PAPER Nr. : 85a

T700 - A PROGRAM DESIGNED FOR EARLY MATURITY & GROWTH POTENTIAL

BY

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TENTH EUROPEAN ROTORCRAFT FORUM

AUGUST 28 – 31, 1984 – THE HAGUE, THE NETHERLANDS

1 ABSTRACT

In the 1960s component development work was begun on a turboshaft engine configuration to replace the T58 for use in modern, medium-sized helicopters. The engine configuration was identified internally as the GE12 and later became the T700-GE-700, the successful competitor for the Army's UTTAS helicopter - now the Black Hawk.

To provide an engine of excellent operational capability, the Army placed a number of design and developmental requirements on General Electric at the program start. Among these requirements were significant advances in cruise fuel consumption, engine maintainability, long life, safety and reliability. These were to be combined with good hot day power, engine simplicity, an advanced control system and, as for any new program, growth capability.

The engine development and qualification program was defined to be consistent with the extensive and conflicting requirements. Special accelerated mission tests were introduced to simulate operational use of the engine. Added endurance and low cycle fatigue tests were run following engine qualification to ensure satisfactory performance when the engine was introduced into normal operating use.

The T700 and its commercial derivative, the CT7, have been selected for 12 aircraft models including two turboprops; they have flown in 10 applications, are qualified in 6, and in service operation in 4. The engine has now been in service for more than 5 1/2 years, the first growth step is already in production and the Step 2 growth engine is being defined. Flight operations of all versions of the engine have recently passed the half-million hour point. Now is an appropriate time to examine how well the program has addressed the Army requirements and see the results that have been achieved in engine maturity and growth potential relative to the design objectives.

2 INTRODUCTION

The T700 engine was originally anticipated by General Electric as a replacement engine for the T58, a successful but aging helicopter powerplant originated in the 1950s. Component development work was begun early in anticipation of a U.S. Army requirement for an advanced turboshaft engine to be used in a utility type of helicopter. This requirement materialized in the 1970s leading to the Sikorsky Black Hawk helicopter, powered by General Electric's T700-GE-700 engine.

The Army wanted a turboshaft powerplant with greatly improved capability relative to previous generation machines and specified a series of difficult objectives for the design and development of the engine. Specific requirements were defined in all of the following areas:

Power - including hot day, high field elevation
Reliability and safety
Cruise sfc - goal: 30% improvement
Long life
Design simplicity - fewer parts
On-condition maintenance capability
Ease of field maintenance
Advanced control system to reduce pilot workload
Growth capability

The T700 was the first helicopter engine to be developed to such an extensive set of requirements and to undergo as rigorous a development test program as that specified for this program by the Army. Engine development was carried out over a four year time period, but production was not begun upon qualification. Rather the Army specified a rugged test period or maturity program of roughly two years with production beginning just prior to the completion of these tests; engine development and maturity testing took a full six years. This plan provided a means to uncover potential problems in the factory and time to incorporate corrective action before placing the engine in service.

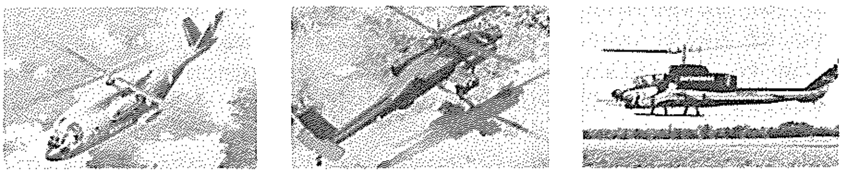
The T700 has proven itself to be the helicopter powerplant of the '80s, winning a number of U.S. and international applications. These constitute the major share of new helicopter programs in the intermediate size. In addition to its original success on the Sikorsky Black Hawk, the T700 and its commercial variant, the CT7, power the following aircraft (Figures 1 & 2):

