NASA/CR—2003-212469 TRA Report No. 3043

Advanced Propulsion System Studies for General Aviation Aircraft

Kathryn A. Elliott and Steven R. Huebner
Teledyne Ryan Aeronautical, Toledo, Ohio

August 2003

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/CR—2003-212469 TRA Report No. 3043

Advanced Propulsion System Studies for General Aviation Aircraft

Kathryn A. Elliott and Steven R. Huebner
Teledyne Ryan Aeronautical, Toledo, Ohio

Prepared under Contract NAS3–27635

National Aeronautics and
Space Administration

Glenn Research Center

August 2003

Document History

This research was originally published internally as AST008 in December 1996.

This report contains preliminary findings, subject to revision as analysis proceeds.

Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

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.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at http://gltrs.grc.nasa.gov

TABLE OF CONTENTS

TABLE OF CONTENTS

GLOSSARY OF ACRONYMS

APU	Auxiliary Power Unit
DEC-CMM	DEC - Computerized Measuring Machine
EDU / PPU	Engineering Development Units / Preliminary Production Units
FSD	Full Scale Development
HP	Horsepower
HEV	Hybrid Electric Vehicle
HSI	Hot Section Inspeciton
I / C	Internal Combustion
JETEC	Joint Expendable Turbine Engine Concept
Ktas	Knots, True Airspeed
lbf	pound-force
lbm / hr / hp	Units for specific fuel consumption; pound-mass per hour per horsepower
lbm / min	pound-mass per min (units for weight flow)
LRP	Low Rate of Production
MALD	Miniature Air Launched Decoy
min	minute
MMAS	Materials Management Accounting System
MPL	Manufacturing Parts List
MRO	Maintenance Repair and Operating
MRP	Material Requirements Planning

GLOSSARY OF ACRONYMS - Continued

nm	nautical mile
N/C	Numerical Control
PCU	Power Control Unit
PRDA	Proposed R D Activity
QA	Quality Assurance
QCGATE	Quiet Clean General Aviation Turbine Engine
QT	Qualification Test
rpm	revolutions per minute
RQL	Rich-Quench-Lean
SBU	Strategic Business Unit
shp	shaft horsepower
SPC	Statistical Process Control
SQA	Supplier Quality Assurance
TBO	Time Between Overhaul
T / O	Take-Off
TQM	Total Quality Management
TRA / TCAE	Teledyne Ryan Aeronautical - TCAE Turbine Engine Unit

1.0 INTRODUCTION

The general aviation industry is poised for a dramatic expansion due to the development of low cost, high performance, low emission gas turbine engines that are applicable for powering light commercial aircraft. Currently being powered by conventional piston engines, these general aviation aircraft can realize improvements in affordability, range, speed and emissions by retrofitting with gas turbine engines. Advanced technologies that have been developed for military applications are now becoming available for transfer to the general aviation industry. For the business jet size aircraft, further advances in materials and propfan technologies also offer significant improvements over the existing turbofan powerplants.

In this study, new technology engines were defined in two power classes: a 200 hp class, for a light, 4-place personal aircraft, and a 1500 pound thrust class for a twin-engined, 6-place business jet type aircraft. These engines were evaluated for retrofitting suitable current production aircraft for comparision to the existing engines. The engines were evaluated for performance using a typical mission for each aircraft as well as a variant mission to further appraise the impact of engine performance. Issues of cost, safety, maintenance and reliability were also addressed for the engine comparisons resulting in the recommendation for the system best suited to general aviation in each power class. Manufacturing plans and dual-use technology development plans were then constructed for these engines.

2.0 BASELINE AIRCRAFT SELECTION

In order to select the best baseline aircraft for comparison with new advanced technology engines retrofit, several criteria were considered. Current, certified production aircraft were certainly preferable due to the availability of accurate flight test drag data for input to the mission analysis. Also, aircraft were chosen based on the minimum retrofit modifications needed to install the new engines so that engine performance increments could be isolated from deltas in aircraft drag characteristics. In this way, a retrofit comparison would be as pure an engine-to-engine comparison as possible. Since the Raytheon Aircraft Company was performing the mission analysis, the baseline aircraft were selected from their fleet of airplanes. (Although the entire industry was scanned for a better business jet match, since there was some difficulty in selecting an aircraft with the proper power and installation characteristics). Selecting the baseline aircraft was worked concurrently with defining the new, advanced technology engines so that the aircraft chosen were appropriate for the engines being defined.

In the light, private type aircraft, a Beechcraft F33 Bonanza, shown in Figure 2.0.1 was selected as the baseline. Powered by a 225 hp I/C engine Teledyne Continental IO-470, this 4 place single prop has a 700 nautical mile range at 6,000 feet. It is an appropriate choice for this power class and has well documented drag polars. Although the sea level static rating of the baseline engine is about 30% higher than the designated 200 hp for the new advanced engines, the baseline engine's cruising speed compares well with the cruise speed expected of the new engines.

For the business class jet aircraft, the baseline selection was a bit more difficult. An industry search for a 6 place, twin-engined business jet in the 3000 lbf (1500 lbf per engine) thrust class resulted in a close match with the Beechcraft King Air C90 shown in Figure 2.0.2. The baseline engines are two Pratt and Whitney Canada PT6A-21's that provide 500 shp for takeoff. The size and type of this aircraft satisfy the guidelines for the study and being a production airplane, the appropriate drag characteristics are readily available. Installation concerns, however, presented a problem. The two advanced technology engines being defined for the business jet class were a turboprop and a propfan configuration. Powered by wing-mounted tractor props, the King Air could be retrofitted with new turboprops. It was not appropriate to consider installing pusher propfans on this aircraft. An industry survey did not furnish any more suitable configurations. However, a research aircraft, the Quiet Clean General Aviation Turbine Engine (QCGATE), presented a very favorable match. The QCGATE aircraft shown in Figure 2.0.3 was designed by Beech in 1977 as part of a preliminary design study. Two aft fuselage mounted Lycoming turbines provided 1500 lbf of takeoff thrust each for the QCGATE, making it a good power match and a candidate for propfan installation. Although the QCGATE is not a production aircraft, the extensive analyses it underwent lend confidence in its accurate characterization. The QCGATE study was well documented and the data available was certainly adequate for this study.

It was decided to proceed with the mission analysis assuming propfans could be installed on the King Air in order to produce an engine-to-engine comparison with that vehicle, and in addition, perform mission analysis with the propfan only on the QCGATE plane to provide a comparison on a vehicle that would realistically support propfan installation. Table 2.1 summarizes the airframe/engine combinations for this study.

Table 2-1
Airframe / Engine Combinations for
General Aviation Advanced Propulsion Systems Study

AIRCRAFT	SEATS	BASELINE ENGINE	BASELINE SLS RATING	ADVANCED ENGINES	ADVANCED SLS RATING
Beechcraft Bonanza	4	Teledyne Continental IO-470-K	225 hp	Model 216 Model 220-2	160 hp 200 hp
Beechcraft King Air	6	Pratt Whitney Canada PT6A-21	500 hp	Model 265 Model 2150	650 hp 1500 lbf
QCGATE	6	Lycoming Turbine	1500 hp	Model 2150	1500 lbf

Figure 2.0.1 Beechcraft F33A Bonanza four/five-seat executive aircraft.

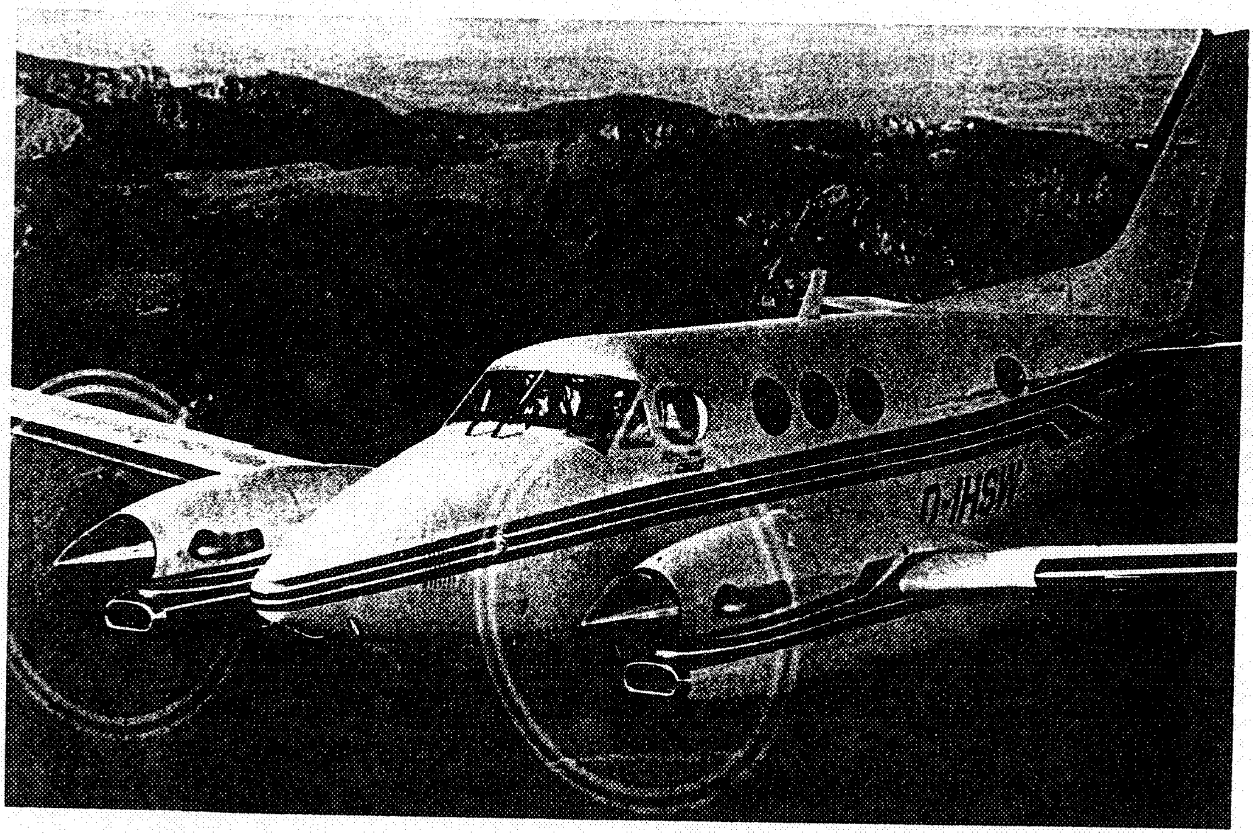


Figure 2.0.2 Beechcraft King Air C90B over the Alps.

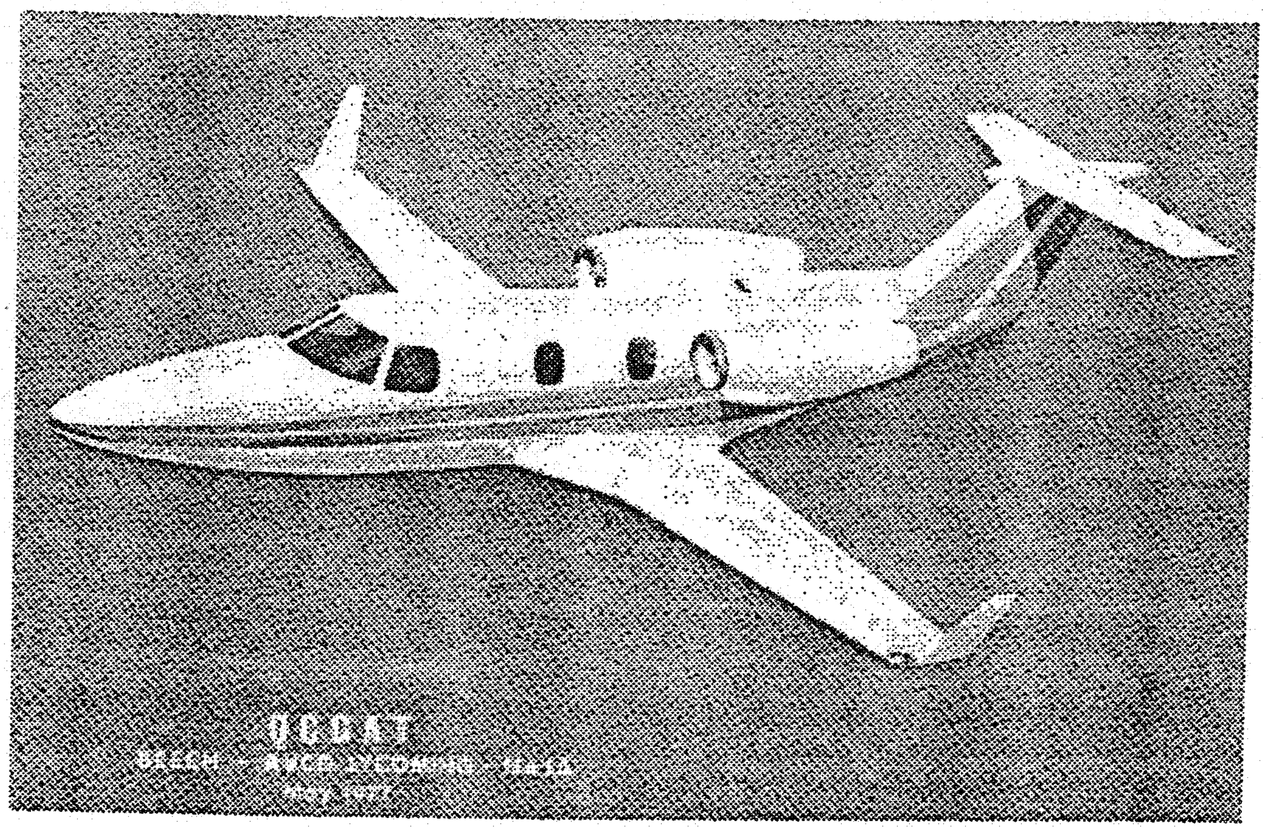


Figure 2.0.3 QCGATE Research Aircraft Configuration.

3.0 ADVANCED TECHNOLOGY ENGINES

Four advanced technology engines were defined for this study: three turboprop configurations and one propfan configuration. Due to the installation requirements for a propfan engine, it was decided to eliminate that configuration from the low power class. Since a propfan engine achieves approximately 10-20% of its total thrust via exhaust gas expansion in a jet nozzle confluent with the propfan discharge air, a forward fuselage nose mounted configuration (as would be required in the Bonanza) is not practical. For the 200 shp class, it was desirable to use a derivative of an engine currently under development for automotive application due to the low cost associated with the high production volume. In order to take full advantage of the cost savings offered by automotive production levels, it is necessary to use the same component hardware as the automotive assembly line. Thus, scaling this engine up to the 1500 lbf class entails a separate production line and would be impractical from a cost viewpoint. The four advanced technology engine configurations are outlined in Figure 3.0.1.

3.1 200 HP CLASS

In the light, private type class of airplane, the two advanced technology engines presented for consideration in this study are the TRA Model 216 and Model 220-2. The Model 216 turboprop is a twinpack configuration using two automotive derivative engines (80 hp each) along with a combining gearbox which provides output to drive a single propeller. The Model 220-2 turboprop is a single shaft engine derived from TRA/TCAE's Model 235 gas generator core also geared to drive a single propeller.

The flight envelope assumed for this type of aircraft, shown in Figure 3.1.1, has a peak altitude of 20,000 feet at a maximum speed of approximately 0.4 Mach number which easily encompasses the cruise condition of 155 ktas at 8,000 feet. Engine performance data was furnished for a matrix of points covering the entire envelope of Figure 3.1.1 for vehicle mission analyses. Installation requirements incorporated in the engine performance analysis were defined by the airframer as:

- o 6 HP load extraction
- o 0.5 lbm/min pressurized bleed air
- o 99% inlet recovery

The baseline for the Model 216 is TRA/TCAE's Model 105 turbo-generator which is curren under development for Ford's Hybrid Electric Vehicle program. Derived from TRA/TCAE's 4 inc diameter engine, the Model 304, the Model 105 incorporates a mixed flow compressor and ceramic radial turbine. The Model 105 uses a recuperator to extract heat energy from the exhaust gas stream to preheat the combustion air in order to reduce the heat required from fuel combustion to reach the engine cycle temperature, thus achieving a substantial fuel saving. A Rich-Quench-Lean (RQL) combustor produces near zero emission levels for the automotive application which further enhances the overall engine concept for transfer to the general aviation market. The aircraft engine would be derived from the automotive production line with appropriate modifications for flight application. In the twinpack configuration for the Model 216, the starter-generator will be replaced with the combining gearbox, the air intake will be faired for a scoop inlet, and the fuel control and vehicle interfaces will be adapted for the general aviation application. The Model 216 produces 160 hp for takeoff at sea level, static conditions with a brake specific fuel consumption of 0.43 lbm/hr/hp. At approximate cruise conditions, the Model 216 produces 116 hp at 0.38 lbm/hr/hp brake specific fuel consumption. Figure 3.1.2 tables the engine performance for the Model 216 at sea level, static and 10,000 feet, 0.4 Mach number.

200 SHP CLASS	1500 LBF. CLASS
Model 216:	**Model 265:**
Automotive Derivative	Model 235 Core
Ceramic Turbine	IHPTET Technology
RQL Combustor	Mixed Flow Turbine
Twin Pack	Turboprop
Turboprop	
Model 220-2:	**Model 2150:**
Model 235 Core	Model 235 Aerodrive Propfan
IHPTET Technology	Mixed Flow Turbine
Mixed Flow Turbine	6x6 Counter-rotating Propfan Blades
Turboprop	

Figure 3.0.1 Advanced Technology Engines Configuration Summary.

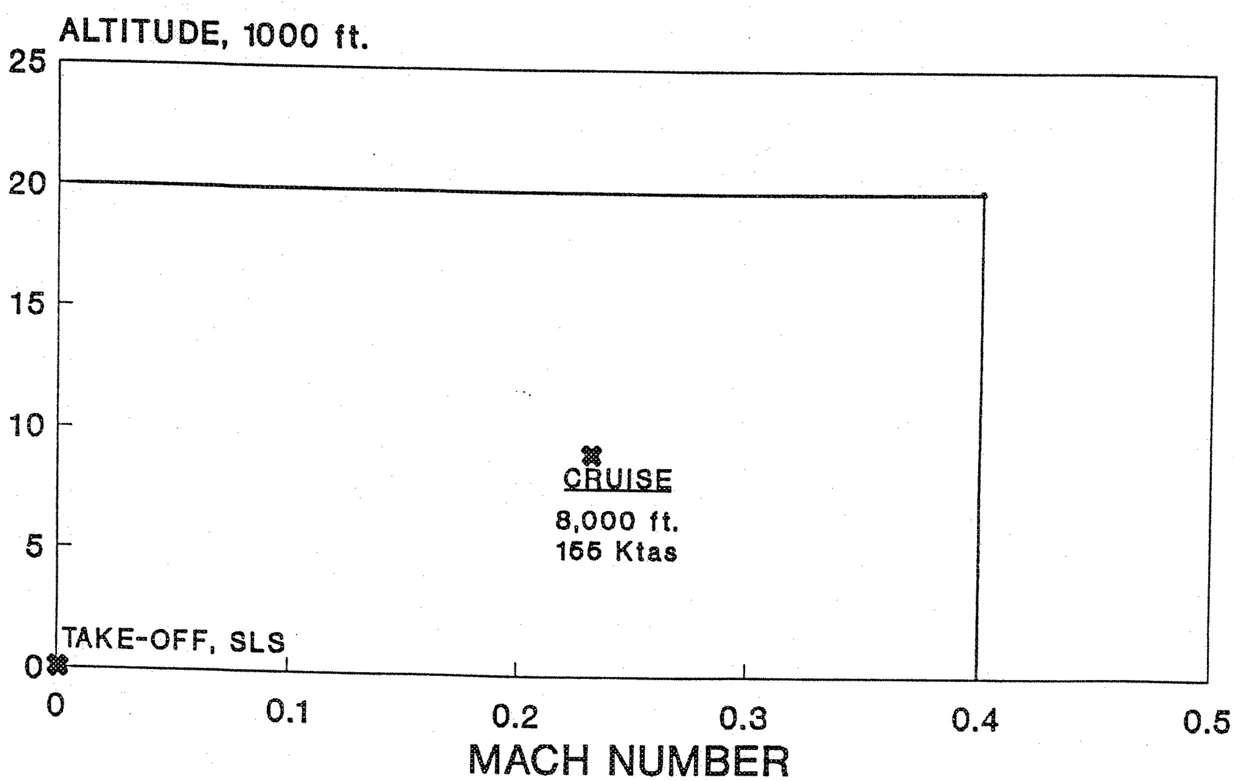


Figure 3.1.1 Light, Private Aircraft Flight Envelope.

MODEL 216 TURBOPROP ENGINE PERFORMANCE

	@ Sea Level, Static, 100% power	@ 10,000 Ft., 0.4 Mn (90% power)
Horsepower, hp	160.	116.
Brake Specific Fuel Consumption, lbm/hr/hp	0.425	.379
Fuel Flow, lbm/hr	68.	44.
Airflow, lbm/s	1.93	1.28
Exhaust Gas Temperature, °F	532.	475
Mech. Rotational Speed, rpm	115,500	104,000
Prop Speed, rpm	2300	2070

Figure 3.1.2 Advanced Technology Engines.

The Model 220-2 is a derivative of TRA/TCAE's Model 235 core gas generator, geometrically scaled for the low power application. The Model 235 core consists of a two-stage, axial compressor plus a centrifugal compressor stage, an annular combustor, mixed flow turbine and a patented liquid ring pump fuel delivery subsystem. The mixed flow turbine is a high-work stage with a turbine rotor inlet temperature of 2250 degrees fahrenheit. The hollow turbine inlet nozzle is cooled with compressor discharge air. The Model 220-2 produces 200 hp at sea level, static conditions with a brake specific fuel consumption of 0.50 lbm/hr/hp. At approximate cruise conditions, the Model 220-2 produces 104 hp at 0.58 lbm/hr/hp brake specific fuel consumption. Figure 3.1.3 tables the engine performance for the Model 220-2 at sea level, static and at 10,000 feet, 0.4 Mach number.

3.2 1500 LB THRUST CLASS

The two advanced technology engines defined for the twin engined business jet type aircraft are the TRA/TCAE Model 265 and Model 2150. The Model 265 is a derivative of the Model 235 core gas generator geared to drive a propeller (as is the Model 220-2). The Model 2150 is a full-up propfan derived from the Model 235 propfan engine.

The flight envelope assumed for this type of aircraft shown in Figure 3.2.1 includes altitudes up to 40,000 feet at Mach numbers as high as 0.8. The cruise point for the C90 King Air is shown at 21,000 feet at 240 ktas, while the cruise point for the QCGATE is higher in the envelope at 35,000 feet, 360 ktas. Installation requirements for the business jet were provided by the airframer and incorporated in the engine performance analysis. On a per engine basis, the installation requirements are:

- o 10 hp load extraction
- o 6 lbm/min pressurized bleed air
- o 99% inlet recovery

The Model 265 is identical to the Model 220-2 previously described in that the Model 265 is a geometric scale of TRA/TCAE's Model 235 gas generator core. The Model 220-2 is scaled for the low power application while the Model 265 is scaled for the high power application and incorporates the installation requirements for the business jet. A layout of the Model 265 in a pylon-mounted installation is shown in Figure 3.2.2 as a pusher configuration although the shaft design could incorporate a more conventional tractor configuration. The Model 265 is rated for 650 hp sea level static, with 0.49 lbm/hr/hp specific fuel consumption. At an approximate cruise condition for the C90 King Air, the Model 265 produces 285 hp at 0.48 lbm/hr/hp. The overall engine performance parameters for the Model 265 at these two conditions are tabled in Figure 3.2.3.

The Model 2150 is a propfan engine scaled directly from TRA/TCAE's Model 235 full-up propfan. The Model 235 propfan uses the core gas generator described for the Models 220-2 and 265 with the addition of a four-stage free turbine driving six unducted counter-rotating propfan blades. The propfan was modelled after the successful General Electric Unducted Fan (UDF) and benefits from that program's technology and expertise. The layout of the Model 2150 aft fuselage mounted propfan is shown in Figure 3.2.4. The full propfan cross-section is shown in Figure 3.2.5 with missile application propfan contours.

MODEL 220-2 TURBOPROP ENGINE PERFORMANCE

	@ Sea Level, Static, 100% power	@ 10,000 Ft., 0.4 Mn (90% power)
Horsepower, hp	200.	104
Fuel Flow, lbm/hr	99.5	60.6
Brake Specific Fuel Consumption, lbm/hr/hp	.50	.58
Airflow, lbm/s	1.19	.75
Exhaust Gas Temperature, °F	1182.	1220.
Mech. Rotational Speed, rpm	113,000	102,000

Figure 3.1.3 Advanced Technology Engines.

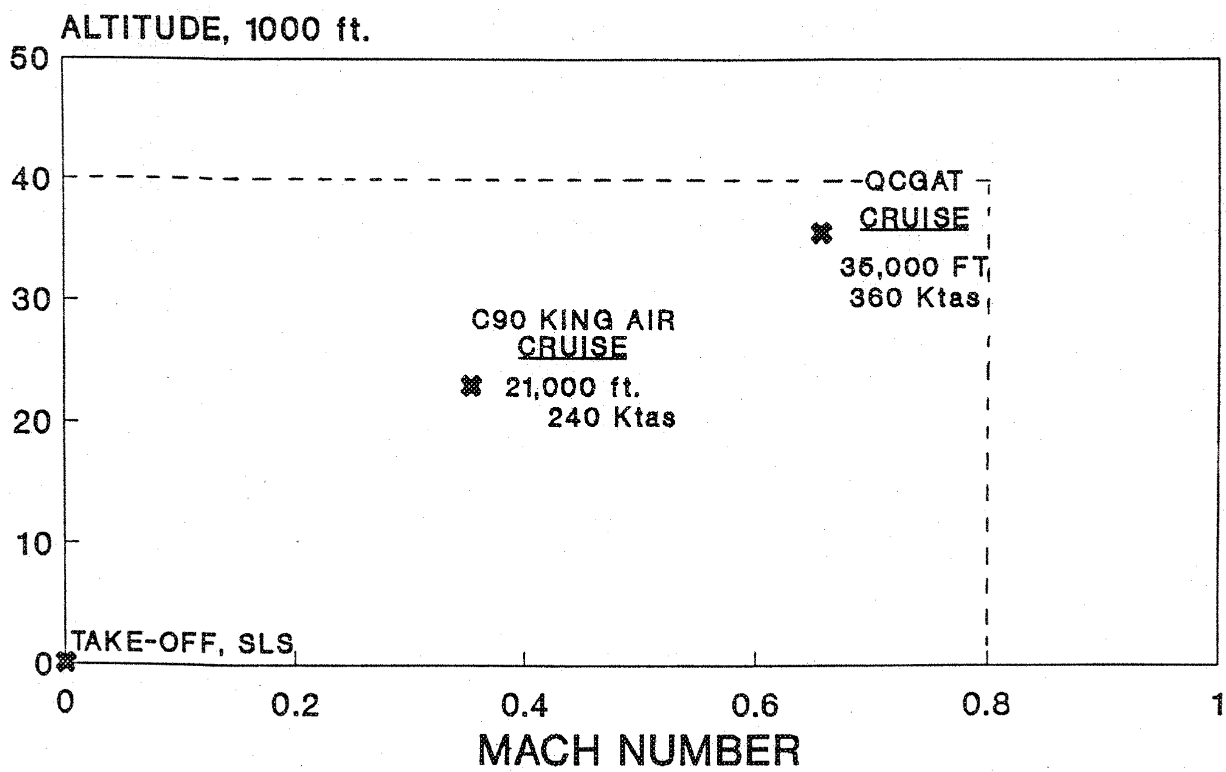


Figure 3.2.1 Business Jet Aircraft Flight Envelope.

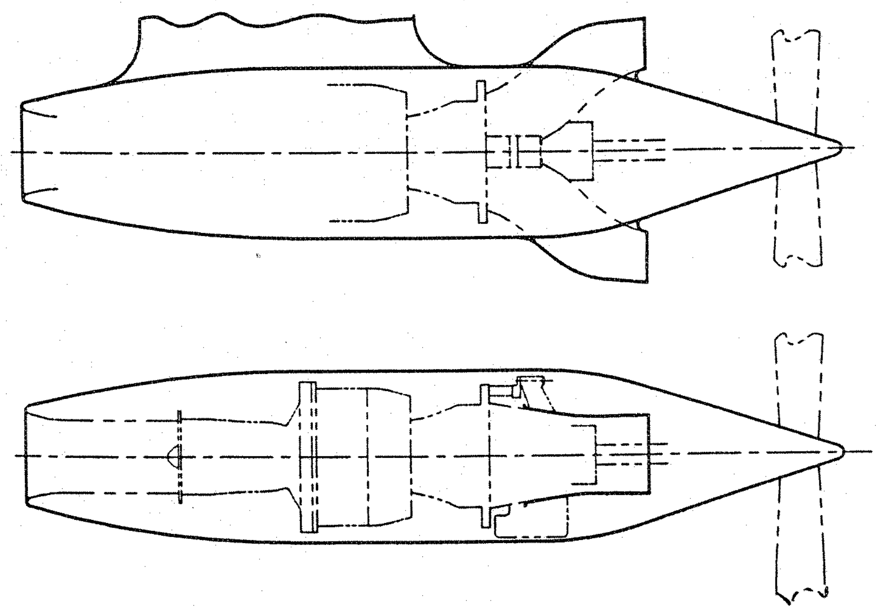


Figure 3.2.2 General Aviation Turboprop Installation, Model 265.

MODEL 265 TURBOPROP ENGINE PERFORMANCE

	@ Sea Level, Static, 100% power	@ 20,000 Ft., 0.4 Mn (90% power)
Horsepower, hp	650.	285.
Fuel Flow, lbm/hr	318.	140.
Brake Specific Fuel Consumption, lbm/hr/hp	.49	0.48
Airflow, lbm/s	3.88	1.95
Exhaust Gas Temperature, °F	1182.	1030.
Mech. Rotational Speed, rpm	62,560	56,300

Figure 3.2.3 Advanced Technology Engines.

