ICAS-98-5,6,3

A98-31644

COMMON CORE DEVELOPMENT APPROACH FOR ALLISON T406/AE FAMILY OF TURBOSHAFT, TURBOPROP, AND TURBOFAN ENGINES

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ABSTRACT

The "Common Core" from which a family of turboshaft, turboprop, and turbofan engines can be derived has been the goal of engine companies for many years. The advantages in terms of development synergy, reduced cost, and in-service experience/support/maintenance commonality are well known and extremely desirable. Many have talked and explored the possibility, but Allison is one of the few engine manufacturers which has actually been able to develop a family of new engines based on a "common core" philosophy. The T406/AE family of engines, developed from the "common core" philosophy, encompasses both military (V-22 Osprey, C-130J, Global Hawk, etc) and commercial (Regional transports and business jets) applications.

This paper provides an overview of the engine family in terms of background, engine configurations/technologies, applications, development program approach/schedules/accomplishments, lessons learned, and future plans.

BACKGROUND

In late 1985, the U.S. Navy selected Allison's turboshaft engine as the power source for the revolutionary V-22 OSPREY tilt-rotor aircraft shown in Figure 1. Designated T406-AD-400 (T406), illustrated in Figure 2, it is a 6000+ shp (4474+ kW) class modern technology, full-authority digital electronic control (FADEC) equipped engine. Initial PFR (Preliminary Flight Rating) engine deliveries started in 1988 and were completed by 1989. A total of 18 PFR engines and three additional dedicated ground test engines were delivered to Bell Helicopter Textron and Boeing Vertol Helicopter (Bell-Boeing) to support flight testing. Evolution of the T406-AD-400 full production qualification engine (FPQ) from the PFR engine started in 1988 and included design changes to enhance engine performance (3% in SFC), durability, and incorporation of contingency power capability of 6830 shp (5093.13 kW) flat rated to 90 degrees F (32.2 degrees C). To date, this engine has in excess of 1000 flight hours and 4000 general run hours. The first commercial derivative of the T406 engine was launched in 1989 with the selection of the AE 2100A turboprop by SAAB for the SAAB 2000, 50 PAX Regional transport. In the following year, IPTN selected the AE 2100C for Indonesia's entry into the 50-65 PAX Regional transport category aircraft with the IPTN N-250. A version of the AE 2100 engine tailored to meet military application, designated AE 2100-D3, was subsequently selected by Lockheed for the C-130Jaircraft. The turbofan derivative of the T406 core engine was launched in early 1990 when Embraer selected the AE 3007A engine to power their EMB 145, 50 PAX Regional jet. And in October of 1990, Cessna selected the AE 3007C turbofan engine to power the Citation X, the World's fastest business jet. Further announcements came from Teledyne Ryan for Global Hawk (AE3007H), C-27J Spartan (AE2100D2) and Shinmaywa US-1 KAI (AE2100).

New opportunities continue to emerge for the AE Common Core Engines in the 50-80 PAX Regional aircraft market and for derivatives of the AE 3007 family in the 30-80 PAX Regional jet market and for medium to large business jets. To meet the needs of the market place, Allison has been positioning the engine family for growth through technology advancements in the hot section. An engine demonstration of that technology was accomplished in 1994 with the AE 301X, a 10,000 lb thrust class turbofan. The T406/AE family of engines and their development history is illustrated in Figure 3.

GENERAL DESCRIPTION OF ENGINES

ENGINE CONSTRUCTION AND SPECIFICATION FEATURES

T406-AD-400

The T406 is a free turbine turboshaft engine. A cross-section of this engine is shown on Figure 4. The gas generator core or high pressure (HP) spool consists of a 14-stage axial compressor with variable geometry stator vanes utilized in the inlet guide vanes and first 5 compressor stages, an annular combustor employing a single passage dump diffuser from the compressor, and a 2-stage axial flow turbine driving the compressor. Power is generated by a close coupled axial flow power turbine on the low pressure (LP) spool. The power output coupling is located on the front of the engine and is concentric with the core. It is driven by a shaft through the bore of the HP spool. The HP spool drives an accessory gearbox through a tower shaft/bevel gear arrangement. Accessories powered through this gearbox include the fuel pump, oil pumps, and a permanent magnet alternator to power engine electrical accessories. Speed reductions within the accessory gearbox for the driven components are accomplished through the arrangement of five integral shaft spur gear sets. The gearbox also has provisions for an airframer supplied starter.

