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# MG5 series Commercial Helicopter Engine Development and Utilization

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**ABSTRACT**

In Japan there have been no commercial aero-engines, which have been domestically developed and finally reached to the practical use.

Recently MG5 series 670kw (900 shaft horse power) class commercial helicopter engine has been developed and received type certification (TC) from Japanese civil aircraft bureau (JCAB) for the first time in Japan. And MH2000A commercial helicopter, which installs two MG5-110 engines, has also certified by JCAB in September 1999 and entered into service in October 1999.

Generally it takes very long time to develop a new aero engine. For this MG5 engine case, as a matter of fact, it took more than thirteen years from the beginning of basic plan of the prototype engine to the entry into service of production type engine.

In this paper, descriptions of MG5 prototype engine development which include the concept design, technical trend study, cost-performance study, power response study, engine structure, engine and component test results are presented.

As for production type MG5-100 / -110 engine, some detail engine descriptions, engine and component tests for Type Certification and post-TC developments are described.

## PROTOTYPE ENGINE DEVELOPMENT

### MG5 ENGINE CONCEPT DESIGNE

In the first stage of proto-type engine development, the "concept design" has been performed as usual. For this MG5 engine, the most important concepts are "all single stage compressor and turbine rotors" and "high pressure-ratio (11 to 1) single stage centrifugal compressor".

To keep the cost of the engine low, the concept of all single stage rotors, which means minimum numbers of engine parts, is very important and to keep the engine performance high, a high pressure-ratio compressor is essential. So the "good Cost / Performance" has been the basic concept of MG5 engine. Even though the absolute number of the specific fuel consumption was not the best one, if the number of rotors could be minimum, and high pressure-ratio compressor could be realized, this engine could be recognized as a "good Cost / Performance" engine.

So, "a single stage centrifugal compressor with pressure ratio of 11 to 1" has been challenged.

In general, when the pressure ratio of single stage centrifugal compressor increases, the adiabatic efficiency will decrease very much. So, keeping the high efficiency with high pressure ratio is a key point. This compressor of MG5 engine is based on the experience of in-house small model high pressure centrifugal compressor (12 to 1) component research program which has been held before the engine development and took nearly ten years.

As a result of employing high pressure ratio in single stage, the rotor speed of compressor impeller and high-pressure turbine is relatively high, and maximum stress of those components are accordingly higher than usual. In this engine, to resolve this point, target low cycle fatigue (LCF) life is reduced a little in the range of usual practical service life.

Another important concept of this engine has been the "power response". A new idea of controlling air flow using variable inlet guide vanes with centrifugal compressor has employed to reduce engine power response time.

### Technology Trend

In the aero engine development planning, the most important parameters are the specific fuel consumption (s.f.c.) and the weight of the engine that affect the aircraft operating cost directly.

As those parameters depend on the engine out put power, we should put the targets in the technology trend of the same class engines. Naturally the technology proceeds with the years, so the target should be higher enough even at the time of servicing. On the other hand, too much higher target causes increasing both engine manufacturing and development costs and decreasing the competitiveness.

Specific Fuel Consumption (s.f.c). In Figure.1 the year trend of s.f.c for small turbo-shaft engines at the time of MG5 engine planning is shown. The s.f.c level is getting lower and lower by the progress of technologies, so the MG5 target has set at the lowest level of 750kw class engines at 1990's.

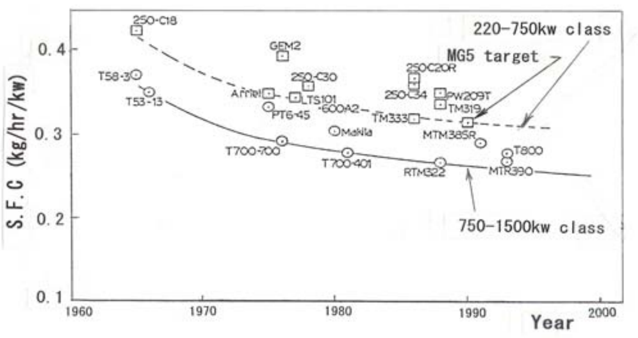


Fig.1 Year trend of specific fuel consumption of small engines


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Power to Weight Ratio. The engine weight has comparable importance with s.f.c., because if the weight can be reduced , the aircraft can install fuel much more than that expected. The year trend of weight to power ratio of small engines with and without reduction gear-box is shown In Figure.2. Naturally the power to weight ratio for engines with gear box is smaller than that for without gear box. The engine weight is getting lighter and lighter along with the years, so the MG5 target has set at the highest level of 750kw class with reduction gear box.

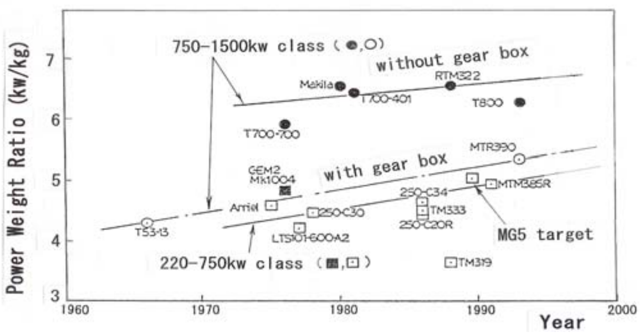


Fig.2 Year trend of power to weight ratio of small engines

Compressor Pressure Ratio. In the planning of the engine performance, as the engine s.f.c is affected by compressor pressure ratio and turbine inlet temperature, some investigation of the trend of those parameters is important. In Figure.3 the year trend of pressure ratio of single stage centrifugal compressor is shown. At the 1990's maximum level has been 9 to 1 in actual utility engine. In MHI small model of pressure ratio 12 to 1 has been studied for long time, but because the efficiency drop causing high pressure ratio was not so small, the target of MG5 has selected at 11 to 1.

