIFICATION

The estimated time schedule for final development and FAA certification for either of the primary engine candidates, 70 Series Model 2013R or 170 Series Model 2034R in a stand alone program is estimated at 28 months. The estimated overall cost for achieving the final development, flight test evaluations, production preparations, FAA certification and making the new powerplant available to the general aviation community is estimated at $13.5 Mil.

Figure 3.0-1 provides a composite schedule reflecting this study being conducted during the latter part of CY1995, a final product development and FAA certification program start on July 1, 1996 with availability of the new powerplant to the end user in CY 1998.

Figure 3.0-2 provides an outline of the overall funding requirement for the 28 month final development and certification program, assuming a July 1, 1996 start and showing the distribution of the funding requirement over calendar and government fiscal years.

NASA STUDY CONTRACT NAS3-27642 AND POTENTIAL FOLLOW-ON
DEVELOPMENT FAA CERTIFICATION

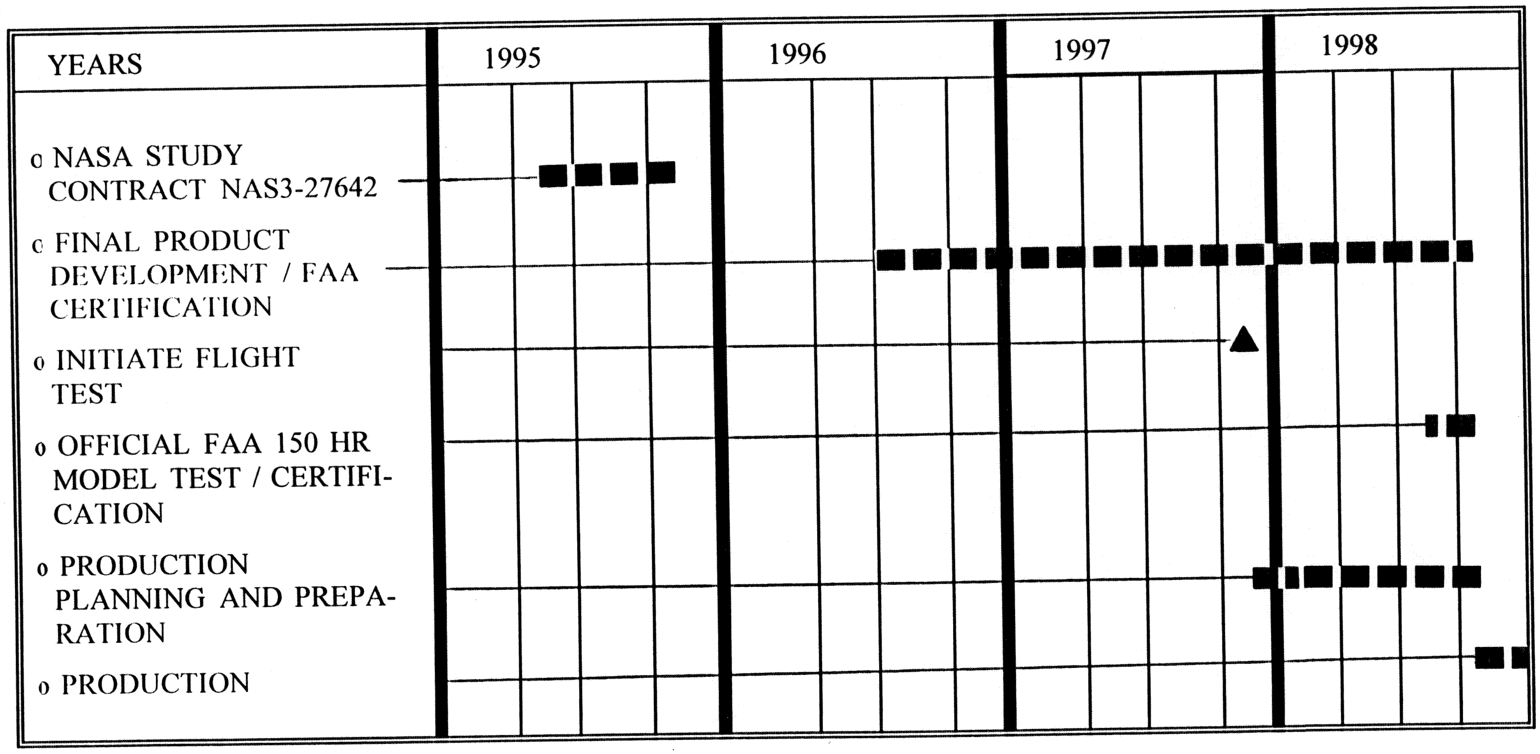


FIG. 3.0-1

ADVANCED GENERAL AVIA ON PROPULSION SYSTEM

Stratified Charge Rotary Engine

Overall Funding Requirement

28 Month Program: 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, 28

	CY 96		CY 97	CY 98	
	GOV. FY 96	GOV. FY 97	GOV. FY 97 / 98	GOV. FY 98	Totals ($)
DEVELOPMENT & ENGINEERING					
• DL, MAT, OH	361,196	626,877	3,810,712	2,009,373	$6,708,158
• G&A	247,000	247,000	1,268,000	934,000	2,696,000
FLIGHT TEST					
• Two Engines, Airplane, Conversion, Test			655,000	125,000	780,000
DEV TEST CELLS			450,000		450,000
SUB TOTALS	608,196	773,877	6,183,712	3,068,373	$10,634,158
PRODUCTION CAPITAL			850,000	2,000,000	2,850,000
PROGRAM TOTAL, BY CY	1,382,073		7,003,712	5,068,373	$13,484,158

FIG. 3.0-2

064-FUNDING.CDR

4.0 TECHNICAL APPROACH/DISCUSSION

4.1 OVERALL PROPULSION SYSTEM ANALYSIS/CONFIGURATION

4.1.1 Critical Examination of the SCRE 40 cu.in. and the 105 cu.in Displacement Power Section Capabilities

The 70 Series, 40 cu.in. per rotor and 170 Series, 105 cu.in. per rotor basic power section sizes were selected as the base sizes for the SCRE family of engines in covering the very wide 125 to 2500 HP power range.

The 40 cu.in.size derives from the earlier NASA Technology Enablement programs initially addressing the lower end of that wide power range, i.e. 320 HP at take-off in a twin rotor version. Also, the research efforts involved in the NASA Technology Enablement programs utilized a single rotor research rig engine for those extensive combustion, power output and efficiency investigations. Industry development work with the 40 cu.in. power section proceeded in parallel with the NASA research work and accumulated a wide range of experience with single and twin rotor versions of the 40 cu.in engines at various power ratings. Selection of the near term and growth power levels for the SCRE family of 40 cu.in. per rotor engines in this study are based upon a combination of the NASA high output and Industry medium output achievements. For example, the primary or twin rotor 40 cu. in., 70 Series engine 2013R has demonstrated the near term (5 year) growth power projection of 340 HP. Furthermore, with the single rotor research rig engine, 200 HP has been demonstrated. This is equivalent to 400 HP in the twin rotor, Model 2013R size and reflects some margin over the projected near term (5 year) growth power level of 340 HP. The further reduction to 250 HP for the near term (3 year) power rating builds in the degree of conservatism necessary in addressing required operational capabilities, meeting mission requirements with reliability and safety margins, meeting time between overhaul requirements, reasonable development/FAA certification costs and product pricing. At the 250 HP take-off power level at introduction (approximately 3 years) with growth to 340 HP (5 years) the twin rotor, 40 cu.in. Model 2013R twin rotor engine will be operating at engine speeds acceptable from the linear seal speed, fuel injection system injections/minute and brake mean effective pressure (BMEP) stand points. Coordination with major airframers indicates that time between overhauls (TBO's) of 2000 hours is acceptable but that 2500-3000 hours is highly desirable. Also, they have indicated that emphasis be placed on achieving lowest specific fuel consumption at maximum cruise power (i.e., 75% take-off) even at some compromise in the take-off condition specific fuel consumption in recognition of the time distribution for these conditions during a typical mission (i.e., < 5% at take-off power). In terms of altitude capabilities the airframers feel that flat rating of take-off power to 20,000 feet altitude is desirable. Flat rating of maximum cruise power to 25,000-27,000 is desirable.

The 105 cu.in. size derives from an earlier joint Deere & Co., and Avco-Lycoming effort involving a twin rotor version at 400 HP at take-off. The engine was operated as a full-up, aircraft engine package achieving an early demonstration of 430 HP at take-off. With the limited test time and experience associated with the 105 cu.in. size (limited to two short term, twin rotor engines tests) and recognition of the desirability for reduced BMEP levels with increased displacement, we have selected 425 HP as the near term twin rotor power level (3 years) and 625 HP as the near term growth (5 years) power level.

The development cycle through FAA certification for either of the primary engine candidates, Model 2013R, 70 Series or Model 2034R, 170 Series is approximately 28 months and is defined in detail in Section 4.4 of this study.

Figure 4.1.1-1 Provides a summary of basic specification data for the near term capability (3 years) SCRE family.

Figures 4.1.1-2 provides a summary of development and FAA certification schedule, cost and projected time between overhaul (TBO) at introduction and long range.

Figures 4.1.1-3 and 4.1.1-4 provides the specification, development, FAA certification and TBO projections for the growth capability (5 years) SCRE family.

FAMILY OF ADVANCED TECHNOLOGY STRATIFIED CHARGE ROTARY AIRCRAFT ENGINES
NEAR-TERM CAPABILITY - 3 YEARS
BASIC SPECIFICATION

	70 Series			170 Series	
MODEL	1007R	2013R Primary	4026R	2034R Primary	4068R
Displacement/Rotor, cu. in.	40	40	40	105	105
No. of Rotors	1	2	4	2	4
Take-off HP	125	250	500	425	850
Take-off RPM	7000	7000	7000	5800	5800
Max. Cruise HP (75%)	93	187	375	318	637
Max. Cruise RPM	6000	6000	6000	4350	4350
BSFC at Take-off, Lbs./BHP-Hr	0.57	0.55	0.55	0.44	0.44
BSFC at Max. Cruise, Lbs./BHP-Hr	0.42	0.39	0.39	0.38	0.38
BMEP at Take-off, psi	175	175	175	138	138
BMEP at Max. Cruise, psi	154	154	154	138	138
Combustion Peak Pressure, psi	1200	1200	1200	1200	1200
Reduction Gear/2000RPM Prop	3:1	3:1	3:1	2.9:1	2.9:1
Engine Dry Weight-Lbs.	325	365	440	538	1015
Engine Wet Weight-Lbs.	385	430	560	628	1195
Nacelle Dia.-in. (T/C Aft)	26	26	26	28	28
Engine Length-in. (T/C Aft)	52.5	57.6	67.74	63.47	77.35
Estimated Recip. Weight/Ref. (Dry-less oil coolers)	275	375	Est. 550-600* Dry if available	542 Dry 631 Wet	None noted

*No engines available at 500HP

Figure 4.1.1-1

FAMILY OF ADVANCED TECHNOLOGY STRATIFIED CHARGE ROTARY AIRCRAFT ENGINES
NEAR-TERM CAPABILITY - 3 YEARS
DEVELOPMENT, FAA CERTIFICATION, SERVICE

	70 Series			170 Series	
MODEL	1007R	2013R Primary	4026R	2034R Primary	4068R
Time to FAA Certification Stand-Alone, Independent Program-Months	30	28	30	28	30
Time to FAA Certification, Δ vs. Primary Engine, Months (No overlap); Less (*f*) overlap	18	0	18	0	18
Time to First Flight, Months	17	17	19	17	19
Development and FAA Certification Cost, Stand-Alone, Independent Program, Million $	12	13.5	16.5	13.5	18.2
Development and FAA Certification Cost, Δ vs. Primary Engine, Million $	5	0	6	0	10
Introductory TBO, Hours	2000	2000	2000	2500	2200
Long Range TBO, Hours	2500	2500	2500	3000	2800

Figure 4.1.1-2

FAMILY OF ADVANCED TECHNOLOGY STRATIFIED CHARGE ROTARY AIRCRAFT ENGINES
GROWTH CAPABILITY - 5 YEARS
BASIC SPECIFICATION

	70 Series			170 Series	
MODEL	1007R	2013R Primary	4026R	2034R Primary	4068R
Displacement/Rotor, cu. in.	40	40	40	105	105
No. of Rotors	1	2	4	2	4
Take-off HP	170	340	680	625	1250
Take-off RPM	8000	8000	8000	5800	5800
Max. Cruise HP (75%)	127	255	510	469	938
Max. Cruise RPM	6000	6000	6000	4350	4350
BSFC at Take-off, Lbs./BHP-Hr	.52	.50	.50	.42	.42
BSFC at Max. Cruise, Lbs./BHP-Hr	.40	.38	.38	.37	.37
BMEP at Take-off, psi	208	208	208	203	203
BMEP at Max. Cruise, psi	172	172	172	203	203
Combustion Peak Pressure, psi	1400	1400	1400	1400	1400
Reduction Gear/2000RPM Prop	4:1	4:1	4:1	2.9:1	2.9:1
Engine Dry Weight-Lbs.	340	380	470	560	1060
Engine Wet Weight-Lbs.	400	445	570	680	1250
Nacelle Dia.-in. (T/C Aft)	26	26	26	28	28
Engine Length-in. (T/C Aft)	52.5	57.6	67.74	63.47	77.35
Estimated Recip. Weight/Ref. (Dry-less oil coolers)	275	570	None Avail.	None Avail.	None Avail.

Figure 4.1.1-3

FAMILY OF ADVANCED TECHNOLOGY STRATIFIED CHARGE ROTARY AIRCRAFT ENGINES
GROWTH CAPABILITY - 5 YEARS
DEVELOPMENT, FAA CERTIFICATION, SERVICE

	70 Series			170 Series	
MODEL	1007R	2013R Primary	4026R	2034R Primary	4068R
Time to FAA Certification, Stand-Alone, Independent Program-Month	36	34	36	34	36
Time to FAA Certification △ vs. Primary Engine, Months (No Overlap); Less (*f*) Overlap	18	0	18	0	18
Development and FAA Certification Cost, Stand-Alone Independent Program - Million $	14	16.5	19	18	24
Development and FAA Certification Cost, △ vs. Primary Engine, Million $	6	0	8	0	12
Introductory TBO, Hours	2000	2000	2000	2200	2000
Long Range TBO, Hours	2200	2200	2200	2600	2400

Figure 4.1.1-4

4.1.2 Comparison of Technology Levels and Definition of Primary (Core) Twin Rotor Power Sections (Envelope, Weight, Influence of Rotor Quantities.)

The Stratified Charge Rotary Engine (SCRE) family as defined in this study involves two rotor sizes (40 cu.in. and 105 cu.in) and a variation in number of rotors (1,2 and 4 for the 40 cu.in. size; 2 and 4 for the 105 cu.in. size). Figure 4.1.2-1 depicts the family and notes near term (3 years) and growth (5 years) ratings.

The overall engine configurations involve conventional equipment in reduction gear and accessory gearbox sections and most of the accessory items are also conventional equipment. The SCRE specific equipment, or that portion of the engine unique to rotary is the "Power Section." This section is separated from the more conventional equipment in Figure 4.1.2-2.

The 40 cu.in. and 105 cu.in. rotary power units have been tested in a variety of programs under NASA contract (40 cu.in.) and under Rotary Power International, Inc. (RPI) programs (40 cu.in. and 105 cu.in.)

The NASA contractual research work with the SCRE has explored very high speeds and power output and defined the very long range potential. These investigations utilized the 40 cu.in. machine (single rotor research engine and twin rotor core engine system) and permit projection and scaling of those technologies to other sizes. Figure 4.1.2-3 defines high power output capabilities demonstrated with the single rotor 40 cu.in. engine, (200 HP, 40 in., 5 HP/cu.in.) referred to the two rotor basis. Figure 4.1.2-4 reflects a demonstrated fuel consumption level of 0.375 lbs/BHP-Hr. These investigations involved supportive 3-d combustion modeling, (Figures 4.1.2-4a and 4.1.2-4b), laser doppler velocimetry (LDV) flow visualization work and extensive supportive analyses. Correlation was achieved between experimental test and the modeling. The research engine achievements can be used as an estimate of performance potential when supported by appropriate development programs for performance, durability and certification.

For the 40 cu.in. rotor size, the NASA research work conducted at RPI and its predecessor organizations (Deere & Co. and Curtiss-Wright) involved investigations to levels substantially higher than any ratings used in the family planning, i.e.

<u>NASA Research Efforts</u>
40 cu.in.

Speed	9600 RPM
BMEP	210 psi
HP/IN^3	5
HP/Rotor	200

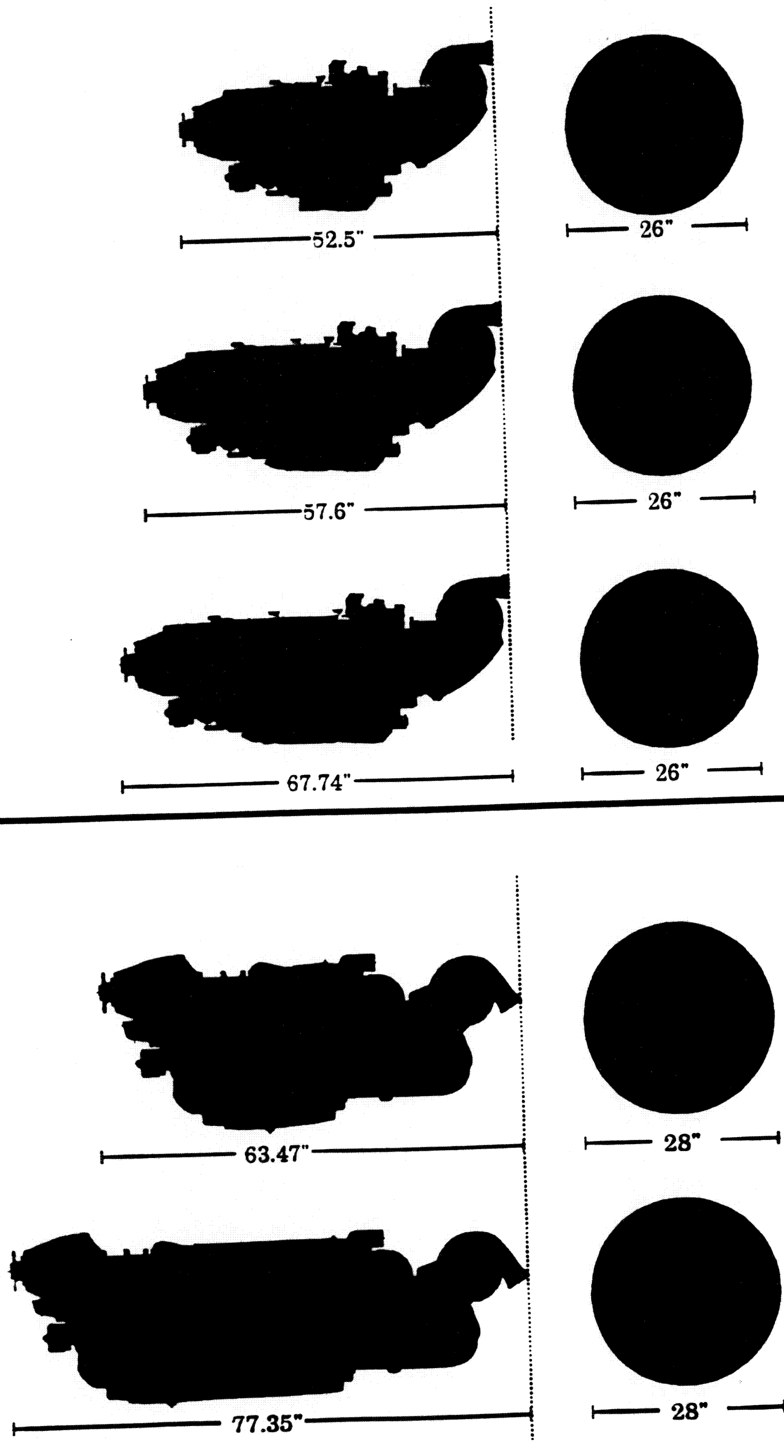
Reference to Figures 4.1.1-1 through 4.1.1-3 (in section 4.1.1) will show adequate margins for near term (3 years) and growth (5 years) engine sizing and performance vs. the NASA research levels.

Figure 4.1.2-5 outlines as a flow diagram the various factors considered in the engine sizing and rating methodology.

Actual design and test experience was gained with the larger displacement, 105 cu.in. rotor during a joint AVCO/Deere aviation engine program in the late 1980's. Additionally, extensive test experience with displacement varying from 4.3 cu.in. to 2500 cu.in. forms a part of the rotary data base at RPI. Aircraft engine configurations in twin rotor 25 cu.in., 60 cu.in., 75 cu.in. and 90 cu.in sizes also form a part of that extensive data base. Basic geometry factors, envelope and weight definition for the core power sections and the family, involving variations in rotor quantities are provided in Sections 4.1.6 Weights and 4.1.7-Drawings.

Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

125 to 1250 HP



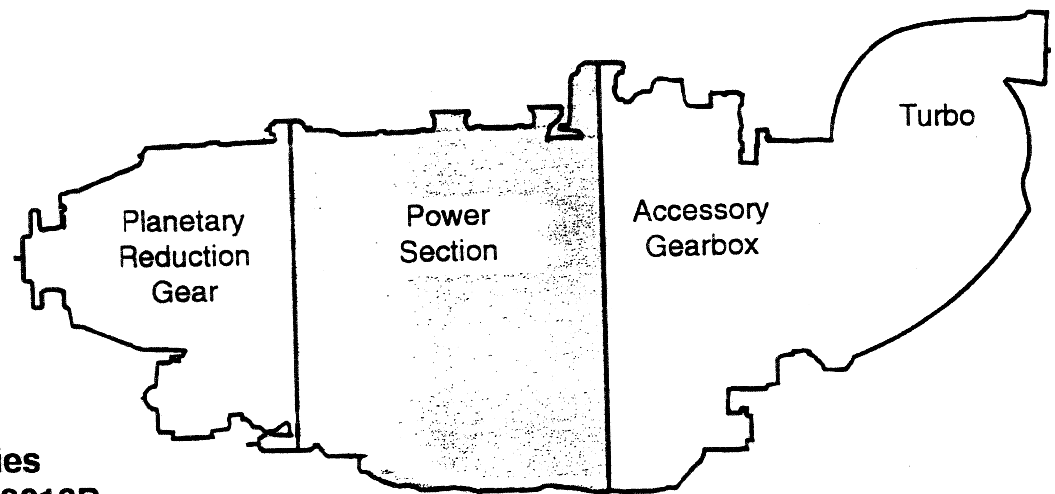
	Engine Silhouette	Nacelle Dia Req'd	Take Off Power Near Term 3 yrs.	Take Off Power Growth 5 yrs.
70 Series				
Model 1007R	52.5"	26"	125	170
Model 2013R primary engine	57.6"	26"	250	340
Model 4026R	67.74"	26"	500	680
170 Series				
Model 2034R primary engine	63.47"	28"	425	625
Model 4068R	77.35"	28"	850	1250

FIG. 4.1.2-1

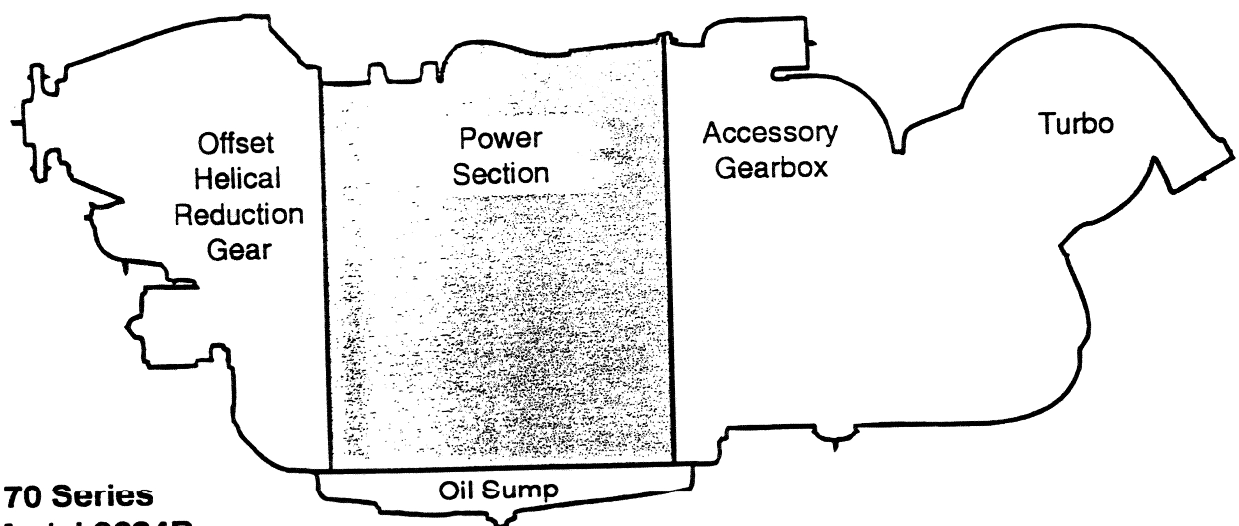
Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

Primary Engines - Aft Mounted Turbos

Reduction Gear and Sump Options



70 Series
Model 2013R
Dry Sump



170 Series
Model 2034R
Integral Sump

FIG. 4.1.2-2

NASA SCRE CRITICAL TECHNOLOGY ENABLEMENT

MAXIMUM POWER

2013R SCORE 70 ENGINE

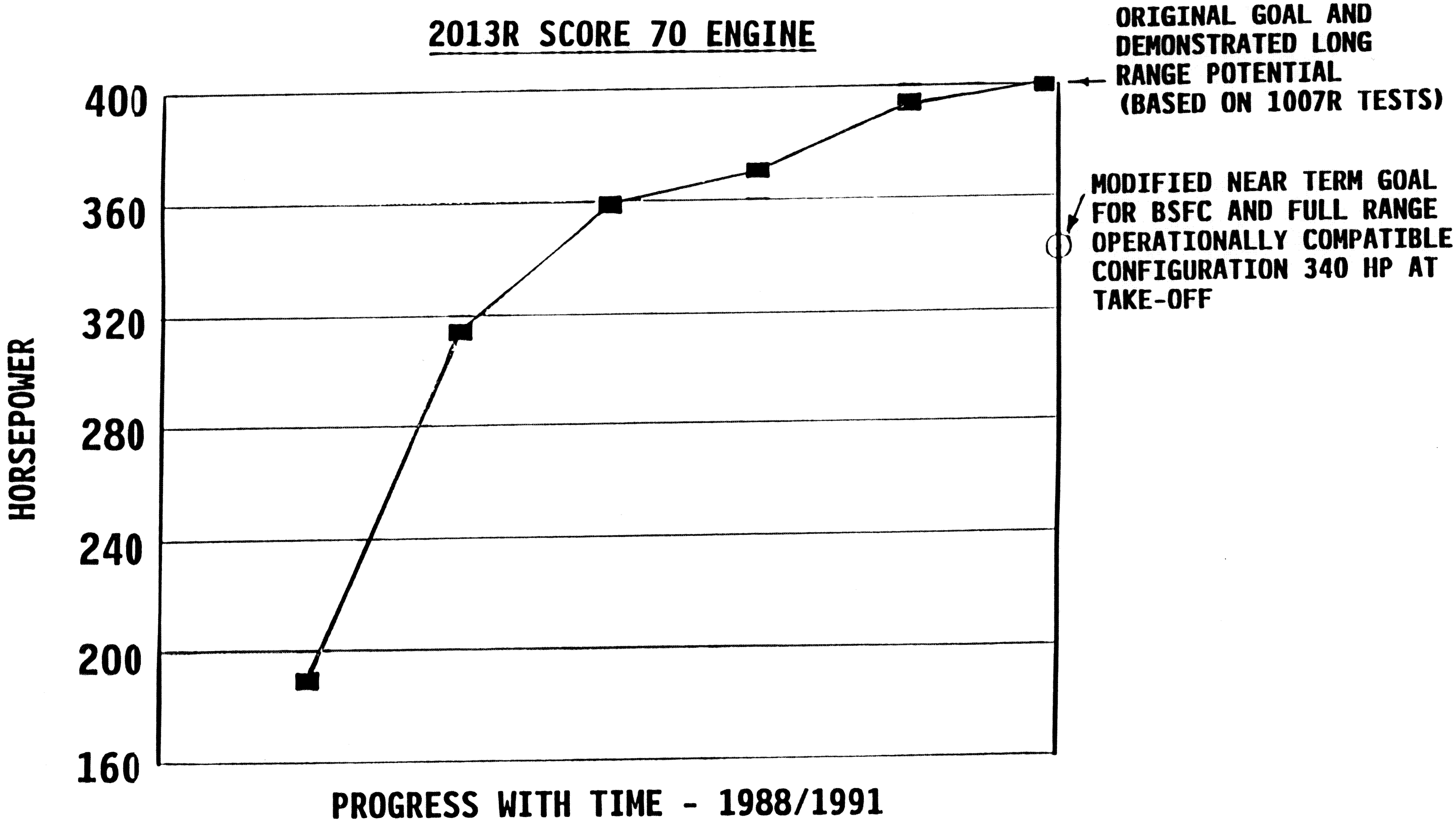


FIG. 4.1.2-3

NASA SCRE CRITICAL TECHNOLOGY ENABLEMENT

BRAKE SPECIFIC FUEL CONSUMPTION

2013R SCORE 70 ENGINE

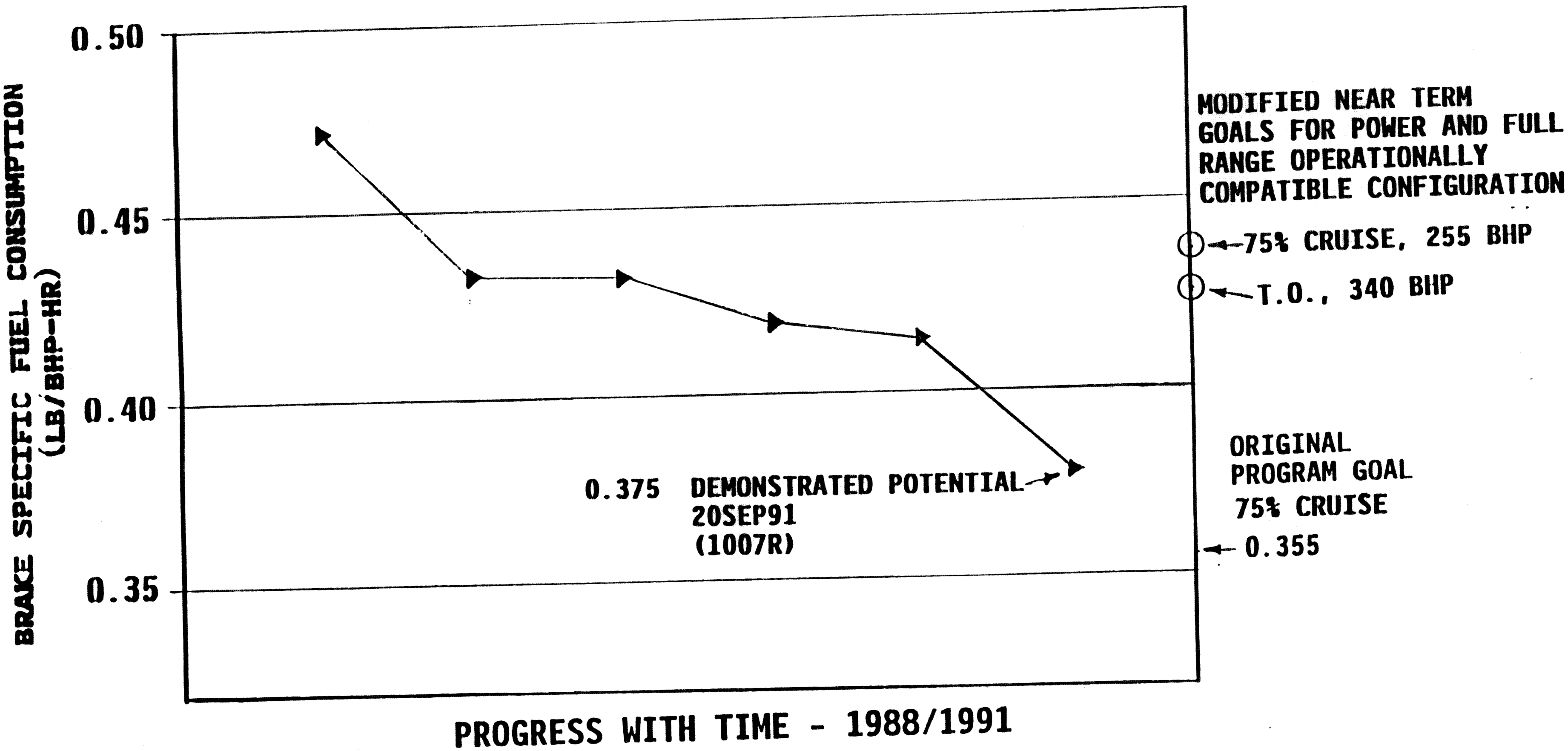
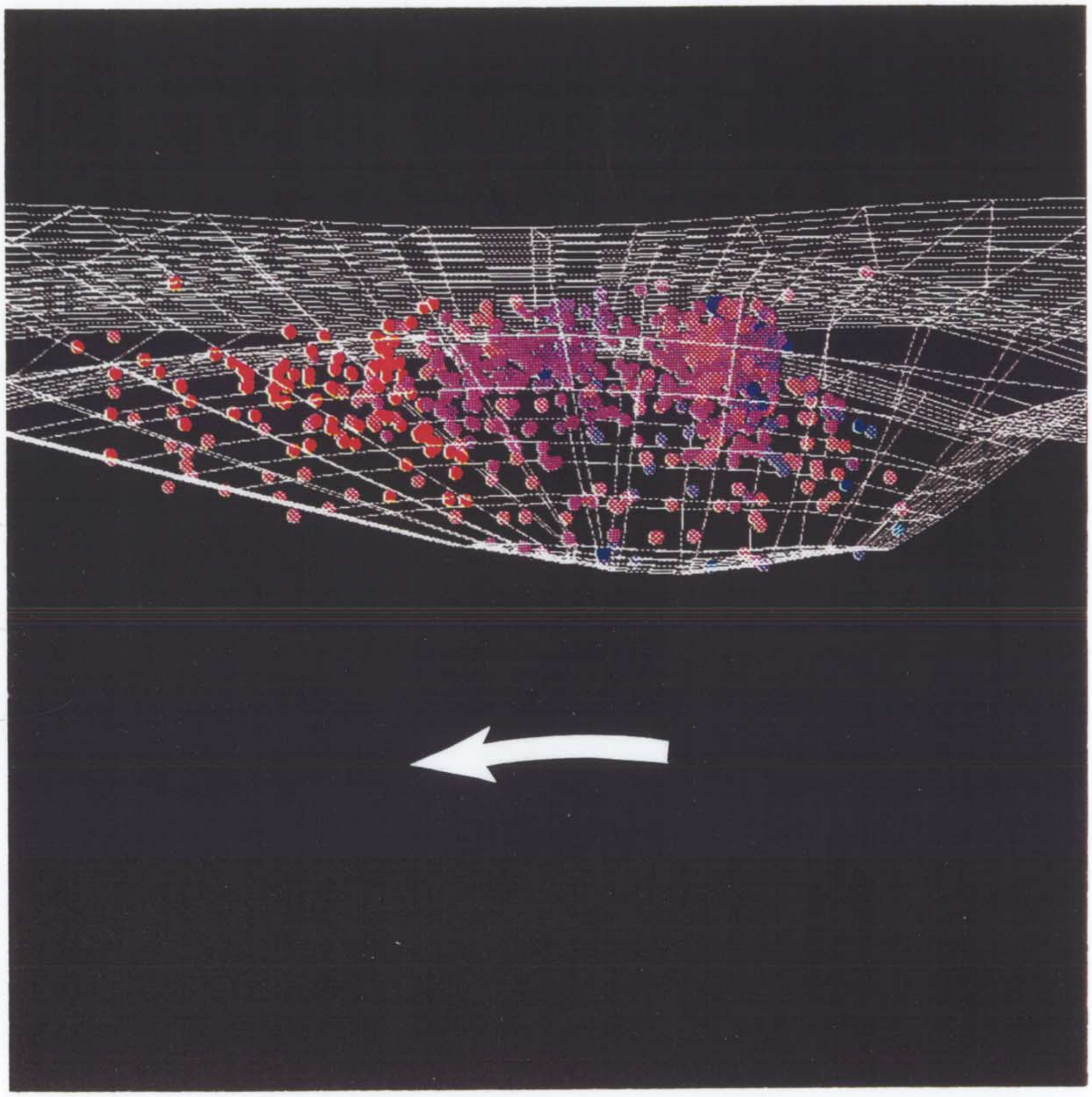
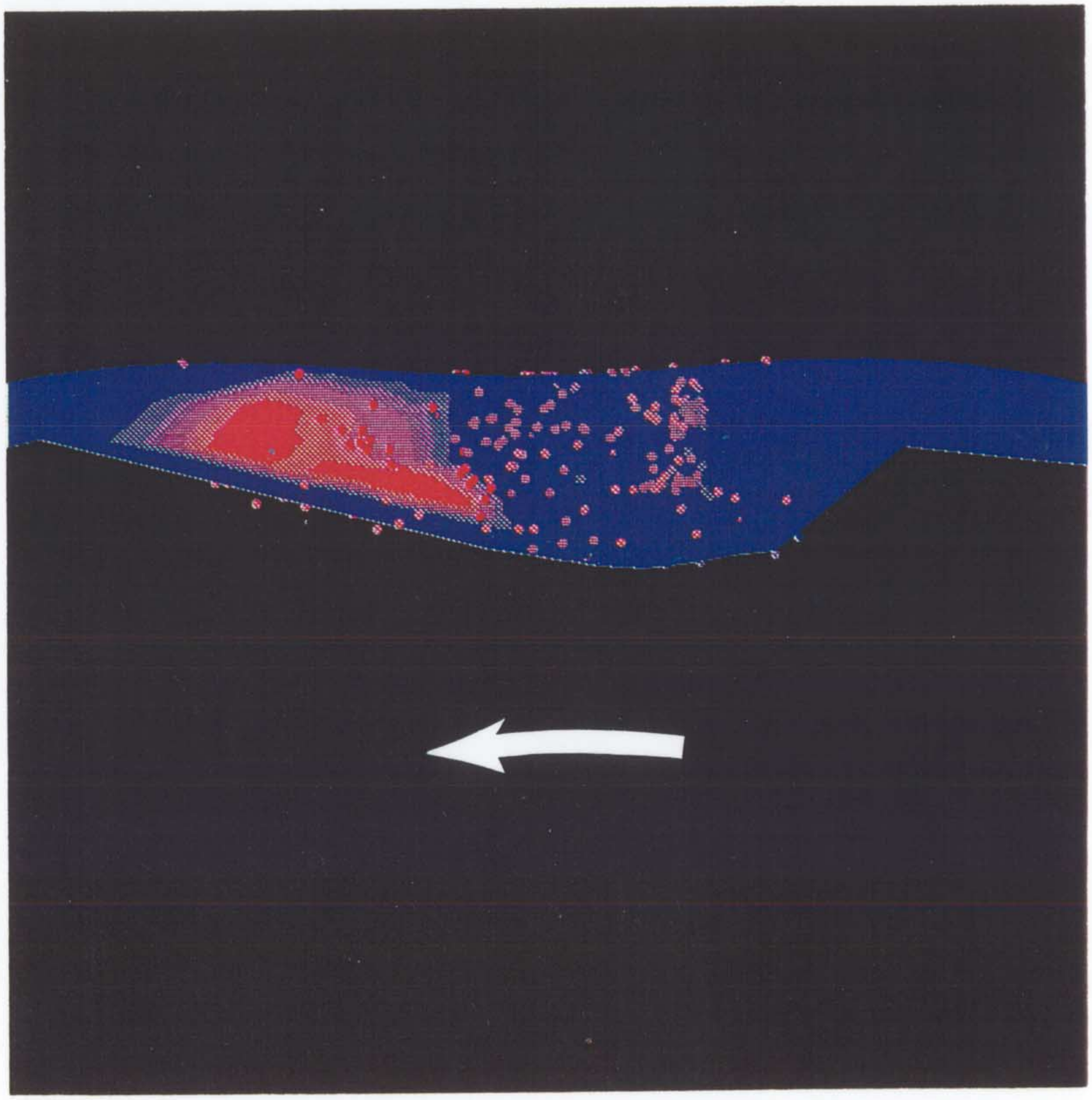


FIG. 4.1.2-4



CFD MODEL: MAGNIFIED PERSPECTIVE VIEW OF GRID
IN ROTOR POCKET REGION.
LIQUID DROPS ARE ALSO INDICATED

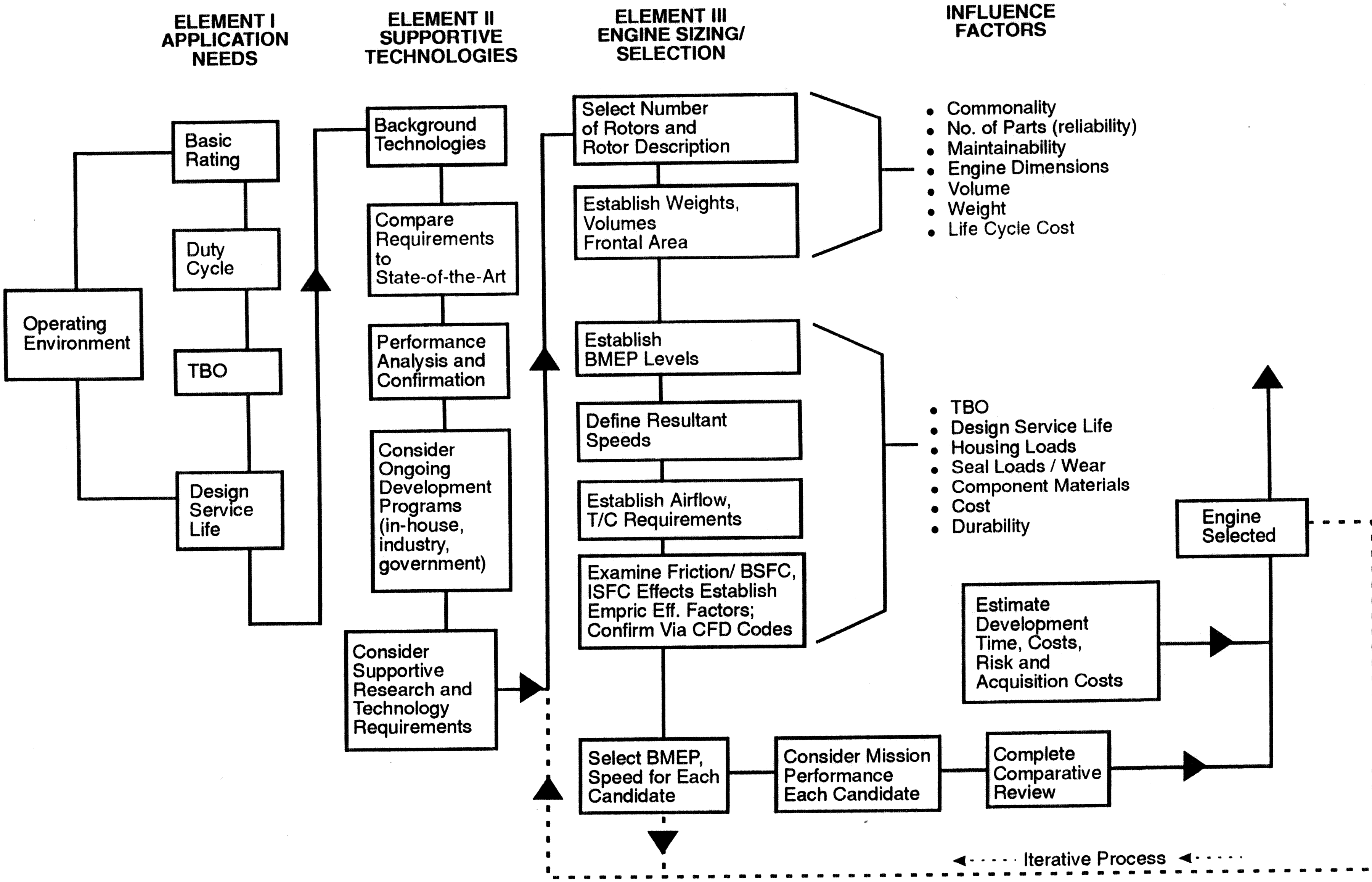
FIG. 4.1.2-4a



CFD MODEL: MAGNIFIED SECTIONAL VIEW
OF BURNED GAS AND LIQUID DROPLETS
IN POCKET REGION OF ROTOR
AND ALONG SYMMETRY PLANE OF ROTOR

FIG. 4.1.2-4b

Advanced Propulsion System Studies for General Aviation Aircraft
Engine Selection Criteria and Methodology



REM

FIG. 4.1.2-5

4.1.3 Turbomachinery and Turbocompounding

The Stratified Charge Rotary Engine (SCRE) operates on the four-stroke Otto cycle and at compression ratios in the 7.5:1 to 9.5:1 range. The SCRE therefore responds to turbocharging in a manner very similar to spark ignition reciprocating aircraft engines. The engine can be flat rated from sea level to various altitudes with conventional turbochargers deriving from aircraft or automotive engine sources. Hence, with available technology turbochargers in the 4:1 pressure ratio range, take-off power for the SCRE can be maintained to 20,000 or 25,000 feet altitude. Typically, general aviation aircraft would require maintaining take-off power to 20,000 feet altitude and maximum cruise power (75% of take-off) to 25,000 feet altitude.