The engine has three sumps incorporating four main shaft bearings. The HP spool has the compressor straddle mounted on two bearings with an overhung gas generator turbine and a power turbine straddle mounted on two bearings. Independent thrust bearings are contained in the front and middle sumps, respectively, for the low and high pressure spools. The lubrication system is a pressurized dry sump arrangement including three micron filtration.

The compressor has evolved from Allison engine experience and advanced technology programs. Individual wheel blade attachments are utilized throughout for maintainability and life cycle cost considerations. Airfoil leading and trailing edge thicknesses are comparable to the rugged T56 for erosion and foreign object damage (FOD) tolerance. Advanced titanium alloys are utilized for all compressor wheels and all airfoils are stainless steel for purposes of durability. The compressor inlet is a cast ring spoke arrangement, while the compressor case is a two-piece design with axial split lines for ease of assembly. Bleed provisions are provided on mid and aft (compressor exit) stages for start, anti-ice, and customer uses.

Compressor airflow is delivered to the annular combustor through a dump diffuser. The combustion liner is an effusion cooled design consisting of an annular sheet metal fabrication. Attached to the outer combustor case are 16 piloted air blast fuel nozzles. The nozzles have separate pilot and main flow tubes located concentric with each other and an internal divider that schedules fuel between pilot and main systems based on fuel pressure.

The gas generator turbine is also an evolutionary configuration. Air-cooling is provided in the first three of the four airfoil rows. Gas generator airfoils with the exception of the first vane are cast single crystal nickel base alloy. The first vane is cast from an equi-axed nickel based alloy. Static structure consists of inner and outer turbine cases. The outer case also provides sealing of high pressure air. The inner case serves to mount the first and second-stage vanes and rotor blade tracks. The inner case structure is designed to optimize tip clearance via a passive mechanical/cooling scheme and serves to limit/meter coolant flow application and prevent leakage of gas from the flow path.

The first-stage vane row consists of convection/film cooled airfoil doublets. The second-stage vane segments include four airfoils with coolant feeding through an outer annulus port to each of the airfoils which are also film convection cooled. The gas generator turbine rotors consist of individual bladed wheels. Both wheels are an advanced forged superalloy. The second-stage blades are uncooled and consist of 'Z' shrouded airfoils. The 'Z' shrouds lock during operation to prevent creep untwist and to inhibit airfoil dynamic responses.

The power turbine is a two-stage uncooled axial flow design that is close coupled and corotates with the gas generator turbine. Both stages have shrouded blade tips with knife seals to minimize leakage losses. Both power turbine rotors have individually attached cast machined blades in forged machined wheels. The same turbine wheel material used in the gas generator is employed in the power turbine and provides significant weight reduction.

The LP spool operates at speeds above the turbine mode and the shaft first bend frequency. Accordingly, the T406 includes squeeze film oil dampers at the LP shaft rear bearing location.

The T406 is controlled by a dual Full Authority Digital Electronics Control (FADEC) commanded fuel pump and metering unit (FPMU). The FADEC communicates with the V-22 digital flight control computer via a MIL-STD-1553B serial data bus. The FADEC logic provides for basic engine control functions such as starting, fuel/compressor variable geometry scheduling, limiting features, and fault detection and accommodation. The T406's outer loop speed governing is integrated with V-22 aircraft flight control logic. Engine FADEC authority in speed governing is limited to overspeed protection to protect from loss of load events. The dual channel FADECs utilize dual redundant engine sensors to provide for maintenance of full control capability with any single failure and many multiple failure scenarios. The FPMU consists of a centrifugal boost pump and an HP gear stage supplying pressurized fuel to the metering valve. Each FADEC lane is capable of commanding one winding of the stepper motor in the FPMU that drives the metering valve. Fault detection and accommodation in each FADEC provides for automatic lane transfer in the event of either lane's incapacitation and a fail fixed mode in event of both lane's failure.

Normal, all-engine operating points from 50% MC to takeoff span the range from 1739.72 to 4584.56 kW (2333 to 6148 shp). These powers are flat rated to 39.4°C (103°F) ambient day. The contingency 10 minute, 1 engine inoperative rating is 5036.46 kW (6754 shp) at static S.L. conditions and 5093.13 kW 6830 shp at 90 ktas. This power capability is flat rated to 32.2°C (90°F).

AE 2100

A three-quarter cutaway view of the AE 2100 is presented in Figure 5. There are a few core engine differences between the T406 and AE 2100 which were driven by customer requirements.