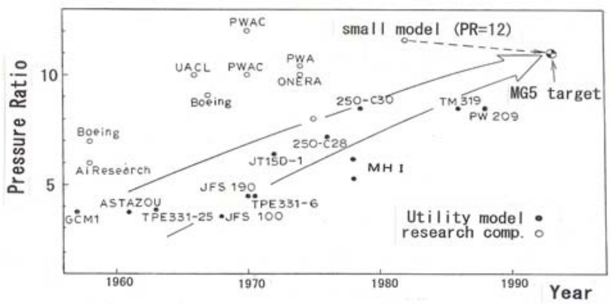


Fig.3 Year trend of compressor pressure ratio of small engines

Turbine Inlet Temperature (TIT). TIT level of small engine is relatively low comparing to the big engines because of the size limitation of cooling blades. Even in the range of small engine, this difference still exists, so the TIT level of 220-750kw class is lower than that of 750-1500kw class, as shown in Figure.4. The target TIT of MG5 is selected at 1100℃ considering future growth potential.

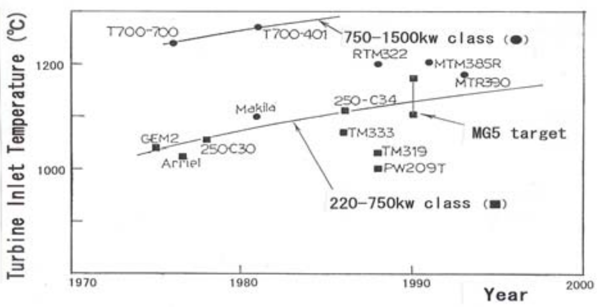


Fig.4 Year trend of turbine inlet temperature

## Optimization of Engine Concept

Generally in the first step of engine development, the "concept design" is performed. From the customer satisfaction point of view, engine concept design should begin with aircraft (helicopter) needs. So, beginning from what kind of characteristics are needed for the aircraft, then what kind of requirements to the engine come from these aircraft needs, and finally what kind of concept should be placed to the engine design to satisfy the requirement. In the flow of those thinking, the optimization of concept is performed.

In Table.1 those flow of optimization of MG5 engine concept is shown and final key words for engine design are summarized.

Table.1 Optimization Study of Engine Concept

| Aircraft Needs | Requirement To the Engine | Key Words for Engine Design |
|---|---|---|
| High Speed | Small Size | All single Stage Component. High Pressure Ratio Centrifugal Compressor. Variable Inlet Guide Vane. Cooled Turbine (High TIT). Simple Structure Minimum Engine Parts |
| | High Power | |
| High Maneuverability | Inlet Distortion Durability | |
| | High Response | |
| Cruise Performance | Low SFC | |
| | Light weight | |
| Environmental Durability | Ingestion Durability | Single Stage Centrifugal Compressor |
| High Reliability | High Reliability | Redundancy for FADEC |
| Maintainability | Maintainability | Modular Structure |
| Weight Growth | Growth Potential | Room for Growth |
| Low Cost | Low Engine Cost | Simple Structure, min. Parts |

For MG5 engine, the most important concepts are "all single stage component rotors" which correspond to minimum engine parts and simple structure i.e. low cost, and "a high pressure ratio (11 to 1) single stage centrifugal compressor" which correspond to high performance.

## Engine Cost Performance

To keep the engine cost low, the concept of all single stage rotor is essential. When plotting the engine specific fuel consumption (s.f.c.) versus number of rotors, as shown in Fig.5, the "good cost / performance" engine is described as that is closer to the origin of the figure. Even if the absolute s.f.c. is not the best one, when the number of rotors could be minimum, this engine can be called as a "good cost / performance" engine.

As a result of MG5 study, the target is placed at the point shown in the Figure.5, which means minimum stages of three(3) and minimum s.f.c. that comes from cycle parametric study described below.

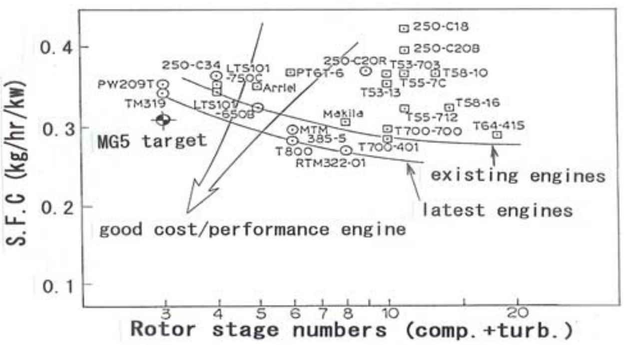


Fig.5 Engine "cost / performance"

## Engine Cycle Parametric Study

To realize better s.f.c., higher pressure-ratio and higher TIT are desirable, but there has been a restriction from the single stage compressor and very small size turbine blades. So, cycle parametric studies of engine s.f.c. and specific power, considering about the relation of adiabatic efficiency to the compressor pressure ratio and turbine aerodynamic loading factor, have been performed as shown in Figure.6 below.