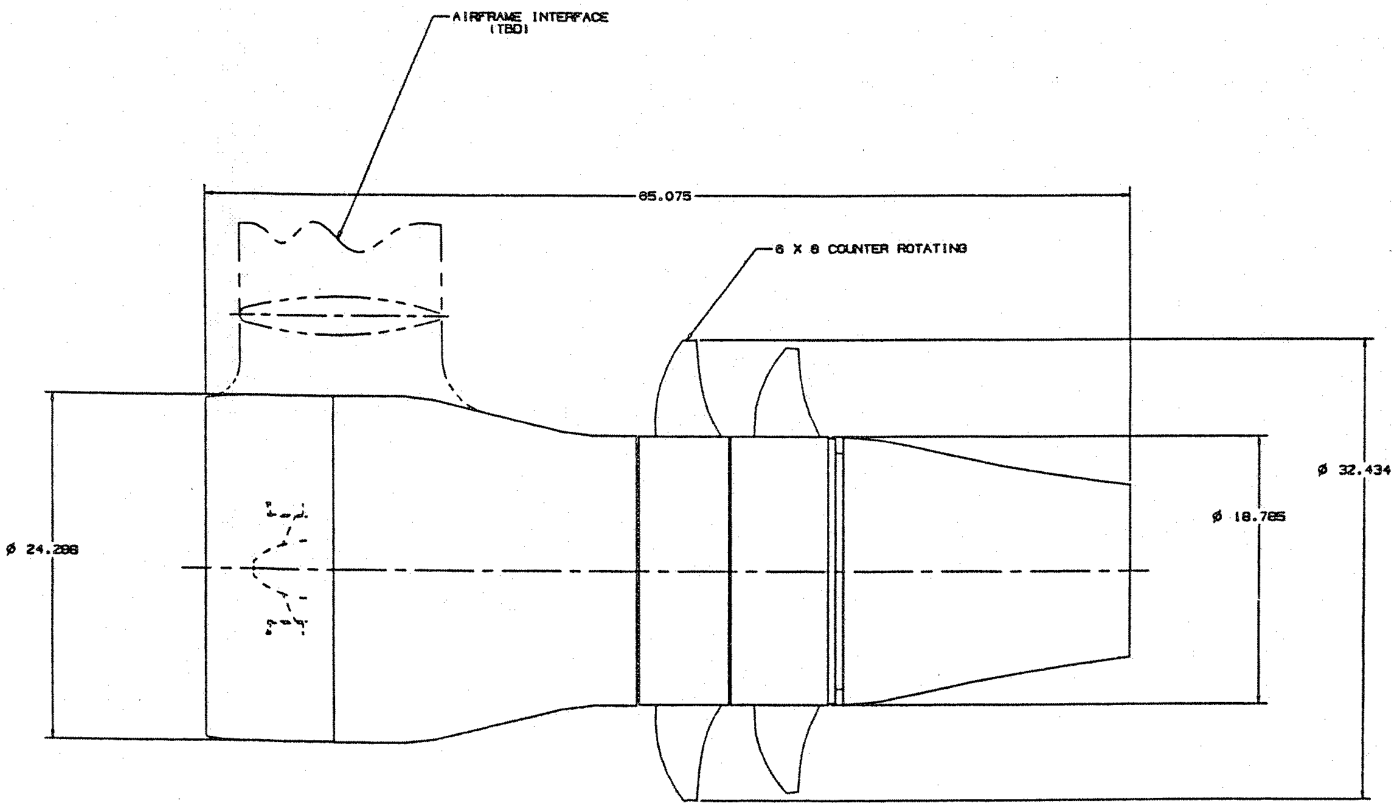


Figure 3.2.4 General Aviation Propfan Installation, Model 2150.

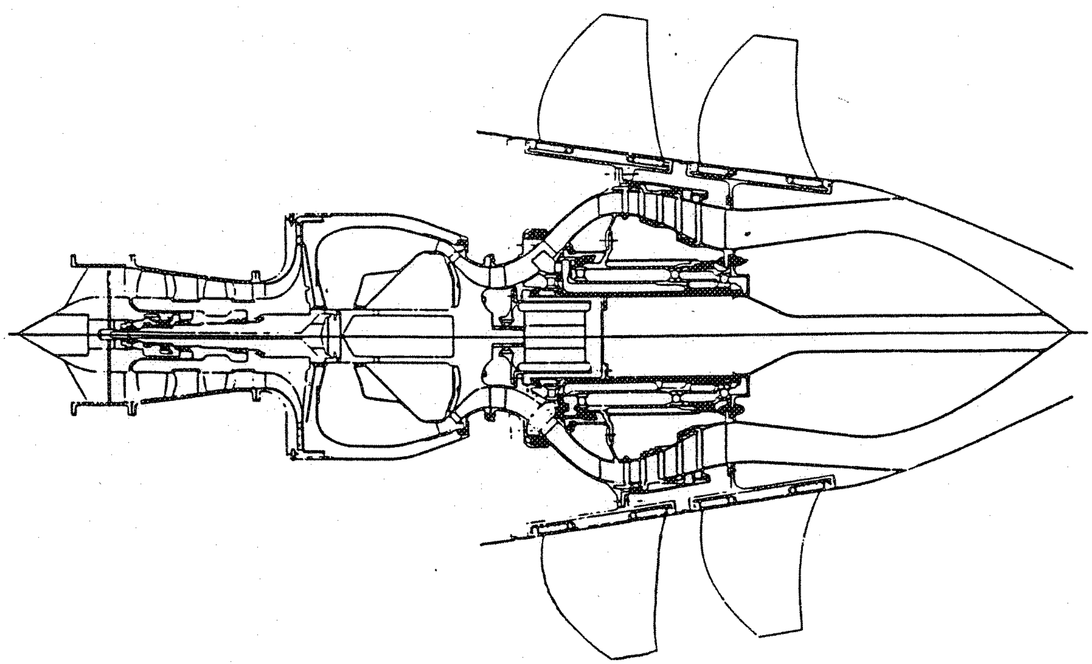


Figure 3.2.5 Teledyne Ryan-TCAE Model 2150 Propfan Engine (Shown with missile application propfan contours).

The Model 2150 is rated for 1500 lbf sea level, static thrust at 0.38 lbm/hr/lbf specific fuel consumption. At the C90 King Air cruise point the Model 2150 produces 425 lbf of thrust at 0.51 lbm/hr/lbf specific fuel consumption. For the cruise conditions of the QCGATE vehicle, the Model 2150 provides 300 lbf thrust at 0.64 lbm/hr/lbf specific fuel consumption. The propeller tip speed was limited to 750 feet per second at take-off for noise considerations. The Model 2150 engine performance is given in Figure 3.2.5 for take-off conditions as well as the approximate cruise points of the C90 King Air and the QCGATE.

MODEL 2150 PROPFAN ENGINE PERFORMANCE

	@ Sea Level, Static, 100% Power	@ 20,000 ft. 0.4 Mn (90% power)	@ 30,000 ft. 0.7 Mn (90% power)
Thrust, lbf	1500	425	300
Fuel Flow, lbm/hr	570.	214	195
Specific Fuel Consumption, lbm/hr/lbf	.38	.51	.64
Airflow, lbm/s	6.88	3.42	2.82
Exhaust Gas Temp., °F	1260.	944.	1005
Mech. Rotational Speed, rpm	47,000	42,300	42,300
Prop Speed, rpm	7100	6000.	7500

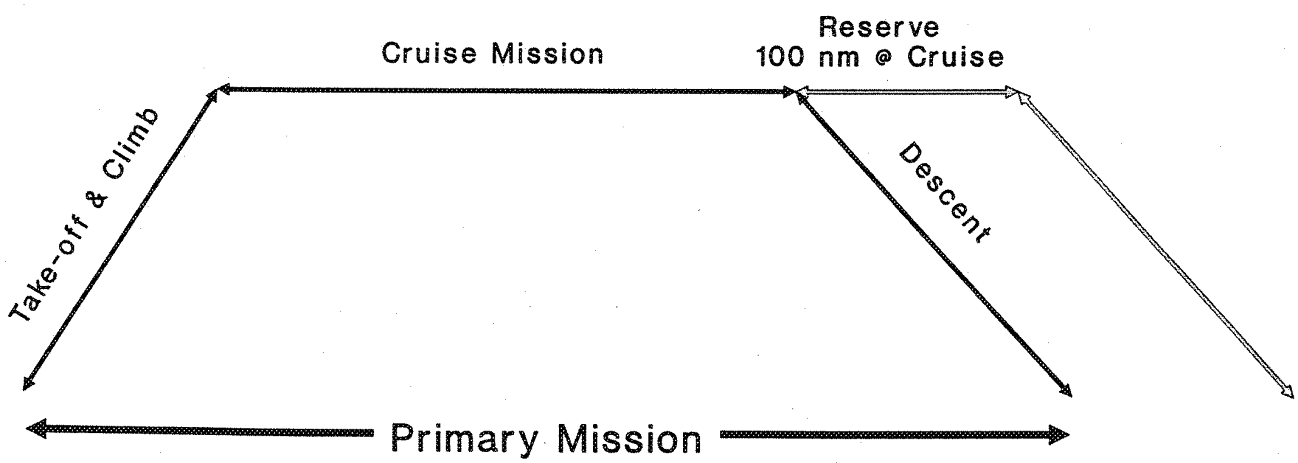
Figure 3.2.6 Advanced Technology Engines.

4.0 MISSION PERFORMANCE EVALUATION

The four advanced technology engines were evaluated as possible replacements for the engines in the selected baseline aircraft. The airframe/engine combinations compared in this study are:

BASELINE	ADVANCED TECHNOLOGY ENGINES
Bonanza / IO-470-K	Model 216, Model 220-2,
C90 King Air / PT6A-21	Model 265, Model 2150
QCGATE / Lycoming Turbine	Model 2150

Takeoff, climb, cruise and descent performance was predicted for a mission that is typical for the baseline aircraft with both current baseline engines and new technology engines. Parameters used to compare the engine performance include takeoff distance, range, speed, mission time, and fuel usage. Takeoff field length relates directly to the sea level static thrust produced by the engine when all other variables (weight, atmosphere conditions) are held constant. The climb performance provides a comparison on the variation of thrust with increasing altitude and is described in terms of time and distance required to achieve the cruise altitude. The overall mission analysis (climb, cruise, descent) reflects the differences in engine fuel consumption and the resultant range capacity of the engine/airframe combination. The components of a typical mission are defined in the diagram:



Aircraft weight and balance become important issues when considering the installation of a new engine in an existing airframe. A reduction in takeoff weight reduces the induced drag which leads to an increase in range that is unrelated to improvements in engine thrust or fuel consumption. A variation in engine weight would usually mean the addition of lead balances in the aircraft nose or tail to maintain similar stability and handling characteristics for the aircraft. The alternative is to relocate the wing on the fuselage which incurs engineering and certification costs that are prohibitive for an engine retrofit project.

Although all of the new technology engines weigh less than the current engines in the baseline aircraft, no reduction in aircraft take-off weight was considered for this study. Thus any improvement in mission time or range can be attributed solely to the performance characteristics of the new technology engine. With the exception of the Model 220-2, the uninstalled weights of the new engines were within 10% of the current engines' uninstalled weights and thus it is appropriate to ignore any reduction in aircraft takeoff weight. The Model 220-2, however, is significantly lighter (75%) than the baseline engine, and would realize the most benefit from a new aircraft design. Not only would a new aircraft be lighter due to the reduced engine weight, but a smaller wing would be required for the same stall speed or field length requirement.

The propellers selected for the Model 216, Model 220-2 and Model 265 engines were identical to those used on the baseline aircraft and are assumed to have the same propeller efficiency (0.80) as those of the baseline engines. This was a reasonable assumption since the propeller speeds anticipated for the new technology engines are similar to those of the current engines.

4.1 BONANZA - TYPICAL MISSION

The typical mission for the Bonanza aircraft is defined for a fixed takeoff weight of 3050 lb including a 600 lb payload and 384 lb fuel weight. For a fixed fuel weight, any improvement in fuel consumption will lead to an increase in mission range. The primary mission consists of a climb to 8000 ft at the best rate-of -climb speed, cruise at maximum speed and descent at 500 ft/min. An additional 100 nm cruise at 8000 ft and the speed for 99% best specific range is included to ensure enough fuel reserve to divert to an alternate airport.

Figures 4.1.1 through 4.1.3 show the results of the typical mission analysis for the Bonanza aircraft with the baseline engine and the new technology engines. The takeoff field length required for each engine is shown in Figure 4.1.1. Both the Model 216 and Model 220-2 have a reduced horsepower capabilities compared to the baseline engine and thus require additional field length to clear a 50 ft obstacle. The climb characteristics (shown in Figure 4.1.2) also reflect the reduced power of the Model 216 which takes longer to get to altitude than the baseline engine, however, the Model 220-2 climbs to altitude in the same time and distance as the baseline engine. For the cruise portion of the mission (Figure 4.1.3), however, the significant improvements in fuel consumption for the Model 216 produce a major increase in range (34%) while maintaining approximately the same cruise speed as the baseline engine. The Model 220-2 has a slightly reduced range at the same cruise speed as compared to the baseline engine, although the 6% reduction in range would be offset by the significant weight savings associated with the installation of this engine in a new airplane. The overall primary mission range is also included in Figure 4.1.3, and since the descent performance is identical for all three engines, the climb and cruise portions of the mission impact these numbers. Figure 4.1.4 summarizes the results of the mission analysis. The Model 216 has 29% less horsepower which translates to a slower climb, however the fuel consumption improvement over the baseline allows for a 34% longer primary mission range. The Model 220-2 is very similar to the baseline engine as a retrofit although the weight advantage offered by this engine could be better realized in a new airplane design.

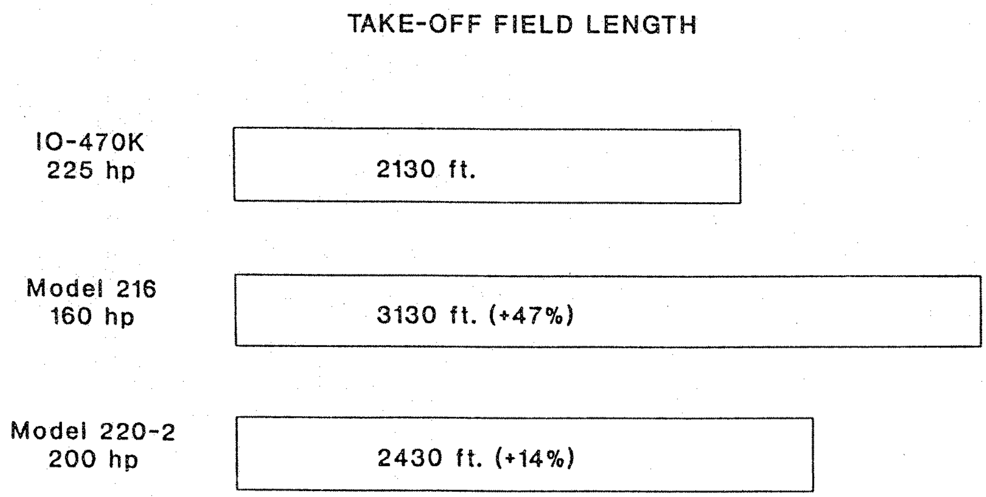


Figure 4.1.1 Typical Mission Evaluation - Bonanza.

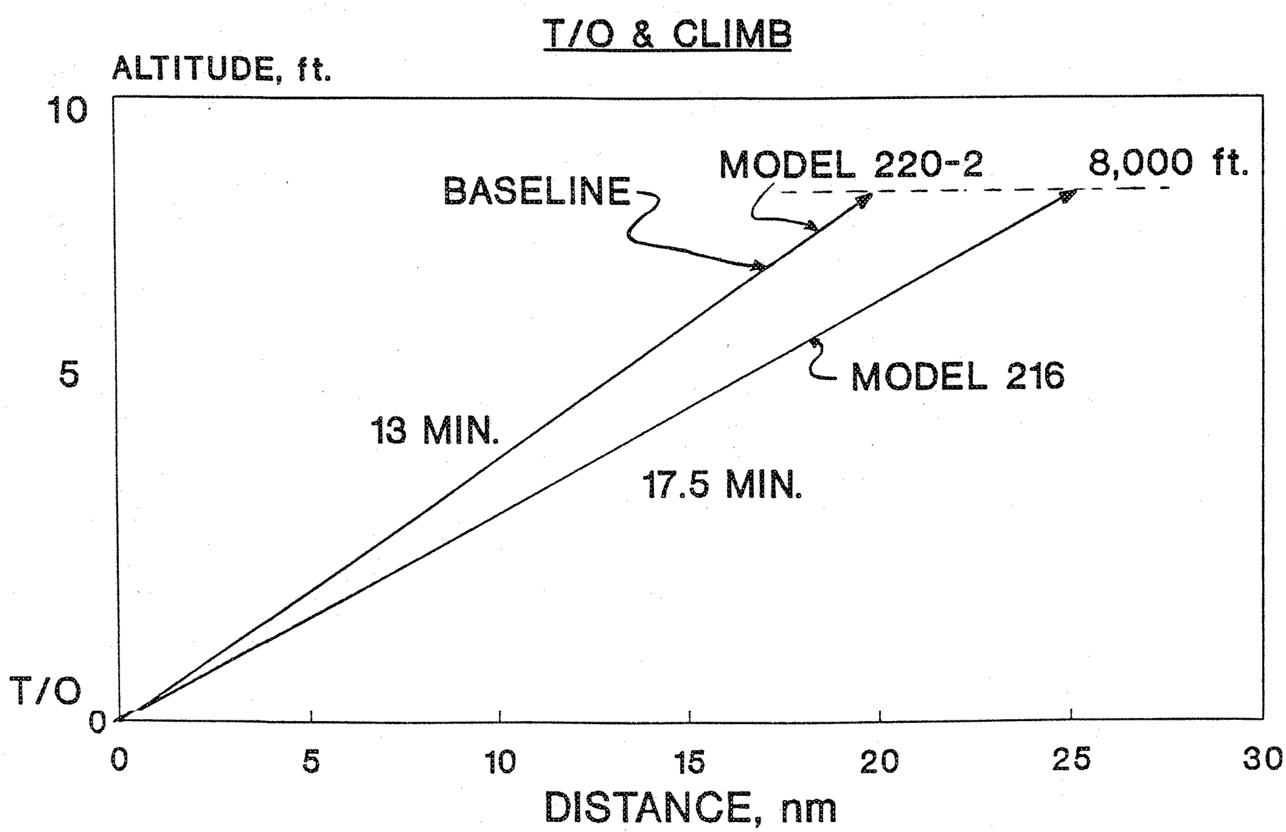


Figure 4.1.2 Typical Mission Evaluation - Bonanza.

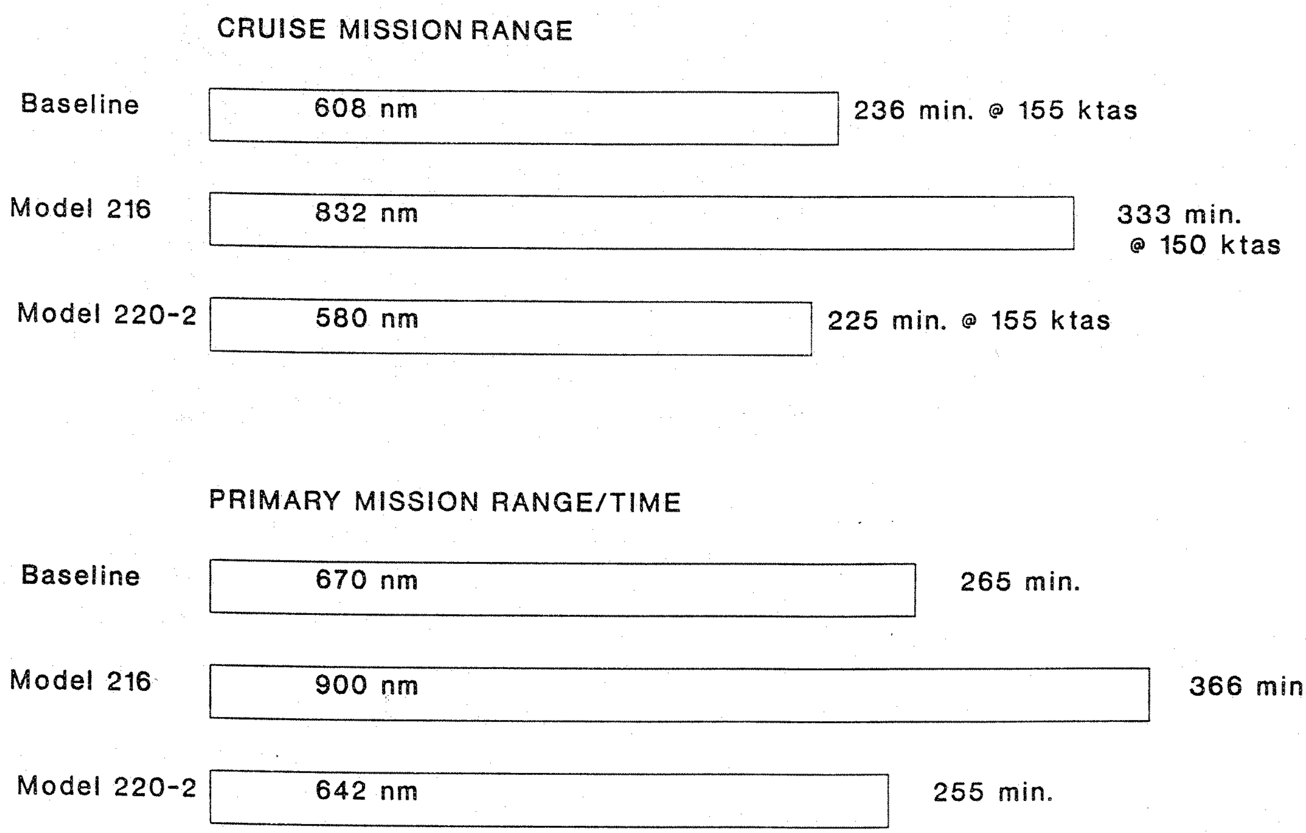


Figure 4.1.3 Typical Mission Evaluation - Bonanza.

SUMMARY - △'s FROM BASELINE ENGINE

	SLS hp	Time to Climb	Cruise Speed	Primary Mission Range	Engine Weight
Baseline	225 hp	13 min.	155 Ktas	670nm	-
Model 216	-29%	+34%	-3%	+34%	-10%
Model 220-2	-11%	0%	0%	-4%	-75%

Figure 4.1.4 Typical Mission Evaluation - Bonanza.

4.2 C90 KING AIR - TYPICAL MISSION

The typical mission used to evaluate the new technology engines with the C90 King Air is given for a fixed takeoff weight of 10,100 lb which includes a 1200 lb payload and 2025 lb of fuel. The primary mission consists of a climb to 21,000 ft at the best rate-of-climb speed, cruise at maximum speed and descent at 1500 ft/min. Again, an additional 100 nm cruise at 21,000 ft and the speed for 99% best specific range is included.

Figures 4.2.1 through 4.2.3 give the results of the mission analysis comparing the new technology engines installed in the C90 King Air with the existing engine for the typical mission. The increased horsepower of the Model 265 allows a 26% shorter takeoff runway than the baseline engine. The Model 2150 propfan takes an additional 11% of runway to clear a 50 ft obstacle. The results for the climb portion of the mission are shown in Figure 4.2.2 and indicate that the Model 265 turboprop is equivalent to the baseline engine, climbing to altitude in 15 minutes over a distance of 36 nm. The Model 2150 propfan, in comparison, takes 3 nm longer to get to cruise altitude, but does it in a shorter time (higher rate-of-climb speed). The results for the cruise portion of the mission, shown in Figure 4.2.3, indicate the significant increase in fuel efficiency for the Model 265, allowing the same aircraft to cruise for 373 nm longer at the same speed than with the baseline engine. The Model 2150 propfan reduces the aircraft cruise to 90 nm less than the baseline engine, however, the 17% increase in cruise speed (281 ktas) is the maximum speed for the aircraft and limits the most efficient operational speed for the propfan. This clearly indicates that this engine generates higher thrust than the baseline engine and may be overpowering the airplane. Figure 4.2.4 summarizes the results of the mission analysis which demonstrates the large gains in mission range with the Model 265 without sacrificing speed or climb characteristics.

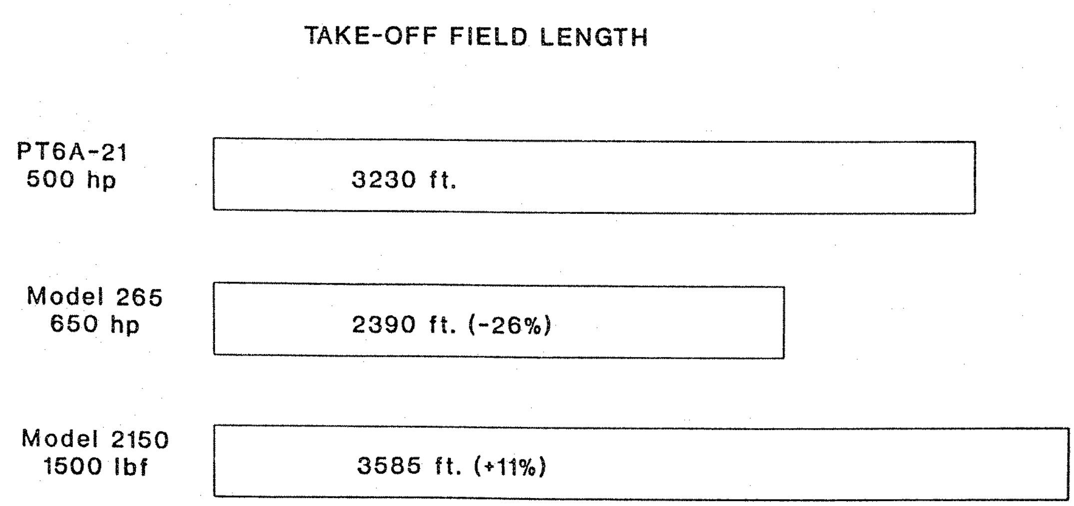


Figure 4.2.1 Typical Mission Evaluation - C90 King Air.

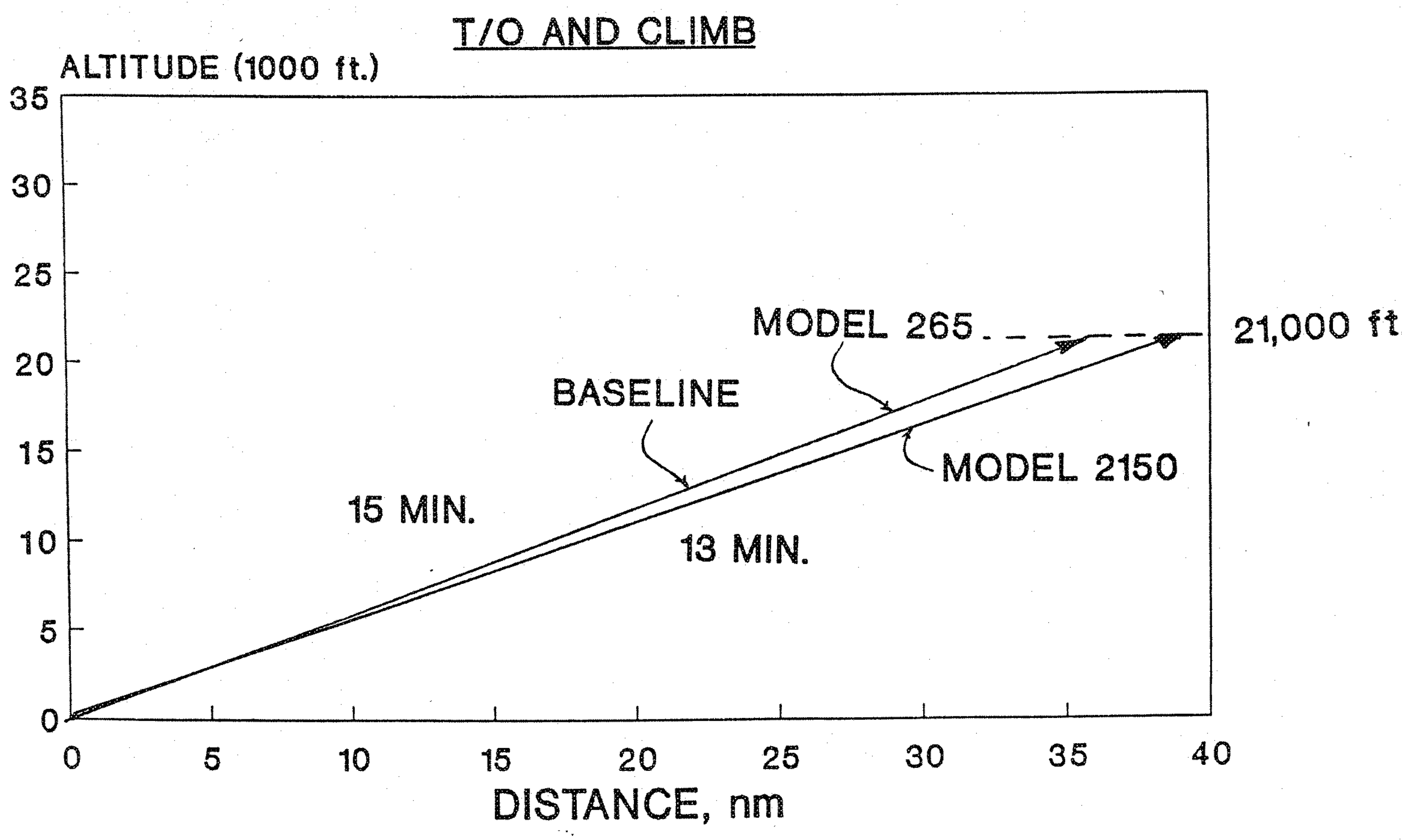


Figure 4.2.2 Typical Mission Evaluation - C90 King Air - T/O and Climb.

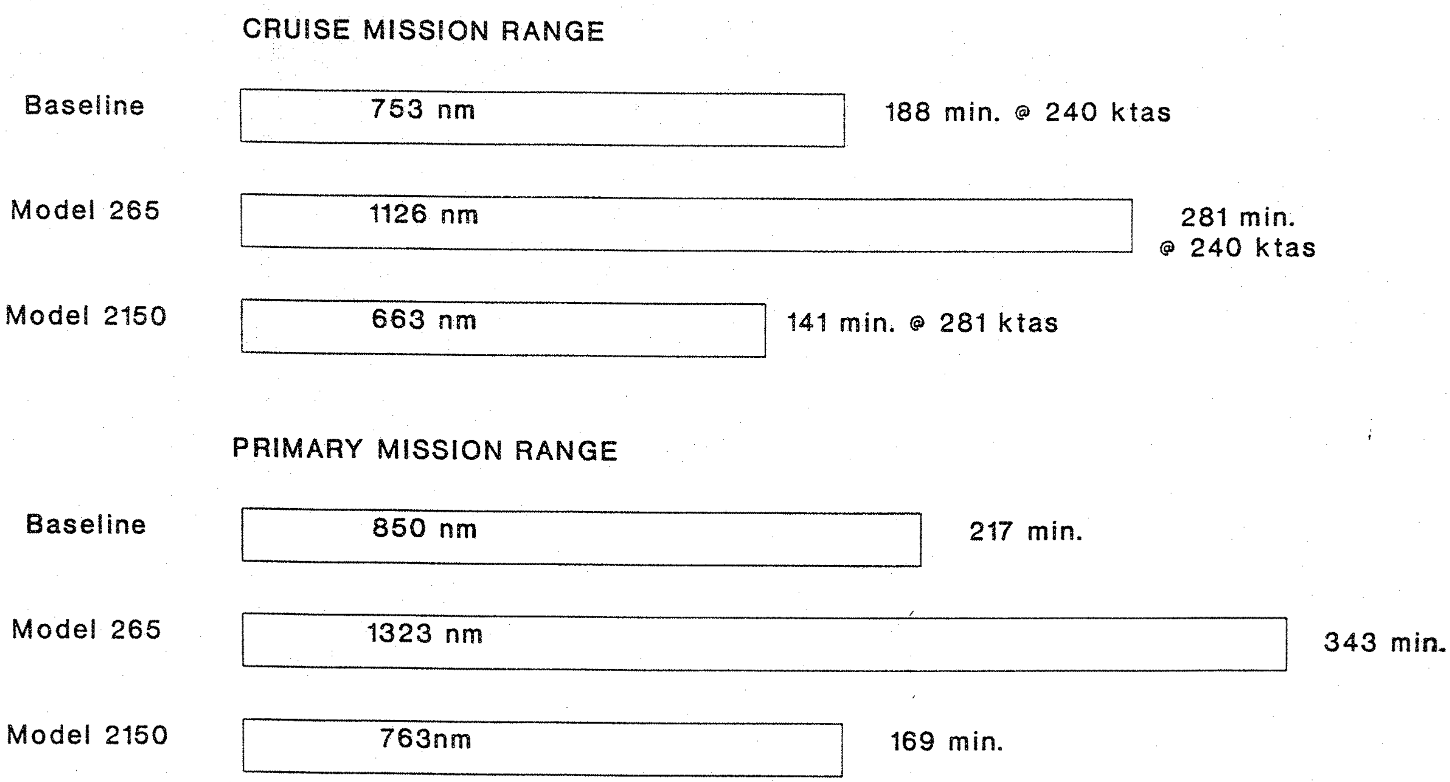


Figure 4.2.3 Typical Mission Evaluation - C90 King Air

SUMMARY - △ 's FROM BASELINE ENGINE

	SLS hp	Time to Climb	Cruise Speed	Primary Mission Range	Engine Weight
Baseline	500 hp	15 min.	240 Ktas	850nm	-
Model 265	+30%	0%	0%	+44%	<10%
Model 2150	+20%	-11%	+17	-10%	<10%

Figure 4.2.4 Typical Mission Evaluation - C90 King Air - Summary.

