Def Sci J, Vol 38, No. 4, October 1988, pp 341-352

XG40 – Rolls-Royce Advanced Fighter Engine Demonstrator

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ABSTRACT

Commenced in 1982, the XG40 programme is central to the demonstration of Rolls-Royce technology appropriate to the requirements of the advanced combat engine for mid 1990's operation. At the same time, the technology in scaled form is viewed as having wider application than for the advanced combat engine alone.

To meet the multi-role requirements of advanced twin and single engined fighters, the combat engine must be designed to give enhanced dry thrust, retain good dry specific fuel consumption and reduce reheated fuel consumption compared with current fighter engines. A thrust/weight ratio of 10 : 1 is targeted and at the same time requirements for operating cost, reliability and durability are stringent.

Advanced materials, manufacturing technology and design of structures have been incorporated to enable the required levels of reliability, durability, component cost and weight to be demonstrated. The engine is in the 90/95 kN nominal Sea Level Static Combat thrust class.

1. INTRODUCTION

XG40 was initiated in 1982 as a major Military Demonstrator Programme aimed primarily at the requirements of the Advanced Combat Engine for 1990's operation.

The programme is jointly funded by Rolls-Royce and the United Kingdom, Ministry of Defence.

2. ORIGINS

Whilst XG40 was initiated as a Component Technology Demonstration Programme, it was conceived to include demonstration of the components in engine demonstrators. Cycle, engine configuration and size were selected accordingly based on possible military applications of the technology.

Received 26 April 1988.

3. PROGRAMME SCOPE AND TIMING

The total programme, (Fig. 1), comprises three sub programmes

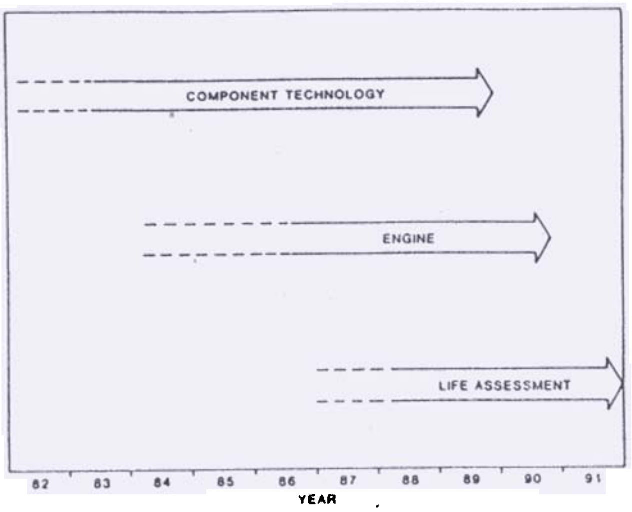

Figure 1. XG40 demonstration programmes.

– Component Technology Demonstration Programme
– Engine Demonstration Programme
– Life Assessment Demonstration Programme

The first of the above three includes aerothermal rig programmes, systems and structures rig programmes and a high pressure single spool (core) engine programme.

The Engine Demonstration Programme combines the HP spool and LP spool in an engine environment including both dry and reheat operation.

The Life Assessment Programme has as its primary purpose, the demonstration of the 'hot end' to meet the component design lives when operating in a real environment. The programme is based on high pressure spool and engine cyclic endurance testing. Sea level and altitude test facilities are used and Accelerated Service Endurance Test (ASET) schedules are included.

Technical behaviour, both aerothermal and structural, is modelled for individual components, assemblies and of course, the high pressure single spools and engines.

4. TECHNICAL CONCEPT

The technical concept of XG40 has been to ensure that for the technology selected :

targets are set to competetive levels

it is possible to demonstrate the technology in a time frame consistent with emerging Advanced Fighter Engine requirements and in particular, with those of EJ200.

designs are based on fore-running research and demonstrator programmes.

Cycle and engine size selections were approached from the above considerations plus parallel objectives that the XG40 engine without scaling should be interchangeably installable in Tornado.

The cycle was neither optimised for the mid 1990's Advanced Fighter requirement generally nor the emerging EJ200 requirement in particular but core size was carefully selected and a range of fan pressure-ratios is included in the programme. Figure 2 shows shows the effect of aircraft role on cycle selection. Figure 3 gives leading particulars of XG40.