Military Applications

UH-60 Black Hawk
T700-700

SH-60 Seahawk
T700-401

HH-60 Night Hawk
T700-401



EH 101
T700-401

AH-64 Apache
T700-701

AH-1T+
T700-401

Figure 1

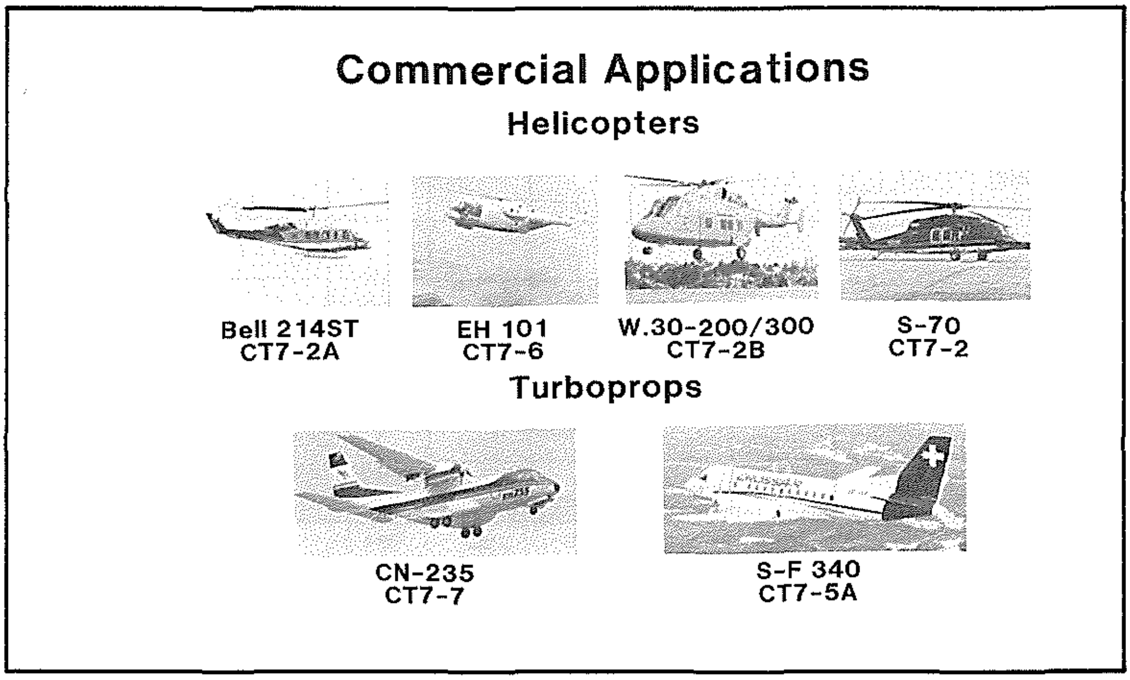


Figure 2

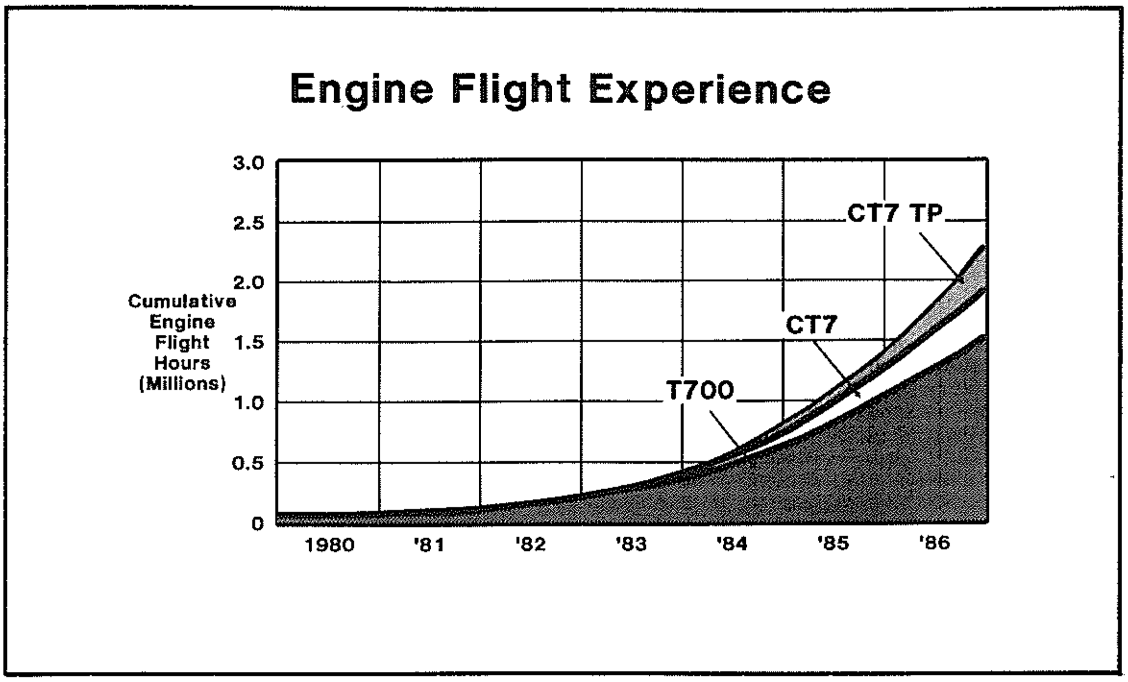
Production Models

Hughes Apache
Sikorsky Seahawk
        Night Hawk
        S-70
Bell 214ST
Saab-Fairchild S-F 340 (Turboprop)

Development Models

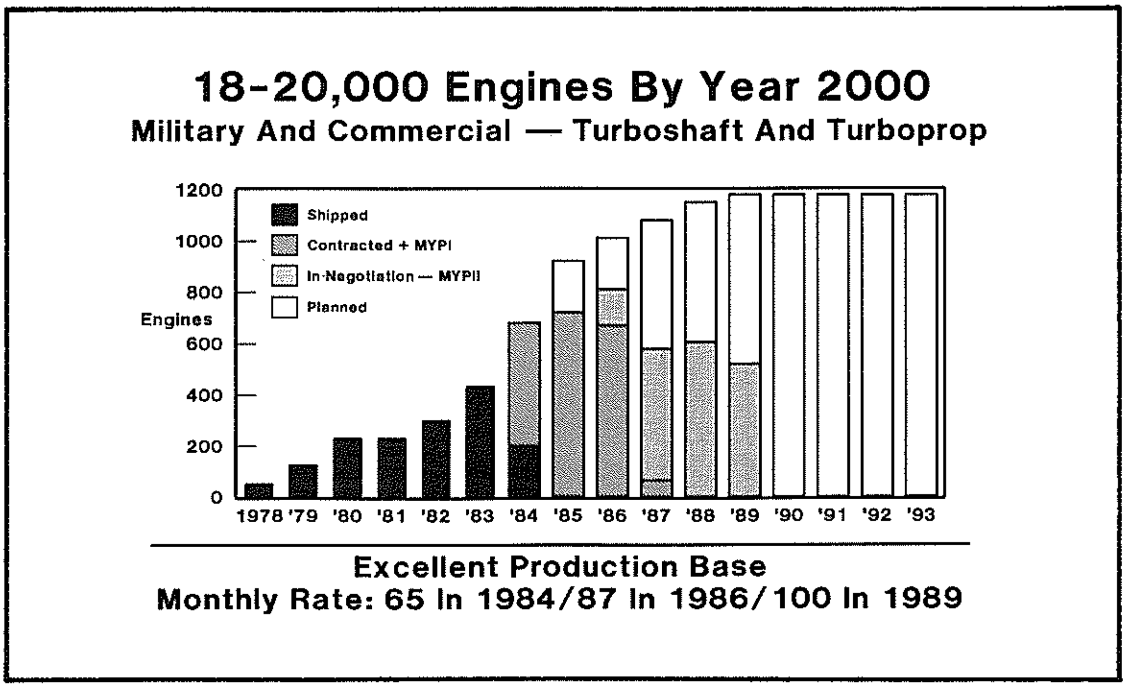
Bell AH-1T+
Westland 30-200 (and -300)
CASA-Nurtanio CN235 (Turboprop)
EH Industries EH 101