4.3 QCGATE - TYPICAL MISSION

The QCGATE airplane was evaluated with the Model 2150 propfan installed for a typical mission that consisted of taking off with 7800 lb, climbing to a cruising altitude of 35,000 ft at the best rate-of-climb speed, cruising at maximum speed, and descent at 1500 ft/min. Also included is an allowance for 100 nm cruise at 35,000 ft at the speed for 99% best specific range.

Figures 4.3.1 through 4.3.3 describe the typical mission evaluation for the QCGATE airplane. Since the baseline engine and the Model 2150 propfan both generate 1500 lbf sea level, static thrust, the take-off field length requirements are identical. The Model 2150 climbs to altitude slightly quicker than the baseline engine and cruises for approximately the same distance, but does so in a shorter time. Thus the primary mission range is nearly identical to the baseline engine although the Model 2150 cruises at a 5% higher speed that the baseline engine. Overall, the summary in Figure 4.3.3 shows the two engines are nearly equivalent except for the higher climb and cruise speeds attained by the Model 2150.

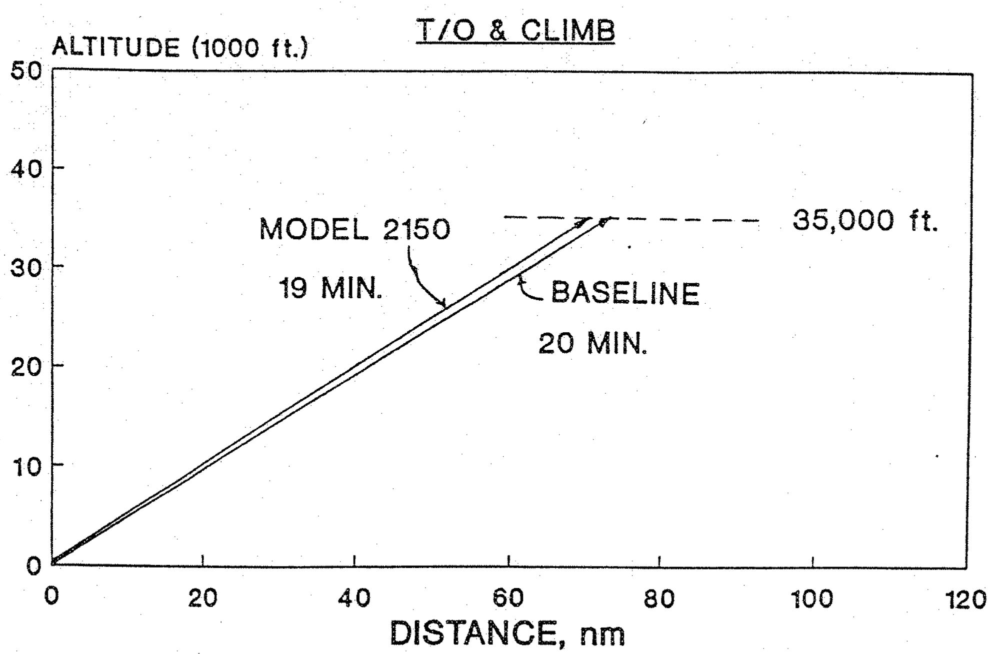


Figure 4.3.1 Typical Mission Evaluation - QCGATE - T/O and Climb.

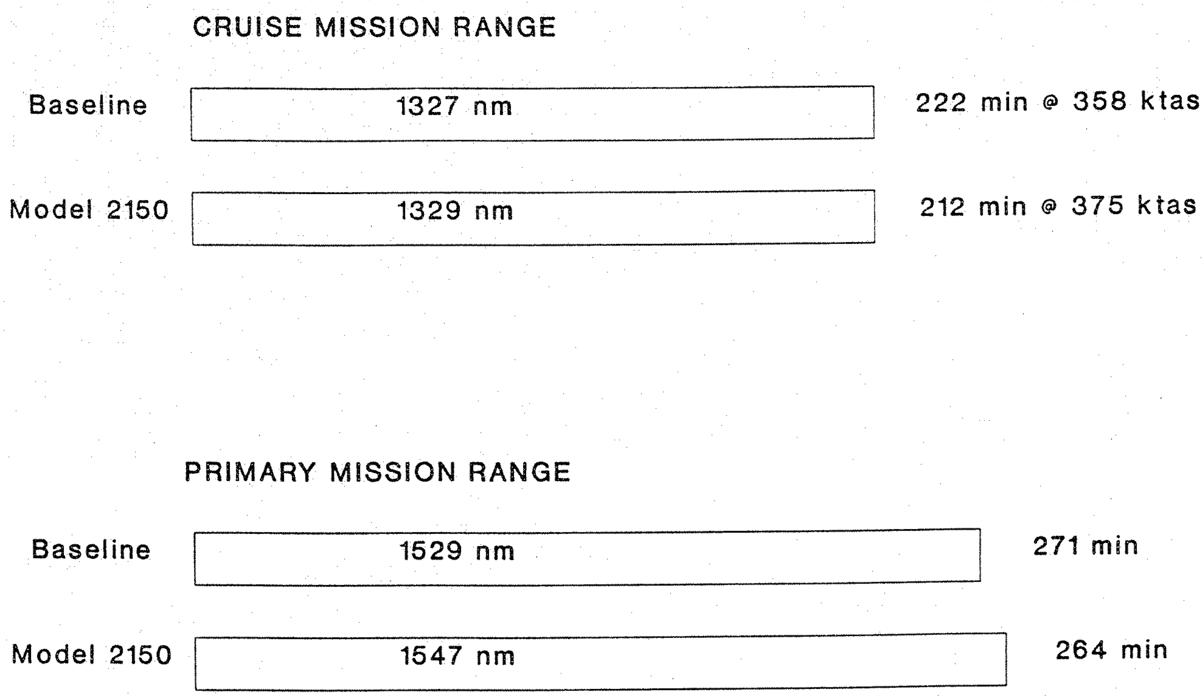


Figure 4.3.2 Typical Mission Evaluation - QCGATE

SUMMARY - △'s FROM BASELINE

	SLS Thrust	Time to Climb	Cruise Speed	Primary Range	Engine Weight
Baseline	1500 lbf	20 min.	358 Ktas	1529 nm	-
Model 2150	0%	-8%	+5%	+1%	-<10%

Figure 4.3.3 Typical Mission Evaluation - QCGATE - Summary.

5.0 MISSION VARIATION IMPACT EVALUATION

The alternate mission selected to evaluate the new technology engines is a long range, rather than maximum speed, mission. This mission was chosen in order to take the maximum advantage of the improvements in fuel consumption for the new engines. The analysis of all the baseline aircraft with all of the engines showed that the specific range increases with altitude. Therefore, the cruise altitudes for the long range mission were set at the highest practical level. For the Bonanza, the cruise altitude was set at 12,000 ft, this being the maximum altitude for an unpressurized cabin. The C90 King Air and the QCGATE missions were analyzed at altitudes just under the aircraft service ceilings: 30,000 ft for the C90 King Air and 40,000 ft for the QCGATE. Cruise speeds were determined in each case for 99% best specific range. The descent portion of the mission was identical to that in the typical mission analysis. The additional 100 nm segment added to the primary mission was run at the typical mission altitudes (8,000 ft for the Bonanza, 21,000 ft for the C90 King Air, and 35,000 ft for the QCGATE), and the speed for 99% best specific range.

5.1 LONG RANGE MISSION - BONANZA

Figures 5.1.1 through 5.1.3 present the results of the long range mission analysis for the Bonanza with the baseline engine, the Model 216 and the Model 220-2 turboprops. Figure 5.1.1 indicates the Model 216 takes longer (both time and distance) to climb to altitude than the baseline engine, while the Model 220-2 climb characteristic is identical to that of the baseline engine. The Model 216 demonstrates a remarkable improvement in range, enabling the same aircraft to cruise for 246 nm longer than the baseline engine at the same speed. The Model 220-2 cruises at a higher speed than the baseline engine, however the distance travelled is 8% less than the primary mission range of the baseline engine. Figure 5.1.3 summarizes the performance deltas for the long range mission in the Bonanza. Although the sea level, static thrust produced by the Model 216 leads to a slower climb, the range attained for the primary mission is 33% longer than the baseline engine. The total primary mission time of 498 minutes (over 8 hours) is probably impractical for a light aircraft without lavatory facilities.

5.2 LONG RANGE MISSION - C90 KING AIR

Figures 5.2.1 through 5.2.3 give the results of the long range mission analysis for the C90 Kin Air with the baseline engine, the Model 265 turboprop and Model 2150 propfan. The Model 26 climbs to 30,000 ft significantly faster, 6 minutes and 15 nm less, than the baseline engine. The Model 2150 takes almost the same distance to climb to altitude as the Model 265 but does it another 6 minutes quicker, for a nearly 30% decrease in time-to-climb from the baseline engine. Figure 5.2.2 shows the Model 265 allows the King Air to cruise for over 530 nm longer than the baseline engine at a higher speed, indicating a tremendous improvement in fuel consumption characteristics for this engine. The Model 2150 provides the same cruise range as the baseline engine, but at a notably higher speed. Figure 5.2.3 summarizes the performance increments for the long range mission analysis of the C90 King Air. The Model 265 turboprop makes a significant impact on the aircraft's capability for climb and range.

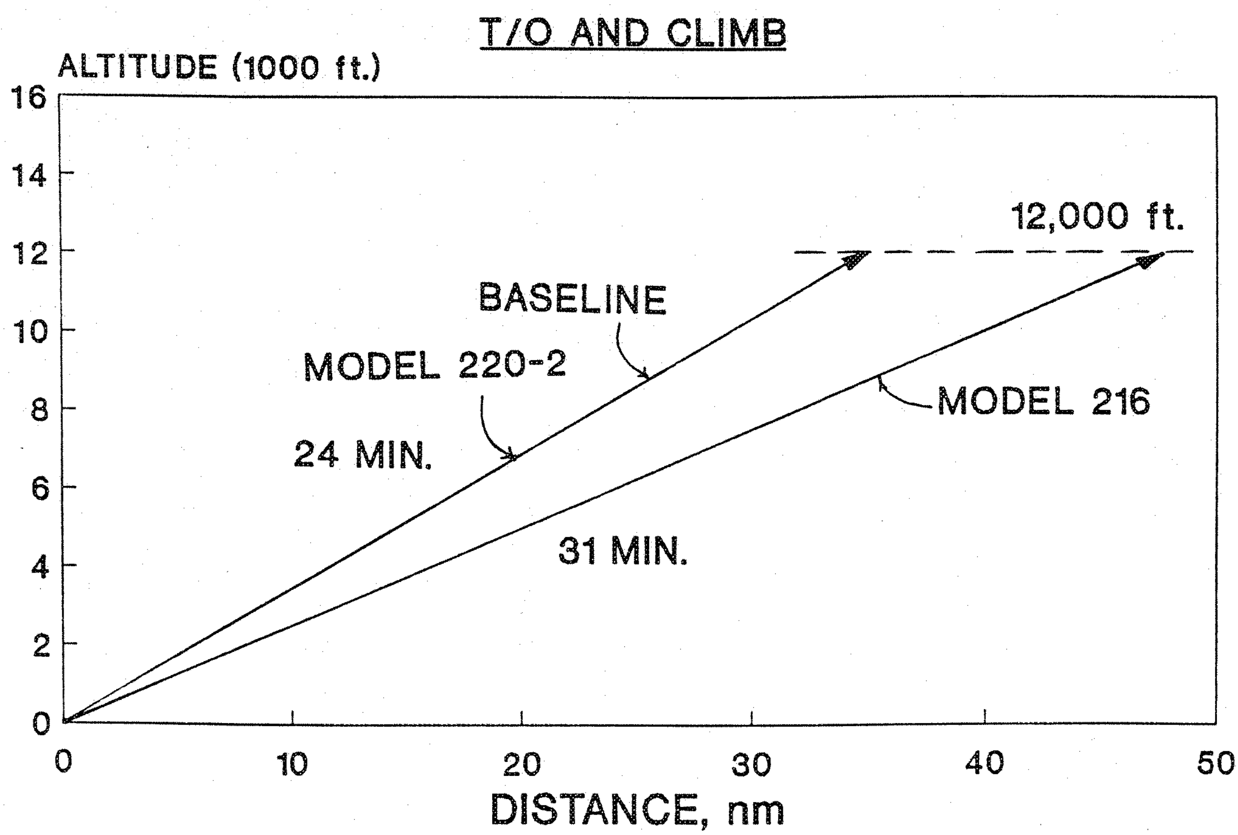


Figure 5.1.1 Long Range Mission Evaluation - Bonanza - T/O and Climb.

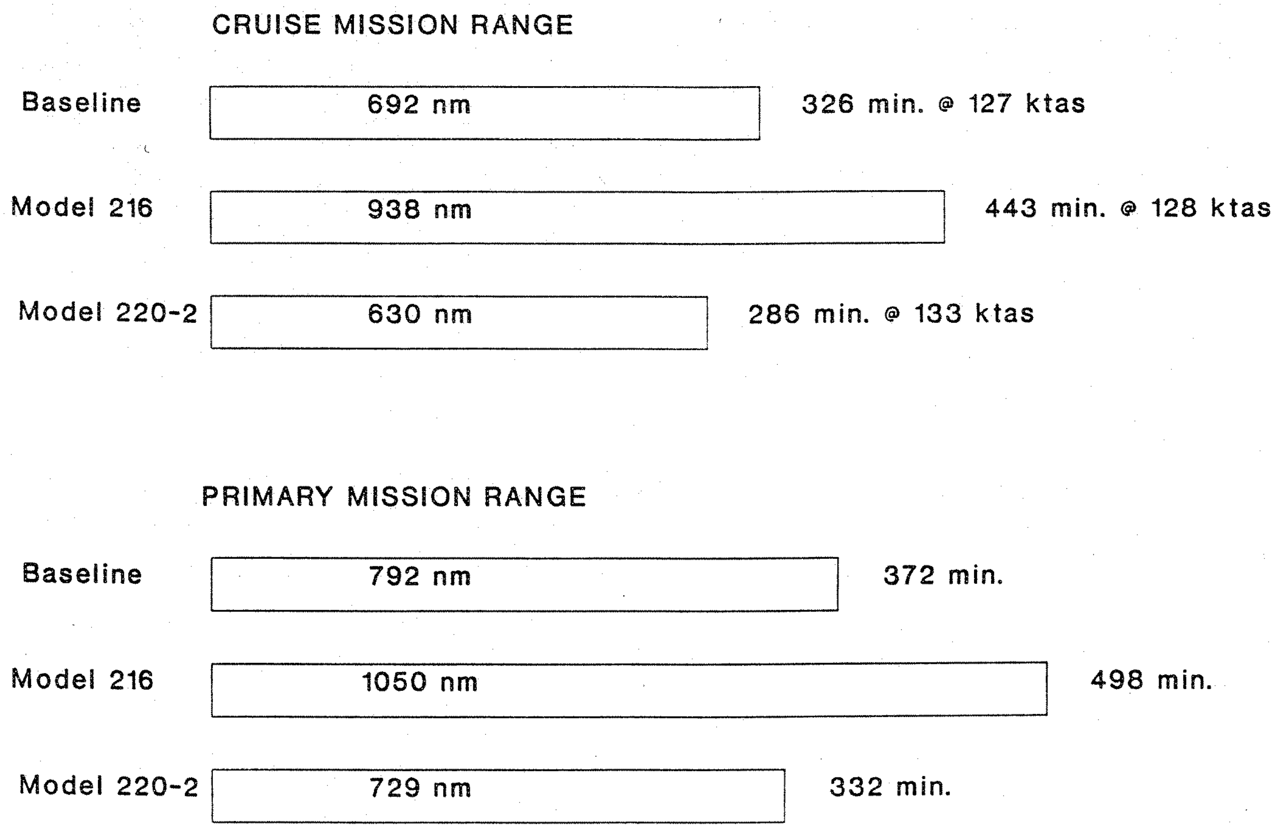


Figure 5.1.2 Long Range Mission Evaluation - Bonanza - Cruise Mission Range vs. Primary Mission Range.

SUMMARY - △'s FROM BASELINE

	Time to Climb	Cruise Speed	Primary Range
Baseline	24 min.	127 Ktas	792 nm
Model 216	+29%	+1%	+33%
Model 220-2	0%	+4%	-8%

Figure 5.1.3 Long Range Mission Evaluation - Bonanza - Summary.

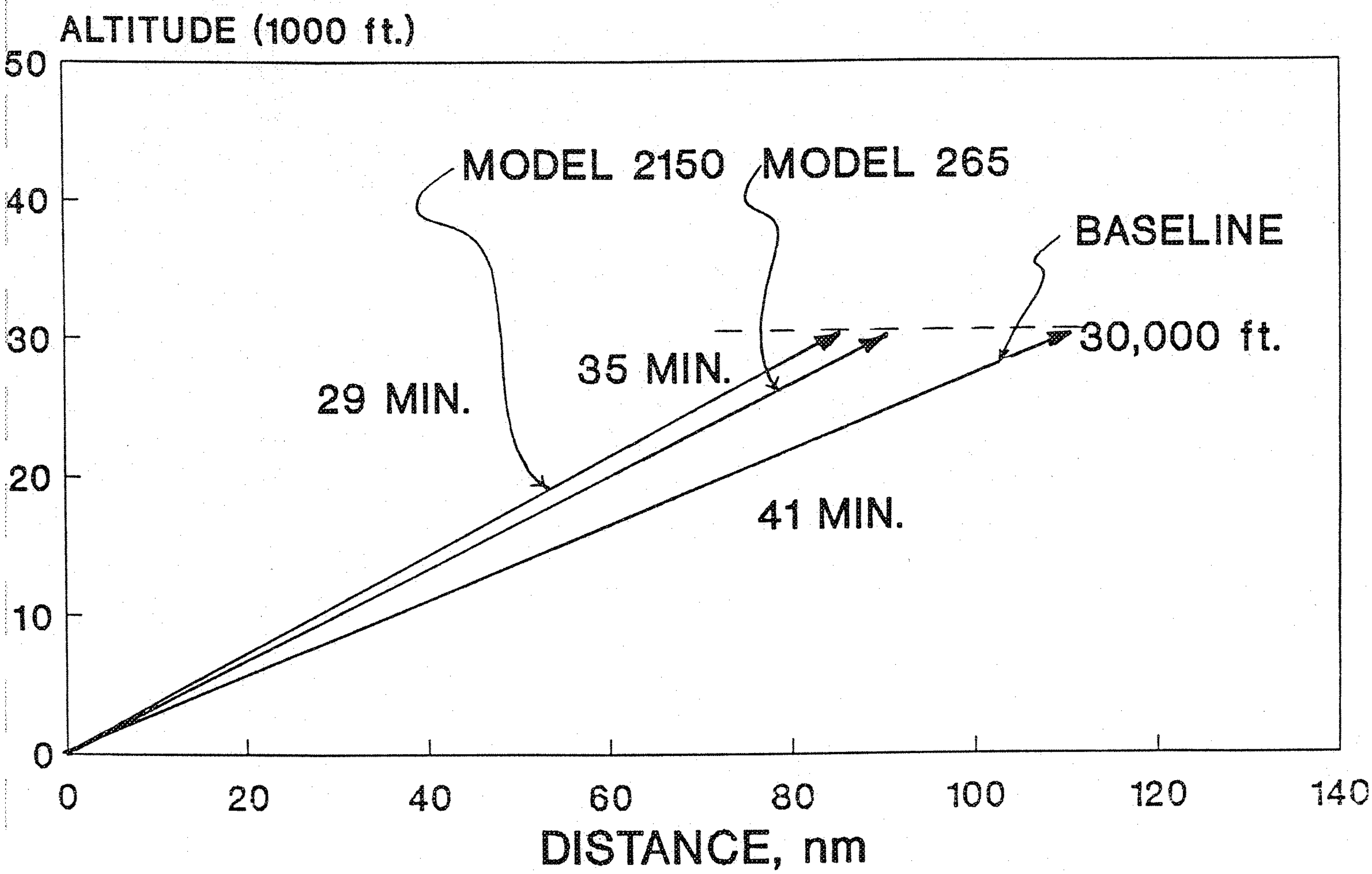


Figure 5.2.1 Long Range Mission Evaluation - C90 King Air - T/O and Climb.

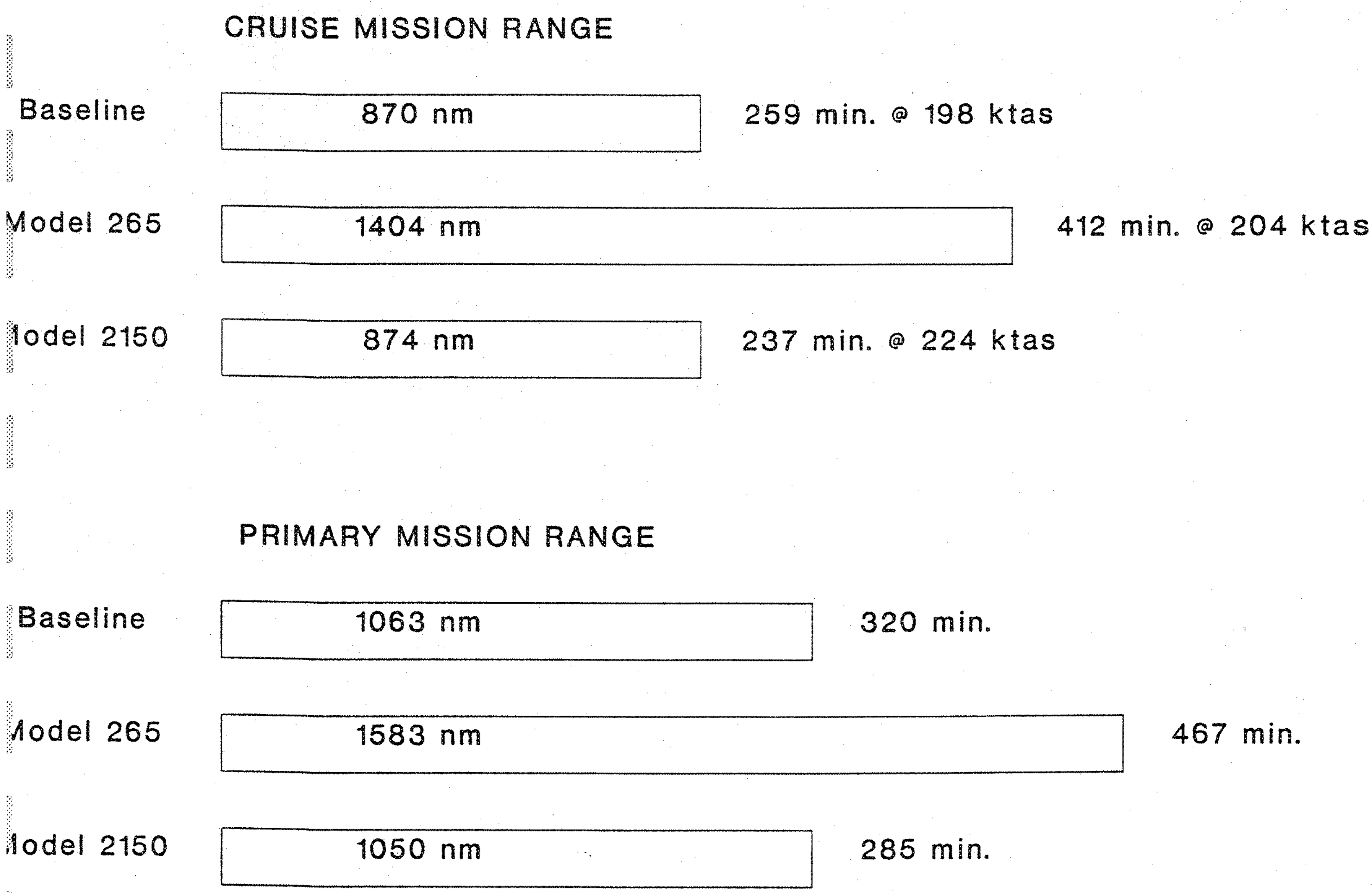


Figure 5.2.2 Long Range Mission Evaluation - C90 King Air

	Time to Climb	Cruise Speed	Primary Range
Baseline	41 min.	198 Ktas	1063 nm
Model 265	-15%	+3%	+49%
Model 2150	-29%	+13%	-1%

Figure 5.2.3 Long Range Mission Evaluation - C90 King Air.

5.3 LONG RANGE MISSION - QCGATE

Figures 5.3.1 through 5.3.3 present the results of the long range mission analysis for the QCGATE airplane with the baseline engine and the Model 2150 propfan engine. The climb characteristics of the two engines are nearly identical, with the Model 2150 enabling the aircraft to attain cruise altitude slightly sooner than the baseline engine. The cruise analysis showed the QCGATE airplane with the Model 2150 installed could fly longer (228 nm longer) and faster than it could with the baseline engine. The overall primary mission range increased by 14% with the Model 2150 propfan in the long range mission as opposed to a 1-2% increase for the high speed mission. This suggests the Model 2150 compares best with current technology engines at cruise speeds of approximately 300 ktas, which is faster than most turboprops and slower than current business jets.

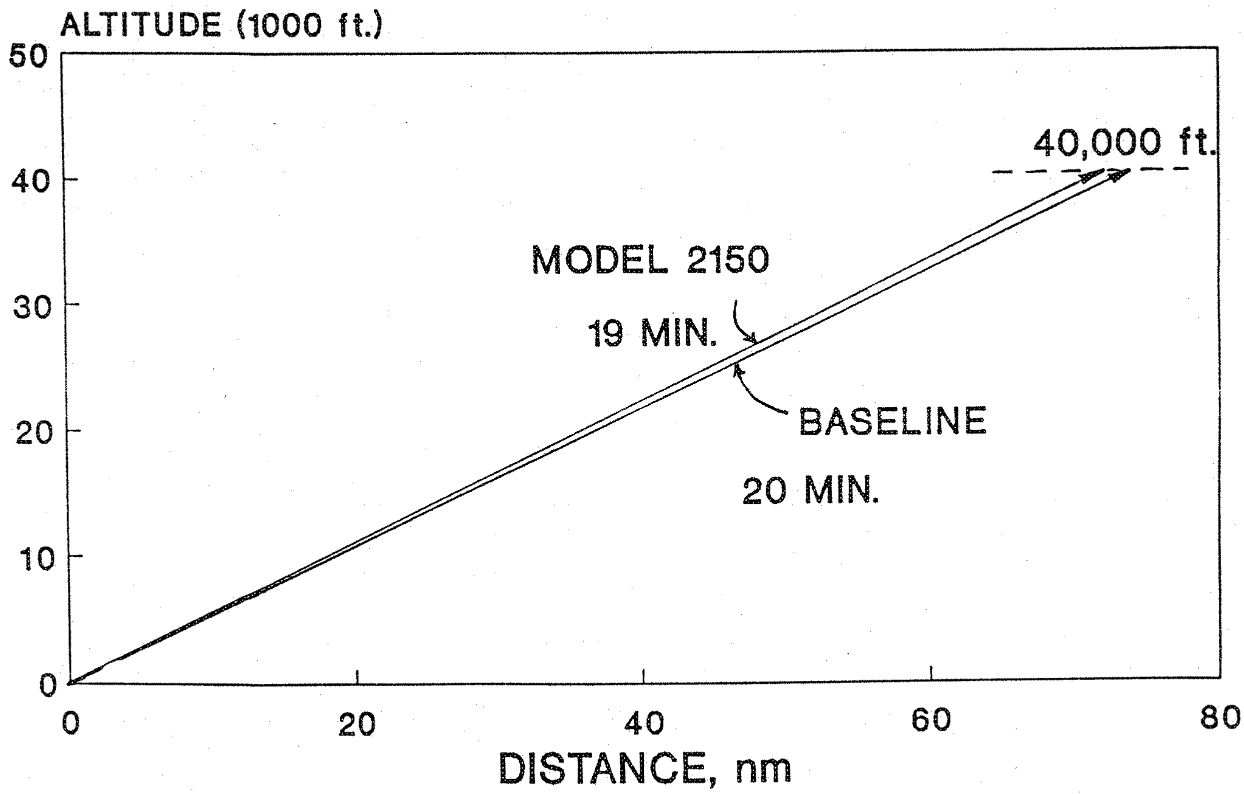


Figure 5.3.1 Long Range Mission Evaluation - QCGATE.

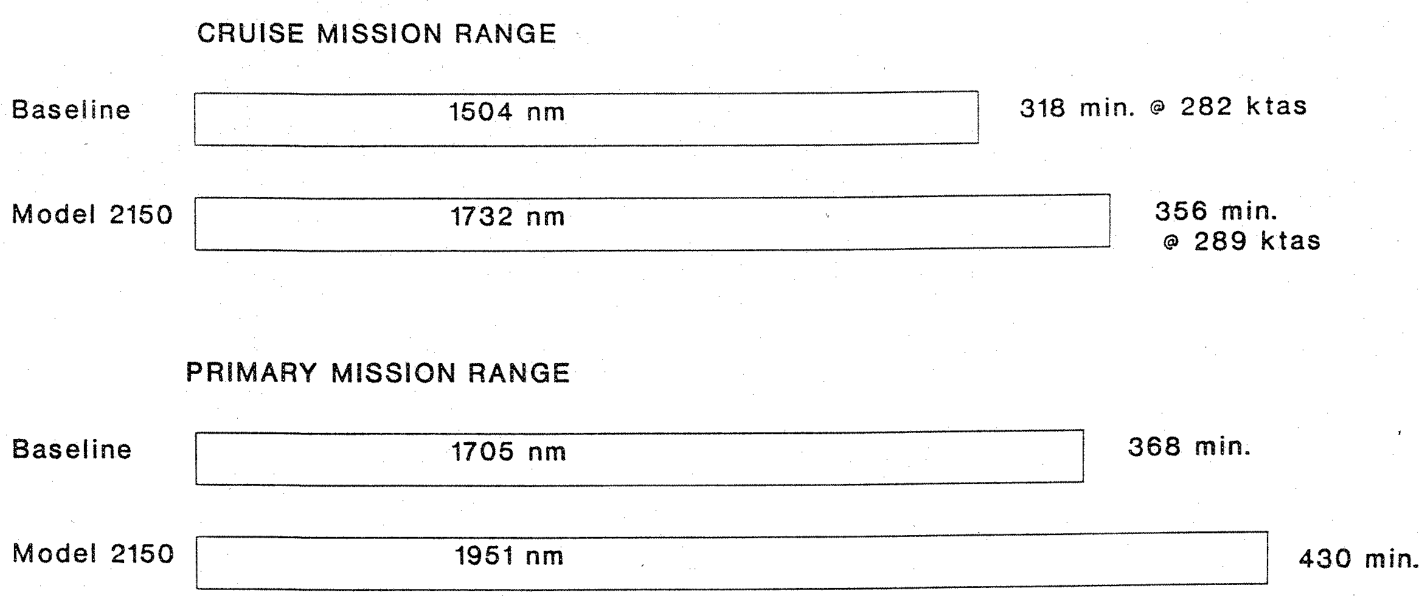


Figure 5.3.2 Long Range Mission Evaluation - QCGATE

	Time to Climb	Cruise Speed	Primary Range
Baseline	20 min.	282 Ktas	1705 nm
Model 2150	-8%	+2%	+14%

Figure 5.3.3 Long Range Mission Evaluation - QCGATE.