Final result of the MG5 prototype engine study , considering future engine growth, has been the pressure ratio of 11 to 1, and the TIT of 1100℃ at 634kw out put power.

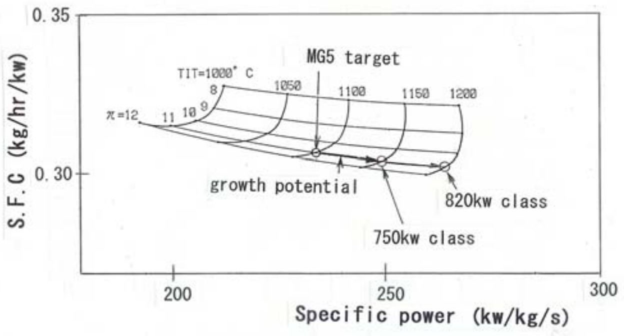


Fig.6 Engine cycle parametric study

## MG5 PROTOTYPE ENGINE

### Final Engine Configuration and Specifications

As a Result of a optimization study of engine concept mainly for the "cost / performance", final engine configuration and specifications as follows. That is a single stage high pressure ratio centrifugal compressor, an inverse flow type annular combustor with twelve fuel nozzles, a single stage cooled axial gas-generator turbine, and a single stage axial shrouded power turbine.

The target out put power has been 634kw(850shp) with growth potential up to 895kw(1200shp).

Those configuration and specifications of MG5 prototype engine are summarized in Table.2.

Table2. Final Engine Configuration & Specification

| | Configuration & Specification |
|---|---|
| Engine | Power Class 634 kW (850 shp),<br>Growth potential up to 895 kW (1200 shp)<br>Best Cost/Performance & min. Parts |
| Compressor | Single Stag Centrifugal with VIGV,<br>Pressure Ratio 11 to 1, Speed 51,870 rpm |
| Combustor | Annular, Inverse flow Type,<br>12 fuel nozzles |
| HP Turbine | Single Stage Axial Cooled Turbine<br>TIT: 1100 deg. C, growth 1250 deg. C<br>Speed 51,870 rpm |
| LP Turbine | Single Stage Axial Un-cooled Turbine, with a Long Through Shaft, Speed 34,500 rpm. |
| Reduction G/B | Two Stages Reduction Type, Accessory Gears, Oil pumps, Oil tank are integrated.<br>Out put shaft speed 6,000 rpm |
| Controller | Double Channel FADEC with Large Hybrid IC (Multi-Chip Module) |

### Engine Structure

Effect of single stage compressor. The number of engine parts is strongly affected by the number of main component rotors. As an example, Alto et al. mentioned that a compressor, constructed with 6 axial and 1 centrifugal, has 527 parts, but in a 2 stages centrifugal compressor has only 20 parts. In MG5 engine, by the effect of single stage compressor, it has only 7 parts in the compressor section.

As stated above, the effect of adopting all single stage rotors (compressor and turbine rotor) contributed to the realization of a "good cost / performance" engine.

Main component arrangement. As in almost all helicopters, engines are placed after the main rotor transmission, the out put shaft of the engines is desirable to be arranged on the engine front face, and naturally the inlet air to the compressor is desirable to be ingested from front or side. So, to satisfy these two needs, recent new engines have an arrangement that the power turbine is putted after the core engine (gas-generator), and the power turbine shaft goes through the gas-generator to the front reduction gear box.

In MG5 prototype engine, this ideal arrangement has employed, and kept this configuration through the MG5 series engines later. The front gear box assembles not only the reduction gears but also accessory drive gears, that contributes to reduce engine parts and also to increase maintainability of the engine. The cross section and out side view of MG5 prototype engine are shown in Figure.7 and Figure.8 below.

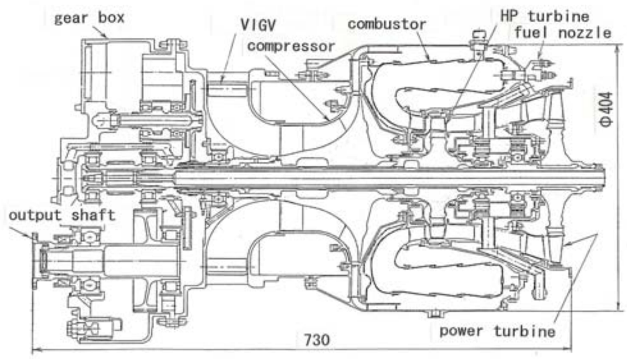


Fig.7 Cross section of MG5 prototype engine

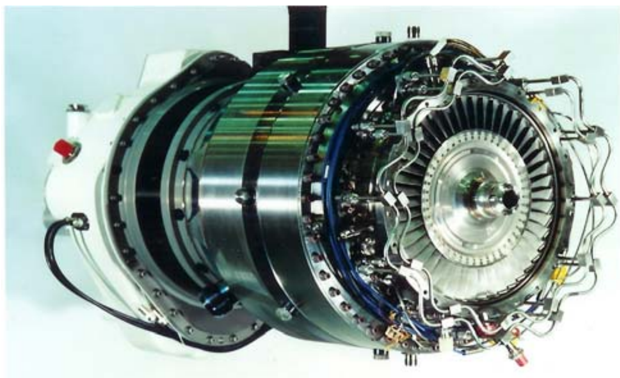

Fig.8 Outside view of MG5 prototype engine

### Engine Performance Tests

Engine tests, which have been performed on the test bench, include Sea Level Static performance, 150Hr Endurance, High Altitude performance and Vibration survey etc., and cumulative test hours reached more than 850 hrs in about three years.