The compressor inlet housing aerodynamics are identical; however, the turboprop application requires attachment provisions for a dual strut/torque tube mount for the Prop Reduction Gearbox (PGB). The turboprop inlet is weight reduced reflecting operation in a lower vibratory environment than the T406. Compressor cases have also been modified to provide a 10th-stage bleed capability. The last power turbine stage is reset to minimize turbine exit swirl for turboprop application.

Other prime differences include a modified control system and the addition of a PGB and exhaust nozzle for the AE 2100. The control system maintains the dual FADEC architecture and FPMU concept. An option for FADEC communication with the aircraft is provided by offering either an ARINC 429 or MIL-STD-1553B serial data bus interface. The AE 2100 FADEC has increased throughput and memory capabilities. The FPMU has been redesigned such that the metering valve is driven by a torquemotor providing for the desired turboprop accommodation of failoff for an engine inflight shutdown.

The AE 2100 utilizes two identical single channel digital electronic controls. The FADEC integrates both engine power and propeller speed control functions in a single unit. Parameters regulated by the control include:

- engine fuel flow
- compressor variable geometry
- propeller blade angle
- ignition
- starter

Each engine requires one power lever (PL) to modulate engine power. In addition to the PL, power management requires five switches for the available power modes; takeoff, flex takeoff, climb, cruise, max continuous. Engine power/torque is programmed by the FADEC as a function of altitude, airspeed, and air temperature and controlled by the commanded fuel flow.

The dual redundant FADEC sensor system provides for the same full control capability with all single and most multiple failure scenarios provided by the T406. Fault detection and channel switch over is accomplished automatically. A reversionary mode addresses the case where both channels' torque sensors are failed.

The FPMU shares many components with the T406 FPMU; however, it uses a torquemotor commanded by each channel to drive the metering valve. While both FADECs perform the control calculations, only one channel is in control at any time. The centrifugal/gear pump combination provides vapor to liquid and suction pumping capability similar to the T406.

The AE 2100 PGB maintains the proven T56 general arrangement shown in Figure 6; a simple offset spur gear first stage driving a compact spur planetary second stage with a fixed ring gear sun gear input and carrier output. Overall reduction ratio is 14:1, although future engine models may provide alternate ratios. This ratio reduces the 100% power turbine output speed to 1100 rpm at the prop flange.

Power output from the engine to the PGB is via a modular phase displacement torquemeter assembly. It consists of a torquemeter shaft, housing, monopole pickups, and an anti-ice shroud. The PGB output shaft includes provisions for a flange mounted propeller via a bolt/dowel arrangement. Propellers of various sizes can be accommodated by changing the prop adapter flange. The PGB output shaft is designed to accommodate a propeller pitch control unit mounted on the Gearbox Monitored Accessory Drive (GMAD) and inserted through the prop shaft centerline.

The AE 2100 lubrication system provides separate pump, filter, and scavenge systems for the core engine and PGB from a common oil tank. Three micron filter systems are utilized for both the PGB and core.

Compressor inlet air is delivered through an airframer supplied 'S' duct and can be tailored for high or low air intake by inverting the PGB housing. An exhaust nozzle at the engine exit is optimized for each application to minimize fuel consumption at the customer desired equivalent power (mechanical power plus shaft horsepower equivalent of jet thrust).

AE 2100 development as of this time has addressed take off ratings up to 6000 shp. All current applications fall within this established capability. Figure 7 compares the AE 2100 takeoff ratings of current applications.

AE 3007

The AE 3007 engine, illustrated in Figure 8, is a 7000 lb thrust class, high bypass ratio turbofan engine. The engine is a mixed flow configuration in which the entire gas flow exits through a common nozzle. A forced (lobed) mixer is incorporated at the aft end of the engine to enhance mixing of the cold bypass flow and hot core gas flow. This enhanced mixing provides benefits in terms of reduced specific fuel consumption and reduced noise.

The single stage fan consists of 24 solid titanium, wide chord blades inserted in a titanium disk. The bypass vanes are composite and they, along with the fan blades and disk, are replaceable on the aircraft. The fan case is aluminum with an integrated Kevlar based containment system. The fan is directly driven by a three stage, uncooled low pressure turbine (LPT) similar to the T406 and AE 2100. The LPT blades incorporate fir tree attachments and "Z" shrouds. A three stage design is required to operate at the lower rotational speeds dictated by fan tip speed requirements while maintaining proper loadings for high efficiency.