As previously stated, the SCRE can utilize conventional turbomachinery spinning off from automotive and truck sources as well as any advanced systems developing for reciprocating aircraft engines. Smaller size, higher efficiencies and lighter weight turbochargers without extensive compromises in cost are continually sought through our suppliers wherein we have used Garret, Mitsubishi, Schwitzer, Holset and others i.e., those from Thermo Mechanical Systems involving variable geometry and multiple stages particularly necessary in high altitude systems.

Figure 4.1.3-1 provides a comparison between the SCRE, flat rated at 400 HP take-off to 25,000 feet altitude vs. a typical turboprop. The lapse rate associated with the turbine engine requires oversizing at sea level (i.e., sizing for 700 + HP) in order to provide the 400 HP requirement at 25,000 feet.

For the 70 Series primary engine, the Model 2013R, a Garret Airesearch turbocharger of about 11 in. diameter and weighing 40 lbs. was chosen for meeting the rather extreme advanced conditions of 400 HP at Take-off, Figure 4.1.3-2. Figure 4.1.3-3 illustrates the predicted turbine performance of the turbocharger. This curve includes corrected gas flow and turbine efficiency. This curve is drawn for a single rotor engine and has been confirmed with the single rotor NASA engine. It is expected that similar performance would be obtained from a similar turbo sized for the two rotor engine wherein the gas flow would be double. The upper-most curve represents 8000 RPM of the engine, the center curve 6000 RPM and the lower 4000 RPM. The actual engine data compared was at less than 2:1 pressure ratio, thus not extending to the higher pressure ratios for which the curves are extrapolated. The data plotted is closely representative of a Garrett T04 "P" 1.14 A/R. The manufacturer's curve is not provided as a result of the turbo manufacturers considering their turbine performance characteristics very proprietary. We expect to be able to decrease the advanced turbocharger weight to the 28-32 lbs. level for the 70 Series family, Model 2013R primary engine at the near term 250 HP rating and 34-36 lbs. for the growth 340 HP rating. For the single rotor member of the 70 Series family, a smaller unit would be used and is estimated at 25 lbs. A reduction in diameter to 9 in. is anticipated. For the four rotor version of the 70 Series, Model 4026R, twin turbos of the configuration selected for the Model 2013R will be considered and traded-off against a single larger unit. These selections will involve extensive supplier coordination, design and experimental test and are beyond the scope of this study.

For the 170 Series primary engine, Model 2034R our baseline is an Airesearch turbocharger which weighs 66 lbs. with mounting brackets. The advanced design is reduced to 45 lbs. for the 3 year near term and reduced to 37 lbs. with aggressive weight reduction in the 5 years growth engine.

Turbocompounding warrants serious consideration with SCRE for the simple reason of high exhaust pulse energy with the instantaneous opening of the exhaust valve. Firstly, this reflects itself in high turbine efficiency possibilities for the conventional turbocharger systems. Or, this energy can be converted into mechanical energy at the crankshaft without serious compromise on the engine performance and durability. The negatives are mechanical complexity, weight and possibly size. We believe that a power recovery of 9% is possible through turbocompounding. Some analytical studies have indicated 17 to 22% recovery possible. However, we believe 9-10% is a conservative but sound estimate. To obtain that additional power at the same speed and brake mean effective pressure is very desirable. However, in addition to added mechanical complexity, a small weight increase and an increased number of parts (high temperature environment parts capability required), extensive laboratory and full scale engine development testing would be required to integrate turbocompounding. We believe the trade-offs to indicate non-applicability for turbocompounding in the 3 year and 5 year engine configurations.

ENGINE LAPSE RATE

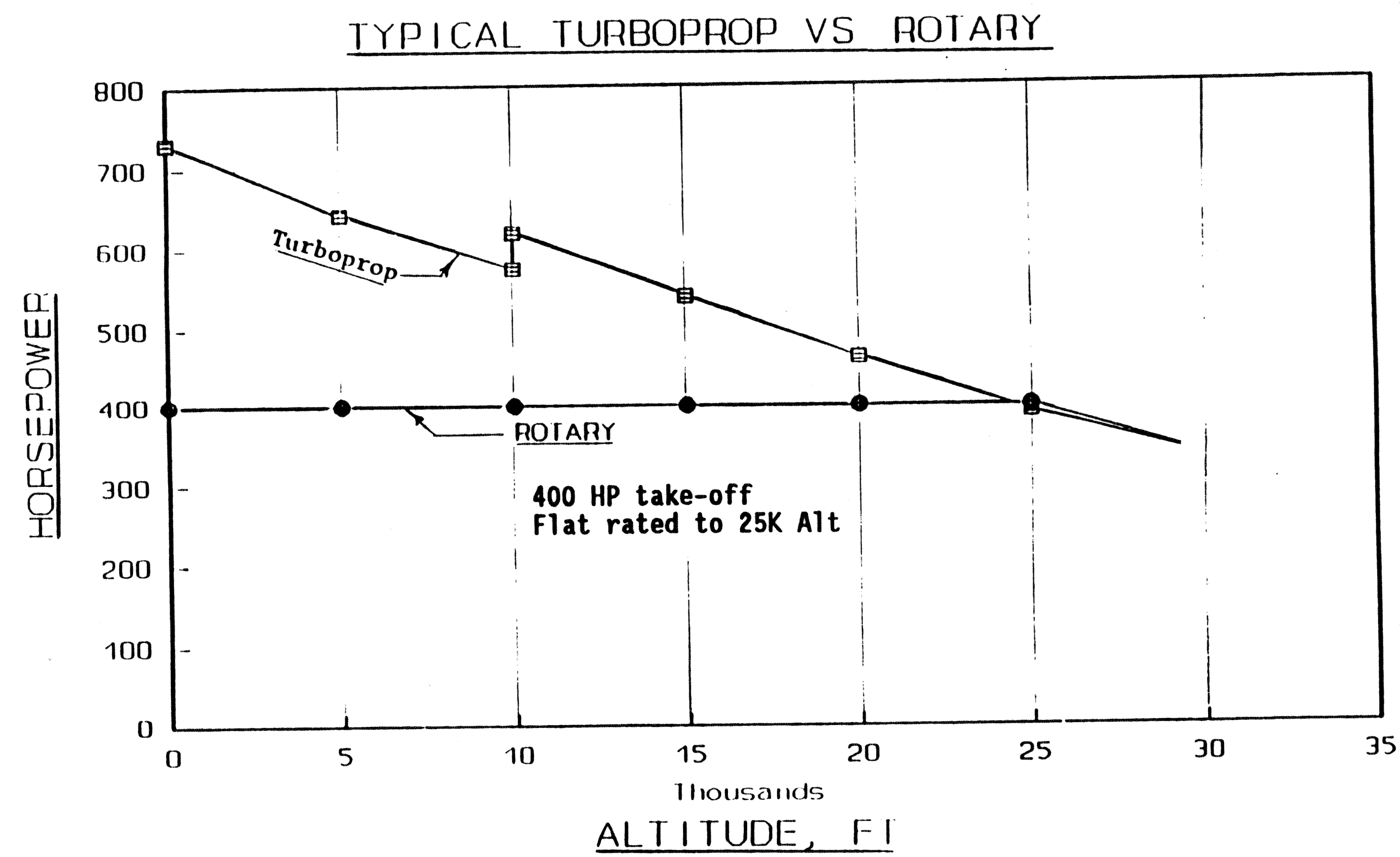


FIG. 4.1.3-1

2013R NASA REFERENCE ENGINE

TURBOCHARGER/INTERCOOLER INSTALLATION

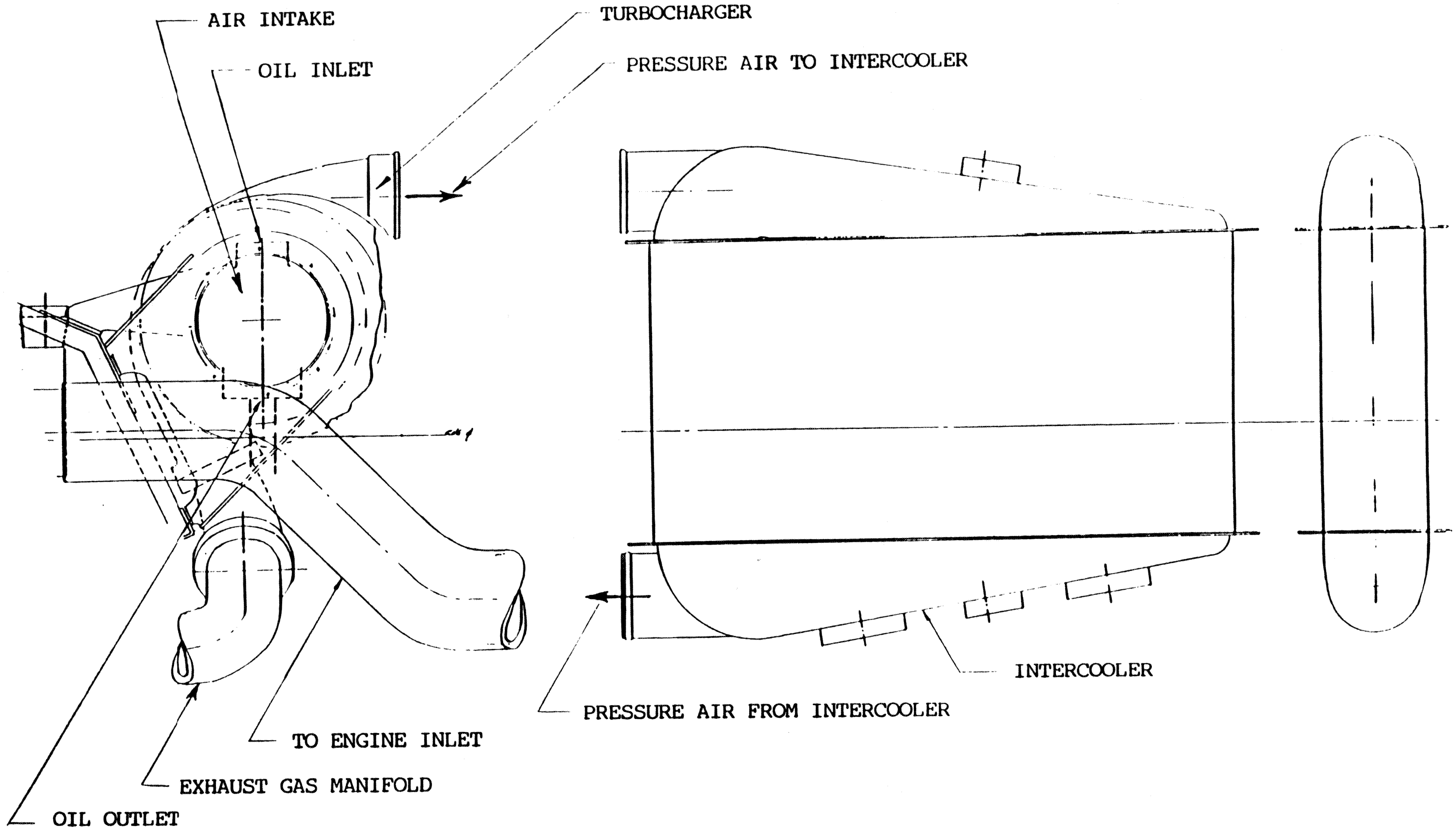


FIG. 4.1.3-2

4.1.4 Accessories

The accessories complement considered in the family of Stratified Charge Rotary Engines (SCRE's) in this study are those related to basic engine operation and those related to aircraft system requirements. The aircraft system requirements were based on current and prior coordination with existing major airframers (Cessna, Beech, Piper) and a current major reciprocating aircraft engine manufacturer (Textron-Lycoming).

Figure 4.1.4 tabulates the overall accessories complement and segrates them into those mounted on the engine (in the categories of engine-required to run accessories and aircraft system related accessories) and those mounted on the airplane.

ACCESSORY PROVISIONS

- o MOUNTED ON ENGINE
  - o ENGINE-REQUIRED TO RUN ACCESSORIES

    FUEL INJECTOR PUMP AND FILTER
    OIL PUMP FILTER AND STRAINER
    OIL SCAVENGE PUMP
    OIL INJECTION PUMP
    COOLANT PUMP
    IGNITION SYSTEM
    STARTER
    TURBOCHARGER

  - o AIRCRAFT SYSTEM RELATED ACCESSORIES

    ALTERNATOR - 100 amp-24 volt
    VACUUM PUMP
    HYDRAULIC PUMP
    FREON COMPRESSOR
    PROP GOVERNOR
    TACHMOMETER

- o MOUNTED ON AIRPLANE

    COOLANT COOLER
    LUBE COOLER
    CHARGE AIR COOLER
    BATTERY
    OIL TANK (IF DRY SUMP ENGINE)

FIG. 4.1.4-1

4.1.5 OIL SUMP

The rotary engine can operate with an oil sump integral with the engine, i.e. cast-in or bolted on at the lower part of the engine or with a dry sump, scavenge pumps and a remotely located oil tank. In either case the oil reservoir must be adequate to hold the quantity of oil required to a) perform the anticipated missions and b) have a specific reserve oil quantity in the sump or the tank at the end of the mission. Also, oil flow rates, total capacity and residence time in the tank for de-aeration purposes are factors in sizing the sump or tank. The dry sump configuration requires mounting of an oil tank in some location near the engine, such that scavenge and oil supply plumbing provisions are not excessively long. Some trade-off factors are as noted in Figure 4.5-1.

Figures 4.1.5-2 and 4,1.5-3 depict wet sump configurations considered for the 170 Series, Model 2034R primary engine used in this study. It can be noted in Figure 4.1.5-3 that while the height is influenced by the integral sump, the nacelle diameter is not significantly influenced.

OIL SUMP

TRADE-OFF CONSIDERATIONS
WET VS. DRY

	WET	DRY
o ENGINE HEIGHT	-	2"-6" LESS
o ENGINE WEIGHT	-	5-10 LBS LOWER
o SYSTEM WEIGHT	-	SAME WHEN TANK, PUMPS AND PLUMBING ADDED
o OIL SCAVENGING	-	REQUIRES SCAVENGE PUMPS
o OIL SUPPLY	INTEGRAL W/ENGINE	REQUIRES REMOTE TANK
o OVERALL PACKAGING	- TBD - (AIRCRAFT DEPENDENT)	
o PLUMBING PROVISIONS	LESS	REQUIRES PIPING TO REMOTE TANK
o PLUMBING JOINT LEAKAGE	LESS LIKELY	MORE JOINTS
o SAFETY	BEST	ACCEPTABLE
o RELIABILITY	BEST	ACCEPTABLE
o AIRFRAMER PREFERENCES	- TBD - (AIRCRAFT DEPENDENT)	
o NACELLE SIZE/SHAPE	-	BEST

FIG. 4.1.5-1

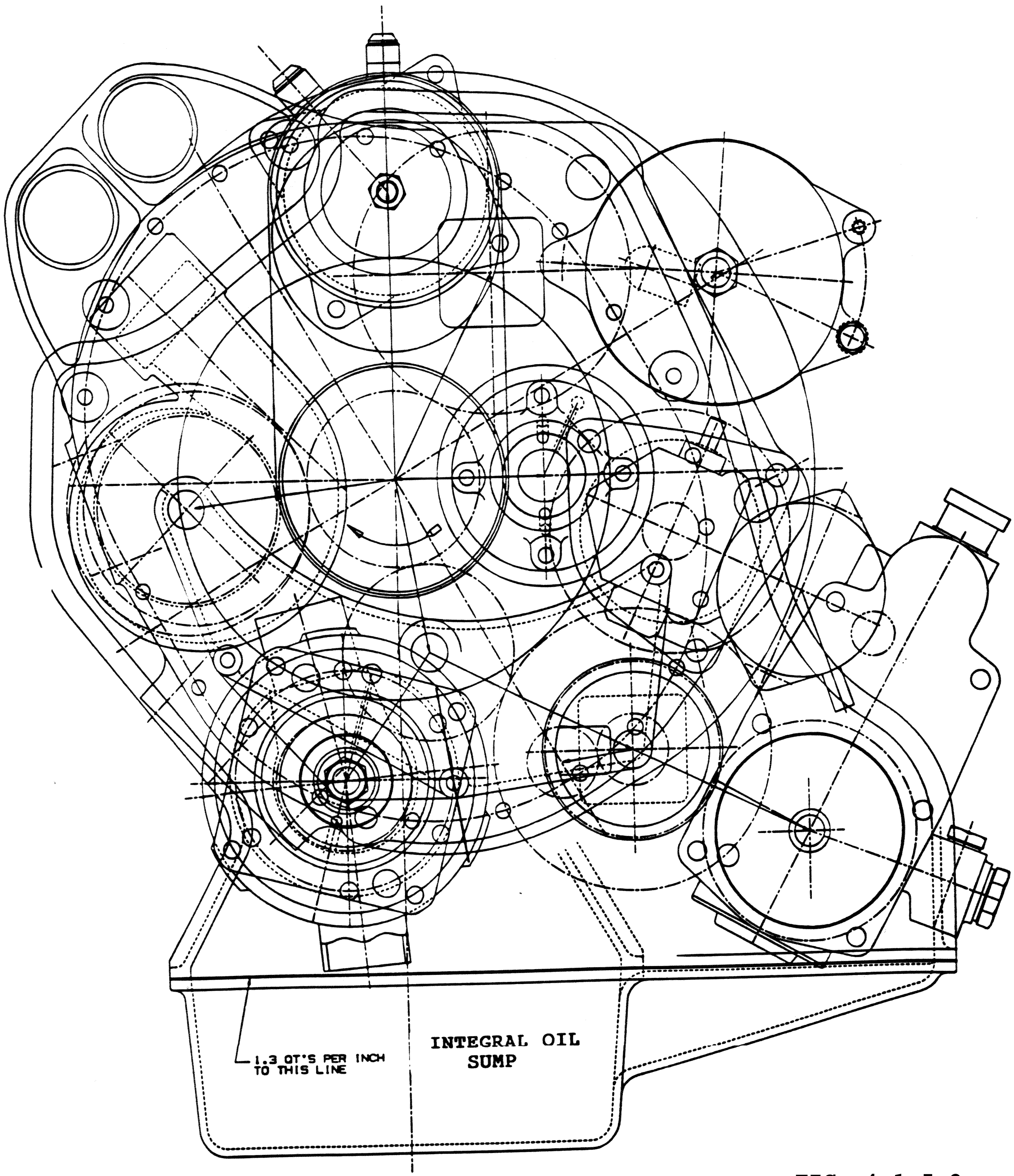


FIG. 4.1.5-2

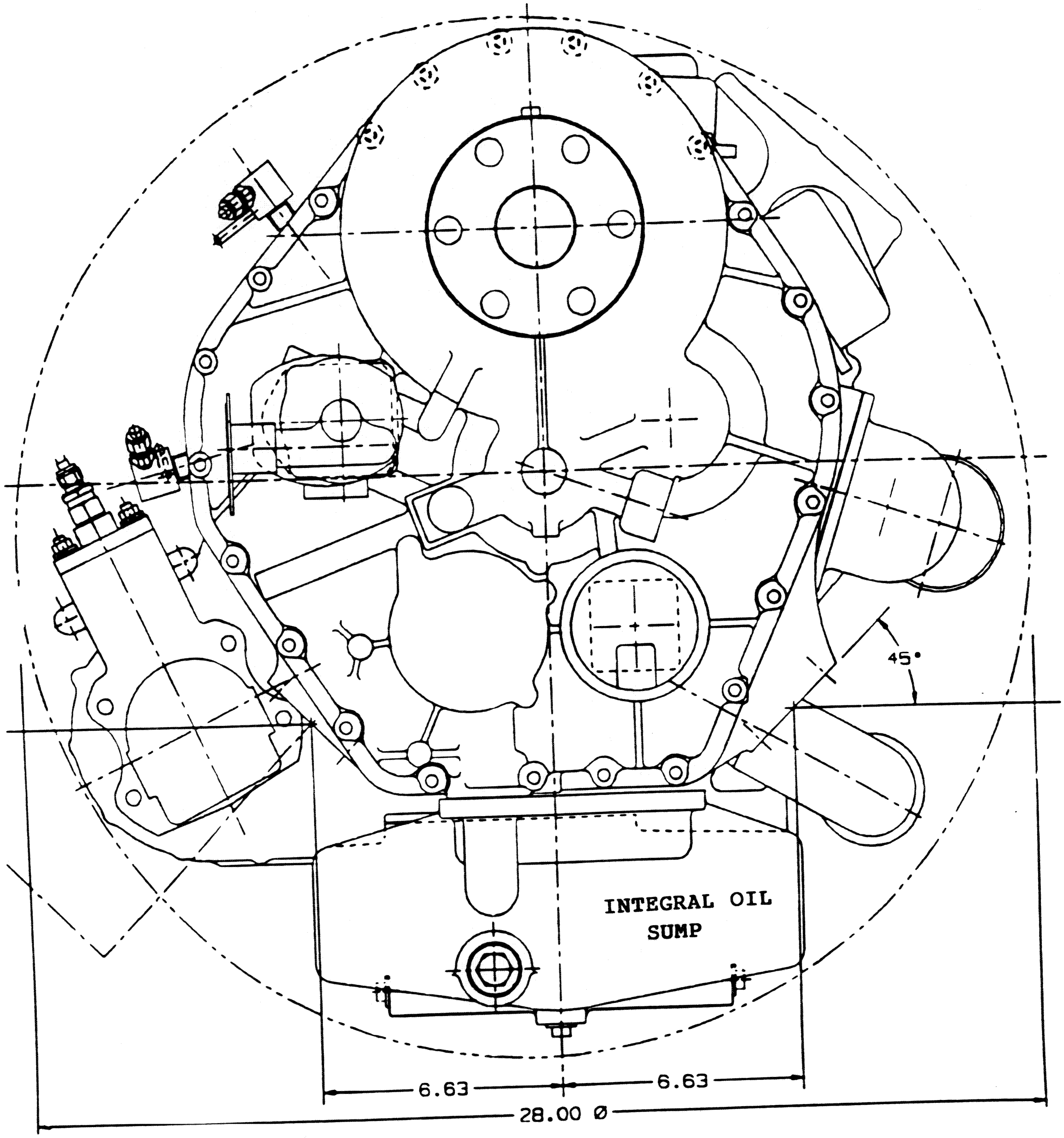


FIG. 4.1.5-3

4.1.6 Weight

Weights were estimated for each of the Stratified Charge Rotary Engine (SCRE's) in the family of engines defined in the advanced propulsion systems study. The primary engines in the two displacement sizes (40 cu.In., Model 2013R and 105 cu.in., Model 2034R) were used as the base weights with additions or subtractions appropriate to the other engines for variation in rotor quantities. The primary engines have been built in prototype form in part and represent a source of component and assembly actual weight data. The weights estimated are on a dry engine basis and "wet-ready to fly" basis, where liquids and heat exchanger weights are included. The weights are summarized in Figure 4.1.6-1.

The 2013R weights derive from several sources including a detailed definition of a 400 HP/8000 RPM aircraft engine package in NASA Contract NAS3-25945, "2013R NASA Reference Engine." The weight total in that case was 480 lbs. as shown in Figure 4.1.6-2. However, while this was based on 70% weighed, 30% calculated weights, it was a conservative estimate and did not consider weight reduction normally an integral part of an aircraft engine development program. However, the analyst in this case stated that with weight reduction a level of 400 lbs. could be achieved for this particular engine and complement of accessories and equipment. Figures 4.1.6-3a and 4.1.6-3b looked at a similar configuration of the Model 2013R except for reduced power (250 HP/7000 RPM) and reorganization of the accessories complement to permit more direct comparison with reciprocating aircraft engines. With a 10% weight reduction, a target weight of 365 lbs. is projected.

Figures 4.1.6-4 provides a tabulation for the 170 Series, Model 2034R engine deriving from the earlier Avco/Deere joint program. The target dry weight is 538 lbs. This will require an aggressive weight reduction program as reflected in Figure 4.1.6-5 which shows actual weights in the first (heavy) prototype were substantially higher. This figure also outlines some major weight reduction requirements even to achieve a 555 lbs. dry weight. However, we believe that during the course of the full scale development and certification program outlined herein, which includes a complete upfront engine design and early-on formal mass properties control program, we will be able to achieve the original 538 lbs. dry target weight without serious compromise in performance, cost or reliability.

FAMILY OF ADVANCED TECHNOLOGY
STRATIFIED CHARGE ROTARY AIRCRAFT ENGINES

ESTIMATED WEIGHTS

	NEAR TERM 3 YRS.		GROWTH 5 YRS.	
70 SERIES	DRY	WET READY TO FLY	DRY	WET READY TO FLY
MODEL 1007R	325	385	340	400
MODEL 2013R PRIMARY ENGINE	365	430	380	445
MODEL 4026R	440	560	470	570
170 SERIES				
MODEL 2034R PRIMARY ENGINE	538	628	560	680
MODEL 4068R	1015	1195	1060	1250

Fig. 4.1.6-1

2013R NASA REFERENCE ENGINE

ENGINE WEIGHT BREAKDOWN

		ENGINE WGT. (LBS)
1.	THE REDUCTION GEAR ASSEMBLY	
	(a) REDUCTION GEAR HSG & NOSE CONE	30.0
	(b) PROPELLER SHAFT ASS'Y	19.0
	(c) TORSIONAL COUPLING	17.0
	(d) PLANETARY REDUCTION GEARING & SUPPORT	36.0
	(e) VACUUM & GOVERNOR PUMPS	8.0
	(f) SUB TOTAL	110.0
2.	POWER SECTION	
	(a) ROTORS	19.0
	(b) ROTOR HSGS	28.0
	(c) INTERMEDIATE HSG	19.0
	(d) PROP END HSG	20.0
	(e) ANTI PROP END HSG	26.0
	(f) ACC. HSG, GEARS, COVERS, ETC.	44.0
	(g) COUNTERWEIGHTS	18.0
	(h) TIE BOLTS (22)	5.0
	(i) CRANKSHAFT	17.0
	(j) EXHAUST SYSTEM	12.0
	(k) INTAKE MANIFOLD & MISC. HARDWARE	7.0
	(l) SUB TOTAL	215.0
3.	ACCESSORIES	
	(a) TURBOCHARGER SUPPORT	8.0
	(b) IGNITION SYSTEM	7.0
	(c) FUEL PUMP	29.0
	(d) FUEL NOZZLE	3.0
	(e) NOZZLE CLAMPS, LINES, ETC.	4.0
	(f) TURBOCHARGER (ESTIMATE)	40.0
	(g) WATER PUMP	8.0
	(h) STARTER	13.0
	(i) ALTERNATOR	19.0
	(j) OIL PUMP	13.0
	(k) OIL METER. PUMP ASS'Y	2.0
	(l) HYD PUMP	2.0
	(m) A/C HYD PUMP	4.0
	(n) OIL FILTER	3.0
	(o) SUB TOTAL	155.0
4.	GRAND TOTAL	480.0

FIG. 4.1.6-2

2013R ENGINE WEIGHT ESTIMATE

250 HP / 7,000 RPM

Note: All weights listed from 2013 R NASA reference engine design, 400 HP, weighed 70%, calculated 30% before Weight Control/ Reduction Program.

A. POWER SECTION

Rotors	19
Rotor Housings	28
Int. Housing	19
Prop End Housing	20
Main prop end housing	26
Accessory housing, gears, cover	44
Counterweights/damper*	18
Tie bolts	5
Crankshaft	17
SUB-TOTAL	**196**

B. REQUIRED TO RUN ACCESSORIES

Turbo	40
Turbo Support	8
Ignition System	7
Fuel Pump	29
Fuel Nozzles	3
Nozzle clamps, lines, etc.	4
Coolant Pump	8
Starter	11
Oil Pump	13
Oil Metering Pump	2
Oil Filter	3
SUB-TOTAL	**128**

Fig. 4.1.6-3a

C. REDUCTION GEAR SECTION		
Reduction Gear	35*	
Prop Shaft	17	
SUB-TOTAL	**52**	
D. MISCELLANEOUS OTHER		
Exhaust System	6	
Intake Manifold/Misc. Hardware	4	
Intercooler	15	
SUB-TOTAL	**29**	
TOTAL A-D		
	196	
	128	
	52	
	29	
	405	
	-40	Weight reduction/400 to 250 HP weight red
Target Dry Weight	**365 lbs**	

* Includes Drives For Aircraft Accessories

Estimated Weight For Aircraft Accessories

Vacuum Pump	4	Accessories required (f) actual aircraft need
Governor Pump	4	
Alternator	19	
Hydraulic Pump	2	
A/C Hydraulic Pump	2	
	31	

Figure 4.1.6-3b

ITEM	RESP.	ORIG. EST. WEIGHT	PROGRAM GOAL WEIGHT	DELTA FROM ORIGINAL	CURRENT ESTIMATED WEIGHT	DELTA FROM ORIG.	DELTA FROM GOAL		WEIGHT REDUCTION PROJECTION: PROJECTED ESTIMATED WEIGHT	DELTA FROM ORIG.	DELTA FROM GOAL
Power section	ReDiv	280.3	252.3	-28.0	290.20	9.9	37.93		290.20	9.9	37.93
F.I. Pump & Inj.	ReDiv	41.1	37.0	-4.1	29.10	-12	-7.89		29.10	-12	-7.89
Oil Pump	AVCO	1.5	1.4	-0.1	2.77	1.27	1.42		2.77	1.27	1.42
Coolant Pump	ReDiv	5	4.5	-0.5	5.00	0	0.5		5.00	0	0.5
Acc'y Housing	AVCO	8	7.2	-0.8	12.00	4	4.8		8.00	0	0.8
Fuel Pump Drive	AVCO	9	8.1	-0.9	8.60	-0.4	0.5		8.60	-0.4	0.5
Oil Metering Valve	ReDiv	1.35	1.2	-0.1	1.50	0.15	0.285		1.50	0.15	0.285
Torsional Isolator	AVCO	5	4.5	-0.5	10.50	5.5	6.		8.00	3	3.5
Reduction Gear	AVCO	58	27.0	-31.0	58.00	0	31		40.00	-18	13
Sump	AVCO	6	5.4	-0.6	8.00	2	2.6		8.00	2	2.6
Alternator	AVCO	13	11.7	-1.3	13.00	0	1.3		0.00	-13	-11.7
Tach Drive	AVCO	0.5	0.5	-0.1	0.50	0	0.05		0.20	-0.3	-0.25
								GEAR LIGHTER	-1.50		
Oil Filter	AVCO	1.6	1.4	-0.2	1.60	0	0.16		1.60	0	0.16
Vac. Pump Drive	AVCO	2	1.8	-0.2	1.00	-1	-0.8		1.00	-1	-0.8
Hyd. Pump Drive	AVCO	1	0.9	-0.1	1.00	0	0.1		1.00	0	0.1
Prop. Gov. Drive	AVCO	2	1.8	-0.2	2.10	0.1	0.3		2.10	0.1	0.3
Starter	AVCO	18	16.2	-1.8	17.00	-1	0.8		17.00	-1	0.8
Starter Drive	AVCO	6.5	5.9	-0.6	5.50	-1	-0.35		5.50	-1	-0.35
Spark Plugs (4)	ReDiv	0	0.0	0.0	1.00	1	1		1.00	1	1
Ignition Coils (4)	ReDiv	0	0.0	0.0	0.00	0	0		0.00	0	0
Ignition System	ReDiv	1.5	1.4	-0.1	3.00	1.5	1.65		3.00	1.5	1.65
Turbocharger	ReDiv	48	43.2	-4.8	55.00	7	11.8		40.00	-8	-3.2
Brackets, Lines, EXHAUST, ETC.	AVCO	25	22.5	-2.5	25.00	0	2.5		25.00	0	2.5
W/G, Controllers	AVCO	15	0	-15.0	15.00	0	15		15.00	0	15
Intercooler	ReDiv	20	18.0	-2.0	25.50	5.5	7.5		25.50	5.5	7.5
Coolant		0	20.0	0.0	0.00	0	0		0.00	0	0
Oil		0	12.0	0.0	0.00	0	0		0.00	0	0
				-95.6		22.52	118.155			-30.28	65.353
		569.35 (DRY)	506 (WET) 506 (WET)		591.87 (DRY)				537.57 (DRY)		27.58 37.775

FIG. 4.1.6-4

WEIGHT ANALYSIS OF 2034 AIRCRAFT ENGINE

COMPONENT	JULY 1993 ACTUAL WEIGHT		RPI DESIGN PROPOSED ESTIMATES OF 21JULY93		POTENTIAL WITH AGGRESSIVE WEIGHT REDUCTION	
REDUCTION GEAR ASSEMBLY						
Front Reduction Gear Hsg.	78.0		16.7	Magnesium	16.7	Magnesium
Reduction Gearing			39.9	No Change	36.0	Lighter Gears
Prop. Shaft Assy.			14.3	No Change	12.0	Shorter on planetary
Rear Reduction Gear Hsg.	21.6		15.1	Magnesium	15.1	Magnesium
Subtotal	99.6		86.0		79.8	
POWER SECTION						
Rotors (2)	58.3	W/seals,springs, etc.	58.3		53	Wall Thickness/invest Cast
Rotor Housings (2)	77.6	W/dowels	77.6	No Change	70.3	Lightening holes, thinner ribs
Intermdeiate Hsg. Assy. (1)	42.0	W/brg.supp. assembly	36.7	Scallop O.D.	36.7	Scallop O.D.
Prop. End. Hsg. Assy. (1)	40.0		35.0	Scallop O.D.	35.0	Scallop O.D.
AntiProp End. Hsg. Assy. (1)	45.0		39.8	Scallop O.D.	39.8	Scallop O.D.
Accy. Hsg. (1)	30.0	W/gears,covers,bolts,et	23.4	Magnesium	23.4	Magnesium
Counterweights (2)	17.6		17.6	No Change	14	Lower Rotor Weight
Tie Rods (22)	8.1	W/ washers & nuts	8.1	No Change	8.1	No Change
Crankshaft (1)	30.0		30.0	No Change	30.0	No Change
Exhaust System (1)	9.9	W/transition pipe	9.9	No Change	9.9	No Change
Intake Manifold (1)	6.8	W/cover & adapter	6.8	No Change	6.8	No Change
Coolant Inlet & Outlet Manifolds	3.0	Calculated (no parts)	3.0	No Change	3.0	No Change
Subtotal	368.4		346.2		330.0	
ACCESSORIES						
Ignition System	23.0	W/plugs,coils,control	23.0	No Change	12	New System
Fuel Pump	30.0	Nippondenso EP-9	30.0	No Change	25	AMBAC M-100 (est)
Fuel Nozzles (4)	2.5		2.5	No Change	4.0	Ganser
Nozzle clamps, lines, etc.	3.0		3.0	No Change	3.0	No Change
Turbocharger	66.3	AirResearch w/brackets	45.0	AirResearch	37.0	Ratio on power & flow from Cessna
Water Pump	12.7	ITT, W/inlet	12.7	No Change	8	Plastic
Starter	18.3		18.3	No Change	13.5	Mitsubishi-lower power
Alternator	17.3	Cannot be found	17.3	No Change	11.5	From Cessna Literature
Oil Pump	5.5		5.5	No Change	5.5	No Change
Oil Metering Pump	7.0	Nichols/Zenith	2.0	Mikuni	2.0	Mikuni
Turbo Support Assy.	8.4		8.4	No Change	6.0	Lighter turbo
Oil Sump Assy.	18.0		7.0	Dry Sump	5	Remote sump
Oil Filter & Base	4.0		4.0		4.0	No change
Thermostat Hsg. Assy.	5.0	W/adapter	3.0	Simplify	3.0	Simplify
By Pass Valve Assy.	2.0		2.0	No Change	2.0	No Change
Controller	3.5		3.5	No Change	3.5	No Change
Subtotal	226.4		187.2		145.0	
BASIC ENGINE SUBTOTAL	694.4		619.4		554.8	
COMPLETE ENGINE PACKAGE						
Charge Air Cooler	30		30		21	Stewart Warner A/A actual weight
Charge Air Hoses & Hardware	90	R.Mount estimate	90	R.Mount estimate	7	Includes headers
Oil Cooler					12	Ratio on power & HR from Cessna
Oil cooler bypass, lines, etc.					3	Estimate
Oil					36	24 Quarts
Engine Coolant Cooler					20	Ratio from oil cooler
Engine Coolant Hoses & Hdw.					4	Estimate
Engine Coolant					24	12 Quarts
Subtotal	120		120		127	
TOTAL PACKAGE - WET	814.4		739.4		681.8	

FIG. 4.1.6-5

4.1.7 Drawings

Conceptual drawings for the primary two-rotor configurations were generated, as necessary, to define the overall propulsion system in terms of external, overall configuration. The starting point for this basic sizing and configuration definition procedure is to define the engine's basic geometry factors.

Figure 4.1.7-1 presents a summary of the basic geometry factors for the 40 cubic inch/70 Series and 105 cubic inch/170 Series engines. These factors permit layout of the crankshaft eccentric, rotor housing width, rotor housing major and minor axes. Around these basic dimensions and geometric proportions, the core single rotor power section can be derived. With spacing between the single rotor power sections for crankshaft main bearings, coolant passages and side plates for combustion section closure, multi-rotor configurations are established. After the core power unit is defined, the external configuration and overall propulsion system package can be defined through providing for accessories (mounting, locating, drive provisions), reduction gearing, plumbing, controls, etc.

Figure 4.1.7-2 provides conceptual cross-sectional definition of the Model 2013R, 40 cubic inch, 70 Series, two rotor primary engine in a propeller shaft, reduction gear version. The reduction gear in this case is of epicyclic design maintaining the propeller shaft and crankshaft on the same centerline. Other reduction gear approaches are possible as discussed in Section 4.1.8.1 of this study. Figure 4.1.7-3 presents a variation in the two rotor, 40 cubic inch, 70 Series primary engine in direct drive version and with some variations in the accessory drive and mounting provisions. This scheme might be considered for helicopter or rotary wing application where direct driving at crankshaft speeds into the helicopter gearbox is possible.

In either of the two rotor engine configurations shown in 4.1.7-2 and 4.1.7-3, the addition or subtraction of unit power sections (rotor housing plus intermediate housing as denoted by "RH + IH" in Figure 4.1.7-3) can be effected to create engines of 1, 2 and 4 rotor construction as considered in the family.

Figures 4.1.7-4 through 4.1.7-8 provide conceptual external, overall definition for the twin rotor, 70 Series, Model 2013R primary engine with some definition of components. The figures noted present the left side view, right side view, prop end view, accessory end view and an accessory end view (with component identifications), respectively.

Figure 4.1.7-8a represents a variation in the 2013R engine configuration for a side mounted turbocharger discussed with NASA LeRC for the "X" airplane. The engine width increases to 30 in. with the engine height remaining at 22 in. This arrangement is probably more suited for single engine aircraft than the elongated, aft mounted turbocharger version fitting within a 26 in. diameter (as shown in the preceding illustrations).

Figures 4.1.7-9 and 4.1.7-10 present conceptual cross-sectional drawings for the twin rotor, 170 Series, Model 2034R (primary engine) and for the four rotor, 170 Series, family member, the Model 4068R. These represent the basic or core engine adaptable to either direct drive or reduction gear configuration.

Figure 4.1.7-11 presents a conceptual layout of the full-up, offset helical, reduction gear version of the Model 2034R primary engine, left side view. Figures 4.1.7-12 and 4.1.7-13 present prop end and accessory end views respectively. Figure 4.1.7-14 shows a variation in reduction gear replacing the offset, external-external helical gear with an epicyclic or planetary reduction gear maintaining the propshaft centerline in the crankshaft centerline position.

Figures 4.1.7-15a and 4.1.7-15b present a conceptual engine installation arrangement for a rotary powered twin engine airplane. The engine used here is the Model 2013R, 70 Series primary engine with aft mounted turbocharger. Coolant radiator oil cooler and intercooler components are shown in position beneath the engine.