Sea Level, Static performance test. A sample of sea level static performance test results is shown in Figure.9. Maximum power reached up to 716KW, 13% more than expected.

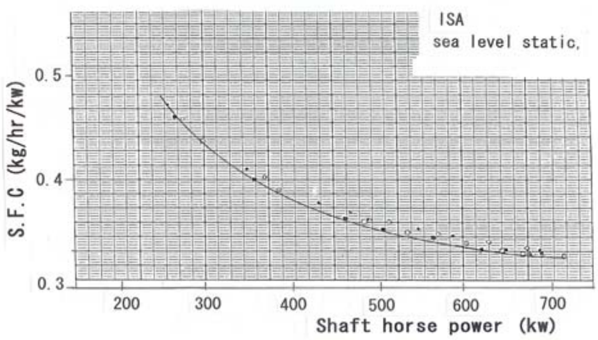


Fig.9 Prototype engine performance test results

High Altitude test. For the aero-engine, high altitude engine performance with parameters of altitude and mach number is essential in the new engine development. At the time of MG5 prototype engine development, there was no altitude test facility in Japan, so other engines developed in Japan has been tested in foreign countries. So, for this MG5 engine MHI constructed in house small size altitude test facility, and made high altitude performance test for the first time in Japan in 1989. A sample test results at altitude 6,000m and mach number up to 0.35 with a parameter of turbine outlet temperature ($T_5$) is shown in Figure.10.

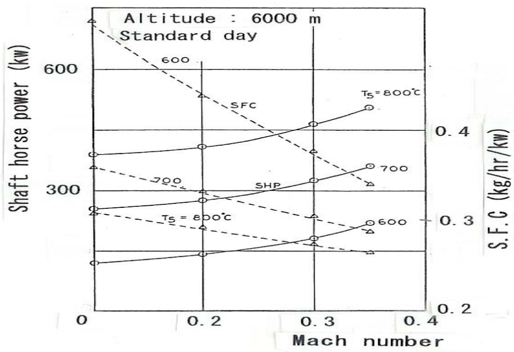


Fig.10 Prototype engine high altitude performance test results

## ENGINE POWER RESPONSE

One of characteristics of MG5 engine is employing a new idea of increasing engine power response, using the combination of variable inlet guide vanes (VIGV) and centrifugal compressor.

### Concept of high response

In ordinary small turbo-shaft engine power up-and-down is performed by increase and decrease of rotational speed, so response time depends on gas-generator rotor inertia. The new idea of increasing response is controlling compressor air flow by VIGV with constant rotational speed. In this case, response time depends only on the VIGV actuator response time and rotor inertia effect can be canceled. In Figure.11, constant power curves (% shaft horse power) are shown by the combination of VIGV angle and rotational speed. In this figure, ordinary engine corresponds to line①, new concept engine corresponds to line③.

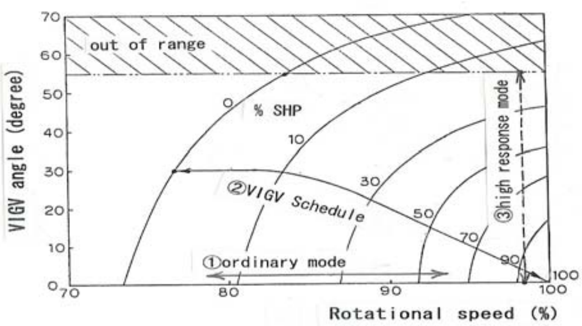


Fig.11 Basic concept of high response of engine power

### Compressor characteristics with VIGV

Before testing those high response concepts in engine, it is necessary to verify compressor characteristics with VIGV, so a compressor rig test has performed. Test results are shown in Figure.12 below.

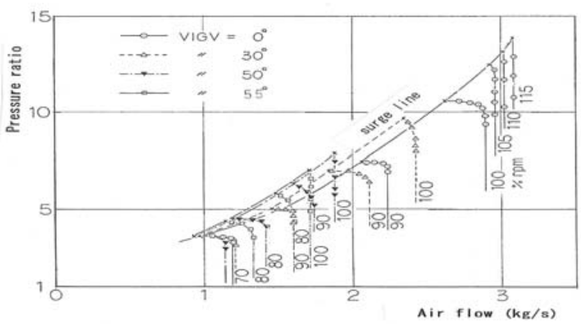


Fig.12 Compressor characteristics with VIGV

### Engine high power response test

After verifying compressor characteristics with VIGV, actual engine high response test which corresponds to the line③ in Figure.11 has performed for both "power up" and "power down" cases as shown in Figure.13.

In "power down" case when VIGV angle changed from 4 degrees (open) to 55 degrees (close) in about one second, the engine out put power changed from 600kw to 165kw in only 1.3 second with constant gas-generator speed of 51,000 rpm. Also in "power up" case the power changed from 165kw to about 600kw in 1.3 second by the VIGV angle change of 55 to 4 degrees.

In both cases power turbine speed is constant with only a little fluctuation, HP (gas-generator) turbine exit temperature changes naturally, between 620 – 800 degree C., and of course no unstable phenomenon like surge has occurred. From these points engine fuel control is also stable corresponding to VIGV angle change.

In ordinary engines the response time is usually 4 to 5 seconds between idle to maximum power. So, although the range of power change was not full, very high response time has demonstrated, and the new concept has verified. In actual prototype engine, VIGV angle is scheduled like a curve② in Figure.11.