6.0 COST, SAFETY, MAINTENANCE, & RELIABILITY COMPARISONS

6.1 COST

The new technology engines were also compared to the existing engines on a basis of cost, safety, maintenance and reliability. For cost comparisons, the acquisition costs of the new engines were estimated for three production levels: high (10,000 engines/yr), mid (5,000 engines/yr), and low (2,000 engines/yr). It should be noted that the engine production rates noted above represent <u>industry-wide</u> production and not the annual production of only one airplane manufacturer in any particular market. The distribution of development and certification costs for the new engines are included in these cost estimates, whereas the existing engines have long since amortized these costs. A comparison of the retail price for the existing Bonanza engine and the new engine prices for the Model 216 and Model 220-2 are given in Figure 6.1.1. The retail price given for the IO-470-L is the price per individual engine; volume purchases by airframe manufacturers would result in a substantially lower price per engine than that given in Figure 6.1.1. The Model 216 may not be price competitive at those discounted rates. However, with the automotive production base, there exists a potential to be price competitive in the future. The Model 220-2 does not appear to be price competitive with the baseline internal combustion engine at this time. A similar cost evaluation is made for the C90 King Air in Figure 6.1.2, which shows the Model 265 has the potential to be less expensive than the baseline turboprop engine. The Model 2150 also appears to cost competitive, however, not to the same degree as the Model 265.

6.2 SAFETY, MAINTENANCE, AND RELIABILITY

Safety, reliability, and maintenance depend on the type of service the aircraft regularly sees and the corresponding level of maintenance. Turbine engines are generally perceived as having a lower failure rate than piston engines, although the turbine engine failures that do occur tend to be more severe. Figure 6.2.1 shows the results of a safety study performed by NASA that indicates the turbine engines safety relative to piston engines based on flight hours. It should also be noted that turbine engines generally power aircraft that have higher seating capacity than those aircraft powered by piston engines. Turbine engines are also generally perceived as requiring less routine maintenance, having a longer time between overhaul, but being more expensive to overhaul. Again, though, this history is based on operating aircraft in an airline or corporate fleet which sees daily operation and has a routine maintenance plan. The private aircraft, such as the F33 Bonanza, have a very different usage pattern, seeing only 1-200 hours per year with not much more than an annual inspection. Thus, it is difficult to compare performance on engines whose histories are in such different environments.

A simple rating of 1-10, with 10 being the best, was applied to each engine for the anticipated safety, reliability and maintenance. Given the lack of in-service data for the new technology engines, these ratings are developed based on the cost per hour of operation required to pay for an engine overhaul. The retail price was considered equal to the cost of an engine overhaul for the new technology engines, since the cost of an overhaul was not available for these engines. Figure 6.2.2 tables these ratings which should be understood more for purposes of comparison than for absolute levels.

The PT6A has perhaps one of the best safety and reliability records in the industry and the new technology engines are assigned the same safety and reliability index as the PT6A. The Model 220-2 has a lower maintenance rating than the baseline engine and the Model 216 since it is expected to cost more to maintain. The Model 265 gets a maintenance rating of 10, based on its low cost, while the Model 2150 scores the same as the baseline engine.

	Existing Engine IO-470-L
New	$36,000
New/Exch	$30,000
Re-Mng	$20,900
Average O'Haul	$14,500
TBO	1500 hr

New Engines		
Annual Production Level	Model 216	Model 220-2
High (10,000 units)	$24,700	$44,300
Mid (5,000 units)	$27,000	$51,500
Low (2,000 units)	$30,900	$53,900

• MODEL 216 HAS POTENTIAL TO BE COST-COMPETITIVE

Figure 6.1.1 Cost Comparison - Bonanza.

	Existing Engine PT6A-21
New	$175,000
New-Exch	$112,000
Average O'Haul	$90-110K
TBO	3500 hr.
HSI	$12-20K

New Engines		
Annual Production Level	Model 265	Model 2150
High (10,000 units)	$44,300	$84,400
Mid (5,000 units)	$51,500	$98,000
Low (2,000 units)	$53,900	$121,000

- **Model 265 is a cost-competitive candidate.**

Figure 6.1.2 Cost Comparison - C90 King Air.

General Aviation Safety

1983 - 1995 Cummulative Powerplant-Caused Accidents

	Piston Engines	Turbine Engines
Aircraft Flight Hours (10^6)	322.8	45.1
Powerplant Accidents		
Total	2,736	245
Fatal	296	35
Powerplant Accident Rate (per 100,000 A/C Hours)		
Total	0.85	0.54
Fatal	0.092	0.078

Source: NTSB, NASDAC, GAMA

Figure 6.2.1 General Aviation Safety: 1983-1995 Cummulative Powerplant-Caused Accidents.

NOTE:	A safety and reliability rating of "7" for the new, advanced technology engines indicates that they are considered equivalent to the extremely safe and highly reliable current production engines (also given a rating of "7"). It does <u>not</u> translate to a percentage (70%) rating.

		Safety	Maintenance	Reliability
Bonanza	**IO-520-BB**	**7**	**6**	**7**
	Model 216	**7**	**6**	**7**
	Model 220-2	**7**	**2.5**	**7**
C90 King Air	**PT6A-21**	**7**	**5**	**7**
	Model 265	**7**	**10**	**7**
	Model 2150	**7**	**5**	**7**

- **10 is best rating**
- **Model 216 and Model 265 rate as good or better than existing technology engines.**

Figure 6.2.2 Safety, Maintenance and Reliability.

7.0 RECOMENDATION FOR SYSTEMS BEST SUITED TO GENERAL AVIATION

As a result of this study and comparative evaluation the Model 216 turboprop and the Model 265 turboprop appear to be clear winners in their respective power classes. The Model 216 has the low cost potential from an automotive production base, provides 30% increase in aircraft range with no reduction in cruise speed. The longer takeoff and climb requirements with the Model 216 could be improved with a lighter aircraft design. A new airplane designed for this engine could incorporate weight savings in several areas: smaller physical size, use of advanced materials, and/or less fuel weight. The Model 265 also has the potential to be cost competitive, while providing almost a 50% increase in aircraft range with no reduction in cruise speed and allowing a 26% shorter runway.

8.0 MANUFACTURING PLANS

8.1 INTRODUCTION/BACKGROUND

8.1.1 Purpose and Background

This is the Manufacturing Plan for Teledyne Ryan Aeronautical, TCAE Turbine Engines, for managing the Model 265 and Model 216 manufacturing and production programs. TRA/TCAE has been awarded certification by British Standards Institution (BSI) for meeting the stringent requirements of the International Organization for Standardization's ISO 9001 standard. TRA/TCAE is committed to the development, economic production and timely delivery of quality products which meet or exceed customer requirements. TCAE's management approach places emphasis on a Total Quality Management (TQM) team effort where the key organizations support the manufacturing group responsible to deliver hardware by supplying facilities, materials and processes. Recording systems support the organizations with management information. Customer interface is maintained through the Product Development Office reporting to the Vice President, Product Development.

The plan has been assembled from information developed and obtained from the on-going production and engine/refurbishment programs.

8.1.2 Program Objectives

The basic strategy is to achieve market share and penetration through pursuit of the following objectives:

1. LOW COST
   - Achieve customer design specifications in a manner compatible with sound engineering and manufacturing practices.
   - Apply proven engine design and/or reliability experience.
   - Maximize use of investment castings.
   - Insure producibility through a concurrent engineering process that involves design engineering, manufacturing engineering/quality assurance and purchasing working together concurrently to complete their respective tasks.

2. HIGH QUALITY
   - Ensure supplier quality by flowing down process control requirements to all casting and purchased part sources.
   - Monitor the casting supplier, "Key process parameters" to anticipate and/or prevent casting quality problems.
   - Control manufacturing quality through the implementation of a TQM process control program which maximizes on machine gaging using variable gages for discrete characteristics and relationship attribute gages for geometric characteristics.
   - Develop and implement an "Automated Quality Assurance System (AQAS)".

3. SCHEDULE PERFORMANCE

- Design, implement and tool a process that will support the low cost, quality objectives. It must facilitate TQM and the commitment to process control. It must also be debugged to minimize non-conformances.

- Produce FSD hardware on production tooling to validate capability and standard hour effort.

- Establish a supplier base capable of providing a supply of defect free hardware on a just-in-time basis.

- Deliver on time at the right cost and quality.

8.1.3 Organization

TRA/TCAE will manage the Production Program through the product development function, as shown in Figure 8.1.3-1. Figure 8.1.3-2 identifies the program management team and establishes the direct reporting relationships of the Program Manager to the Director of Product Development.

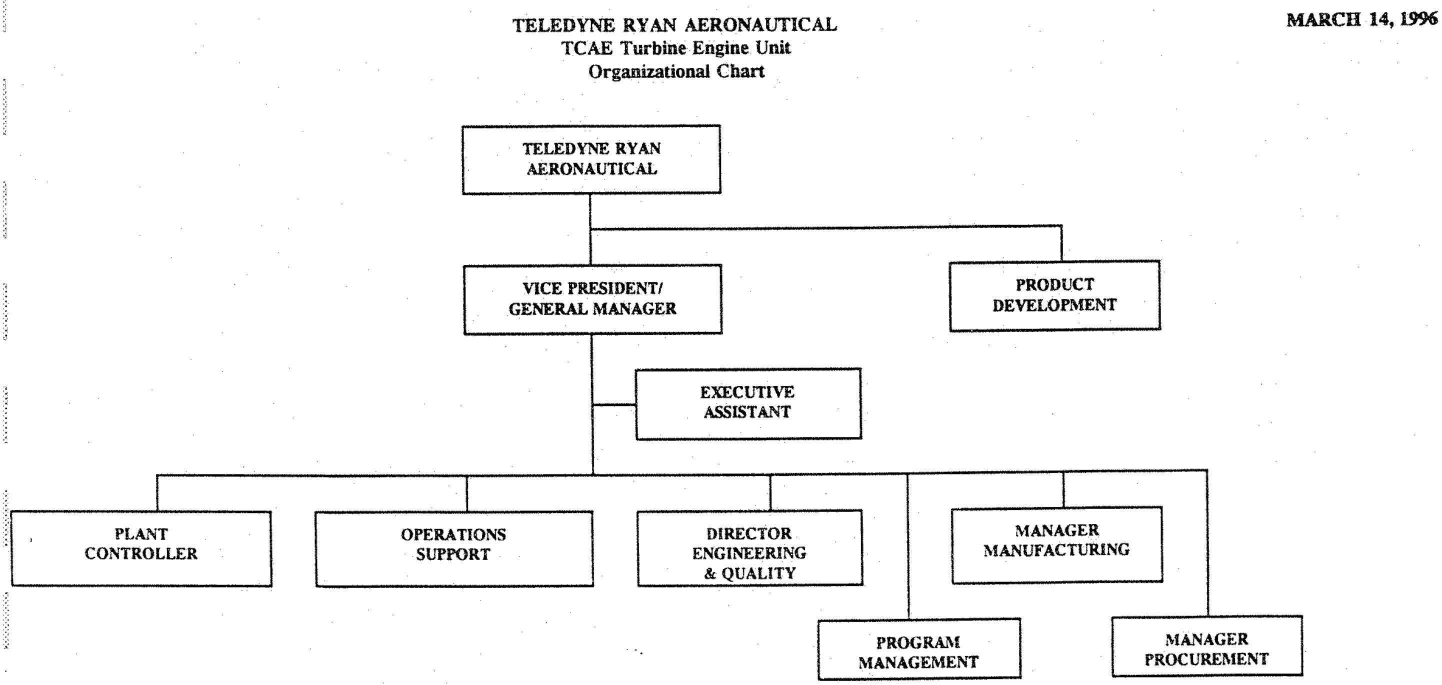


Figure 8.1.3-1 Teledyne Ryan Aeronautical, TCAE Turbine Engines.

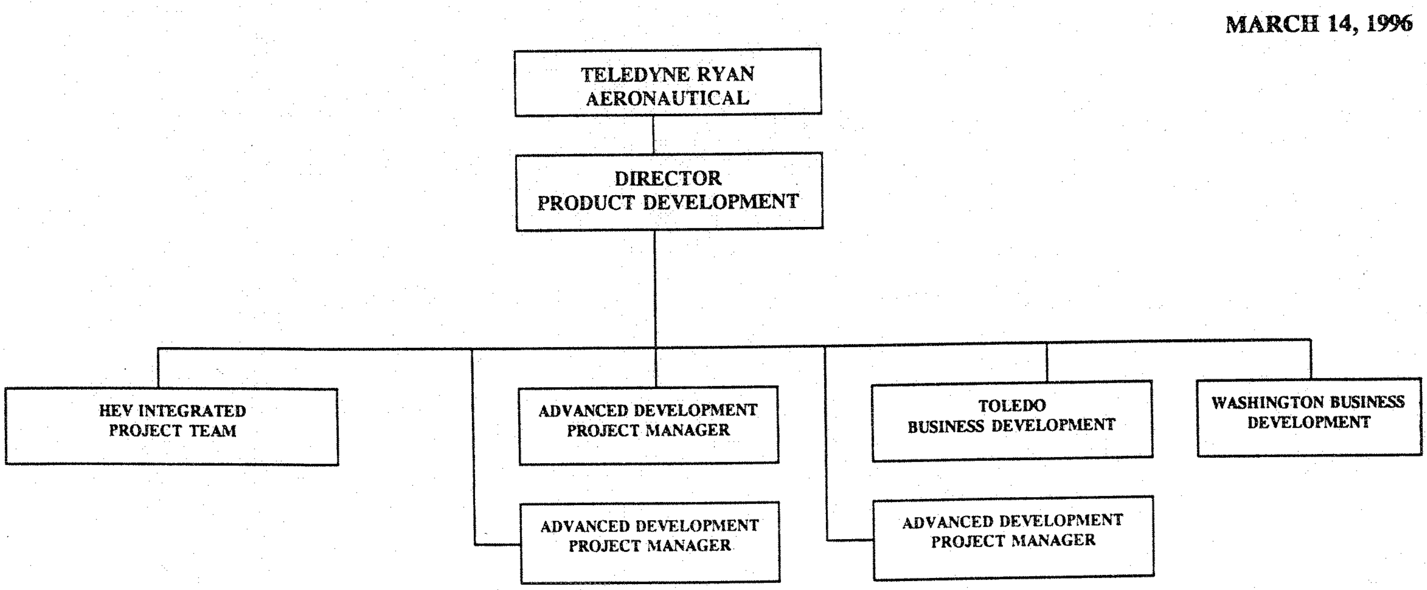


Figure 8.1.3-2 PRODUCT DEVELOPMENT TEAM: The Program Manager reports directly to the Vice President of Product Development.

8.2 MAKE-OR-BUY PLAN

It is the policy of TRA/TCAE that the production hardware will be produced internally or purchased consistent with the company's goals and strategies. The Make-or-Buy Plan for a given program, once established, can be changed only with management approval. The plan is reviewed for changes by the Make-or-Buy Committee as conditions warrant. To faciliate control, the Make-or-Buy Plan is maintained on the combined Engineering/Manufacturing Parts Lists. Formal change approval is required to change the Make-or-Buy parts lists.

The Make-or-Buy Committee is composed of the following management:

Program Manager
Financial, Program Cost Analyst
Manufacturing representative
Quality Assurance representative
Materials representative
Production Control representative

This committee meets as required to review engineering change requests for make-or-buy impact.

8.2.1 Cost Considerations

Various factors influence the cost of performing operations in-house versus buying the operation. Some of these are:

- Current vendor cost of the item;
- Quantity associated with economic lot size, and current and future demand;
- The cost of raw material and cost of manufacture;
- Projected plant work load with respect to overhead cost;
- Capital requirements resulting from additional tooling, equipment, and facilities;
- Available manpower that can be devoted to the program;
- Delivery requirements.

Each of the above items can impact the cost of individual parts and can be reflected in the overall-engine price. Therefore, they are the cost considerations used in establishing the Make-or-Buy Plan.

The factors affecting cost are evaluated. These factors are utilized by the Make-or-Buy Committee in Make-or-Buy decisions and the committee chairperson is responsible for ensuring that this occurs.

8.2.2 Buy Items

Through its detailed estimating procedure, Manufacturing Engineering develops its buy recommendations for items that are not economical to make in-house. Such items as screws, bolts, and other small items fit this category. Some items that are considered critical, such as gears, fuel controls, pyrotechnics, electrical/electronic items, castings, and forgings, are available from specialized sources. A numeric Manufacturing Parts List (MPL), which is also the Engineering Parts List, identifies the make/buy items. Buy items are identified by the letter "B".

8.2.3 Make Items

Each production program part is reviewed and estimated as required by Manufacturing/Engineering/Industrial Engineering. Make items include shaft assembly parts where close tolerance machining, balancing and electron beam welding are required.

They are generally components for which the company has developed unique manufacturing capabilities. This manufacturing ability is not readily available elsewhere and would require excessive cost for vendor qualification, training and tooling for these items. All of the make items considered the material requirements, lead time for materials, tooling, facilities, manufacturing technology and qualification of parts. The make items are identified in the MPL by the letter "M".

8.3 SUBCONTRACTING/PROCUREMENT PLAN

TRA/TCAE's Procurement overall goal is to maintain at all times, and under all conditions, a continuous supply of goods and services necessary to support research, development, production and sales schedules. Procurement gives prime consideration to these interests while seeking to maintain and further long-term, mutually profitable, ethical supplier relationships. Some elements of this responsibility are:

- ENSURE the uninterrupted flow of production by obtaining and ensuring delivery of acceptable quality of goods and services, at the right time and price.
- DEVELOP reliable alternate sources of supply to meet TRA/TCAE requirements.
- TREAT all prices and technical information submitted by suppliers as confidential in order to preserve a good business reputation and obtain competitive prices.
- CONSIDER suppliers as partners with whom long-term relationships are mutually beneficial.
- COMPLY, in all respects, with Government Regulations, and with all other applicable laws without qualification or evasion.
- PURCHASE materials and services for the company's use at the maximum end-use value per dollar spent.
- RESOLVE complaints on all purchased goods and services.
- PROVIDE leadership for the management of inventories of purchased goods so as to meet the use requirements of TRA/TCAE's departments at the lowest possible cost.
- INITIATE and maintain effective and professional relationships with suppliers, actual and potential.
- ENHANCE the Company's image through positive personal conduct and methods of doing business.
- INFORM management of changes in the supplier/competitor network.

The Procurement Department is responsible to the Manager of Procurement (Toledo) who reports directly to the Vice President and General Manager. Procurement of goods and services is conducted by procurement organizations in Toledo and San Diego. The San Diego Procurement Department is responsible for all production, spares, and blanket order requirements. The Toledo Procurement Department is responsible for all research and development facilities, vendor assisting, MRO and tooling requirements. Problems are handled by appropriate management levels as necessary.

On 26 April 1996, we were granted a continuation of the approval of our Purchasing system. This is a result of a successful Contractor Purchasing System Review (CPSR) dated 23 March 1993.

Supplier selection is an important function of the Procurement Department and requires the consideration of several factors. In making the selection, the Procurement Department coordinates closely with other departments to ensure that all requirements are being met.

While all departments are important during the supplier selection process, the Supplier Quality Assurance (SQA) function should be highlighted for its close working relationship with the Procurement Department.

The Supplier Quality Assurance Surveillance Program has been designed to comply with MIL-STD-1535A and CMPPUB 4855/5 (17 Nov. 83) as modified by PMA-1-280-89 (25 April 1989).

The subcontractor management activity is performed under the direction of the Toledo Division Manager of Procurement. Supplier surveillance by Quality Assurance is accomplished through the Toledo Division personnel.

The Director of Quality Assurance at Toledo has the prime responsibility for the supplier quality assurance program. Systems, procedures and paperwork will be modified as required to optimize the procurement/source inspection cycle.

Periodic audits of suppliers are accomplished on a scheduled basis, the frequency depending upon supplier history, complexity, or critical nature of the item produced, and the extent of quality flowdown requirements. Group I and complex Group II suppliers are audited at least annually. Other suppliers are audited, as a minimum, on a two-year cycle.

The Toledo Division currently utilizes four full-time Quality Engineers to support Toledo. Ratings are prepared for each supplier each quarter based on the previous 12 months' material receipts. On-site quality audit frequencies can be increased if suppliers' ratings do not meet a minimum level designated by QA Management.

The Procurement Quality System activities are defined and coordinated as a joint effort between Toledo and San Diego QA Management. Contract requirements are reviewed by both divisions as a prerequisite to quality system modifications. The operating guidelines are also developed through the coordinated efforts of Toledo-San Diego Supplier QA personnel.

Regular reporting mechanisms are in place to provide supplier status on schedule and quality performance. This database provides accurate and timely control of production parts and a means of tracking procurement activity from the issuance of a purchase requisition through receipt.

To develop a total lead time for the purchase of material set back and the generation of a Production Plan, 10 weeks is added to the supplier lead time and includes:

1.	Purchasing processing time to turn a requisition into a purchase order.		6 Weeks
2.	Transportation from supplier to Toledo		2 Weeks
3.	Receiving inspection/receiving time to process paperwork and move parts into the Bond Room.		2 Weeks
		TOTAL:	10 Weeks

This combined cycle is then loaded into the Bill-of-Material to support Material Requirements Planning (MRP) and the ultimate evolution to Just-in-Time (JIT) deliveries.

The total lead time does not include the two to four weeks it takes to receive the customer contract order, develop a master schedule, and then turn the master schedule into purchase requisitions.

8.4 RESOURCES AND MANUFACTURING CAPABILITY

8.4.1 Industrial Facilities

TOLEDO FACILITY

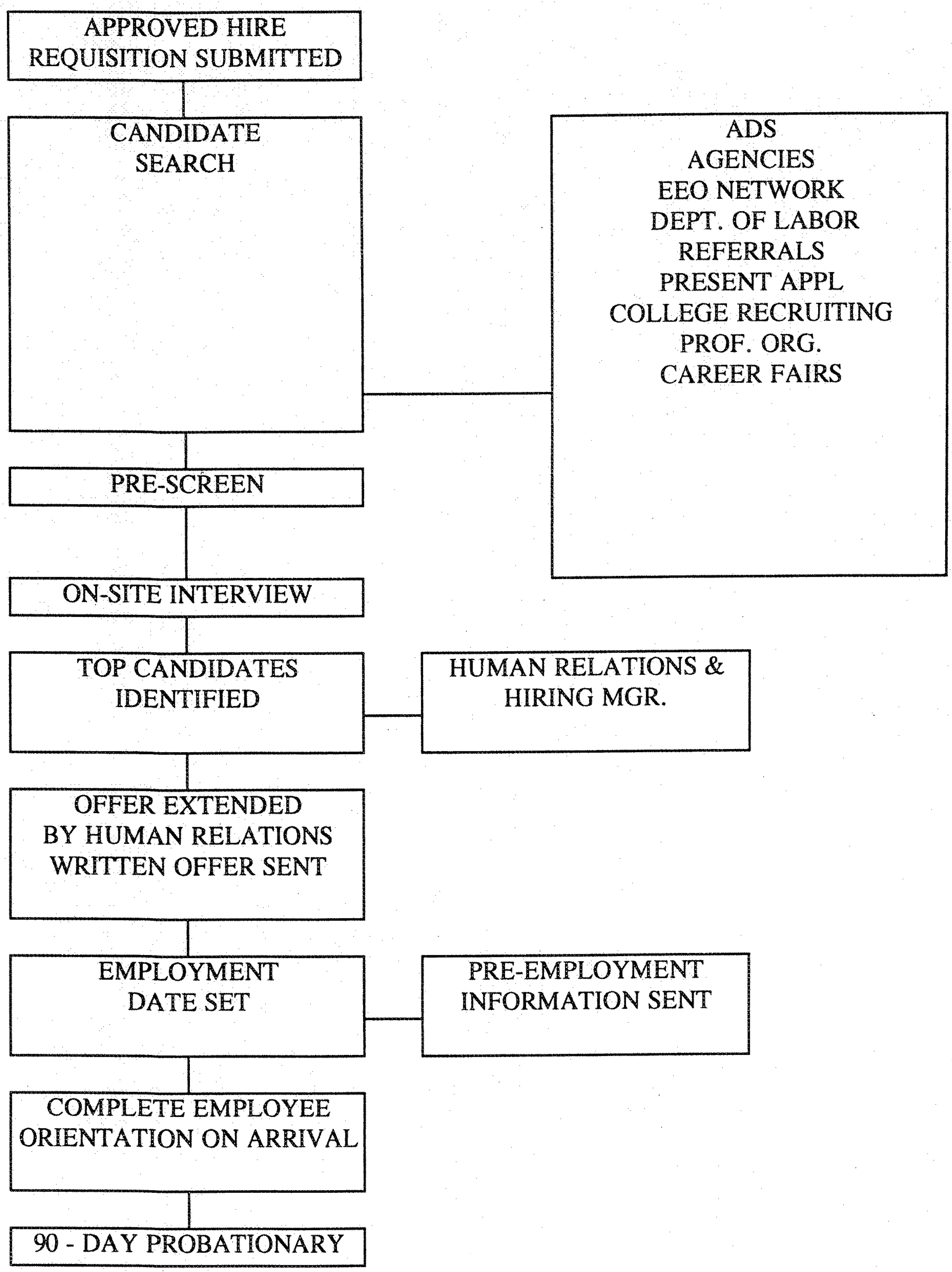
The Naval Weapons Industrial Reserve plant in Toledo, Ohio operated by Teledyne Ryan Aeronautical, TCAE Turbine Engines, is a complete Government-owned, company-operated facility for manufacture of small gas turbine engines.

This main facility consists of six main buildings centered on a 30 acre plot, with a total of 348,000 square feet of roofed floor space. The largest building, Building 1, has 280,000 square feet of roofed floor space and houses the Administration, Test, Engineering, and Manufacturing organizations. Building 2 has 39,000 square feet of roofed floor space and houses an environmental test system and test cells. Building 3 has 17,000 square feet of roofed floor space and houses the production and R&D sea level test cells. Building 4 is the central powerhouse, housing six oil or gas fired low pressure steam boilers, three air compressors supplying 90 psig factory air, and other support equipment. Buildings 5 and 6 are maintenance and storage buildings.

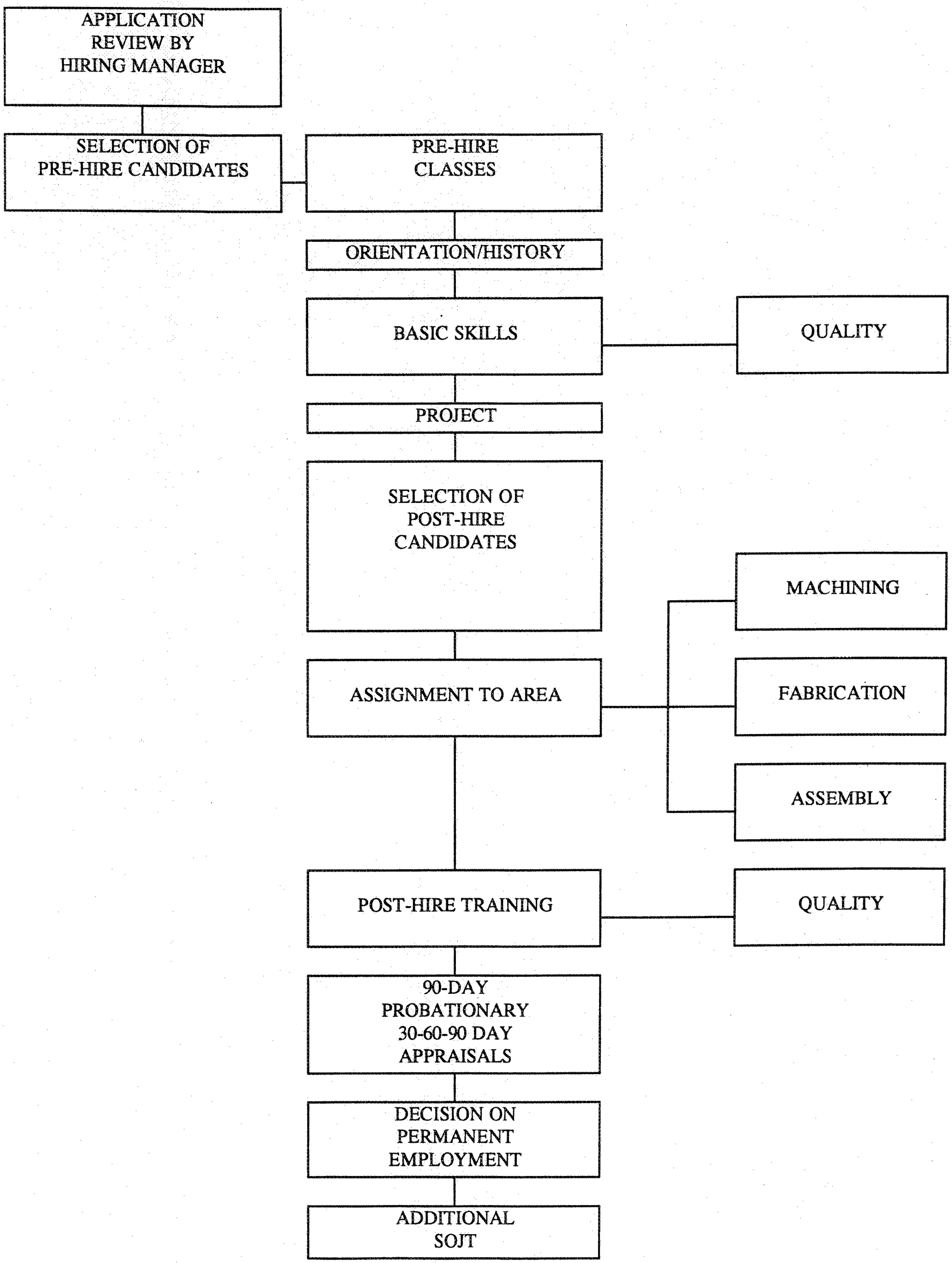
Building 1 floor space allocated to Manufacturing and Support departments totals 230,700 square feet.

8.4.2 Manpower Planning

Manpower planning for the program will take into account the requirements for quantity, type and level of personnel skills required. Hiring requirements and training programs will be established to meet the plan.



The training process for entry level production employees is as follows:



8.4.3 Manufacturing Approach

The manufacturing approach to be taken is a phased plan that is rate driven. The first phase, which is production and engineering oriented, will produce the engines through the pre-Qualification Test (QT) phase. The QT phase will provide the necessary technical transfer to provide effective training transitions for production. Full scale development (FSD) phasing into full production will then occur.

As rates increase, specific machines will be dedicated for production and multiple machine manning will be implemented where appropriate.