Three turboshaft engine models have been qualified to power the military aircraft versions while three turboshaft and two turboprop versions have been certificated for application on six civil aircraft. Recently the T700 and CT7 engine models in service use have passed the 1/2 million engine flight hour milestone. Engine shipments exceed 1500 and currently stand at 65 per month; this is expected to increase over the next few years to a rate of 100 per month in 1989. By the year 2000, we expect to have shipped 18,000 to 20,000 engines of the T700 family. Engine flight hour buildup and shipments are shown in Figures 3 and 4.



Engine Flight Experience

Figure 3



18-20,000 Engines By Year 2000

Military And Commercial — Turboshaft And Turboprop

Excellent Production Base

Monthly Rate: 65 In 1984/87 In 1986/100 In 1989

Figure 4

The T700/CT7 engines have served in a wide variety of environments around the world. Aircraft powered by these engines operate in hot and cold climates, mountainous regions, desert areas, regions that are hot and humid and in locations with salt atmospheres. See Figure 5. In addition, there will soon be a number of shipboard-based vehicles in operation with the U.S. Navy.

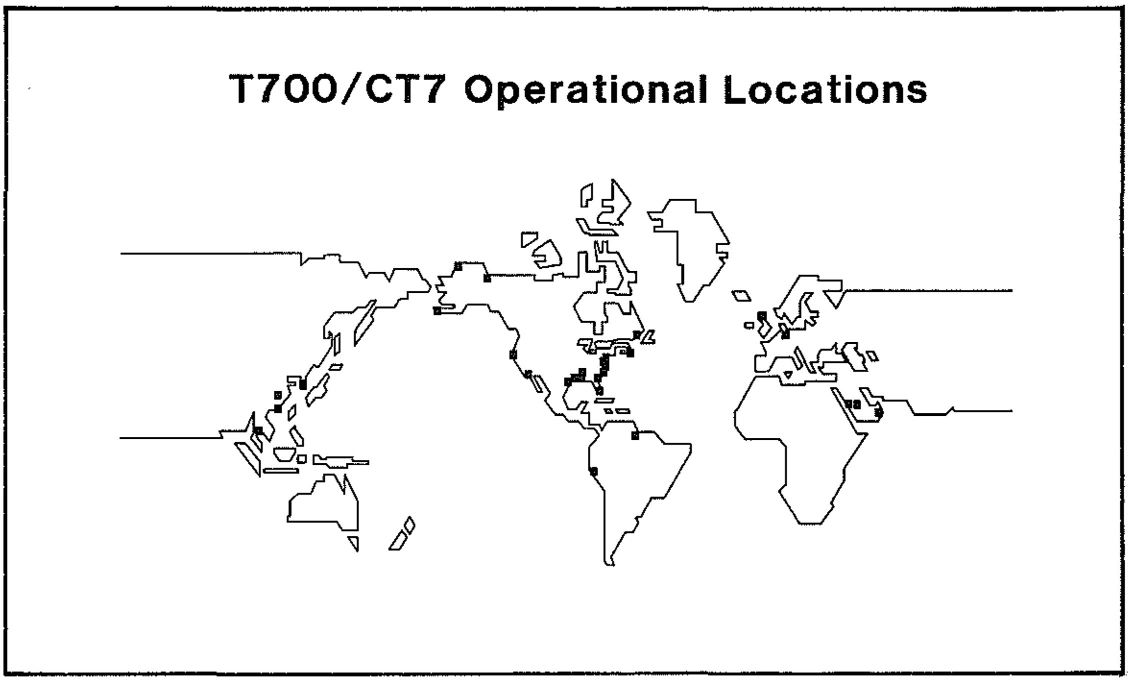


Figure 5

3 EARLY MATURITY

Design

Experience with U.S. Army helicopters in the 1960s revealed a number of operational difficulties and deficiencies. In undertaking a new helicopter powerplant design, the Army decided to include elements in the design and development process to prevent these problems. Areas to be addressed were the following:

Reliability

- High shop visit rates
- Foreign object damage
- Pilot workload
- Oil loss
- Fuel leakage, fires

Maintenance

- Parts shortages
- Inspection problems
- Down time
- Maintenance difficulty and cost
- Maintenance-induced failures

To meet these objectives, the engine was designed with a number of special features as shown on Figure 6. These items were all directed toward improved operational reliability to increase aircraft availability and reduce shop visits, parts requirements and operating costs.