Geometric Factor	Engine: 40 Cubic Inch 70 Series	Engine: 105 Cubic Inch 170 Series
Displacement, D (in^3)	40.424	105.13
Eccentricity, e (in)	.607	.835
Generating Radius, R (in)	4.189	5.745
Oversize, a (in)	.032	.060
Width/eccentricity, w/e	5.0	5.0
Width, W (in)	3.036	4.175
R/e, K	6.900	6.880
R_h (in)	4.221	5.805
K^1	6.954	6.952
Major Axis (in)	9.656	13.280
Minor Axis (in)	7.228	9.940

Figure 4.1.7-1

MODEL 2013R PRIMARY ENGINE
CONCEPTUAL LONGITUDINAL CROSS SECTION

Planetary Reduction Gear Version

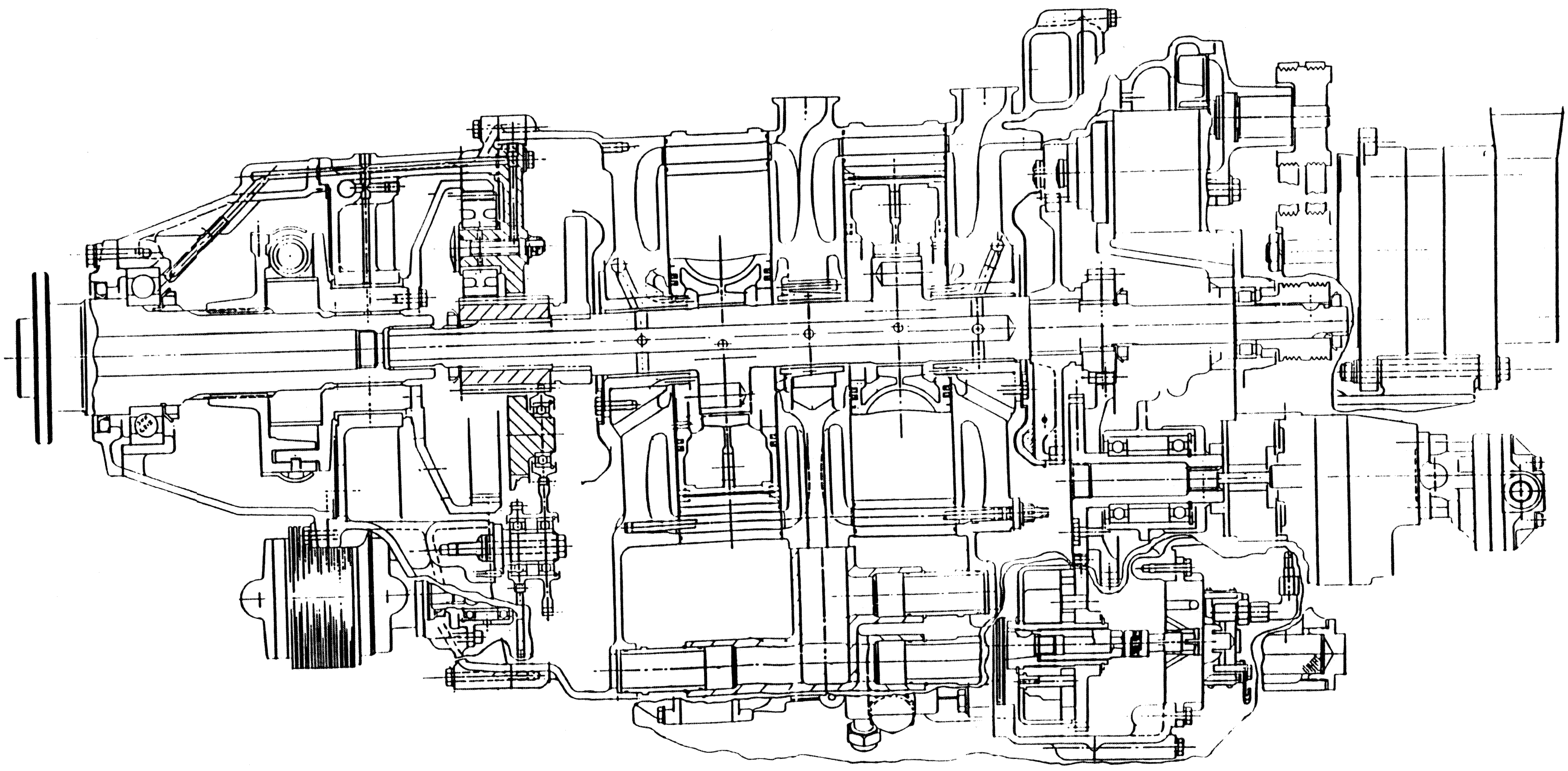


FIG. 4.1.7-2

MODEL 2013R PRIMARY ENGINE
CONCEPTUAL LONGITUDINAL CROSS SECTION

Direct Drive Version

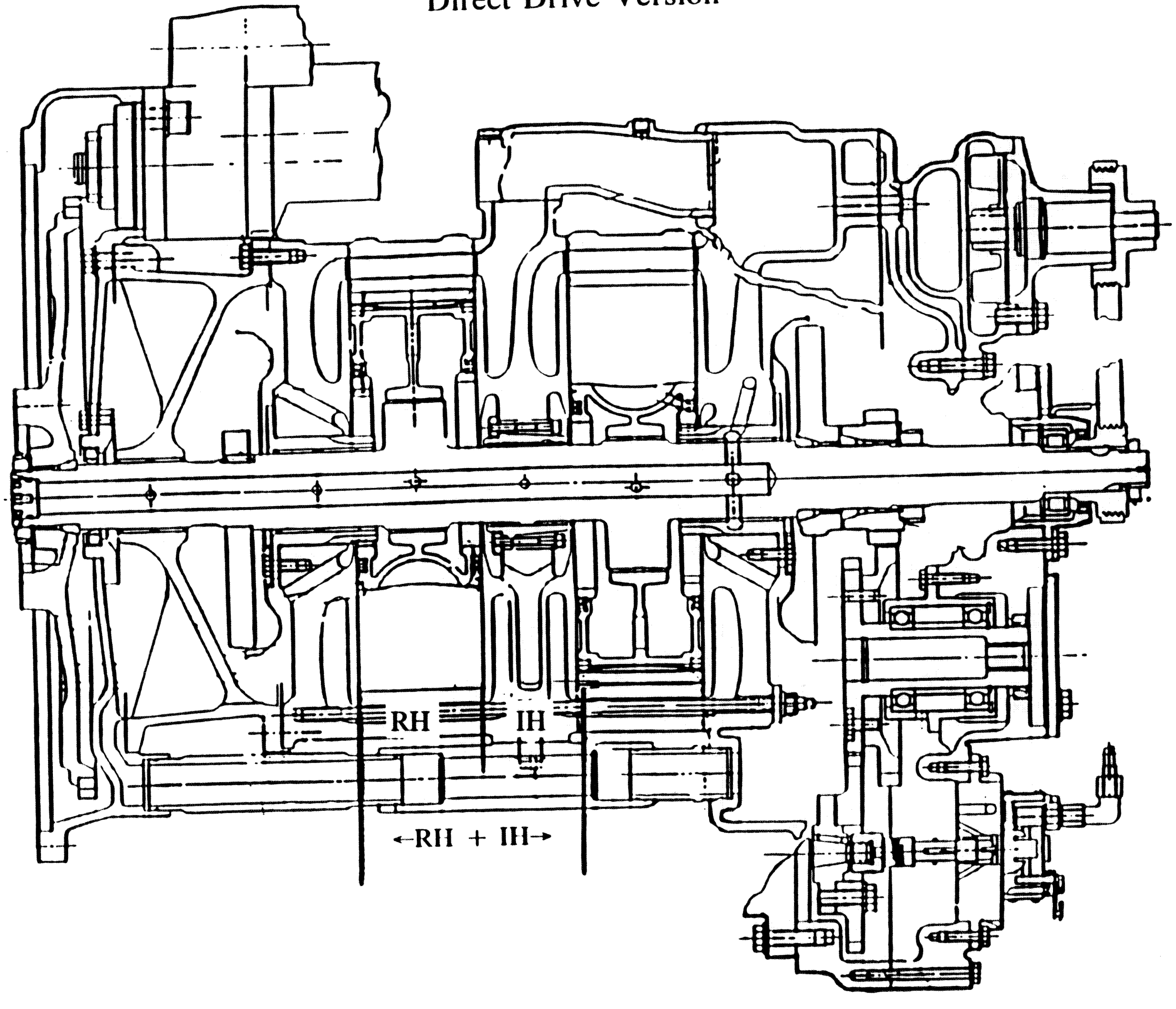
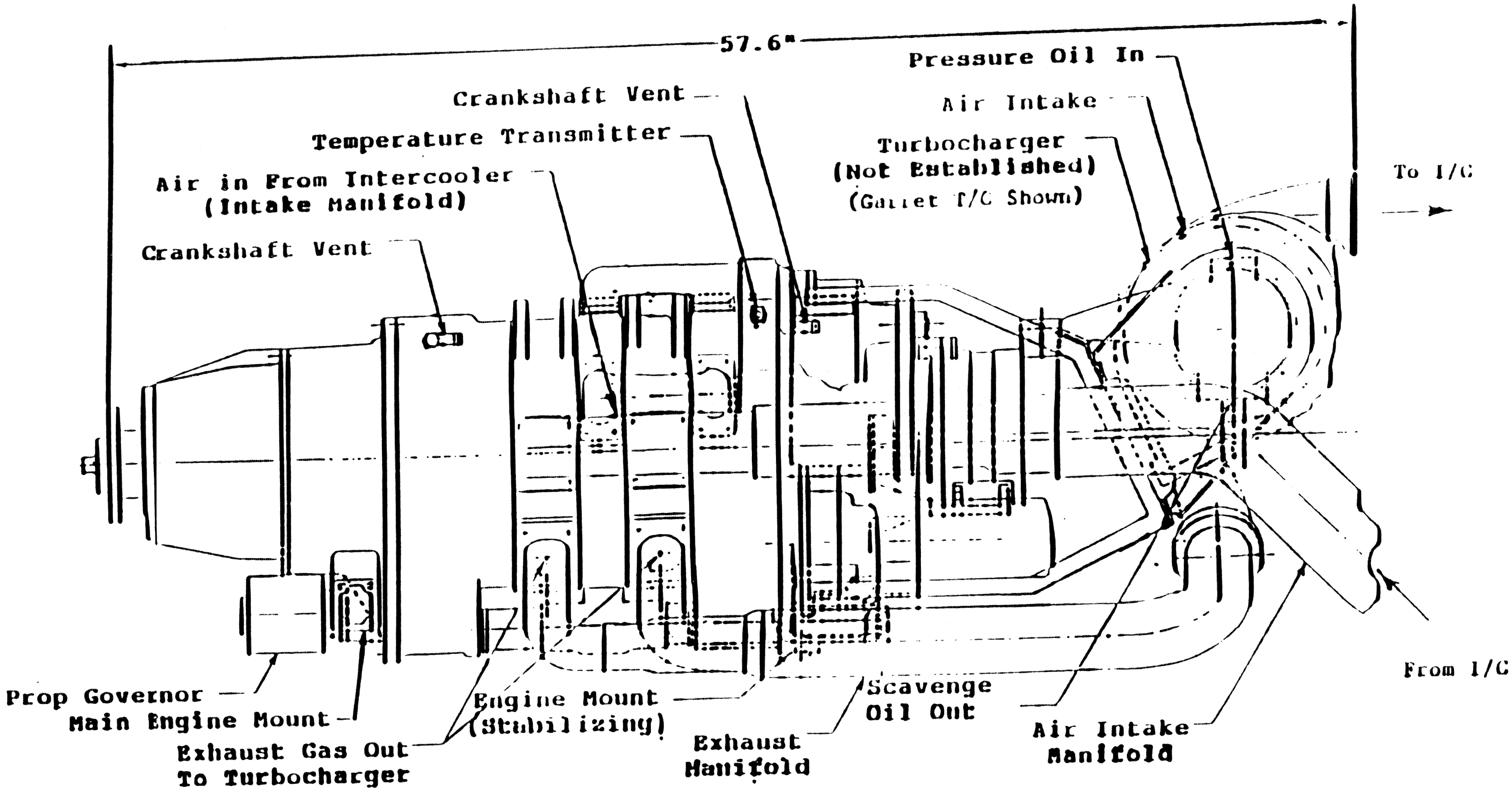