<u>Prototype and Pre-QT Phase</u>

Engineering will assemble and test these engines in the R&D area. Assembly processes and testing procedures will be created during this time frame.

<u>QT Phase</u>

This phase is accomplished by:

- Static parts and selected rotating parts are initially produced on hard tooling;
- The shaft assembly is produced on hard tooling;
- Final engine assembly is completed in the production assembly area;
- Testing is in the production testing facility.

<u>Engineering Development Units (EDU) / Preliminary Production Units (PPU)</u>

These engines will be the final link between the QT phase and full production. This phase will introduce a pilot lot release with appropriate larger lots being released as learning occurs.

PRODUCTION APPROACH

The production approach starts with the integrated production developing into dedicated automated production as deliveries increase.

The production program and product general flow of manufacturing starts with the part make/buy decision through placing finished parts into stock. The manufacture of the part is as directed on the individual part master routing sheet. When the fab order is released to the shop by Inventory Control, material moves from stock to a designated machine. The material is machined or processed on equipment. The individual operation is designed to accomplish that operation on a particular part. All incoming hardware and completed shop hardware will be stored in the Bond Room until scheduled to be removed by Inventory Control.

In preparation for assembly operations, all completed parts by lot are routed through final inspection for a final paper check and authorization to gain finish stock status. Production Control initiates engine build authorization and provides the fabrication orders to the stock room for kitting and delivery finished parts and sub-assemblies to the assembly area for subsequent engine build-up. Engine build-up starts with assembly of detail parts from the kit into sub-assemblies. These sub-assemblies are then assembled into major components. Major components are assembled followed by a final assembly into a complete engine. During assembly, the quality inspector verifies configuration, inspects and completes the inspection check. A log of inspection checks and assembly checks are made for each engine. The completed engine is installed on a test stand for delivery into the test cell for testing per engineering test specifications. The completed tested engine is then packaged and shipped in accordance with the required program requirements.

8.4.4 Manufacturing Engineering Approach

A five-phase plan will be used to develop the manufacturing processes.

1. Develop a commercial machining concept;
2. Expand concept into a preliminary process plan which will include:
    a) Identification of operations and machines
    b) The method of holding and clamping the part
    c) A rough cut at the operational sequence outline or characteristics to be generated by each tool at each operation
3. A final manufacturing process or tech transfer package
4. Fabrication and procurement of fixtures, tools and gages
5. Prove out in the shop.

At steps 1, 2, and 3, manufacturing engineering, quality and manufacturing must agree before the next step is started. After step 3 and with a consensus on the process, funds are released for fabrication and procurement.

Processing ground rules will be established to minimize cost, maximize configuration control and to provide consistent quality and may include the following:

- Total drawing review is to be made between Engineering, Operations, and Quality personnel;

- Total part processing review is to be made between Manufacturing Engineering and Quality personnel;

- Process planning and tool design are to be developed to minimize the need for highly skilled shop labor;

- Process all parts utilizing Numerical Control (N/C) equipment (where possible) to reduce human error and rework levels;

- Qualify castings properly at the vendors to eliminate costly inspection and initial qualification machining;

- Combine operations wherever possible to reduce set-up costs;

- Eliminate redundant inspection steps common to engine fabrication without sacrificing quality by providing the operator with the necessary tools to perform dimensional inspections at the work station instead of re-mounting parts for end inspection.

8.4.5 Quality Approach

A single quality system currently in use at the Toledo, Ohio facility is designed to meet the system requirements of ISO 9001, MIL-Q-9858A and any additional customer-imposed quality assurance system requirements. A Total Quality Management approach has been adopted to ensure the realization of the basic program goals - low cost, high volume, quality gas turbines delivered on time. The Teledyne Ryan Aeronautical Quality Manual documents in a comprehensive manner the implemented quality system and its relationship to customer requirements and the ISO 9001 standard.

The Vice President and General Manager of TRA/TCAE has the ultimate responsibility to assure that the directives and contracting guidelines defined by the corporation, Teledyne, Inc., the company, Teledyne Ryan Aeronautical, and the Strategic Business Unit, TRA/TCAE, are fully executed. The Director of Quality Assurance and Engineering is responsible for the effective functioning of the quality system. The system description consists of 1.) general policy statements and procedures which affect all company personnel and, 2.) detailed procedures and operating instructions which provide a means of complying with the specific ISO Quality System elements and any additional customer-imposed quality-related provisions.

The Quality System description consists of the following types of documents:

- Quality Manual (QM)
- Strategic Business Unit (SBU) Policy Statements (PS)
- Organizational Policy Statements (OPS)
- Standard Procedures (SP)
- Quality Assurance Procedures (QAP)
- Operating Instruction (OI)
- Quality Work Instruction (QWI)

A matrix of the ISO system elements and the corresponding TRA/TCAE policies, procedures and work instructions which describe the method of compliance to these elements is included in the Quality Manual, and is revised as required. TRA/TCAE compliance to the above noted documents is continuously monitored through the internal quality audit program.

8.4.6 Work Measurement

Labor Standards are used as the basis for performance monitoring, manpower planning, capacity planning, equipment/facilities planning, factory scheduling, shop loading, and proposals. In addition:

- Manufacturing uses standards for production efficiency and productivity monitoring, for identifying and isolating problem areas and determining corrective action, and for new equipment plans.

- Inventory Control uses standards as well as efficiency and/or productivity to generate long range manpower planning. Production planning, manufacturing lead time calculations, machine load analysis, manpower planning and capacity planning.

- Program Office uses standards as well as efficiency and/or productivity for budgeting and proposals.

8.4.7 FSD Assembly and Test Plan

All engine components will be delivered to the cell for assembly. The parts will be assembled per documented assembly instructions.

Each engine will then be moved into the test cell and mounted on the test stand. Utilizing quick-disconnect fittings, all necessary engine services will be installed. The Acceptance Test will be performed and the data analyzed for acceptability.

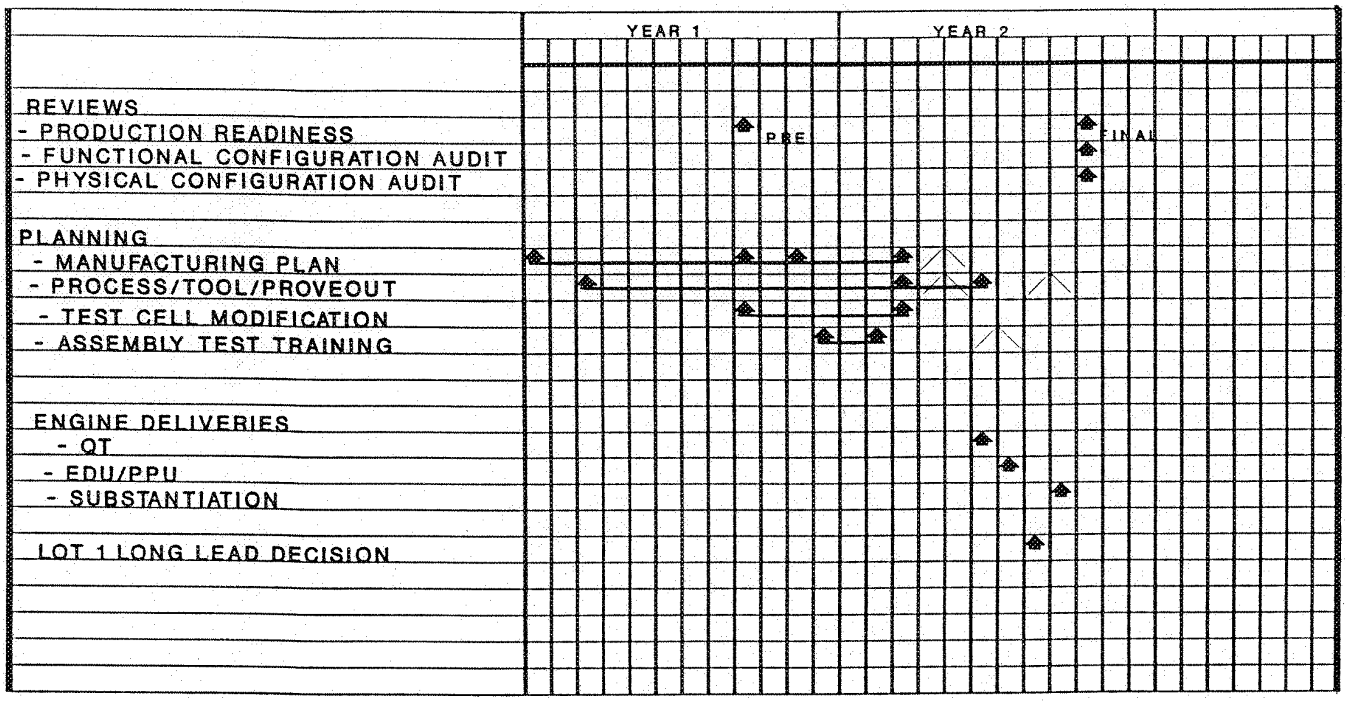
The test cell occupancy can be 1½ to 2 hours, per engine. This allows for installation and removal of the engine, a test of approximately ½ hour, data analysis, and scheduled stops/checks.

At 2 hours per engine, an 18-hour day would yield 7 to 8 engines, allowing for lunches and other minor downtimes. Testing in one test cell would then yield up to 35 to 40 engines in a 5 day week.

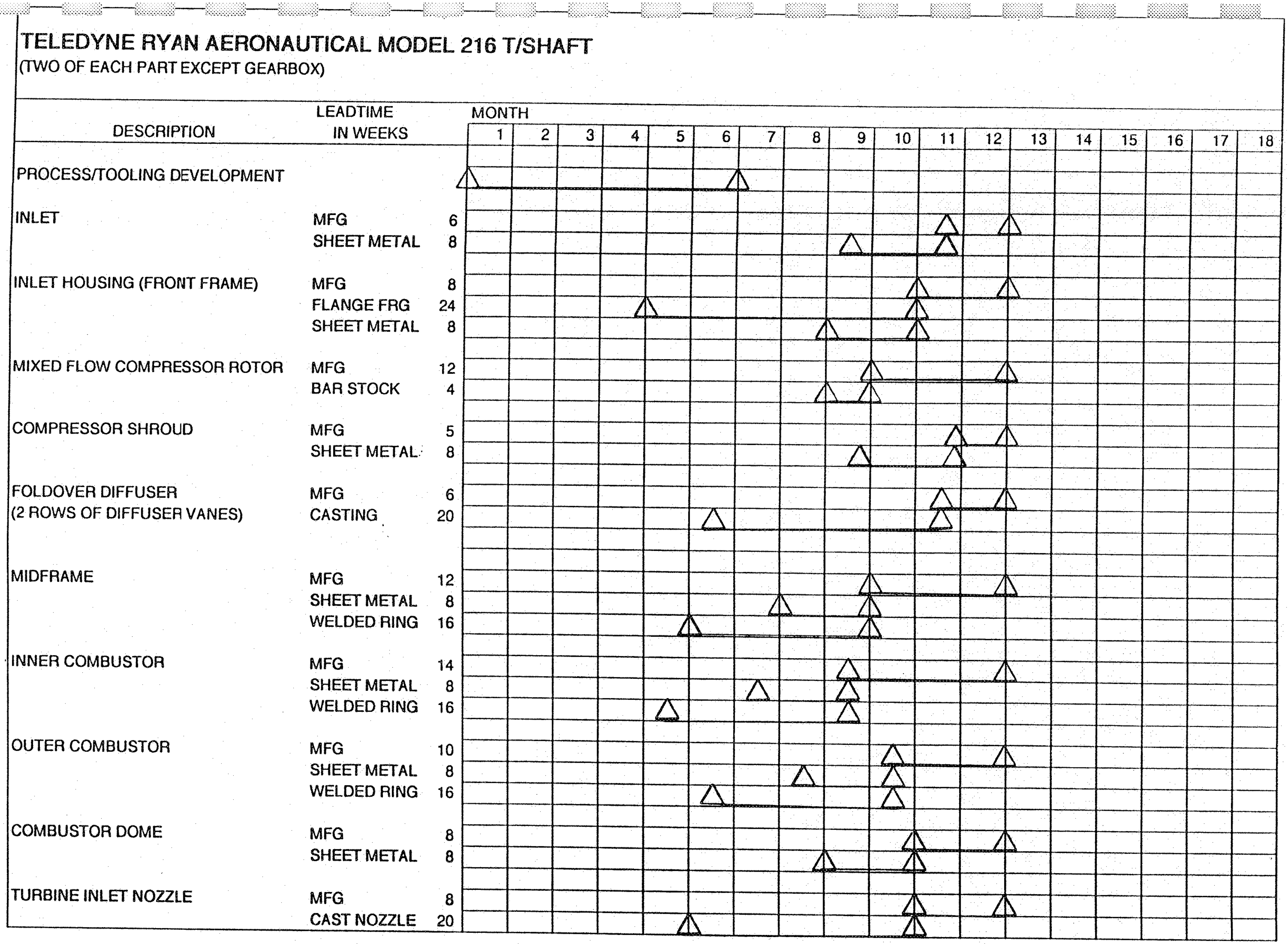
SECTION 8.5

MANUFACTURING PLAN

MANUFACTURING MASTER SCHEDULE



IMPLEMENTATION PLAN



[216]

-1-

12-Jun-96

TELEDYNE RYAN AERONAUTICAL MODEL 216 T/SHAFT

(TWO OF EACH PART EXCEPT GEARBOX)

DESCRIPTION	LEADTIME IN WEEKS		MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IN-FLOW TURBINE RCTOR	MFG	8										△		△						
	FORGING	24				△						△								
TRANSITION DUCT	MFG	4											△	△						
	SHEET METAL	16							△				△							
RECUPERATOR	BUY	30					△							△						
EXHAUST DUCT	MFG	12									△			△						
	CASTING	20				△					△									
JET NOZZLE	BUY	24						△						△						
FUEL CONTROL	BUY	48	△											△						
GEARBOX	MFG	16								△				△						
(2 INPUTS/1 OUTPUT)	CASTING	20								△										

[216] 12-Jun-96

IMPLEMENTATION PLAN

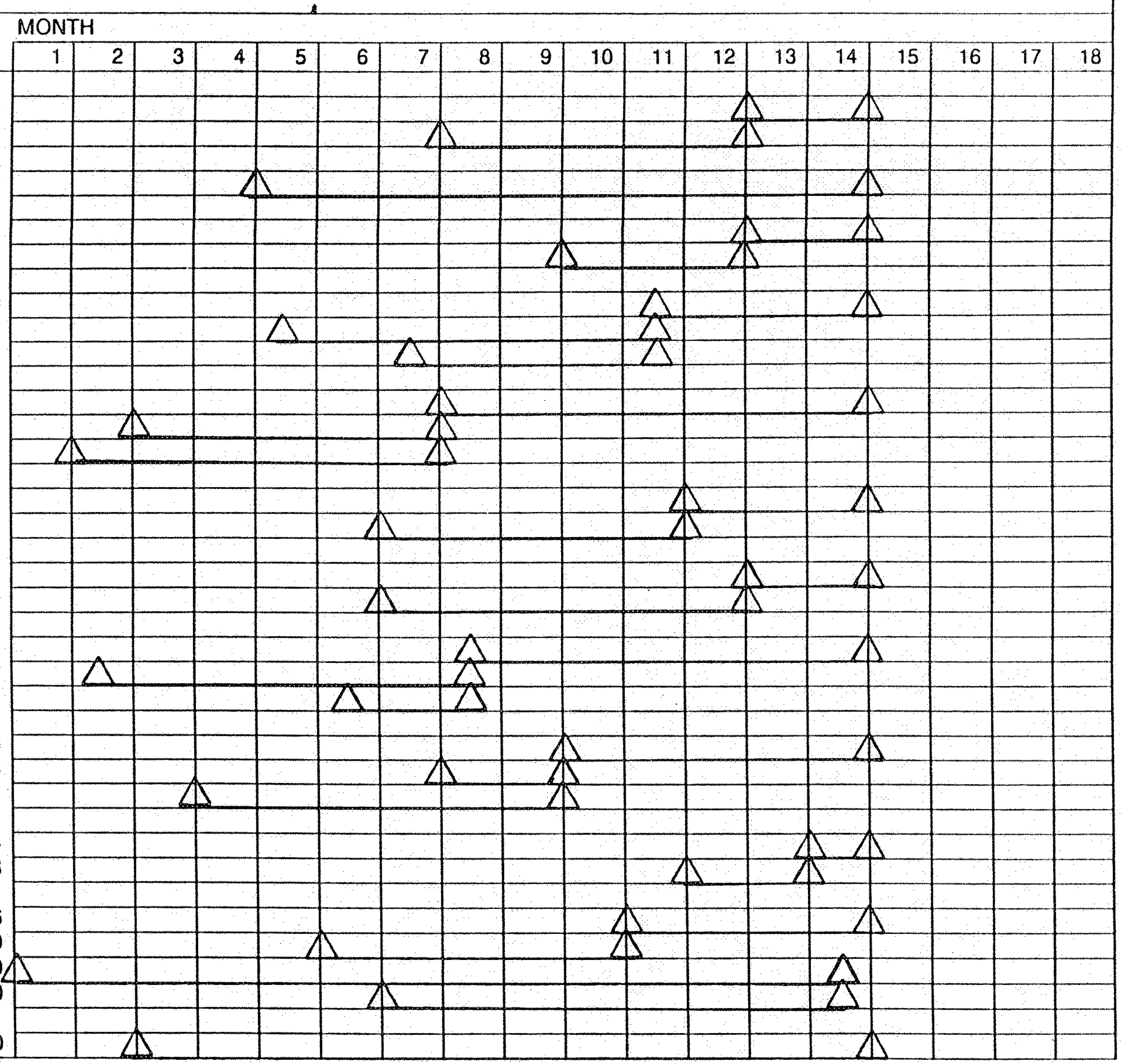
TELEDYNE RYAN AERONAUTICAL MODEL 265 T/SHAFT & MODEL 220-2

DESCRIPTION	LEADTIME IN WEEKS		MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
PROCESS/TOOLING DEVELOPMENT																				
INLET	MFG	6																		
	SHEET METAL	8																		
IGV HOUSING	MFG	6																		
	CASTING	20																		
INLET FAIRING	MFG	4																		
	CASTING	20																		
INLET GUIDE VANES	MFG	4																		
	CASTING	20																		
AXIAL ROTOR, 1ST STAGE	MFG	6																		
	CASTING	20																		
STATOR VANE, 1ST STAGE	MFG	7																		
	CASTING	20																		
INNER SUPPORT, 1ST STAGE	MFG	6																		
	FORGING	24																		
MANIFOLD BLEED, 1ST STAGE	MFG	6																		
	WELDED RING	16																		
AXIAL ROTOR, 2ND STAGE	MFG	6																		
	CASTING	20																		
STATOR VANE, 2ND STAGE	MFG	7																		
	CASTING	20																		
INNER SUPPORT, 2ND STAGE	MFG	6																		
	FORGING	24																		
MANIFOLD BLEED, 2ND STAGE	MFG	6																		
	WELDED RING	24																		
AXIAL COMPRESSOR SHROUD	MFG	5																		
	WELDED RING	24																		
CENTRIFUGAL COMPRESSOR ROTOR	MFG	12																		
	CASTING	20																		

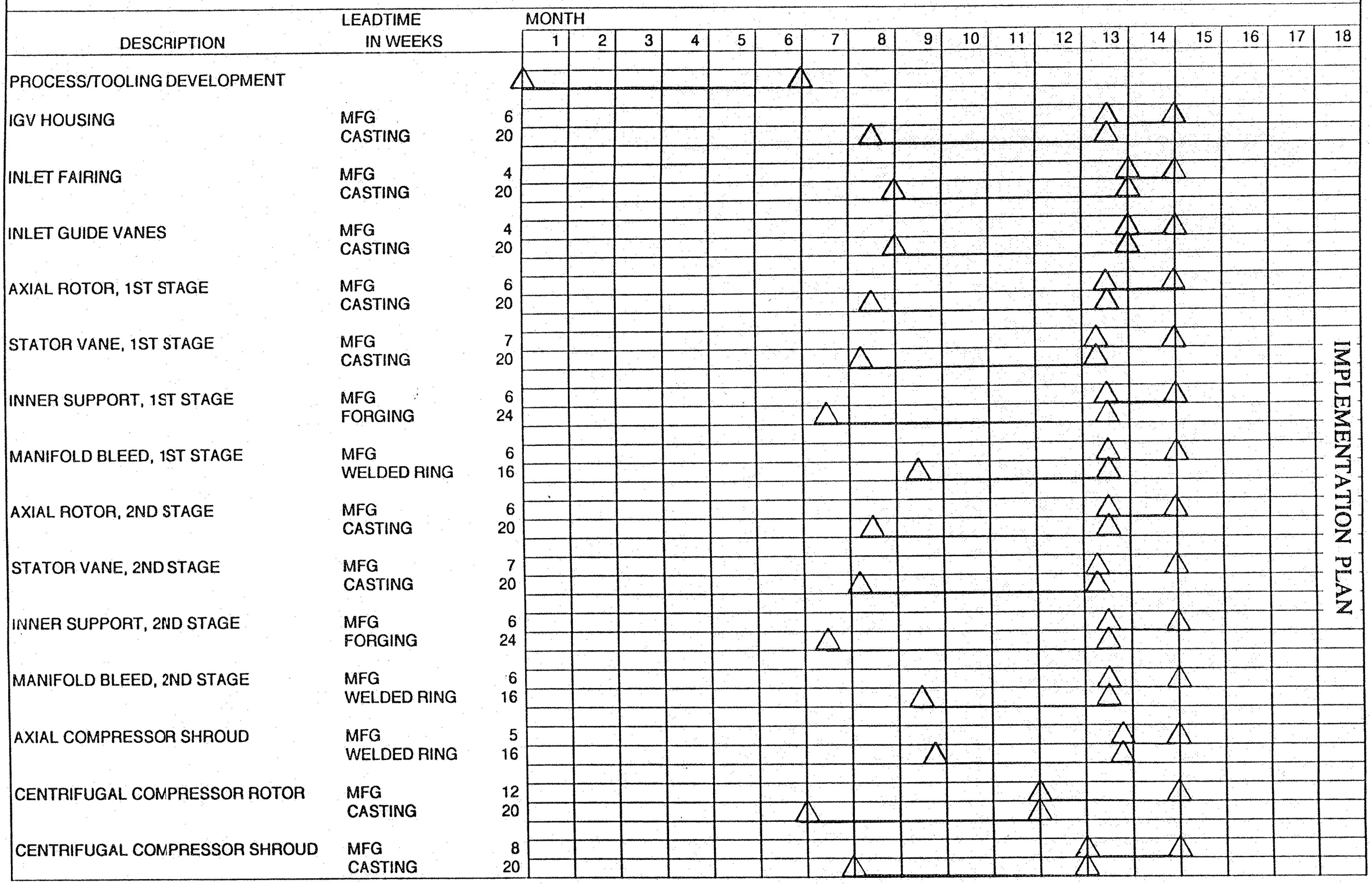
[265_220] -1- 12-Jun-9

TELEDYNE RYAN AERONAUTICAL MODEL 265 T/SHAFT & MODEL 220-2

DESCRIPTION	LEADTIME IN WEEKS	
CENTRIFUGAL COMPRESSOR SHROUD	MFG	8
	CASTING	20
RADIAL DIFFUSER	BUY	40
COMPRESSOR COVER (W/AXIAL DESWIRL VANES)	MFG	8
	SHEET METAL	12
COMBUSTOR HOUSING	MFG	14
	SKIN	24
	WELDED RING	16
TURB INLET NOZZLE ASSY (INNER/OUTER COMBUSTOR SHELLS & TIN)	MFG	28
	CAST NOZZLE	20
	CMBR SHELL	24
MIXED FLOW TURBINE ROTOR	MFG	12
	CASTING	20
TURBINE SHROUD	MFG	8
	FORGING	24
SHAFT	MFG	26
	FORGING	24
	BAR STOCK	8
EXHAUST DUCT	MFG	20
	SHEET METAL	8
	FORGED RING	24
JET NOZZLE	MFG	4
	SHEET METAL	8
GEARBOX	MFG	16
	CASTING	20
	BEARINGS	60
	GEARS	30
FUEL CONTROL	BUY	50



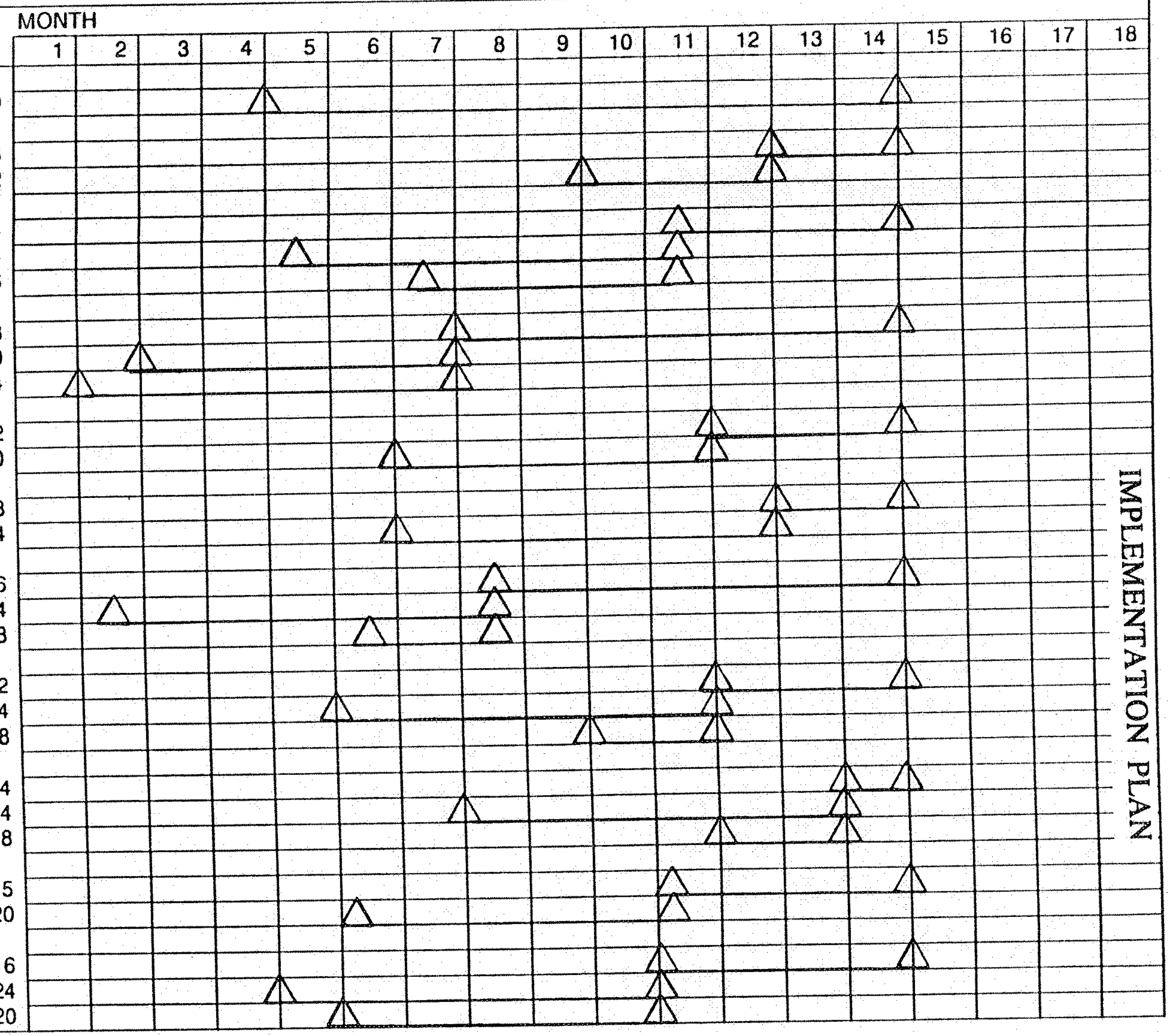
TELEDYNE RYAN AERONAUTICAL MODEL 2150 PROPFAN

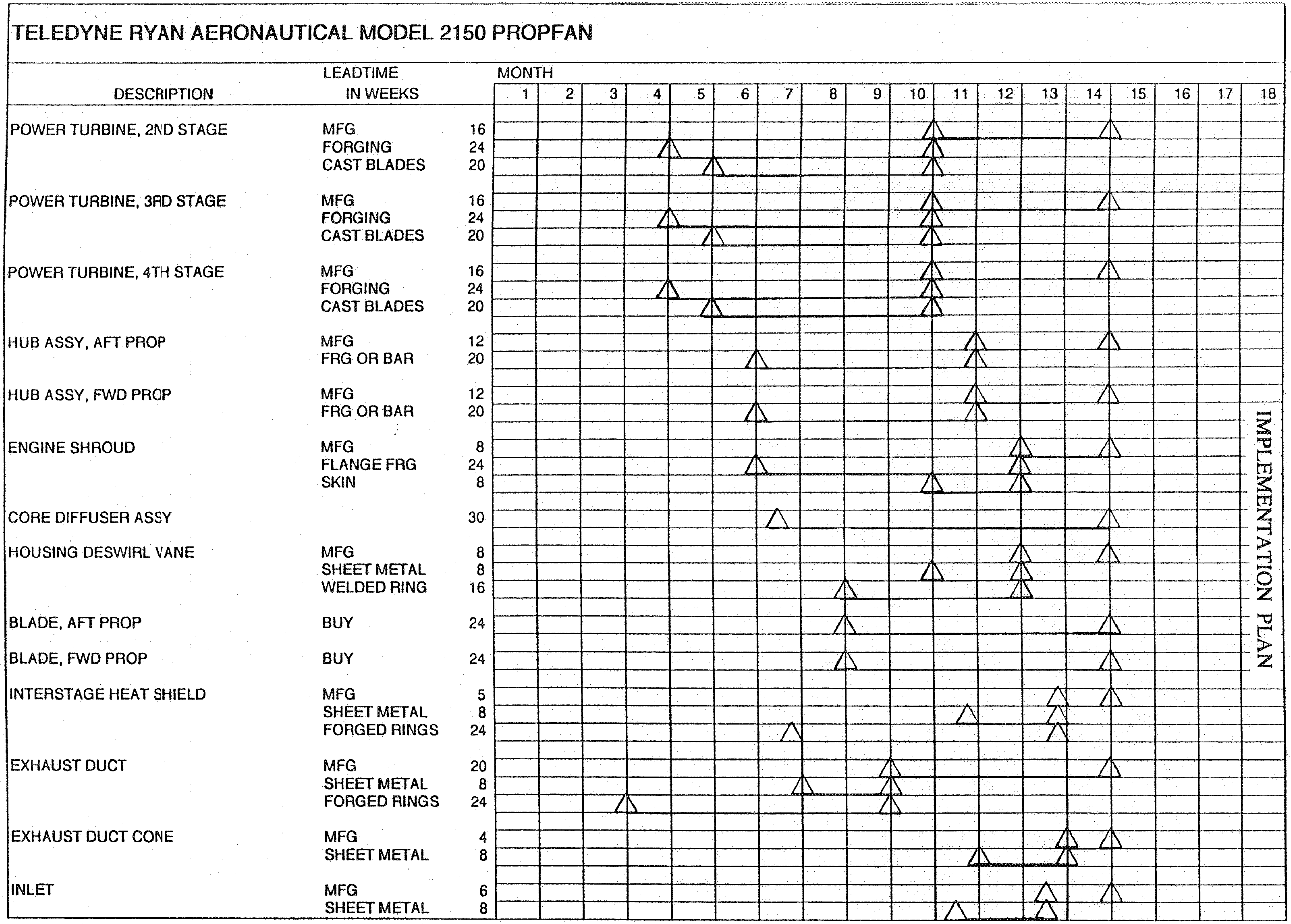


[2150] -1- 12-Jun-

TELEDYNE RYAN AERONAUTICAL MODEL 2150 PROPFAN

DESCRIPTION	LEADTIME IN WEEKS	
RADIAL DIFFUSER	BUY	40
COMPRESSOR COVER (W/AXIAL DESWIRL VANES)	MFG	8
	SHEET METAL	12
COMBUSTOR HOUSING	MFG	14
	SKIN	24
	WELDED RINGS	16
TURB INLET NOZZLE ASSY (INNER/OUTER COMBUSTOR SHELLS & TIN)	MFG	28
	CAST NOZZLE	20
	CMBR SHELL	24
MIXED FLOW TURBINE ROTOR	MFG	12
	CASTING	20
TURBINE SHROUD	MFG	8
	FORGING	24
SHAFT	MFG	26
	FORGING	24
	BAR STOCK	8
TRANSITION DUCT	MFG	12
	FORGING	24
	SKIN	8
JET NOZZLE	MFG	4
	FORGING	24
	SKIN	8
POWER TURBINE INLET NOZZLE	MFG	15
	CAST NOZZLE	20
POWER TURBINE, 1ST STAGE	MFG	16
	FORGING	24
	CAST BLADES	20





[2150] -3- 12-Jun-9

8.6 PRODUCTION PLANNING

8.6.1 Management Systems

TRA/TCAE's method for production scheduling starts with the long range forecast, but is only put into practice with receipt of a contract. Priorities are established to support on-time engine delivery for all components and subassemblies using the Bill of Material and MRP system. The systematic flow-down of policy and detail procedures that authorize pre-production planning and implementation of production activities is as follows.