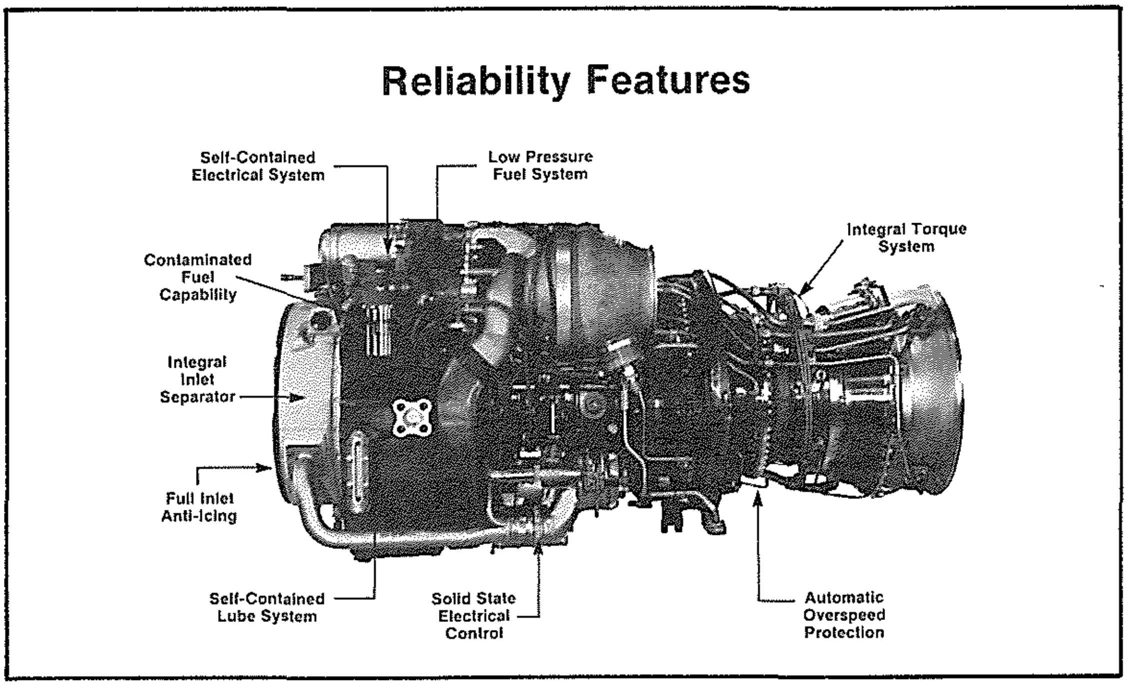

Reliability Features

Figure 6

The inlet particle separator, an integral part of the engine, was incorporated to reduce the effects of foreign objects; engine reliability was addressed by utilizing an all steel, wide chord compressor blade configuration in the compressor and the incorporation of a revolutionary, machined-ring combustor configuration. The self-contained lubrication system and suction fuel system were utilized to reduce or eliminate problems arising from oil loss and fuel leakage.

Previous engine designs had required significant maintenance on hot section parts, especially combustor liners. Typically replacements for liners were required every 600 to 1,000 hours, requiring substantial cost, down time and maintenance action. The machined ring design used on the T700 was intended to go at least 5,000 hours without replacement providing a great operational benefit. So far it appears the design intent has been more than met with no engine-caused combustor replacements required in military operation.

In addition, the problems observed in maintenance and maintainability were addressed by conscious attention to these elements in the design process:

Accessibility - top-mounted accessories
Number of parts - reduced by 1/3
Modular design
Line replaceable units
Simplified external maintenance
Few, common tools required

Top-mounted accessories make for simplified maintenance in a helicopter powerplant since engines are top-mounted in the vehicle. Design attention to maintainability is important in the detailed definition of the mounting and connection of the accessories (line replaceable units) and the external configuration of the engine, since experience shows that a large part of the engine-maintenance is done in these areas and often under trying conditions. On the T700, all the line replaceable units can be removed and replaced in 2.3 hours; each component requires typically 4 to 6 minutes with the longest time item taking only 15 minutes. A small kit of ten common tools is the only requirement to separate modules and to remove and replace any of the line replaceable units.

Development Tests

The T700 was subjected to the usual development and qualification testing as defined for earlier programs. In addition, the various engine models have been subjected to accelerated endurance and mission testing as summarized on Figure 7. General Electric in collaboration with the U.S. Army and Navy has defined an Accelerated Mission Test (AMT) and an Accelerated Service Mission Endurance Test (ASMET) to demonstrate engine durability for the specific intended missions. Low cycle fatigue (LCF) capability has been demonstrated during the accelerated testing and on tests specifically designed for LCF cycles. Factory engine tests have accumulated over 45,000 hours to date and 19,000 hours were accumulated prior to the first engine shipment. Accelerated testing has simulated a total of 35,800 equivalent mission hours.

