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# DESIGNING TURBOSHAFT ENGINES FOR THE COMMERCIAL OPERATOR

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# DESIGNING TURBOSHAFT ENGINES FOR THE COMMERCIAL OPERATOR

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Military and commercial engine designers share a common goal of producing highly reliable engines. However, the military trend is toward sophisticated, complex helicopter engines with emphasis on mission capabilities and high performance while commercial engine owners and operators emphasize reliability and maintainability resulting in slightly heavier, less fuel efficient but simple, durable, low cost engines.

The Model 250-C24 engine, an example of an Allison engine being designed for the commercial light-twin market, will replace the durable Model 250-C20B 420 shp engine, the present principal power-plant for the rapidly expanding single and light twin-engine helicopter market.

While the Model 250-C24 features decreased fuel consumption, OEI ratings and substantial increases in hot-day performance, the design of the engine provides for increased durability and reliability, reduced complexity and part count, less maintenance and decreased operating costs. These features plus the 25 million hours of operating experience of the C20 engines provide the basis for the next generation of rugged Model 250 engines designed specifically for commercial operators.

## I. Background

Since its introduction in 1962, Allison's Model 250 engine series has had a dominant position in the light turboshaft helicopter market. From the original military T63 engines produced for the U.S. Army Light Observation Helicopters (LOH), Allison has developed the commercial C18, C20, C28 and C30 derivatives, representing incremental increases in horsepower, and produced to date over 19,000 engines for 27 turboshaft and 26 turboprop installations (Figure 1).

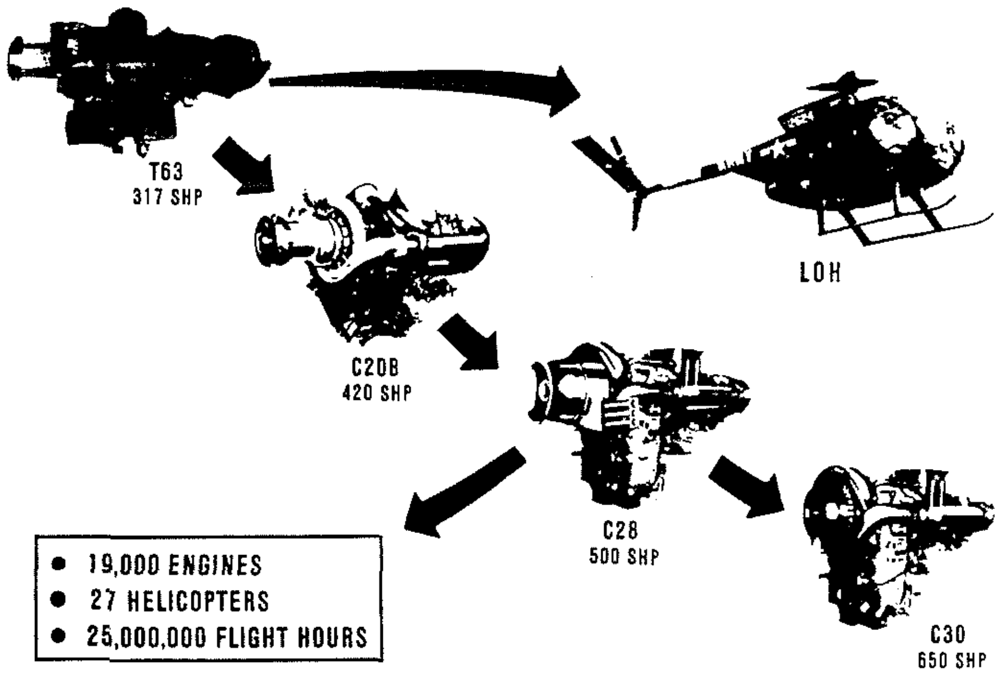


Figure 1. Model 250 Engine Series.

Historically, rotorcraft have been refined into reliable, effective machines by the military; the gas turbine turboshaft engine, with its high-horsepower-to-weight ratio and longer time-between-overhauls (TBO), has been the impetus behind the broader use of helicopters. Although the military market for small helicopters has diminished by an annual rate of 14% over the last ten years, the commercial market has been expanding at a 12% rate, more than tripling the annual production rate of commercial helicopters from 1970 to 1980. A strong demand for helicopters is indicated for the next decade with the fastest growing segment of the market expected to be light twin-turbine models. The light twin helicopter production has grown from 4% of the market in 1970 to 29% in 1980 and is expected to attain 43% by 1990. The single engine helicopter, 74% of the market in 1970, dropped to 51% in 1980 and is projected to be only 45% by 1990, but at an annual unit production increase. The light twin-engine market is being driven by several factors: aircraft payload advantages are enhanced by the increased power available, and the second engine provides more security to the commercial aircraft, personnel and mission. Also, an increasing number of world governments have already instituted or have pending legislation restricting the operation of single-engine helicopters over heavily populated regions.