PROGRAM INTEGRATED SCHEDULE	Maintains all programs schedules.
PRODUCTION MASTER PLAN	Maintains all production requirements and schedules.
CUSTOMER P.O. OR CONTRACT	Contract or purchase order is received at TRA/TCAE.
W.A. ISSUED	Work authorization, including sales order, is issued to Functions.
UPL REVIEWED	Unified Parts List (UPL) is reviewed for all Engineering and Manufacturing detail.
MANUFACTURING DETAIL OF UPL REVIEWED	Manufacturing Bill of Material (BOM is reviewed for detail of all manufactured and purchased parts). Routers are reviewed to insure completeness of operation detail. Process detail reviewed for planned changes.
SALES ORDER DETAIL RELEASED TO MFG.	Sales order detail is entered into the Manufacturing system (Sales Order and Project files).
GENERATE MATERIAL REQUIREMENTS PLAN (MRP)	Manufacturing system is regenerated to include new demands. Order Action reports are generated to review system suggested purchase orders and work orders.
FINALIZE ORDER SIZES AND TIMING	Review all assets, and determine net quantities few purchase and manufactured parts. Determine lot sizes and in-process dates.
ESTABLISH LOT RELEASE PLAN	Enter work orders into the planning system to generate work center and manpower analysis reports.
ISSUE REQUISITIONS FOR PURCHASE PARTS	After final analysis of all assets, issue purchase requisitions for purchase parts with material due dates per the Work Order Release Plan.
RECEIVE AND ACCEPT PURCHASE PARTS	Monitor supplier deliveries to schedule. Receive parts and monitor through Receiving Inspection to Bond Room.
RELEASE WORK ORDERS FOR PRODUCTION	Issue Work Order shop paper (BOM/Router/Kit List) to shop floor per production schedule. Castings, forgings, raw stock, tools and gages released as required by schedule.
MONITOR MANUFACTURING PERFORMANCE	Operations (as completed) are moved by document and are recorded in manufacturing shop floor system. Work orders opened and completed to schedule are monitored and reported on weekly.
FINISHED LOTS STATUSING	Finished lots are closed in the system by the Bond Room Attendant.

The term "Program Integrated Schedule" is used for the highest schedule in the work authorization system.

The contract requirements received by the Program Office are analyzed and passed to the appropriate area through the Work Authorization system. The Sales Order/Work Authorization specifies the requirements with which Production must comply. These are traceable to the customer requirements through the Production Master Plan and the Program Integrated Schedule. The MRP Plan is generated to support the Shop Schedule and the Production Engine Master Schedule. This forms the basis for subsequent lot releases for fabrication and procurement.

The Production Master Plan for production is developed from the Program Integrated Schedule. This schedule develops all major milestones required by the program's various contract requirements. It schedules all critical milestones start and completion dates at the highest status position. Individual detail schedule reports are statused separately and then are stationed on the chart. The Production Master Plan integrates all manufacturing plans within the program. This includes development of part processes, tool engineering and design, tooling and fixture fabrication, qualitu planning and component fabrication.

The Engine Delivery Schedule is developed from the Program Integrated Schedule. This schedule details the number of engines required for shipment by month, by year. The Engine Delivery Schedules are "set back" from the engine delivery requirements by one month.

Criteria for establishing lot sizes and lead times is consistent with the Standard Procedures, Operating Instructions and the MRP system based on approved Manufacturing Parts List, Unified Process Instructions, routines and procurement lead times. Based on the MRP generated lot release plan, work orders are released on the parts' scheduled start dates and suggested lot sizes.

Production execution is completed by having daily status meetings by the designated team members. Performance statusing is performed weekly in the Operations Meeting. Ongoing auditing per ISO 9000 and MMAS requirements ensures quality and cost compliance.

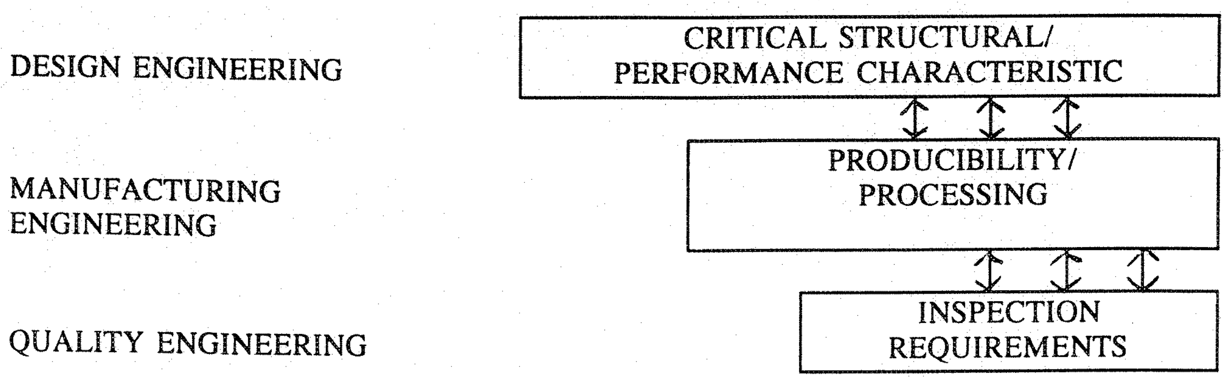
8.7 PRODUCIBILITY PLAN

8.7.1 Introduction

The producibility plan defines a structured program which will be set-up and established to ensure that the system designs for each component can be produced simply and easily with proven manufacturing processes and a high probability of compliance with the engineering design.

Producibility is defined as the combined effect of those elements or characteristics of a design and the production planning for it that enables the item, described by the design, to be produced and inspected in the quantity required. It permits a series of trade-offs to achieve the optimum of the least possible cost and the minimum time, while still meeting the necessary quality and performance requirements.

A producibility review team (Program Manager, Manufacturing Engineering, Quality Engineering, and Design Engineering) will be put in place, early in the program, to ensure a manufacturing perspective. The review team captain is the single point of contact for all producibility engineering matters and approves all drawings. This approval is an integrated part of the configuration control program. It is through this procedure that the review team captain has the power to accept or reject design changes based on the producibility factor. The review team captain has the responsibility to draw on expertise in other functional organizations to fully evaluate a proposed design and/or in conducting trade studies.



While the design is being optimized and tracked for compliance with performance and reliability requirements during engine testing, the processing concepts will be developed; including the definition of how each characteristic will be gaged at the work station to eliminate the need for final inspection. The machining plan for each casting and fabrication will be developed using the concurrent engineering approach.

Simultaneous definition of final part configuration and corresponding machining and gaging techniques result in parts which are easier to produce and inspect at the work station. Manufacturing and Quality will have an input on tolerances, datums and the geometric relationships, while maintaining a clear identification of what is important to engine performance.

Section 8.7.2 highlights the subcontractor involvement in producibility relative to the casting process. Section 8.3 summarizes the approach used in the final assessment of the design and manufacturing processes to assure that variability is minimized in critical component characteristics.

8.7.2 Producibility Review Cycle

It is the intent of TRA/TCAE to involve the supplier in the producibility process from the part's conception whether we are procuring a casting and/or a fabrication. Prior to the design of an individual component, casting sources will be involved in looking at generic engine cross-sections to obtain their input on the component casting designs, to facilitate the tooling design and processing of the parts.

The castings are then designed and drawn. The initial casting drawings are Level II. These drawings are reviewed by all Design disciplines, Manufacturing, Quality, and the casting suppliers. The idea behind these reviews early in the program is to design the part for manufacturability and inspectability at a low cost without compromising the design, quality, or part integrity.

The Level III drawings are stand alone, mono-detail. This means that all the pertinent information is placed on the drawings. All specifications have been reviewed and details required have been extracted and placed in note form. The information does not leave room for interpretation problems and conflicts.

To control the castings in production from a Quality and consistency standpoint, we work with all of the casting suppliers since the early phases of the program in a couple of areas. First, we assist in identifying all critical characteristics in the design and the suppliers identify those characteristics critical in controlling the process.

Statistical Process Control (SPC) is employed early in the process, plastics/wax plastic assemblies, to identify problems beginning to happen. This allows for a pro-active problem solving effort rather than a reactive effort to a problem that exists and is too late to correct. To further enhance this process, functional gaging is being provided to support this activity when deemed necessary. SPC will be continued at the final casting state. The goal is to eliminate the need for a source inspector by reviewing X and R charts from the supplier on the critical characteristics and implementing a supplier release program with internal Bond Room audits.

Since the suppliers will be responsible for qualifying each casting, a qualification or target machining fixture is being supplied to assure a consistently qualified casting when the machining begins.

Process control will be the key to success for the foundries. A casting review team will be established comprised of Manufacturing Engineering, Quality, Materials Lab, and Procurement personnel. The team will make regular visits to the suppliers to address any problems. This team will approve all of the fixed process plans and perform audits to assure the process remains in control. Once the processes are frozen at the foundry, all changes to significant processes will need producibility approval. This will not happen unless the process change is justified and sufficient data to evaluate the impact is provided. The same process control techniques will be employed in the fabrications as well as all of the machining. SPC will be used to monitor a process and track dimensional characteristics.

To continue the team approach, the suppliers will be asked to look at cost drivers in the processes and propose possible alternatives to both reduce the unit cost as well as enhance the process in the foundry. This will be an on-going producibility effort. New technologies in inspection are currently being evaluated which, for example, include a three-dimensional software package that operates with a DEC-CMM (Computerized Measuring Machine) and also the use of CAT SCAN's for non-destructive dimensional control.

8.7.3 Engineering Producibility Analysis

The generalized approach to producibility analysis follows a basic four-step process which translates the product design into a controlled manufacturing process.

1. Identify Customer Design Requirements: These design requirements are defined in the prime item specification in terms of performance, life and specific hardware requirements such as weight and size. The requirements need to be met to achieve the mission and environmental scenarios.

2. Translate Customer Design Requirements into Subsystem/Component Requirements; This process is performed in two steps:

    a. Identify subsystem performance and structural requirements/goals that will satisfy the customer design requirements; e.g., efficiencies, pressure ratios, design margins.

    b. Identify specific hardware characteristics that impact the subsystem's performance and structural requirements. This will be accomplished using the simultaneous engineering approach by conducting drawing reviews with representatives from Manufacturing, Quality, and Design Engineering. The drawings will also be reviewed by casting suppliers. The results will be documented in a critical hardware characteristic format. The analysis would document the impact on subsystem performance/structural characteristics of changes in critical dimensions, surface smoothness, material properties, etc.

    Suppliers and in-house Manufacturing and Quality personnel are therefore informed of critical characteristics that impact performance and structural requirements; plus they have provided input into drawing changes for improving producibility.

3. Identify Manufacturing Processes that Impact Hardware Characteristics: An analysis will be used to identify variables in the manufacturing process that cause variability in critical hardware characteristics. Thus, the analysis also identifies the need for control procedures at various steps in the process and provides a checklist for quality audits to assure that control procedures have been defined and are being followed. The result may also identify areas for process changes which reduce the need for control procedures.

4. The last step is to identify where SPC should be implemented. SPC plans and procedures are then reviewed/developed as part of the production planning process.

9.0 DUAL-USE TECHNOLOGY DEVELOPMENT PLANS

9.1 MODEL 216 TURBOPROP DUAL USE TECHNOLOGY

The Model 208\216 Twinpack is part of the dual-use technology network in place at Teledyne Ryan Aeronautical, TCAE Turbine Engine Division. TRA's turbine engine Model 304 provides the baseline for multiple military and commercial applications ranging from small weapon systems to Hybrid Electric Ground Vehicles to light aircraft for general aviation. Figure 9.1.1 lays out the dual-use technology development flowpath which includes the Model 208\216 Twinpack.

The Model 304 is currently being developed in parallel for both commercial and military applications. On the military side, the Model 304 has been proposed for use in the Miniature Air Launched Decoy (MALD). Upgrading the cycle temperatures with a ceramic turbine in the Model 304-2 version provides efficiency improvements to incorporate in the Next Generation MALD with continuing technology developments feeding future small weapon systems.

The Model 304 has also been used as the baseline for the Model 105-1 in support of the Ford Motor Company's Hybrid Electric Vehicle. TRA is currently under contract from the Ford Motor Company to develop the Model 105 for use as an electrical power generator in Ford's Hybrid Electric Vehicle (HEV). This program will also take advantage of the ceramic turbine upgraded version in the Model 105-2. The anticipated production numbers for the Model 105-2 are extremely high in accordance with the automotive market which results in a very desirable unit cost. Once the design and development is completed on the Model 105-2 with production ready development underway, TRA will be in a position to pursue several other applications for the Model 105 and its derivatives such as: Stationary and Portable Power Generators (both in military and commercial markets), Auxiliary Power Units for Aircraft (again, both military and commercial) and other Hybrid Electric Ground Vehicles (also military and commercial).

The ceramic production version of the Model 105 forms the basis for the Model 208\216 Twinpack. The Model 208\216 Twinpack takes the gas generator hardware from the Ford HEV Model 105-2 production line (including the recuperator, less the PCU and starter/generator), and adds a combining gearbox to create the Model 216 Twinpack which will power a light type aircraft for general aviation such as the Beech Bonanza.

The Model 208/216 Twinpack development for use in the general aviation market benefits from turbine engine technology currently being developed for both military (small weapons systems) ar commercial applications (electrical power generators) and will contribute to the further technology development leading to products in both markets.

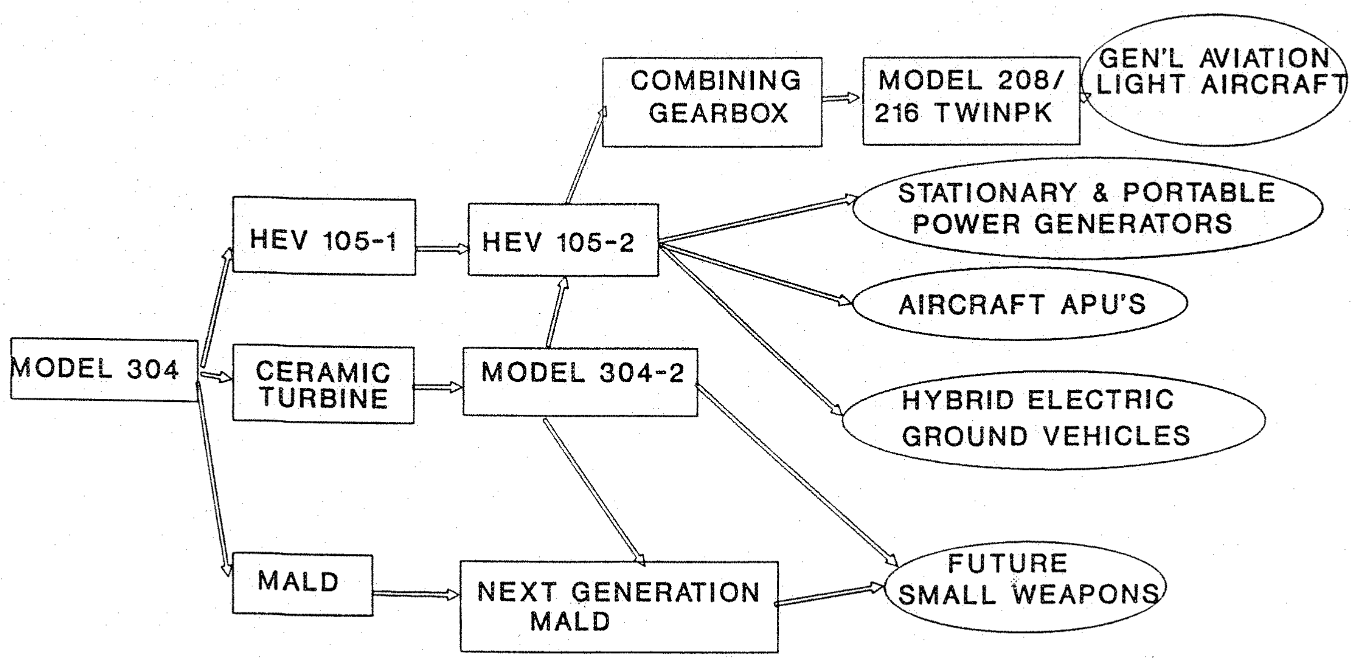


Figure 9.1.1 Dual-Use Technology Development - Model 208\216 Twinpack.

9.2 MODEL 208\216 TWINPACK SCHEDULE & FUNDING REQUIREMENTS

The Model 208 is anticipated to incorporate the gas generator hardware from the Ford HEV Model 105-2 production line and thus the schedule and funding requirements given here are dependent upon the completion of its final design and demonstration and subsequent production. A total program cost of $8.3M (broken out below) is projected to accomplish a flight demonstration test by late 2005. Figure 9.2.1 provides the rough schedule and estimated funding requirements for the Model 216 Twinpack to achieve a flight demonstration by late 2005. Also included on the schedule is the Ford HEV Model 105 schedule for final design and demonstration leading in to production ready development and final production ready status, achieving Low Rate Production by 2003. The Model 105-2 is scheduled to be demonstrated in late 1997/early 1998 which would kick-off the Preliminary Design phase for the Model 208.

The Preliminary Design, Task 1.0, is a nine month effort at $0.3M which includes the manpower and company resources to outline the requirements for the combining gearbox design and define the twinpack configuration and the modifications for installation and interfacing changes due to transitioning the engine from an automotive application to a man-rated aircraft (such as the fuel control, inlet and exhaust configurations, alternator/starting mechanism, customer bleeds, etc.).

Based on the results of the Preliminary Design phase, Task 2.0, Gearbox Detailed Design and Task 3.0, Twinpack Demo would be initiated in parallel in early 1999. Lasting approximately 18 months at a cost of $2.0M, the Gearbox Design task will include hardware procurement and culminate in a rig test demonstration. The Twinpack Demo task will be conducted in parallel with the Gearbox Design since there will be necessary information provided back and forth between these two tasks. As the gearbox is rig tested, it will feed into the Twinpack Design such that a full-up demonstration of the twinpack configuration will be completed in 2001. The $0.8M for the Twinpack Demo includes the test hardware for the demonstration, assuming the core gas generator component hardware will be available in-house from the Ford HEV program, which is scheduled to be in production-ready development at this time.

Upon successful completion of the twinpack demonstration, Task 4.0, Twinpack Development will commence. The $4.6M funding level includes four sets of component hardware provided by the Ford HEV Model 105-2 production line over a total development period of three years. Approximately two-thirds into the Development period, the Final Configuration will be selected and subsequent effort will focus solely on this configuration. Concurrent with the Twinpack Development Task, the aircraft should be selected and developed as well, such that at the completion of the Twinpack Development, the aircraft will be ready to support preparation for the Flight Demonstration, Task 5.0, to be completed by late 2005. This phase of the schedule, funded at $0.6M includes technical support on the part of TRA and two sets of engine hardware plus spares provided for the flight demonstration test.

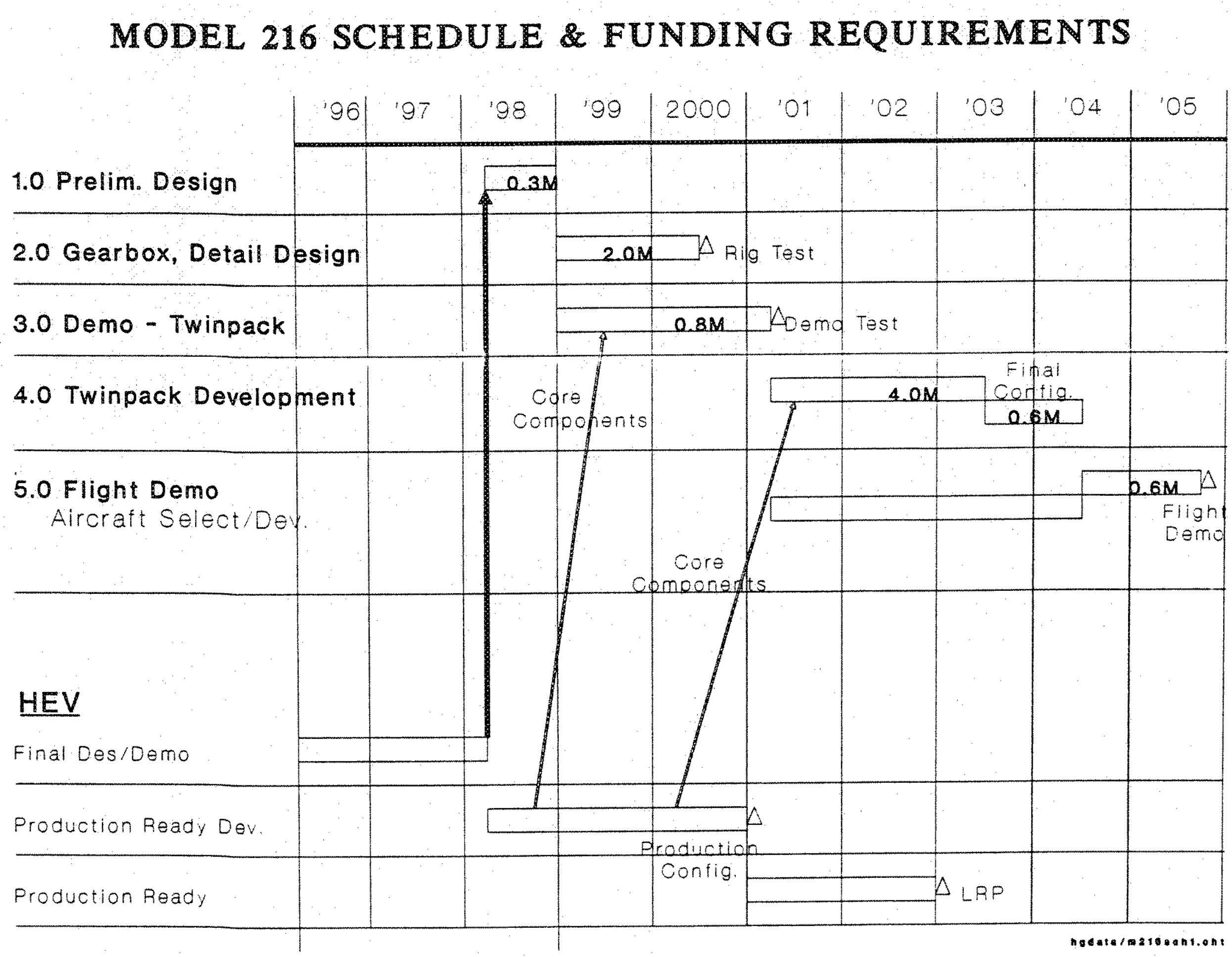


Figure 9.2.1 Model 216 Schedule and Funding Requirements.

9.3 MODEL 265 TURBOPROP DUAL USE TECHNOLOGY

The Model 265 is also part of the dual-use technology network in place at Teledyne Ryan Aeronautical - TCAE Turbine Engines. The JETEC program supplies the technology base for a host of potential military and general aviation products ranging from missiles and reconnaissance vehicles to general aviation's business jets and light aircraft. Figure 9.3.1 outlines the dual-use technology flowpath which includes the plan for the Model 265 propfan.

The JETEC Phase II demonstrator is a full-up propfan with aero-turbines driving two rows of counter-rotating propellers. The Model 235 is a similar propfan being developed specifically for military applications in missiles and reconnaissance vehicles.

The Model 265 is a geometric scale of the Model 235 core, taking advantage of the advanced technology gains in improved component efficiencies and aggressive cycle temperatures. The Model 265 turboprop adds a power turbine to the Model 235 core which is geared to drive a single propeller.

9.4 MODEL 265 TURBOPROP SCHEDULE AND FUNDING

The schedule and funding requirements for the Model 265 are outlined in Figure 9.4.1. The total program cost is estimated at $19.0 M and is broken down into five major tasks. The Task 1.0 Design effort would consist of the design effort required to execute the scale of the Model 235 core and the tasks necessary to convert the limited life technology demonstrator into a man-rated, production ready, flight weight design. This $2M would include consideration of design details such as bird, ice and water ingestion, maneuver loads, environmental vibration, inlet and exhaust effects, start and customer bleeds, fuel control requirements, electrical power requirements and start requirements. Additionally, a power turbine design would be required to drive the gearbox.

The Gearbox Design, Task 2.0 funded for $1.5M, would be based on technologies developed in the propfan gearbox PRDA program which supported the JETEC effort. This design would be a simplified version of the propfan gearbox, since only one prop is driven in this turboprop engine. The gearbox design effort would be integrated with the power turbine design.

The Task 3.0 Gearbox Development would consist of rig testing to verify the design relative to the Model 265 flight power and torque requirements. This $3.5M task would culminate in a rig test which would demonstrate gearbox durability.

Task 4.0, Engine Development would be a series of engine tests to verify the design capabilities of the engine. The early tests would address the core requirements, while the later test would evaluate the full turboprop engine. Redesigns would be incorporated as necessary to address any development problems. As low cost technologies are verified in the JETEC Phase III program, these technologies will be transitioned into the Model 265 development program. Likely candidates for such technologies are vapor lubrication for bearings and gears, and a double vortex combustor. The major goal of this $10M effort is to assure that the engine is ready for a flight demonstration test and the subsequent FAA certification effort.

Task 5.0, Flight Demonstration funded at $1-2M will provide the necessary hardware and manpower support for the flight demonstration test. The early phase of this task will address the integration of the engine into the selected airframe. This would include support for items such as fuel control/flight computer communication, customer bleed requirements, inlet and exhaust design, electrical power requirements, fuel system requirements and mounting. This task will culminate in the flight demonstration test.

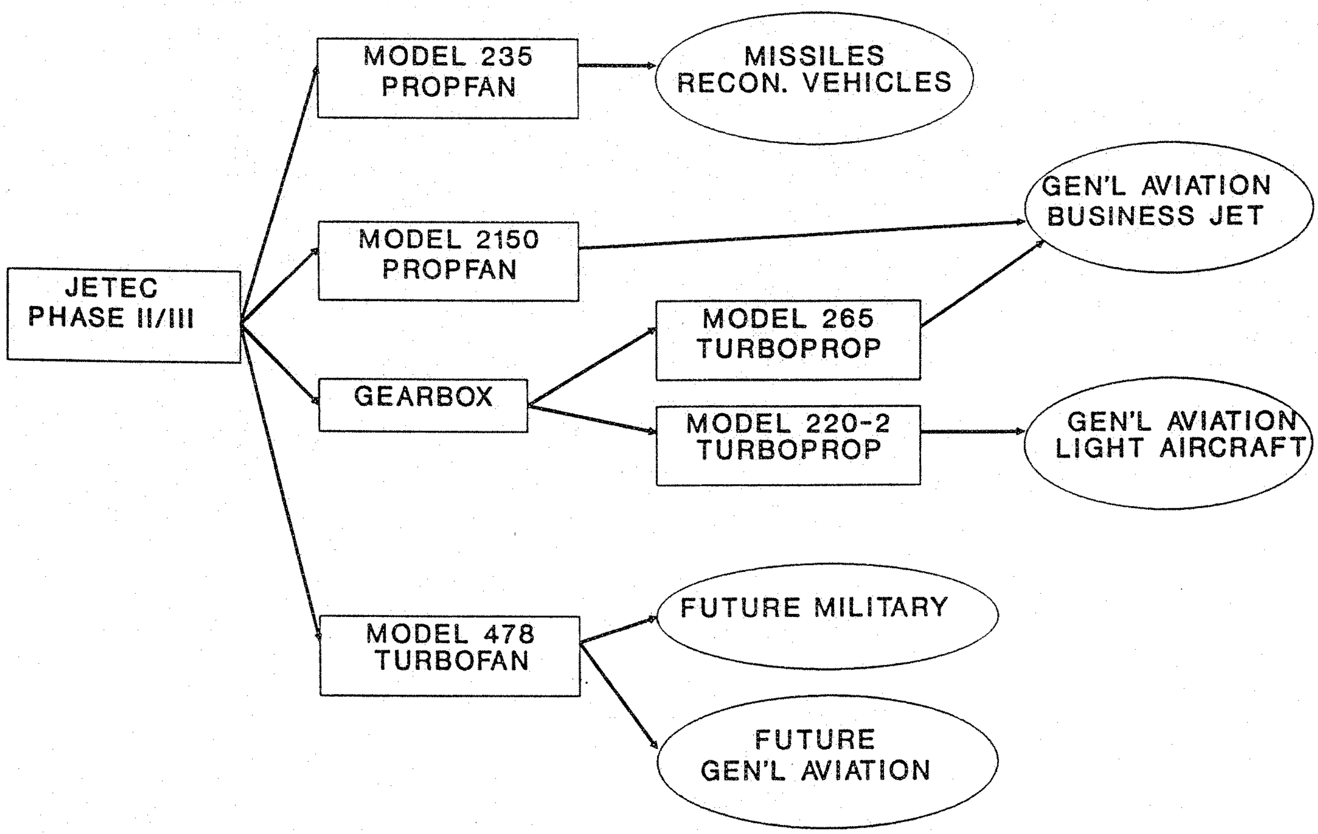


Figure 9.3.1 Dual-Use Technology Development Plan.