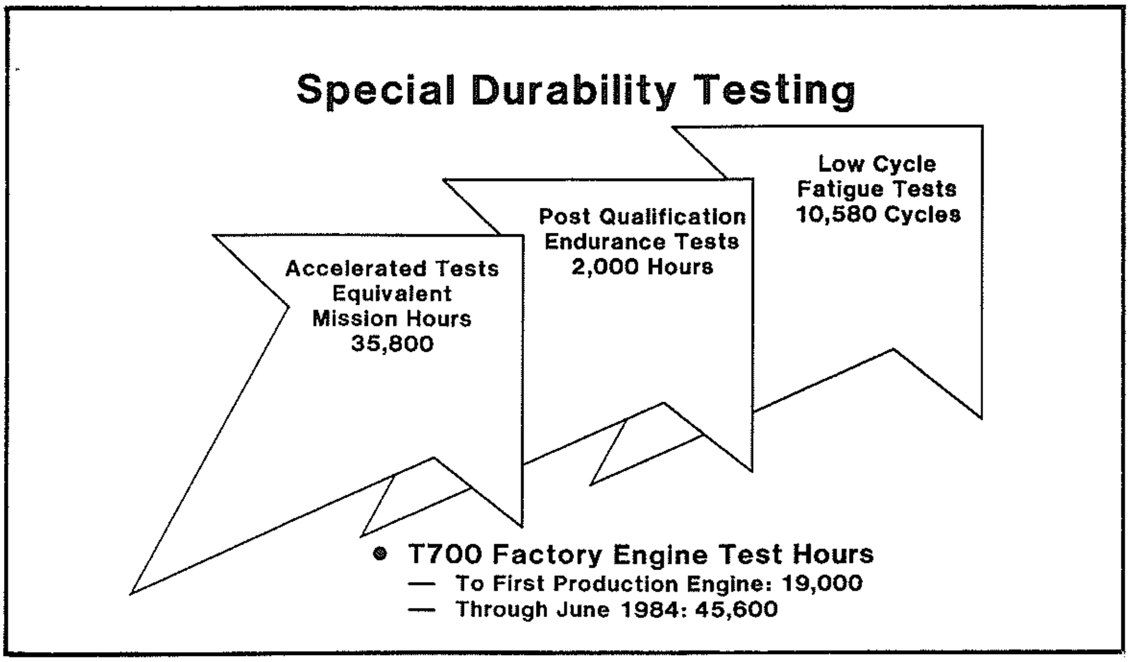


Figure 7

This testing has led to 16 design changes that helped to smooth the introduction of the engine into service and prove the value of this type of maturity program. The time allotted to this phase of the program permitted the incorporation of many of these changes into the first production engine.

Field Operations

What impact has this extensive and rugged development and maturity program had on the service behavior of the engine? With almost 1300 engines flying and just over 1/2 million flight hours accumulated, the T700 family has established an unprecedented level of reliability for this type of powerplant. Engine in-flight shutdowns and shop visits approach the values established by large turbofan engines on widebody commercial transports. In addition, the reliability levels have nearly met the goals GE established for the mature engine. These are objectives to be met in 1986 when 1.5 million flight hours are reached on the entire engine family (See Figure 8).

Reliability Measures

Rates Are Engine-Caused Events Per Thousand Engine Flight Hours

	T700		Internal	T58-10	CF6-50
	Cumulative	1983	Goal	1983	1983
• In-Flight Shutdown Rate	0.07	0.04	0.02	0.01	0.02
• Shop Visit Rate	0.30	0.25	0.10	0.67	0.28
• Engine Flight Hours (Millions) Cumulative	0.50			3.50	24

Figure 8

The engine shop visit rate due to foreign object damage is .21 per 1,000 engine flight hours, about half the rate of engines operated in the 1960s. While simpler and better maintenance practices help, this must be due at least in part to the impact of the inlet particle separator. A proposal to add an inlet screen is currently being reviewed by the Army. This would further reduce the effects of large objects and ice.

In the five years since the first production engine was put into operation, all of the scheduled flight line maintenance required only 1.9 man-years of labor. This means that all the engines could have been serviced by 0.4 man if we could have moved him from base to base quickly enough. In fact one complaint we have from the U.S. Army is that the personnel assigned to maintain the engines on the flight line have so little to do they are losing their training.

Two other points further demonstrate the reliability of the engine; (1) the U.S. Army program was established on the basis of procuring 50 percent spare engines. Actual service use has demonstrated a need for about 15 percent spares, providing a substantial savings of 70 percent in spare engine procurement. Over half the spare engines are consistently "ready for issue" with no open holes in the fleet. And (2) the Army plan was to maintain engine support capability on three levels: flight line, intermediate and depot. Because of the engine reliability and the excellent maintainability and maintenance features, most of the intermediate work can be done on the line. As a result, consideration is being given to the elimination of the intermediate maintenance level which would provide additional significant savings.

Finally, the excellent engine reliability results in a high degree of availability as demonstrated by the percentage of engines that have never been removed from service. These are shown by engine "age-groups" on Figure 9. Seventy-eight percent of engines under 1,000 hours and forty-two percent over 1,000 hours have never been removed.

T700 Service Experience

Through June 1984

Engine Age Group Operating Hours	Number Of Engines	Engines Never Removed	
		Number	Percent
0-1,000	1,116	868	78
1,000-1,500	49	21	43
1,500-2,000	12	5	42
2,000-2,500	6	2	33
Engines Over 1,000 Hours	67	28	42

Figure 9

4 GROWTH

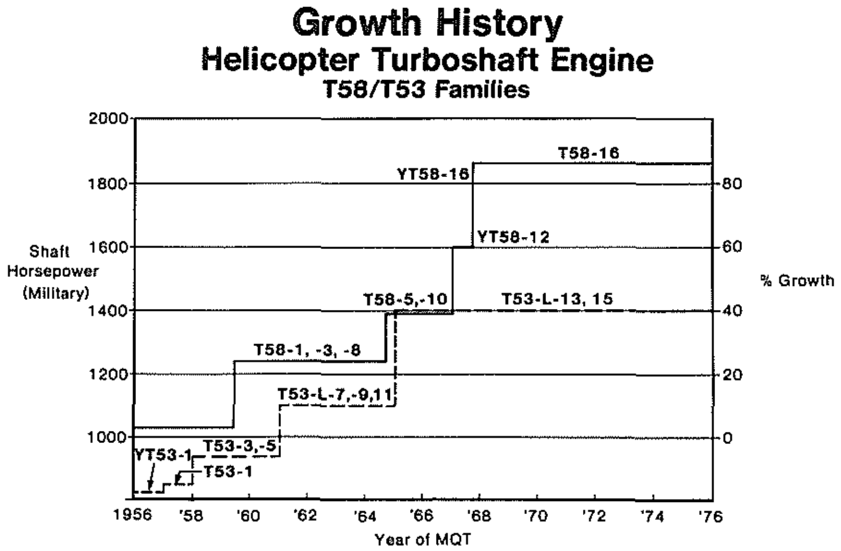
Background

Engine power growth is achieved through one or more of the following three items:

airflow
cycle temperature
cycle efficiency

The impact of the last item is usually small, since component efficiency improvements available are not large and practical changes to cycle efficiency - except as a by-product of temperature increase - are also minor.

Historically all successful aircraft turbine powerplants have undergone an extensive growth program either to keep up with weight increases in their primary applications or to obtain additional applications. Typical of these growth programs are those represented in Figure 10. The growth steps of four programs are shown and they are remarkably similar. Note that total growth in all cases runs about 50 to 60 percent over a ten to twelve year period.



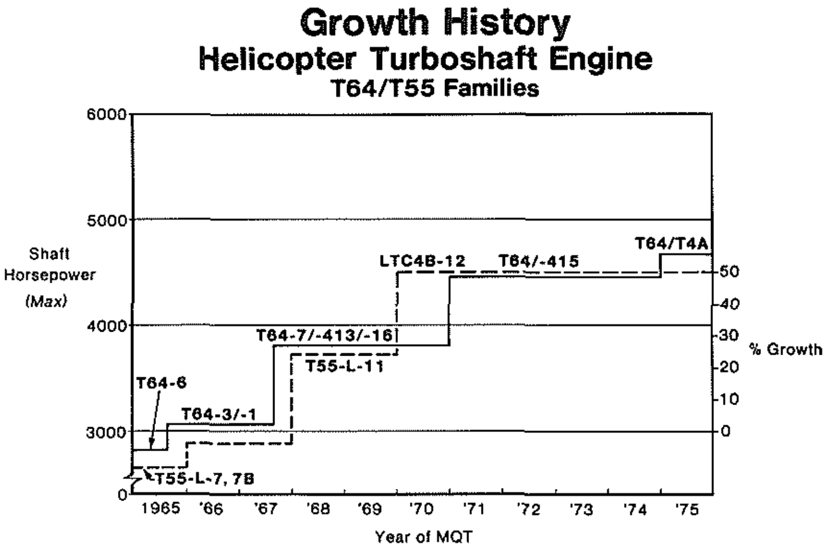


Figure 10

T700 Growth Plans

A similar scenario is visualized for the T700 engine. With five production aircraft models currently flying the first step growth engine (10%) is already in production and a major component of the second step - the high flow compressor configuration - has been committed to production for the two turboprop engine models. The current T700 engine family is summarized on Figure 11, showing the various engine models and applications. Engines in the 10% growth group (Step 1) have a "tuned-up" compressor with increased airflow over the T700-700 and operate slightly higher in cycle temperature than the base engine.

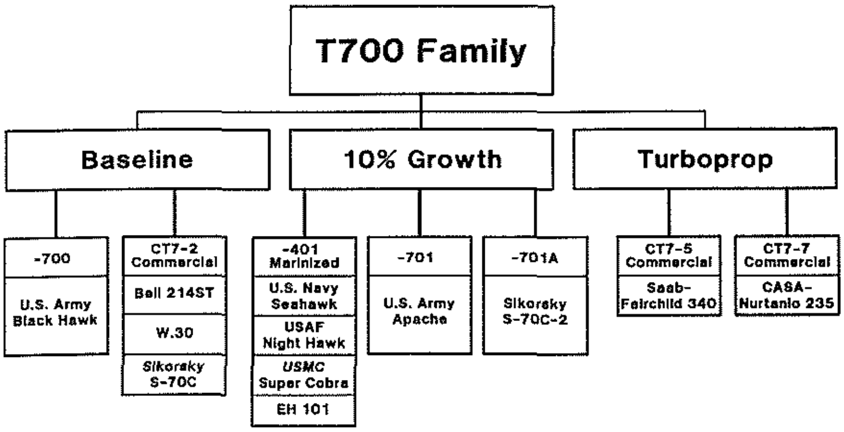


Figure 11

The turboprop engine models incorporate a new compressor design which will be used in the T700 Step 2 growth engine. Redesigned turbines for both the high and low pressure systems will also be incorporated, having new flow path and blade aerodynamics to rematch with the high-flow compressor. The Step 2 growth engine will be more than 30% power increase over the -700 engine.

Beyond the Step 2 engine, further growth can be achieved by an increase in cycle temperature (Step 3) and finally by the addition of a booster stage coupled to the power turbine shaft. The booster stage has the capability of increasing flow through the engine core and can provide a power increase of 15 to 20 percent. A booster stage added to the Step 3 growth engine would give in excess of 70% power increase over the -700. These additional growth steps are shown on Figure 12.