Figure 4.1.7-3

2013R NASA REFERENCE ENGINE

PRELIMINARY INSTALLATION DRAWING

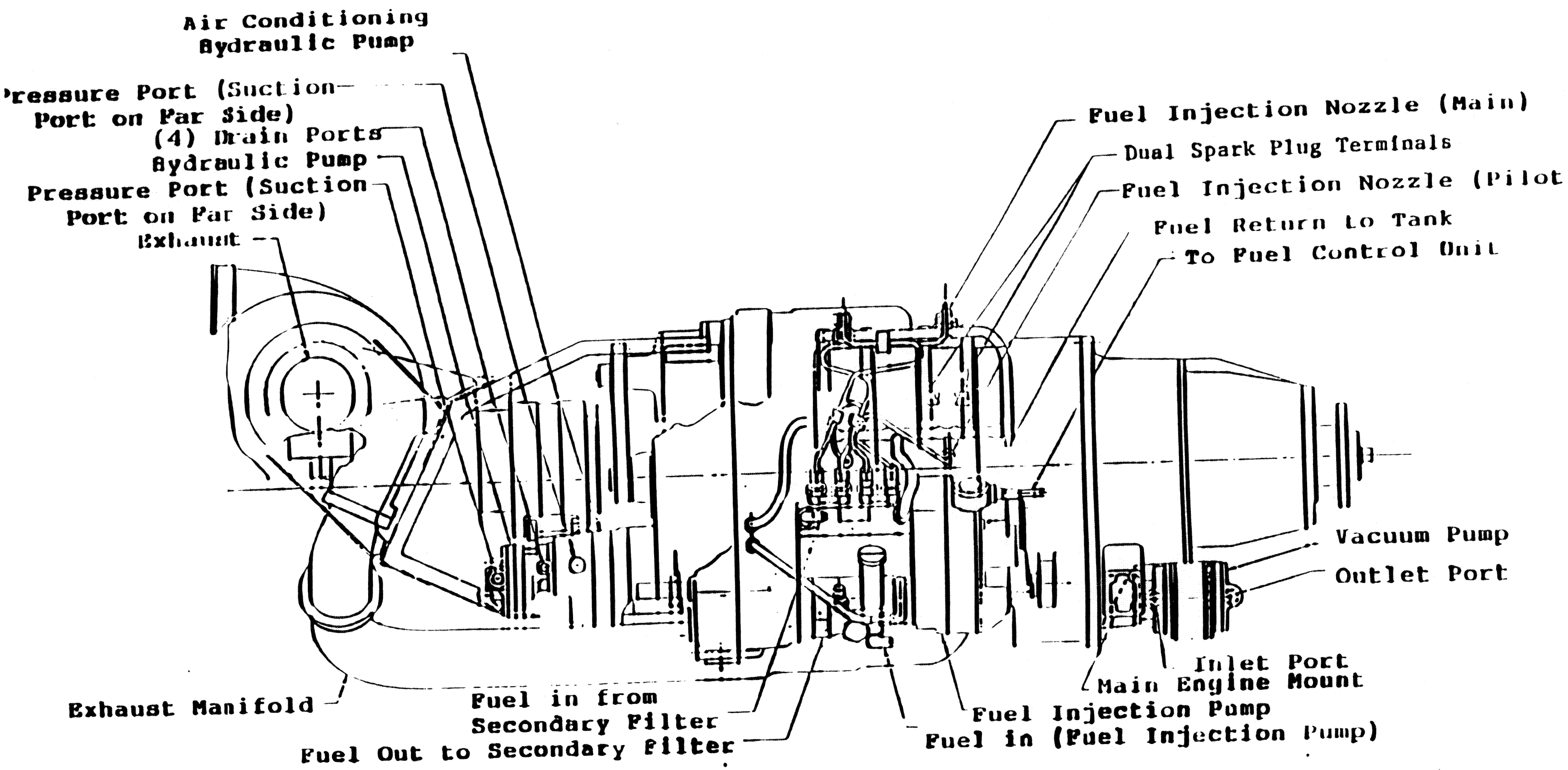


LEFT SIDE

Figure 4.1.7-4

2013R NASA REFERENCE ENGINE

PRELIMINARY INSTALLATION DRAWING



RIGHT SIDE

Figure 4.1.7-5

2013R NASA REFERENCE ENGINE

PROP END VIEW

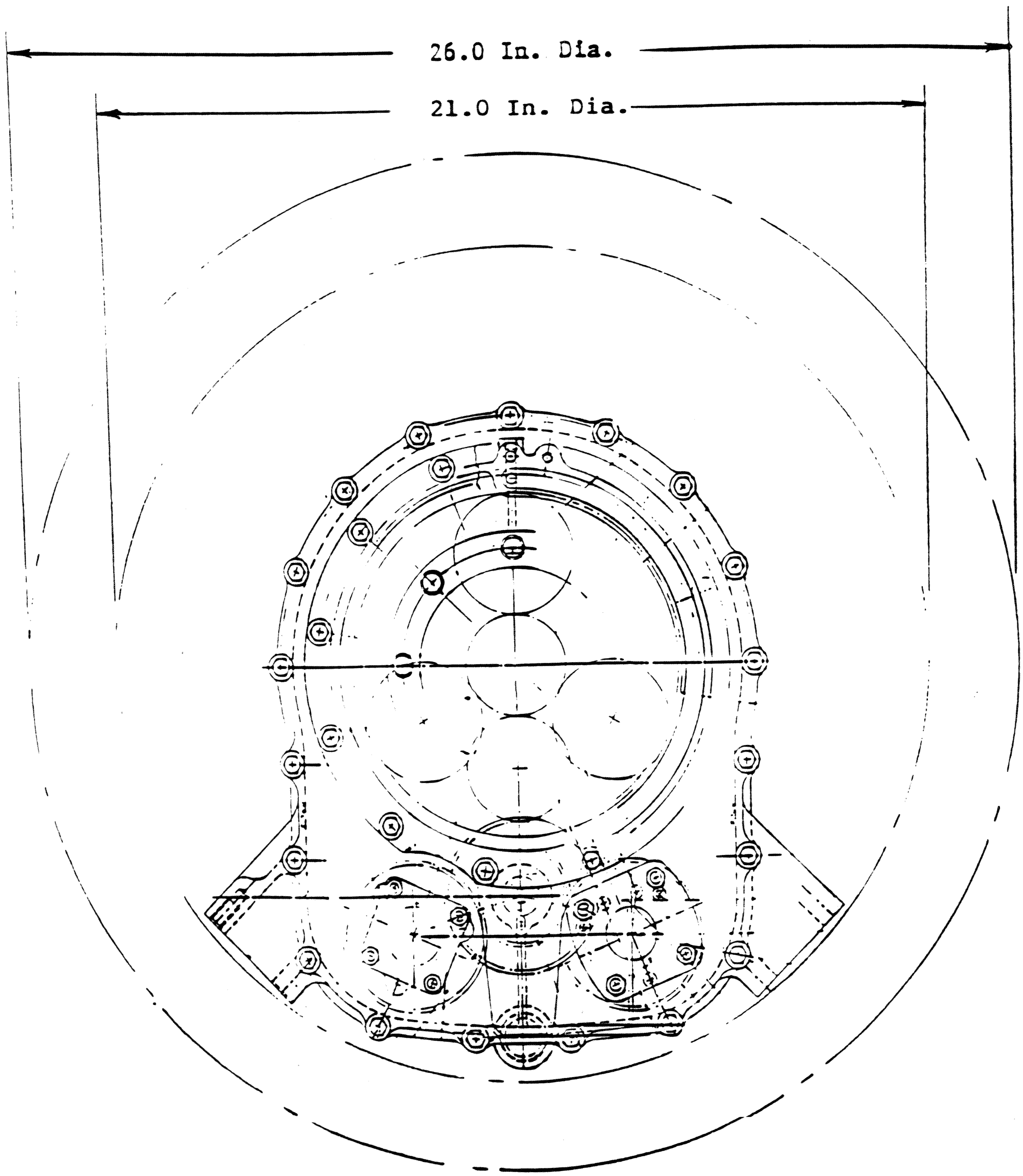


Figure 4.1.7-6

2013R NASA REFERENCE ENGINE

ACCESSORY END VIEW

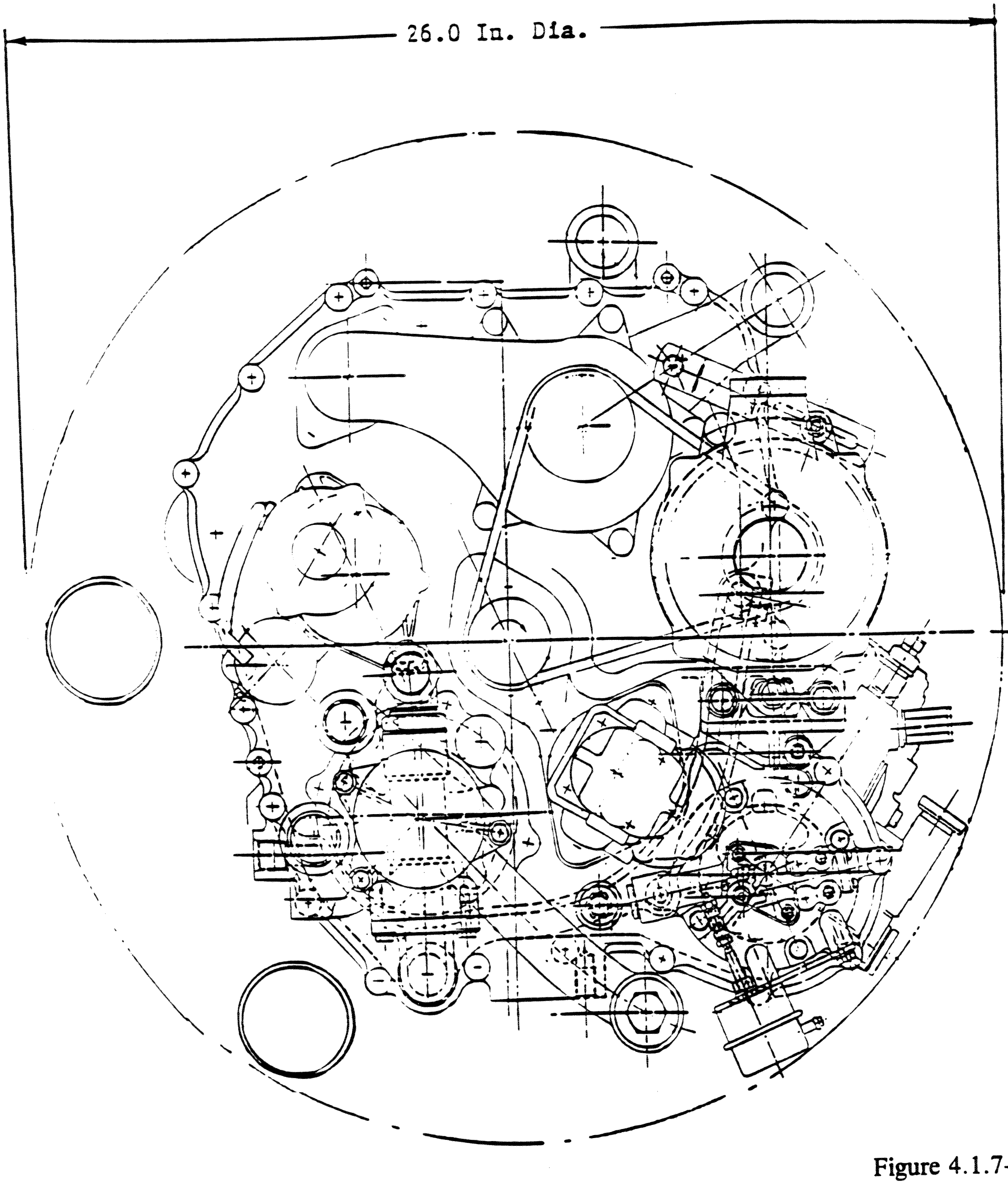


Figure 4.1.7-7

2013R NASA REFERENCE ENGINE

PRELIMINARY INSTALLATION DRAWING

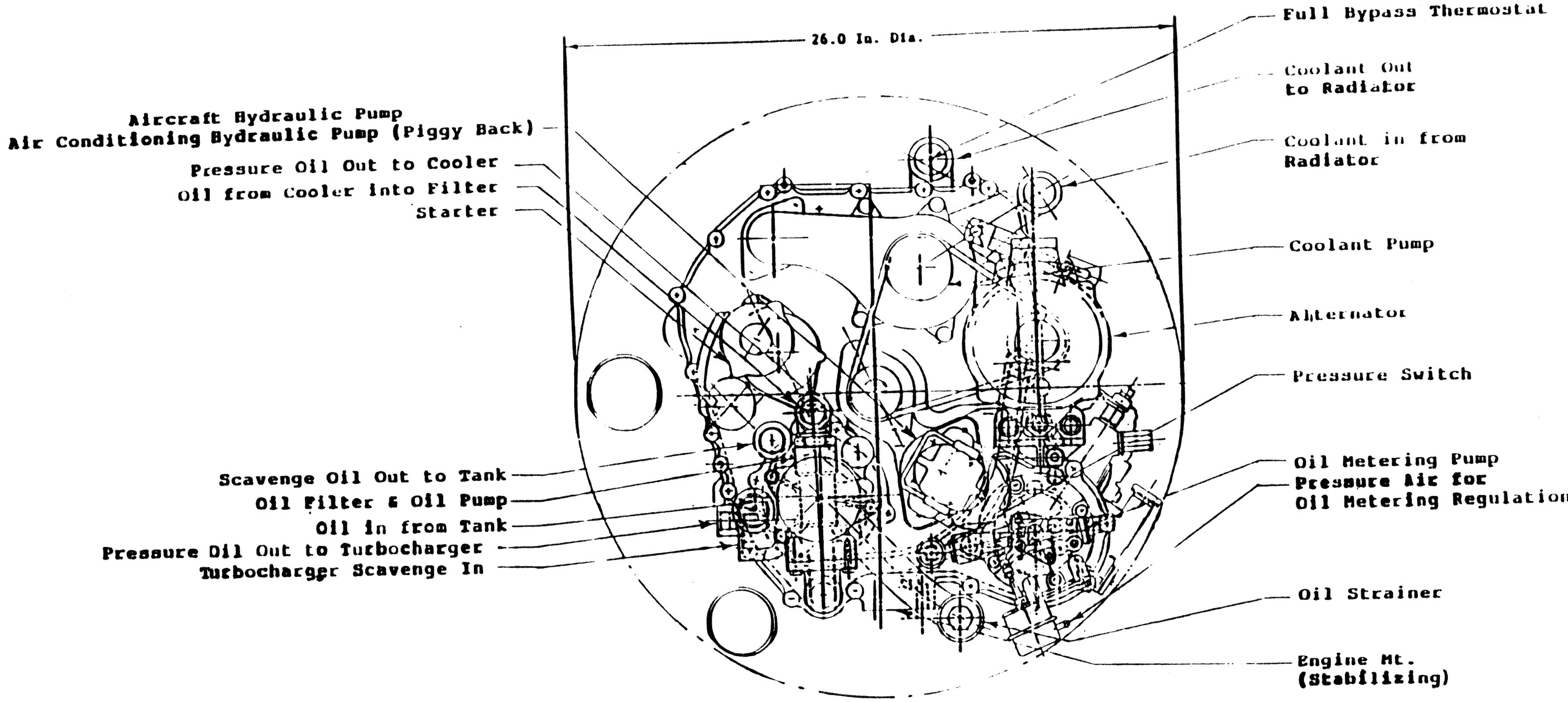


Figure 4.1.7-8

STRATIFIED CHARGE ROTARY AVIATION ENGINE

FOR NASA LeRC "X" AIRPLANE

MODEL 2013R

250 BHP / 7000 RPM

JET-A-FUEL

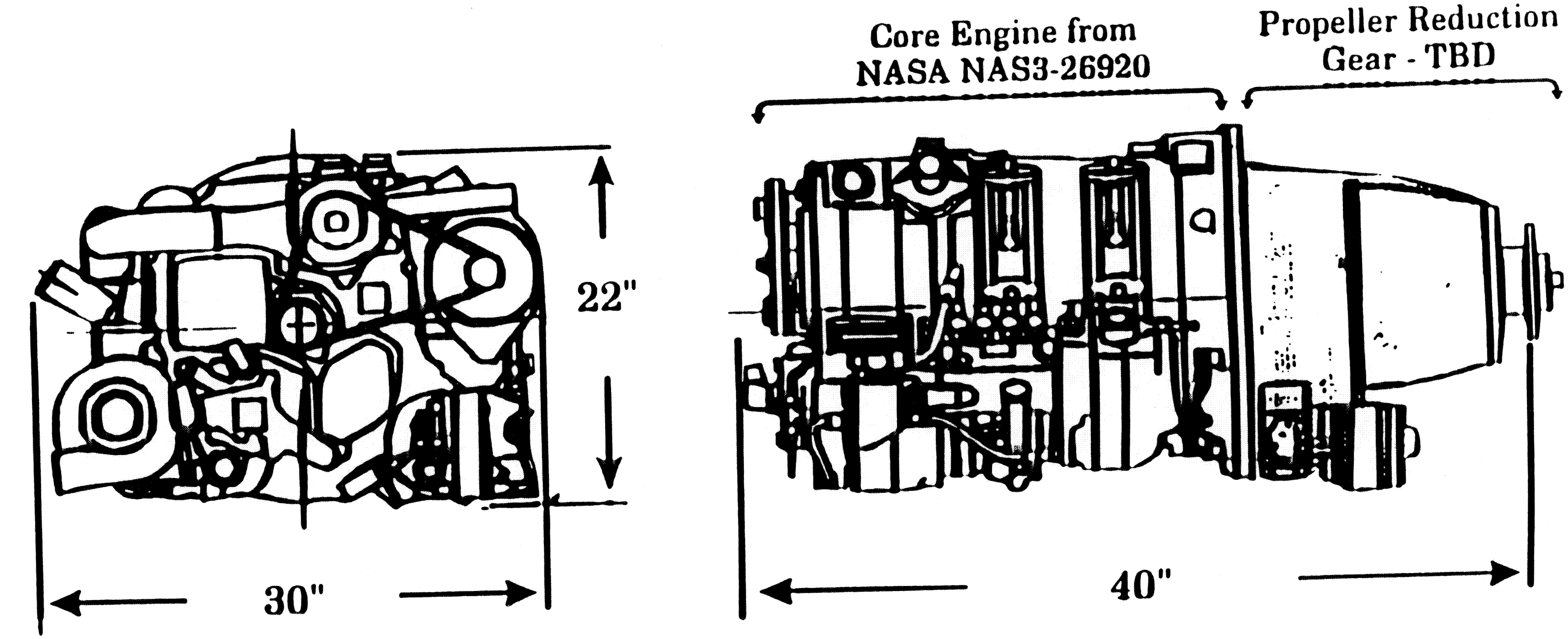


FIG. 4.1.7-8a

MODEL 2034R 170 SERIES ENGINE
CONCEPTUAL LONGITUDINAL CROSS SECTION

Core Engine/Direct Drive or Reduction Gear

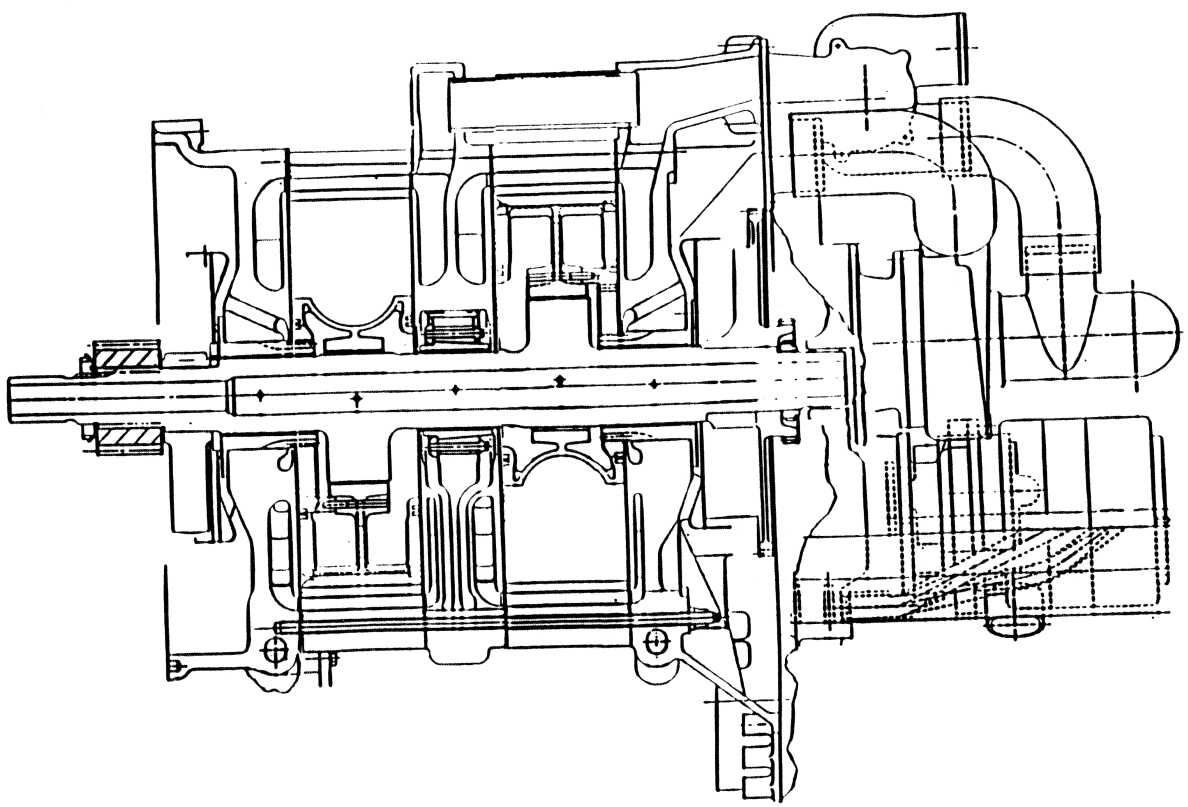


Figure 4.1.7-9

MODEL 4068R 170 SERIES ENGINE
CONCEPTUAL LONGITUDINAL CROSS SECTION

Core Engine/Direct Drive or Reduction Gear

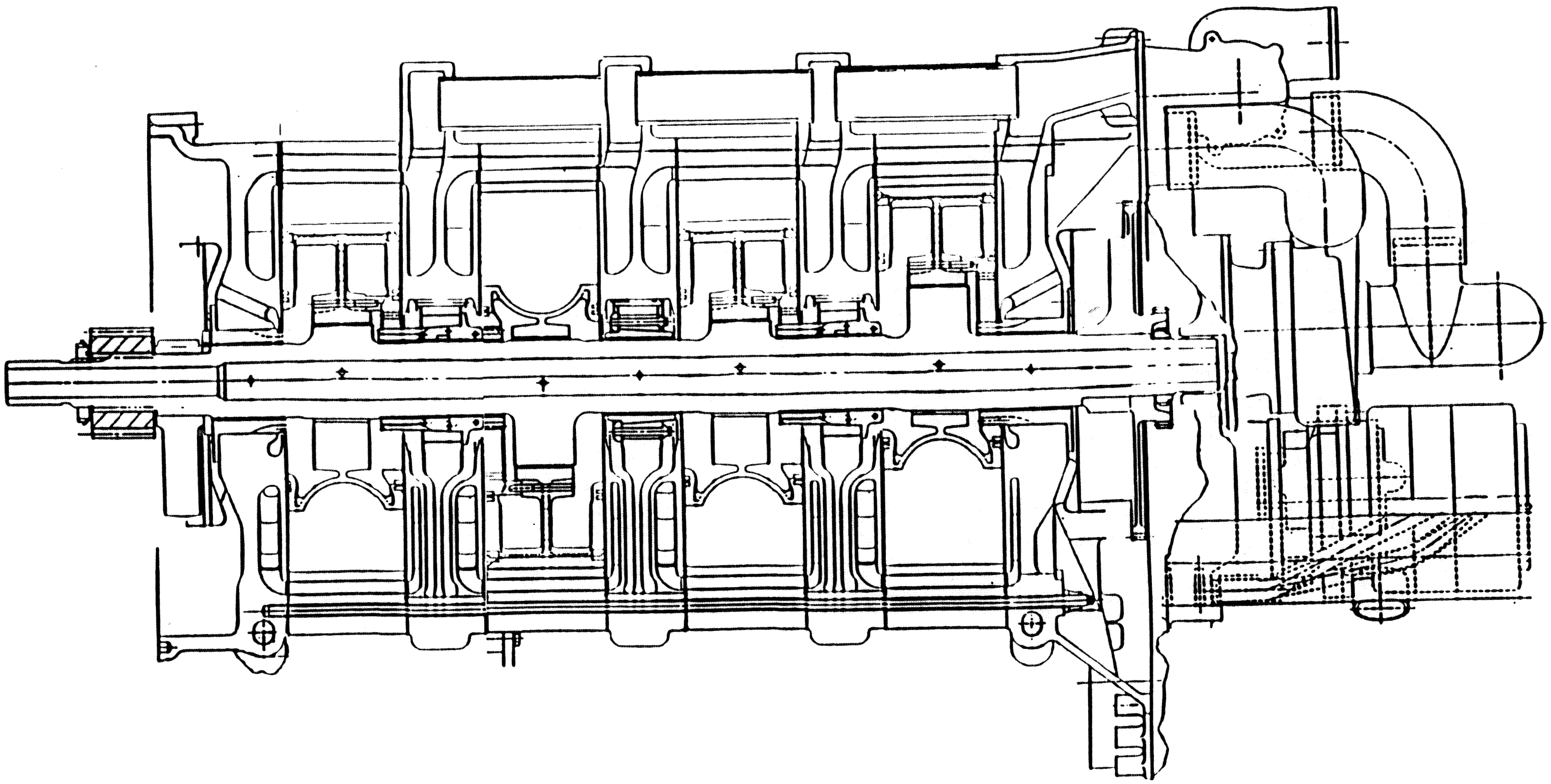


Figure 4.1.7-10

MODEL 2034R PRIMARY ENGINE

Left Side View

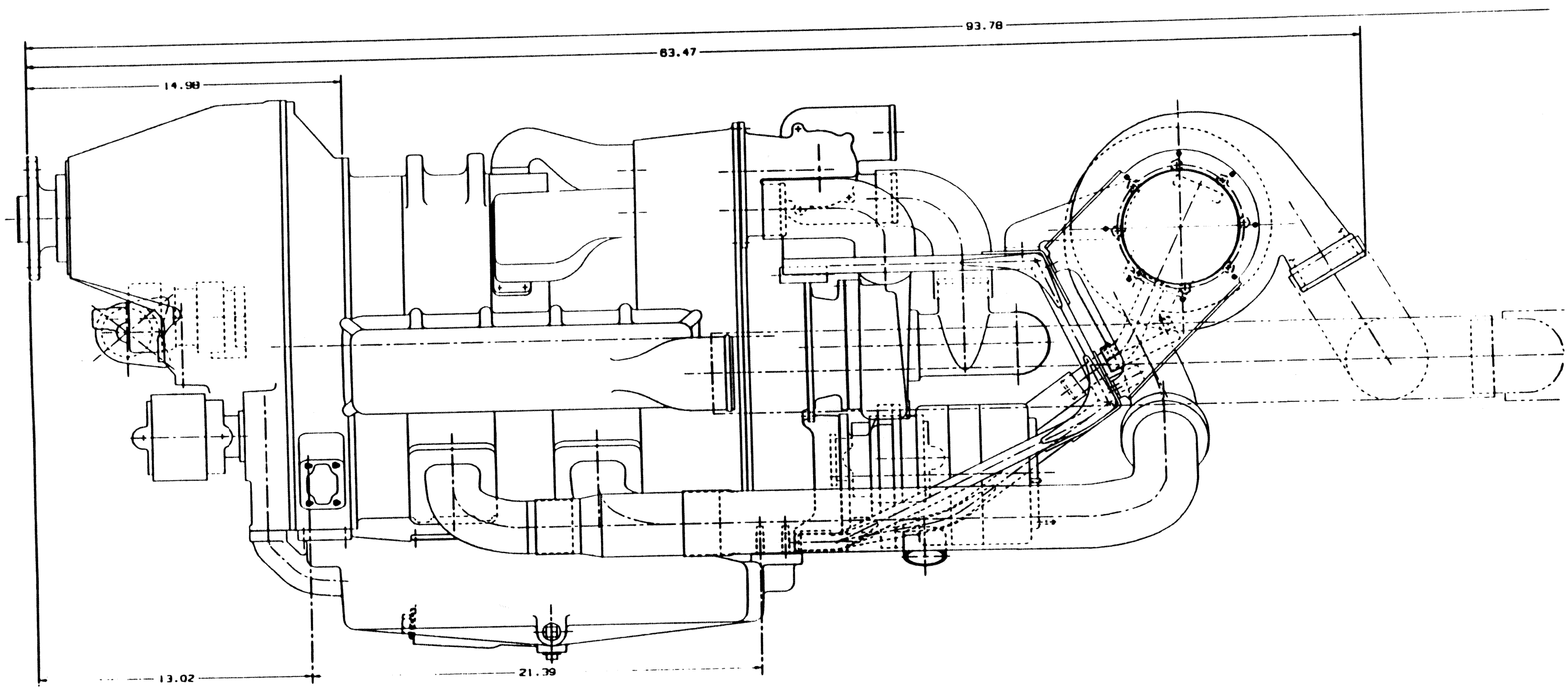


Figure 4.1.7-11

MODEL 2034R PRIMARY ENGINE

Prop End View

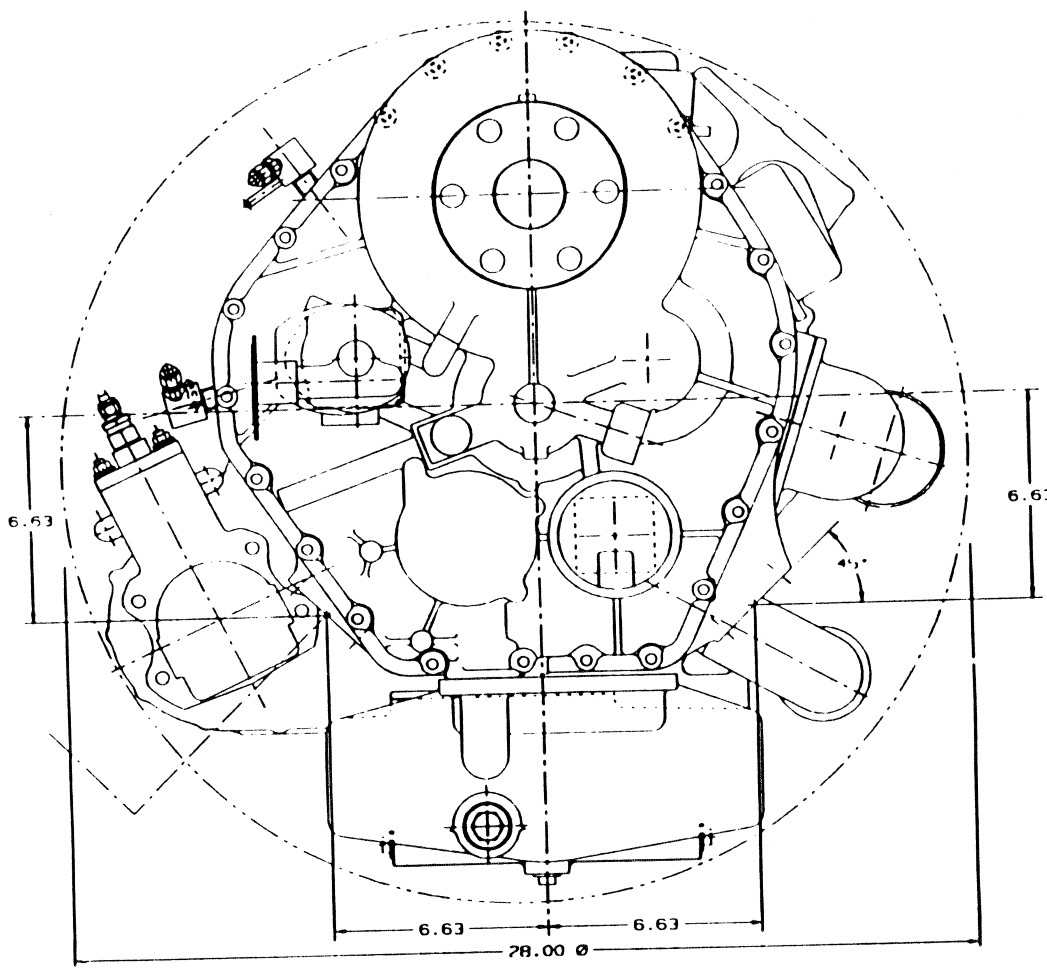


Figure 4.1.7-12

MODEL 2034R PRIMARY ENGINE

Accessory End View

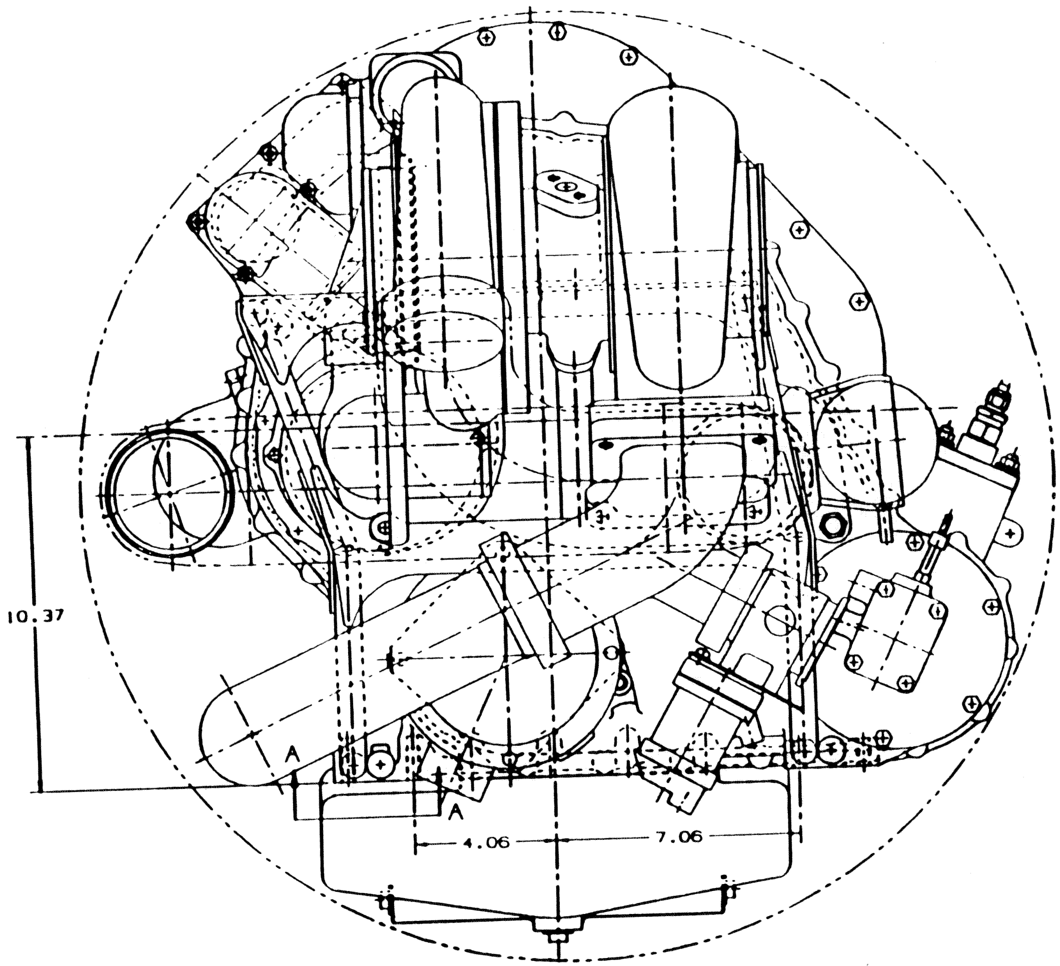


Figure 4.1.7-13

MODEL 2034R

IN-LINE REDUCTION GEAR

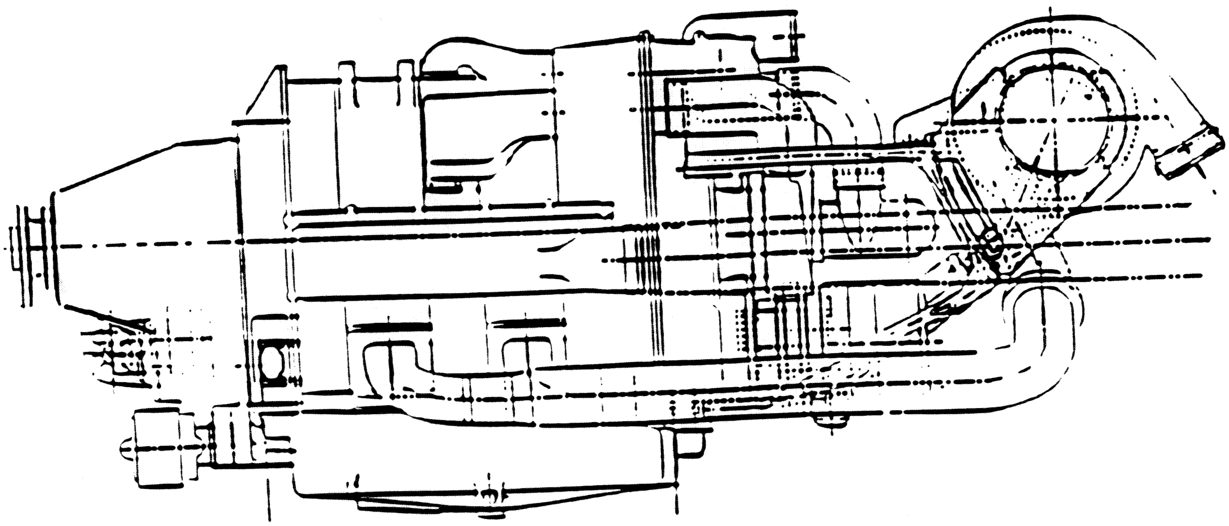
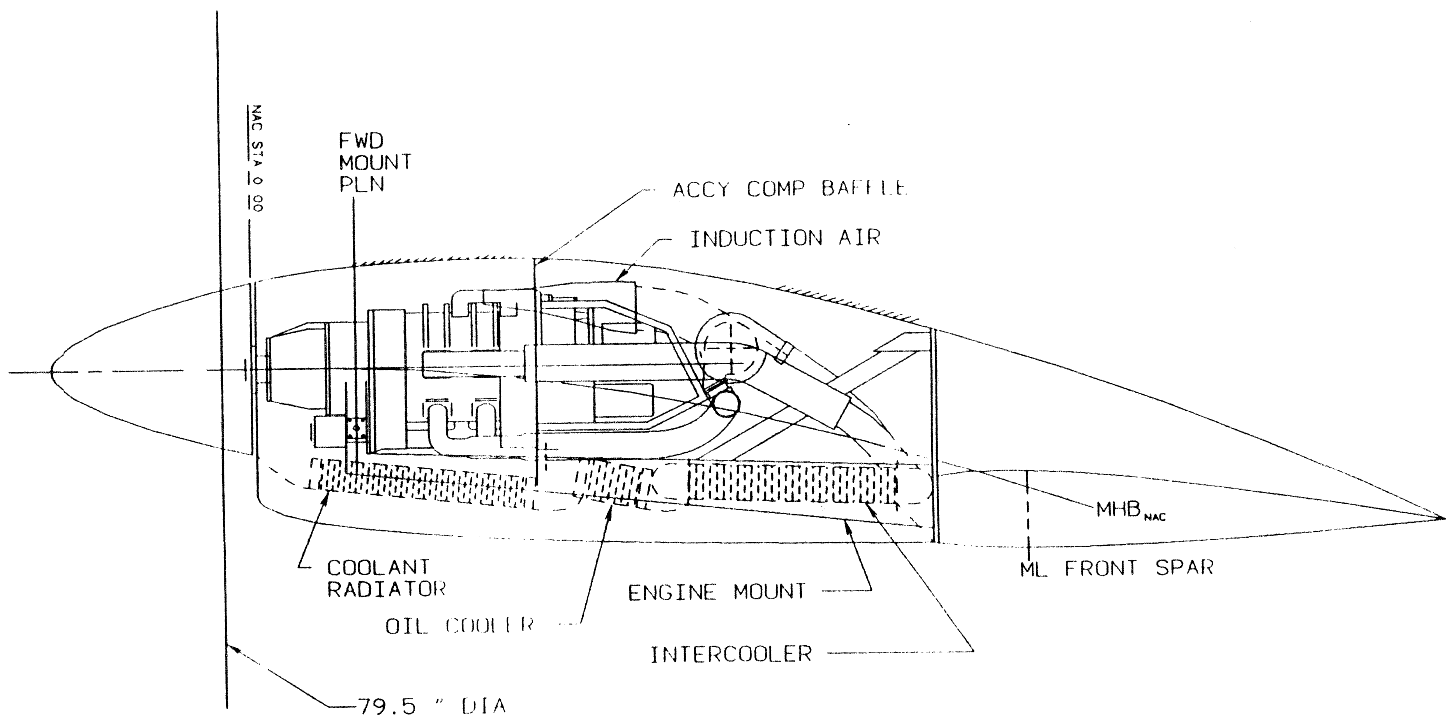


Figure 4.1.7-14

ROTARY-POWERED TWIN STUDY



Beechcraft ADVANCED DESIGN

FIG. 4.1.7-15a

016-TWIN1.CDR

ROTARY-POWERED TWIN STUDY

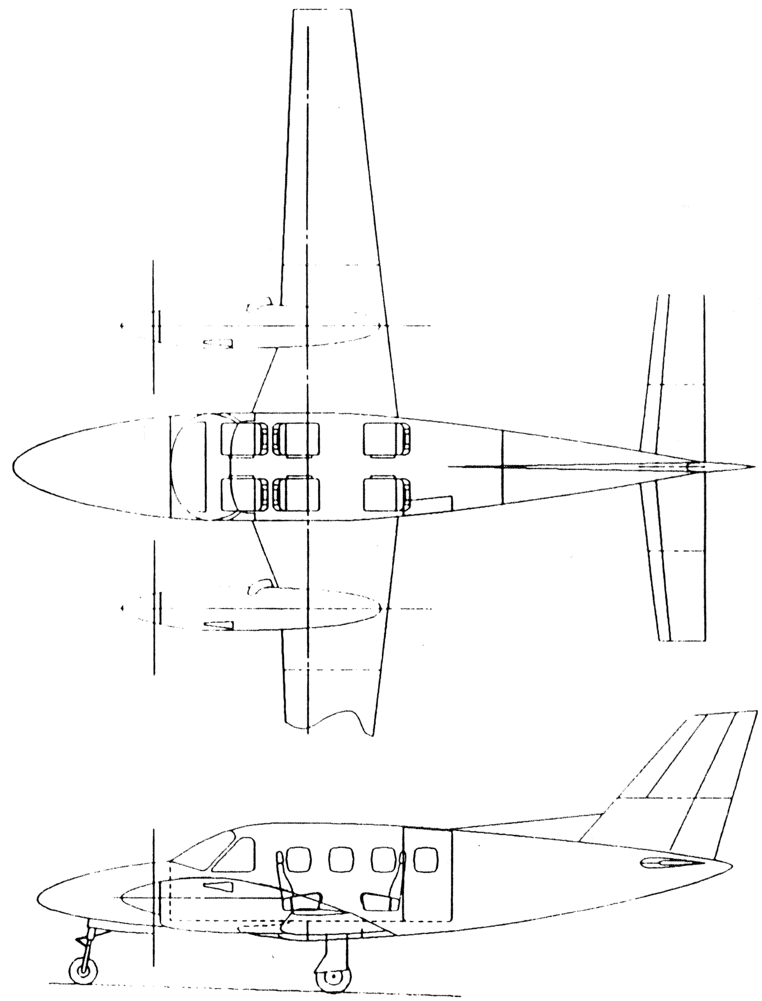


FIG. 4.1.7-15b

016-TWIN2.CDR

4.1.8.1 Reduction Gearing

Selection of the reduction gearing for a particular rotary engine and a particular installation will depend upon coordination between the airframers, engine builder, the suppliers of particular equipment to be integrated, i.e. propeller and provisions for accessory drives, counter rotation and other factors noted in Figure 4.1.8.1-1.

Typical types of reduction gearing used between crankshaft and propeller shaft are shown in Figure 4.1.81-2. There are advantages and disadvantages for each configuration and these must be evaluated in the selection process.

For the 70 Series primary engine in this study the planetary reduction gear type was considered most appropriate. Crankshaft speeds of up to 8500 RPM vs propeller speeds at 2500 RPM (and probably ultimately lower), weight, size and shaft centerline locations were factors influencing the decision. Figures 4.1.8-1-3a through 3c depict the reduction gear cross section and gear diagrams for clockwise and counterclockwise rotation respectively.

For the 170 Series primary engine an external - external, helical reduction gear was used. This results in some elevation of the propeller centerline for added ground clearance. Figure 4.1.8.1-4a reflects the cross section for standard rotation, while Figure 4.1.8.1-4b reflects introduction of an idler for reversed rotation.

FACTORS INFLUENCING REDUCTION GEAR ASSEMBLY SELECTION

- PROPELLER
- PROPELLER TO ENGINE SPEEDS
- FRONTAL AREA
- WEIGHT
- RELIABILITY
- COUNTER ROTATION REQUIREMENTS
- ACCESSORY DRIVES PROVISIONS
- EXPERIENCE
- COST

FIG. 4.1.8.1-1

REDUCTION GEAR CONFIGURATIONS

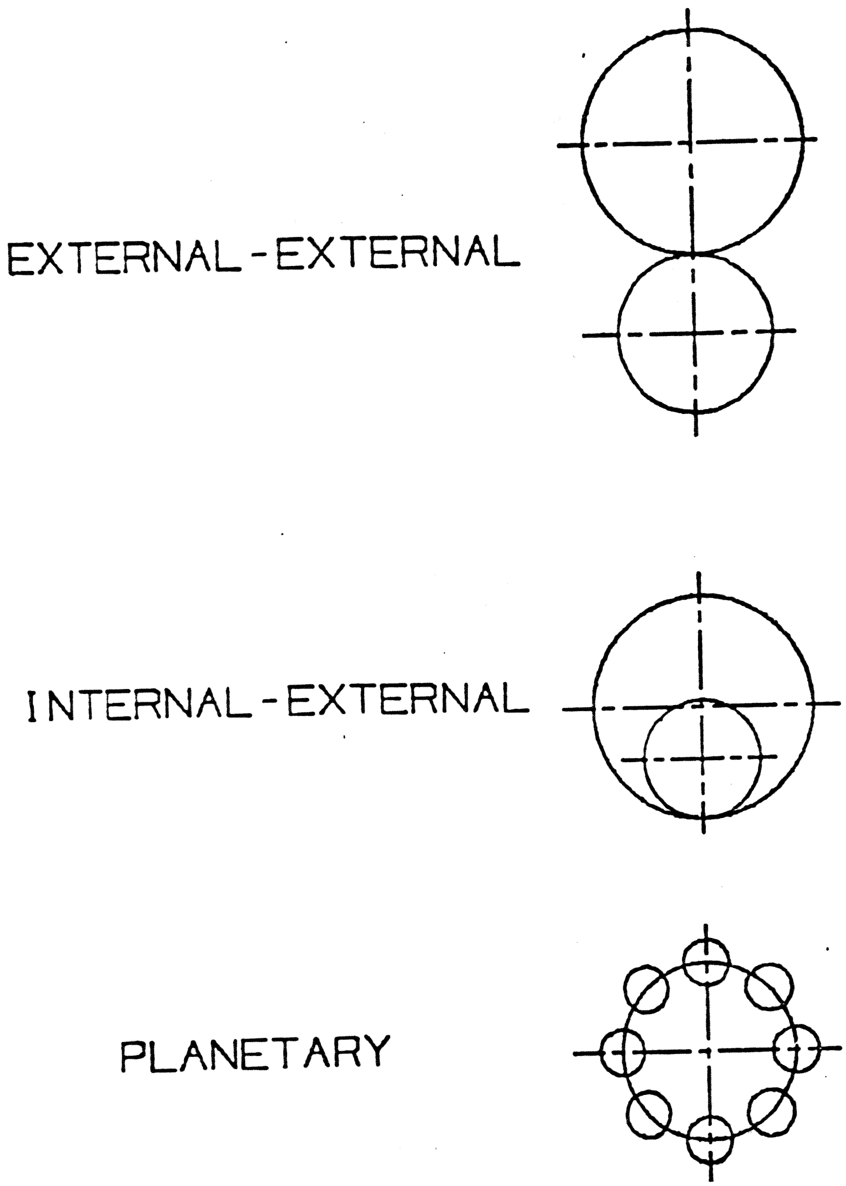


FIG. 4.1.8.1-2

REDUCTION GEAR HOUSING & NOSE CONE

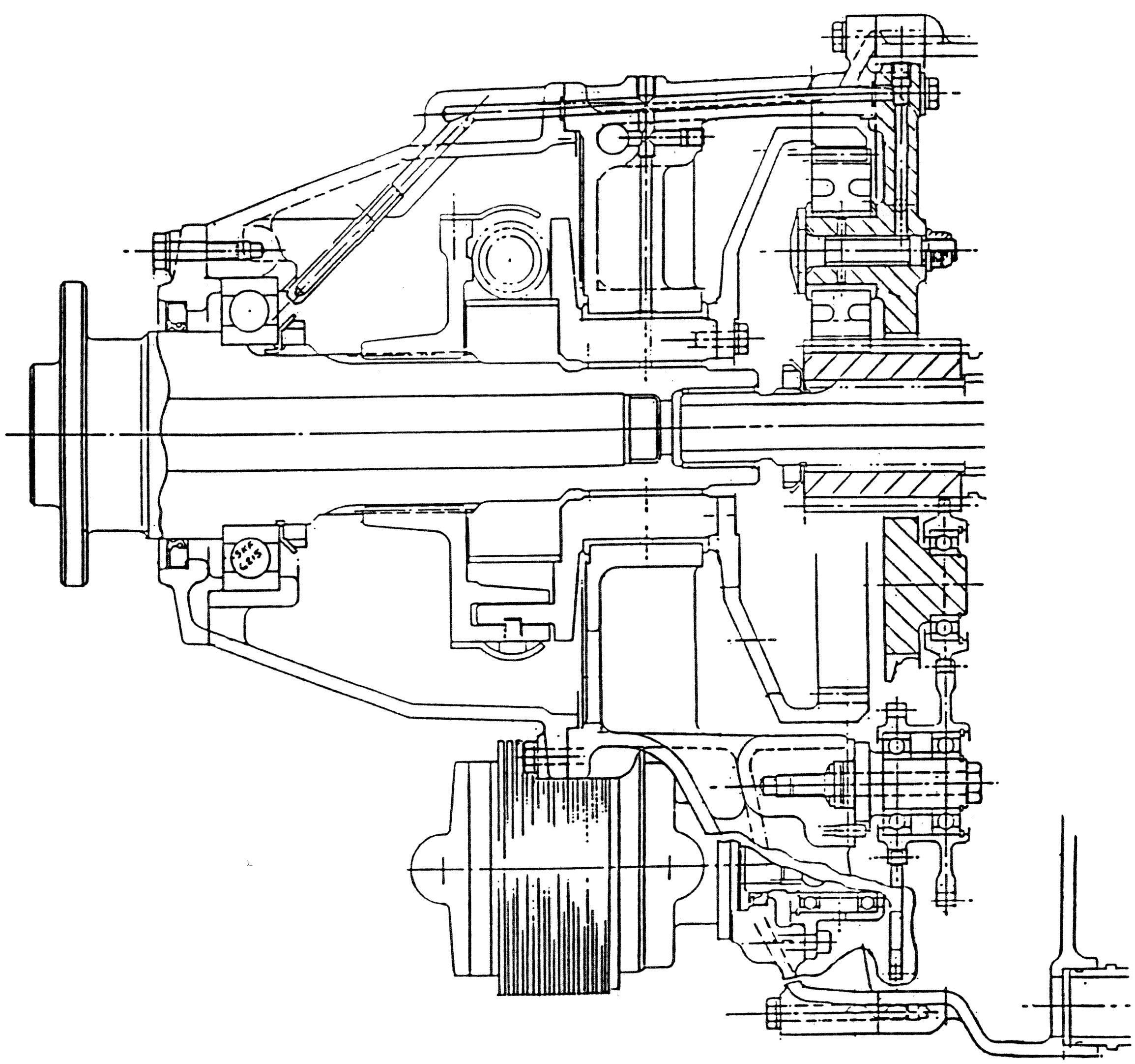


FIG. 4.1.8.1-3a

2013R NASA REFERENCE ENGINE

CLOCKWISE PROP REDUCTION GEARING

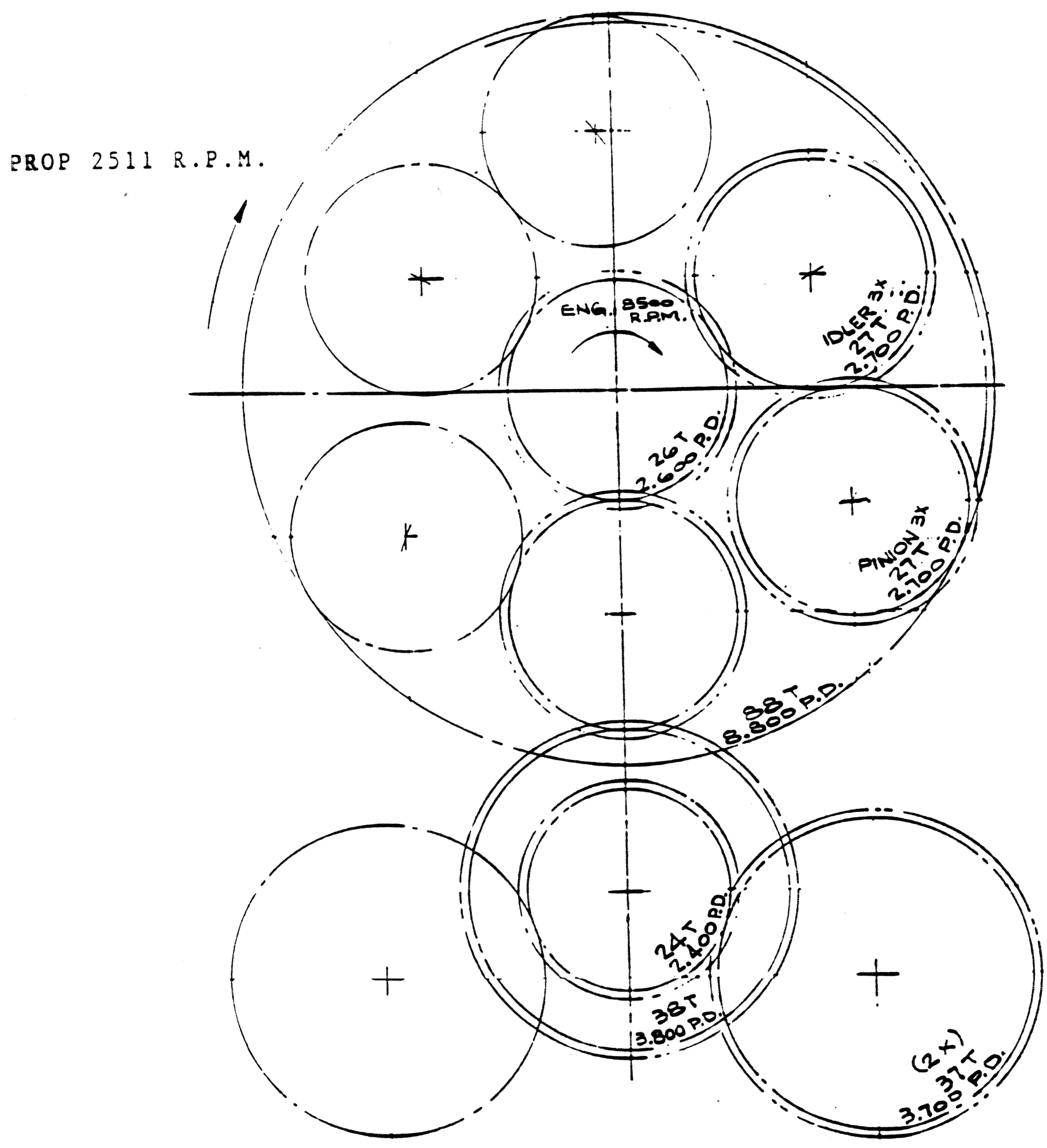


FIG. 4.1.8.1-3b

2013R NASA REFERENCE ENGINE

COUNTERCLOCKWISE PROP REDUCTION GEARING

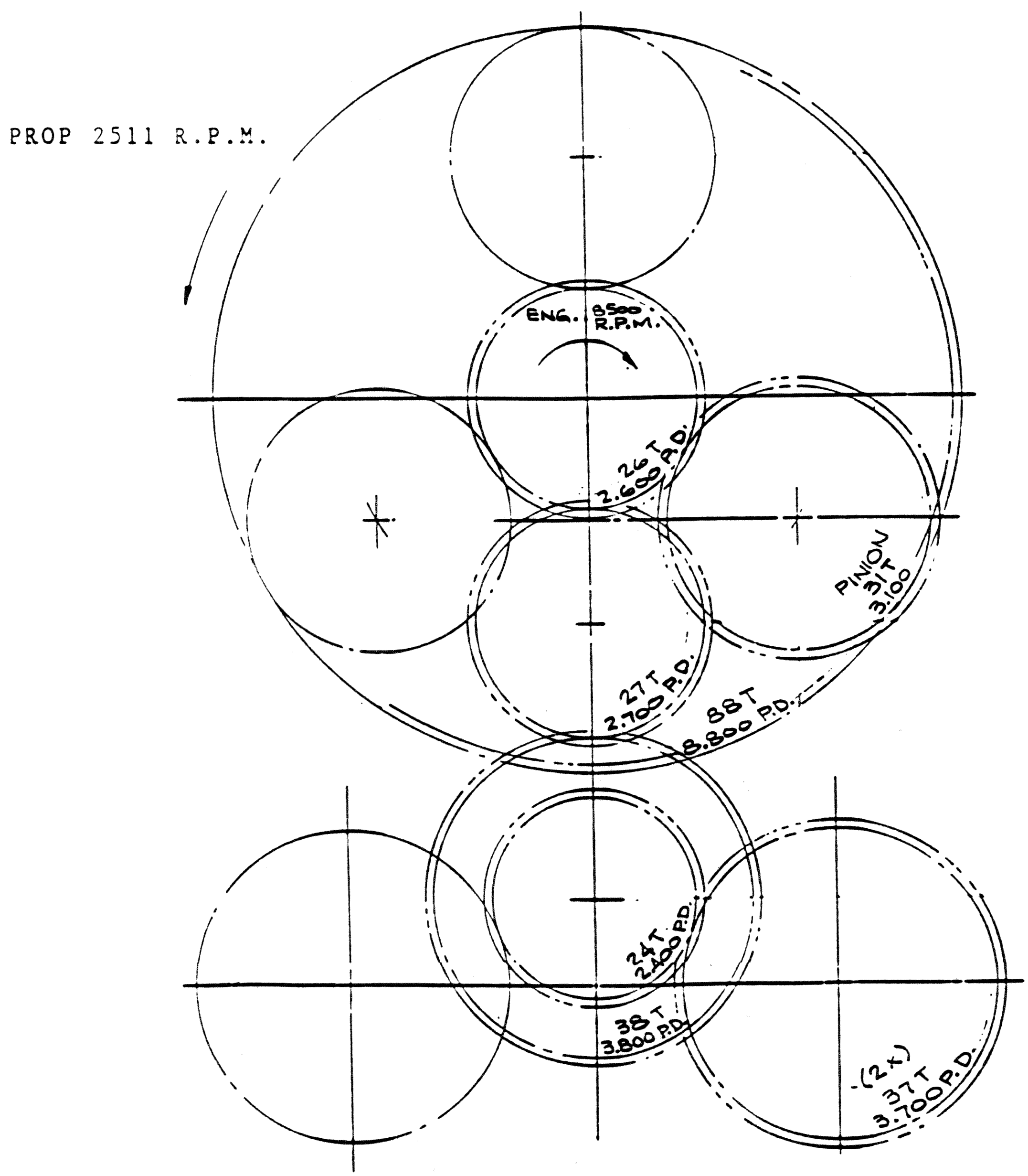


FIG. 4.1.8.1-3c

REDUCTION GEAR

MODEL 2034R

STANDARD ROTATION

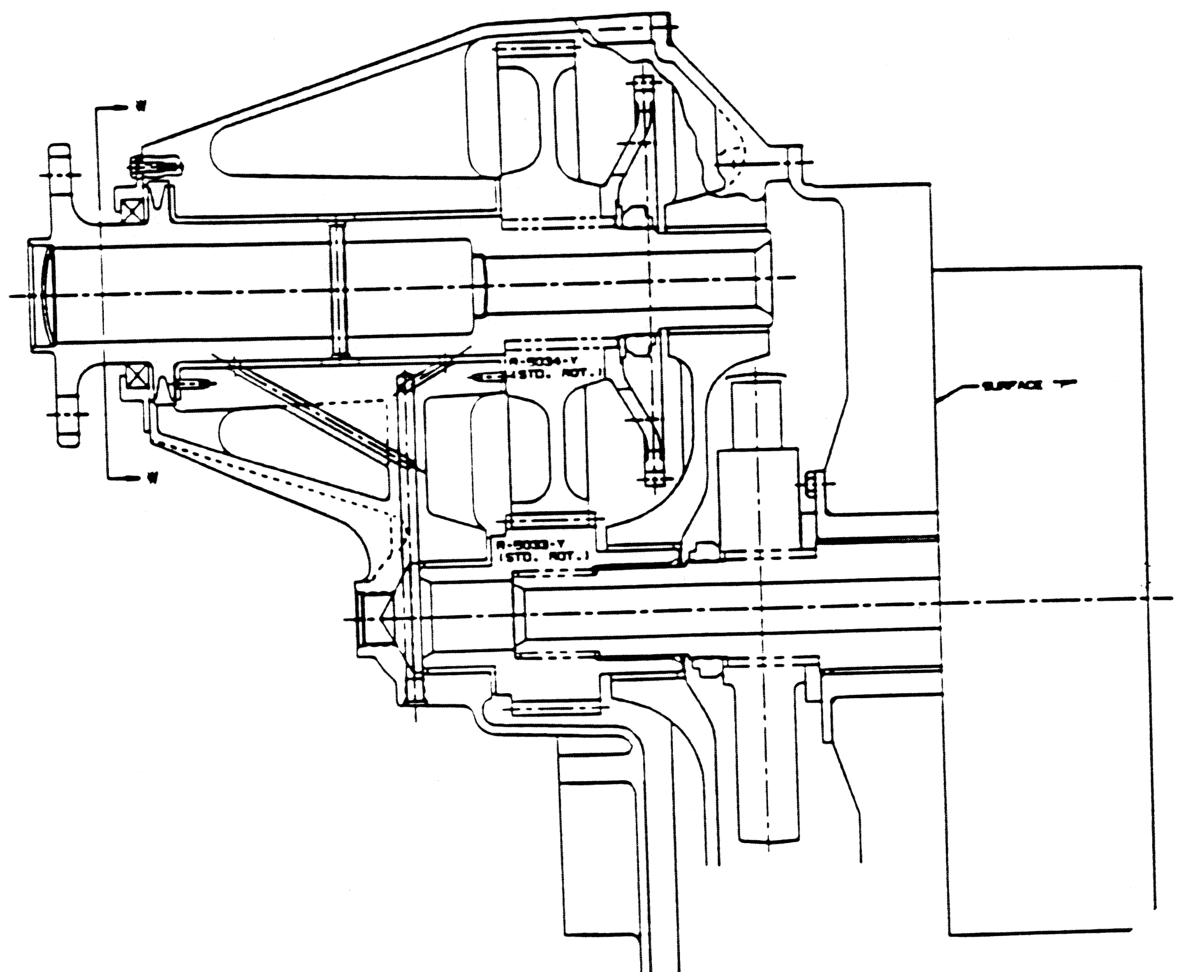


FIG. 4.1.8-4a

REDUCTION GEAR
MODEL 2034R
REVERSE ROTATION

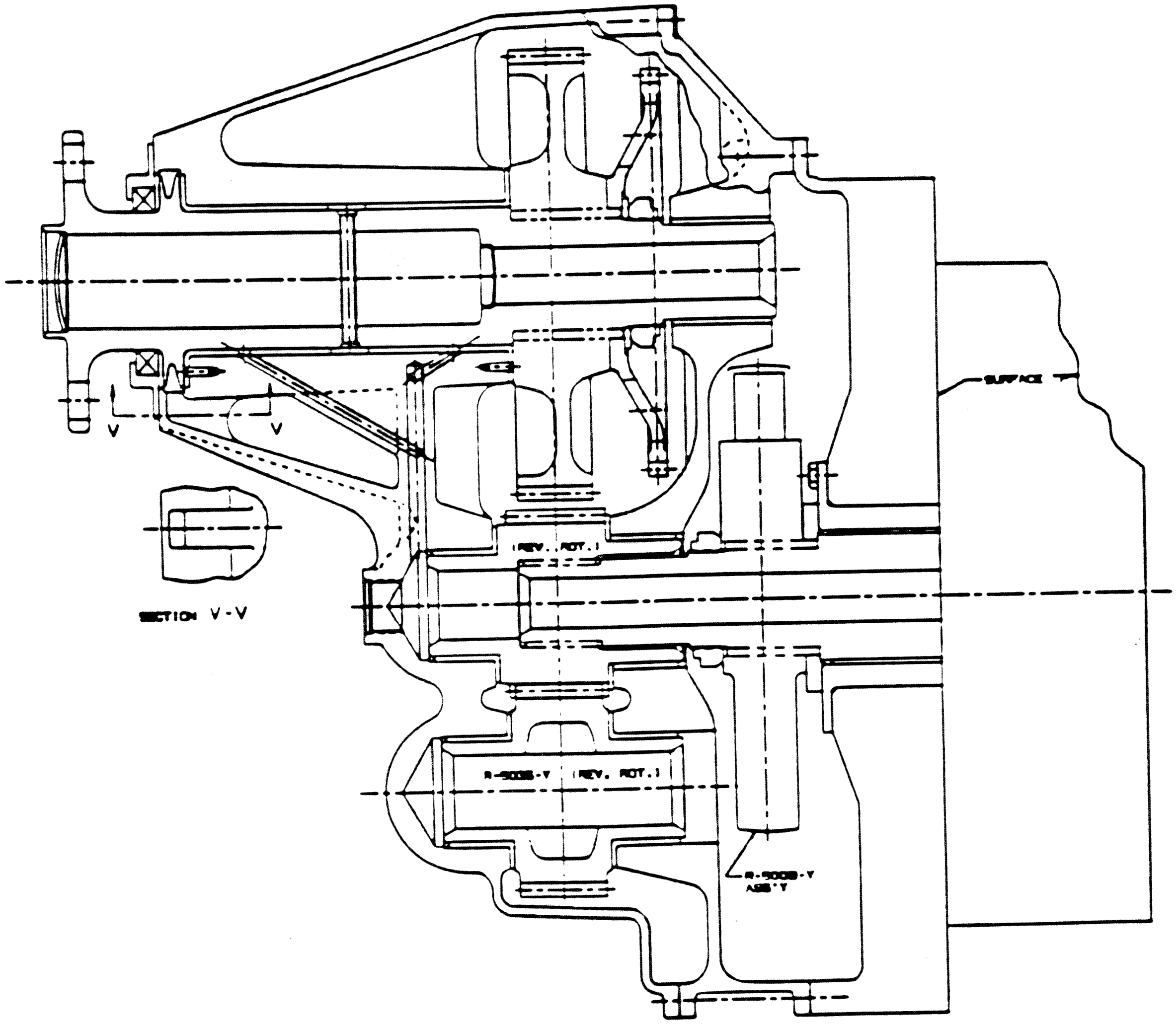
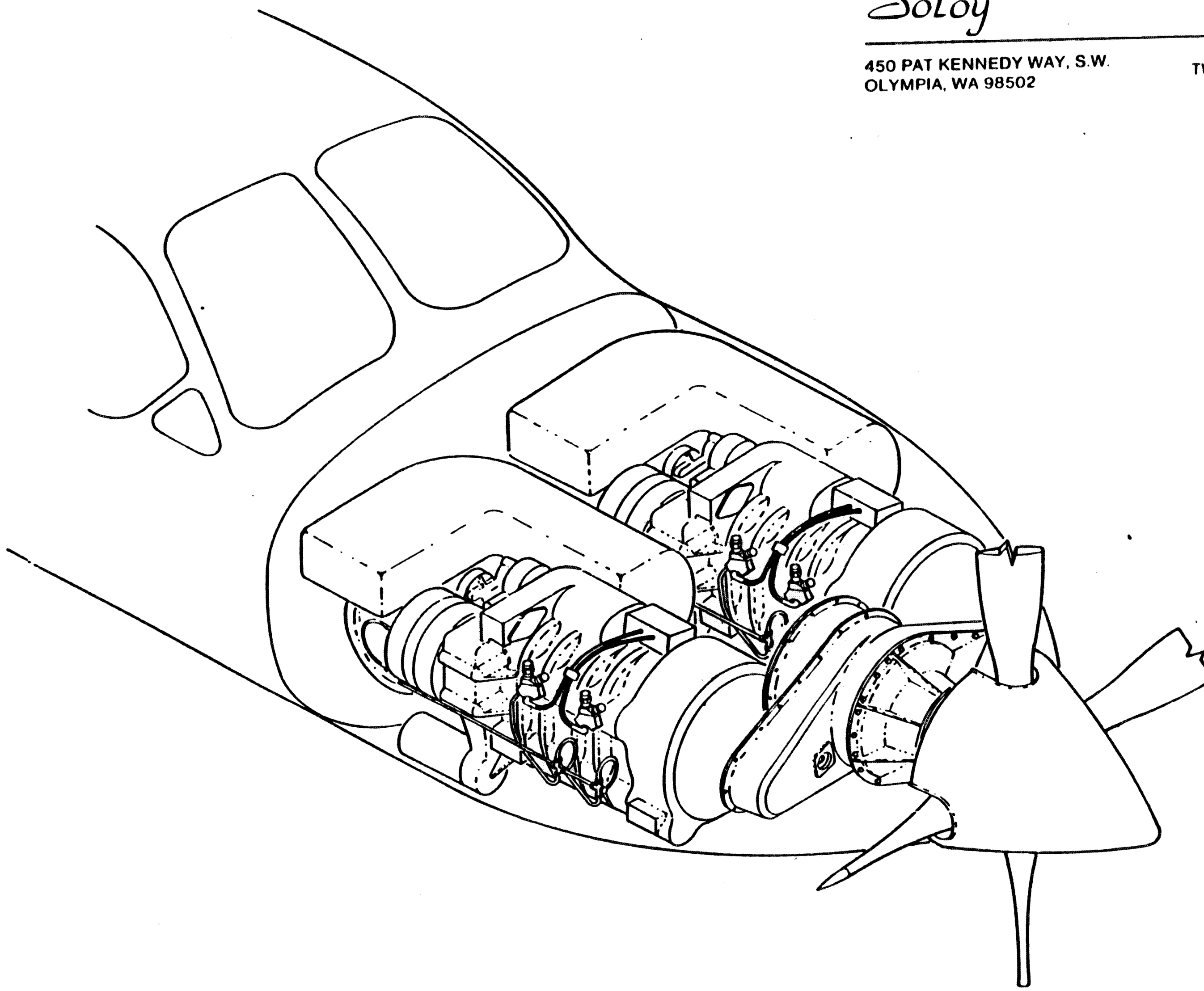


FIG. 4.1.8.1-4b

Soloy

450 PAT KENNEDY WAY, S.W.
OLYMPIA, WA 98502

(206) 754-7000
TWX 510-785-0241



SOLOY DUAL PAC
INCORPORATING THE SCORE™
MODEL 2013R AVIATION ENGINE

FIG. 4.1.8.2-1

4.1.8.2 Dual Pac Arrangements

The stratified Charge Rotary Engine (SCRE) is very similar to the small turbine in terms of being light in weight, diametral in shape, having heavy fuel (Jet-A) capability and having a relatively high crankshaft speed. Hence, the SCRE offers a very attractive package for consideration of Dual Pac configurations.

The Dual Pac concept derives from work conducted at Soloy Corporation and their work with two small turbines into a combining gearbox with a single propeller shaft. Certification efforts are in progress with the Soloy Dual Pac configuration using twin PT-6 turbine powerplants. Certification as a twin engine aircraft and the attendant redundancy, increased reliability, possibly reduced insurance costs, etc. are expected.

We have discussed adaptability of the SCRE in the 70 Series Model 2013R "primary" engine and 170 Series, Model 2034R "primary" engine with Mr. Joe Soloy, President of Soloy Corporation and Mr. George Baena, Engineering Manager. The core power sections from either of these candidate engines is readily adaptable to Dual Pac arrangements and result in attractive packaging.

Figure 4.1.8.2-1 presents an aircraft propulsion system general arrangement for a Dual Pac configuration utilizing the 70 Series, Model 2013R "primary" engine. This concept drawing does not optimize the "primary" engine for the best arrangement in the compound installation i.e., accessories selection, placement of exhaust ducting, intake ducting, direction of rotation, etc. The concept drawing simply takes the Model 2013R with aft mounted turbocharger and intercooler, removes the propeller reduction gear and installs the compound Dual Pac gearbox w/propeller shaft.

Key features of the SCRE making it attractive to future general aviation application are also very significant here in that a lower cost, fuel efficient alternative to the turbine is available.

Key differences between the SCRE and reciprocating engines relative to selection of the SCRE for consideration in Dual Pac designs are: a) the diametral shape of SCRE vs. the flat, horizontally opposed reciprocating engines and b) the SCRE's non-dependency on Avgas.

Figure 4.1.8.2-2 summarizes Dual Pac possibilities for four engines in the SCRE family considered in this study. These are the two and four rotor versions of the 70 Series and 170 Series. The single rotor engine in the 70 Series is not considered a candidate for a Dual Pac configuration since the single rotor engine is not attractive from a power to weight ratio standpoint.

Figure 4.1.8.2-3 summarizes the estimated dry weight for the four Dual Pac configurations. The method used to estimate the weights is very approximate since specific designs for the combining gearboxes are not available. We attempted to be conservative using 2 LBS/10HP as a factor in estimating the weights for the gearboxes. This is conservative relative to typical high speed, advanced design aircraft industry gearbox weights of as low as 1 LB/10HP.