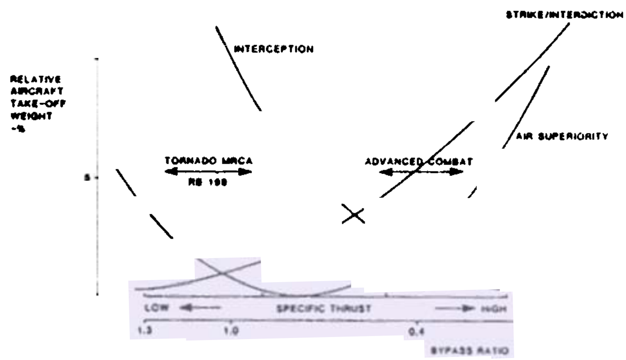

Figure 2. Cycle options for combat aircraft

THRUST/WEIGHT CLASS	10:1
FAN PRESSURE RATIO	3.9
OVERALL PRESSURE RATIO	26.0
REHEATED THRUST	90 Kn PLUS
DRY THRUST	50 Kn PLUS
MAXIMUM SOT	1800 K PLUS

Figure 3. XG40 leading particulars.

High thrust/weight ratio and high specific thrust require high values of fan pressure ratio and turbine inlet temperature. Low reheat fuel usage is particularly important for Advanced Combat Aircraft missions and this requires high turbine inlet temperature and high fan pressure ratio.

Component design lives have been set at levels consistent with achieving competitive maintenance material costs.

In the configuration and design of XG40, reliability and maintainability objectives that are appropriate to a new 1990's Advanced Combat Engine have been taken into account. XG40 has been designed for full modularity and is capable of accommodating engine health and performance monitoring systems.

XG40 is a key vehicle for the demonstration of advanced manufacturing techniques and processes and examples of these are given later.

Complementary programmes for advanced control systems and accessories are underway. Hydromechanicals representative of production are specified for XG40 : the digital electronic controllers are initially test bed mounted.

The configuration of XG40 is shown in Fig. 4.

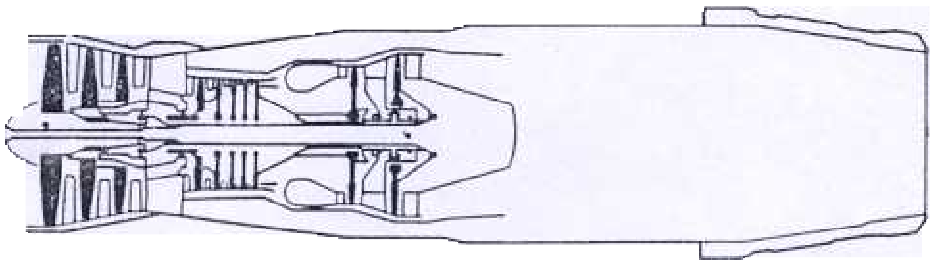

Figure 4. XG40 configuration.

5. ASPECTS OF COMPONENT DESIGN

5.1 Fan

With the wide bypass ratio variation between extreme operating points, variable geometry should offer aerodynamics advantages, although conflicting with cost, weight and reliability objectives. Demonstrations of both variable inlet guide vanes and variable outlet guide vanes are included in XG40 to compare with the datum design which has no inlet guide vanes.

All stages of blades are unsnubbered with advantages to performance and bird and foreign object ingestion resistance and are designed to latest flutter free criteria. The bladed discs are representative of production structures and the demonstration of vibration and flutter free characteristics is included in the programme.

The fan is overhung with the advantages over straddle mounting of avoidance of vulnerability of structures to bird ingestion FOD and unbalance.

5.2 Intercasing Between Fan and HPC

This casing is an internal cast titanium structural component challenging to manufacturing technology to keep sections thin, hence weight down.

5.3 HP Compressor

The design pressure ratio of the HP compressor is 6.5. It is a 5 stage machine with low aspect ratio blades. For investigatory reasons variable IGV's and a variable 1st stage stators are incorporated. Since specifying the initial HP compressor, emerging requirements for advanced combat aircraft for power off take for active control evolved and surge margin targets for XG40 were revised. Improved blading was specified.