This new idea of high response is patented in many countries.

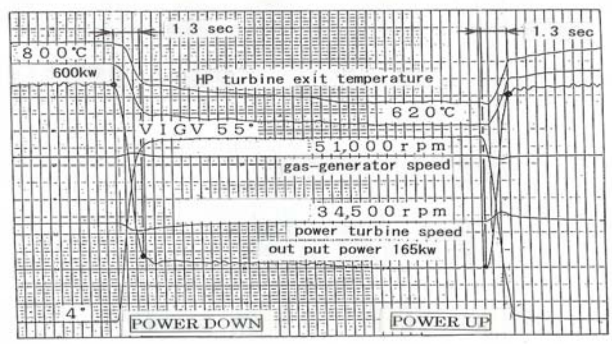


Fig.13 Prototype engine high response test results

## COMMERCIAL HELICOPTER ENGINE

### MG5-100 / -110 ENGINE

After the basic development test for proto-type engine and component, MG5-100 / -110 production type engine for MH2000 commercial helicopter has been designed and applied for JCAB Type Certification in 1995.

Of course both engines are based on prototype MG5 engine, and main components and structure has been kept. The first production type MG5-100 engine is 600kw class which is certified in June 1997, second production type MG5-110 is up-rated about 10% from –100 engine and certified in April 1999 and entered into service in October 1999.

MG5-100 / -110 engine out side view is shown in Figure.14 below.

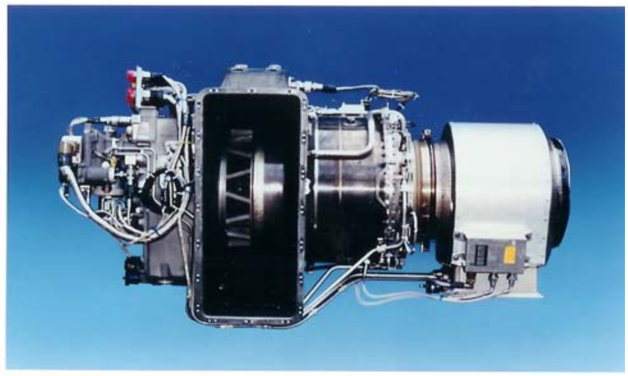

Fig.14 MG5-100 / -110 engine outside view

**Engine Specification**

Engine specifications such as power ratings, dimensions, weight and rotational speeds are summarized in Table.3.

Table.3  MG5-100 / -110 Engine Specifications

| | | MG5-100 | MG5-110 |
|---|---|---|---|
| Rating (kw) | 2.5MIN.OEI | NA | 688 |
| | 30MIN.OEI | 627 | 654 |
| | Take Off | 597 | 654 |
| | MAX. Continuous | 582 | 576 |
| | MAX. Cont.（90%rpm） | NA | 518 |
| Dimension | (Length, mm) * | 1,154 | 1,170 |
| | (Width, mm) * | 574 | 574 |
| | (Height, mm) * | 675 | 730 |
| Dry Weight（kg） * | | 154 | 154 |
| Speed (rpm) | High Pressure Shaft | 51,600 | 51,870 |
| | Power Turbine Shaft | 32,500 | 32,500 |
| | Output Shaft | 5,700 | 5,700 |
| | Ditto at 90%rpm | NA | 5,130 |

*Including inlet and exhaust duct, oil cooler and blower

**Engine Operating Range**

The operating rage of MG5-110 is summarized in Table.4.

Table. 4  Engine Operating Range

| Items | Operating Range |
|---|---|
| Altitude | 0 to 4500m (15000 feet) |
| Speed | 0 to 0.3 Mach |
| Temperature | -35 to International Standard Air +30 C |
| High Pressure Shaft Speed | Max. Allowable (Stable) 103% |
| | Max. Allowable (Transient) 106% |
| Output Shaft Speed | Max. Allowable (Stable) 105% |
| | Max. Allowable (Transient) 121% |
| Oil Temperature | -35 to 105 degree C |
| Fuel Temperature | -35 to 57 degree C |
| Main Fuel | Jet A1 |

**Engine Structure**

As already stated, the engine structure is the same as prototype which described in Table.2. The cross section is shown in Figure.15 and detail description of each component is as follows.

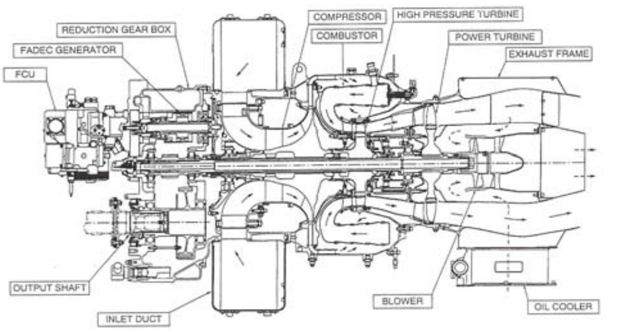


Fig.15 Cross section of MG5-100/-110 engine

Compressor. Compressor impeller which is machined from Ti-6246 forging raw material, has 11 full length blades, 11 first and 22 second splitters. Diffuser, which is also machined, consists of channel type radial and vane type axial diffusers. And 32 inlet guide vanes, made of aluminum precision casting, are arranged in circular position and driven by a ring gear.