Family of Advanced Technology Stratified Charge Rotary Aircraft Engines

Compounding / Dual PAC Considerations - 5 Years
680 to 2500 HP

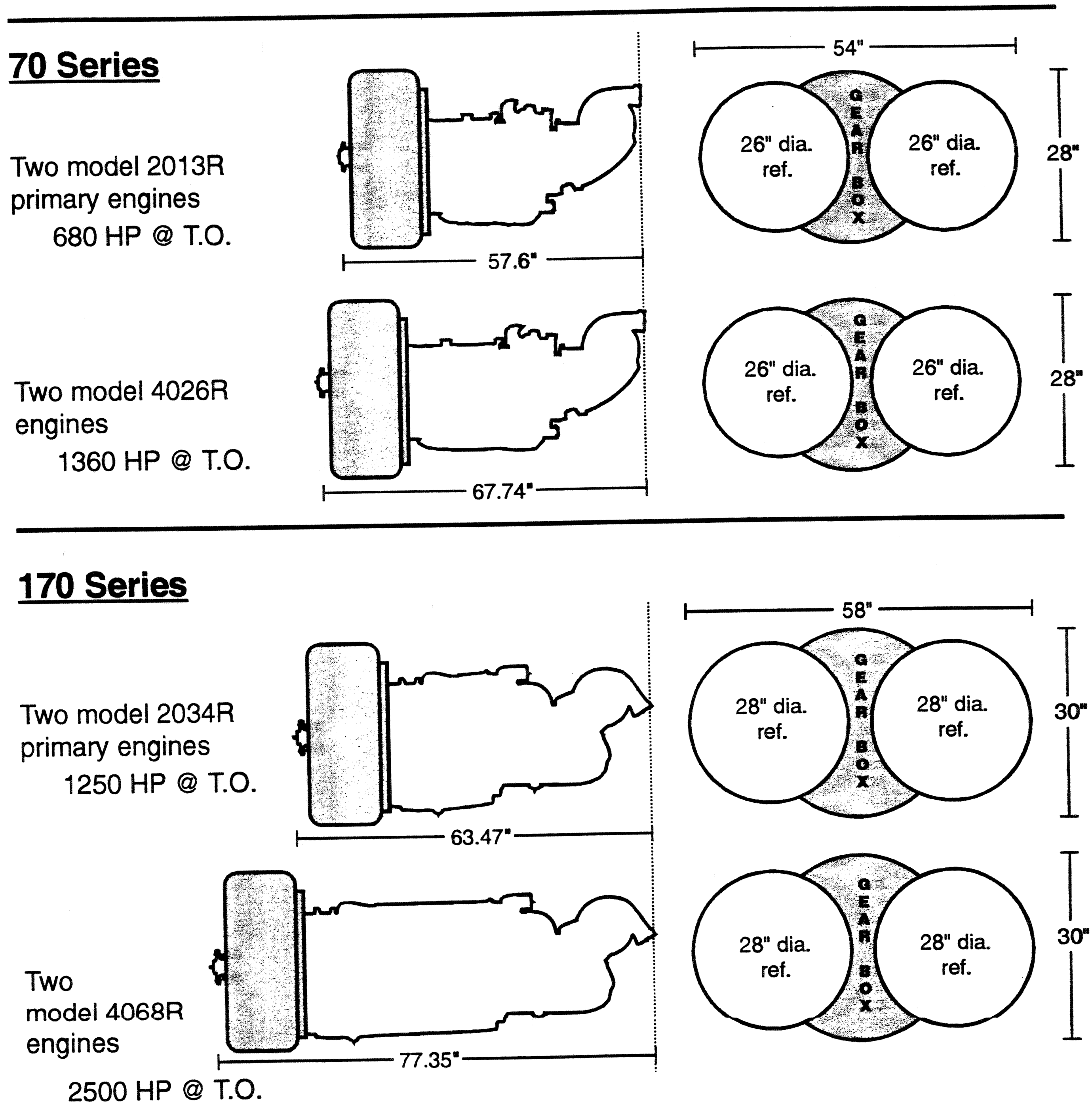


FIG. 4.1.8.2-2

DUAL PAC CONFIGURATIONS

ESTIMATED DRY WEIGHTS

70 SERIES	HP	TWO ENGINES PLUS GEARBOX DRY WEIGHT-LBS
TWO MODEL 2013R PRIMARY ENGINES W/DUAL PAC	680	896
TWO MODEL 4026R ENGINES W/DUAL PAC	1360	1212
170 SERIES		
TWO MODEL 2034R PRIMARY ENGINES W/DUAL PAC	1250	1370
TWO MODEL 4068R ENGINES W/DUAL PAC	2500	2620

FIG. 4.1.8.2-3

4.1.8.3 Torsional Isolation

As is the case with reciprocating intermittent combustion engines, compatibility between the torsional system of the infinite inertia propeller, engine component inertias and connecting spring rates for the rotary must be examined and defined. However, it should be noted that in general, calculations for the mass-elastic system are simple for the rotary engine - propeller system in contrast to that for the reciprocating engines.

The rotary engine crankshaft is relatively simple in form, short in length and torsionally very stiff. In general, for single or multi-rotor rotary engines, the rotating inertias for such components as rotors, crankshaft eccentric lobes, balance weights, etc. can be lumped and treated analytically as a single inertia. Hence, the torsional system becomes a simple two inertia system of engine and propeller with an interconnecting spring.

Since the propeller inertia is infinite, relative to the engine lumped inertia, any torsional motion resulting from system excitation consist of the engine system moving torsionally against the propeller. With this simple, two inertia system selection of the proper coupling or de-tuning system between the engine and propeller to accommodate any excitation is relatively easy. Critical speeds can be avoided or de-tuned to permit unrestricted full range operation from start-up to idle and maximum speed (take-off plus overspeed provisions).

In the case of the rotary engine, excitation resulting from second engine order (2X crankshaft speed) are the only ones of any significance. Several approaches have been utilized for torsional isolation in rotary aircraft engine designs.

- o Mechanical spring damper system
- o Viscous damper system
- o Tuned pendulum damper system

All of these systems can perform the necessary function achieving torsional isolation and protection against potentially destructive critical speed vibration in fixed wing or rotary wing aircraft. Selection of the particular system is dependent upon the reduction gear, driven equipment and all drive train components, i.e., accessory drive provisions integrated with the engine and other factors.

Figures 4.1.8.3-1(a) and 4.1.8.3-1(b) show a torsional isolation system for the 70 Series, Model 2013R "primary" engine consisting of a spring damper system integrated into the crankshaft, propeller shaft and epicylic reduction gear system.

Figure 4.1.8.3-2 shows a torsional isolation system for the 170 Series, Model 2034R "primary engine" consisting of a tuned pendulum damper system integrated into the crankshaft counterweight system. This system was tested in the Model 2034R testing and performed satisfactorily. The tuned pendulum damper type of torsional vibration isolation is well known in the reciprocating aircraft industry and is a functional, fully reliable system. For rotary engines, integration of the damper into the counterweight system results in a weight effective solution.

REDUCTION GEAR HOUSING & NOSE CONE

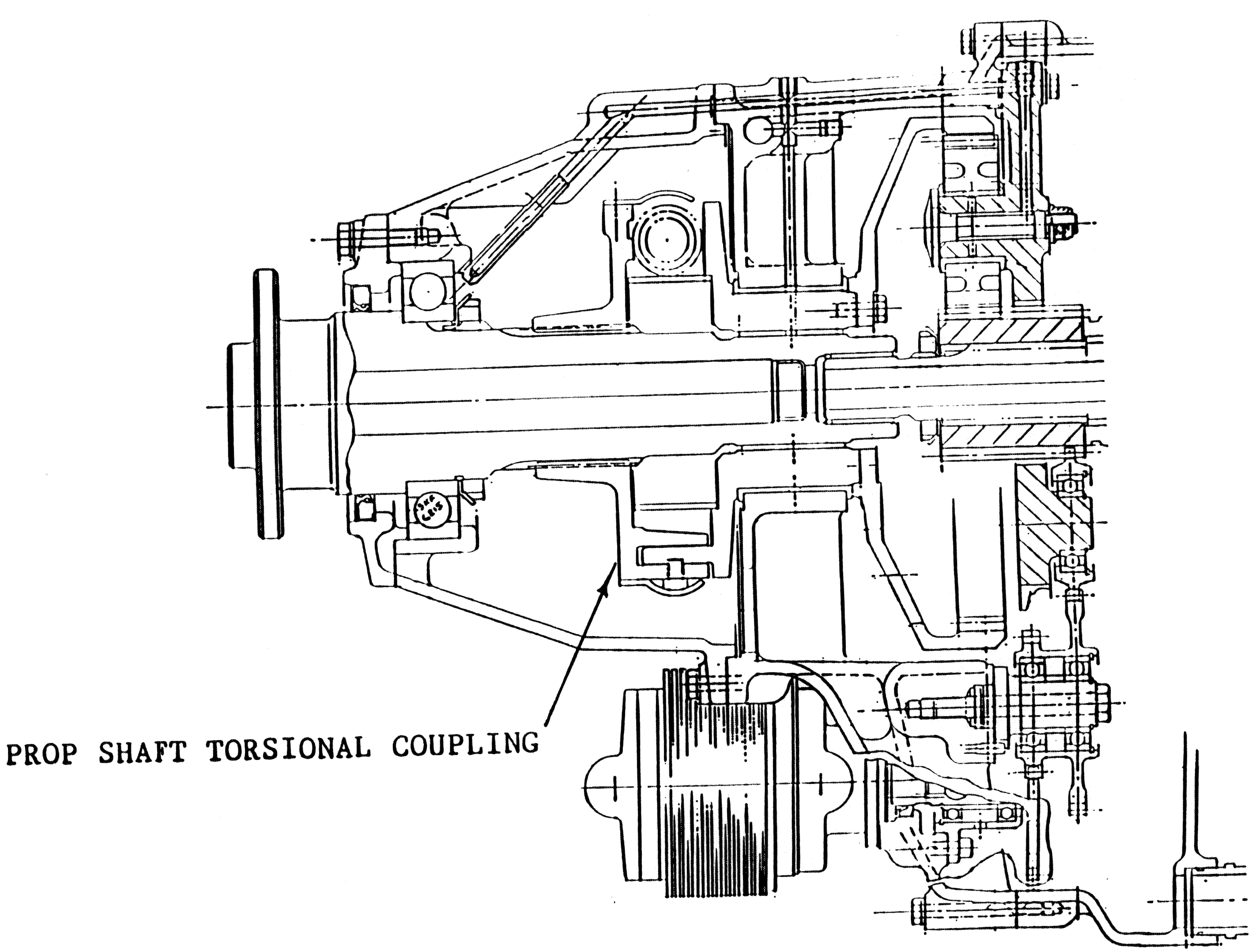


FIG.4.1.8.3-1(a)

PROP SHAFT TORSIONAL COUPLING

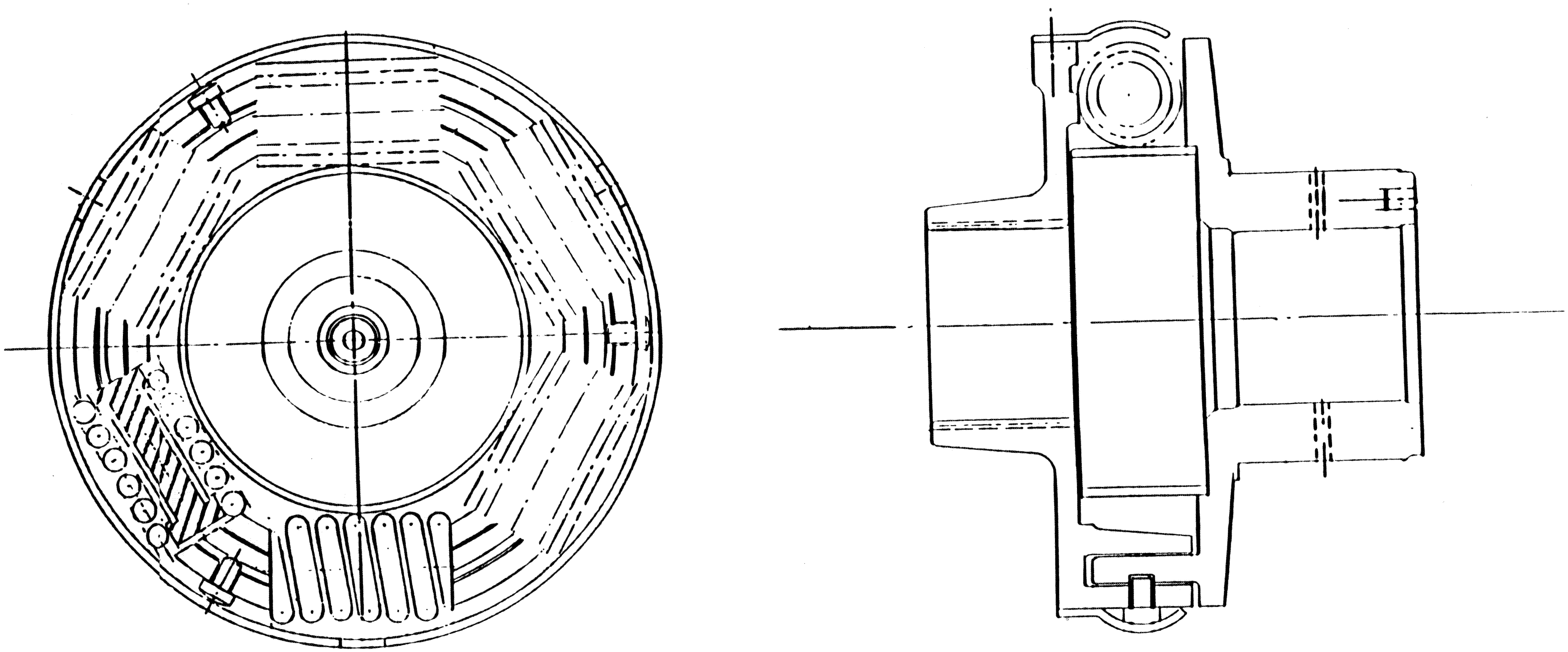
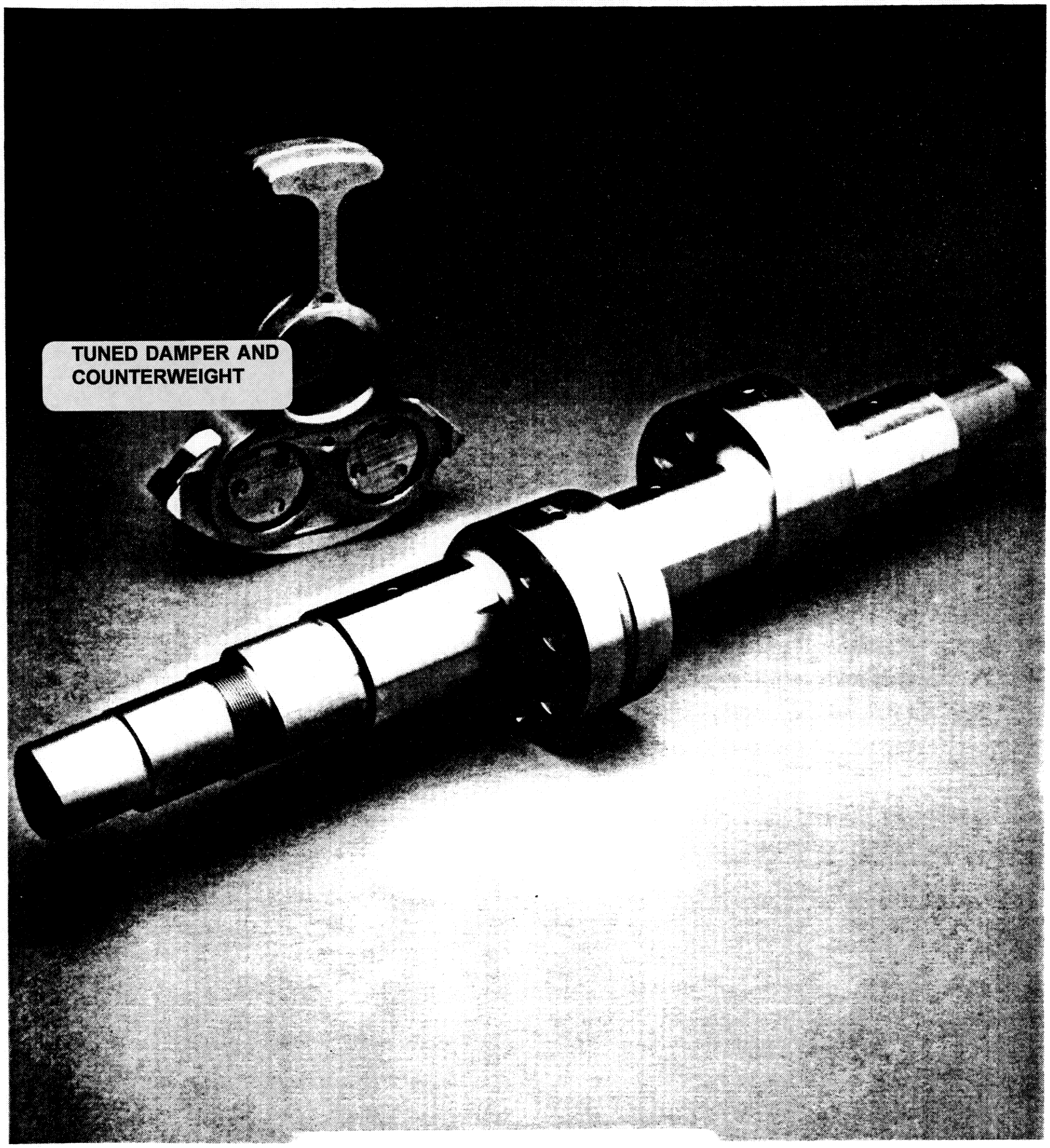


FIG. 4.1.8.3-1(b)



2034R - CRANKSHAFT AND
COUNTERWEIGHT

FIGURE 3.31

FIG. 4.1.8.3-2

4.1.8.4 - DUAL SPARK PLUGS

Dual spark plugs at the pilot fuel injection nozzle will be required per our coordination with FAA.

Various studies have been conducted to confirm successful positioning and placement of two spark plugs in the 40 cu-in. 70 Series rotor housing and in the larger, 105 cu.in., 170 Series rotor housings.

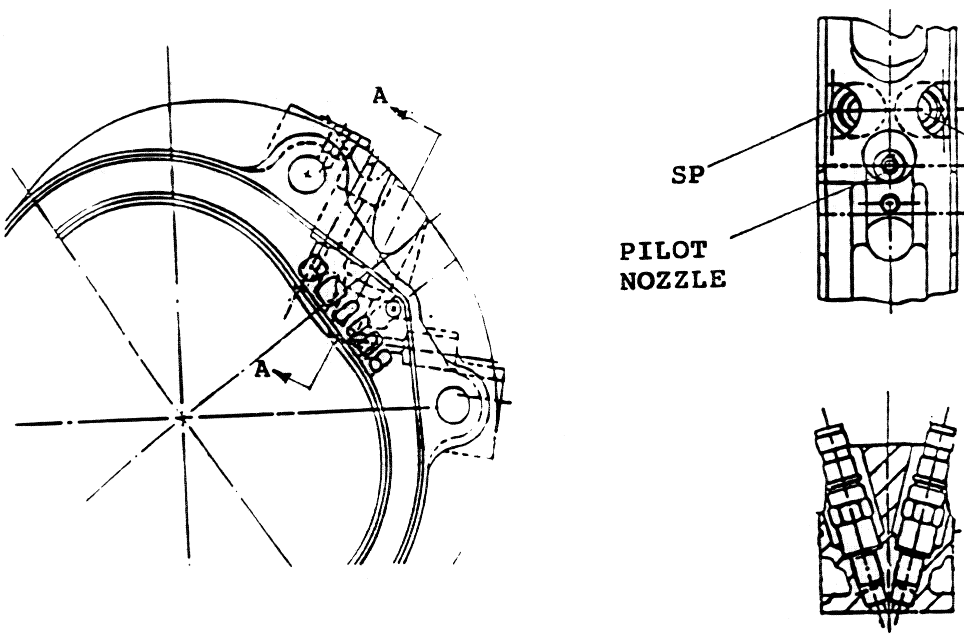
Figure 4.1.8.4-1 shows the dual spark plug installation for the 40 cu.in., 70 Series rotor housing.

We examined a variety of spark plug types and can place two spark plugs at the pilot nozzle location. This location is slightly after top center, as can be noted in Figure 4.1.8.4-1, and proper coolant flow passages and housing structural integrity was maintained.

Figure 4.1.8.4-2 shows a similar situation for the 105 cu.in, 170 Series housing. Here the space allowance is much greater and the dual plugs are easily accommodated.

Figure 4.1.8.4-3 shows a two spark plug configuration considered for performance investigations in earlier NASA research work. While not locating dual, and therefore somewhat redundant ignitors specifically at the pilot nozzle this arrangement may meet FAA requirements for two spark plugs and assure combustion even if the one at the pilot nozzle were to fail. Some performance degradation would most likely occur but some "get-home" capability is maintained.

40 CU.IN., 70 SERIES MODEL ROTOR HOUSING DUAL IGNITION

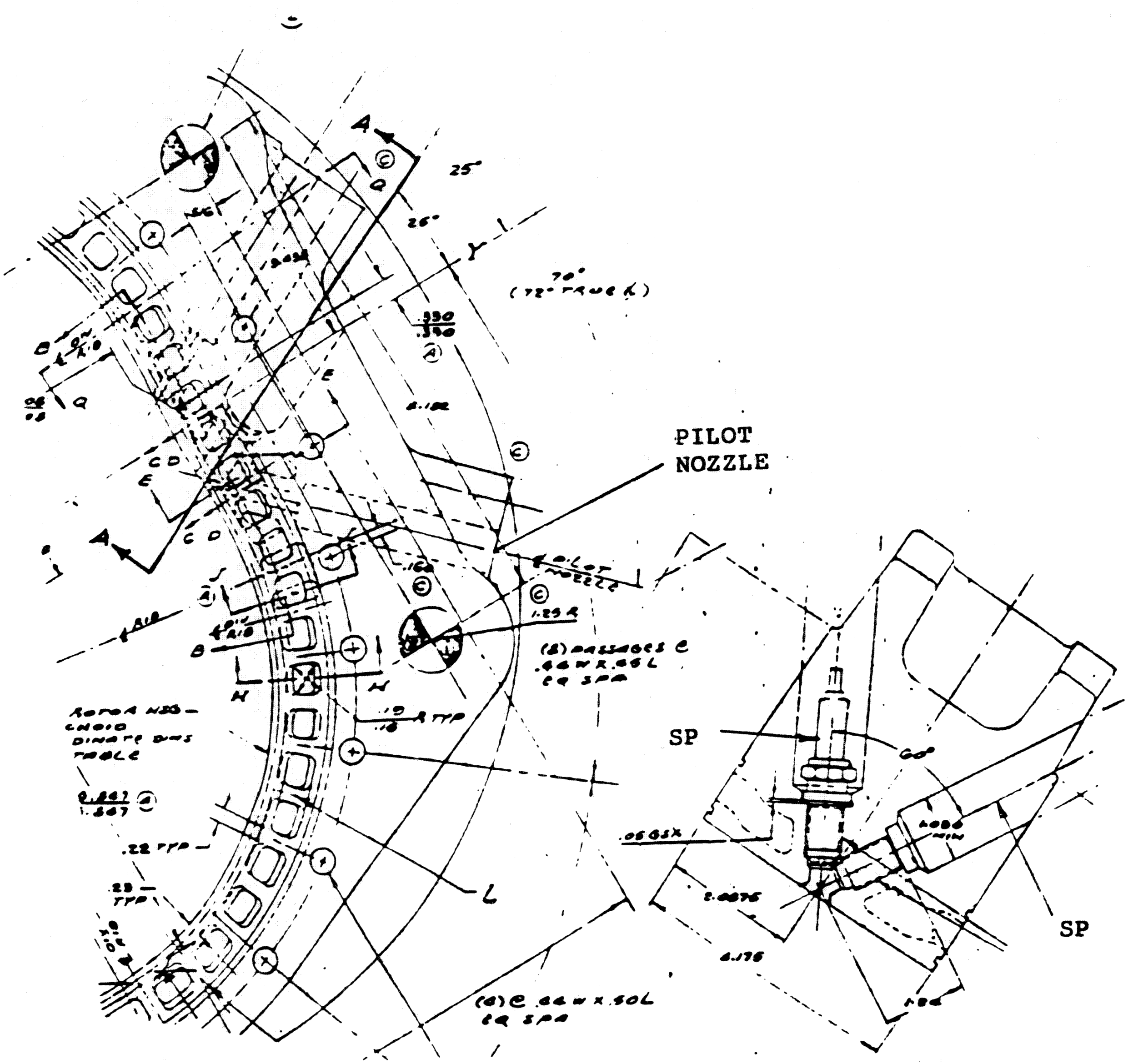


SECTION A-A

TWO SPARK PLUGS AT PILOT NOZZLE

FIG. 4.1.8.4-1

105 CU.IN., 170 SERIES MODEL ROTOR HOUSING DUAL IGNITION



SECTION A-A

TWO SPARK PLUGS
AT PILOT NOZZLE

FIG. 4.1.8.4-2

2013R NASA REFERENCE ENGINE

TWO SPARK PLUG INSTALLATION - BEFORE & AFTER TDC

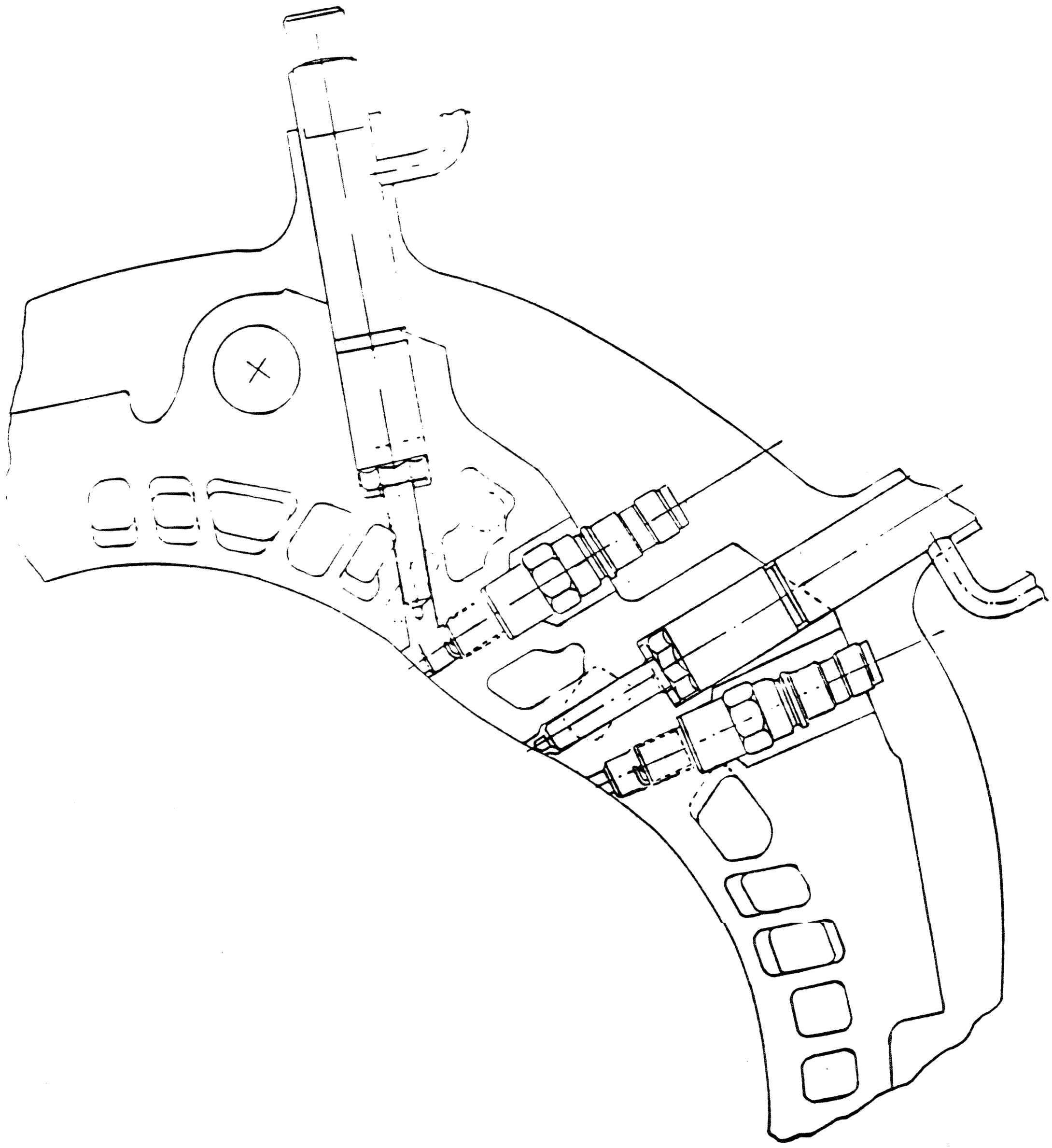


FIG. 4.1.8.4-3

4.1.8-5 Trade-off Analyses/Materials

Lighter weight, lower cost materials were considered where appropriate within the limits of maintaining required performance, safety and reliability capabilities. For the Stratified Charge Rotary Engine (SCRE) in general, the materials selection does not differ substantially over a wide range of engine displacements and power ranges. That is, all of the major housings are cast aluminum, the crankshaft is steel with carburized or induction hardened journals, counterweights and bolting complement are steel, rotor is cast nodular iron, stainless steel or carbon steel. Various lighter weight, lower cost components utilizing composites construction, nylon, etc have been considered in some lightly loaded parts such as accessory drive gears; titanium has been considered as a possible rotor material and as a substitute for some other steel components (through bolts, etc) where the weight vs. cost trade-off may permit its usage. On-going apex and side seal materials evaluations were considered and their influences on cost and durability while having little or no impact on size and weight.

Factors influencing our selection of materials are:

- Prior Experience (Engine Test)
- Basic Mechanical Properties (Modulus of Elasticity, Ultimate Tensile Strength, Yield Strength, Notch Sensitivity, Fatigue Strength, Creep Strength, etc)
- Loading (Static, Dynamic, Steady, Vibratory)
- Machinability
- Castability
- Weld Repair Capability
- Temperature Capability
- Corrosion Factors
- Weight
- Cost
- Availability

4.1.9 Required Technical Innovation

One area wherein technical innovation and further advancement of the state-of-the art would provide significant return and improve reliability, safety and basic performance is in the Advanced Electronic Fuel Injection System. This has been identified as the critical technology in past technology enablement efforts with the Stratified Charge Rotary Engine (SCRE). Evaluation of the advanced, high speed unit injector (HSUI) system during contract NAS3-26920 was basically limited to single rotor operation except for a brief checkout on the twin rotor engine. Further testing and further refinement of this system is necessary. Innovative improvements and modifications are needed to achieve a) full range operational capabilities with uniform, regular combustion, b) high efficiencies throughout the start-up to take-off power range with particular emphasis on the maximum cruise point and, c) reduced light load smoke. Testing during the NAS3-26920 program did not complete a) an evaluation of the fuel flow rate at the end of injection and, b) pilot fuel flow quantity. Further investigation of these parameters may provide improved fuel consumption at cruise power ratings. Also, subsequent refinement to a single lever control system integrating the engine and propeller control functions would be desired. A system schematic for the HSUI advanced fuel injection system is shown in Figure No. 4.1.9-1.

A more complete technical discussion on this critical technology item is provided in the SAE Technical Paper Series, number 950452, presented at the International Congress and Exposition, Detroit Michigan, February 27 — March 2, 1995.

HSUI System Schematic

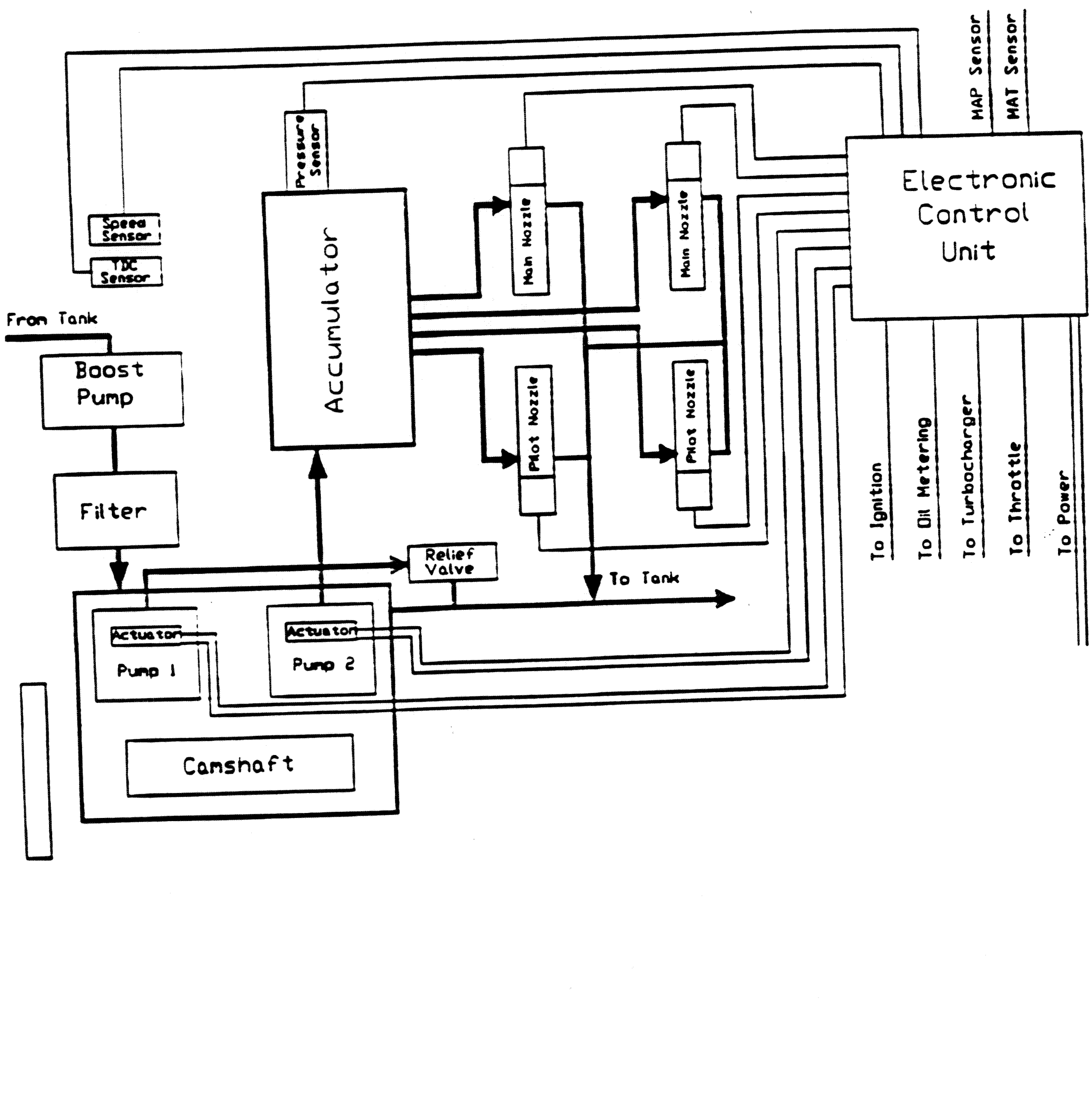


FIG. 4.1.9-1

4.1.10 Manufacturing Challenges

The primary manufacturing challenges for the Stratified Charge Rotary Engine (SCRE) are to conduct an extensive and effective value engineering program. reduce tolerances and fits/finishes to less costly levels. evaluate those changes in engineering test programs and achieve a cost effective. high performing product. Cost studies by the major manufacturing entities of Deere & Co.. General Motors. Curtiss-Wright, Textron Lycoming and others all indicate that the SCRE will be 5-15% lower in cost than equivalent power reciprocating engines. However, to achieve that low cost will require a substantial reduction in parts tolerances and fits relative to current engines. In addition. there are some special areas in SCRE needing cost reduction. i.e. trochoid coating and finishing, rotor seal slots finishing and improved side housing surfaces.

Various studies have concluded that the tolerance relief needed for cost reduction can be incorporated without serious compromises in performance. Also, that the trochoid coating, seal and side housing face performance and durability can be achieved with lower systems and that some reduction in cost will result from high volumes and learning.

4.2 BENEFITS OF THE PROPOSED PROPULSION SYSTEM

The Stratified Charge Rotary Engine (SCRE) family of advanced general aviation propulsion systems offers a variety of benefits to new aircraft and to many existing aircraft (through retrofit).

These benefits are:

- MULTI-FUEL capability of the SCRE permits usage of alternate fuels such as Jet-A. This is a major factor supporting the Stratified Charge Rotary Engine vs the piston engine which is dependent upon Avgas. Avgas is in short supply in many parts of the world and is very costly in Europe. Multifuel capabilities will become increasingly important in the United States as the aviation portion of the Clean Air Act of 1991 takes effect and leaded fuels usage is restricted.

- PERFORMANCE - The Stratified Charge Rotary Engine operates efficiently over a wide load and speed range. Specific fuel consumption levels are equal to or better than the best reciprocating engines. However, with the Stratified Charge Rotary Engine this performance can be achieved with Jet-A fuel which is not possible with the Avgas dependent reciprocating engine. Power density for all versions is superior to most reciprocating aircraft engines. Altitude performance for the turbocharged rotary offers flat rating of take-off power to 20,000 ft. altitude and max. cruise (75%) power to 25,000-27,000 ft. altitude. This altitude performance can be achieved with conventional turbochargers (<4:1PR) and intercooling. These characteristics are equivalent to the more advanced reciprocating engines with similar turbomachinery. These are very desirable characteristics avoiding severe lapse rates as experienced in turbine engines.

- SIZE of the Stratified Charge Rotary Engines is significantly smaller and the shape is circular, thus allowing for improved profiles in new aircraft design. Even with a Dual-Pac arrangement, two Rotary Engines can be accommodated in the space formally required for one piston engine. In the area of retrofit the Rotary can be installed with space to spare, thus allowing for changes in the cowling of the aircraft that reduce drag and increase speed, thereby improving range, improving payloads and reducing costs due to shortened time enroute for flights.

- FUEL CONSUMPTION rates for the Stratified Charge Rotary Engine are comparable or better than the piston while outperforming the turbine by a wide margin.

- SAFETY AND RELIABILITY are enhanced by the fact that the rotary design, with its reduced and none opposed internal movements has a greatly reduced exposure to catastrophic failure. The incidence of catastrophic failure is further lessened due to the simplicity of the design of the rotary engine resulting in far fewer moving parts and total parts. With a liquid cooled powerplant the safety of cabin temperature systems is tremendously improved. The piston engines available today are at the limit of design capabilities, as evidenced by the difficulty in sustaining overall performance at an acceptable maintenance and cost level when power exceeds 300 HP.

- o INITIAL COSTS of the Stratified Charge Rotary Engine are approximately 25% of the turbine engine, and are competitively priced with the piston engine (without factoring in the inherent advantages of the Rotary over the piston). While there is a required retrofit of existing aircraft to accommodate the Rotary Engine there is no major airframe modification as is typical of turbine engine retrofit.

- o LIQUID COOLED capabilities provide quantum benefits. An air cooled engine must deal with "shock cooling" or having the engine become rapidly cooled as the aircraft descends and engine manufacturers must take this into account when manufacturing the engine and allow appropriate tolerances. In effect these engines are built "partially worn" to accommodate this factor. Liquid cooled engines do not have this problem. The liquid cooling also has an extremely positive effect on increasing engine life and also offers a safer cabin temperature management system.

- o TOTAL LIFE CYCLE COSTS are greatly enhanced due to the inherent advantages of the engine. One major feature of the Rotary Engine is the potential for 3000 Hour time between overhaul (TBO), which dramatically extends engine life as compared to the piston engine. Alternate fuels, higher speeds, greater hauling capacity, higher altitudes, increased ranges and reduced acquisition costs when compared to the turbine create a dramatic breakthrough for the aviation community.

- o OPERATIONAL CHARACTERISTICS are smooth and vibration free, throttle response and engine operation are predictable and responsive.

- o DURABILITY and MAINTAINABILITY are enhanced by virtue of the design simplicity, shape and size, longer maintenance intervals and significantly reduced moving parts. A comparison of the internal moving parts of the Rotary versus the piston serves testimony to the ruggedness of the engine.

- o NOISE & EMISSIONS - The Rotary engine exhaust noise is of a higher frequency than comparable reciprocating powerplants and hence the noise is easier to attenuate. Casing mechanical noises in the Rotary engine are lower than comparable reciprocating engines by virtue of having no valve train and lower shaking forces. Emissions levels for the Stratified Charge Rotary engine are low for all conditions of taxi, take-off, climb, cruise and idle. (NO_x is particularly low; CO is low by virtue of operation at .03-.04 F/A ratio; unburned HC is equivalent to the reciprocating engines).

We believe the afore itemized benefits of the proposed propulsion system remain consistent with NASA LeRC's summary of system benefits and comparison between turboprop, gasoline spark ignition engines and rotary in the circa 1982 studies, Figures 4.2-1 and 4.2-2.

Figure 4.2-3 provides a comparison of some existing piston engines, including the advanced technology, liquid cooled TS10L-550 engine with some rotary engine options. The TS10l-550 engine is dependent upon aviation gasoline. The 170 series model 2034R engine offers a competitive package at higher HP, Jet-A capability, low BMEP for high TBO and an improvement in cruise BSFC.

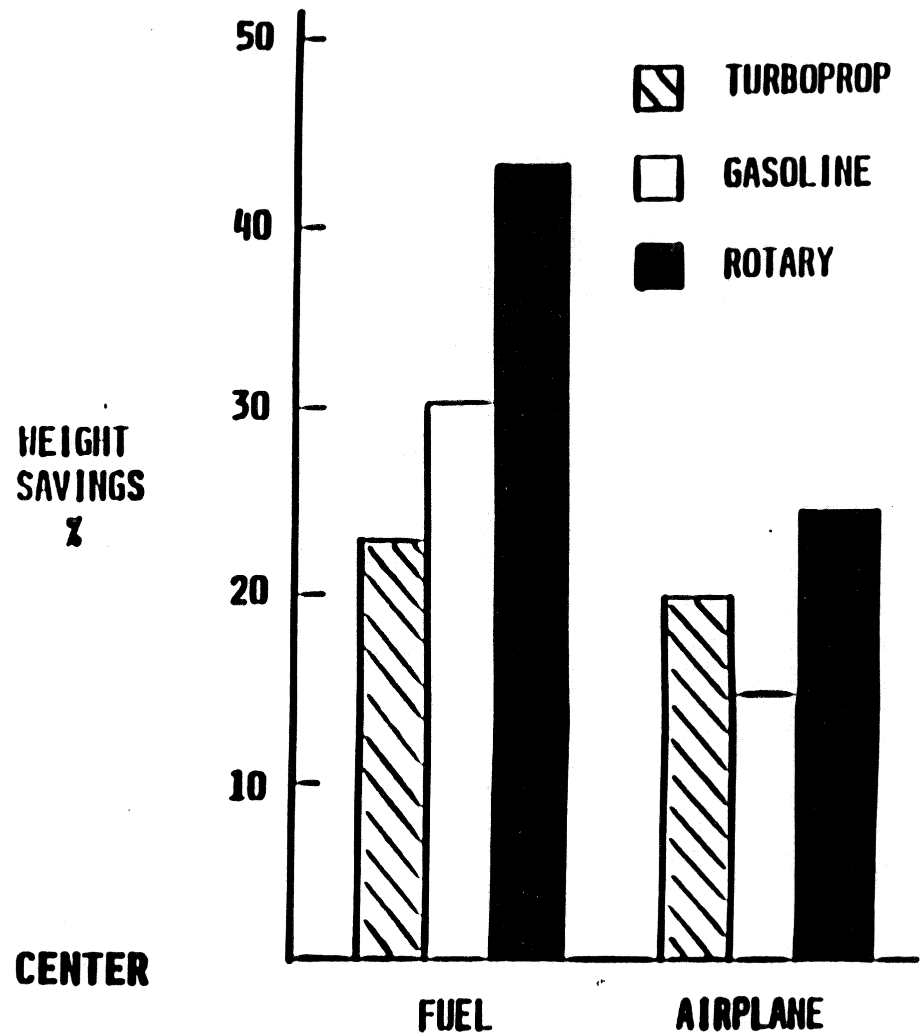
Figure 4.2-4 provides an engine comparison between Lycoming recip, Lycoming turbine and SCRE provided by Avco during the Avco/Deere joint program. Except for a slight difference in take-off Power (340 vs. 350), take-off BSFC (.50 vs. .45) and 26 in. diameter vs. 18 in. x 18 in., these numbers are representative of the projected 70 Series growth engine in Fig. 4.2-3. In contrast to the recip, the SCRE is non-Avgas dependent, has better BSFC and is lighter. Also, in contrast to the turbine, a substantial reduction in BSFC is available.

