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TEST OF A HOT-GAS ROTOR
OF THE 1.5 T CLASS

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1. INTRODUCTION

Subsequent to the development of the one-man helicopter Do 32 a contract was awarded by the Federal Ministry of Defense for the development of the experimental helicopter Do 132.

It was planned to examine within the framework of this development whether the efficiency of a reaction helicopter could be increased by means of hot gas drive and whether the simplicity of the cold cycle drive could be maintained.

Due to financial reasons the programme had to be limited to the development of the dynamic system and its testing on the test stand on the basis of a specific testing programme that was set up in accordance with the arising interest of the German army in unmanned rotor platforms.

In spring 1977 this programme was successfully carried out.

2. DESCRIPTION OF THE DYNAMIC SYSTEM OF THE DO 132 AND THE TEST SETUP

2.1 Dynamic System of the Do 132

The dynamic system consists of a gas generator, a rotor driven by blade tip jets and the blade control system.

The drive system of the hot cycle rotor is illustrated in Figure 1.

The hot drive gases flow from a gas generator - a modified gas turbine (P & W PT6-A20) - through the hollow rotor mast, rotor hub, and the blades to the blade tip nozzles.

The hot gases are ducted in thin-walled pipes that are separated from the load carrying structures by means of an insulation. Figure 2 shows the hot cycle rotor with the gas generator on the test stand.

The distribution of the gases to the two blades takes place in the rotor hub (Figure 3). The flapping of the semi-rigid two-bladed rotor requires special structural measures with respect to the gas pipes. The hot gas is ducted via a distribution sphere in the rotor hub to the gas pipes in the rotor blades.

Figure 4 shows the rotor hub with the gas pipes, the load carrying structures, and the blade bearings.
The structure of the rotor blades is illustrated in Figure 5.

A thin-walled oval pipe constitutes the gas duct in the rotor blades for the hot gases with a temperature of about 700^{0} C. The hollow blades are coated with a highly efficient very thin insulation layer. The gas pipe is only fixed in the blade root area and can extend with the nozzle towards the blade tip to compensate temperature induced elongation.

Figure 6 shows the temperature distribution in the rotor blade structure.

In the rotor mast bearing (Figure 7) a blocking air sealing system is mounted. This sealing system consists of a labyrinth seal on the side of the hot gas pipe and a graphite seal between the sealed area and the atmosphere. The compressed air supply of the blocking air sealing system prevents the hot gas to penetrate into the ball bearings and prevents leakage.

In order to guarantee a low vibrational level the rotor is mounted on a bulkhead, which is provided with springs and dampeners.

The rotor is equipped with a conventional swash plate control system incorporating hydraulic actuators.

The most important engine and rotor data are as follows:

Gas Generator (H = O, ISA)

- Gas power	575 kW
- Mass flow	2,65 kg/s
- Gas pressure	2,3 bar
- Gas temperature	1013 K

Rotor

- Number of blades	2
- Rotor diameter	10,80 m
- Blade solidity	$\sigma_{0,7} = 0,05$
- Moment of inertia around the rotor axis	1350 kgm^2
- Blade profile	NACA 63$_4$ - 021
- Blade chord	420 mm
- Twist	5,9^{0}
- Cross section of the gas duct in the blade	119 cm^2
- Nozzle cross section	57 cm^2

2.2 Test Setup

The hot cycle rotor system was installed on a test stand of about 10 m height. The complete dynamic system was mounted on a frame which was located on a thrust measurement scale.

The operation of the supply systems as well as the engine control and the blade pitch control were carried out from the panel desk in the control room. (Figure 8.)

The measured values of the rotating part of the rotor were transmitted via a heat-insulated data box on top of the rotor hub, a slip ring set, and cables to the control room.

The measured data were indicated and recorded in the control room. Figure 9.

3. TEST PERFORMANCE AND RESULTS

3.1 Test Programme

The bench tests were designed to furnish proof that the rotor is qualified for the use on rotor platforms. According to this requirement the following criteria had to be taken into account:

- maximum rotor thrust
- maximum r.p.m. at maximum engine performance
- 50 h endurance test with a typical load spectrum for platforms
- maximum cyclic pitch at maximum engine performance

3.2 Test Preparation

Prior to the test runs the natural frequencies of the rotor and the test stand were determined in a static vibration test.

The temperature-dependent extension of the gas pipes in the rotor blades and the protection of the light-alloy construction against overheating were extremely critical. Therefore, special precautions had to be taken.