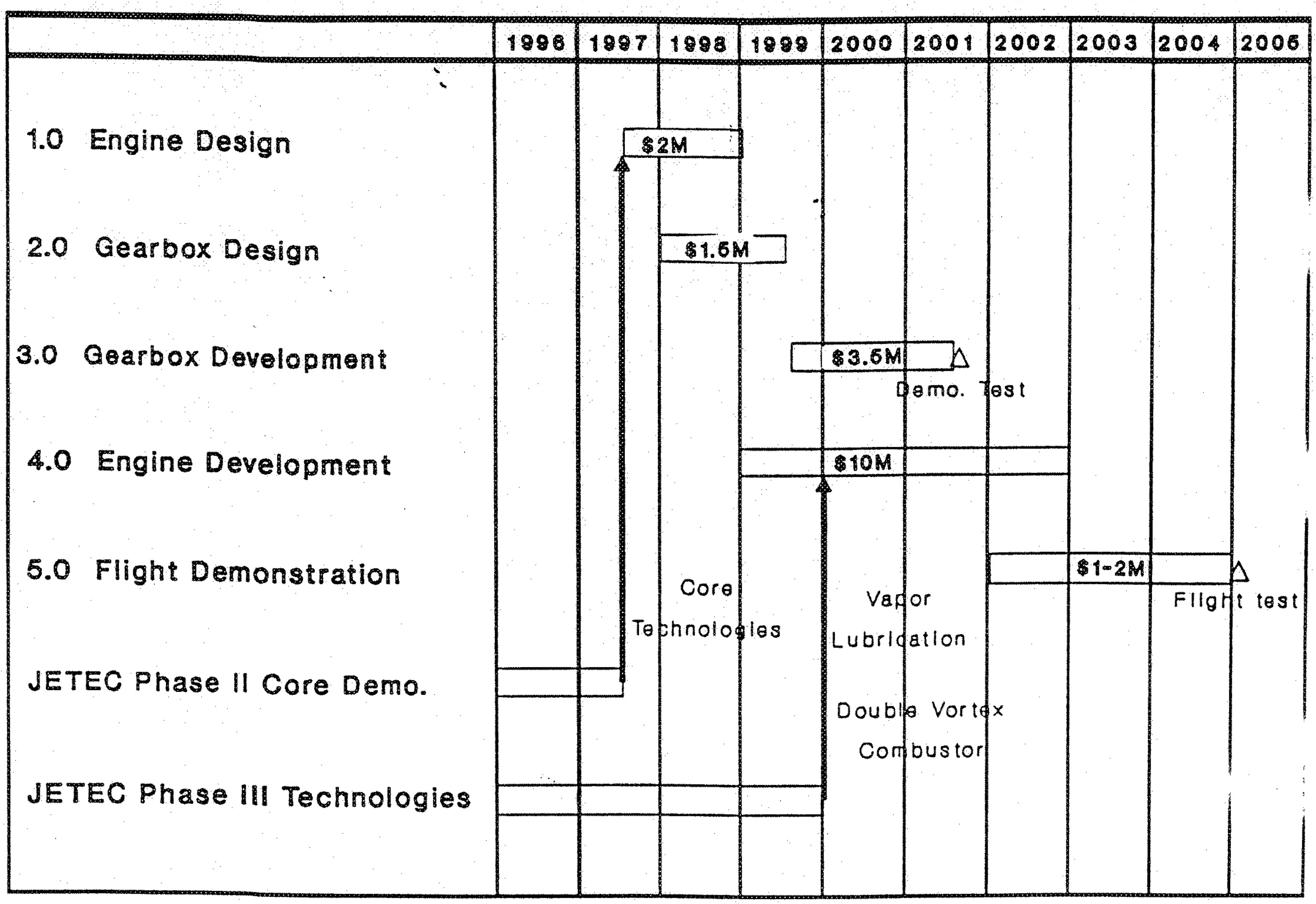


Figure 9.4.1 Model 265 Schedule and Funding Requirements.

10.0 NEW TECHNOLOGY

There were no nonpatentable discoveries or patentable inventions developed or identified during the performance of this study.

11.0 CONCLUSIONS

This study has shown that advanced technology turbine engines can provide a dramatic improvement in range and fuel consumption as compared to existing engines in both light, private type and business type current production aircraft. However, the advantages gained by the new technology engines and cost considerations make a direct retrofit to existing aircraft appear to be impractical. For the light, private type aircraft, the Model 216 would allow the F33 Bonanza to operate for a mission flight time that is actually too long for a vehicle without lavatory facilities. The range capability offered by this engine could be better realized in a new aircraft design. The new design would be significantly lighter since it would require smaller fuel tanks and less fuel to fly the same mission as the current Bonanza. The increase in take-off field length and slower rate-of-climb required by the Model 216 in the Bonanza may be offset by installing the Model 216 in a lighter, new design aircraft. The Model 220-2 performs similarly to the baseline engine in the F33 Bonanza, however its uninstalled engine weight is 75% less than the current engine. The Model 220-2 could also provide similar or better performance to the Bonanza in a new, lighter aircraft that takes advantage of this reduced engine weight. For the business jet type aircraft, the Model 265 also provides increased range as compared to the baseline engine in the C90 King Air. The Model 265 range capability is also nearing the impractical limit and the improvements in fuel consumption could better be taken advantage of in a new aircraft design.

12.0 REFERENCES

1.0 "Jane's, All the World's Aircraft, 1994-1995", pp.481-482, 484, Butler and Tanner Ltd., London, 1994.

2.0 "General Aviation Safety, Maintenance, and Reliability Data," memorandum, W. Baumgarten, NASA-LeRC, to J. Gallman, Raytheon Aircraft Co., 31 May 1996.

APPENDIX A

NASA Advanced Propulsion Systems Studies

for

General Aviation Aircraft

Final Report

Raytheon Aircraft Company

to

Teledyne Ryan Aeronautical

May 1996

RAYTHEON AIRCRAFT CORPORATION
9709 E. Central
Wichita, KS 67201-0085

Cage Code 70898

NASA
ADVANCED PROPULSION SYSTEMS STUDIES
FOR GENERAL AVIATION AIRCRAFT

REPORT NUMBER: E25125
WORK ORDER: 29627

Prepared for

Teledyne Ryan Aeronautical
TCAE Turbine Engines
1330 Laskey Road
Toledo, OH 43612-0971
May, 1996

Prepared By: John Gallman
John W. Gallman, Ph.D.
Technical Specialist,
Preliminary Design

Approved: D. R. Koerbel
Duncan Koerbel
Manager, Preliminary Design

Approved: Bob Anderson
Bob Anderson
Manager, Contracted
Research and Development

REV	BY	DATE	APPROVED	DESCRIPTION OF REVISION
1	J. Gallman	18 JUNE 1996		Fig 9 and corresponding text (p. 19) corrected to agree with data in Table 16.

Table of Contents

1.0 Introduction

Many people have suggested that new low cost turbine engines would enhance the development of 4-6 place personal transportation aircraft and revitalize the light aircraft industry and infrastructure in the United States. Historically, high development costs and a relatively high fuel consumption prevented the use of turbine engines in light general aviation aircraft. However, recent advances in small turbine engines for military weapon systems and for automobile applications make it reasonable to consider the development of a new turbine engine that is competitive in both cost and performance with current internal combustion engines.

Several engines, currently under development by Teledyne Ryan Aeronautical, have been evaluated in this study as possible replacements for the engines in current production aircraft. A comparison of aircraft performance with current and new technology engines clearly identifies a performance increment caused by a new engine and defines a lower bound on the performance of a new airplane designed for this new engine. This evaluation of potential engines in current production aircraft is the first step toward the definition of a new class of turbine powered personal transportation aircraft.

This study evaluates two advanced technology turboprop engines for a light 4-place aircraft that requires approximately 200 hp, one 600 hp turboprop, and one 1500 lbf propfan engine. Three baseline production aircraft/engines have been selected for the evaluation of these new engines. The airframe/engine combinations compared in this study are

Baseline	Advanced Technology Engines
Bonanza/IO-470-K	Model 216, Model 220-2
C90 King Air/PT6A-21	Model 265, Model 2150
QCGATE/Lycoming Turbine	Model 2150

Takeoff, climb, cruise, and descent performance was predicted for a mission that is typical for the baseline aircraft with both current baseline and new technology engines. This mission was then altered to take advantage of the specific characteristics of the new engines. Baseline and new technology engines are compared on the basis of takeoff distance, range, speed, fuel usage, mission time, acquisition cost, safety, reliability, and maintenance.

2.0 Analysis Methods and Assumptions

2.1 Mission Analysis

Analyses of takeoff field length, climb, cruise, and descent are used in this study to compare baseline and new technology engines. An increment in takeoff field length provides a direct comparison of sea level static thrust and helps to identify a minimum static thrust requirement for new engines. Comparisons of climb performance focus on the variation in thrust with increasing altitude. An overall mission analysis (climb, cruise, descent) identifies differences in engine fuel consumption and the resulting range capability of the engine-airframe combination.

For a fixed baseline aircraft the takeoff field length is inversely proportional to the engine horsepower or thrust. In this study, increments in takeoff field length are evaluated using statistical correlations, presented in Ref. 1, of takeoff field length with the parameter

$$\frac{W^2}{(\sigma)(C_{L_{\max}})(S)(BHP)}$$

where W is the aircraft takeoff weight, σ is the ratio of air density at takeoff altitude to the air density at sea level, $C_{L_{\max}}$ is the aircraft maximum lift coefficient in takeoff configuration, S is the wing reference area, and BHP is the maximum static horsepower at the takeoff altitude. For a propfan or turbofan aircraft horsepower is replaced with thrust.

Numerical integration in time and or weight is used to analyze the climb, cruise, and descent performance with both baseline and new technology engines. The climb analysis is based on an approximate relationship for the increment in time required to climb a small increment in height [2],

$$\Delta t \cong \frac{2}{RoC_i + RoC_f} \Delta h$$

where RoC_i and RoC_f are the rates of climb at the initial and final altitudes that define the increment in height, Δh. Distance or range traveled during climb is then a sum of the distance traveled during each time interval,

$$\Delta s = \Delta t \, V \cos\left(\sin^{-1}\left(\frac{RoC}{V}\right)\right)$$

where V and RoC the average speed and climb rate for the time interval. Descent analysis is identical to the climb analysis with a rate-of-descent replacing the rate-of-climb in the above equations. Range is simply a sum of $\Delta t V$ for a given fuel weight. For range, the increment in time is an increment in fuel weight divided by the fuel flow rate.

2.2 Cost, safety, reliability, and maintenance

Unfortunately, accurate estimates of acquisition cost, safety, reliability, and maintenance rely heavily on the in-service record for a given engine. Evaluation of acquisition cost is simply a comparison of current baseline engine prices [4] with those estimated by Teledyne Ryan for the new engine. Evaluation of safety, reliability, and maintenance is based on recommended time between overhaul and overhaul cost. A simple 1-10 rating will be given to each of the baseline and new technology engines.

2.3 Airframe, Engine Weight

Aircraft weight and balance becomes an important issue when considering the installation of a new engine in an existing airframe. A lighter engine may produce a reduction aircraft takeoff weight for the same payload and fuel weight. This reduction in takeoff weight leads to a reduction in induced drag and an increase in range that is independent of any improvement in engine thrust or fuel flow. Unfortunately, a change in the installed propulsion system weight frequently forces the use of lead weights in the aircraft nose or tail to avoid any significant change in aircraft stability or handling qualities. These balance weights could be avoided by changing the longitudinal location of the wing with respect to the aircraft fuselage. However, engineering and certification costs for a new wing attachment structure are prohibitive for an engine retrofit project.

Even though the uninstalled weights of the new engines considered in this study were less than the uninstalled weights of the baseline engines, no reduction in aircraft takeoff weight was considered for the mission analysis studies. Consequently any improvement in mission time or range can be attributed solely to the new engine. Although it is appropriate for an engine retrofit study to ignore any reduction in aircraft takeoff weight, significantly greater improvements in aircraft performance can be obtained with an airframe designed specifically for a new engine.

The reduction in takeoff weight for a new aircraft is greater than the reduction in engine weight because a smaller wing will be required for the same stall speed or field length requirement. This will be particularly true for the Model 220-2 which is approximately 350 lb or 75% lighter than the baseline engine. With the exception of the Model 220-2, the reduction in uninstalled weight associated with the other engines was less than 10% of the baseline engine weight.

2.4 Propellers

An appropriate propeller was selected for the Model 216, Model 220-2, and the Model 265 engines. These propellers are identical as those used on the baseline aircraft and are assumed to turn at the same rate as in the baseline application. This has the effect of assuming the same propeller efficiency (0.75-0.85) for both baseline and new technology engines and avoids the potential for choosing poor propellers for evaluation of good engines. It does however assume that a propeller could be designed to operate at the rotational rate required by the new engines with the same efficiency as the baseline propellers. Since the propeller speeds anticipated for the new engines are similar to the propeller speeds used on current production aircraft, it should not be too difficult to match the efficiency with a new propeller.

3.0 Selection of Baseline Aircraft

Baseline aircraft were selected from the current fleet of certified production aircraft based on the compatibility with the Teledyne Ryan's new engines. Aircraft produced by Raytheon Aircraft Company that required little modification for an engine retrofit were considered the most desirable for this study. Accurate flight test drag data would be available for these aircraft and an unmodified aircraft would enable the prediction of performance increments based on engine thrust and fuel burn only. Significant modifications to aircraft drag or weight during installation of a new engine would make it more difficult to identify the aircraft performance increments caused by the new engine technology.

A Beechcraft F33 Bonanza (see Fig. 1) was selected for the evaluation of the Model 216 and Model 220-2 turboprop engines. The 225 hp internal combustion engine, which is typically operated at 75% power during cruise, compares well with the maximum power rating of 160 hp for the Model 216 and the maximum power rating of 200 hp for the Model 220. The straight tail F33 is similar in size to earlier versions of the V-Tail Bonanza that were powered by 185 hp engines. Furthermore, the similarity with the F33A and A36 Bonanzas enabled direct comparison of flight-test derived drag polars with the drag polars developed for current production models.

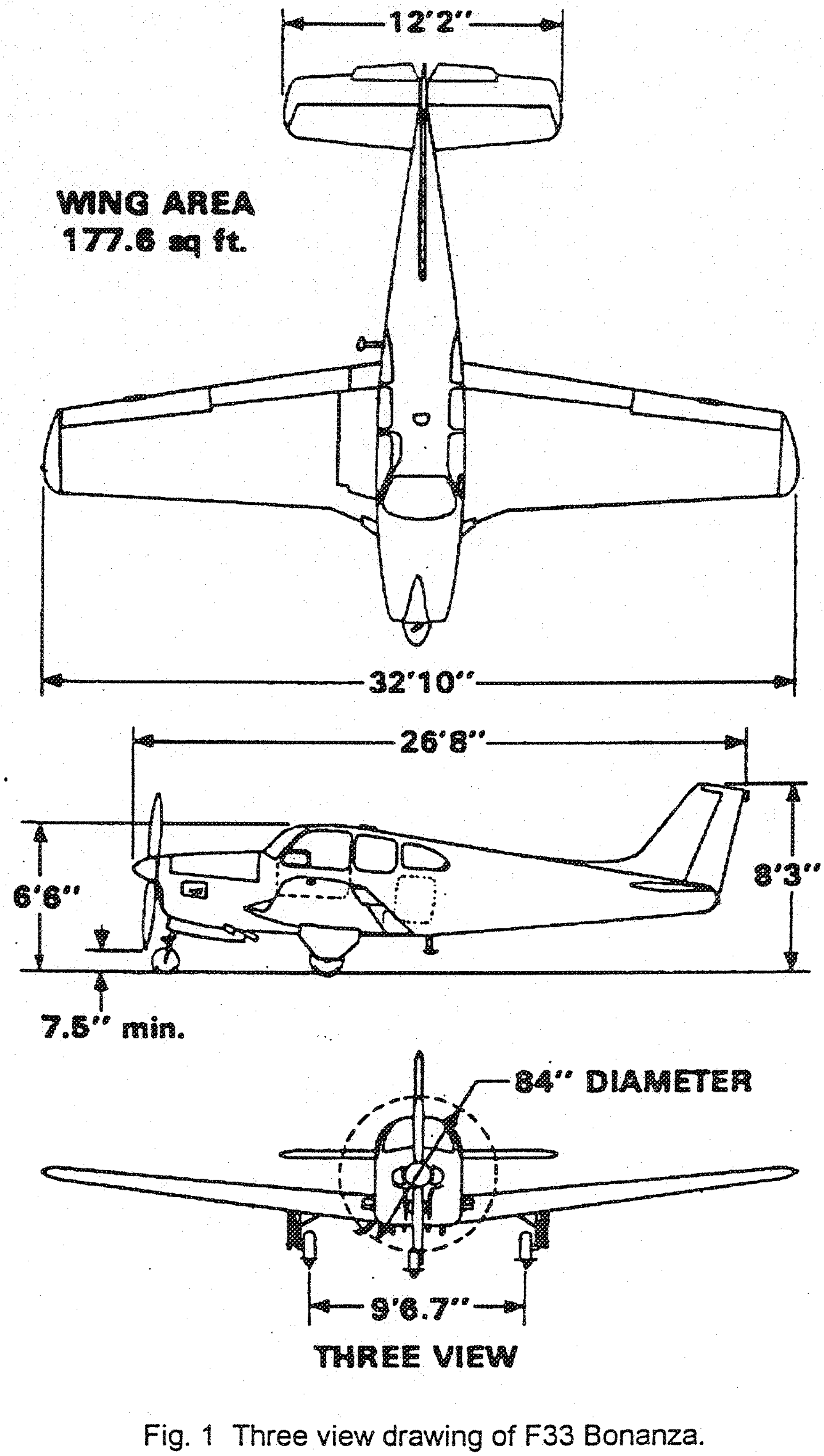


Fig. 1 Three view drawing of F33 Bonanza.

A C90 King Air (see Fig. 2) was selected for the evaluation of the Model 265 turboprop. The Model 265 turboprop has a sea level rating of 650 hp versus 500 hp for the baseline engine. However the baseline engine maintains 500 hp up to approximately 10,000 ft, whereas the Model 265 drops off in power to approximately 550 hp at this altitude. Above 10,000 ft both engines drop off in power at approximately the same rate.

Selection of a baseline aircraft for the Model 2150 propfan with 1500 lb of sea level thrust proved to be a bit challenging. The most appropriate installation of this engine is an aft fuselage mount similar to most twin engined business jets. The smallest twin engine business jet with aft fuselage mounted engines is the Cessna CitationJet, which requires two 1900 lb thrust engines [3]. A model 400A Beechjet, which requires two 2900 lb thrust engines, was obviously inappropriate without a significant increase in takeoff field length and or decrease in cruising speed. Since a certified twin engined business jet with a requirement of approximately 1500 lb of thrust per engine was unavailable, two aircraft were selected for the evaluation of this engine.

A C90 King Air and the QCGATE aircraft, the result of a 1977 Beech Aircraft Corporation preliminary design study, were selected as the baseline aircraft for evaluation of the Model 2150 propfan. It is unlikely that the King Air would be converted from a wing mounted turboprop to an aft engined propfan. However, the thrust requirements are appropriate for the Model 2150 and flight-test derived drag polars are readily available for this configuration. Since a new propfan aircraft would most likely compete in the turboprop market, it seems reasonable to assume the Model 2150 could be installed on an aircraft that has the same drag and weight characteristics as the King Air. The QCGATE aircraft shown in Fig. 3 was designed in 1977 as part of a preliminary design study. The QCGATE engine, produced and tested as part of this research effort, developed 1500 lb of thrust at sea level. Figure 3 shows that the QCGATE aircraft is a two engine business jet with aft engine mounts that are appropriate for the installation of the Model 2150 propfan. To increase the credibility and accuracy of the drag estimates of the QCGATE aircraft compressibility drag coefficients developed from the Model 400A Beechjet are added to the incompressible drag polar estimated for the QCGATE in 1977.

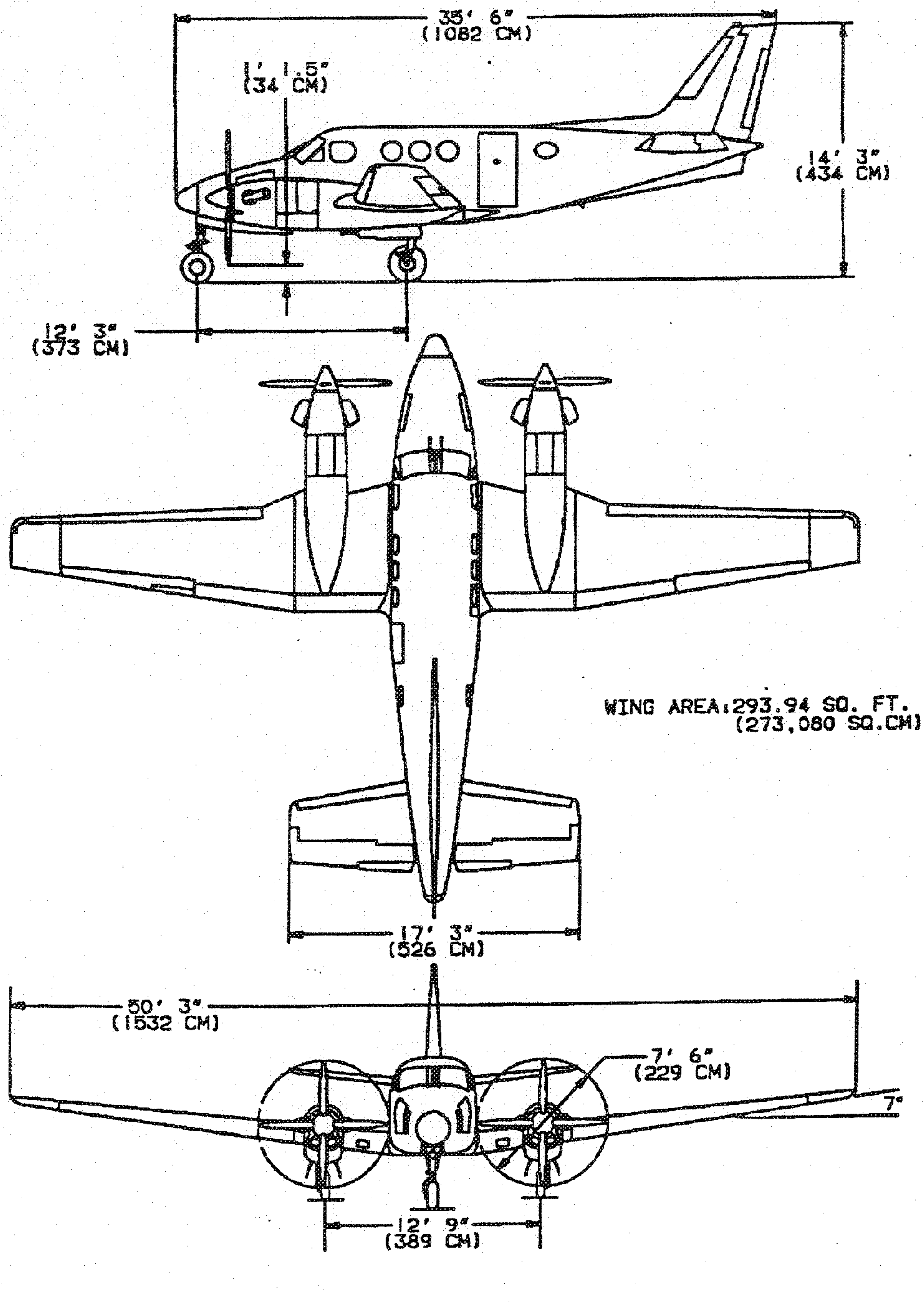


Fig. 2 Three view drawing of Model C90 King Air.

Fig. 3 QCGATE research aircraft configuration.

4.0 Engine Evaluation for Typical Mission

A typical mission is defined in terms of a fixed payload, a fixed fuel weight, and a cruise altitude for each of the baseline aircraft. All of the typical missions involve a climb at best rate-of-climb speed, cruise at maximum speed, descent at a specified rate, and an additional 100 nm cruise at the speed for 99% best specific range. This additional 100 nm cruise segment ensures sufficient reserve fuel to divert to an alternate airport. For a fixed fuel weight, any decrease in engine fuel consumption will lead to an increase in range for the typical mission. Any variation in thrust from the baseline engine will produce a variation in rate-of-climb or maximum cruise speed.

4.1 Takeoff field length comparisons

Increments in takeoff field length were calculated for the three aircraft at maximum takeoff weight, sea level, and for standard atmosphere. Since aircraft weight is assumed to be constant, the increment in takeoff field is only a function of the maximum horsepower or thrust rating of the engine. The 65 hp reduction in takeoff power associated with the Model 216 turboprop produces an increase of 47%, or approximately 1000 ft, in the takeoff field length of the F33 Bonanza. The F33 Bonanza with a Model 220-2 turboprop has 25 hp less than the baseline aircraft and uses an additional 14% of runway to clear a 50 ft obstacle. The increase of 150 hp associated with the Model 265 turboprop enables the C90 King Air to clear a 50 ft obstacle with 26%, or approximately 840 ft, less runway. With the Model 2150 propfan it takes an additional 11% of runway for the King Air to clear a 50 ft obstacle. For the QCGATE aircraft, there is no difference in the takeoff thrust or field length with either the baseline engine or the Model 2150 propfan.

4.2 F33 Bonanza with Model 216 and 220-2 turboprops

Tables 1 through 3 show the mission results for the F33 Bonanza with the baseline engine, the Model 216 turboprop, and the Model 220-2 turboprop. In all three cases, the aircraft begins the climb phase at 3050 lb with 600 lb of payload and 384 lb of fuel. The mission consists of a climb to 8000 ft at the best rate-of-climb speed, cruise at maximum speed, descent at 500 ft/min, and an additional 100 nm cruise at 8000 ft and the speed for 99% best specific range. The baseline F33 Bonanza climbs to altitude in 13 min., cruises for 608 nm at a maximum speed of approximately 155 ktas. Table 1 shows that the primary mission range (climb+cruise+descent) of 670 nm is obtained in 265 minutes with a total fuel burn of 345 lb. Table 2 shows that the Model 216 turboprop enables the same aircraft to climb to altitude in 17 minutes, and cruises for 832 nm at a speed of approximately 150 ktas. The primary mission range is 230 nm greater than the baseline aircraft indicating a significant increase in the fuel efficiency for the Model 216 engine (see Fig. 4). Table 3 shows that the Model 220-2 turboprop produces a time-to-climb of 13 min. and a cruise segment range of 580 nm at approximately 155 ktas. The total mission range is 642 nm in 255 min. This 6% reduction in range with the Model 220-2 would be offset by the weight savings associated with the installation of this engine in a new airplane.

Table 1 Typical mission for F33 Bonanza with baseline engine.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	86.10	94.90	12.91	23.00	19.60	184.00	167.00
Cruise	3027.00	153.40	155.60	236.17	304.34	608.30	163.00	163.00
Descent	2723.00	168.80	150.00	16.00	17.30	42.40	149.00	127.00
Cruise	2697.00	116.30	115.60	51.75	39.43	100.00	92.00	91.00

Table 2 Typical mission for F33 Bonanza with the Model 216 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	83.30	92.60	17.45	17.90	25.80	160.00	142.00
Cruise	3032.00	148.40	151.20	333.06	318.90	831.90	147.00	147.00
Descent	2713.00	168.80	150.00	16.00	14.50	42.40	144.00	125.00
Cruise	2699.00	120.20	119.70	50.00	32.70	100.00	95.00	94.00

Table 3 Typical mission for F33 Bonanza the Model 220-2 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	86.00	94.20	13.32	19.50	19.90	197.00	166.00
Cruise	3030.00	153.10	155.50	225.29	298.60	579.50	163.00	163.00
Descent	2732.00	167.50	150.00	16.00	19.70	42.40	150.00	127.00
Cruise	2666.00	130.10	130.13	46.11	46.20	100.00	111.00	111.00

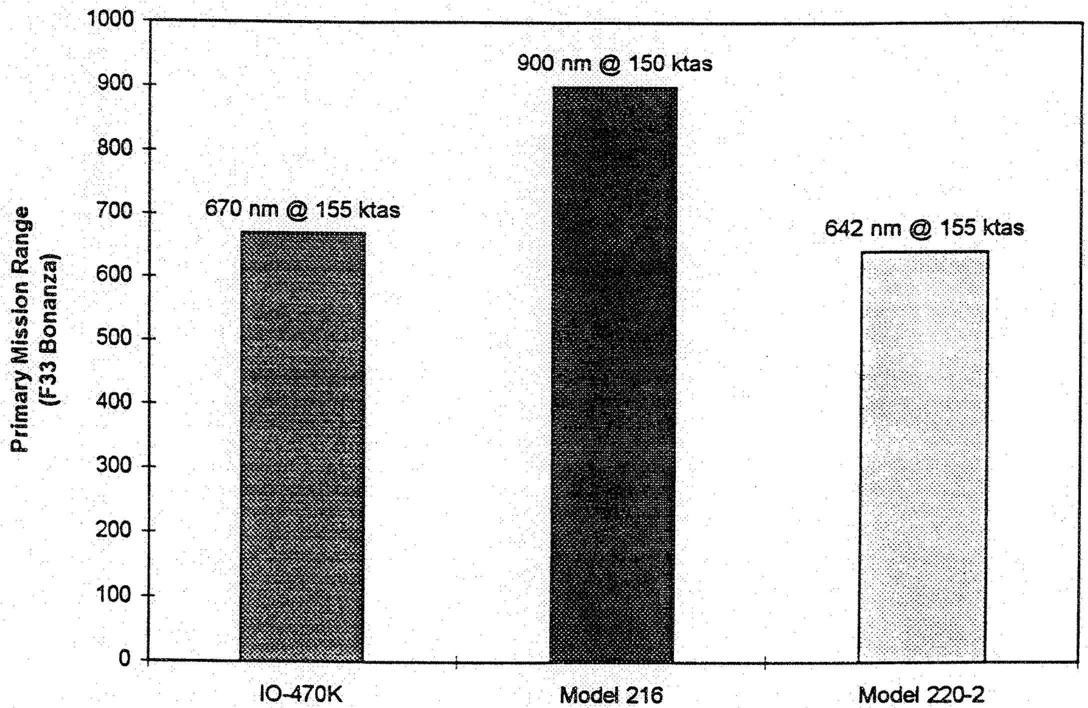


Fig 4 Primary mission range for F33 Bonanza on typical mission.

4.3 C90 King Air with Model 265 and 2150 engines

Tables 4 through 6 show the same mission results for the C90 King Air with the baseline engine, the Model 265 turboprop, and the Model 2150 propfan. In all three cases, the aircraft begins the climb phase at 10100 lb with 1200 lb of payload and 2025 lb of fuel. The mission consists of a climb to 21000 ft at the best rate-of-climb speed, cruise at maximum speed, descent at 1500 ft/min, and an additional 100 nm cruise at 21000 ft and the speed for 99% best specific range. Table 4 shows that the baseline King Air climbs to altitude in 15 minutes, cruises for 753 nm at a maximum speed of approximately 240 ktas. Primary mission range (climb+cruise+descent) of 850 nm is obtained in 217 min. with a total fuel burn of 1859 lb. Table 5 shows that the Model 265 turboprop enables the same aircraft to climb to altitude in 15 minutes, and cruises for 1126 nm at a speed of approximately 240 ktas. The primary mission range is 373 nm greater than the baseline aircraft indicating a significant increase in the fuel efficiency for this engine. This 44% increase in range at the same cruise speed is a remarkable improvement (see Fig. 5). Table 6 shows that the Model 2150 propfan produces a time-to-climb of 13 min. and a cruise segment range of 663 nm at approximately 281 ktas. Total mission range is 763 nm in 169 min. The 11% reduction in time-to-climb, and 17% increase in cruise speed clearly indicate that this engine generates more thrust than the baseline engine.

Although not shown in Table 6, the entire cruise mission is flown at the maximum operating Mach number for the C90 King Air.