Appendix 8.1 provides additional comparisons between SCRE, recip and turbines in actuaL airplane performance.

Figure 4.2-5 provides a generalized summary comparison between Piston, Turbine and Rotary engines.

ADVANCED PROPULSION SYSTEM BENEFITS

- LIGHTER
- MORE EFFICIENT
- COMPACT
- LOW DRAG INSTALLATION
- MULTIFUEL
- MORE DURABLE, RELIABLE
- LESS MAINTENANCE
- LESS NOISE, VIBRATION
- CLEANER



SOURCE: NASA LEWIS RESEARCH CENTER

FIG. 4.2-1

SCRE ADVANTAGES RECOGNIZED BY NASA, CESSNA, BEECH AND MOST COMPETITIVE AIRCRAFT ENGINE BUILDERS

OPERATIONAL

- MULTI-FUEL CAPABILITY
- LOW FUEL CONSUMPTION
- MORE RAPID FLIGHT DESCENTS (LIQUID COOLING)
- LOW VIBRATION (FULLY BALANCED)
- SUPERIOR LOW TEMPERATURE STARTING (-36°C/32°F) WITHOUT AIDS
- IMPROVED RELIABILITY/LOW NUMBER OF PARTS
- LOW NOISE LEVEL
- SAFE CABIN HEAT

AIRFRAME

- LOW DRAG (SMALL FRONTAL AREA)
- LOW ENGINE WEIGHT
- REDUCED COOLING AIR DRAG
- COOLANT COOLERS CAN BE WING DE-ICERS

OTHER

- SIMPLE MAINTENANCE - NO VALVES OR CAMS
- FAMILIES OF ENGINES
- RETROFITABLE
- LOW EXHAUST EMISSIONS
- PROVEN PRODUCIBILITY

SOURCE: NASA LEWIS RESEARCH CENTER

FIG. 4.2-2

GENERAL AVIATION FIXED WING ENGINE COMPARISONS

	PISTON ENGINES				ROTARY OPTIONS	
	TSIO-520	Air Cooled	GTSIO-520	TSIOL-550 Liquid Cooled	70 Series Growth	170 Series Near Term
MODEL	BE	WB	K	—	2013R	2034R
Power at Take-off - BHP	310	325	435	350	340	425
RPM at Take-off	2600	2700	3400	2600	8000	5800
Rated Manifold Pressure-in.Hg Abs.	38.0	39.5	44.5	40.0	53	47
Engine Displacement, in.^{3}	520	520	520	552	80	210
Power at Max. Cruise - BHP	235	248	325	260	255	318
RPM at Max. Cruise	2400	2500	2900	2500	6000	4350
BSFC at Take-off-Lbs./BHP-Hr	.68	.63	.70	0.63	0.50	0.44
BSFC at Max. Cruise - Lbs./BHP-Hr	.39	.42	.47	0.39	0.38	0.38
BMEP at Take-off, psi	182	183	195	194	208	138
BMEP at Max. Cruise, psi	149	151	171	150	172	138
Introductory TBO - Hrs	-	-	-	2200	2000	2500
Actual TBO Hours	2000	2000	1600	-	-	-
Engine (W*H)(w/o turbocharger)-in.	(33.5*23.0)	(33.5*20)	(34*26)	(33.5*22.0)	(26.0*26.0)	(28.0*28.0)
Engine Length (w/o turbocharger)-in.	41	41	43	42.6	44.5	48.4
Engine Dry Weight-Lbs.	566	559	616	542	380	538
Engine Wet Weight-Lbs.	584	577	637	631	445	628

TSIOL-550:
- o The competition

2034R:
- o Competitive package
- o Higher Power
- o Jet-A Capability
- o BMEP @ Good Level for introduction to service
- o Cruise SFC 2.5% improvement vs. piston engine (best)

Figure 4.2-3

ENGINE COMPARISON

	TIO-540-J	LTP -101 TURBINE	S/C ROTARY AIRCRAFT
TAKEOFF	350 B¶ @ 2575 RPM TO 20,000 FT., 65 LB/¶-HR	600 B¶ @ 32000 RPM .55 BSFC @ SEA LEVEL 400 BHP @ 20,000 FT., .60 BSFC	350 B¶ @ 6000 RPM TO 20.000 FT., .45 BSFC
CRUISE	75% TO 25.000 FT .45 LB/¶-HR BSFC	75% AT S.L., .57 BSFC	75% TO 25.000 FT .38 LB/¶-HR BSFC
WEIGHT	521 LBS.	335 LBS	400 LBS
HEIGHT	22.6 IN.	22.8 IN.	18 IN.
WIDTH	34.2 IN.	23.3 IN.	18 IN.
LENGTH	51.5 IN.	37.37 IN.	57 IN.
FUEL	100 LOW LEAD AVGAS (MIN)	JET A JP 4	JET A
			40% FEWER PARTS

FIG. 4.2-4

GENERAL COMPARISON

PISTON, TURBINE, ROTARY ENGINES

ITEM	PISTON	TURBINE	ROTARY
Initial Cost	low	4 to 5X Piston	Same as Piston
Fuel Usage	low	20% higher vs Piston	2 to 15% lower vs Piston
Weight/Power	high	low	medium
Service Intervals	1600/2000 Hrs.	3000/5000 Hrs	2500/3000 Hrs.
Power Ability	low	high	medium/high
Low Altitude Efficiency	high	low	high
Alternate Fuel Capability	none-must have leaded AVGAS	Various JP Fuels, Jet A, JP-5, JP-8	AVGAS and JP Fuels, Jet A, JP-4, JP-5, JP-8

FIG. 4.2-5

4.3 REVIEW OF PAST AND ON-GOING NASA PROGRAMS FOR RELEVANT TECHNOLOGY

Our review of past programs included a detailed review of final reports on rotary engines (Curtiss-Wright), reciprocating spark ignition engines (Teledyne Continental, Aircraft Products Division), reciprocating diesel aircraft engines (Teledyne Continental, General Products Division) and the GATE studies (as summarized in NASA Technical Memorandum 79073, "New opportunities for Future Small Civil Turbine Engines - Overviewing the GATE studies") all in the late 70's early 80's time frame. Also, for rotary we reviewed the follow-on technology enablement contracts during the 1980's and through 1995. Further, we reviewed reports for small business incentive research efforts related to low friction coatings and thermal insulating coatings (i.e. NASA LeRC H. Sliney, Moller, Adiabatics). Also, we have taken into consideration in our estimates of sizing, performance and system capabilities potential improvements which can be related to projected advances from those prior efforts and actual demonstrated laboratory performance on component and/or twin rotor engine systems. Also, we have taken into consideration the rate of progress and resources applied in the prior long term technology enablement efforts in quantifying our projections of the resources requirements and schedules to achieve performance and reliability levels needed for FAA certification, production and entry into the fleet.

In terms of on-going programs i.e., during 1994 and 1995 we have maintained a dialogue with NASA LeRC in their planning toward a low cost, jet-A fuel aircraft powerplant: participated in the NASA LeRC managed workshop and follow-on coordination; provided data for rotary in support of NASA contractor ERAST analyses, provided data to a variety of university teams in NASA sponsored aircraft design competitions, briefed NASA AGATE management and coordinated possible rotary contribution or involvement there and briefed Dr. Robert Whitehead, et al at NASA Headquarters relative to a proposed industry consortium approach for a cost shared final development and FAA certification program. All of these NASA contacts, in addition to our contacts with reciprocating and turbine engine personnel (Textron-Lycoming, Teledyne Continental, Allison, Williams, Allied Signal) and various airframers (Cessna, Piper, Beech, Cirrus, Questar, Dimona, Sikorsky, Piasecki, Schweizer) and others i.e., Lockheed-Martin have influenced our planning and definition of what is required to transition the Stratified Charge Rotary Engine technology to the general aviation community.

We also reviewed potential value that might be derived from future 3-d combustion modeling efforts building upon the NASA/JDTI efforts in NAS3-25945 and NAS3-24628, Flow visualization and laser doppler velocimetry (LDV) laboratory investigations and performance analyses via NASA codes. Also, we have considered a possible effort with AGATE toward an advanced electronic control in a single level control system combined with the advanced electronic fuel injection system created in NAS3-26920.

4.4 PRELIMINARY TECHNOLOGY DEVELOPMENT PLAN, SCHEDULE, AND ESTIMATED COST

A preliminary development plan was defined in detail by outlining the specific technical tasks necessary through the design, detail and analysis, procurement, assembly and test elements of the program through FAA certification and production. The focus engine used was the 170 Series Model 2034R rated at 425 BHP/5800 RPM. This is the "primary" engine in that series for the SCRE family. Variations in these requirements in terms of time and cost for other engines in the family are projected as plus or minus differential appropriate to the different candidates. Trade-offs between the 170 Series (Model 2034R) as a primary engine in that series vs. the 70 Series primary engine (Model 2013R) were examined and led us to the conclusion that there was a negligible difference in total costs or time between those two candidate engines for a stand-alone program. While there are differences in prototype engine costs, fuel injection system costs, assembly time and costs, fuel and oil costs, etc. these tend to balance out somewhat or are negligible differences relative to the basic overall costs.

Figure 4.4-1 and 4.4-2 provide a summary of technology development plan tasks and schedules, reflecting a 28 month period necessary to conduct the final development and FAA certification program. Flight testing is included in the tasks noted therein as well as the time allowances for dynamometer and propeller test stand testing. Figures 4.4-3 and 4.4-4 provide a detail description of the testing necessary with a breakdown by engine number and build number.

The overall costs estimated to achieve the final development, FAA certification and production preparations were shown in Section 3.0 of this study report, specifically Figure No. 3.0-2. Those costs were in four categories with the major element related to the technology and being the "development and engineering costs." An analysis of these costs is provided in Figure 4.4-5 and attachments herein.

For cost estimating purposes, Rotary Power International, Inc. (RPI) departmental disciplines and material/other direct cost codes were used. Also, RPI departmental labor rates by year projected for the period through CY1998 were used. For overhead cost estimates we applied an overhead projected for the proposed "Rotary Aircraft Engines Corporation," (RAEC) since formation of a separate organization is planned specifically for reduced overhead purposes.

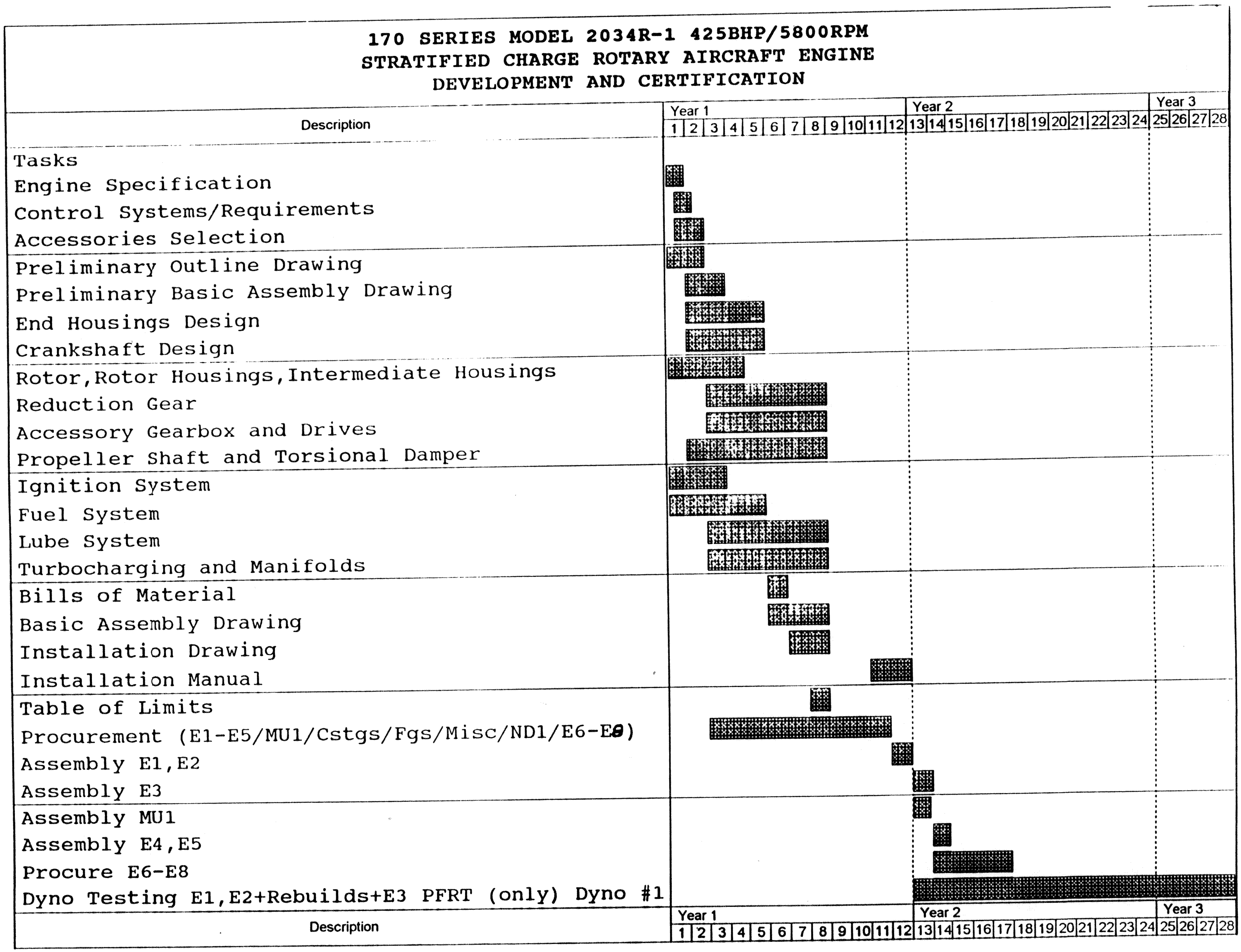

170 SERIES MODEL 2034R-1 425BHP/5800RPM
STRATIFIED CHARGE ROTARY AIRCRAFT ENGINE
DEVELOPMENT AND CERTIFICATION
Description
Year 1
Year 2
Year 3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Tasks
Engine Specification
Control Systems/Requirements
Accessories Selection
Preliminary Outline Drawing
Preliminary Basic Assembly Drawing
End Housings Design
Crankshaft Design
Rotor,Rotor Housings,Intermediate Housings
Reduction Gear
Accessory Gearbox and Drives
Propeller Shaft and Torsional Damper
Ignition System
Fuel System
Lube System
Turbocharging and Manifolds
Bills of Material
Basic Assembly Drawing
Installation Drawing
Installation Manual
Table of Limits
Procurement (E1-E5/MU1/Cstgs/Fgs/Misc/ND1/E6-E8)
Assembly E1,E2
Assembly E3
Assembly MU1
Assembly E4,E5
Procure E6-E8
Dyno Testing E1,E2+Rebuilds+E3 PFRT (only) Dyno #1
Description
Year 1
Year 2
Year 3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

FIG. 4.4-1

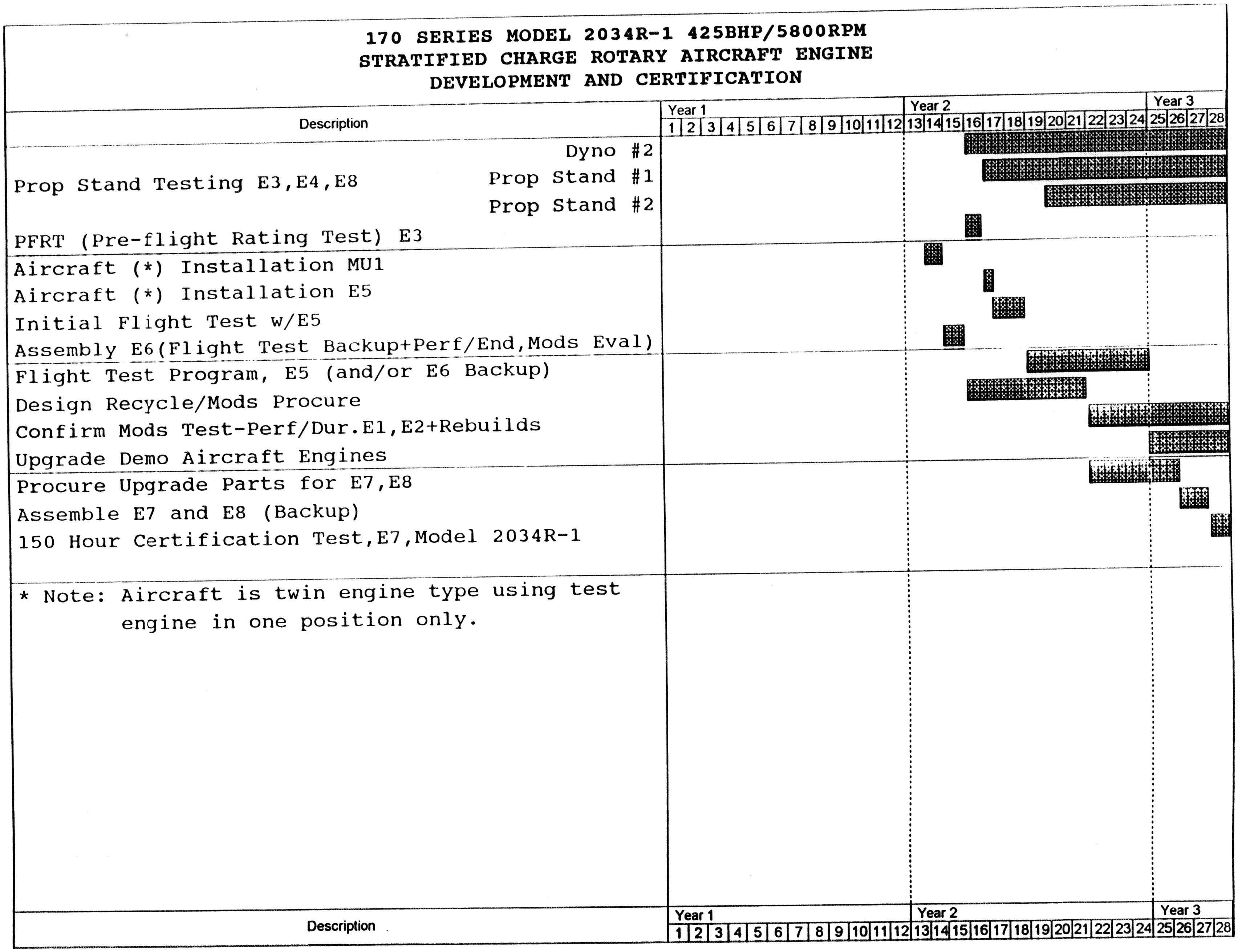

170 SERIES MODEL 2034R-1 425BHP/5800RPM
STRATIFIED CHARGE ROTARY AIRCRAFT ENGINE
DEVELOPMENT AND CERTIFICATION
Description
Year 1
Year 2
Year 3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Prop Stand Testing E3,E4,E8
Dyno #2
Prop Stand #1
Prop Stand #2
PFRT (Pre-flight Rating Test) E3
Aircraft (*) Installation MU1
Aircraft (*) Installation E5
Initial Flight Test w/E5
Assembly E6(Flight Test Backup+Perf/End,Mods Eval)
Flight Test Program, E5 (and/or E6 Backup)
Design Recycle/Mods Procure
Confirm Mods Test-Perf/Dur.E1,E2+Rebuilds
Upgrade Demo Aircraft Engines
Procure Upgrade Parts for E7,E8
Assemble E7 and E8 (Backup)
150 Hour Certification Test,E7,Model 2034R-1
* Note: Aircraft is twin engine type using test engine in one position only.
Description
Year 1
Year 2
Year 3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

FIG. 4.4-2

170 SERIES MODEL 2034R-1 425BHP/5800RPM
STRATIFIED CHARGE ROTARY AIRCRAFT ENGINE
DEVELOPMENT AND CERTIFICATION

Description	
DYNO NO.1	
E1-1 Startup	50HRS.
E2-1 Startup	50
E1-2 Performance Calibration	100
E3-1 PFRT	100
E1-3 Performance Calibration	150
E2-2 Performance Calibration	100
E2-3 Oil Metering/Consumption	300
E1-4 Performance Calibration	150
E2-4 Controls Setup	50
E2-5 Mission Duty Cycle (Perf.)	100
E2-6 Mods Evaluation (Perf.)	300
E2-7 Mods Evaluation (Perf/End)	600
Total	2050HRS.
DYNO NO. 2	
E1-5 Oil Metering/Consumption	300HRS.
E1-6 Controls Setup	100
E1-7 Mission Duty Cycle (Perf/End)	100
E1-8 Mission Duty Cycle (Perf/End)	200
Total	700HRS.
Total Dyno Hours = 2,750	
Description	

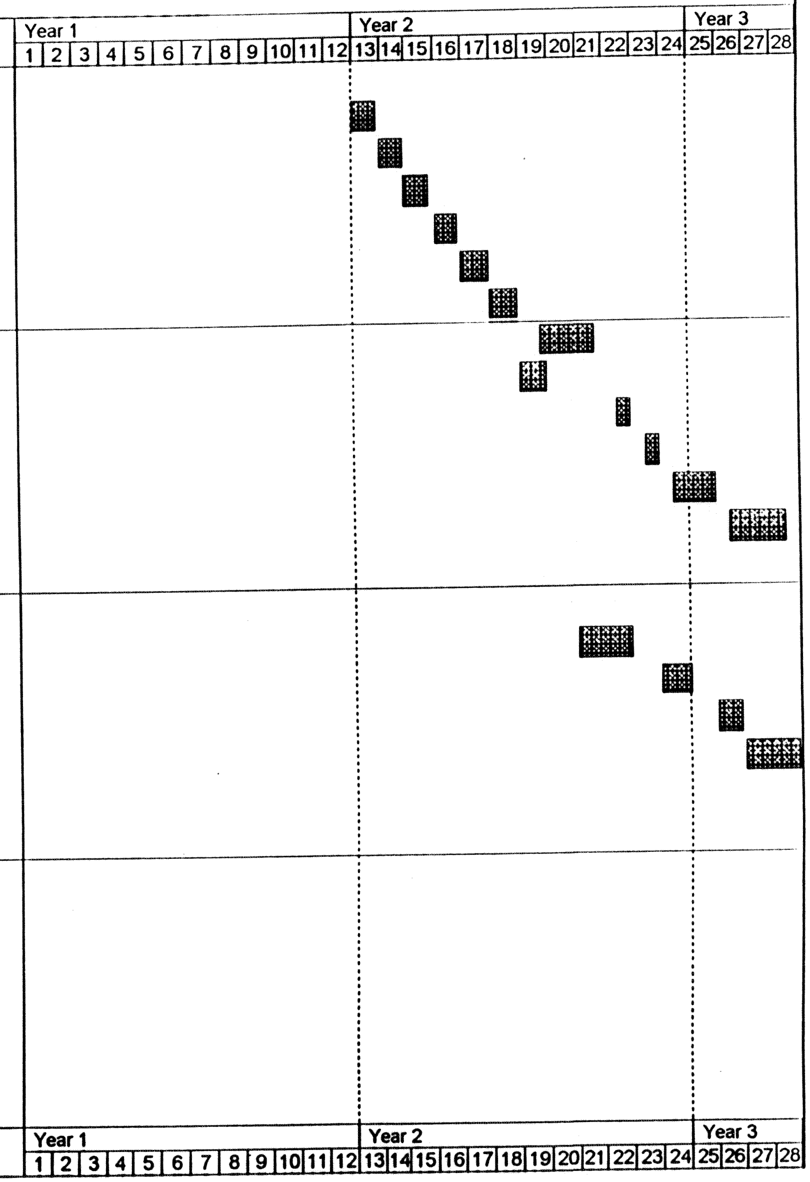


FIG. 4.4-3

170 SERIES MODEL 2034R-1 425BHP/5800RPM
STRATIFIED CHARGE ROTARY AIRCRAFT ENGINE
DEVELOPMENT AND CERTIFICATION

Description	
PROP STAND NO. 1	
E3-2 Performance	250HRS.
E3-3 Endurance	600
E3-4 Mods Evaluation	1000
Total	1850HRS.
PROP STAND NO. 2	
E4-1 Performance	200HRS.
E4-2 Mission Duty Cycle (Endurance)	600
E4-3 Mission duty Cycle (Endurance)	600
Total	1400HRS.
PROP STAND NO. 1	
E7-1 150 Hr. Certification Test	150
Overall Total Prop Stand Hours	3,400Hrs.
Description	

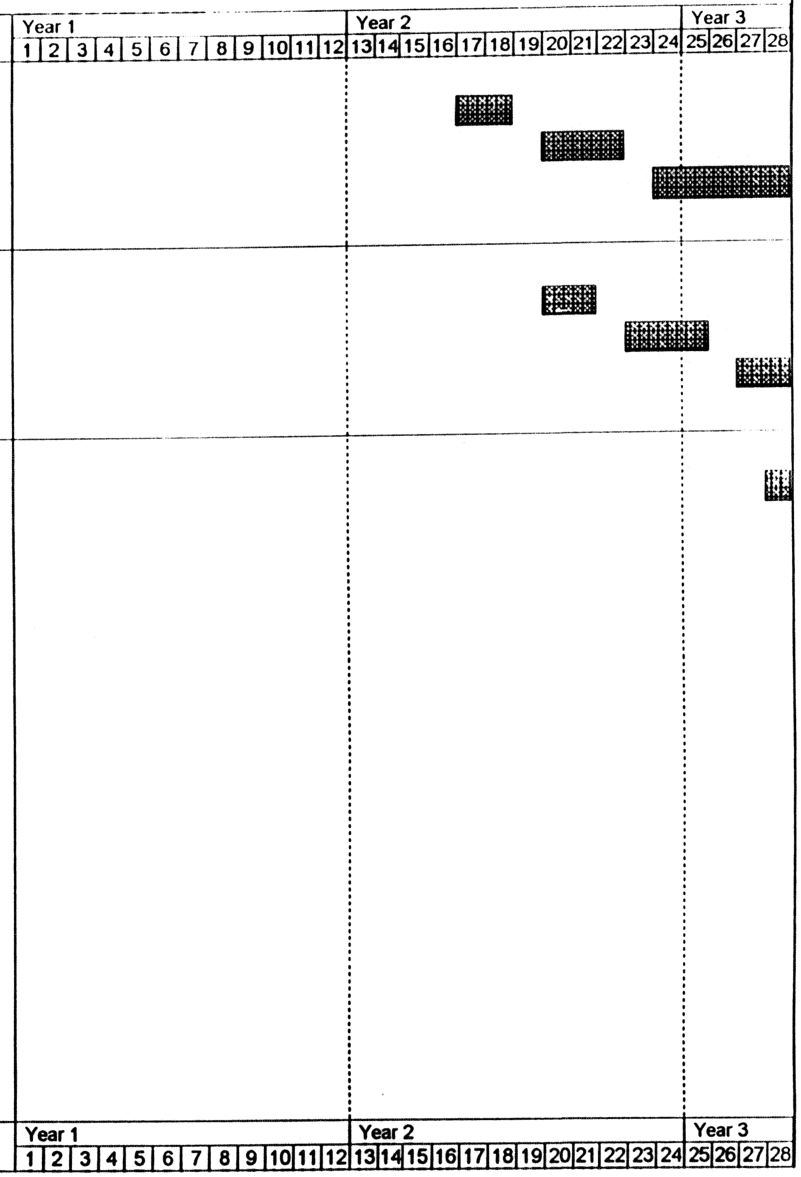


FIG. 4.4-4

STAFFING ESTIMATE AND RESOURCES REQUIREMENT

ASSUMING JULY 1, 1996 START-UP

28 MONTHS PROGRAM

CAL. YEAR	1996	1997	1998	TOTALS
STAFF HOURS	15463	42219	39401	97083
DIRECT LABOR,$	439329	1151911	1077185	2668425
OVERHEAD,$	298744	783301	732488	1814533
MATERIALS,$	150000	1875500	199700	2225200
TOTAL COST,$	888073	3810712	2009373	6708158

SEE ATTACHED DETAILS FOR MONTHLY DISTRIBUTION, DEPARTMENTAL DISTRIBUTION, DEPARTMENTAL AND MATERIAL CODES, LABOR RATES, OVERHEAD RATES AND SUPPORTIVE PLANNING ESTIMATES

FIG. 4.4-5

SUPPORTIVE COST ANALYSIS
DETAILS FOR FIGURE 4.4-5

T: PSB344
2

Rotary Power International, Inc
TIME-PHASED REPORT

DATE PRINTED 27 OCT 95 08:31

ISAL: 2034D SC Rot. Aircraft Eng.170Series

BY CID

FN ROC	WK.PG	CE	JUL96	AUG96	SEP96	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97
		SH	1830	2358	2560	3385	2949	2381	2745	2368	2209	2543
		DL	56561	71413	72738	93677	80621	64319	79470	67753	63914	71942
		OH	38461	48561	49462	63701	54821	43738	54040	46072	43462	48921
		M$	2000	10000	12000	22000	52000	52000	77000	162000	162000	302000
		FC	97022	129974	134200	179378	187442	160057	210510	275825	269376	422863
		ST	97022	129974	134200	179378	187442	160057	210510	275825	269376	422863
		SP	97022	129974	134200	179378	187442	160057	210510	275825	269376	422863

CE	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	NOV97	DEC97	JAN98	FEB98	PAGE LINE TOTAL
SH	3080	3645	4012	4014	3980	5391	4234	3998	4871	4656	67209
DL	84962	96675	108794	107212	106393	146564	112253	105979	133838	127528	1852606
OH	57775	65738	73980	72904	72347	99663	76332	72067	91010	86719	1259774
M$	302000	202000	264500	2000	12000	164000	112000	114000	60000	52000	2137500
FC	444737	364413	447274	182116	190740	410227	300585	292046	284848	266247	5249880
ST	444737	364413	447274	182116	190740	410227	300585	292046	284848	266247	5249880
SP	444737	364413	447274	182116	190740	410227	300585	292046	284848	266247	5249880

LEGEND:

SH = STAFF HOURS
DL = DIRECT LABOR
OH = OVERHEAD
M$ = MATERIAL DOLLARS
FC = FACTORY COST

ORT: PSB344
E: 3

Rotary Power International, Inc
TIME-PHASED REPORT

DATE PRINTED 27 OCT 95 08:31

POSAL: 2034D SC Rot. Aircraft Eng.170Series

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S	FN ROC	WK.PG	CE	MAR98	APR98	MAY98	JUN98	JUL98	AUG98	SEP98	OCT98	REM.	PAGE LINE TOTAL	REPORT LINE TOTAL
			SH	4664	4206	3600	3977	3379	3294	3427	3327		29874	97083
			DL	125451	113778	98742	109033	92633	90039	93021	93122		815819	2668425
			OH	85307	77369	67146	74143	62991	61226	63254	63323		554759	1814533
			MS	39700	10000	10000			10000	10000	8000		87700	225200
			FC	250458	201147	175888	183176	155624	161265	166275	164445		1458278	6708158
			ST	250458	201147	175888	183176	155624	161265	166275	164445		1458278	6708158
			SP	250458	201147	175888	183176	155624	161265	166275	164445		1458278	6708158

'ORT: PSB344
E: 4

Rotary Power International, Inc
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S / S DESCRIPTION	FN ROC	WK.PG	CE	JUL96	AUG96	SEP96	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	NOV97	DEC97	JAN98	FEB98	PAGE LINE TOTAL
00 velopment & Certification	9912		M$															10000	10000	10000	10000	10000	10000	60000
PORT CE TOTALS			IM	10.4	13.4	16	18.4	19.4	18.6	15.6	14.8	13.15	14.45	17.5	21.7	22.8	23.9	23.7	29.3	29.4	29.4	29	29.1	410
			M$	2000	10000	12000	22000	52000	52000	77000	162000	162000	302000	302000	202000	264500	2000	12000	164000	112000	114000	60000	52000	2137500

ORT: PSB344
E: 5

Rotary Power International, Inc
TIME-PHASED REPORT

DATE PRINTED 27 OCT 95 08:33

OPOSAL: 2034D SC Rot. Aircraft Eng.170Series

BY WBS BY ROC.CD

S / S DESCRIPTION	FN ROC	WK.PG	CE	MAR98	APR98	MAY98	JUN98	JUL98	AUG98	SEP98	OCT98	PAGE LINE TOTAL	REPORT LINE TOTAL
00	9912		M$	10000	10000	10000			10000	10000	8000	58000	118000
velopment & Certification													
PORT CE TOTALS			IM	26.5	23.9	22.5	22.6	19.2	19.6	20.4	18.9	173.6	583.6
			M$	39700	10000	10000			10000	10000	8000	87700	2225200

RT: PSB344
E: 2

Rotary Power International, Inc
TIME-PHASED REPORT

DATE PRINTED 27 OCT 95 08:33

POSAL: 2034D SC Rot. Aircraft Eng.170Series

BY WBS BY ROC.CD

FN	ROC	WK.PG	CE	DESCRIPTION	JUL96	AUG96	SEP96	OCT96	NOV96	DEC96	JAN97	FEB97	MAR97	APR97	MAY97	JUN97	JUL97	AUG97	SEP97	OCT97	NOV97	DEC97	JAN98	FEB98	PAGE LINE TOTAL
00	2010		IM	velopment & Certification	2	2	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2	2	2	2	1.4	1.4	1.4	1.4	31.6
00	2020		IM	velopment & Certification	3	5	6	6	6	5	4	3	2.4	2.4	2.4	2.4	1.4	1.4	1.4	5	5	5	4	4	74.8
00	2030		IM	velopment & Certification	2.4	2.4	2.4	3	3	3	3	3	3	3	4	5	7	7	7	7	7	7	7	7	93.2
00	2040		IM	velopment & Certification	3	4	5	6	6	6	4	3	1.6	1.6	1.6	1.6	1.4	1.4	1.4	4	4	4	4	3.6	67.2
00	2050		IM	velopment & Certification									.45	.75	1.5	4.5	5.5	7	7	7	7.7	7.7	7.7	8.5	65.3
00	3010		IM	velopment & Certification			.6	.6	1	1	1	1.6	1.6	2	2.5	2.5	2	1.8	1.8	1.5	1.5	1.5	1.8	1.8	28.1
00	3020		IM	velopment & Certification			.6	.6	1	1	1	1.6	1.6	2	2.5	2.5	2	1.8	1.8	1.5	1.5	1.5	1.8	1.8	28.1
00	6020		IM	evelopment & Certification				.8	1	1.2	1.2	1.2	.8	.8	.8	.8	.5	.5	.5	.5	.8	.8	.8	.5	13.5
000	6040		IM	evelopment & Certification									.3	.5	.8	1	1	1	.8	.8	.5	.5	.5	.5	8.2
000	9902		M$	evelopment & Certification							50000	50000	50000												150000
000	9903		M$	evelopment & Certification								100000	100000	300000	300000	200000	250000			150000	100000	100000	50000	40000	1690000
1000	9904		M$	Development & Certification				10000	40000	40000	25000	10000	10000												135000
1000	9906		M$	Development & Certification	2000	10000	10000	10000	10000	10000							2000	2000	2000	2000	2000	2000			64000
1000	9910		M$	Development & Certification			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	12500			2000		2000		2000	38500

ORT: PSB344
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TIME-PHASED REPORT

DATE PRINTED 27 OCT 95 08:33

POSAL: 2034D SC Rot. Aircraft Eng.170Series

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S / S DESCRIPTION	FN ROC	WK.PG	CE	MAR98	APR98	MAY98	JUN98	JUL98	AUG98	SEP98	OCT98	PAGE LINE TOTAL	REPORT LINE TOTAL
00 velopment & Certification	2010		IM	1.4	1.4	1.4	1.4	1.2	1.2	1.2	1.4	10.6	42.2
00 velopment & Certification	2020		IM	2	1.4	1.4	1.4	1	1	1	1	10.2	85
00 velopment & Certification	2030		IM	7	7	7	7	6	6	6	6	52	145.2
00 velopment & Certification	2040		IM	3	1.6	1	1	1	1	1.6	1.6	11.8	79
00 velopment & Certification	2050		IM	8.5	8.5	7.7	7.7	6	6	6	4.5	54.9	120.2
00 velopment & Certification	3010		IM	1.8	1.5	1.5	1.5	1.5	1.7	1.8	1.8	13.1	41.2
00 evelopment & Certification	3020		IM	1.8	1.5	1.5	1.5	1.5	1.7	1.8	1.8	13.1	41.2
000 evelopment & Certification	6020		IM	.5	.5	.5	.5	.5	.5	.5	.3	3.8	17.3
000 evelopment & Certification	6040		IM	.5	.5	.5	.6	.5	.5	.5	.5	4.1	12.3
1000 Development & Certification	9902		M$										150000
1000 Development & Certification	9903		M$	27700								27700	1717700
1000 Development & Certification	9904		M$										135000
1000 Development & Certification	9906		M$										64000
1000 Development & Certification	9910		M$	2000								2000	40500

RPI DEPARTMENT DESCRIPTIONS AND MATERIALS/OTHER DIRECT COST CODES

SCREBUS.195

DEPT.	DESCRIPTION	MAT'L. & ODC CODE	DESCRIPTION
1020	Program Management	9901	Raw Material
2010	Engrg.Program Managers	9902	Castings & Forgings
2020	Design Engineering	9903	Finished Parts
2030	Development Engineering	9904	Tooling
2040	Design Support	9905	Test Equipment & Instr.
2050	Engineering Test	9906	Consultant
3010	Quality Engineering	9907	Outside Testing
3020	Quality Control	9908	Computer Cost
6020	Purchasing	9909	Misc. Purchasing
6030	Production Control/Materials	9910	Travel
6040	Facilities	9911	Publications
		9912	Fuel & Oil
6050	Manufacturing Operations	9913	Pack & Ship
		9918	Subcontract

SCREBUS.95

RPI DEPARTMENTAL LABOR RATES BY YEAR, THRU 1998

SCREBUS.95

Rotary Power International, Inc
HOURLY RATES REPORT

DATE PRINTED 27 OCT 95 08:34

...E TABLE: AIR95
CALC. FACTOR: F1 Hourly Rate

DEPT	DESCRIPTION	JAN94	JAN95	JAN96	JAN97	JAN98
1020	Program Management	39.35	40.98	43.03	45.18	47.44
2010	Engrg.Project Managers	43.33	45.71	48.00	50.40	52.92
2020	Design Engineering	29.50	30.62	32.15	33.76	35.45
2030	Development Engineering	26.03	27.27	28.63	30.06	31.56
2040	Design Support	18.30	19.13	20.09	21.09	22.14
2050	Engineering Test	16.72	17.50	18.37	19.29	20.25
3010	Quality Engineering	23.41	24.88	26.12	27.43	28.80
3020	Quality Control	14.74	15.36	16.13	16.94	17.79
6020	Purchasing	19.62	20.53	21.56	22.64	23.77
6030	Production Control/Materials	14.36	15.04	15.79	16.58	17.41
6040	Facilities	20.78	21.87	22.96	24.11	25.32
6050	Manufacturing Operations	25.70	29.43	30.90	32.44	34.06
7010	Business Development	65.00	67.14	70.50	74.02	77.72

RAEC OVERHEAD RATE AND MATERIAL ESCALATION BY YEAR, THRU 1997

SCREBUS.195

Rotary Power International, Inc
RATE TABLE REPORT

DATE PRINTED 27 OCT 95 08:34

.IE TABLE: AIR95
POOL: E
DESCRIPTION: Engineering Burden

FCTR	FACTOR DESCR.	JAN94	JAN95	JAN96	JAN97	JAN98
F1	Hourly Rate					
F2	Overhead Rate	.6800	.6800	.6800	.6800	.6800
F3	Material Escala	1.0000	1.0000	1.0000	1.0000	1.0000
F4	G&A	.0000	.0000	.0000	.0000	.0000
F5	IR&D/B&P	.0000	.0000	.0000	.0000	.0000
F6	COC labor	.0000	.0000	.0000	.0000	.0000
F7	COC factory cos	.0000	.0000	.0000	.0000	.0000
F8	Fee	.0000	.0000	.0000	.0000	.0000

..