The core of the AE 3007 engine is essentially common with the T406 and AE 2100 engines. It includes the same axial flow compressor. The compressor exit diffuser/outer combustor case is fabricated from the same Ti 6-2-4-2 casting and supports the combustion liner, the 16 piloted fuel nozzles, the two igniters, and provides pressurized air sources for the customer bleed system and the acceleration bleed valve control. The combustion liner is the same effusion cooled, annular configuration with demonstrated low emissions, excellent altitude relight characteristics, and uniform exit temperature profiles. The high pressure turbine maintains the two stage, air-cooled, axial flow configuration with the first three airfoil rows (1V, 1B, 2V) air-cooled and the last blade uncooled. All airfoil castings are identical but cooling control orifices in the cooled airfoils are adjusted to meter modifed flow rates. Likewise, the gas generator turbine static and rotating structure is identical with the exception of tailored cooling passages that admit additional flow commensurate with higher turbofan operating temperatures.

As illustrated in Figure 9, the AE 3007 engine is mounted from the front frame and the rear mount ring. Four mount pads, provided on the front frame, are designed to accomodate either fuselage or underwing mounting. The titanium rear ring provides the rear mount provisions. Depending on application, the rear ring is designed either for universal mounting (ie fuselage left and right) with four mount points or with two mount points and the capability for rotation to accomodate left and right engines. The mounting system is designed to provide full capability with a failed mount.

A composite, acoustically lined outer bypass duct connects the front frame to the rear ring. In addition to its excellent acoustic attenuation characteristics, the duct acts as a stiff outer load path to minimize aircraft maneuver loads from reaching the core flowpath structures. Through this feature, core clearances remain tighter and performance retention is improved. Six large access panels are provided in the outer bypass duct to enhance maintainability of engine core features.

The accessory gearbox, located on the bottom of the engine, is driven off the gas generator shaft via a bevel gear/tower shaft arrangement. It provides mounting provisions and drive for three engine provided accessories FPMU, oil pump, and permanent magnet alternator (PMA) and four aircraft accessories (two generators, an air turbine starter, and a hydraulic pump). These major LRUs (line replaceable units) and others including the oil tank, oil filter, fuel-cooled oil cooler, and fuel flow meter are located on the outside of the bypass duct in a cooler environment. This arrangement of accessories is incorporated for reliability and maintainability of these components.

The lubrication system of the AE 3007 engine is a self contained system consisting of the oil tank, pump, filter, fuel-cooled oil cooler, and air-cooled oil cooler. The filter is on the pressure side of the pump and incorporates three micron filtration for significant improvement in the life of oil wetted components. The oil pump provides both pressure and scavenge capability to the system.

The control system consists of off-engine-mounted, dual redundant FADECs , dual redundant engine sensors, CVG (compressor variable geometry) actuator, and the FPMU. Interface between the engine

FADECs and the aircraft is all electrical and consists of ARINC 429 data buses and a number of hardwired analog and discrete signals. The FADECs automatically control the corrected fan speed to a customer coordinated schedule as a function of Mach number, altitude, ambient temperature and throttle setting. In addition to automatic fan speed scheduling, the AE 3007 control system provides for automatic take off thrust control (ATTCS), auto-relight and on-command synchronization of either fan or core speeds. Engine automatic limiting is provided for fan speed (N1), core speed (N2), and measured gas temperature (ITT-16 thermocouples located in the LP turbine first vane).

The sea level static ratings for the AE 30	**AE 3007A**	**AE 3007C**
Thrust, lbf	7200	6400
Flat rate temperature, deg F	ISA + 14.4	ISA + 27

COMMON CORE DEVELOPMENT APPROACH

Allison's primary goals for the T406/AE engine family were:

- o Provide the best engine for the customer in each application
- o Maintain the maximum amount of commonality possible
- o Divert from commonality only as customer requirements dictate
- o Continually strive for re-establishment of commonality with the "best" features developed in each of the individual development programs

As stated previously, the advantages for maximum commonality within the entire engine family are numerous and obvious. Experience from each of the individual development programs substantially accelerates the maturity of the entire family of engines. This reduces expenditures for the individual programs and significantly enhances the product reliability at introduction. Secondly, in-service experience can be read across to other members of the engine family to again accelerate product maturity in minimum time. For Regional customers or overhaul facilities with mixed fleets of turboprops and turbofans, commonality enhances maintainability and support through common tools, training and procedures. Finally, commonality reduces cost through economies of increased common parts volume. For Military operators, it is easy to see the logistics benefits of a common core. Consider the high probability of C-130J's; - C-27J's, V-22's and Global Hawks, all operating in the same theater of action, under different allied flags.