In order to find out whether there is an unhampered extension of the gas pipes due to gas temperature, potentiometers were mounted on the blade tips for the measurement of the extension.

While the extension is supported by the centrifugal force, the frictional force between the gas pipe and the insulation which is caused by the gas pressure acts as a counterforce.

Extreme frictional force may cause a buckling of the pipes. This may lead to cracks, reductions of cross-sections, and unbalances.

Furthermore, the gas pipes were examined with an endoscope in short intervals.

In order to detect possible overheating of the blade structure caused by insulation defects or cracks in the gas pipes the blade surface was provided with thermocolours with colour change at certain temperatures. Thus, the blade condition could be checked after each run.

Probes were installed on all critical points of the rotor in order to guarantee a continuous control of the temperature and loads.

3.3 Tests and Test Results

Maximum rotor thrust, maximum r.p.m. at maximum engine performance

A thrust of about 1500 daN and a rotational speed of 375 min^{-1} were achieved. The measured values of the vibrations, temperatures, and strains were below the fixed limit values.
Figure 10 shows a plot with rotor and engine data.

The achieved thrust was greater than it had been expected according to the conventional rotor theory.

It is assumed that the drive gases influence the tip vortex and thus reduce the induced drag.

Figure 11: Within the framework of a research project [1] it could be shown that with the same propulsion power of the rotor, the thrust of the reaction rotor is greater than that of the mechanically driven rotor, if all geometrical data of the rotor are identical.

50 h Endurance Test

The following requirements had to be met for the 50 h endurance test:

- operation of the rotor with a nominal thrust of 1150 daN
- stationary cyclic pitch of 0,5°
- collective and cyclic pitch inputs including gust simulation

The 50 h endurance test was successfully concluded.
The individual cycles of the test lasted one and two hours.

During the endurance test several measured values for the function control were recorded.

Some of the temperatures are listed in the following:

Outside temperature	8° C
Gas temperature	671° C
Blade surface at the blade sleeve	69° C
Temperature between blade and insulation	98° C
Distribution sphere	440° C
Spherical shell	360° C
Rotor bearing	110° C
Rotor mast	110° C

Cyclic Control Inputs at Maximum Engine Performance

In this test a cyclic pitch of 8° could be applied to the rotor. Here, special attention had to be paid to the gas distributor.

There, the measured values of vibrations, temperatures, and strains were below the permissible limit values.

4. COMPARISON WITH OTHER SYSTEMS

The test results of the hot cycle rotor have to be compared with those of competitive systems, i. e. with the cold cycle rotor and the mechanically driven rotor.

At the achieved state of art of the hot cycle rotor a comparison of the complexity, efficiency, and safety aspects of the system is sufficient.

Complexity

The dynamic system of the helicopter with a reaction rotor has a smaller number of parts than the system of the helicopter with a mechanically driven rotor. Gear box, tail rotor, and drive shafts are not necessary and in the case of the hot cycle rotor no power turbine and engine gear box are needed either.

The comparison has shown that the dynamic system of the hot cycle rotor Do 132 has only half as many parts as the UH-1D.

With respect to the complexity cold and hot cycle rotors are more or less equal. The somewhat greater number of parts of the cold cycle rotor is counterbalanced by the more costly blade and rotor hub construction of the hot cycle rotor.

Efficiency

Concerning the hot gas output of the gas generator the following propulsion efficiencies are obtained for the rotor drive performance:

Cold cycle rotor	about 28 %
Hot cycle rotor	about 35 %
Mechanically driven rotor	about 75 %

The result is a greater fuel consumption and higher fuel costs for the reaction drive.

This disadvantage of the reaction drive is partially offset by the already mentioned tip vortex. With the same rotor power the thrust is about 10 % greater which is equivalent to an improvement of the propulsion efficiency of approximately 4 %.

Safety Aspects

At the present state of art no experience is available as far as the safety of operation of the hot cycle system is concerned. However, the reaction rotor is characterized by certain properties which promise operational advantages.

Thus, for instance dynamic take-offs and overload take-offs can be carried out. The r.p.m. of the rotor being independent of the engine allows to store energy in the relatively heavy rotor for take-off. Besides that, the dangerous areas in the V-H diagram, especially at ground level, are reduced.

Concluding from the experience gained by cold an hot cycle rotors the following applications are possible:

- Heavy-lift helicopters

  In this case the reaction drive with hot gas or also mixed gas offers considerable advantages. As is known, the weight of the drive system increases out of proportion to the size in the case of a mechanically driven rotor. However, at present there is no requirement to be expected in this field.