The HP compressor rotor comprises a first stage disc, a second to fourth stage drum and a fifth stage disc integral with the compressor drive shaft. Titanium is used for stages 1 to 4, including high temperature titanium for the drum. The 5th stage disc and drive shaft is in nickel-based superalloy. Circumferential root fixing is used in stages 2 to 5.

Good rotor and stator tip clearance control is achieved by matching thermal response rates of the gas path casings with the rotors. These casings, made in low expansion steel, are isolated from the main structural engine casing made in titanium and have carefully designed thermal capacity and controlled environment.

5.4 Combustion Chamber

High combustion chamber temperature rise and operating fuel/air ratio require a relatively high proportion of the combustor air stream to be fed to the primary zone to ensure low smoke levels are met; the resultant air available for combustor wall cooling and dilution is reduced. (Fig. 5).

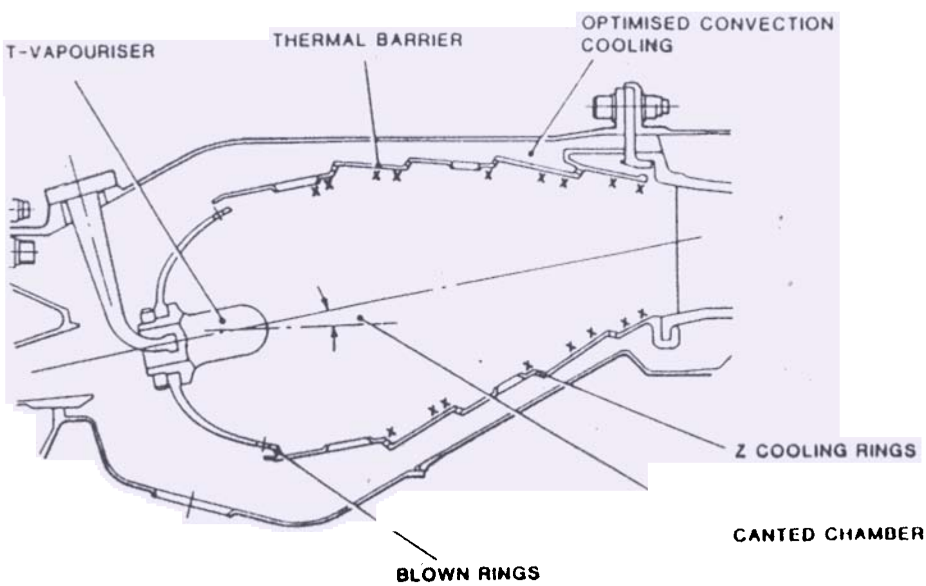

Figure 5. XG40 combustor

Sizing of the combustor for relight has taken into account RB199 experience. The chamber has a conventional dump diffuser upstream, and vaporiser fuel injection has been selected to attain the shortest, lightest (and lowest cost) design; temperature traverse achievements are at least comparable with alternative injection systems.

Nickel-based superalloys are used for the combustor. Wall cooling is by fine hole Z rings plus external convection improved by minimising annulus areas and including external turbulation on the combustor walls. Thermal barrier coatings are also specified.

5.5 HP Turbine

The single stage shroudless HP turbine is based on data from RB199 and RB211 turbine designs, together with data from UK research and demonstration programmes.

Rotor blade cooling, which is multipass with films, is high pressure fed via low radius pre-swirl with fully sealed coverplate. Blade damping is provided for. A Rolls-Royce in-house low density single crystal nickel-based superalloy has been specified, but the rotor design can accept higher density alloys.

XG40 is making an important contribution to the demonstration of single crystal turbine blade manufacturing technology.

Significant demonstrations of aerofoil thermal barrier coatings and advanced blade tip treatments to resist oxidation and abrasion are designed in. Initially the HP turbine has passive tip clearance control, but demonstration of active control systems is planned.

HP turbine discs and coverplate have been designed in nickel-based powder superalloy.

Nozzle Guide Vanes (NGV's) have inserts with multiple impingement surface films and trailing edge exhaust. The leading edge has shower head cooling. Platforms have impingement cooling. Thermal barrier coatings on aerofoils and platforms are to be demonstrated.