Prior to discussing details of the "Common Core" developments within the T406/AE Engine Family, it may be instructive to define the principals, processes, and organizational structure used to control and optimize the development, maturation, and future expansion of the engine family.

The first, and most important, principal is to provide the Customer (i.e. the aircraft manufacturer and airlines) with the best engine and service possible. In order to properly serve each Customer, we have defined "focal point" personnel within each of the major legs of Allison's matrix organization whose total responsibility is to understand and coordinate the activities required to meet their Customer's needs. As illustrated in Figure 10, "focal points" are defined in the Program Office, Engineering, and Customer Support. In addition to providing point-of-contact focus to each of the Customer's needs, the philosophy of "focal points" provides project segregation and utmost security of proprietary information among competing Customers. The "focal points" within Engineering are termed "Application Engineers". As illustrated in Figure 11, the applications engineers coordinate with the Chief Project Engineer of each product line (i.e. turboprop, turboshaft, or turbofan engines). The Chief Project Engineer has the responsibility for developing the specific core engine with capabilities to meet the needs of all of the applications engineers to the maximum extent possible. In addition to maintaining technical excellence of the engine, the Chief Project Engineer has an additional responsibility to maintain the maximum amount of commonality with the entire T406/AE engine family. This process is greatly facilitated by using a single Design organization for the entire T406/AE Engine Family. The Chief Design Engineer, T406/AE Engines coordinates with all of the Chief Project Engineers to maintain commonality to the maximum degree possible and facilitate communication of "lessons learned" among the various programs. If commonality issues cannot be resolved within constraints placed on the Chief Design Engineer and the Chief Project Engineers, the Chief Engineers of the two product lines determine if sufficient reasons exist to recommend commonality diversion to senior management. This approach has proven to be very effective in providing each Customer the "best" engine for his application while maintaining maximum commonality.

A second guiding principal is one of apportioned development. According to this principal, major development areas are assigned to either the turboprop/turboshaft or turbofan project organizations. Major development tasks are assigned by the Executive Vice President, Engineering to the Chief Engineers of either the Large Turboshaft/Turboprop or Turbofan project organizations. The tasks are generally assigned to the organization with the most pressing near term desire for the improvements. Coordination between the Chief Engineers insures proper accountability of the requirements of the entire engine family. Duplicate development tasks are thus avoided. Currently, the turboprop/turboshaft organization is assigned the task of performance enhancement while the turbofan organization is responsible for engine growth.

Even though commonality is a strong incentive, Allison has evaluated each of the engines in the family and has changed common parts, as required, to best meet the needs of the customers.

The 50 PAX Regional market, though similar in some respects, presents different requirements for the turboprop vs the turbofan engine.

Take-off conditions set increased requirements for the turbofan powered Regional aircraft compared with the turboprop powered aircraft. This is primarily due to thrust lapse rates between the ultra high bypass ratio propeller and the turbofan. At the cruise conditions, the increased aircraft speed of the turbofan powered aircraft again places increased requirements on the turbofan core. (High Altitude with 3007 H issues.

To address the increases in core temperature and speed for the turbofan, the core has been modified in several areas and, thus, in the near term, moved away from commonality. In the high pressure turbine, increased cooling air was added to the first three airfoil rows and single crystal blading was added in the uncooled 2nd stage blade row. The combustion liner was modified from a film-convection cooled configuration to an effusion cooled configuration which made more efficient use of cooling air. Effusion cooling consists of single thickness outer and inner walls with laser drilled, angled holes precisely located and spaced to minimize average wall temperatures and gradients formed by discrete combustion behind the individual fuel nozzles. Also, fuel nozzles were changed to improve their tolerance to carbon formation under high compressor discharge temperature conditions. Basic development of these components was conducted under the turbofan FSED (Full Scale Engineering Development) program. To provide increased durability in the turboprop and turboshaft engine and to return to a more common core configuration, many of the improved core components including the effusion combustor system fuel nozzle and selected turbine parts have been incorporated in the turboprop and turboshaft engines.