- Rotor platforms

  Due to its configuration - without tail rotor - the reaction rotor is well qualified for rotor platforms. The possible alternative of a coaxial rotor is considerably more complex. In the case of the tethered rotor platform the fuel consumption is of minor importance since the fuel is supplied via the tether.

- Compound helicopters

  The tip driven rotor may well be regarded as a promising alternative for compound helicopters. When the rotor is operated in autorotation in forward flight, the operation with poor efficiency can be limited to the short period of hover flight and transition.

CONCLUSION

The development and evaluation of the Do 132 rotor proved that the propulsion efficiency of a reaction rotor can be improved by using hot gas of a gas generator instead of cold gas delivered by a compressor.

The temperature problem can be solved. A 50 h endurance test showed the principal qualification for rotor platforms.

REFERENCES

[1] P. Dick, K.-H. Mohr, H. Zimmer
Experimentelle und theoretische Arbeiten zur Beeinflussung des Blattspitzenwirbels bei Reaktionsrotoren (Experimental and theoretical work in order to influence the blade tip vortex or reaction rotors)
Do 4.14/3 Zukunftstechnik Luftfahrt (Future Aeronautics)

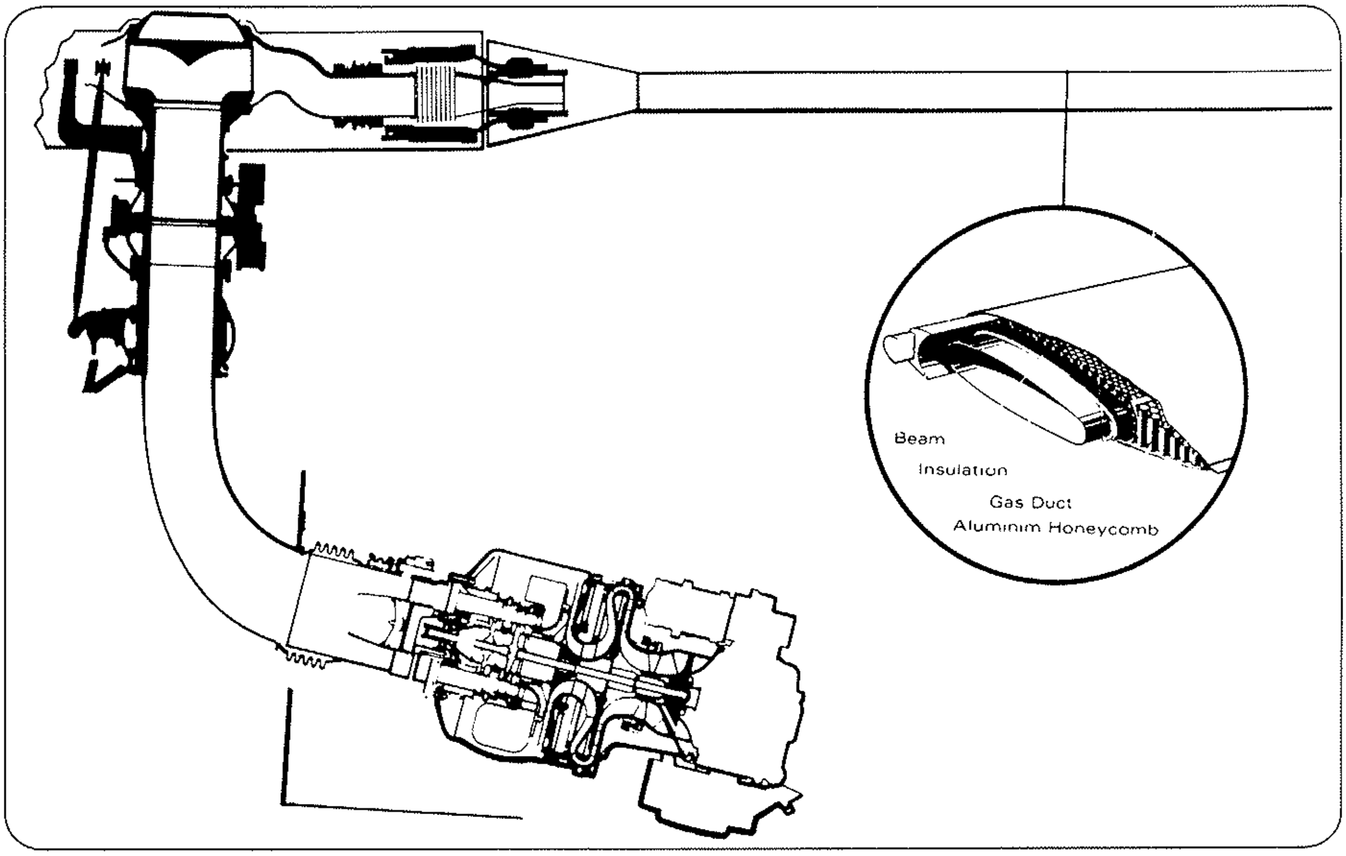

Fig. 1 Drive System

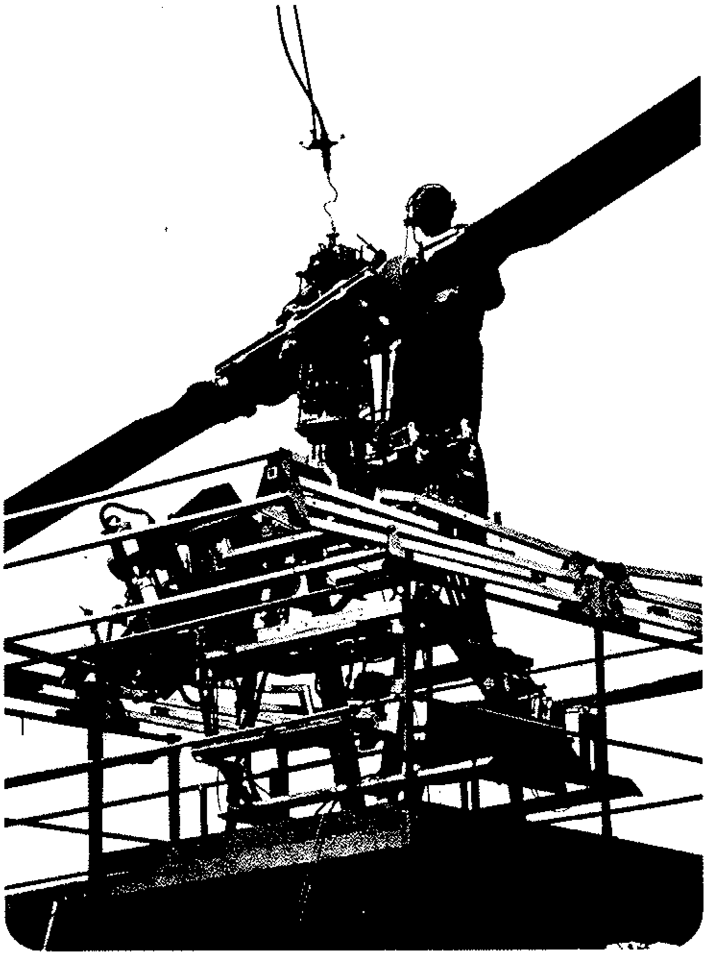