5.6 LP Turbine and Exhaust

The single stage LP turbine has a structural NGV and a shrouded rotor. The HP and LP spools contra-rotate, with a low deflection LP NGV. A multi-blade narrow chord exit guide vane assembly enables the gas to be deswirled before main diffusion.

The rotor blade is cast in the same single crystal material as the HP turbine.

The engine rear bearing support structure has been positioned through the LP NGV with benefits to HP turbine tip clearance control. The NGV and turbine rotor blade are cooled by third stage HP compressor bleed.

An important manufacturing technology demonstration has been the integral cast exhaust diffuser which includes the narrow chord hollow section exit guide vanes. Initially uncooled, potential for uprating with cooling is provided.

5.7 Oil/Air System

Separated bearing chambers have been designed, thus avoiding hot, weak-mixture intershaft spaces with the accompanying risk of oil, fire and carbon formation. Heat to oil is reduced by the design of low pressure bearing chambers sealed with brush seals and by the use of external bearing track cooling in main thrust bearings.

Conventional oil pumping and scavenging systems have been designed, but XG40 has alternative advanced designs for pumping and scavenging utilising the centrifugal fields in the bearing chambers.

5.8 Air System

The new features incorporated in XG40 include extensive use of brush seals and .P pressurisation from total head air system scoops in the intercasing.

5.9 Reheat System

High turbine exit temperatures of the advanced combat engine set new challenges, particularly to turbine stream fuel injection and flameholder systems.

Cooled metal fuel injectors have been designed and, for the baseline design of XG40, cooled metal structures are used for flameholder systems. Uncooled hot composites for selected flameholder systems have also been studied, however, and demonstrations commenced. Swirl burners present a further possible alternative allowing in principle the elimination of hot stream flameholders.

The extra vitiation of the turbine stream reduces its boost potential, but increases its proneness to buzz, thus XG40 is designed with special reference to reducing buzz.

Cooling air flow for the jet pipe and nozzle has been designed to be minimised in order to increase the boost potential of the bypass stream.

Multi-staged operation of the reheat has been designed in conjunction with advancements in fuel metering.

Fig. 6 illustrates the reheat combustion zone.

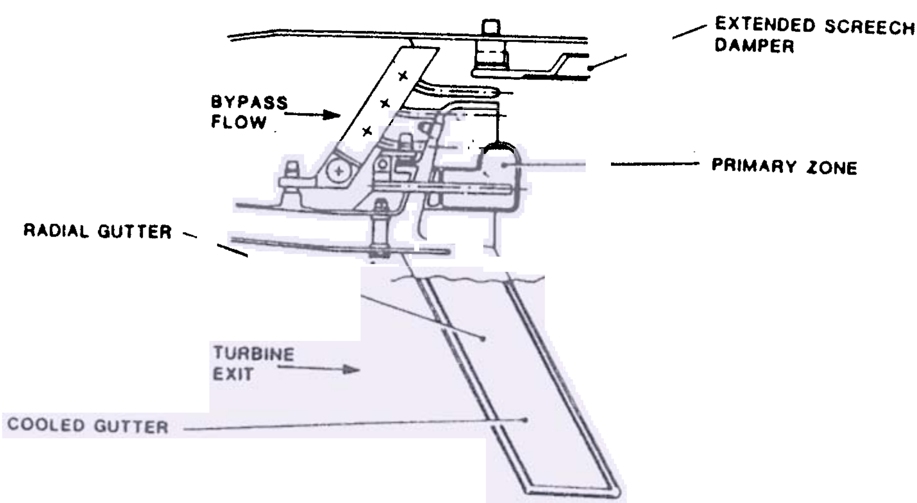

Figure 6. XG40 afterburner.

5.10 Engine Control

Dry engine control is designed to demonstrate variable geometry features including fully variable dry nozzle control, and to optimise turbine blade temperature control.

Reheated engine control is designed to permit closed loop control from alternative inputs, including fan duct Mach No. Reheat staging is designed for fully transient operation.

6. PROGRAMME STATUS

There follows a statement of progress and achievements at the time of going to press

6.1 Fan

Full scale aero rig programmes of both a 3.4 pressure ratio fan and a 3.9 pressure ratio fan have been successfully completed. The fan aero rig programme is now concentrated on the latter fan.