## II. Market drivers and engine parameters

The realization of widened commercial applications of helicopters has broadened the exposure of both the engine and the airframe to a variety of missions, duty cycles, pilots, and maintenance scenarios. Typically, Allison's experience has shown that commercial deployment can be a more hostile ride for an engine than its military predecessor. Therefore, it is critical to recognize the needs of the eventual commercial owner/operator in the design phase of a new engine.

In general, the emphasis on engine design parameters that most original equipment manufacturers (OEM) or military agencies place on the design of a new engine contrasts sharply with priorities established by the commercial operator (Figure 2).

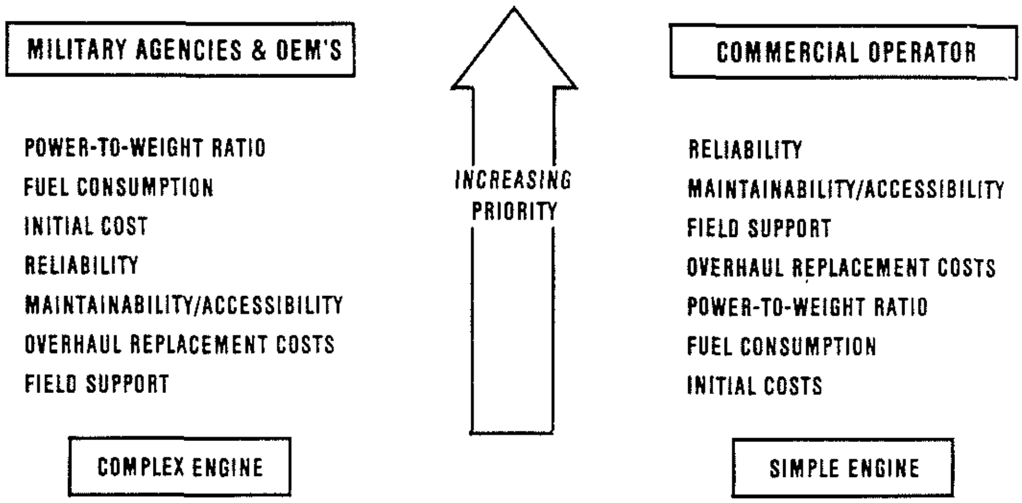


Figure 2. Advanced Helicopter Engines--Market Drivers-Engine Parameters.

Historically, military and helicopter-supplier program offices alike readily adopt stringent power-to-weight and fuel consumption goals for the engine designer for a specific military mission or for competitive advantage. These goals have been so severe, particularly for the more difficult, smaller engine, that various, untried technologies were prematurely introduced into production. The result can be an extremely lightweight, complex, expensive engine with unproven reliability that is costly and difficult to maintain and support in the field. The required training, special tools and procedures necessary at the depot level also increase cost factors. Additional development is required to place such an engine into production status, a more difficult and complex task, which demands a larger investment and which must be amortized into the engine selling price.

The commercial owner/operator, in business for profit, has different priorities. Engine reliability is primary--fewer aircraft and engines required to support customers, less aircraft downtime, fewer mission aborts, and decreased operating costs--resulting from fewer repairs, smaller maintenance support staffs, and less spare parts inventory. Secondly, for overhaul, the engine must be modular, its components accessible, and the engine manufacturer's representatives available--each of which serves to reduce expenditures in support of the engine and to decrease operating costs. While both engine weight and fuel consumption are important, the operator prefers the simple, reliable engine.

## III. Model 250-C24 engine

Allison Gas Turbine Operations has recently committed to the design and development of a new small turboshaft engine, the Model 250-C24, scheduled for 1986, to replace the successful, durable Model 250-C20B 420 shp engine, the principal powerplant for the rapidly expanding single- and light-twin market. Designed with the commercial operator's priorities in mind, this engine represents the conscious blend of Allison's extensive commercial engine experience with modest increases in technology.

To effectively address the design of small gas turbine engines such as the Model C20B and C24 engines, considerable experience in dealing with the more difficult class of problems associated with engines of this size is necessary. Figure 3 shows a variety of problems that restrict design flexibility and pose potential barriers to improvements in structural integrity and performance in smaller engines. These problems range from the consideration of manufacturing limits, such as material strengths in thin sections or the blockage associated with airfoil leading and trailing edge radii, to Reynolds and Stanton number effects on performance and heat transfer considerations, or to the increased performance sensitivity to tip clearance effects. Small engine operating experience, with the evolution of new technologies specifically addressing small engines, provides a timely basis for the new engine design.