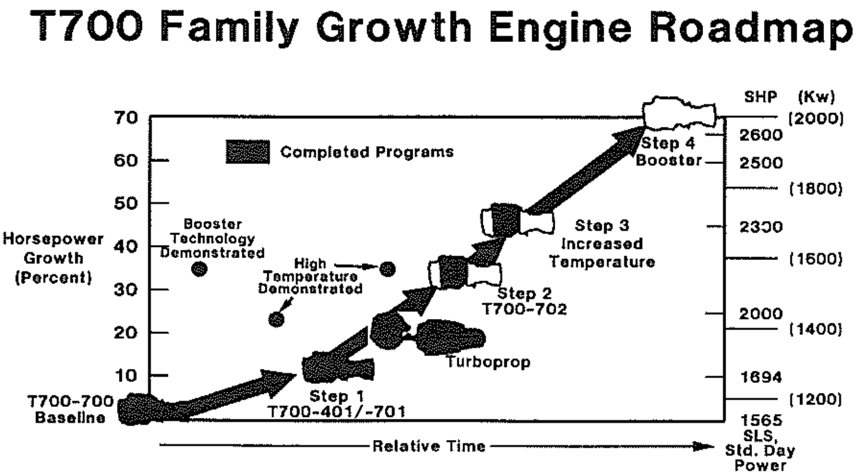


Figure 12

Growth engines will incorporate proven technical advances from other programs. Step 2, 3 and 4 configurations will make use of new material advances, improvements in cooling system and component design approaches and manufacturing processes that have been developed recently on both large and small engine designs. Advances that maintain or improve the reliability of operation will be utilized assuring that future versions will maintain the unequalled integrity of the T700 engine family.

Special attention was given in the design of the early versions of the T700 engine to the difficult and conflicting requirements specified by the U.S. Army. The need for low sfc and growth capability indicated high cycle temperature while the requirement for reliability, safety and long life meant conservative metal temperatures. The solution was found in the development of advanced cooling configurations (Figure 13) for small turbine engines (Ref. 4). As a result, the T700 family is successfully operating at cycle temperatures above those planned for competitive engines that are now in design and development stages.

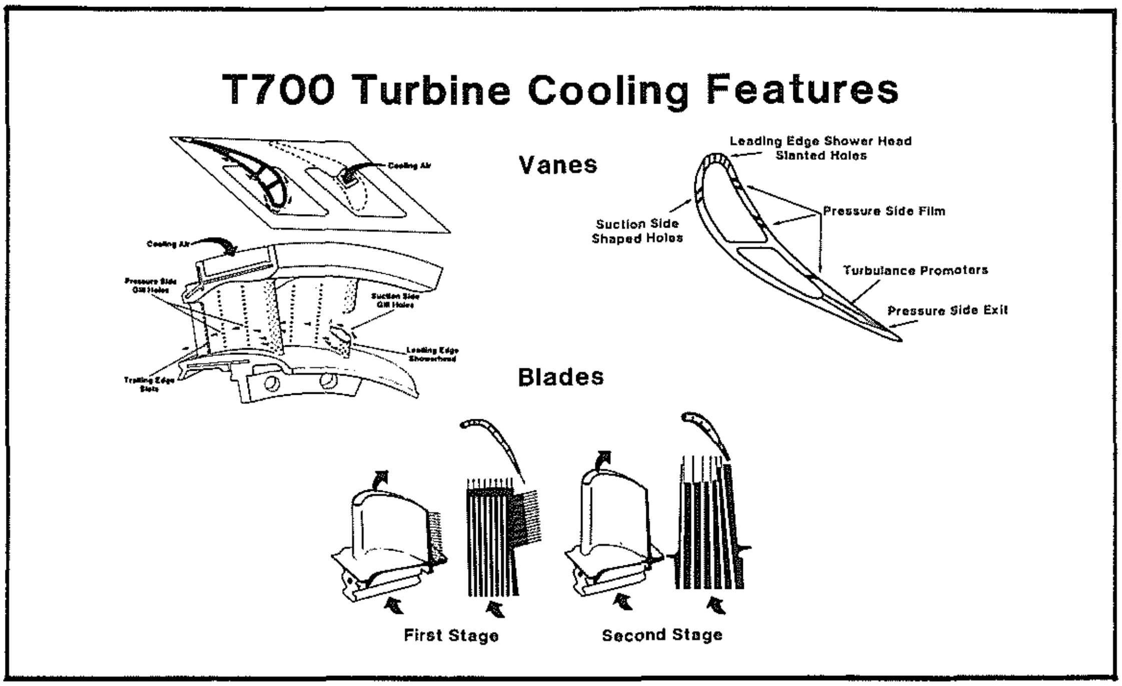


Figure 13

Demonstration Tests

Testing has been done on full scale engines to demonstrate both temperature and airflow techniques of increasing power. A booster configuration has been tested on a -700 engine model and elevated temperature testing has been conducted on both a T700-700 and -701 engine.

The booster tests were conducted in 1979-1980 and demonstrated the feasibility of this novel configuration. All test objectives were met and a power of increase of nearly 22% was demonstrated.

High temperature demonstrations have been made on the -700 engine at 200°F (110°C) above the maximum (redline) temperature of the engine. Recently tests have been done on the -701 configuration to 375°F (208°C) above its redline temperature at Intermediate Rated Power. These tests confirm the feasibility of the growth step temperature requirements and demonstrate excellent margin for the currently planned Step 2, 3 and 4 engines.

Step 1 Growth Engine

The T700 Step 1 growth is currently in production as the T700-GE-401 and -701 engines which produce about 10% more power than the -700. Growth power for these engine models has been obtained by a 3% airflow and a 50°F cycle temperature increase. Minor benefits have been obtained from a component efficiency "clean-up" program and an improved cooling system is utilized to permit the higher temperatures and maintain life.