SUPPORTIVE PLANNING ESTIMATES

SCREBUS.195

170 SERIES 2034R-1 ROTARY AIRCRAFT ENGINE

DEVELOPMENT AND CERTIFICATION PROGRAM

1995

MONTH		1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
LABOR														
DEPT NO.	CATEGORY													
1020	PROGRAM MGMT		SH/REM INCD. IN ~~RAEC~~ OH + SH ASSIST 6020/6040											
2010	PROJECT ENGRG	2.0	2.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	
2020	DESIGN ENGRG	3.0	5.0	6.0	6.0	6.0	5.0	4.0	3.0	2.4	2.4	2.4	2.4	
2030	DEVEL ENGRG	2.4	2.4	2.4	3.0	3.0	3.0	3.0	3.0	3.0	3.0	4.0	5.0	
2040	DESIGN SUPT.	2.0	4.0	5.0	6.0	6.0	6.0	4.0	3.0	1.6	1.6	1.6	1.6	
2050	TECHNICIANS	–	–	–	–	–	–	–	–	.45	.75	1.5	4.5	
3010/20	QUALITY	–	-	0.6	0.6	1.0	1.0	1.6	1.6	1.6	2.0	2.5	2.5	
6020	PURCHASING	–	–	-	0.8	1.0	1.2	1.2	1.2	0.8	0.8	0.8	0.8	SEE NOTE
6040	FACILITIES	–	–	–	–	–	–	–	–	0.3	0.5	0.8	1.0	1020
TOTAL HEADCOUNT														
MATERIALS														
9904	PATTERNS				10	40	40	25	10	10				
9902	CAST./FORG.							50	50	50				
9903	FIN.PARTS								100	100	300	300	300	
9906	CONSULTANT	2	10	10	10	10	10							
9910	TRAVEL			2	2	2	2	2	2	2	2	2	2	
9912	FUEL & OIL/COOL													
TOTAL MATERIALS														

LABOR: HRS-MW-MM
MAT: $ - $00 - $000

R. MOUNT

170 SERIES 2034R-1 ROTARY AIRCRAFT ENGINE

DEVELOPMENT AND CERTIFICATION PROGRAM

MONTH		13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
LABOR														
DEPT NO.	CATEGORY													
1020	PROGRAM MGMT	—	—	—	SEE PG 1			—	—	—	—	—	—	
2010	PROJECT ENGRG	2.0	2.0	2.0	2.0	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	
2020	DESIGN ENGRG	1.4	1.4	1.4	5.0	5.0	5.0	4.0	4.0	2.0	1.4	1.4	1.4	
2030	DEVEL ENGRG	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	
2040	DESIGN SUPT.	1.4	1.4	1.4	4.0	4.0	4.0	4.0	3.6	3.0	1.6	1.0	1.0	
2050	TECHNICIANS	5.5	7.0	7.0	7.0	7.7	7.7	7.7	8.5	8.5	8.5	7.7	7.7	
3010/20	QUALITY	2.0	1.8	1.8	1.5	1.5	1.5	1.8	1.8	1.8	1.5	1.5	1.5	
6020	PURCHASING	0.5	0.5	0.5	0.5	0.8	0.8	0.8	0.5	0.5	0.5	0.5	0.5	SEE NOTE
6040	FACILITIES	1.0	1.0	0.8	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1020
TOTAL HEADCOUNT														
MATERIALS														
9904	PATTERNS													
9902	CAST./FORG.													
9903	FIN.PARTS	250			150	100	100	50	40	277				
9906	CONSULTANT	2	2	2	2	2	2							
9910	TRAVEL	12.5			2		2		2	2	2	2	2	
9912	FUEL & OIL/COOL			10	10	10	10	10	10	10	10	10		
TOTAL MATERIALS														

LABOR: HRS-MW-MM

MAT: $ - $00 - $000

R. MOUNT

70 SERIES 2034R-1 ROTARY AIRCRAFT ENGINE

DEVELOPMENT AND CERTIFICATION PROGRAM

MONTH		25	26	27	28									TOTAL
LABOR														
DEPT NO.	CATEGORY													
1020	PROGRAM MGMT	—	—	—	—SEE PG 1									
2010	PROJECT ENGRG	1.2	1.2	1.2	1.4									
2020	DESIGN ENGRG	1.0	1.0	1.0	1.0									
2030	DEVEL ENGRG	6.0	6.0	6.0	6.0									
2040	DESIGN SUPT.	1.0	1.0	1.6	1.6									
2050	TECHNICIANS	6.0	6.0	6.0	4.5									
3010/20	QUALITY	1.5	1.7	1.8	1.8									
6020	PURCHASING	0.5	0.5	0.5	0.3									SEE NOTE
6040	FACILITIES	0.5	0.5	0.5	0.5									1020
TOTAL HEADCOUNT														
MATERIALS														
9904	PATTERNS													
9902	CAST./FORG.													
9903	FIN.PARTS													
9906	CONSULTANT													
9910	TRAVEL													
9912	FUEL & OIL/COOL	10	10	8										
TOTAL MATERIALS														

LABOR: HRS-MW-MM
MAT: \$ - \$00 - \$000

R. MOUNT

SUPPORTIVE COST DATA

ENGINES	NO. OF BUILDS	NO.OF REBUILDS	MAJOR	MINOR
E1	8	8	4	4
E2	7	7	3	4
E3	4	3	2	1
E4	3	2	1	1
E5	2	1	1	-
E6	2	1	1	-
E7	2	1	1	-
E8	1	0	-	-
ESTIMATED CORE ENGINE REBUILDS		23	13	10
ESTIMATED REDUCTION GEAR REBUILDS		23	5	20

ENGINE HARDWARE

8 TOTAL ENGINES @ 140k EA.*) 6 DEV/CERT	$ 840,000
) 2 FLIGHT	280,000
13 MAJOR REBUILDS @ 18% (CORE ENGINE,120K)	280,800
10 MINOR REBUILDS @ 10% (CORE ENGINE,120K)	120,000
5 MAJOR REBUILDS @ 18% (R/G, 20K)	18,000
20 MINOR REBUILDS @ 10% (R/G, 20K)	40,000
PLUS ALLOWANCE FOR MISC.EXTRA CASTINGS, ETC AND CONTINGENCY ON R/G (SHOWN IN CASTINGS/FORGINGS)	100,000
SUB TOTAL	$1,678,800
OVERALL CONTINGENCY FOR SHORTENED CYCLE PROCUREMENT AND TEST @ 25%	419,700
GRAND TOTAL	$2,098,500

NOTE: SHOW 1,718,500 IN 9903
280,000 IN FLIGHT PARTNER PROGRAM
100,000 IN 9902

*BASED UPON 2116R PROTOTYPES @ CURRENT COST OF 184K,
ESTIMATE 2034R-1 @ 120K* TOTAL CORE ENGINE PLUS 20K R/G = 140K EA.
RE DISCUSSION REM, WTF, LDR 10/27/84
* 65% FACTOR LDR/REM EST.

REM

SCREBUS.195

PATTERNS/TOOLING

NOSE SECTION (NEW)	20,000
R/G HOUSING	20,000
PE HOUSING (NEW)	30,000
ROTOR HOUSING (MODS)	15,000
ROTOR (MODS)	20,000
INTERMEDIATE HOUSING (MODS)	15,000
ACCESSORY HOUSING (NEW)	25,000
CRANKSHAFT (NEW POSSIBLE MODS) (SHOW IN CAST./FORG.)	50,000
TOTAL	$195,000

NOTE: SHOW 145K IN 9904
50K IN 9902

CONSULTANTS

FUEL INJECTION/CONTROLS (A.MEYER)	25,000
TURBOCHARGER (TBD)	15,000
PERFORMANCE (D. MEYERS)	2,000/MONTH 1ST TO 6TH MONTH 13TH TO 18TH MONTH

TRAVEL

PROCUREMENT SUPPORT,)	2K/MO	3RD-12TH MO.
DESIGN,ENG.PROJ.MGMT..)	2K	16TH MO.
MISC)	2K	20TH MO
	TOTAL 26K	

FUEL, OIL AND COOLANT

6150 HRS. TOTAL TEST TIME
300 HP AVG. EST. POWER LEVEL
0.42 LBS/HP-HR AVG EST. SFC

REM

SCREBUS.195

FUEL

$\frac{6150 \text{ X } 300 \text{ X } .42}{7}$ = 110.700 GAL

@ $1 GAL — USE 111K

OIL

1% OF W_f — 1107 GAL

@ $4/GAL — USE 5K

(4428)

COOLANT

4 TEST STANDS

200 GAL/TEST STAND

INITIAL FILL, FLUSH, LEAKAGE

800 GAL ETHYLENE - GLYCOL

@ $2/GAL EST. — USE 2K

($1600)

NOTE: As noted in Page 1. Supportive Cost Data. the cost of two engines for flight program is separated into "Flight Test" category

REM 10/28

SCREBUS.195

4.5 POTENTIAL MARKET IMPACT, ESTIMATED SALES, AND U.S. JOB CREATION (R&D, MANUFACTURING, AND INFRASTRUCTURE)

Final development, FAA certification and production of the Stratified Charge Rotary Engine (SCRE) would provide an aviation powerplant capable of addressing a wide domestic and foreign, commercial and military market in need of an <u>affordable, near-term solution engine offering jet fuel capabilities at reciprocating engine prices.</u>

Figures 4.5-1a through 4.5-1c outline potential markets in general, on a long range basis, following introduction, successful performance and acceptance in a particular segment of the market. The overall market consists of a variety of fixed wing, helicopter, aviation auxiliary power units, unmanned military vehicles and other spin-offs, i.e., vehicular and marine (listed here since they would impact manufacturing volumes and thereby engine cost). For a realistic, conservative estimate of the near term potential market impact we have chosen to explore one particular segment or area of penetration wherein we and one of our potential consortium partners, Textron-Lycoming feel SCRE is particularly needed. This is in a broad range of from 350 to 650 HP, competing with high cost/inefficient turbine engines and with Avgas dependent, growth limited reciprocating engines particularly in the higher end of that power range. That power range covers a market wherein retrofit of many existing aircraft with an advanced powerplant is feasible through a de-rate of the engine to the lower power level. This is possible since the rotary can still be weight competitive vs. the existing reciprocating engines at these power levels. Also, by considering both commercial and military application (to expand the engine production volume), different requirements for time between overhauls and safety/reliability margins permit some nearer term application of higher power density. Hence, for this particular look at a potential market we use the 170 Series, Model 2034R over a wide range of power through an initial design for initial application at 500-575 HP, de-rated to as low as 350 HP and then up-rated on a longer term basis to 650 HP.

Figures 4.5-2 through 4.5-4 provide an estimate of the market impact and estimated sales assuming FAA certification and production for the 170 Series, Model 2034R in late CY 1998. This would require start-up of the 28 Month final development and certification program by July 1, 1996.

Figure 4.5-2 provides an approximate Profit and Loss and Cash Flow Projection for a proposed (fictitious) organization (Rotary Aircraft Engine Corporation, RAEC) showing orders, sales, inventory, backlog, gross sales, cost of sales and cash flow over a ten (10) year period 1999 - 2008. Positive cash flow is achieved in the fourth year from start-up as shown in Figure 4.5-2a. A significant sales volume is conservatively estimated and is very reasonable to achieve. However, the early-on negative cash flow and time to a return or investment has restricted investor interest to date. Figure 4.5-3 provides engine pricing and extensions denoting the timing and sales volumes for particular models. Figure 4.5-4 provides a cost/price analysis.

An estimate of U.S. job creation associated with R&D, Manufacturing and Infrastructure was prepared for the chosen market segment and plan discussed in the preceeding paragraphs. Figure 4.5-5 provides an integrated graphical summary over the first 48 months from start-up, including development/FAA certification, (to the 28th month), production preparations, (18th to 28th month) and early production (28th to 48th month). The integrated graphical summary is of total headcount for combined in-house direct and indirect personnel. Figure 4.5-6 provides a tabulation of direct and indirect headcount by month for the in-house estimated job creation. The direct labor figures for the R&D/Product Development phase (0-28th month) derive from the detailed development/ FAA certification plan in Section 4.4 of this study. Infrastructure jobs out of plant at vendor facilities are estimated at 75 to 100% of the level shown for the in-house jobs.

Some comments are appropriate here in terms of the overlap between production and the R&D phase, jobs created, in-house vs infrastructure, make-buy decisions and total production.

- Production planning and preparation is active during the last year of R&D/Product Development. This results in the 80 plus headcount in the mid portion of Figure 4.5-5.

- The absolute level for production headcount would increase significantly for additional application of the particular engine used in this estimate or for increased sales due to provision of other members of the engine family to a broader market spectrum.

- Our planning considers that out-sourcing is probably likely for the majority of parts in the engine bill of materials. Special rotary parts, i.e., rotors, rotor housings, intermediate, end housings and crankshaft would be machined in-house after purchase of castings or forgings from vendors. However, the majority of parts which are non-rotary engine specific can probably be purchased from outside sources more economically. Similarly, all accessory items and systems are "buy" items. For the "make" parts, the proposed organization, RAEC, would have to provide for trochoid grinding, lapping, end housings and intermediate housing machinery, rotor and crankshaft machinery, etc. in a space claim at some existing facility or new "green field" facility.

Figure 4.5-7 provides a preliminary outline of the plant layout considered appropriate to the proposed RAEC organization providing space for the machining of the special rotary parts as well as the complete plant requirements. The cost for the two propeller test cells were included in Section 3.0, Figure 3.0-2 Overall Funding Requirement as part of the $450K for development test cells cost ($300 dyno stand, $75K each for two prop stands). Figure 4.5-8 provides a list of production machines and associated equipment necessary to prepare for production. The $2.85 mil was included in Section 3.0, Figure 3.0-2 as "Production Capital." Figure 4.5-9 lists some barriers to market entry.

SCRE MARKET IN GENERAL DOMESTIC AND FOREIGN

- O FIXED WING PROPULSION
  - o REDUCTION GEAR/PROPELLER SHAFT VERSIONS
  - o DIRECT DRIVE-DUCTED FAN VERSIONS
  - o GENERAL AVIATION
  - o BUSINESS AND COMMUTER AVIATION
  - o MILITARY VARIANTS OF THE ABOVE

- O HELICOPTERS
  - o DIRECT DRIVE VERSIONS
  - o STRONG INTEREST AT SIKORSKY
  - o NEED AFFORDABLE JET FUEL CAPABILITY
    - ----- o COMMERCIAL
    - ----- o MILITARY

- O AVIATION AUXILIARY POWER UNITS
  - o GROUND POWER UNITS (VS. DIESELS, TURBINES)
  - o AIRBORNE ENERGY EFFICIENT UNITS (VS. TURBINES)
    - ----- o STRONG INTEREST AT MITCHELL AND DEHAVILLAND
    - ----- o SUPPORTED BY USAF/McDONNELL DOUGLAS STUDIES

- O UNMANNED AERIAL VEHICLES

- O VEHICULAR AND MARINE SPIN-OFFS

FIG. 4.5-la

RETROFIT APPLICATIONS

- LARGE MARKET IN RETROFIT APPLICATION IDENTIFIED FOR 170 SERIES
  - FIXED WING
  - COMPETING WITH HIGHER HP RECIPS AND SMALL TURBINES
    - RECIPS - DURABILITY LIMITATIONS
      - NEED AVGAS
    - TURBINES - INITIAL COST
      - OVERHAUL COSTS
- RETROFITTERS INTERESTED/INVOLVED
  - RAM
  - SOLOY
  - BEECH DUKE 60

FIG. 4.5-1b

THE EUROPEAN MARKET

- HIGH PRICES FOR AVIATION GASOLINE THROUGHOUT EUROPE
  - 4 TIMES JET FUEL PRICES
- LIMITED AVAILABILITY OF AVIATION GASOLINE
- SEVERE NOISE RESTRICTIONS ARE IN EFFECT

  ENGINES -ADDED MUFFLING/PERFORMANCE PENALTIES
  - SCRE MUFFLING COST, SIZE, WEIGHT LOWER THAN RECIP

  PROPELLERS - LARGER DIAMETER/LOWER SPEEDS
  - INCREASES REDUCTION GEAR REQUIREMENTS ON SCRE (HIGH CRANK SPEEDS)
- NEW RECIP AIRPLANES ARE BEING PRODUCED
  - Vs. STAGNANT U.S. MARKET
- EXTENSIVE KIT BUILDING MARKET WITH SOPHISTICATED DESIGNS
  - ADVANCED ENGINES ARE OF INTEREST
- LESSENED PRODUCT LIABILITY BURDEN

FIG. 4.5-1c

ROTARY AIRCRAFT ENGINES,
Profit & Loss and Cash Flow Projection Corp. (RAEC)
$ in 000's

P&LRA9 (A88) YEAR END - DECEMBER 31	1996	1997	8	9	2000	1	2	3	4	5	6	7	8	TOTALS
QUANTITY:														
ORDERS				550	650	650	730	810	900	970	1,020	1,040	1,150	8,470
SALES				300	590	680	760	840	930	1,000	1,050	1,100	1,150	8,400
INVENTORY				111	159	180	200	221	241	256	269	281	538	
BACKLOG				250	310	280	250	220	190	160	130	70	70	70
GROSS SALES														
ENGINES			0	23,300	48,500	56,415	64,215	72,155	82,020	89,250	94,975	101,225	106,725	738,780
PARTS/ACCESSORIES			0	0	1,436	2,098	2,413	2,727	3,084	3,425	3,685	3,924	4,159	26,951
OVERHAUL/REPAIR			0	466	3,300	8,075	14,087	22,723	33,611	43,558	56,757	67,205	79,658	329,440
TOTAL GROSS SALES			0	23,766	53,236	66,589	80,714	97,605	118,715	136,234	155,417	172,354	190,542	1,095,171
RETURNS & ALLOWANCES														
ENGINES			0	466	970	1,128	1,284	1,443	1,640	1,785	1,900	2,025	2,135	14,776
PARTS/ACCESSORIES			0	0	29	42	48	55	62	69	74	78	83	539
OVERHAUL/REPAIR			0	9	66	162	282	454	672	871	1,135	1,344	1,593	6,589
TOTAL RETURNS & ALLOWANCES			0	475	1,065	1,332	1,614	1,952	2,374	2,725	3,108	3,447	3,811	21,903
NET SALES														
ENGINES			0	22,834	47,530	55,287	62,931	70,712	80,380	87,465	93,076	99,201	104,591	724,004
PARTS/ACCESSORIES			0	0	1,407	2,056	2,364	2,673	3,022	3,357	3,611	3,846	4,076	26,412
OVERHAUL/REPAIR			0	457	3,234	7,914	13,805	22,268	32,939	42,687	55,622	65,861	78,065	322,852
TOTAL NET SALES			0	23,291	52,171	65,257	79,100	95,653	116,340	133,509	152,308	168,907	186,731	1,073,268
COST OF SALES														
ENGINES			0	9,810	20,060	23,120	25,840	28,560	32,550	35,000	36,750	38,500	40,250	290,440
PARTS/ACCESSORIES			0	0	704	1,028	1,182	1,336	1,511	1,678	1,805	1,923	2,038	13,206
OVERHAUL/REPAIR			0	228	1,617	3,957	6,903	11,134	16,469	21,344	27,811	32,930	39,032	161,426
TOTAL COST OF SALES			0	10,038	22,381	28,105	33,925	41,031	50,530	58,022	66,366	73,353	81,320	465,072
GROSS MARGIN														
ENGINES			0	13,024	27,470	32,167	37,091	42,152	47,830	52,465	56,326	60,701	64,341	433,564
PARTS/ACCESSORIES			0	0	704	1,028	1,182	1,336	1,511	1,678	1,805	1,923	2,038	13,206
OVERHAUL/REPAIR			0	228	1,617	3,957	6,903	11,134	16,469	21,344	27,811	32,930	39,032	161,426
TOTAL GROSS MARGIN			0	13,252	29,791	37,152	45,175	54,623	65,810	75,487	85,942	95,554	105,411	608,196
OTHER														
INSURANCE/LIABILITY			0	416	932	1,165	1,413	1,708	2,078	2,384	2,720	3,016	3,334	19,165
LICENSE/ROYALTY				133	366	756	960	1,033	1,700	890	1,012	253	267	7,370
AMORT DEV & ENG	484	484	484	484	484	484	484	484	484	484	484	484	484	6,295
DEPRECIATION														0
OVERHEAD	494	1,268	1,325	1,695	1,851	2,036	2,193	2,357	2,557	2,757	2,957	3,157	3,357	28,004
INVENTORY	0	0	0	3,783	5,398	6,120	6,800	7,744	8,444	8,969	9,406	9,844	10,302	
R&D ONGOING	0	0	0	0	33	66	99	132	165	198	231	264	297	1,485
TOTALS	978	1,752	1,809	6,510	9,063	10,628	11,949	13,458	15,427	15,682	16,810	17,018	18,041	139,127
PRETAX PROFIT/(LOSS)	(978)	(1,752)	(1,809)	10,524	26,125	32,644	40,027	48,908	58,826	68,773	78,538	88,379	97,671	545,877
CUMULATIVE PRETAX	(978)	(2,730)	(4,540)	5,985	32,110	64,754	104,781	153,689	212,515	281,289	359,827	448,206	545,877	
CASH FLOW:														
GAIN/(LOSS)	(978)	(1,752)	(1,809)	10,524	26,125	32,644	40,027	48,908	58,826	68,773	78,538	88,379	97,671	545,877
ADD DEPR/AMORT	484	484	484	484	484	484	484	484	484	484	484	484	484	6,295
LICENSE FEE														0
(INC)/DECR IN INV	0	0	0	(3,783)	(1,615)	(723)	(680)	(944)	(700)	(525)	(438)	(438)	(458)	(10,302)
CAPITAL														0
ENG DEV					(250)	(250)	(500)	(500)	(500)	(500)	(500)	(500)	(500)	(4,000)
YEARLY CASH FLOW	(494)	(1,268)	(1,325)	7,226	24,744	32,156	39,331	47,949	58,110	68,233	78,085	87,926	97,198	537,870
	(494)	(1,762)	(3,087)	4,139	28,883	61,039	100,370	148,319	206,429	274,662	352,746	440,672	537,870	

FIG. 4.5-2

CUMULATIVE PRE-TAX CASH FLOW
FIRST 4 YEARS

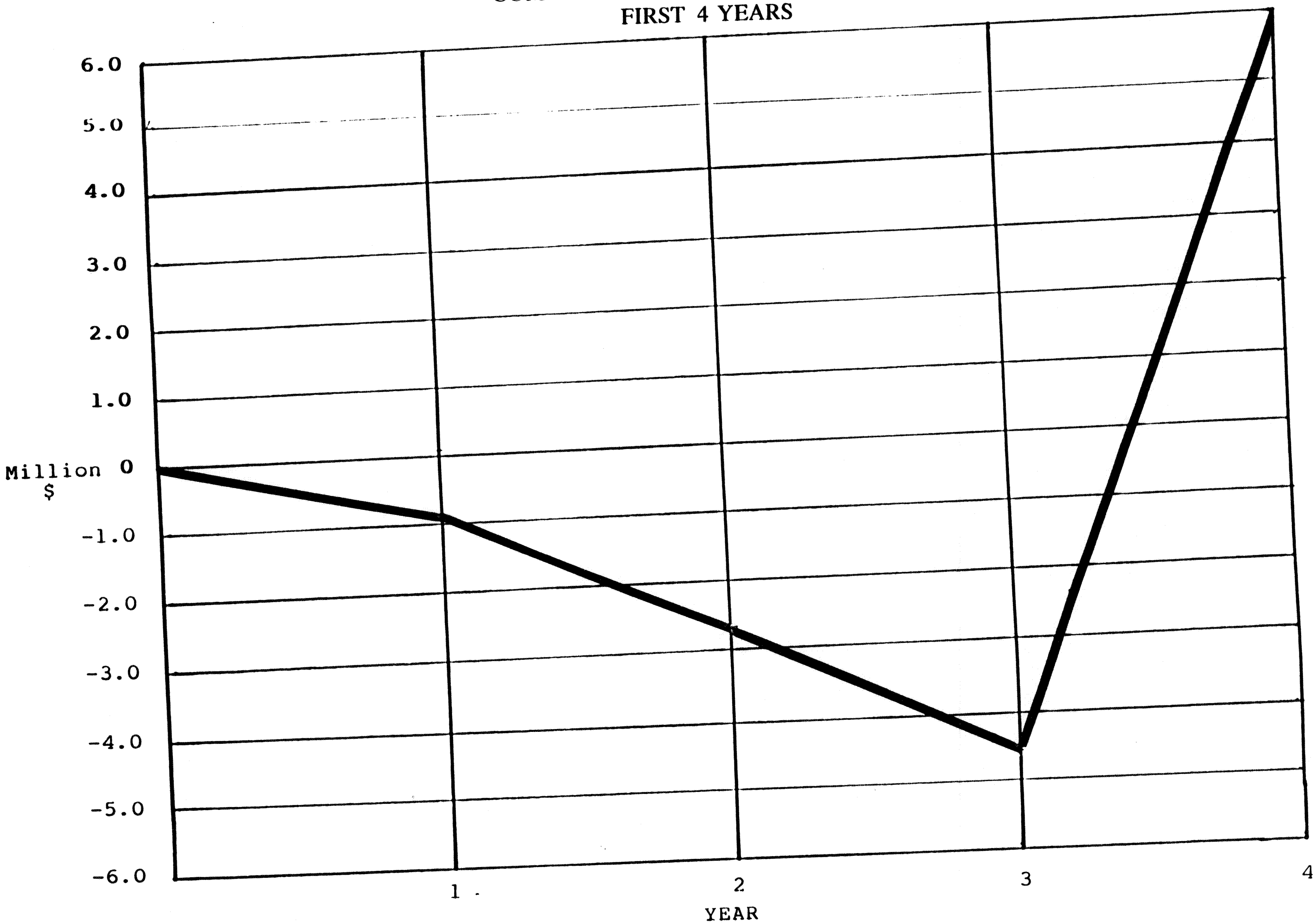


FIG. 4.5-2a

P&I RA98

NGINE PRICING & EXTENSIONS														TOTALS
ISCAL YEAR	1996	1997	1998	9	2000	1	2	3	4	5	6	7	8	
														0
50 HP														
ORDERS				0	40	75	100	125	150	175	200	225	250	1,340
PRODUCTION				0	250	250	250	250	250	250	250	250	250	250
BACKLOG														
OEM PRICING				50	50	51	51	52	52	52	52	53	53	
ROSS SALES				0	2000	3825	5100	6500	7800	9100	10400	11925	13250	69,900
ET SALES				0	1960	3749	4998	6370	7644	8918	10192	11687	12985	68,502
														0
25 HP														
ORDERS				0	75	100	125	150	175	200	225	250	275	1,575
PRODUCTION				30	30	30	30	30	30	30	30	30	30	30
BACKLOG														
OEM PRICING				59	60	62	64	66	68	70	72	75	77	
ROSS SALES				0	4500	6200	8000	9900	11900	14000	16200	18750	21175	110,625
ET SALES				0	4410	6076	7840	9702	11662	13720	15876	18375	20752	108,413
														0
500 HP														
ORDERS				250	275	275	275	275	275	275	275	275	275	2,725
PRODUCTION					20	20	20	20	20	20	20	20	20	20
BACKLOG														
OEM PRICING				75	76	78	81	83	86	88	91	94	96	
GROSS SALES				18750	20900	21450	22275	22825	23650	24200	25025	25850	26400	231,325
NET SALES				18375	20482	21021	21830	22369	23177	23716	24525	25333	25872	226,699
575 HP														
ORDERS				50	100	120	140	160	180	200	200	200	200	
PRODUCTION														
BACKLOG														
OEM PRICING				91	93	96	98	101	104	107	111	114	117	
GROSS SALES				4550	9300	11520	13720	16160	18720	21400	22200	22800	23400	163,770
NET SALES				4459	9114	11290	13446	15837	18346	20972	21756	22344	22932	160,495
650 HP														
ORDERS				0	100	110	120	130	150	150	150	150	150	
PRODUCTION														
BACKLOG														
OEM PRICING				116	118	122	126	129	133	137	141	146	150	
GROSS SALES				0	11800	13420	15120	16770	19950	20550	21150	21900	22500	163,160
NET SALES				0	11564	13152	14818	16435	19551	20139	20727	21462	22050	159,897
TOTAL GROSS SALES				23,300	48,500	56,415	64,215	72,155	82,020	89,250	94,975	101,225	106,725	738,780
TOTAL NET SALES				22,834	47,530	55,287	62,931	70,712	80,380	87,465	93,076	99,201	104,591	724,004
COST OF GOODS														
UNIT COST				33	34	34	34	34	35	35	35	35	35	
TOTAL UNITS				300	590	680	760	840	930	1000	1050	1100	1150	8,400
TOTAL COS				9810	20060	23120	25840	28560	32550	35000	36750	38500	40250	290,440
GROSS MARGIN				13024	27470	32167	37091	42152	47830	52465	56326	60701	64341	433,564
AVERAGE PRICE				78	82	83	84	86	88	89	90	92	93	88
GROSS MARGIN PERCENT				0.570	0.578	0.582	0.589	0.596	0.595	0.600	0.605	0.612	0.615	0.599
NET SALES				22834	47530	55287	62931	70712	80380	87465	93076	99201	104591	724004
AVERAGE UNIT SELLING PRICE				76	81	81	83	84	86	87	89	90	91	86

PRODUCTION ASSUMPTIONS: 10 ENGINES PER MONTH & 2500 A YEAR. BACKLOG OF NO MORE THEN 30 DAYS OR 300 ENGINES SPLIT 250 UNITS FOR 350 HP, 30 UNITS FOR 450
20 UNITS FOR 500 HP.

FIG. 4.5-3

RAENG2

'ARY ENGINE COST/PRICE ANALYSIS

YEARS	1998	9	2000	1	2	3	4	5	6	7	8
ST OF GOODS %		3	3	3	3	3	3	3	3	3	3
DUCTIVITY GAINS %		0	1	1	1	1	1	1	1	1	1
LUME GAINS %		0	0	0	0	1	1	1	1	1	1
ST OF GOODS		981	996	1006	1016	1026	1031	1036	1041	1047	1052
DUCTIVITY GAINS		0	332	335	339	342	344	345	347	349	351
LUME GAIN		0	0	0	0	342	344	345	347	349	351
FECTIVE ANNUAL COST*	32700	33191	33522	33858	34196	34367	34539	34712	34885	35060	35235
QUIRED TO HOLD GM 33%	48806	49786	50284	50786	51294	51551	51809	52068	52328	52590	52853
ICE INCREASE PER YEAR %	0	1	2	3	3	3	3	3	3	3	3
ICE AFTER DISC/PROMO/REBATES	48806	49294	50280	51788	53342	54942	56590	58288	60037	61838	63693
FFECTIVE GROSS MARGIN	16106	16104	16758	17931	19146	20575	22051	23576	30018	30919	31847
FFECTIVE GROSS MARGIN &	33	33	33	35	36	37	39	40	50	50	50
VERSION 425 HP	58806	59394	60582	62399	64271	66199	68185	70231	72338	74508	76743
VERSION 500 HP	73806	74544	76035	78316	80665	83085	85578	88145	90790	93513	96319
VERSION 575 HP	90000	90900	92718	95500	98365	101315	104355	107486	110710	114031	117452
VERSION 650 HP	115000	116150	118473	122027	125688	129459	133342	137343	141463	145707	150078
ETAIL ENGINE PRICE @ 20% MARK-UP											
350 HP VERSION	61007	61618	62850	64735	66677	68678	70738	72860	75046	77297	79616
425 HP VERSION	73507	74243	75727	77999	80339	82749	85232	87789	90422	93135	95929
500 HP VERSION	92257	93180	95044	97895	100832	103857	106972	110182	113487	116892	120398
575 HP VERSION	112500	113625	115898	119374	122956	126644	130444	134357	138388	142539	146815
650 HP VERSION	143750	145188	148091	152534	157110	161823	166678	171678	176829	182134	187598

Gross Margin maintained at 50% FY 2003 to FY 2005.
32700 Cost from detailed Engine Cost Schedule.
Version 425 HP equal to 350 HP plus $10,000.
Version 500 HP equal to 425 HP plus $15,000.
Version 575 HP equal to $90,000.
Version 650 HP equal to $115,000.

FIG. 4.5-4

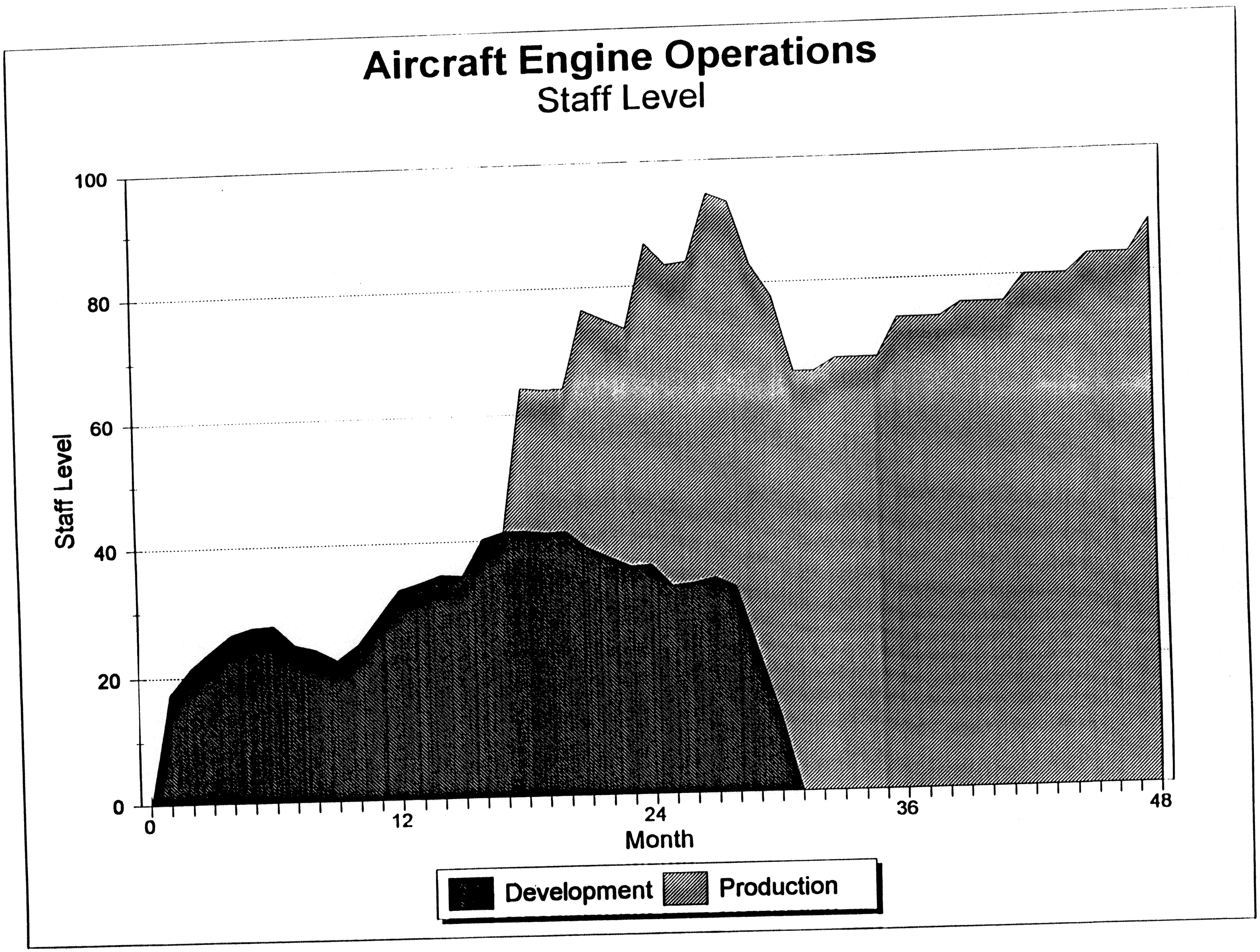

Aircraft Engine Operations
Staff Level
100
80
60
40
20
0
Staff Level
0
12
24
36
48
Month
Development
Production

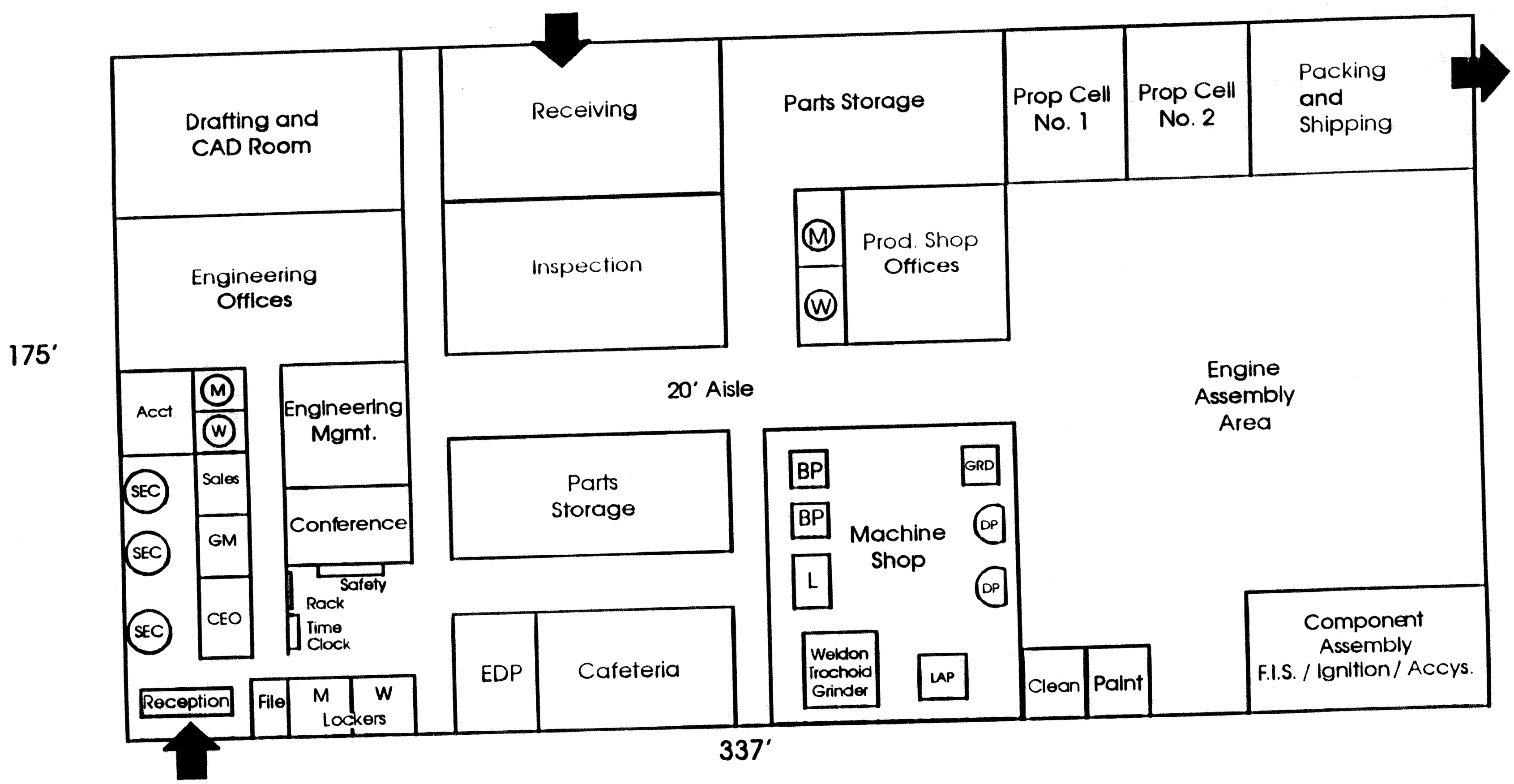
FIG. 4.5-5

U.S. JOB CREATION
HEADCOUNT

	R&D/PRODUCT DEV.			PRODUCTION			TOTALS	
MONTH	DIRECT	INDIRECT	MGMT/SALES	DIRECT	INDIRECT	MGMT/SALES	R&D/PD	PRODUCTION
1	10.4	4	3				17.4	
2	13.4	4	4				21.4	
3	16	4	4				24	
4	18.4	4	4				26.4	
5	19.4	4	4				27.4	
6	18.6	4	5				27.6	
7	15.6	4	5				24.6	
8	14.8	4	5				23.8	
9	13.15	4	5				22.15	
10	14.45	4	6				24.45	
11	17.5	5	6				28.5	
12	21.7	5	6				32.7	
13	22.8	5	6				33.8	
14	23.9	5	6				34.9	
15	23.7	5	6				34.7	
16	29.3	5	6				40.3	
17	29.4	5	7	6	11	6	41.4	23
18	29.4	5	7				41.4	
19	29	5	7				41	
20	29.1	5	7	18	14	6	41.1	38
21	26.5	5	7				38.5	
22	23.9	5	8				36.9	
23	22.5	5	8	27	16	8	35.5	51
24	22.6	5	8				35.6	
25	19.2	5	8				32.2	
26	19.6	5	8	35	18	8	32.6	61
27	20.4	5	8				33.4	
28	18.9	5	8				31.9	
29	[PHASE OUT 3 MOS]			38	20	8	PHASE OUT ↓	66
30		↓					0	
31		0						
32				40	20	8		68
33								
34								
35				42	22	10		74
36								
37								
38				42	24	10		76
39								
40								
41				44	24	12		80
42								
43								
44				44	24	12		83
45								
46								
47				50	24	14		88
48								

FIG. 4.5-6

Rotary Aircraft Engines Corporation (RAEC)
Plant Layout



TOTAL AREA 58,975 SQ. FT.	
General Office	Shop
175' x 72' 12,600 sq. ft.	175' x 265' 46,375 sq. ft.

Approximate Scale 1/4" = 10'

FIG. 4.5-7

RAEC PRODUCTION MACHINES AND ASSOCIATED EQUIPMENT

ASSUMES RAEC GRINDS TROCHOID AND LAPS TROCHOID, CASTINGS, FORGINGS, ALL OTHER MACHINING OUTSOURCED

TROCHOID GRINDER (SIMILAR TO RPI WELDON)*1	$ 550,000
TROCHOID LAPPER (SIMILAR TO RPI LAPPER)*2	125,000
CMM INSPECTION EQUIPMENT*3	350,000
SUPPORTIVE BASIC MACHINE TOOLS (BRIDGEPORTS, LATHE, GRINDER, DRILL PRESSES, ETC.)	110,000
CLEANING STATION (ENVIRONMENTALLY ACCEPTABLE)	80,000
PAINT STATION (ENVIRONMENTALLY ACCEPTABLE)	120,000
VENDOR TOOLS	750,000
IN-HOUSE TOOLS	250,000
HANDLING EQUIPMENT	100,000
PARTS STORAGE RACKS/BINS	75,000
ASSEMBLY BENCHES 20 @ 750	15,000
ASSEMBLY CARTS 4 @ 4000	16,000
PACKING/SHIPPING STATION	45,000
RECORDS/INVENTORY COMPUTERIZED SYSTEM	60,000
CAD EQUIPMENT W/RPI INTERFACE CAPABILITY*4	150,000
PERSONAL COMPUTER STATIONS GENERAL 27 @ 2000 (486 PROCESSOR MINIMUM)	54,000
TOTAL	$2,850,000

*1 RPI PAID $625,000; RAEC EQUIPMENT TO COVER 170 TO 40 SIZING.

*2 RPI PAID $180,000; RAEC EQUIPMENT TO COVER 170 TO 40 SIZING.

*3 RPI PAID $350,000; RAEC NEEDS SAME BASIC CAPABILITY AS RPI.

*4 RPI PAID $150,000; RAEC/RPI INTERFACE REQUIRED FIRST 2 YEARS.

REM

FIG. 4.5-8

BARRIERS TO MARKET ENTRY

- LACK OF SUPPORTING INFRASTRUCTURE
  - PRODUCT DISTRIBUTION NETWORK
  - SALES
  - SERVICE
    - NEED A PARTNER?

- COST AND TIME FOR FINAL PRODUCT DEVELOPMENT AND CERTIFICATION
  - CRITICAL TECHNOLOGY OF ELECTRONIC FUEL INJECTION SYSTEM IS INCLUDED IN DEVELOPMENT PLAN
  - VALUE ENGINEERING NECESSARY TO ACHIEVE MANUFACTURING COST GOALS

- PRESENTLY DEPRESSED GENERAL AVIATION MARKET
  - IMPROVEMENT IS ANTICIPATED IN 1996 AND BEYOND AS PRODUCT LIABILITY LEGISLATION IMPACTS THE INDUSTRY

FIG. 4.5-9

5.0 CONCLUSIONS

5.1 The high-commonality, affordable, and environmentally-superior family of advanced intermittent combustion, Stratified Charge Rotary Engines (SCRE) defined herein offers a viable near term solution for propulsion needs in a new generation of general aviation aircraft.