Improved design methods have been successful in achieving flutter free operation over the required operating range without snubbers and this fan has also been shown to be satisfactory under severely distorted inlet flow.

6.2 Intermediate Casing

The challenge to manufacturing was to achieve an integral casing in titanium with complex coring and fine wall sections. RR worked closely with the casting supplier and successful castings have been produced.

6.3 HP Compressor

Both the initial design and the revised aerodynamic design referred to earlier have been aero rig tested. Improvements in surge pressure ratio have been attained and gains in efficiency up to 90 per cent design speed.

6.4 Combustion

The aerothermodynamic targets set for the combustor have been met, including temperature traverse quality. One minor redesign of forward cooling rings has been required to achieve design flames tube wall temperatures.

Smoke results taken from the HP single spool engine testing to date confirm the design objectives.

6.5 HP Turbine

The shroudless rotor blade is the key component of the HP turbine around which both manufacturing and major engineering demonstration test programmes have been built.

Casting the blade advanced further aspects of single crystal casting core manufacturing technology and casting technology. Economical use of cooling air has placed demands on fine hole machining techniques; XG40 has played a strong part in providing the incentives to derive the required machining techniques which not only yield the small number of components for the demonstration programme needs, but have good process capability for production. Other important areas of manufacturing technology advance are being demonstrated, including thermal barrier coatings on nozzle guide vanes, blades and liners; rotor blade and liner tip treatments, directionally solidified and single crystal material nozzle guide vanes in monolithic and multipiece designs.

Turbine aerodynamics have been demonstrated in full scale plastic cold flow rig testing and design efficiency has been attained. Priority has been given to testing on the HP single spool engine, (Fig. 7), and the engine turbine performance has met

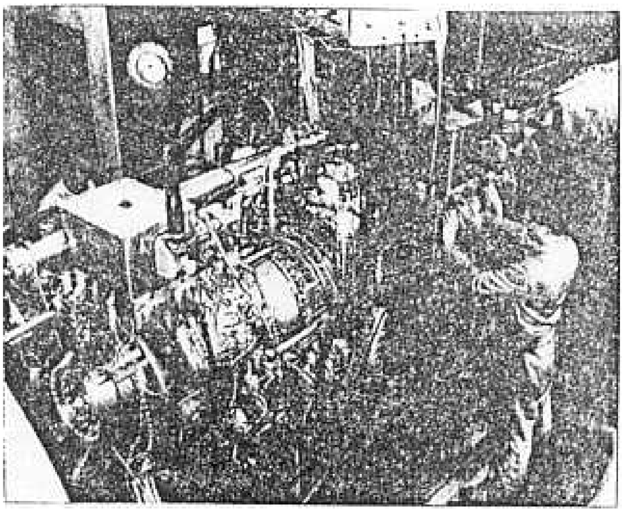

Figure 7. XG40 high pressure single spool engine installation in high altitude test plant

design point expectations. Further detailed exploration of performance is planned for the HP single spool engine, including demonstration of tip clearance effects; a thermally driven variable turbine shroud ring arrangement is incorporated for the latter testing.

For turbine blade cooling programmes, resin models of blades have been made for measurement of internal pressure loss and heat transfer coefficients. Direct assessment of vane and blade cooling has been made in dedicated thermal paint tests on the HP single spool engine. In general, a level of over cooling has been seen on the initial design, which was deliberately cautious. Refinements to cooling readily achieved by alterations to film cooling will be demonstrated. Transient temperature surveys on the turbine disc and blades are planned.

The demonstration and evolution of satisfactory rotor blade structural dynamics is carried out on the HP single spool engine.

The HP single spool is run in an altitude test facility to get correct engine conditions. Supporting fatigue rigs and both static and dynamic damping rigs are used in the rotor blade dynamics programme.

To date, a full datum strain gauge test programme with the blade undamped has been carried out over the full running range. A damped version is in the programme. Structural improvements to increase high cycle fatigue strength have also been identified. Cyclic testing of the rotor blade is a major element of the XG40 Life Assessment Programme. A second HP single spool engine is being built for cyclic testing and an engine will follow.