For several years Allison has benefited from both independent and U.S. Government-funded research on small engine technologies such as seal design and material coatings, aerodynamic components, small air-cooled components, high-strength coatings, high work, high-load-coefficient turbines, and rotor dynamics (Figure 4). However, successful commercial engine de-

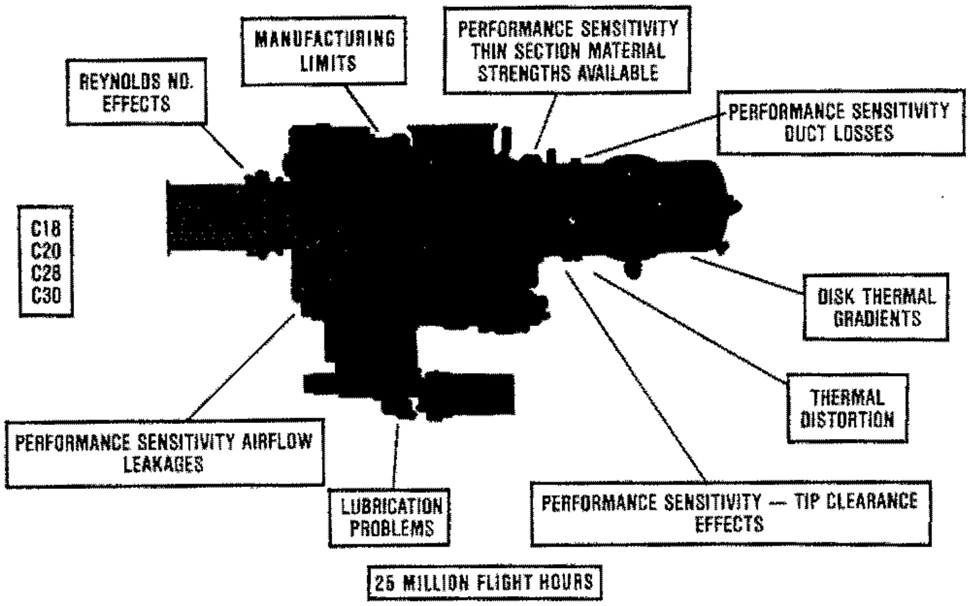


Figure 3. Small Engine Experience.

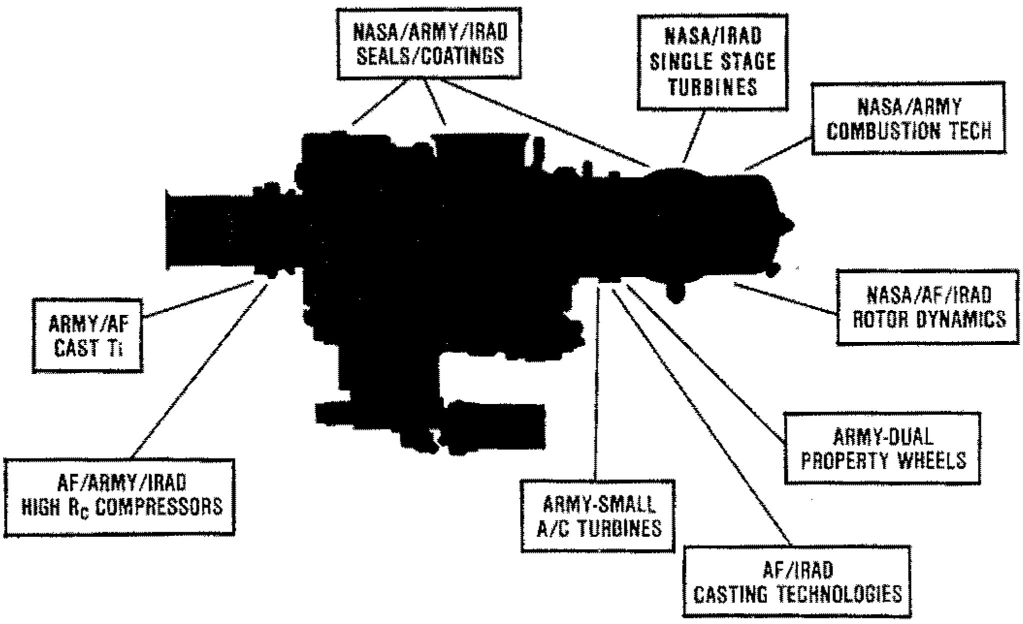


Figure 4. Small Engine Technology.

sign must temper new technologies with past field service experience and adopt only those concepts that represent extremely low risk and may be easily supported at the depot maintenance level. For example, component technologies exist today to provide military engines at power-to-weight ratios in excess of 3.5 shp/lb with specific fuel consumption decreases over today's production engines of 18-20%, but the next generation of reliable, cost-effective commercial engines is more properly positioned at power-to-weight ratios of 2.5 shp/lb and fuel consumption decreases of 10-13%.

