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Engineering Notes

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Static Pressure Distribution in the Inlet of a Helicopter Turbine Compressor

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Introduction

PEARSON and McKenzie[1] used the "parallel compressor model" to demonstrate that when the airflow into a compressor is distorted, the velocity at the inlet to the compressor will be virtually constant with consequent variations in the static pressure. Reid[2] measured the response of a lift engine model compressor to distortions of the inlet flow and noted that the distortions resulted in only small changes in the nondimensional maximum mass flow rate. The parallel compressor model has been used extensively to determine the effects of flow distortions, albeit in different engine configurations. Williams[3] used a modified two-compressors-in-parallel model for an S-duct inlet. Hynes et al.[4] formulated a distortion model based on an eigenvalue analysis and concluded that the parallel compressor model is recovered as a limiting case of the model proposed. Biesiadny et al.[5] used a refined parallel compressor model, assuming that temperature distortion is responsible for more swirl than is the case with pressure distortion.

Although the refined parallel compressor models proposed have provided a useful tool for understanding and modeling the distortion characteristics and their effects on the compressor, it is assumed in the model that the compressor tends to induce a constant air inlet velocity with static pressure gradients that are in sympathy with the gradients of total pressure.[1,3–5] For the specific helicopter engine intake tested, it was found that a constant static pressure exists at the compressor inlet. This finding was substantiated by measurements made of the flow angularity and total and static pressures at the inlet of a gas turbine, and a static bench for a range of DC(60)[2] distortion factors varying from 0 to 24.13%.

Several methods to measure pressure distortion exist, some of which are described by Reid,[2] the ARP 1420,[6] AIR 1419,[7] the K_{DA} and K_θ.[8] Four basic elements have been identified to be important for distortion measurement[6]: 1) circumferential intensity, 2) extent and 3) multiple-per-rev elements defined at constant radius, and 4) a radial intensity element. The DC(60) distortion factor, defined by Reid,[2] is the ratio of the variation of the total pressure for a 60-deg sector on the distortion measurement plane from the average pressure of that plane to the average dynamic pressure at the same plane. Although this descriptor does not provide for the radial intensity or multiple-per-rev elements mentioned previously, Reid[2] suggested that engine performance is influenced more severely by circumferential distortion than radial distortion. Also, as the study only addresses time-averaged behavior, the lack of a multiple-per-rev element was accepted, especially in view of the fact that Turbomeca,[9] the manufacturer of the Turmo IVB engine used for the experiments, only supplied distortion limits in terms of the DC(60) index. Consequently, the DC(60) index was used throughout the experiments.

Experiments

Tests were conducted on two rigs: 1) a static test bench and 2) a Turbomeca Turmo IVB gas turbine shown in Fig. 1. Air was drawn through the static test bench by means of a radial compressor located far downstream of the test section. In the case of the gas turbine it was run close to its maximum power. Because it was not possible to install a rotating pressure rake on the gas turbine, or to fit the required number of bosses onto the inlet duct to support probes upstream of the gas turbine, detailed measurements of the flow distortions caused by the distortion generator were measured on the static test bench. The tests on the static test bench were carried out using the same mass flow as that obtained on the gas turbine.

It was assumed that at similar flow rates the flow distortions measured on the static test bench would be similar to those obtained on the gas turbine, particularly if the swirl of the air downstream of the distortion generator is small. Some variations in the DC(60) index of the flow into the gas turbine would not in any case materially affect the conclusions drawn from the results, because it is not the precise magnitude of the distortions that are relevant, but rather their effects.

The flow distortions on the static test bench were measured using the rotating rake. Measurements were made at angular intervals of 10 deg. The mass flow, which was measured in the duct downstream of the test section, was kept constant for all tests at 4.9 kg/s. As the air was drawn directly from the atmosphere through a straight duct, temperature variations were taken to be small. The density of the ambient air was 1 kg/m^3. The tests on the Turmo IVB engine were carried out with the bellmouth section, distortion generator, and subsequent 500-mm duct used on the static test bench fitted to the inlet to the gas turbine. The spindle speed for all the tests was maintained at 33,000 rpm with adjustments to the throttle setting being made where necessary. At zero flow distortion, this corresponded to an engine power of 98% of the maximum power of 704 kW, and a mass flow rate of air to the turbine of 4.9 kg/s. The engine power was measured by means of a hydraulic dynamometer. The airflow to the gas turbine was measured for the case of zero flow distortion using the calibrated bellmouth. To ensure that the pressure readings were not affected by large inclinations of the flow to the pressure probes, the swirl was measured in the measurement plane on the gas turbine engine for the case where the DC(60) distortion index was 11.59%. The flow angles were measured by means of a three-hole yaw probe. The swirl angles were measured by setting the yaw probe parallel to the flow.