Combustor. Combustion chamber is fabricated and welded from hastelloy-X sheet metal, and has twelve(12) fuel nozzles and two(2) ignitors. Each hybrid type fuel nozzle consists of pressure atomizer type primary and air-blast type secondary portions.

High pressure turbine. High pressure turbine rotor consists of 33 directionally solidified (DS) Mar.M247 precision casting cooled blades, forged and machined Inco718 disk and side plate which forms cooling air passage with the disk, and connected with compressor impeller by a tie rod. 17 cooled nozzle vanes are also DS Mar.M247 precision casting.

Power turbine. Power turbine rotor consists of 46 Inco713 precision casting shrouded blades, forged and machined Inco718 disk, and steel long shaft which goes through compressor and HP turbine rotor, and counter rotates with gas-generator. Turbine nozzle is an Inco713 integrated ring casting which have 28 vanes. Power turbine casing, made of Inco713 precision casting, forms also a middle frame and oil sump of two turbines.

Reduction gear box. Reduction gear box consist of two stage gears, accessory gears which drive starter-generator, fuel control unit, and oil pumps etc. High pressure oil pump, two scavenge pumps, oil tank, and permanent magnetic generator for FADEC are integrated in this gear box.

Engine system. As a different characteristic, MG5 series engine have an inlet duct, exhaust duct, oil cooler and blower for oil cooler as engine parts, that reduced the interface points between engine and air frame and realized an easy handling on the air frame.

Also considering the engine maintainability, MG5 can be separated in three big modules, that is gear box module, core engine module, and power turbine module, as shown in Figure.16.

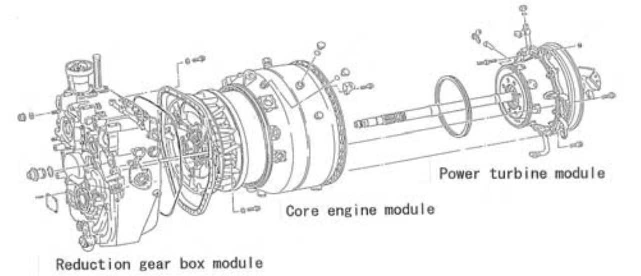


Fig.16 MG5-100 / -110 engine module structure

**Structural Integrity**

In the aero-engine, for the purpose of flight safety, component structure integrity design is very important, and each component must have enough stress margins accordingly. To ensure those stress margins, component stress proof tests are conducted in the engine development.

Design results of those items are summarized in Table.5 as a stress integrity. Each component has enough stress margins, even when operated at allowable maximum rotational speed shown in the table.

Over speed, over temperature. Assuming the engine over speed, over temperature was occurred in some reason, engine must endure 5 minutes test of 115% speed of maximum allowable speed, and +45℃ of maximum allowable temperature, individually. In MG5, as shown in the table, compressor and HP turbine has verified that there is no permanent deformation at 118% (103*1.15%), and power turbine at 121% (105*1.15%), by the analysis and test. Also for over temperature engine has operated +45℃ at maximum allowable speed. The stress margins in the table means a room for the allowable stress, when operated at the condition stated.

Disk burst. Engine main disks are required to be designed that disk burst does not occur under the speed of 122% of maximum allowable speed. In MG5, as shown in the table, compressor and HP turbine has verified that disk burst does not occur at 126%

(103*1.22%) speed, and power turbine at 128% (105*1.22%), by component tests. The stress margins in the table also means a room for the allowable stress, when operated at the condition stated.

Blade containment. In the aero-engine, casings are required to contain blades, even if a blade is separated from disk in the flight condition. In MG5 also, casings are designed to have enough room to absorb the separated blade energy, and engine tested for HP turbine blade, component spin pit tested for power turbine blade for proof. The stress margins in the table means a room for the allowable energy absorption, when operated at the condition stated. (A blade penetrates the casing at 100%).

Table.5 Summary of Structure Integrity

| Items | Part name | Speed (rpm) | Stress Margin |
|---|---|---|---|
| Over speed | Compressor impeller | 118% | 162% |
| | HP turbine blade | | 199% |
| | HP turbine disk | | 136% |
| | LP turbine blade | 121% | 121% |
| | LP turbine disk | | 145% |
| Over temp. (+45℃) | HP turbine blade | 103% | 146% |
| | HP turbine disk | | 177% |
| | LP turbine blade | 105% | 160% |
| | LP turbine disk | | 191% |
| Disk burst | Compressor impeller | 126% | 169% |
| | HP turbine disk | | 141% |
| | LP turbine disk | 128% | 151% |
| Blade containment | HP turbine case | 106% | 125% |
| | LP turbine case | 121% | 110% |

Disk service cycle life. As mentioned before, target low cycle fatigue life is reduced a little in the range of usual service life, that is 9000cycles for cold parts and 4500cycles for hot parts.

**FADEC and Control System**

FADEC is separated from the engine high temperature environment and mounted on air-frame avionics room, designed as double channel system for high reliability. It controls fuel flow and VIGV angle, corresponding to pilot's power requirement (corrective lever angle), keeping the out put shaft speed constant.

The basic concept of double channel FADEC is "one fail operative and two fails safe", so even if one channel is failed it controls the engine completely, and if two channels failed it freezes the control in the condition of just before failure. Software of FADEC is based on DO-178.

In the Table.6 basic functions of FADEC are summarized.