Fig. 2 Rotor System and Test Stand

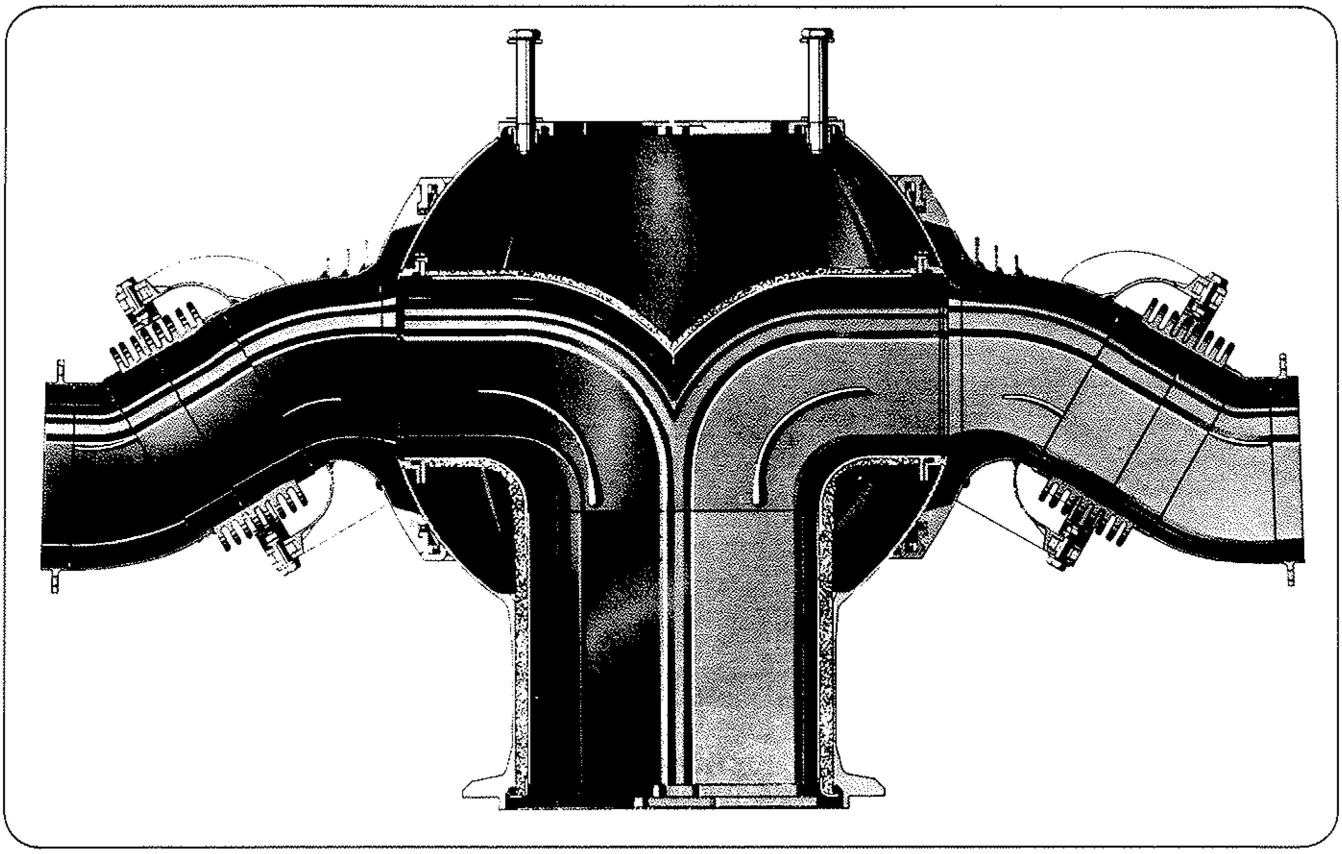

Fig. 3 Gas Distributor

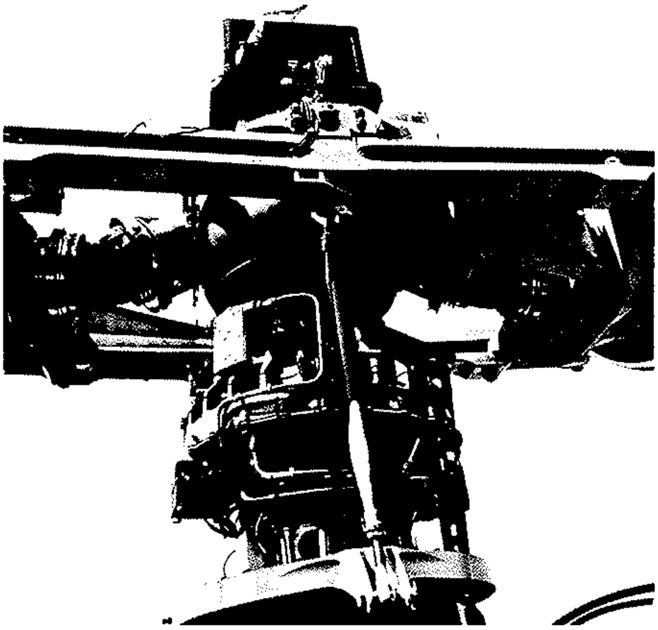

Fig. 4 Rotor Hub

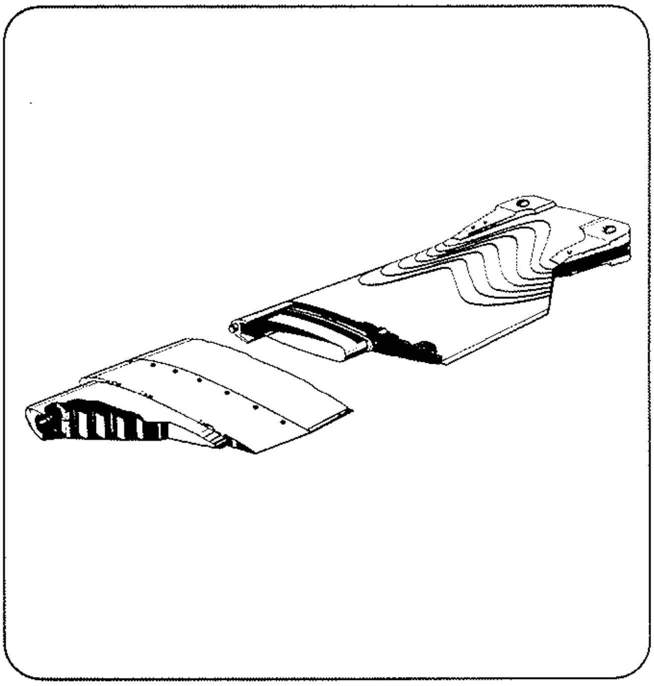

Fig. 5 Rotor Blades

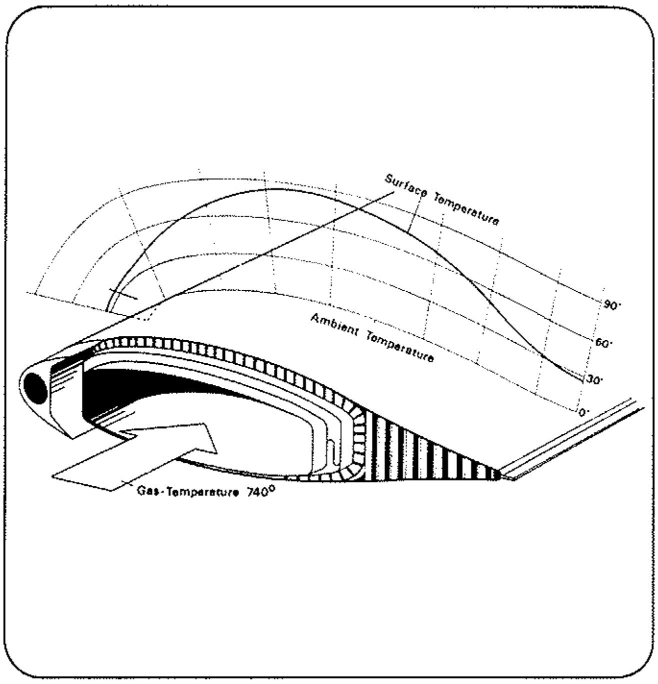

Fig. 6 Temperature Distribution in the Rotor Blade