Table 4 Typical mission for C90 King Air with baseline turboprop engine.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	10100.00	119.80	153.70	15.11	155.00	35.70	500.00	353.00
Cruise	9945.00	237.40	243.10	187.99	1579.70	753.10	378.00	380.00
Descent	8365.00	281.40	226.00	14.00	124.30	60.90	349.00	330.00
Cruise	8241.00	188.50	187.70	31.90	165.80	100.00	214.00	211.00

Table 5 Typical mission for C90 King Air with the Model 265 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	10100.00	132.80	154.30	14.76	113.80	35.70	650.00	376.00
Cruise	9986.00	236.50	242.50	281.97	1697.00	1126.30	397.00	398.00
Descent	8289.00	281.40	226.00	13.94	93.60	60.70	367.00	339.00
Cruise	8196.00	188.60	187.90	31.87	120.60	100.00	225.00	223.00

Table 6 Typical mission for C90 King Air with the Model 2150 propfan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)
Climb	10100.00	167.80	182.00	13.44	185.10	39.00
Cruise	9915.00	280.80	281.40	141.45	1546.80	663.30
Descent	8368.00	281.40	226.00	14.00	117.70	60.90
Cruise	8250.00	208.20	206.80	28.91	175.00	100.00

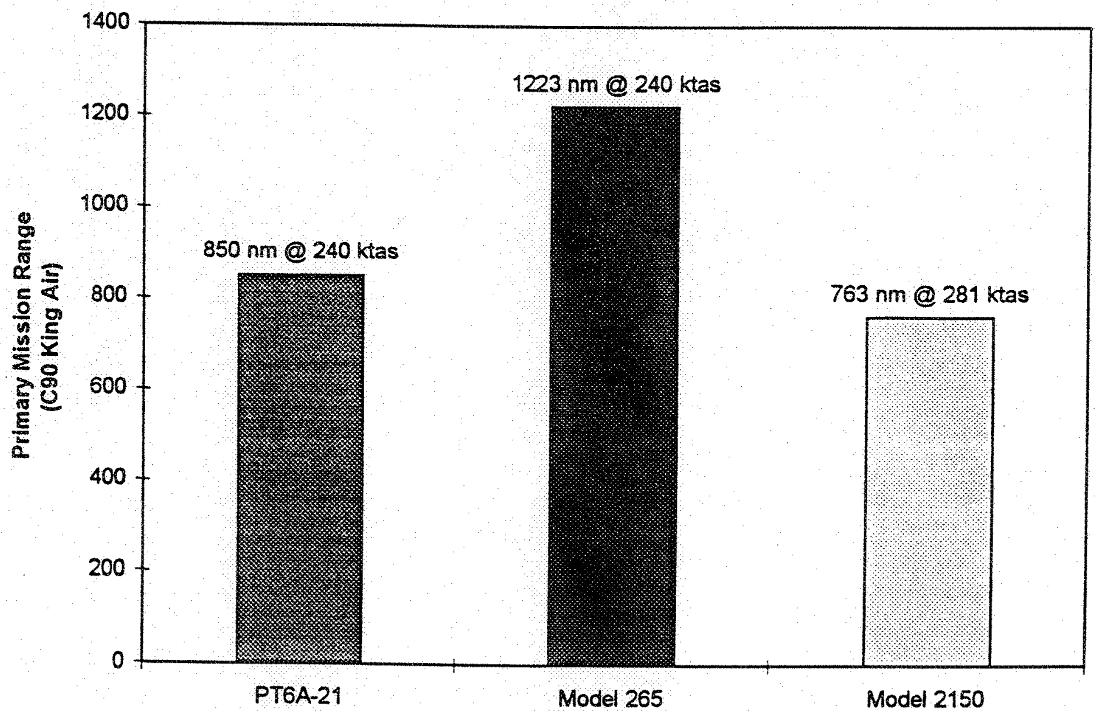


Fig 5 Primary mission range for C90 King Air on typical mission.

4.4 QCGATE with Model 2150 propfan

Tables 7 and 8 show the mission results for the QCGATE with the baseline engine and the Model 2150 propfan. In both cases, the aircraft begins the climb phase at 7800 lb with 1000 lb of payload and 2000 lb of fuel. The mission consists of a climb to 35000 ft at the best rate-of-climb speed, cruise at maximum speed, descent at 1500 ft/min, and an additional 100nm cruise at 35000 ft and the speed for 99% best specific range. The baseline QCGATE climbs to altitude in 20 min., cruises for 1327 nm at a maximum speed of approximately 358 ktas. Primary mission range (climb+cruise+descent) of 1529 nm is obtained in 271 minutes with a total fuel burn of 1886 lb. Table 8 shows that the Model 2150 propfan enables the same aircraft to climb to altitude in 19 minutes, and cruises for 1329 nm at a speed of approximately 375 ktas. The primary mission range is nearly identical (1547 nm) to the baseline, but the cruise speed is 5% higher with this new engine (see Fig. 6).

Table 7 Typical mission, QCGATE with baseline turbofan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	Ti (lb)	Tf (lb)
Climb	7800.00	182.50	247.20	20.24	213.00	73.90	1969.80	731.50
Cruise	7587.00	351.90	363.20	222.42	1543.20	1327.20	648.00	644.40
Descent	6044.00	265.10	226.00	28.77	130.10	127.70	309.50	345.80
Cruise	5914.00	228.70	226.20	26.39	113.70	100.00	363.60	358.00

Table 8 Typical mission, QCGATE the Model 2150 propfan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	Ti (lb)	Tf (lb)
Climb	7800.00	210.90	254.80	18.57	193.60	73.20	2324.40	711.80
Cruise	7606.00	370.10	380.40	212.27	1573.90	1328.80	701.40	699.80
Descent	6032.00	265.10	226.00	32.71	131.60	145.10	373.40	346.50
Cruise	5901.00	266.60	266.20	22.52	100.80	100.00	430.70	428.60

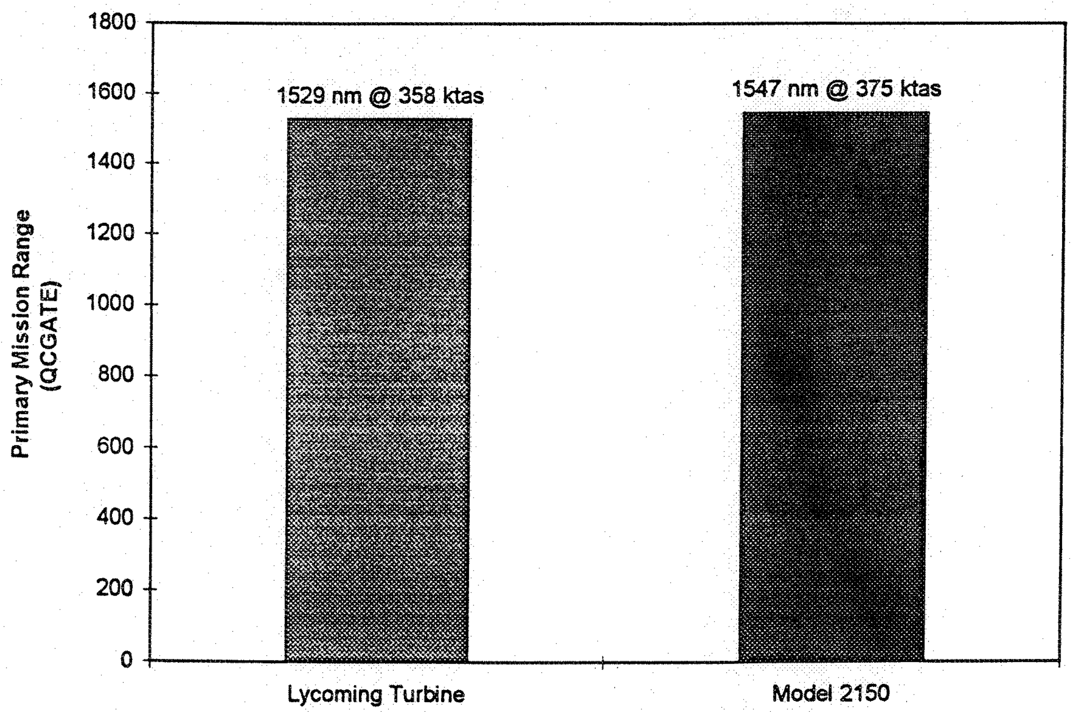


Fig 6 Primary mission range for QCGATE on typical mission.

5.0 Engine Evaluation for Long Range Mission

The alternate mission used to evaluate the new technology engines is a long range, rather than maximum speed, mission. This long range mission will increase the increments in range caused by a reduction in fuel consumption, but has the potential of producing mission times that are impractical for small airplanes without a lavatory. If the lower speed associated with maximum range is acceptable, the best way to take advantage of a reduction in fuel consumption is to size a new airplane with a reduced fuel capacity and the same range as the baseline mission. Significant improvements in range associated with the new engines can be viewed as the potential for a decrease in size and cost of a next generation personal transportation aircraft.

Analysis of all the baseline aircraft with all of the engines showed that the specific range (nm/lb-fuel) increases with altitude. Consequently, with the exception of the F33 Bonanza, the altitude chosen for all of the long range missions was just below the baseline aircraft's service ceiling. For the Bonanza, the typical missions are short enough to question the utility of very high cruise altitudes and the lack of cabin pressurization makes it impractical to cruise above 12500 ft.

5.1 F33 Bonanza with Model 216 and 220-2 turboprops

Tables 9 through 11 show the results for a climb to 12000 ft, cruise at the speed for 99% best specific range, descent at 500 ft/min, and an additional 100 nm cruise at 8000 ft and the speed for 99% best specific range in a F33 Bonanza. With the baseline engine the Bonanza climbs to altitude in 24 min., cruises for 692 nm at a speed of approximately 128 ktas. Table 9 shows that the primary mission range (climb+cruise+descent) of 792 nm is obtained in 372 min. with a total fuel burn of 345 lb. Table 10 shows that the Model 216 turboprop enables the same aircraft to climb to altitude in 31 minutes, and cruises for 939 nm at a speed of approximately 128 ktas. The primary mission range is 258 nm greater than the baseline aircraft indicating a significant increase in the fuel efficiency for this engine (see Fig. 7). Table 11 shows that the Model 220-2 turboprop produces a time-to-climb of 24 min. and a cruise segment range of 630 nm at approximately 133 ktas. Total mission range is 729 nm in 332 min. with this engine. These results show the same relative performance increments presented for the typical mission in Tables 1 through 3. The range has increased and cruise speed decreased for all new engines, leaving percentage changes from the baseline aircraft approximately the same as for the typical mission.

Table 9 Long range mission for F33 Bonanza with baseline engine.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	86.10	97.40	23.49	39.00	36.60	184.00	144.00
Cruise	3011.00	130.80	124.10	325.73	279.80	692.00	114.00	98.00
Descent	2731.00	179.50	150.00	23.23	25.80	63.30	141.00	127.00
Cruise	2705.00	116.30	115.60	51.75	39.40	100.00	92.00	91.00

Table 10 Long range mission for F33 Bonanza with the Model 216 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	83.30	97.40	30.95	29.90	47.20	160.00	132.00
Cruise	3020.00	130.10	125.10	443.37	300.00	938.50	110.00	97.00
Descent	2720.00	179.50	150.00	23.52	21.40	64.20	139.00	125.00
Cruise	2699.00	120.20	119.70	50.00	32.70	100.00	95.00	94.00

Table 11 Long range mission for F33 Bonanza with the Model 220-2 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	3050.00	86.00	98.30	23.50	32.30	36.30	197.00	150.00
Cruise	3018.00	134.90	131.50	285.75	276.90	630.20	120.00	108.00
Descent	2741.00	179.50	150.00	23.10	28.70	62.90	147.00	127.00
Cruise	2712.00	130.10	130.10	46.11	46.20	100.00	111.00	111.00

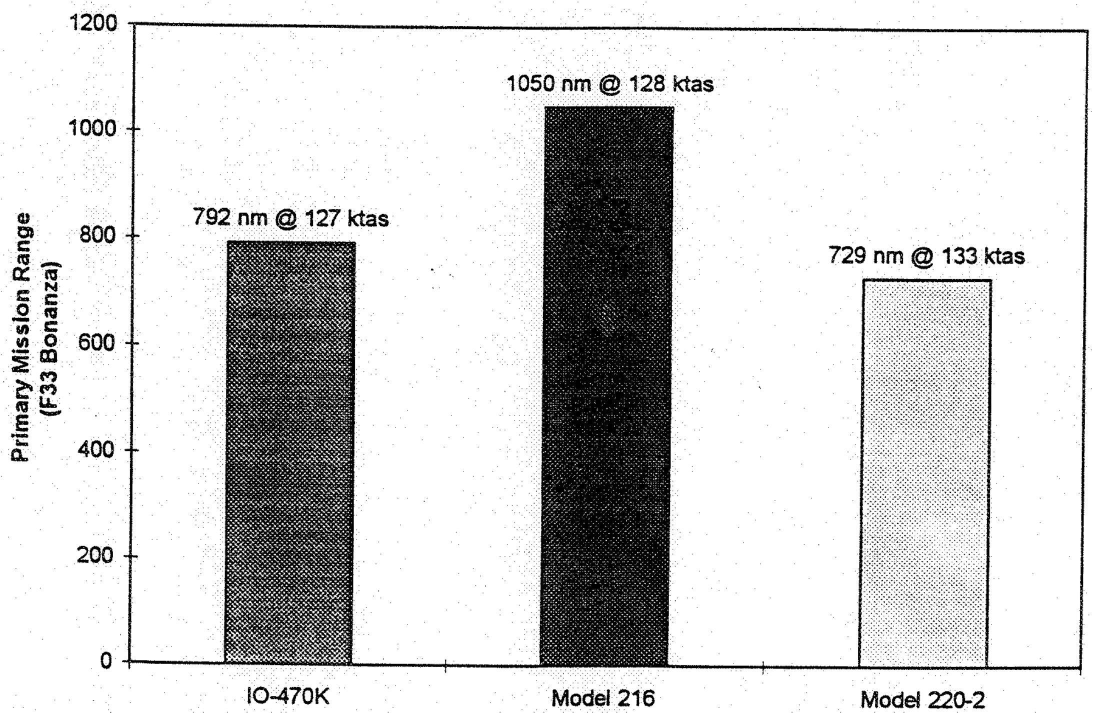


Fig 7 Primary mission range for F33 Bonanza on long range mission.

5.2 C90 King Air with Model 265 and 2150 engines

Tables 12 through 14 show the results for a climb to 30000 ft, cruise at the speed for 99% best specific range, descent at 1500 ft/min, and an additional 100 nm cruise at 21000 ft and the speed for 99% best specific range in a C90 King Air. Table 12 shows that with the baseline engine, the King Air climbs to altitude in 41 min., and cruises for 870 nm at a speed of approximately 198 ktas. Primary mission range (climb+cruise+descent) of 1063 nm is obtained in 320 min. with a total fuel burn of 1859 lb. Table 13 shows that the Model 265 turboprop enables the same aircraft to climb to altitude in 35 min., and cruises for 1404 nm at a speed of approximately 204 ktas. The primary mission range is 521 nm greater than the baseline aircraft indicating a significant increase in the fuel efficiency for this engine. This represents a 49% increase in range, 5% more than was presented for the typical mission (see Fig. 8). Table 14 shows that the Model 2150 propfan produces a time-to-climb of 29 min. and a cruise segment range of 874 nm at approximately 224 ktas. Total mission range is 1050 nm in 285 min. with this engine. The increase in cruise speed for approximately the same range as the baseline aircraft is a benefit of this engine. Since this cruise speed of 224 ktas is approaching the maximum cruise speed of the baseline aircraft, this engine should produce the same or better range as the baseline aircraft when operated at 240 ktas (see Tables 4 and 6).

Table 12 Long range mission, C90 King Air with the baseline turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	10100.00	119.80	164.60	40.89	314.80	104.40	500.00	231.00
Cruise	9785.00	194.90	200.70	259.41	1385.00	869.60	238.00	217.00
Descent	8400.00	271.00	226.00	20.00	159.20	88.50	192.00	330.00
Cruise	8241.00	188.50	187.70	31.90	165.80	100.00	214.00	211.00

Table 13 Long range mission, C90 King Air with the Model 265 turboprop.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	HPi	HPf
Climb	10100.00	132.80	168.70	35.07	211.30	90.80	650.00	273.00
Cruise	9889.00	212.20	196.30	412.22	1573.50	1404.40	284.00	221.00
Descent	8315.00	271.00	226.00	19.94	119.50	88.20	197.00	339.00
Cruise	8196.00	188.60	187.90	31.87	120.60	100.00	225.00	223.00

Table 14 Long range mission, C90 King Air with the Model 2150 propfan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)
Climb	10100.00	167.80	192.90	28.65	315.40	86.70
Cruise	9785.00	230.90	216.40	236.79	1385.40	874.30
Descent	8399.00	281.40	226.00	20.00	148.90	88.50
Cruise	8250.00	208.20	206.80	28.91	175.00	100.00

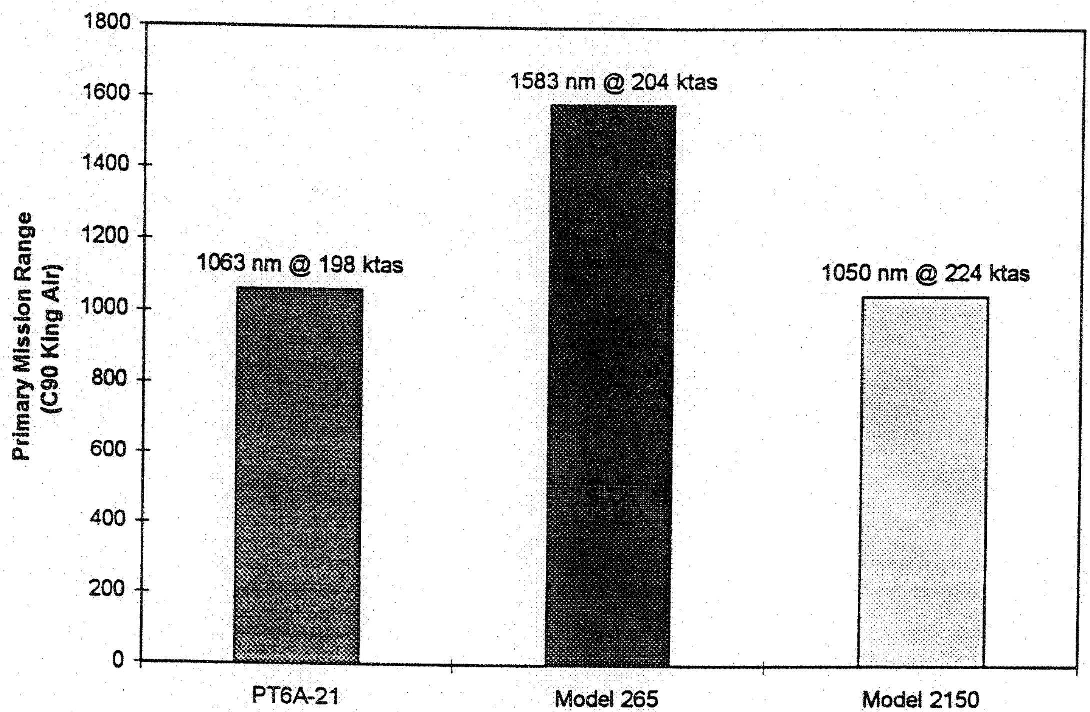


Fig 8 Primary mission range for C90 King Air on long range mission.

5.3 QCGATE with Model 2150 propfan

Tables 15 and 16 show the results for a climb to 40000 ft, cruise at the speed for 99% best specific range, descent at 1500 ft/min, and an additional 100 nm cruise at 35000 ft and the speed for 99% best specific range in a QCGATE aircraft. Table 15 shows that with the baseline engine, the QCGATE climbs to altitude in 20 min., cruises for 1504 nm at a speed of approximately 283 ktas. Primary mission range (climb+cruise+descent) of 1705 nm is obtained in 368 min. with a total fuel burn of 1886 lb. Table 16 shows that the Model 2150 propfan enables the same aircraft to climb to altitude in 19 min., and cruises for 1951 nm at a speed of approximately 289 ktas. Figure 9 presents a comparison of primary mission range with the two engines. This 14% increase in range with the Model 2150 propfan is in contrast to the 1-2% increase shown in Fig. 6 for the high speed cruise mission. This suggests that the Model 2150 compares best with current technology engines at cruise speeds of approximately 300 ktas. This speed is greater than most current turboprops (see Figs. 5 and 8) and less than current business jets.

Table 15 Long range mission, QCGATE with baseline turbofan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	Ti (lb)	Tf (lb)
Climb	7800.00	182.50	247.20	20.24	213.00	73.90	1969.80	731.50
Cruise	7587.00	301.90	263.00	318.49	1543.20	1503.70	536.50	418.00
Descent	6044.00	265.10	226.00	28.77	130.10	127.70	309.50	345.80
Cruise	5914.00	228.70	226.20	26.39	113.70	100.00	363.60	358.00

Table 16 Long range mission, QCGATE with the Model 2150 propfan.

	Wi (lb)	Vi (ktas)	Vf (ktas)	t (min)	Fuel (lb)	Dist (nm)	Ti (lb)	Tf (lb)
Climb	7800.00	210.90	254.80	18.57	193.60	73.20	2324.40	711.80
Cruise	7606.00	299.40	279.40	356.19	1573.90	1732.30	533.00	441.30
Descent	6032.00	265.10	226.00	32.71	131.60	145.10	373.40	346.50
Cruise	5901.00	266.60	266.20	22.52	100.80	100.00	430.70	428.60

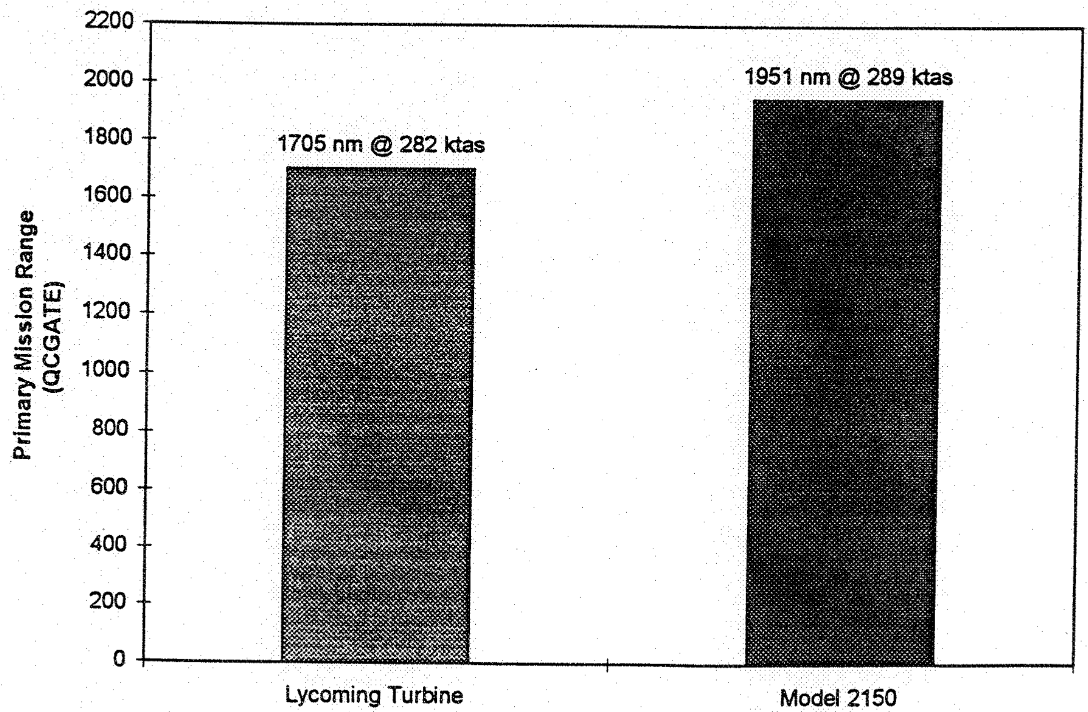


Fig 9 Primary mission range for QCGATE on long range mission.

5.4 Cost, safety, reliability, and maintenance

Tables 17 and 18 provide an initial comparison of acquisition cost for the baseline and new technology engines. The prices listed in Table 17, obtained from Ref. 4 or the engine manufacturer, are representative of what an individual would have to pay for a new engine or an engine overhaul. Volume purchases of new engines by airframe manufacturers lead to significant discounts below the retail price listed in Table 17. Further complicating the acquisition cost comparison are the number of units over which the development cost of a new engine must be distributed, see Table 18. The baseline engines shown in Table 17, particularly the piston engine, have paid for their development and certification costs many years ago. The number of new engines that are required to pay for these costs, see Table 18, are in excess of current production rates for general aviation aircraft. In 1995, Raytheon aircraft delivered approximately 140 piston aircraft and 35 C90 King Airs.

A simple 1-10 rating that includes consideration of the retail prices listed in Tables 17 and 18, potential discounts available to airframe manufactures, and the large number of new engines required to produce the price estimates shown in Table 18 is given to each of the baseline and new technology engines. A rating of 10 is considered the best and a rating of 1 indicates an uncompetitive engine price. Table 19 shows that neither the Model 216 or the Model 220-2 turboprop engines are cost competitive with the baseline internal combustion engine. The reduction in cruise speed and takeoff field length associated with these engines leads to an overall value that is considerably less than the current baseline engine and makes it difficult to recommend a retrofit of the F33 Bonanza with one of these engines. The Model 265 has the potential to be less expensive than baseline turboprop engine. A purchase price of $53,900 for this engine leads to a rating of 10 in Table 20. However, this price and rating are based on a production run of 2000 rather than a more typical run of 200 engines. Table 20 shows that the Model 2150 has the same rating as the baseline turboprop. However, this appears to be competitive with small turbofan engines (see JT-15D in Table 17). Any increase in cost for this engine, associated with development of the propfan technology or a decrease in the production run would make it difficult for this engine to compete.

Table 17 Cost, overall and inspection data for baseline engines.

	IO-470-L	PT6A-21	JT-15D-5
New	$36,000	$175,500	$504,000
New-Exchg	$30,000	$112,000	$214,000
Re-Mng	$20,916	N/A	N/A
Avg o'Haul	$14,500	$90-110K	$165-190K
TBO	1500 hr	3500 hr	3000 hr
HSI		$12-20K	$25-35K

Table 18 Cost estimates for new technology engines.

	Model 216	Model 220-2	Model 265	Model 2150
2000 units	$30,900	$53,900	$53,900	$121,000
5000 units	$27,000	$51,500	$51,500	$98,000
10000 units	$24,700	$44,300	$44,300	$84,400

Table 19 Cost, safety, maintenance, reliability ratings for 200 hp class engines.

	Cost	Safety	Maintenance	Reliability
IO-520-BB	7	7	6	7
Model 216	5	7	6	7
Model 220-2	1	7	2.5	7

Table 20 Cost, safety, maintenance, reliability ratings for 600 hp class engines.

	Cost	Safety	Maintenance	Reliability
PT6A-21	5	7	5	7
Model 265	10	7	10	7
Model 2150	5	7	5	7

Safety, reliability, and maintenance depend on how the aircraft is operated and how it is maintained. A general industry perception is that turbine engines require less routine maintenance, have longer times between overhaul, and are much more expensive to overhaul. However, most turbines are operated by airlines or corporate flight departments that operate the engines daily and keep them on a routine maintenance plan. A personal transportation aircraft, such as an F33 Bonanza, may only be operated for 1-200 hours per year and receive no more than an annual inspection. Without in-service maintenance data, it is difficult to say how one of these new turbine engines would compare with the internal combustion engine in this environment.

Tables 19 and 20 show a 1-10 rating, with 10 being best, for the anticipated safety, reliability, and maintenance of the baseline and new technology engines. Given the lack of in-service data, these ratings are developed based on the cost per hour of operation required to pay for an engine overhaul. The retail price was considered equal to the cost of an engine overhaul for the new technology engines, since the cost of an overhaul was not available for these engines. Table 19 shows that all the 200 hp class engines received approximately the same rating, except the Model 220-2, which is significantly more expensive to maintain. Table 20 shows that the Model 265 is significantly less expensive to maintain. The Model 2150 is judged to be equivalent to the baseline turboprop or turbofan with respect to safety, reliability, and maintenance.

6.0 Conclusions

Several new technology turbine engines were evaluated for application in light general aviation aircraft and shown to be very competitive with current day engines with respect to fuel consumption, but more expensive to purchase and operate. The Model 216 has a particularly low fuel consumption that produces an increase in range of 230 nm for an F33 Bonanza on a typical mission. The Model 220-2 turboprop is similar in performance to the baseline Bonanza engine with a significant reduction in propulsion system weight. This weight savings could lead to a significant reduction in the cost of a new airplane designed for this engine. Poor takeoff field length performance with Models 216 and 220-2 indicate that future development should focus on an increase in power for application in a 4 passenger personal transportation aircraft. The Model 265 enabled the C90 King Air to takeoff from a 26% shorter runway and cruise for an additional 373 nm without a decrease in speed. This significant improvement at the same or lower acquisition cost suggests that further studies be conducted to evaluate the performance of a new airplane designed for this engine. The Model 2150 propfan produces the appropriate thrust and fuel consumption for an aircraft that cruises slightly faster than current turboprops. Future development of this engine should focus on the influence of the propfan on interior cabin noise and the evaluation of it's performance in a new, faster, turboprop-class aircraft. Overall the cost and performance of these new turbines provide a promising alternative for future personal transportation aircraft.

7.0 References

1. Reymer, D. P., "Aircraft Design: A Conceptual Approach," AIAA Education Series, American Institute of Aeronautics and Astronautics, Inc., Washington, D.C., 1989, pg. 88.

2. Perkins, C. D., and Hage R. E., "Airplane Performance Stability and Control," John Wiley & Sons, Inc, New York, 1949, pg. 161.

3. Business & Commercial Aviation, "Business Airplanes," pg. 49-77, May 1995

4. Aircraft Bluebook-Price Digest, Intertec Publishing, VOL. 96-1, Spring 1996.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
August 2003

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
Advanced Propulsion System Studies for General Aviation Aircraft

5. FUNDING NUMBERS
WU–22–538–07–10–00
NAS3–27635

6. AUTHOR(S)
Kathryn A. Elliott and Steven R. Huebner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Teledyne Ryan Aeronautical
TCAE Turbine Engine Unit
1330 Laskey Road
Toledo, Ohio 43612–0917

8. PERFORMING ORGANIZATION REPORT NUMBER
E–14007

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR—2003-212469
TRA Report No. 3043

11. SUPPLEMENTARY NOTES
This research was originally published internally as AST008 in December 1996. Project Manager, Joseph D. Eisenberg (retired). Responsible person, Susan M. Johnson, organization code 2200, 216–433–2163.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category: 07 Distribution: Nonstandard
Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

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

In this study, new technology engines were defined in two power classes: a 200 hp class, for a light, 4-place personal aircraft, and a 1500 pound thrust class for a twin-engined business jet type aircraft. These engines were evaluated for retrofitting suitable current production aircraft for comparison to the existing engines. The engines were evaluated for performance in a mission typical for each aircraft, as well as a variant mission to further appraise the impact of engine performance. Issues of cost, safety, maintenance, and reliability were also addressed for the engine comparisons resulting in the recommendation for the system best suited to general aviation in each power class. Manufacturing plans and dual-use technology development plans were then constructed for these engines.

14. SUBJECT TERMS
Propulsion; Turbine engines; General aviation; Propfan; Turboprop

15. NUMBER OF PAGES
124

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	