Table.6 Functions of FADEC

| Basic Concept of FADEC : One Fail Operative, Two Fails Safe. | |
|---|---|
| Main Control Functions | Fuel flow Control (Constant Shaft Speed) |
| | VIGV Control |
| | Start & Stop Control |
| | Acceleration & Deceleration Control |
| | Functions of Limiters |
| Matching with Airframe | Torsional Instability |
| | Torque Balance between two Engines |
| Data Communication | Between Two Engines |
| | Engine to Cockpit and GSE |
| Engine Back up | Automatic Re-ignition after Blow Out |
| | Evasion from Acceleration Surge |
| Reliability & Maintainability | Two Channels Redundancy Administration |
| | Data Administration for Maintainability |
| Training | OEI training mode |

The flow of data and signals in control system is shown in Fig.17 as a block diagram.

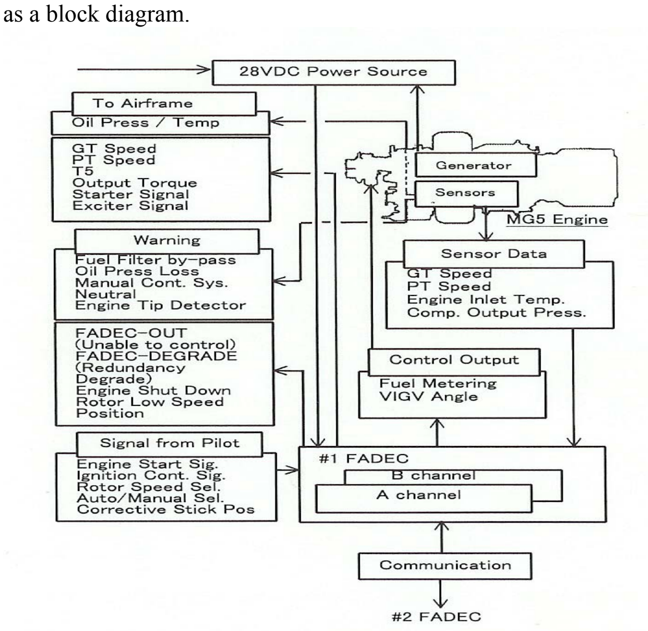


Fig.17 Control system block diagram

**FCU and Fuel System**

Fuel system consists of fuel control unit (FCU), fuel pressure switch and fuel nozzles, as shown in Figure.18 below. IN this system, FCU includes fuel metering valve driven by stepping motor, high pressure and low pressure fuel pump, VIGV control valve and actuator, over speed governing valve, filter etc. It also includes manual control device for driving fuel metering valve directly in the case of emergency.

New traction roller type fuel metering valve consists of four planetary rollers and flexible outer ring, have many characteristics such that it can control primary and secondary fuel at a time, it's driving torque is so small, and it can also work as a fuel shut off valve etc. This new idea is patented in many countries.

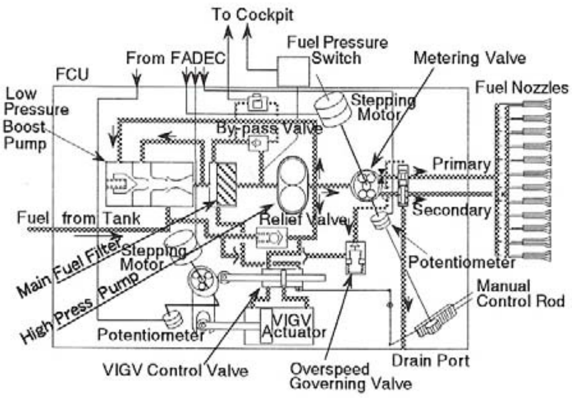


Fig.18 FCU and Fuel system

**Oil System**

Engine oil system is shown in Figure.19.

It consists of an oil pump, two scavenge pumps, oil separator, de-aerator, relief and by-pass valves, oil tank including emergency one, air cooled oil cooler, blower for cooler, two chip detectors in the scavenge lines etc.

This blower is installed on the power turbine shaft directly and ingests cooling air through oil cooler and struts of engine exhaust duct. So, this configuration does not require any oil line interface between engine and air-frame, and improves the maintainability of the MG5.

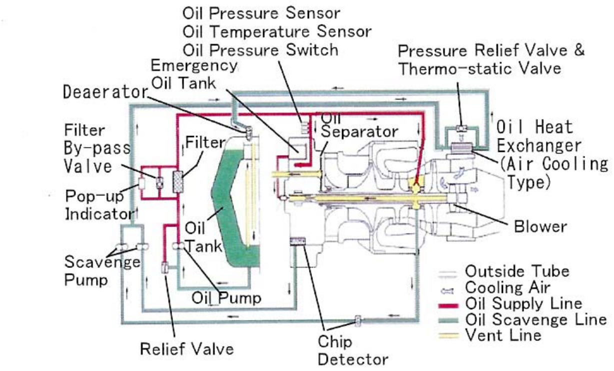


Fig.19 Oil system

**ENGINE TYPE CERTIFICATION**

**Engine Tests**

The engine and component certification tests are conducted under the Japanese Airworthiness Regulations which is equivalent to FAR part33 and finally certified by JCAB for the first time in Japan as a commercial aero-engine in June 1997 for MG5-100 and in April 1999 for MG5-110.

Type certification engine tests are summarized in Table.7.