In the case of the gas turbine, the static pressure at the array locations was measured by means of a pitot tube and a Forthmann probe. The total pressure was measured by means

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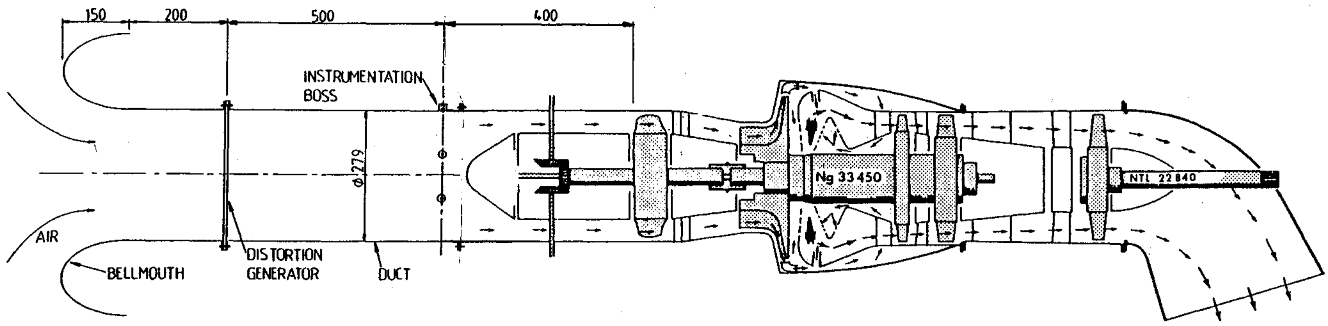

Fig. 1 General arrangement of Turbomeca Turmo IVB gas turbine and inlet cowl. Dimensions in mm.