In a similar vein, the turboprop engine is developing further performance enhancements to both the high pressure compressor and high pressure turbine. Extensive use of 3-D aerodynamics and optimized stage matching is being developed in the compressor. Second generation single crystal airfoils are being developed for the high pressure turbine 1st and 2nd blades and 2nd vane. These improvements are being concurrently qualified in the T406 military program and certified in the commercial turboprop and turbofan engines. In addition to core commonality, this process shows the strong economic benefits of dual-use technology development for both the military and U. S. Industry. Each of Allison's major development programs in the T406/AE Common Core Family have unique requirements and issues which must be addressed. These unique developments will be summarized below. However, even though these unique issues are a primary focus of the individual project teams, the synergy of core development is strong and substantially aids in the maturing process of the critical core components. A simple view of the improved core maturity can be seen by adding the total number of development/flight test hours associated with each of the programs. This is illustrated in Table I.

TABLE I TOTAL T406/AE FAMILY DEVELOPMENT (AS OF 3/31/94)

	DEVELOPMENT	FLIGHT TEST	TOTAL
T406 No. of engines	12	18	30
Engine test hours	6,991	4,204	11,195
AE 2100			
No. of engines	7	9	16
Engine test hours	3,300	6,900	10,200
AE 3007			
No. of engines	7	3	10
Engine test hours	2,900	300	3,200
TOTAL	13,191	11,404	24,595

This total number of development test hours understates the increase in maturity associated with the unique T406/AE Family development approach. In addition to the large number of test hours accumulated, this Family Plan approach increases the scrutiny being placed on the core development. Inputs from the military, Regional turboprop community, Regional turbofan community, and business jet community are all encouraged, heard, and considered as experience is gained and improvements are defined and implemented. This same synergy in production will again substantially accelerate the maturity of the entire product line as a wide variety of operational scenarios will exercise the core. Improvements to the core required to address specific operator deficiencies will be carried over to the rest of the product line and will thus minimize operational problems for the rest of the fleet.

UNIQUE DEVELOPMENTS

T406

The T406 is the basis for Allison's common core engine. The T406 specification is derived from Military Specification MIL-E-008593E with tailoring to the requirements imposed by tiltrotor application. Unique features of the T406 core, i.e. items subsequently modified for turboprop or turbofan applications, generally relate to added complexity cost or weight to meet unique tiltrotor requirements. The two most noteworthy unique items relate to lubrication system and structural design.

The T406 is required to operate steady state over a wide range of attitudes including 45° nose down to 115 ° nose up with roll values of ±25°. Transient requirements, i.e. 30 second capabilities substantially expand on this range. T406 lube system components including the oil tank and engine sumps have unique design features not required for other types of more typical engine operation.

The T406 design provided for unique multi attitude servicing and low level oil indication throughout the attitude operational range. Hence, the turboprop and turbofan engines replace the T406 oil tank with more conventional designs tailored to each application.

The T406 utilizes a pressurized dry sump lubrication arrangement featuring air pressure buffered carbon seals to discourage leakage over the range of operational altitudes. Internal sump design has emphasized features such as slingers and redundant, multi location scavenge pickups to prevent oil leakage during nose up and nose down operation.

Neither turboprop nor turbofan sumps require the extreme attitude range. All three core engines started with identical engine sumps. Beneficial modifications derived from the commercial programs in the form of enhanced seals and improved low speed scavenge capabilities have been incorporated in the T406. On the other hand, Allison has begun to delete those additional features necessary for all attitude operation from the prop and fan sumps. This has been done in such a manner that the same basic sump castings are maintained and the unique features could readily be reinstated at a future date.

Of the three core applications, tiltrotor usage of the turboshaft generally sets the most severe surge margin requirements. This derives from several factors; the turboshaft has the most demanding transient requirements, operates in a more significant distortion environment and along with the turboprop operates with a higher operating line, i.e. higher pressure ratio at a flow, due to its matching characteristics. Hence, development of the core compressor which initiated with the T406 has remained as a T406 development activity.

Compressor development has revolved around maintaining or enhancing operating line efficiencies while improving the surge line. Compressor interstage development has provided the ability to establish front, mid and aft stage performance including radial pressure, temperature and efficiency profiles. Surge margin enhancement has included studies to optimize airfoil shapes, solidities and radial work profiles. The current compressor configuration provides for nearly a 90% polytropic efficiency with a nominal 17% surge margin at sea level. This surge margin generally degrades with lower Reynolds' numbers associated with high altitude operation.