The Model 250-C24 engine, emphasizing increased performance and improved reliability with simpler design and construction, features several improvements over the C20B engine. Since the engine is targeted for both present and future light-twin market, the thermodynamic cycle is sufficiently flexible to accommodate both Category A and Category B rating philosophies. The engine will be flat-rated out to hot-day conditions [32°C (90°F)], providing increased power at those flight conditions where helicopters most often operate without incurring unnecessary weight penalties in the gearbox. In addition, increased component efficiencies will permit operation at decreased rotational speeds and temperatures, allowing significant improvements in durability.

The Model 250-C24, while designed for the same engine airflow as the Model 250-C20B, offers characteristic increases in guaranteed uninstalled power (Figure 5) for either rating philosophy. In addition to the availability of OEI ratings, the engine provides additional 10% hot-day, take-off power for the potential Category A rating and 18% for the potential Category B rating. Moreover, the thermodynamic power available increases flexibility for alternate derivative models and ratings. This additional power translates to operator/owner productivity and increases in profits.

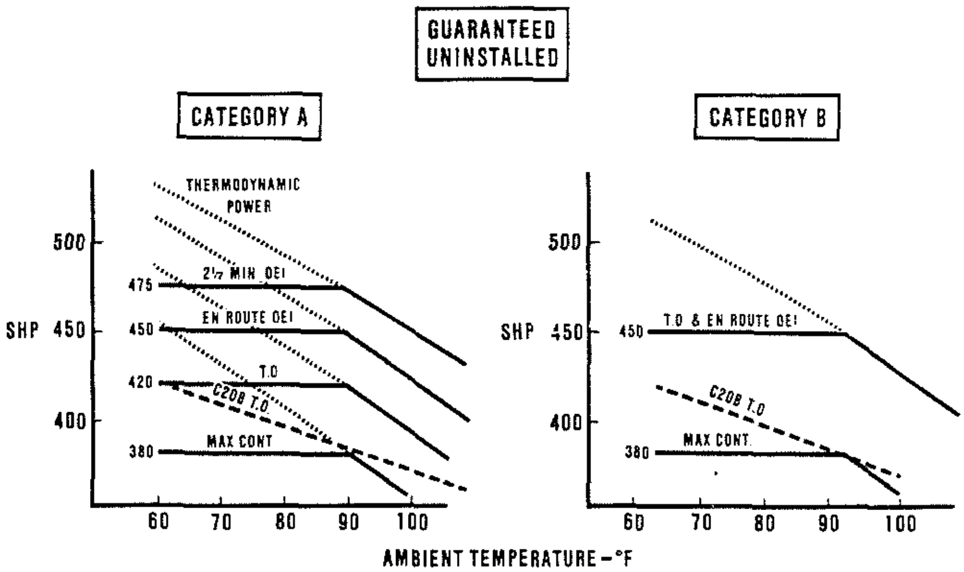


Figure 5. Model 250-C24 Potential Ratings.