5.2 The basic technologies upon which the family of SCRE's herein defined is based (combustion, Jet-A and other fuel usage capabilities, power output, efficiencies) have been achieved and demonstrated in preceeding NASA LeRC research and technology contractual programs.

5.3 Transition of the basic SCRE technologies from current status to fully developed, FAA certified, full-up production aircraft engine system status is achievable in approximately 28 months from start-up.

5.4 An industry consortium involving Rotary Power International, Inc., Textron-Lycoming and Lockheed-Martin and/or others as tentatively defined and discussed with NASA Headquarters can effect achievement of the final development and FAA certification. This industry team is prepared to initiate such an effort with upfront cost sharing support from NASA LeRC (as the NASA propulsion center) through" proof-of-concept" flight demonstration (occurring in the 17th month of such a program) followed by Industry's completion of development, certification and production.

6.0 RECOMMENDATIONS

6.1 NASA support of an industry team effort toward final development/FAA certification for one of the SCRE family of engines, i.e. the 170 Series, Model 2034R twin rotor primary engine defined herein.

6.2 Continued research and technology efforts toward further advancement in the state-of-the-art for the required technical innovation areas discussed herein (Ref. Section 4.1.9). These include fuel injection, combustion and emissions.

6.3 Near term flight demonstration with SCRE operating on Jet-A fuel i.e., the 70 Series, Model 2013R twin rotor primary engine at 250 HP take-off rating (Ref. Proposal to NASA LeRC, "X" airplane).

7.0 REFERENCES

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2. G. L. Huggins and D. R. Ellis, "Advanced General Aviation Comparative Engine/Airframe Integration Study",Cessna Aircraft Co., Wichita, KS, Cessna-AD 217,1981. (NASA CR-165564).
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4. C. Jones and R.E. Mount: "Design of a High Performance Rotary Stratified Charge Aircraft Engine", AIAA PAPER 84-1395. June 1984.
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7. James P. Mitchell et al, "Energy-Efficient Multifuel Auxiliary Power Unit (APU), WRDC-TR-89-2132, Aero Propulsion Laboratory, Wright Patterson Air Force Base, OH, December 1989.
8. Advanced System Propulsion Studies, Naval Air Development Center, Warminster, PA, Contract No. N62269-90-C-003, Final Report.
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10. William T. Figart and Robert E. Mount, "Advanced Stratified Charge Rotary Aircraft Engines - The Transition from Research to General Aviation Application," SAE, 1993 General, Corporate & Regional Aviation Meeting and Exposition, Century 11 Convention Center, Wichita, Kansas, May 18-20, 1993.
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12. Robert E. Mount, "Advanced Technology, Jet-A Fuel Stratified Charge Rotary engines for General Aviation," AIAA/FAA 3rd Joint Symposium on General Aviation Systems, Starksville, Mississippi, May 24 & 25, 1994.

8.0 APPENDIX

8.1 Model 2034R - Retrofit Potential

During the joint Deere/AVCO program AVCO Lycoming personnel examined a variety of production aircraft as candidates for rotary engine retrofit.

The rotary engine considered was the model 2034R at 400-500hp. The AVCO designations were:

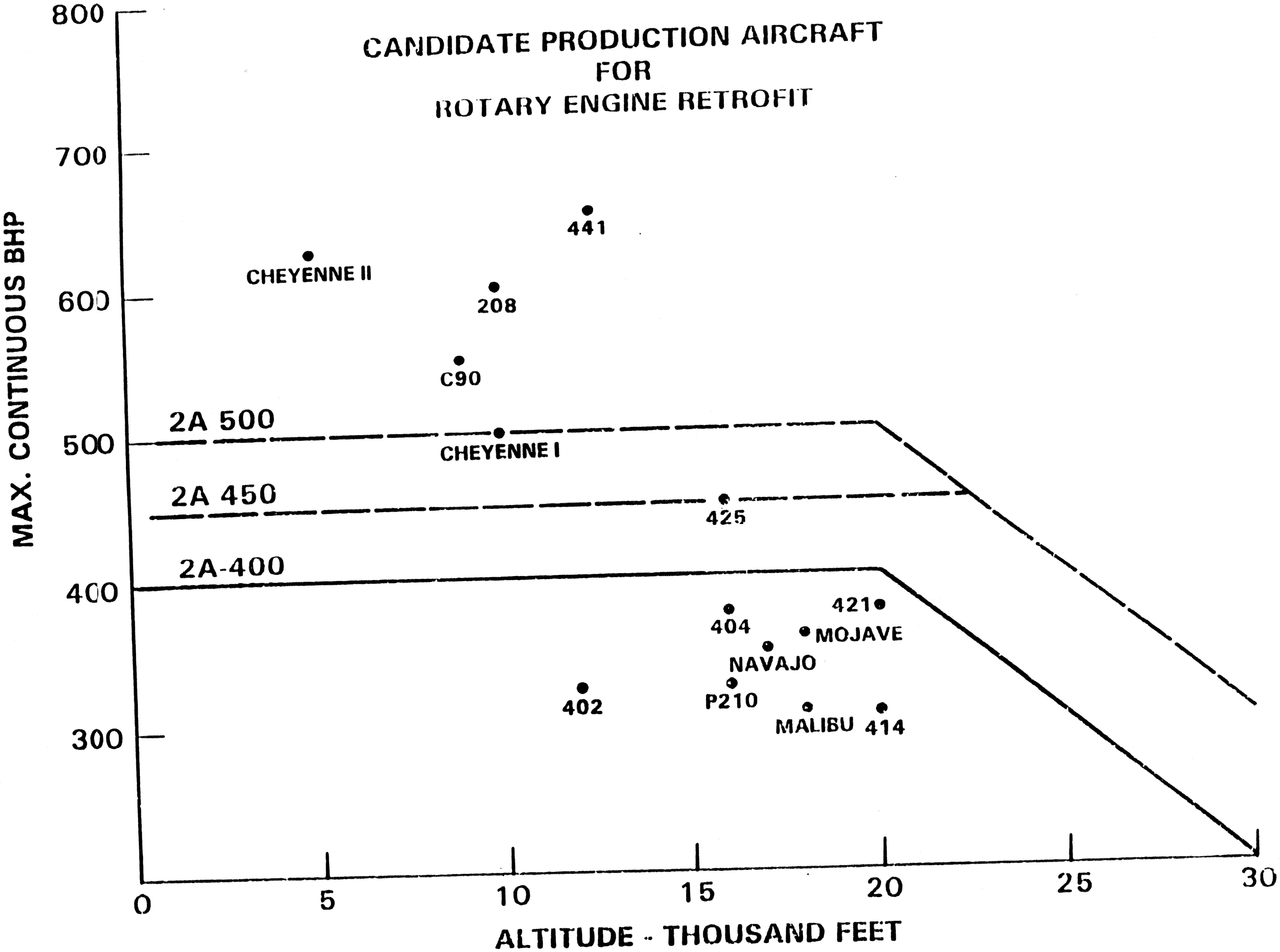
Model	Horsepower
2A-400	400
2A-450	450
2A-500	500

The study identified a wide variety of retrofit candidates including aircraft currently powered by turbine engines.

The study is included here for reference ("Production Aircraft Candidates for Rotary Engine Retrofit," AVCO Lycoming Textron, Williamsport Division).

PRODUCTION AIRCRAFT CANDIDATES FOR ROTARY ENGINE RETROFIT

Avco Lycoming TEXTRON
Williamsport Division


CANDIDATE PRODUCTION AIRCRAFT
FOR
ROTARY ENGINE RETROFIT
MAX. CONTINUOUS BHP
800
700
600
500
400
300
441
CHEYENNE II
208
C90
2A 500
CHEYENNE I
2A 450
425
2A-400
421
404
MOJAVE
NAVAJO
402
P210
MALIBU
414
0
5
10
15
20
25
30
ALTITUDE - THOUSAND FEET

CANDIDATES FOR ROTARY RETROFIT

- **NON-PRESSURIZED TWIN - PISTON:**

  PIPER NAVAJO   CESSNA 404

- **PRESSURIZED TWIN - PISTON:**

  PIPER MOJAVE   CESSNA 421

- **PRESSURIZED TWIN - TURBINE:**

  PIPER CHEYENNE I   CESSNA 425

CANDIDATE FLEET

	NUMBER MANUFACTURED	ESTIMATED NUMBER AT ENGINE TBO/YEAR
PIPER NAVAJO	1870	400 - 450
CESSNA 404	396	60 - 90
PIPER MOJAVE	50	2 - 5
CESSNA 421	1911	400 - 450
PIPER CHEYENNE I	193	5 - 10
CESSNA 425	214	30 - 40

CANDIDATE FLEET

- THE CANDIDATE FLEET TOTALS 4600 AIRCRAFT
- 400 HOURS/YEAR = AVERAGE UTILIZATION
- 20 - 25% OF FLEET AT SCHEDULED ENGINE OVERHAUL EACH YEAR
- 900 - 1050 AIRCRAFT REQUIRE ENGINE OVERHAUL EACH YEAR
- CONVERTING 15% OF THE OVERHAULS TO NEW ROTARY ENGINES = 270 to 315 ENGINES EACH YEAR
- 16 - 19 MILLION AVERAGE ANNUAL REVENUE FOR ENGINE SALES AT $60,000 UNIT PRICE
- 10 - 12 MILLION POTENTIAL ANNUAL REVENUE FOR CONVERSION OF AIRCRAFT AT $75,000 EACH

COST COMPARISON

CONVERT CESSNA 425 TO ROTARY VS. OVERHAUL OF PT6A-112

	OVERHAUL	ROTARY
TOTAL COST FOR 2 ENGINES	180,000	120,000
COST TO CONVERT AIRCRAFT	- - -	75,000
		195,000
REVENUE FROM SALES OF TURBINES	- - -	50,000
	180,000	145,000

AIRCRAFT MODEL	NAVAJO	CE-404	MOJAVE	CE-421	CE-425	CHEYENNE I
ENGINE MAKE	AVCO	TCM	AVCO	TCM	P & W	P & W
RATED H.P.	350	375	350	375	450	500
VS.						
ROTARY MODEL	2A 400	2A 400	2A 400	2A 400	2A 450	2A 500
RATED H.P.	400	400	400	400	450	500
CRUISE ALTITUDE - FT.	10,000	10,000	20,000	20,000	20,000	20,000

PERFORMANCE IMPROVEMENTS

CRUISE H.P.	+37	+17	+37	+24	+32	+80
CRITICAL ALTITUDE FOR CRUISE H.P.	- - -	- - -	- - -	- - -	+4500′	+8000′
CRUISE - KNOTS	+14	+6	+10	+9	+6	+25
LBS/HOUR FUEL	-34	-36	-16	-29	-124	-86
N. MILES/GAL. FUEL	+1.6	+1.3	+1.2	+1.5	+1.2	+1.25

AIRCRAFT MODEL	NAVAJO	CE-404	MOJAVE	CE-421	CE 425	CHEYENNE I
ENGINE MAKE	AVCO	TCM	AVCO	TCM	P & W	P & W
RATED H.P.	350	375	350	375	450	500
VS.						
ROTARY MODEL	2A 400	2A 400	2A 400	2A 400	2A 450	2A 500
RATED H.P.	400	400	400	400	450	500
CRUISE ALTITUDE - FT.	10,000	10,000	20,000	20,000	20,000	20,000

PERFORMANCE IMPROVEMENTS

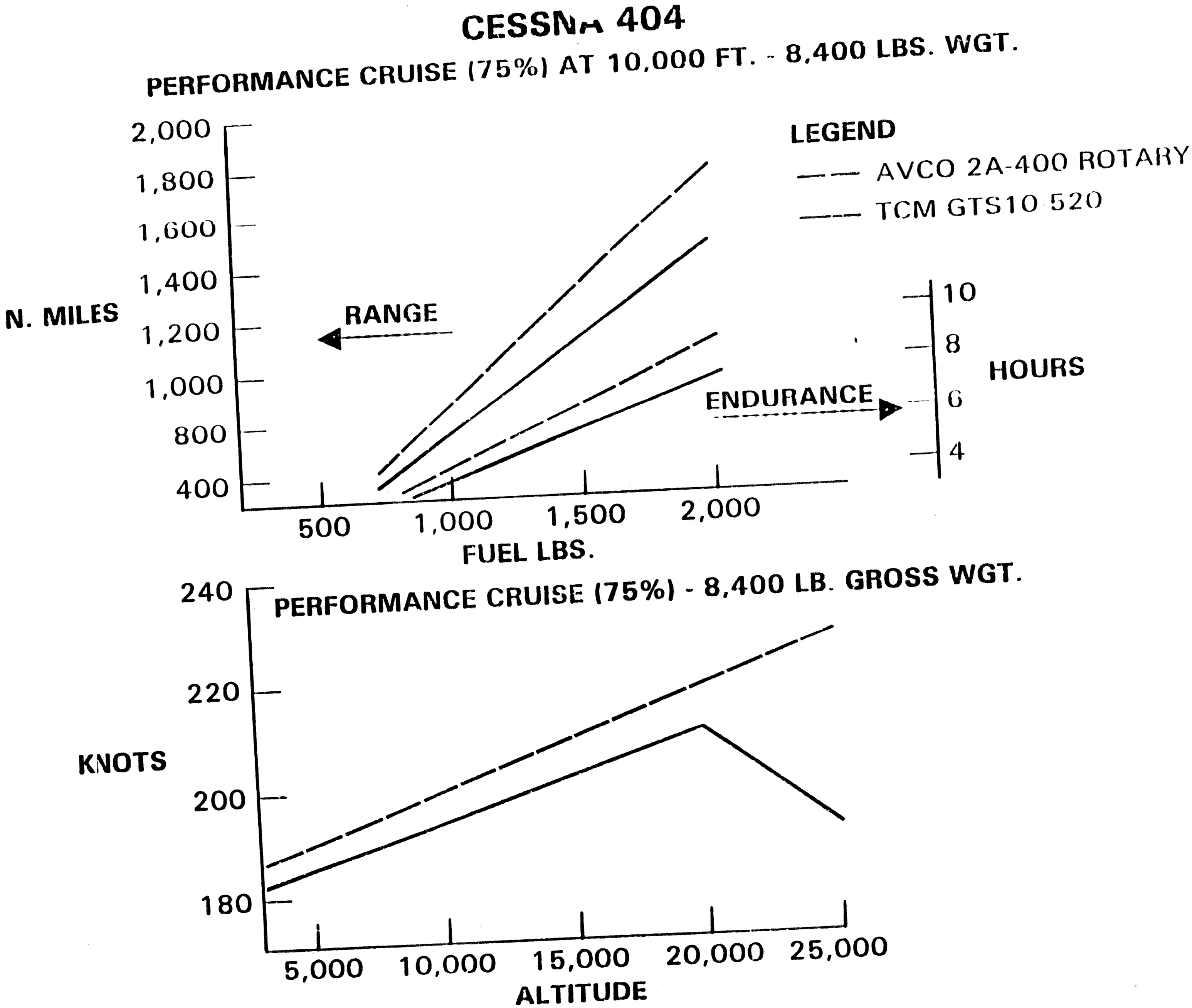
CRUISE H.P.	+15%	+6%	+14%	+9%	+8%	+22%
CRITICAL ALTITUDE FOR CRUISE H.P.	- - -	+25%	- - -	- - -	+25%	+66%
CRUISE SPEED	+7%	+3%	+4%	+4%	+3%	+11%
FUEL CONSUMPTION	-13%	-14%	-7%	-11%	-25%	-19%
RANGE	+23%	+19%	+12%	+18%	+36%	+36%

ROTARY ECONOMY PER 1000 N. MILES

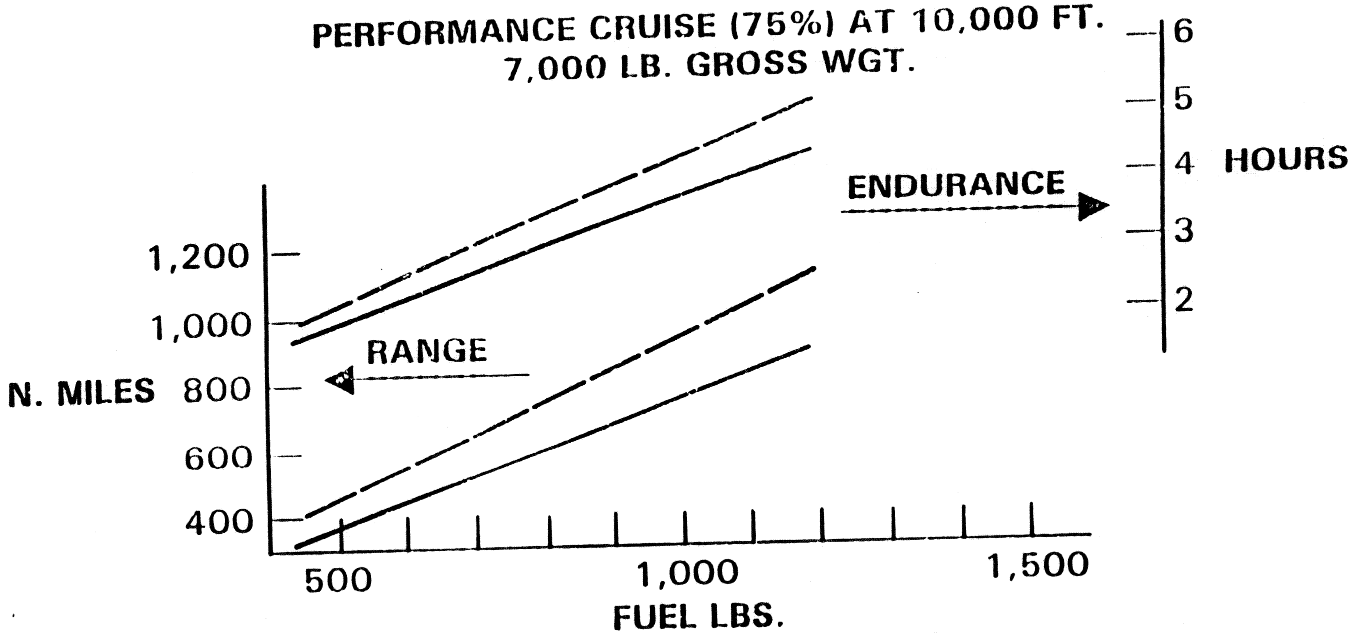
	CE 404	NAVAJO	CE 421	MOJAVE	CE 425	CHEYENNE I
LOWER COST/HOUR	21.40	15.45	19.70 (1)	15.0	34.32 (4)	23.93
LOWER COST/TRIP	124.00	106.00	93.00 (2)	82.00	144.00	142.00
REDUCE FUEL REQ'T./GALS.	55	45	40	34	80	79
SAVE TIME - MINUTES	12	24	6	12	6	24
INCREASE PAYLOAD - LBS.	330 (3)	270	240	204	525 (5)	517

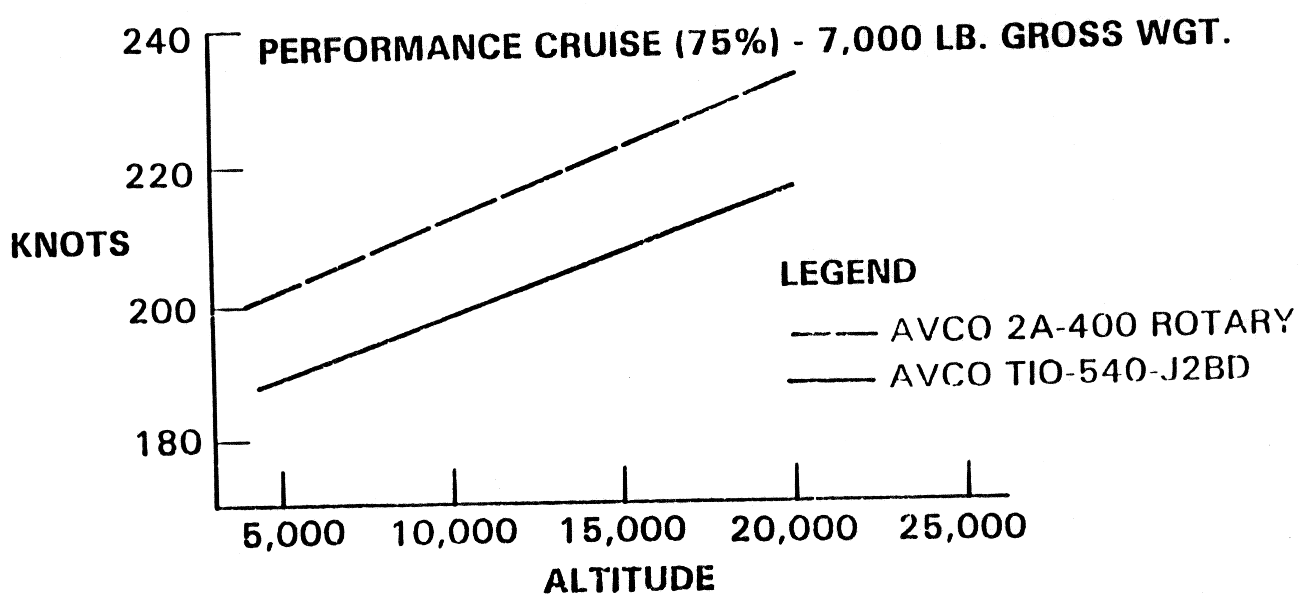
(1) 24% REDUCTION IN HOURLY COST
(2) 26% REDUCTION IN TRIP COST
(3) EQUIVALENT TO 2 PASSENGERS
(4) 27% REDUCTION IN HOURLY COST
(5) EQUIVALENT TO 3 PASSENGERS

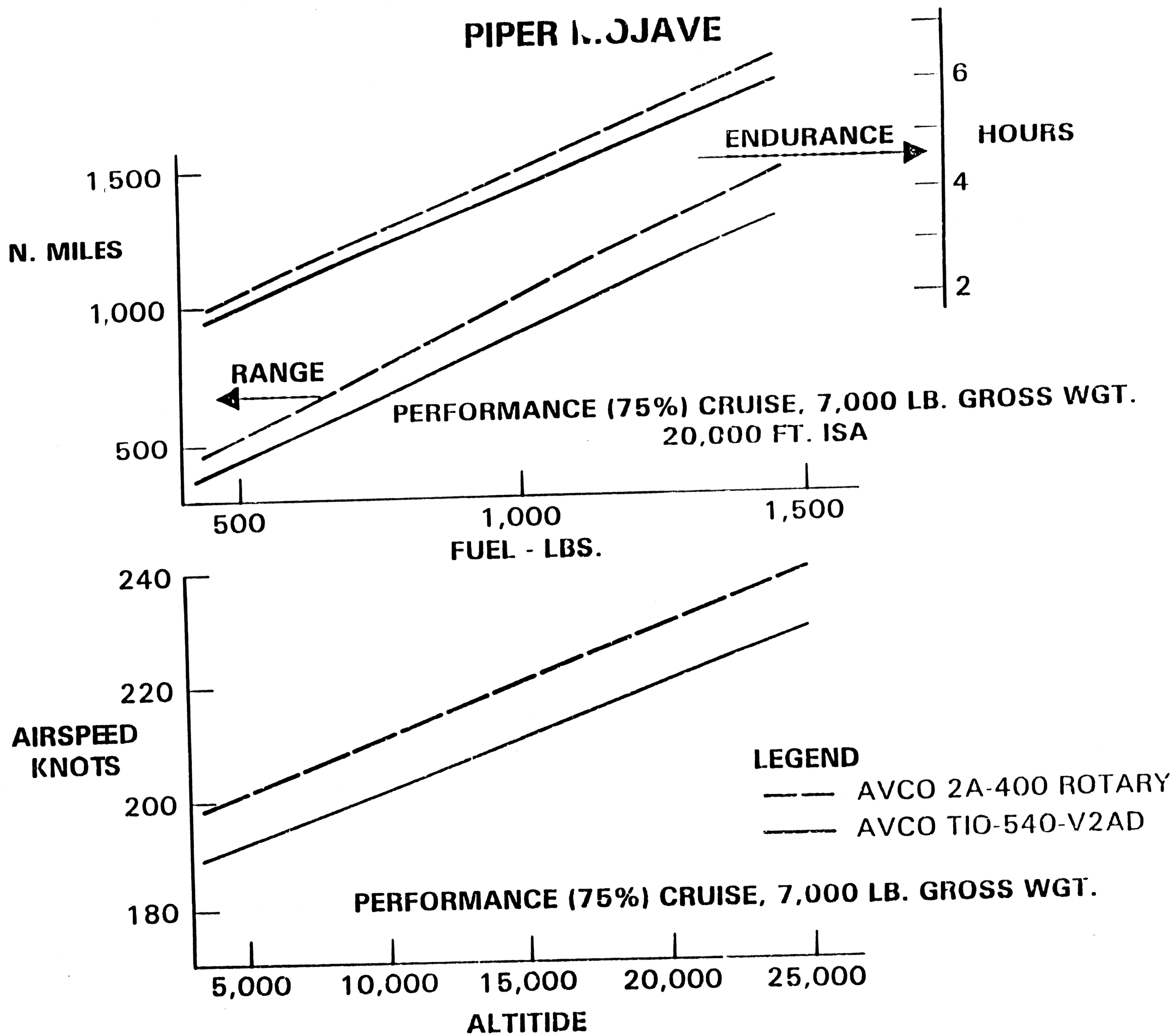
TYPICAL BENEFITS


CESSNA 404
PERFORMANCE CRUISE (75%) AT 10,000 FT. - 8,400 LBS. WGT.
LEGEND
AVCO 2A-400 ROTARY
TCM GTS10 520
N. MILES
2,000
1,800
1,600
1,400
1,200
1,000
800
400
RANGE
ENDURANCE
10
8
6
4
HOURS
500
1,000
1,500
2,000
FUEL LBS.
PERFORMANCE CRUISE (75%) - 8,400 LB. GROSS WGT.
KNOTS
240
220
200
180
5,000
10,000
15,000
20,000
25,000
ALTITUDE

NAVAJO CHIEFTAIN

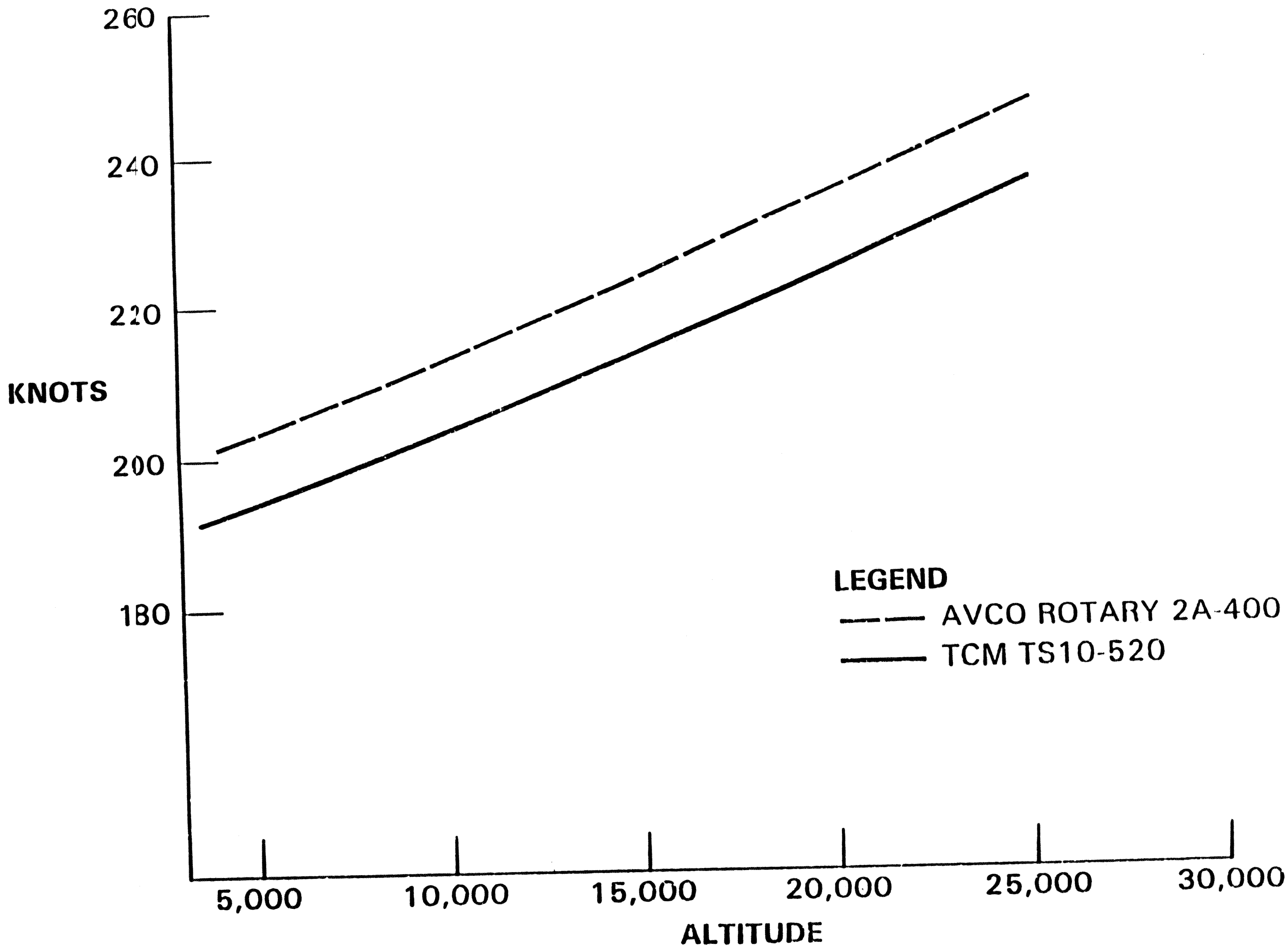





PIPER MOJAVE
N. MILES
1,500
1,000
500
ENDURANCE
HOURS
6
4
2
RANGE
PERFORMANCE (75%) CRUISE, 7,000 LB. GROSS WGT.
20,000 FT. ISA
500
1,000
1,500
FUEL - LBS.
240
220
200
180
AIRSPEED
KNOTS
LEGEND
AVCO 2A-400 ROTARY
AVCO TIO-540-V2AD
PERFORMANCE (75%) CRUISE, 7,000 LB. GROSS WGT.
5,000
10,000
15,000
20,000
25,000
ALTITIDE

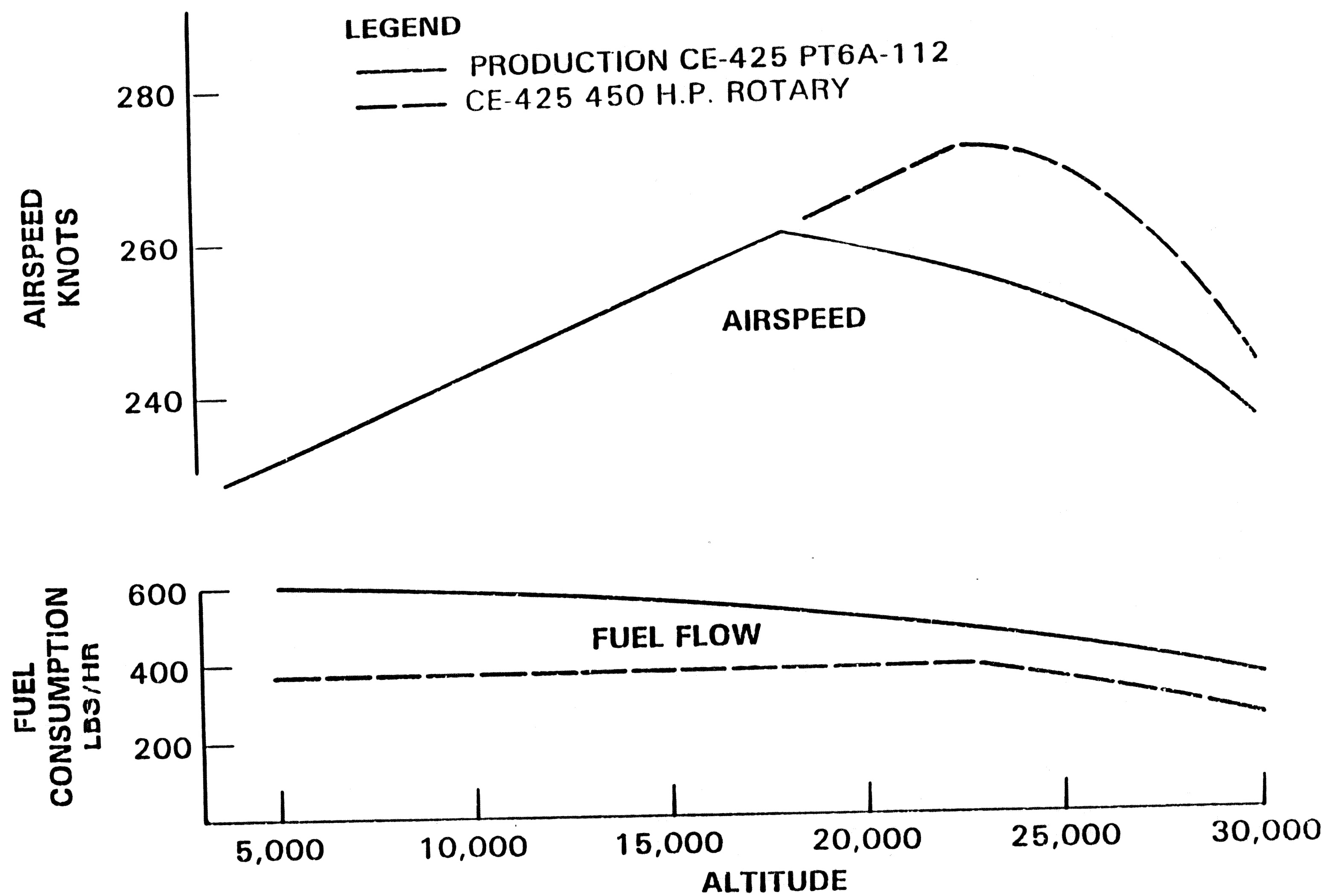
CESSNA 421 CRUISE PERFORMANCE

7450 LB. GROSS WEIGHT - 75% RATED POWER



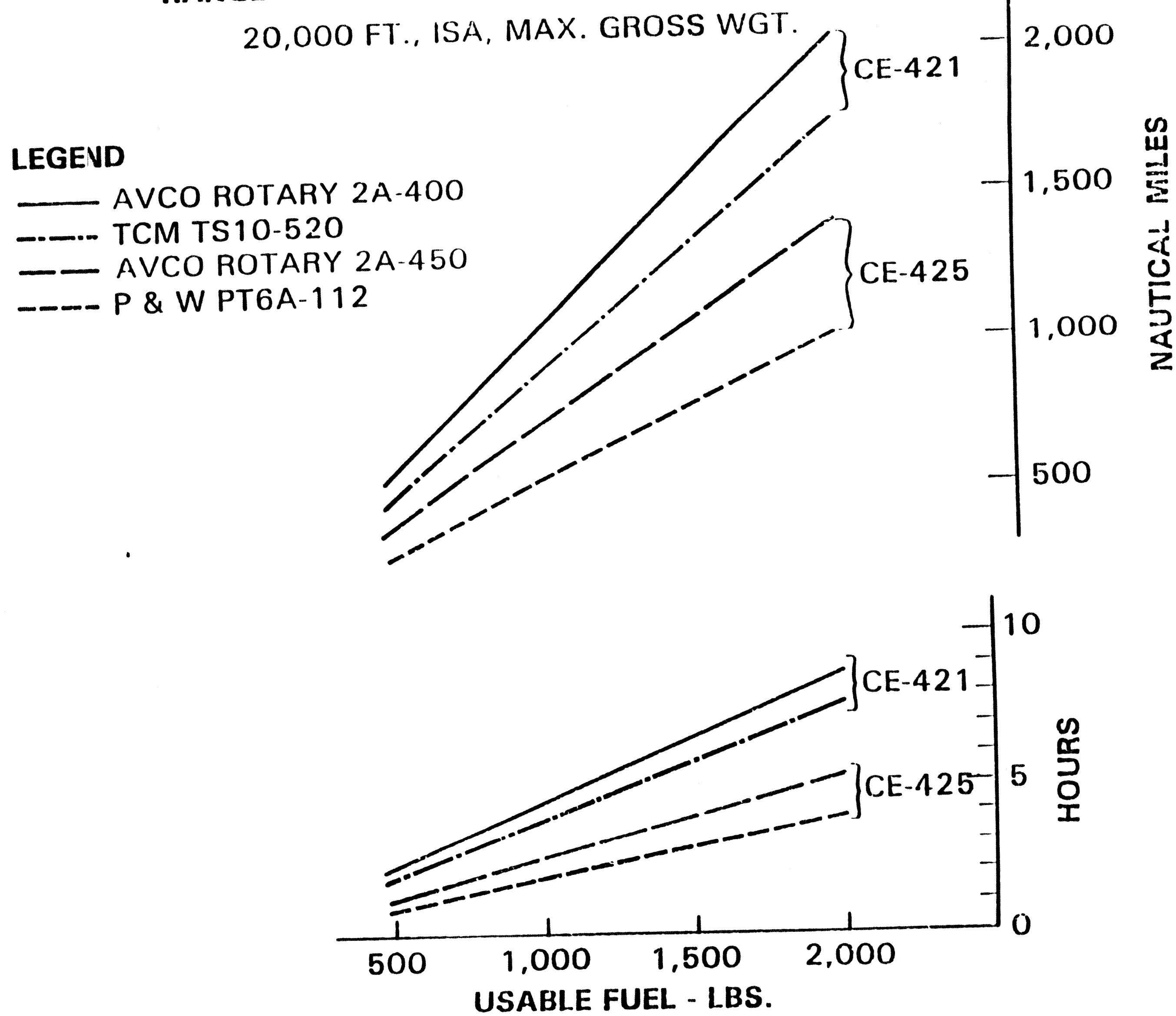
CESSNA CE-425

MAX. CONTINUOUS CRUISE AT RATED POWER - 8,600 LB. GROSS



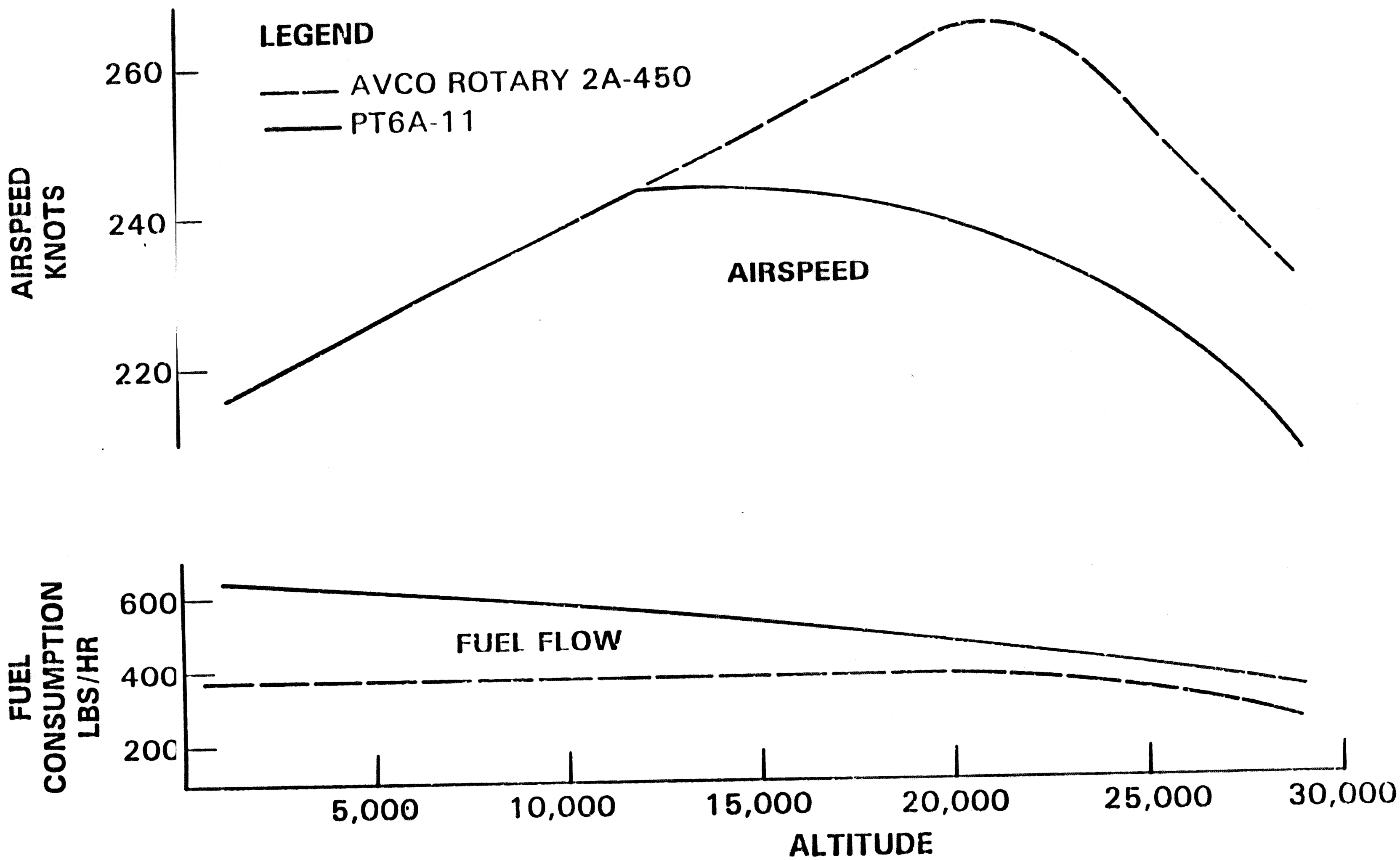
CESSNA 421 AND 425

RANGE AND ENDURANCE AT MAX. CONTINUOUS CRUISE POWER



PIPER CHEYENNE I

MAX. CONTINUOUS CRUISE AT RATED POWER
8,700 LB. GROSS



9.0 NEW TECHNOLOGY

No new technologies were developed or discovered during the performance of this contract.

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6. AUTHOR(S)

R. Mount

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P.O. Box 128
Wood-Ridge, New Jersey 07075

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12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This study defines a family of advanced technology Stratified Charge Rotary Engines (SCRE) appropriate for the enablement of the development of a new generation of general aviation aircraft. High commonality, affordability, and environmental compatibility are considerations influencing the family composition and ratings. The SCRE family is comprised of three engines in the 70 Series (40 in.^{3} displacement per rotor), i.e. one, two, and four rotor and two engines in the 170 Series (105 in.^{3} displacement per rotor), i.e., two and four rotor. The two rotor engines are considered the primary engines in each series. A wide power range is considered covering 125 to 2500 HP through growth and compounding/dual pac considerations. Mission requirements, TBO, FAA Certification, engine development cycles, and costs are examined. Comparisons to current and projected reciprocating and turbine engine configurations in the 125 to 1000 HP class are provided. Market impact, estimated sales, and U.S. job creation (R&D, manufacturing and infractures) are examined.

14. SUBJECT TERMS

Stratified charge; Rotary engine; Aircraft; Propulsion; General aviation; Engine

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