Step 2 Growth Engine (T700-702)

This engine configuration has been designed for the follow-on Black Hawk and Apache programs. It utilizes an improved version of the high flow compressor from the turboprop program - having 15% flow increase from the T700-700 - and incorporates advanced technology turbine designs in the high pressure and low pressure systems. Improved materials and cooling system designs have been applied and a monocrystal turbine blade configuration is incorporated in the high pressure assembly. Both turbines have new flow path and aerodynamics. Advanced technology from other development programs has been utilized in the design of:

Inlet Particle Separator
Cooling System
Digital Electronic Control
Compressor Aerodynamics

The Step 2 growth engine is designed to operate only slightly higher in temperature than Step 1, well below the capability of the engine and even further below the tests that have been run to demonstrate operating temperature feasibility. Therefore, additional temperature capability is available to provide another growth step by "throttle-push" which produces the Step 3 growth engine of Figure 12.

The T700-702 revitalized technology will produce a substantial improvement over the -701 in specific fuel consumption, maintaining the dominant position the T700 has established for this class of engine. No existing engine can match its fuel consumption and projections made for new designs now in process also fall short.

In the design of the -702, attention is again being given to those elements that have made the T700 family unequalled in its class in performance, reliability, maintenance, operating cost and customer acceptance.

The -702 will be a "drop-in" replacement for current production models of the T700 engine. No modification of the aircraft will be required for installation. Production engines can be available in 1991.

Step 3 Growth Engine

The Step 3 engine is the same configuration as Step 2. Since Step 2 can reach its required power with minor temperature increase, the full temperature capability of the engine provides an additional engine growth step. Cooling flow is increased with cycle temperature to maintain the excellent life and reliability. The Step 3 engine produces about 45% power increase over the T700-700.

Step 4 Growth Engine

The Step 4 booster engine configuration has been demonstrated as a feasible method to obtain about 20% more power. Specific fuel consumption is essentially the same as for the base engine at the same power rating (not the same horsepower). Since the booster stage simply supercharges the base engine this improvement could be applied with similar percentage results to the -700, Step 1, 2, or 3 engines. The Figures and discussion assume the booster is applied to the Step 3 configuration. A typical booster configuration is shown in comparison with the current engine in the cutaway drawing of Figure 14.

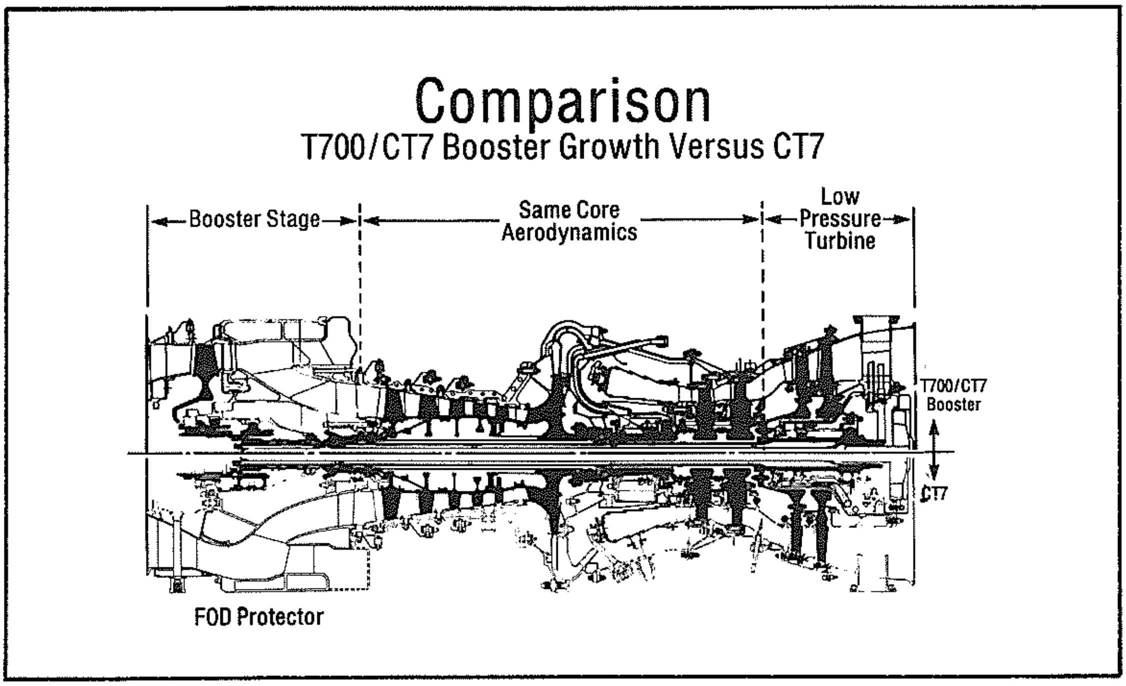


Figure 14

Currently all growth effort is directed toward the Step 2 program and there is no requirement for the power levels associated with the booster design so this engine must wait for an appropriate future requirement.

5 CONCLUSION

Maturity

The T700 engine has been developed to a revolutionary new plan defined jointly by the U.S. Army and General Electric. This plan was intended to provide early engine maturity, improved field operation and better fulfillment of mission objectives. A review at the half-million hour point shows that the program has been especially successful in meeting these objectives.

Growth

The T700 engine growth plan shows the capability for a total horsepower growth of 70%, similar to previous turboshaft engine programs. Feasibility of this plan has been established by current production versions of the engine family, a demonstration test program on a booster engine configuration and two test series demonstrating the engine capability to operate well above the current levels of temperature. An active program is now in place for the T700-702 (Step 2) engine which will produce a shaft horsepower more than 30 percent over the -700 level.

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