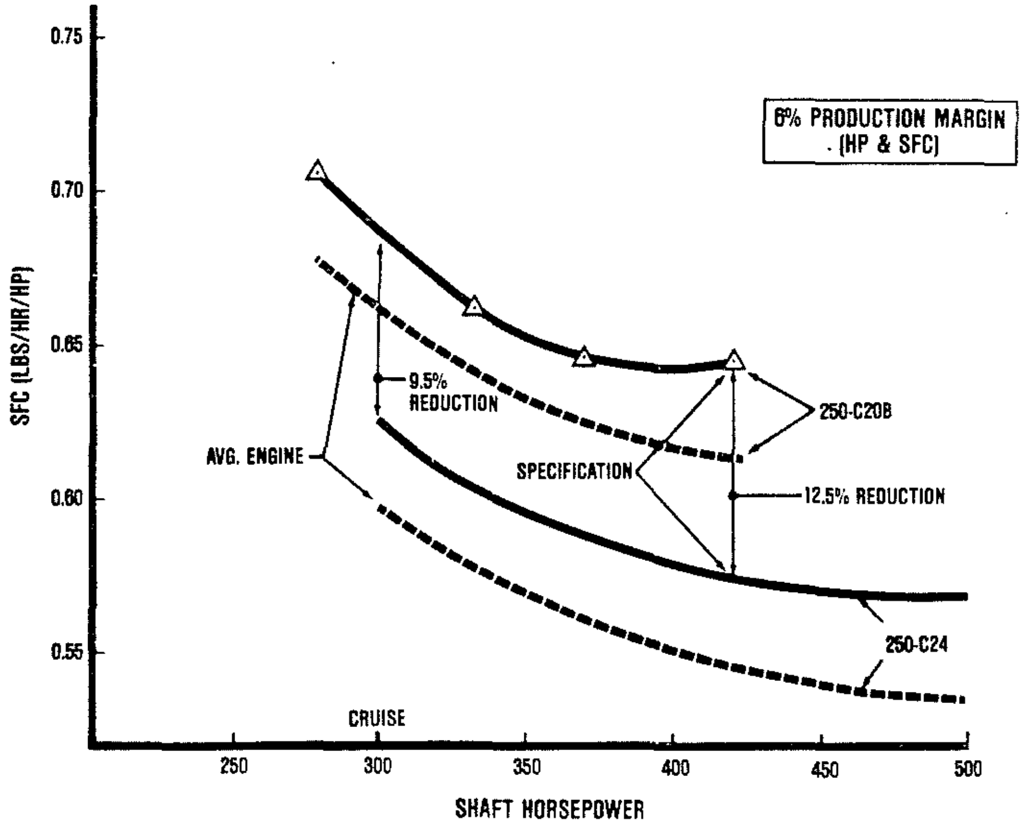


Figure 6. Model 250-C24; Sea Level, Standard Day.

The Model 250-C24 engine also offers a decrease in specific fuel consumption (sfc). Figure 6 compares the sfc (lb/hr/hp) versus power spectra of the two engines. At a comparable take-off rating of 420 shp, the C24 design goal provides a decrease in sfc of 12.5% reduction over the C20B at guaranteed specification values, with expected average engines lowering approximately another 4%. At the more critical cruise rating of around 3000 shp, the sfc reduction expected is approximately 9.5%. These improvements represent significant reductions in direct operating cost (DOC) to the commercial owner/operator but preserve the simple engine configuration that previously provided the lowest operating cost per hour in the industry.

The C24 engine will significantly increase the payload-range performance of a candidate light twin helicopter over a C20B, particularly under hot-day conditions. For example, a C24 powered light twin helicopter, cruising at 125 ktas on a hot day can realize either an increase of 1000 pounds gross weight capacity or 300 nautical miles range increase over a C20B powered twin (Figure 7). Similarly, in terms of comparative fuel costs (Figure 8), the hot-day power and sfc comparison between the C24 and C20B indicates that lower fuel costs available with the C24 represents a significant reduction in total oper-

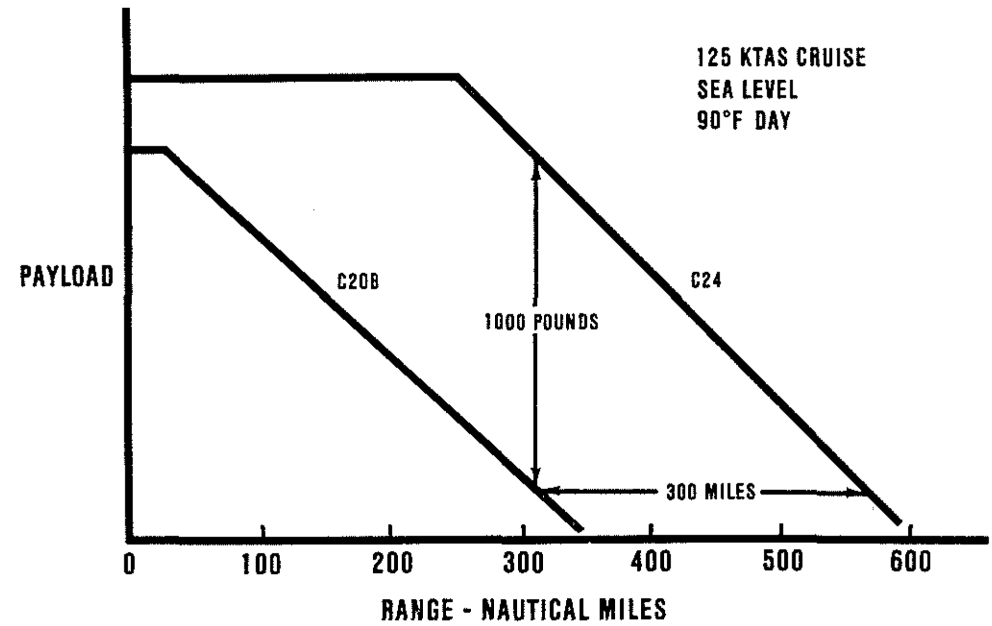


Figure 7. Light Helicopter Performance.