Table.7 Type Certification Engine Tests

| Engine Test Items | Brief Contents |
|---|---|
| High Altitude Test | Performance Test at High Altitude. |
| Inlet Distortion Test | Engine Run with Inlet Distortion Plate. |
| Vibration Test | Engine Run at Critical Speeds, Vib. Survey. |
| High, Low Temp. Test | Engine Starting at –35 to 57 degree C. etc. |
| Over Temp. Test | 5 min. Operation at Over Temperature. |
| Over Speed Test | 5 min. Operation at Over Speed. |
| Water Ingestion Test | Engine Run in 500mm/Hr Rain |
| Bird, Ice, Hail Ingestion | Engine Run with Bird, Ice, Hail Ingestion. |
| 150Hr Brock Test | Endurance Test of 6Hr Pattern *25 cycles. |
| Electric Power Cut off | Safety Verification with Elec. Power off. |
| Icing Test | Engine Run in the Icing Condition. |
| IMI (*) Test | Accelerated Endurance to establish TBO(*). |
| Alternative Fuel Test | 6 Hr Endurance Test with Alternative Fuel. |

(*) IMI : Initial Maintenance Inspection
TBO: Time Between Overhaul

**Component Tests**

Type certification tests for main components are also conducted under the JCAB regulations which is also equivalent to FAR33, and summarized in Table.8.

Table.8 Type Certification Component Tests

| Test Items | Brief Contents |
|---|---|
| FADEC Functional & Environmental Test | FADEC Hardware & Software (DO-178) Verification and Proof. |
| Contaminated Fuel Test | FCU Operating with Contaminated Fuel. |
| Oil cooler Firing Test | Fire Durability Verification and Proof. |
| Static Load Test | Engine Carcass Static Loading Test |
| Over Speed Test | High Pressure Rotor Spin Pit Test |
| Containment Test (Power turbine) | Casing Durability Verification and Proof Test with Blade off in the Spin Pit. |
| LCF - Comp. Impeller | Cold and Hot Cyclic Spin Pit Test. (Target cycle×two times) |
| LCF - G. Turbine Disc | |
| LCF - P. Turbine Disc | |
| Oil Tank Pressure Test | Tank Pressurizing Proof Test. |

All the requirements of Airworthiness Regulations, including design and manufacturing, engine and component analysis / test are finally satisfied and summarized in a compliance report which is the basis of certification. All the range of operation as a commercial aero-engine, are restricted in the range of the proof test results which is described in the report, by the reason of flight safety. And some of the operating range are shown in Table.4.

**Post-Certification Engine Test**

Even after the event of entry into service, MG5 engine has been running on the test bench as a post-TC development, and the TBO extension program is still under way.

Cumulative engine running hour is an important index for the reliability, and in MG5 engine current running hour is approx. 3000Hr on the bench, 9500Hr on the aircraft and TBO is 1800Hr.

Total engine running hour including another derivative of MG5 prototype engine accumulates approx. 35000Hr at the moment.

These numbers are still not long enough for the commercial aero engine, so post-certification test will be conducted further more.

**MH2000 COMMERCIAL HELICOPTER**

The first application of MG5-110 is MH2000A commercial helicopter, which entered into service in October 1999.

As described in references by Kobayashi and Sakura (2002), the development of the MH2000 twin-engine commercial helicopter was started in 1995, and production type MH2000A was certified by JCAB in September 1999. In addition to its unique features of a short-term development period, and the first purely Japanese made commercial helicopter, MH2000 was developed both the aircraft and its engine MG5 at the same time in the same company, which is the first case in the aircraft industry in the world.

In Fig.20 and 21, pictures and 3-view drawing are shown.

Fig.20 MH2000A commercial helicopter pictures

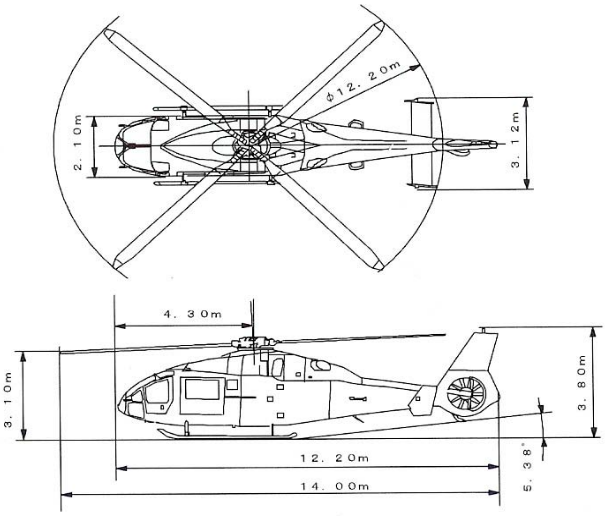


Fig.21 MH2000A out side view drawing

## CONCLUSION

Here, regarding MG5 series engine, beginning from the first step of concept design of prototype engine, and finalizing at the Type Certification as a commercial turbo-shaft MG5-100 / -110 engine, a general description of aero-engine development and it's utilization has presented briefly.

From the engineering point of view, there are some important points such as "Single stage centrifugal compressor which has world highest pressure ratio of 11 to 1", "World minimum size cooled turbine blade", "New concept of engine-power-response increase" and "Employment of new planetary-roller-type fuel flow valve" etc.

And, as a utilized commercial areo-engine point of view, MG5-100 / -110 engine has a memorial meaning of the first engine in Japan which received Japanese Civil Aircraft Bureau (JCAB) Type Certification.

Although Japan is recognized as a highly developed industrial country, she is still a developing country in the field of Aircraft and Aero-engine. So, it is appreciated that this report and the results of MG5 engine Development and Utilization will help the commercial engine developments in future in this country.

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