6.6 LP Turbine and Exhaust

Casting of this rotor blade, which is relatively high aspect ratio and shrouded, required considerable casting expertise to achieve the dimensional control required.

The turbine aerodynamics have been demonstrated initially with plastic blades and vanes on a cold flow rig at 0.87 scale to permit the use of an existing research rig. Design efficiency was achieved and no aerodynamic redesign is required. A full scale rig with engine standard vanes and blades in metal will be tested. In engine performance of the LP turbine is satisfactory.

From the testing completed to date on the engine, limited evidence from thermal paint suggests the nozzle guide vane is overcooled.

Detailed modelling of the NGV support suggested the running deflections would be only marginally acceptable. Therefore, early in the demonstration of the LP turbine, X-ray of this section was included in the initial engine testing and showed the structure operated satisfactorily.

Casting the exhaust diffuser with its integral cascade of vanes proved a major challenge to the supplier but was successfully completed closely to requirements, and the first unit has been run on the initial engine test. Durability will be demonstrated later in the Life Assessment Programme.

6.7 Reheat System

A phase 1 design has been demonstrated and a lighter weight phase 2 design, which differs in having unshrouded colanders, is on test.

Pressure loss, performance, stability, buzz and screech targets have been met. The screech shroud requires cooling development, which has commenced. Initial temperature surveys of the cooled metal flameholders and fuel injectors are encouraging. XG40 has radial turbine stream gutters; alternative sections and cooling designs are included in the programme. Burning length variation will be demonstrated in the reheat programme to provide data for weight vs. performance trade off.

6.8 Nozzle

XG40 base line demonstration programme is not planned to demonstrate advanced nozzles. An existing slave nozzle actuated with an advanced version of the RB199 air actuation system is operating satisfactorily on the engine

6.9 Controls

Engine starting and initial control in the dry mode, sea level static, has been demonstrated satisfactorily on the first engine test, Fig. 8 shows the engine installed in the sea level test bed. Initial operation of one of the rows of variable vanes in the HP compressor has been unsatisfactory with hunting, so modifications have been introduced.

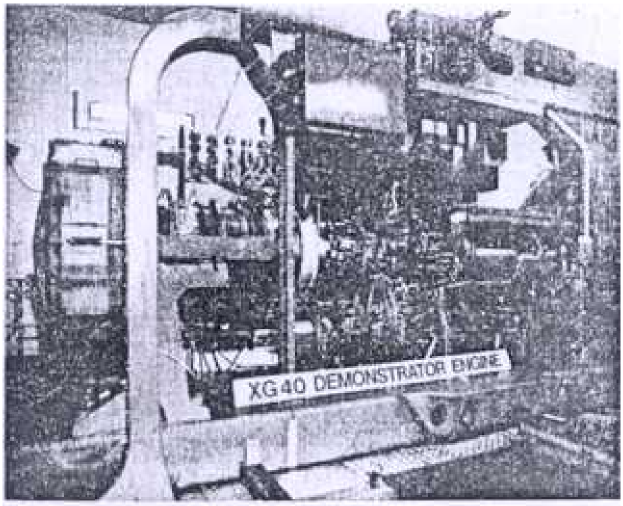

Figure 8. XG40 engine installed in test plant.

6.10 Engine Performance

Overall performance demonstrated to date in the dry mode closely met the predictions synthesised from rig component performance.

6.11 HP Single Spool

The following testing has been completed to date :-

HP turbine rotor blade dynamics survey

Component performance assessment

Starting characteristics

Smoke measurement

Low speed windmilling characteristics

Turbine X-ray of various steady state conditions

HP compressor variable vanes rescheduling

Air/oil system trimming

Hot end temperature paint test

The future programme includes HP turbine rotor blade dynami[illegible] de[illegible]il performance and component transient temperatures.

6.12 Engine

The following testing has been completed to date :

Auto starting

Full dry performance

Oil/air systems

Oil consumption

Whole engine dynamics

X-ray LP spool

Hot end temperature paints

Controls

Test cell installation performance effects

Advanced data acquisition system demonstration

The current engine testing incorporates the 3.9 pressure ratio fan and includes full dry and reheated demonstration up to specified thrust levels.

ACKNOWLEDGEMENTS

This work has been carried out with the support of the Procurement Executive, Ministry of Defence.