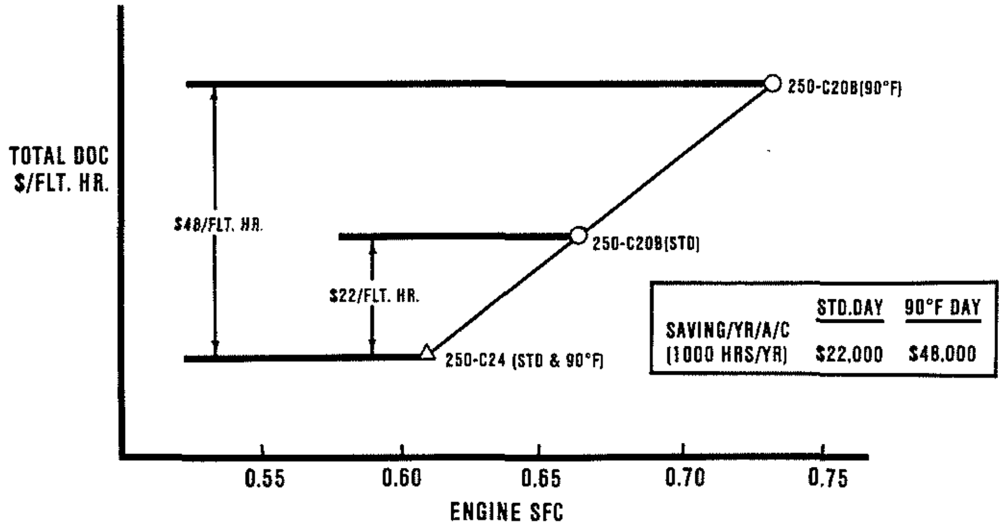


Figure 8. Light Twin Helicopter--Comparative Fuel Costs.

ating costs approaching an 8% reduction of the total direct operating cost of the aircraft. Dependent upon usage rates, this increase in productivity and mission capability and reduction in direct operating costs could permit the recovery of the cost of the engine in less than two years.

The design goals of the Model 250-C24 engine, in addition to providing increased power with decreased fuel consumption, focus on aspects of engine design that economically impact the commercial operator as follows:

- o sfc--12.5% lower than 250-C20B
- o reliability--greater than 250-C20B
  - MTBR 6400 hrs ⟶ 10,000 hrs
  - MTBIFSD 57,000 hrs ⟶ 100,000 hrs
- o gasifier turbine component lives--at least twice 250-C20B
- o scheduled maintenance cost
  - 70% of 250-C20B
- o specific weight--same as 250-C20B
- o production performance margin--same as 250-C20B

Of highest priority is the reliability of the engine at all phases of its service life from introduction to maturity. The C20B engine has established a design maturity and developed a stable maintenance philosophy that has made it the workhorse of the light-helicopter industry. The engine has reached a fleet average inherent mean-time-between-removals (MTBR) in excess of 6400 flight hours and a mean-time-between-in-flight-shut-downs (MTBIFSD) in excess of 57,000 hours with a minimum of life-limited components. The Model 250-C24 design problem list is derived from the C20B service-revealed deficiencies currently being tracked and monitored on engines around the world. Particular attention is being given to the elimination of potential corrosion and erosion damage in the gas path; incorporation of more durable bearings and gears that potentially generate metal and activate magnetic chip detectors; and new, improved coatings and seal designs. The projected potential reliability at maturity of the Model 250-C24 engine is a MTBF in excess of 10,000 hours and a MTBIFSD in excess of 100,000 hours.

The C24 immediately adopts the C20B improvements previously released to production. These reliability improvements, along with a design commitment to double the gasifier component lives, makes the goal of 30% reduction in maintenance costs readily achievable--a direct reduction in cost of engine ownership.

To further ensure that the subsequent cost to support the engine in the field remains predictable and controllable, especially in terms of the cost of spare parts as well as to control the engine initial acquisition costs, the design process has been expanded beyond normal parochial limits to formally address current and future manufacturing, processing, quality and procurement considerations.

The Model 250-C24 engine retains the Allison characteristic mid-engine drive configuration--the single can combustor, the simpler fuel system, and the flexibility of both front and rear power splitting from the gearbox (Figure 9). The engine mount locations are identical to the Model 250-C20B and the en-