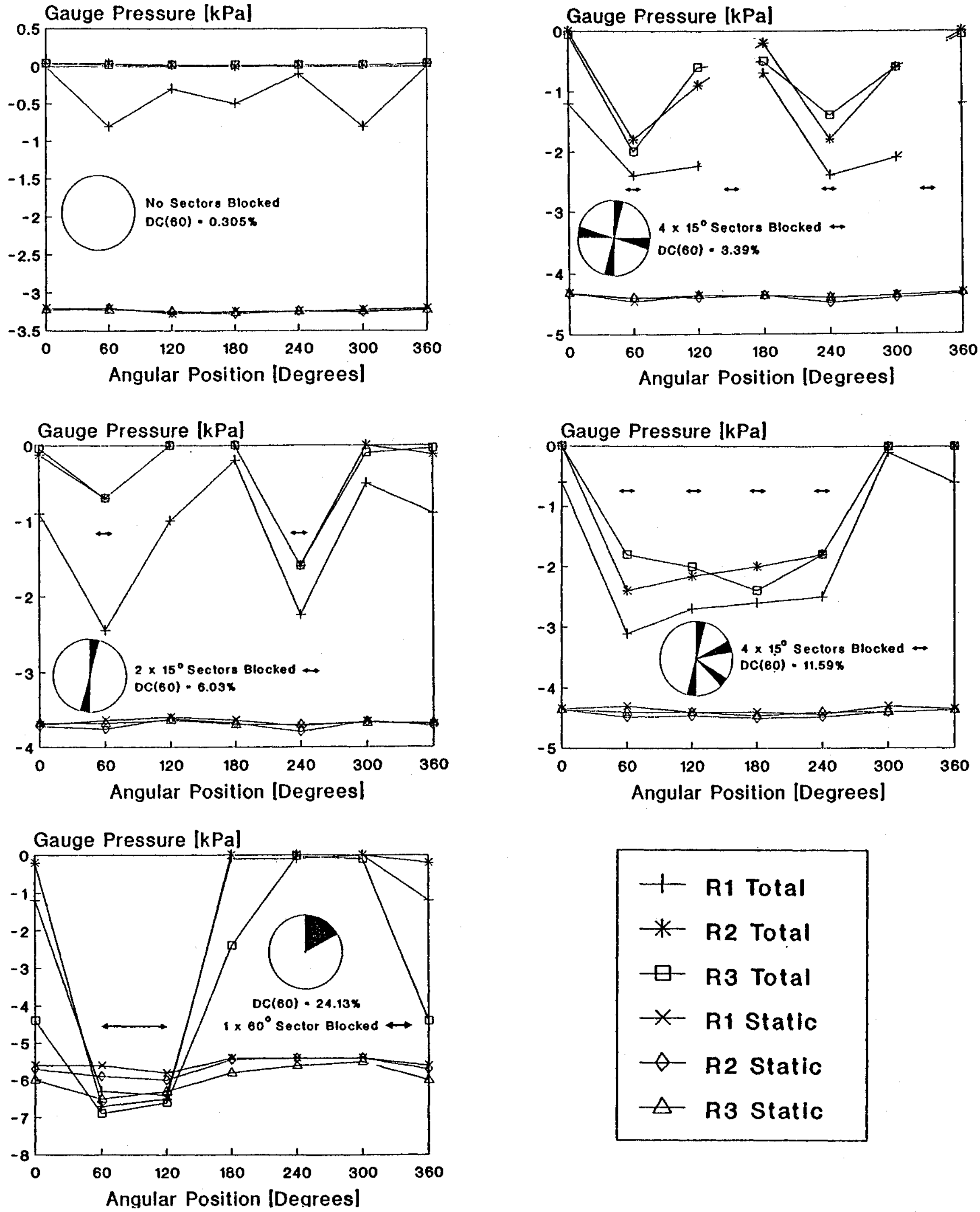

Fig. 2 Variation of static and total pressures at the inlet plane to the Turmo IVB gas turbine.

of the pitot tube. All pressures, including those on the static bench were measured relative to atmospheric pressure by means of a manometer with a resolution of 0.05 kPa. Details of the array locations are presented in Fig. 2. Tests were carried out with the five flow distortion configurations shown in Fig. 2.

Results

The flow angularities measured on the Turmo IVB engine for a distortion of 11.59% are presented in Table 1 against the nondimensional probe depth. It may be seen from the results that for this case the flow angularities were small with a maximum swirl angle of 2.0 deg. This indicated that the readings of the total and static pressure were not affected by the flow angularity. It also indicated that large angular accelerations of the air did not occur.

The small flow angularities downstream of the distortion generator were further evidenced by the data presented in Fig. 2, where it may be seen that the angular positions at which low total pressures occur, correspond to the locations of the areas of blockage of the distortion generator. Where insufficient data points were available to clearly indicate the effects of the flow distorters, the graphs are left blank.

The variations of the static and total pressure distributions at the inlet plane to the Turmo IVB gas turbine are presented in Fig. 2. As may be seen from Fig. 2, the distortions strongly affect the total pressure and have negligible effect on the static pressure. From the data obtained, the static pressure is virtually constant around the inlet up to DC(60) values of 24.1%, which is substantial for most engines. The variation of power measured for the Turmo IVB engine with DC(60) index is presented in Fig. 3.

As may be seen from Fig. 3, the effect of the flow distorters was to decrease engine power by about 3.7% over the range of distortions tested. Because the engine power is proportional to the mass flow through the engine, it is reasonable to assume that the mass flow through the engine was almost constant for all the tests, irrespective of the large variation in the DC(60) index.

Table 1 Flow swirl angle at engine entrance plane for DC(60) = 11.59%

Array point	Depth x/D, %	Angular location, deg 0	60	120
R1	3.22	0.5	−1.0	0.0
R2	13.6	0.0	−1.5	0.0
R3	32.3	0.0	−2.0	0.0
R3	68.1	0.0	1.5	−0.5
R2	86.7	0.0	0.0	−0.5
R1	97.1	0.0	0.0	−1.0

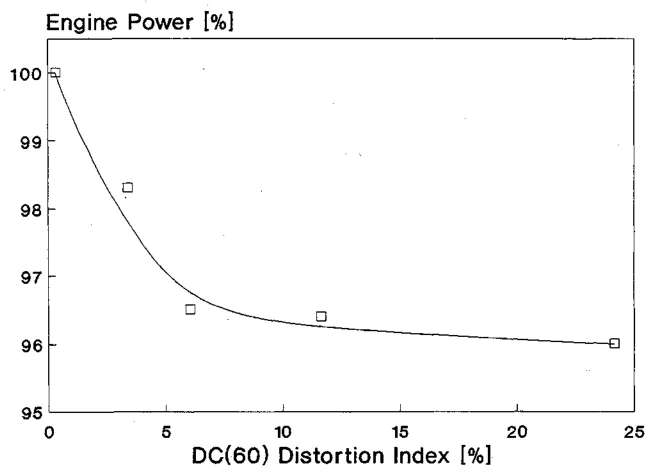

Fig. 3 Variation of engine power with DC(60) distortion index.

Conclusions

1) The primary variation of the flow in an engine inlet of the type of gas turbine tested resulting from flow distortions is of the dynamic pressure with variations of the static pressure being small.

2) The swirl resulting purely from flow distortions is small for the engine tested. This is consistent with the minimal static pressure variations in the angular direction that would otherwise be associated with large angular accelerations of the flow.

3) As was found by Reid,[2] the mass flow through the gas turbine does not vary to a large extent, irrespective of the comparatively large variations in the velocity at the inlet to the gas turbine.

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Static Aeroelastic Characteristics of a Composite Wing

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Introduction

STATIC aeroelasticity is a problem involving the response of a flexible structure to aerodynamic loading and is a

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