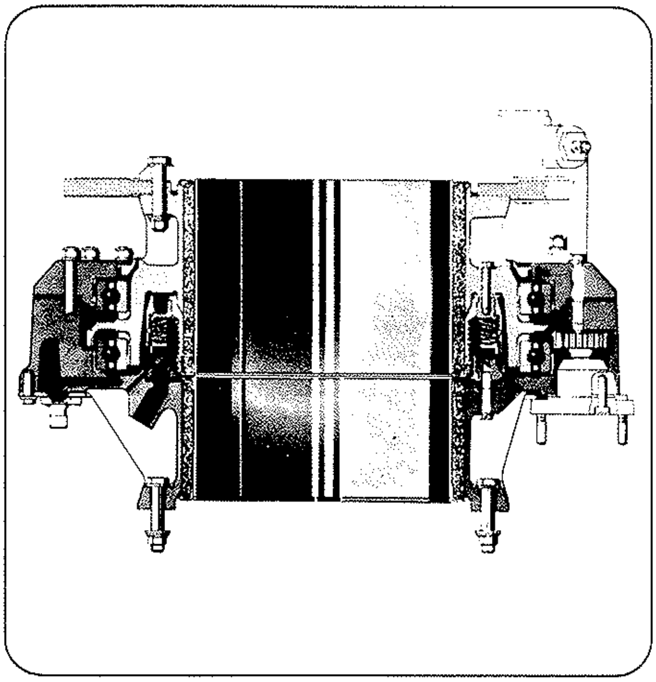

Fig. 7 Rotor Bearing

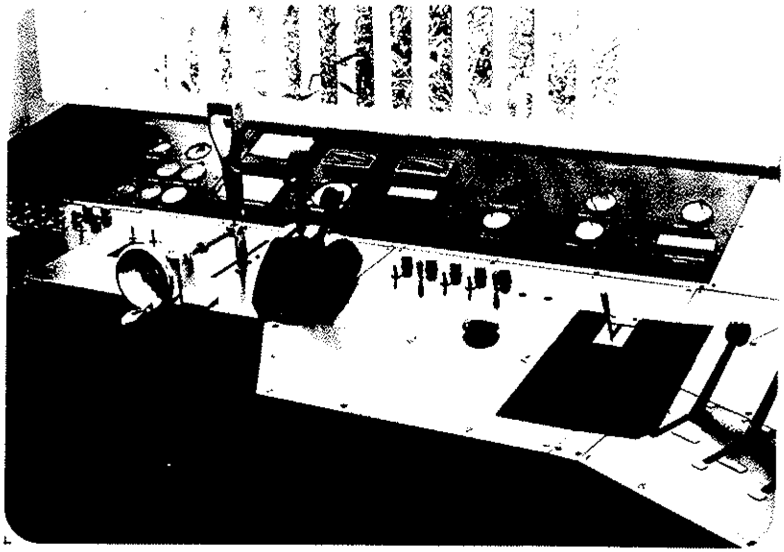

Fig. 8 Control Desk

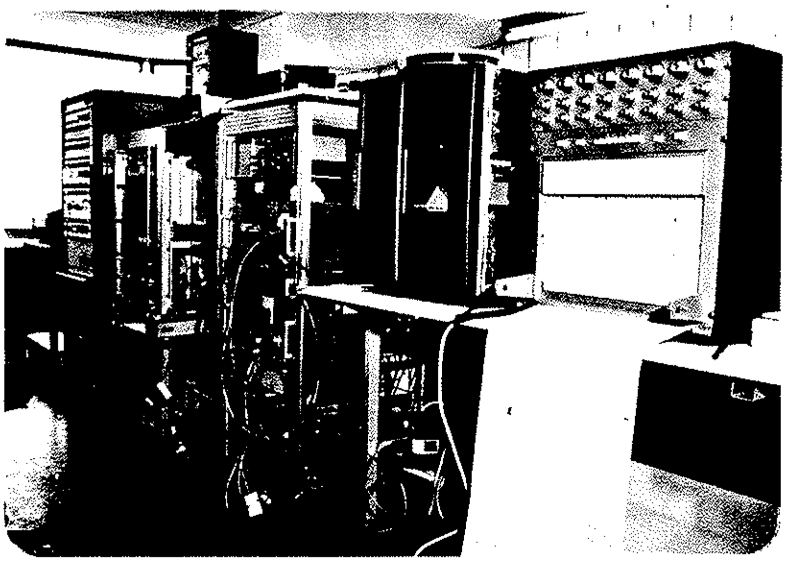

Fig. 9 Measuring System

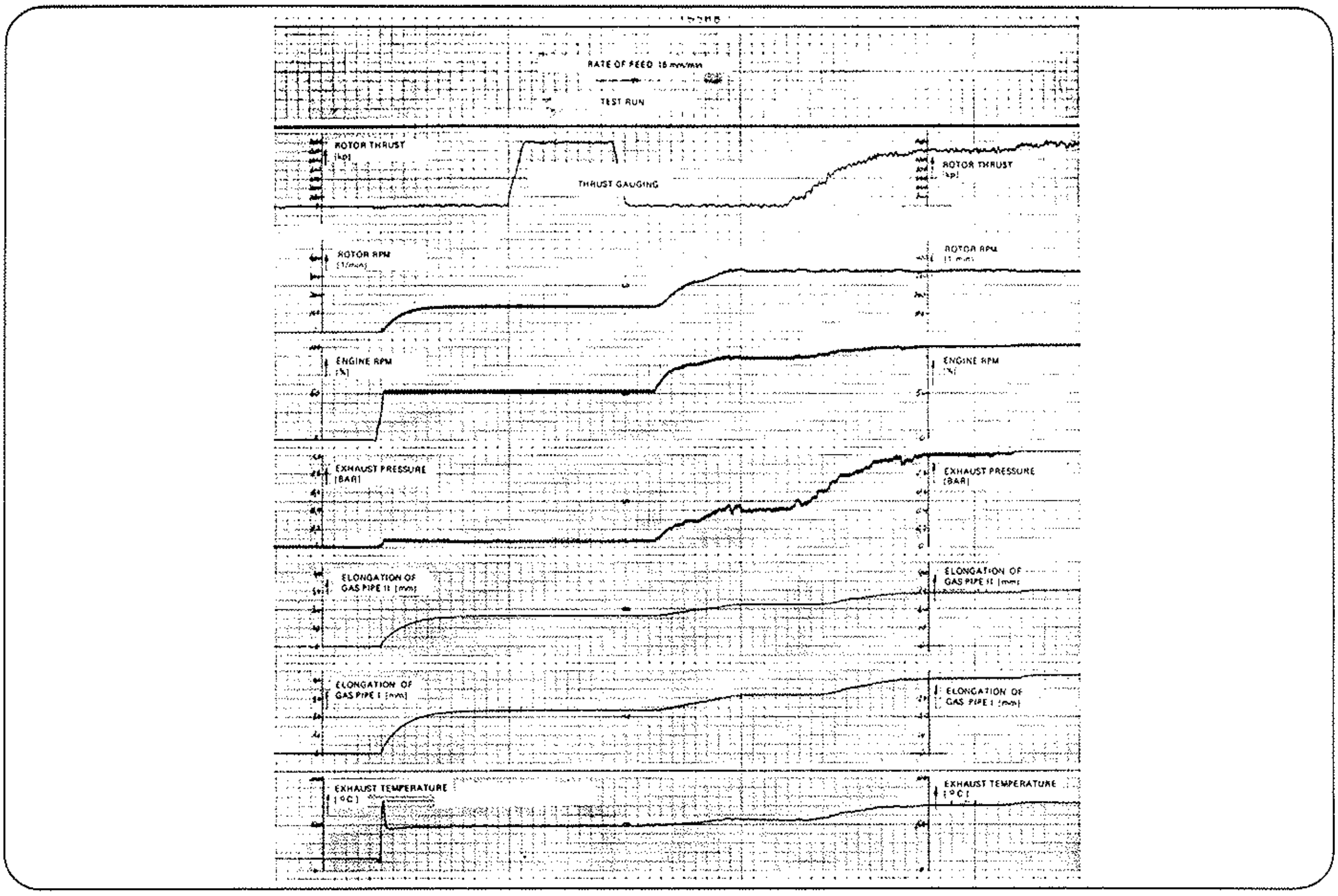

Fig. 10 Plot

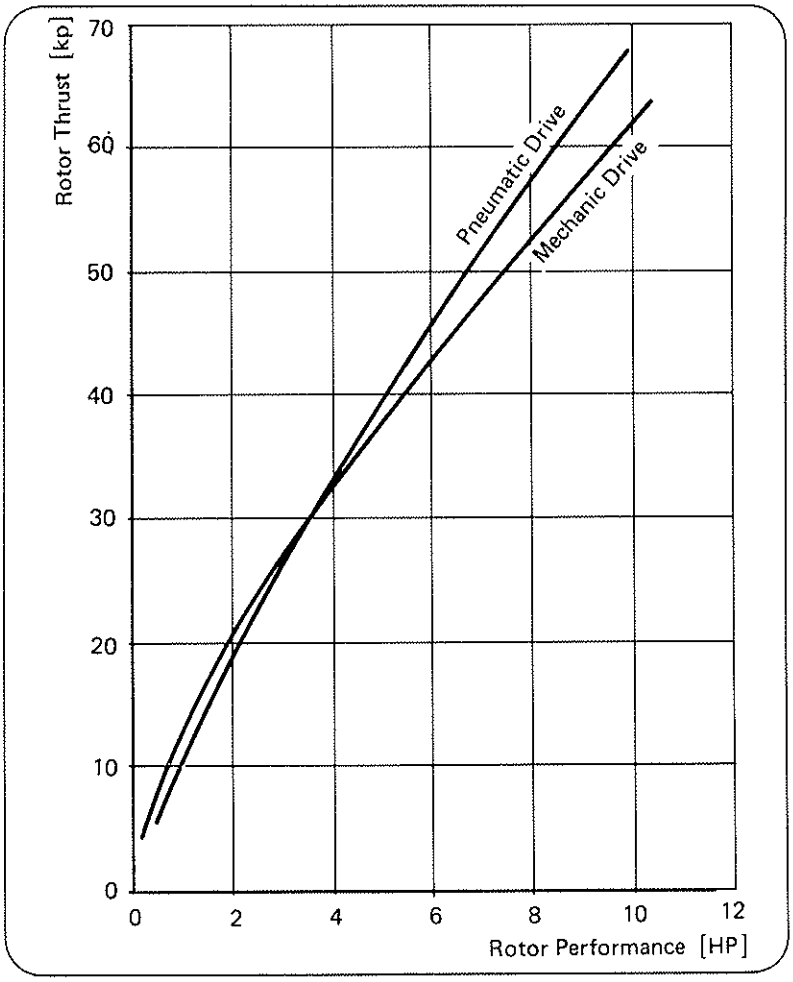

Fig. 11 Rotor Thrust Versus Rotor Performance of a Model Rotor