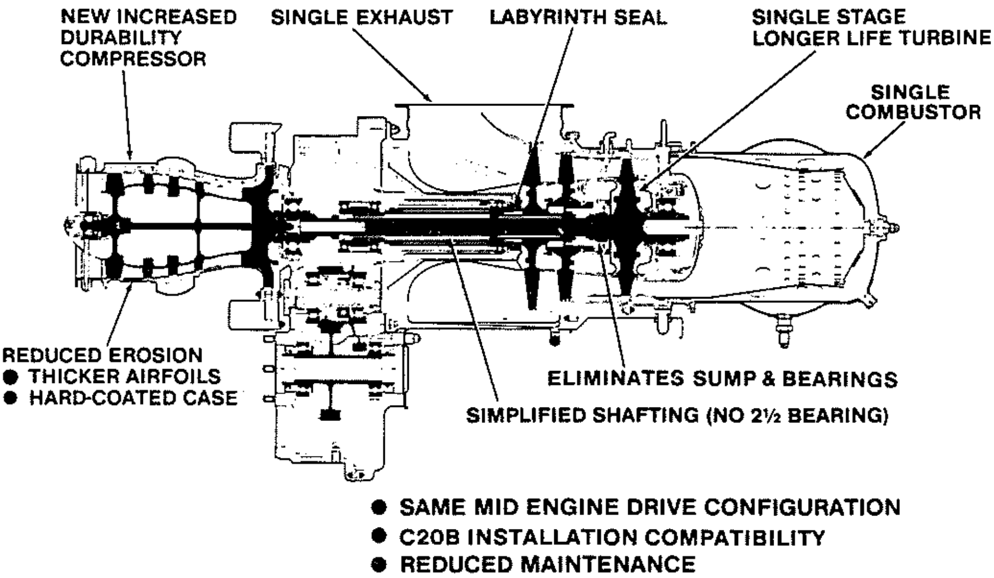


Figure 9. Model 250-C24 Cross Section.

gine, with the exception of a two-inch increase in turbine assembly length, achieves installation commonality.

The C24 axial-centrifugal compressor is identical in length to the C20B while featuring an increase in pressure ratio and in thermodynamic efficiency. The axial compressor has two fewer stages with thicker, more erosion resistant airfoils and a corrosion resistant case. Initially scheduled for certification with a protected inlet, the airfoils have been designed to withstand unprotected inlet ingestion requirements.

The two-stage C20B gasifier turbine has been replaced with a single stage turbine incorporating aerodynamic improvements developed under contract to the U.S. Air Force. While providing the same aerodynamic efficiency as the two-stage turbine, metal temperature reductions of approximately 54°C (130°F) in the airfoil and 149°C (300°F) in the disk rim are expected. These decreases in metal temperature will result in increases in component creep-rupture and thermal-fatigue lifetimes. The disk will also feature a stronger cast material and an alternate rim construction, thus providing even further increases in component life while maintaining the low-cost aspect of the cast configuration. The length increase in the engine resulting from the larger exhaust collector serves to reduce the exhaust pressure losses associated with the mid-engine drive configuration.

To reduce the necessary maintenance of the engine as well as the cost of ownership, one additional engine change in the C24 is a new shafting configuration available from damped bearing technology. This permits a simpler configuration with fewer parts and the following features:

- o reduced part count
  - o gasifier coupling assembly--five parts to two parts
  - o eliminates two bearings
  - o power turbine sump eliminated
- o reduced maintenance
- o improved alignment and balance characteristics
- o reduced smoke and carbon formation
- o reduced oil flow and heat rejection
- o reduced vibration signature
- o performance improvements
  - o exhaust collector pressure drop
  - o balance piston losses
  - o gaspath blockage

Specifically, the new single-stage gasifier shaft assembly eliminates the gasifier tiebolt, spline adapter, spur adapter gearshaft, and the compressor to turbine hollow coupling shaft. Two bearings are also eliminated along with a power turbine oil sump and the associated routine cleaning and inspection requirements. The resulting configuration is less sensitive to potential unbalances in the turbine module and less restrictive to exacting alignment checks during assembly. These changes all serve to reduce spare parts and maintenance costs.

The Model 250-C24 engine also accommodates several installation features requested by current C20B operators and airframe manufacturers such as:

- o digital electronic supervisory fuel control (analog & manual back-up)
- o twin engine torque/temp limiting and sharing
- o suction fuel system
- o anti-icing for IFR
- o fuzz burner (manual) mag plugs
- o optional flow meter kit
- o optional rear mount
- o integral oil scavenge filter
- o increased vibration limits

For new installations, a digital electronic supervisory fuel control unit (DCU) will be available with both analog and manual back-up capabilities. This control will be an upgrade from the DCU developed for the Bell/U.S. Army Advanced Helicopter Improvement Program (AHIP) and recently certified by the FAA for the Model 250-C30L and -C30R engines. A significant difference will be the capability of twin engine torque sharing. The C24 engine will also incorporate a suction fuel system with a vapor-to-liquid ratio of 0.42 to improve flight safety by eliminating pressurized fuel delivery lines. To permit an upgrade of older installations, standard C20B fuel delivery and control systems will also be available.

The C24 engine will utilize manual (fuzz burner) magnetic chip detectors, offer as options a flow-meter kit and a rear-engine mount on the turbine, require use of an engine supplied external oil scavenge filter, and provide for increased low frequency installation vibration limits.

The overall Model 250-C24 project schedule targets certification and initial production for fall of 1986 (Figure 10); prototype development rig hardware is currently being evaluated. Compressor aerodynamic rig work has confirmed gains in pressure ratio and efficiency with the reduced number of stages. Similarly, turbine aerodynamic rig efforts have served to validate turbine component efficiencies and loadings in the single stage gasifier, running with turbine tip clearances that experience dictates are required to accommodate tip-ring distortion prevalent in small gas turbines. Potential field service anticipated problems for the damped bearing, ranging from possible misassembly to oil starvation, to shock testing, and up to 200 times unbalance limits, have been explored through the shafting rig program. These efforts have been concurrent with the detailed design.

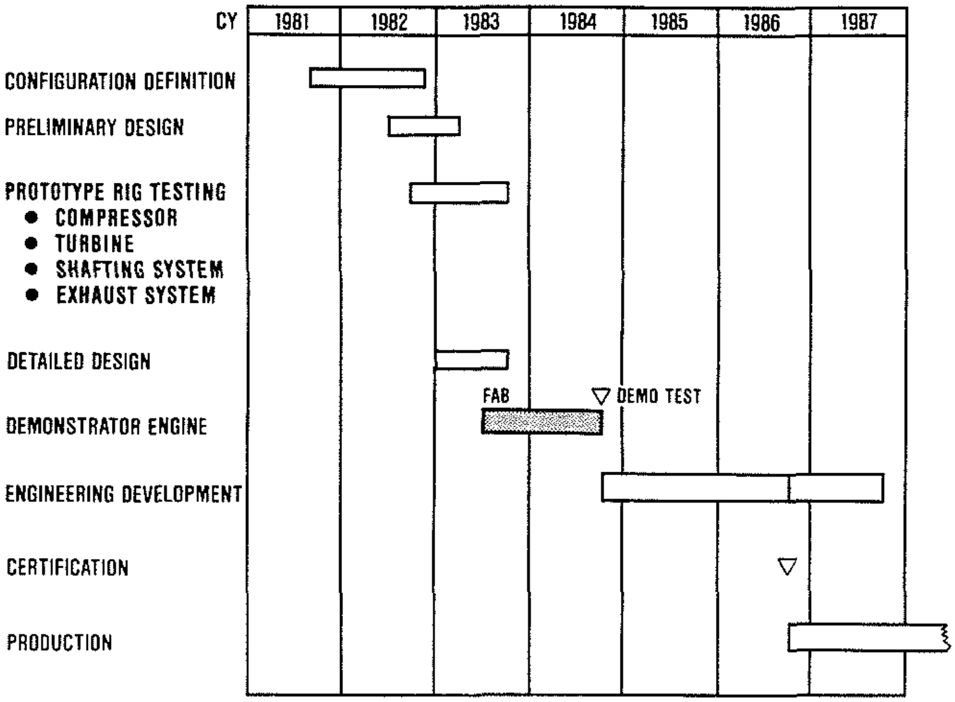


Figure 10. Model 250-C24 Overall Project Schedule.

The development program features an increased level of preproduction endurance testing prior to certification. Severe thermal cyclic testing from maximum temperature conditions to cold, rammed and blown cool-down conditions should reveal early cyclic or thermal fatigue damage to the engine hot section.

Simulated flight endurance tests and accelerated mission tests constructed from Allison's extensive single- and twin-engine flight experience will identify the potential for service revealed deficiencies. Scheduled testing will be at test-to-service severity ratios in excess of 3:1 in creep/stress rupture damage and greater than 4:1 in terms of cyclic damage rates. The in-house development testing scheduled for the C24 represents more than twice the amount of engine testing conducted on prior Model 250 engine models. This testing will serve to minimize the participation of the commercial operator in engine development.

## IV. Conclusion

While Allison and other engine manufacturers are developing both advanced military engines and engines configured specifically for the commercial market, it is critical to recognize the appropriate divergence of the overall goals of the military and commercial users. The commercial operator is committed to generating a profit. Engine performance is a concern only as it relates to airframe productivity and fuel cost budget allocations, typically not the largest factors comprising direct operating cost. The engine must be reliable, durable, simple in construction and relatively easy to disassemble and maintain, even if an associated weight penalty is incurred.

While minimizing his initial investment for the total helicopter system, the commercial operator's ultimate concern is to control annual expenditure in support of the system--to be able to own, operate, and maintain the engine at a minimum cost.

While the Model 250-C24 engine features decreased fuel consumption and increases in hot-day performance, the design provides for increased durability and reliability, reduced complexity and part count, less maintenance, and decreased operating costs. The conscious incorporation of these design parameters and the millions of flight hours operating experience of the reliable C20 engine provide the basis for the next generation of rugged Model 250 engines designed specifically for commercial owner/operators. The Model 250-C24 engine is designed to be:

- committed to operator profit
- reliable, durable, simpler
- inexpensive to acquire, more inexpensive to own