Development of Block type Inlet Distortion Simulating Device for Gas Turbine Engine Inlet Distortion Test

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Abstract

In late 1960's, engineers of the engine manufacturer experienced that the distortion of inlet flow of turbofan and turbojet engine could cause the surge in compressor and affect overall engine operational performance, which result in the deterioration of stability of the engine. In this study, block type of inlet distortion simulating device has been developed in order to investigate the effect of inlet distortion on the deterioration of overall engine operational performance. The inlet distortion simulating device was installed in front of engine inlet in order to simulate distortion of inlet flow. The degree of inlet distortion was measured by rakes installed upstream the inlet distortion simulating device and between the engine inlet and inlet distortion simulating device. Before applying the inlet distortion simulating device to real engine, preliminary tests were performed with a simulated engine in order to verify the degree of inlet distortion by the device. Preliminary inlet distortion tests were performed in Altitude Engine Test Facility(AETF) of Korea Aerospace Research Institute(KARI) and results showed that the inlet distortion simulating device could be used in simulating various inlet distortion cases.

Key Word : Gas-Turbine Engine, Inlet Distortion Simulation, Pressure Distortion

Introduction

During flight of aircraft, interaction between engine and aircraft body can induce spatially non-uniform pressure and temperature of the engine inlet flow. This phenomenon is called as inlet distortion. The inlet distortion reduces the surge margin of the compressor and could cause surge in the compressor. Thus, the inlet distortion results in the deterioration of engine performance and maneuverability of the aircraft. The spatial non-uniformity of inlet pressure distribution can be caused by followings;

1) Shape of intake
2) High angle of attack or yaw maneuver
3) Strong cross-winds or interaction between engine and aircraft body

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The non-uniformity of inlet temperature distribution can be caused by inappropriate design of test facility, inflow of the engine exhaust gas at reverse thrust or indraft of the exhaust gas of other aircraft.

In this study, inlet pressure distortion simulating device was designed and manufactured in order to simulate the non-uniformity of pressure at engine intake, and tests were conducted in the Altitude Engine Test Facility(AETF) of Korea Aerospace Research Institute(KARI).In this paper, the detailed configuration of the inlet distortion simulating device is presented and the applicability of the device is discussed.

Inlet Distortion Device

Degree of Inlet Distortion

The degree of inlet pressure distortion should be defined in order to estimate the effect of the inlet distortion on the engine performance. The distortion coefficient used in United Kingdom is defined as Eq. (1)

$$DC(\theta) = \frac{P_f - P_\theta}{q_f} \tag{1}$$

In Eq. (1), q_f is the mean dynamic pressure, P_f is the mean total pressure at engine inlet, and P_Θ is the mean total pressure within Θ degree where the pressure distortion is most significant. Depending on the range of angle Θ, Eq. (1) can be expressed as DC(60), DC(90), or DC(120) for the Θ range of 60°, 90°, and 120°, respectively. In this paper, the degree of inlet distortion is expressed using DC(90).

Measuring equipment of the degree of inlet distortion

The degree of inlet distortion was measured by inlet distortion measuring equipment and the equipment was installed in the front and in the rear of the inlet distortion simulating device.

The inlet distortion measuring equipments which was installed in front of the inlet distortion simulating device consisted of three sets of three rakes which measured total pressure, total temperature, and boundary layer total pressure, respectively. Figure 1 show the rakes installed in front of the inlet distortion simulating device. The boundary layer rakes were used only for measuring the flow condition of engine inlet and removed during the inlet distortion tests to eliminate the flow non-uniformity caused by them. The measurement location of total pressure was distributed evenly in the measurement area and the static pressure was measured by static pressure taps installed on the duct surface. Figure 2 show the rakes installed in front of the inlet distortion simulating device.

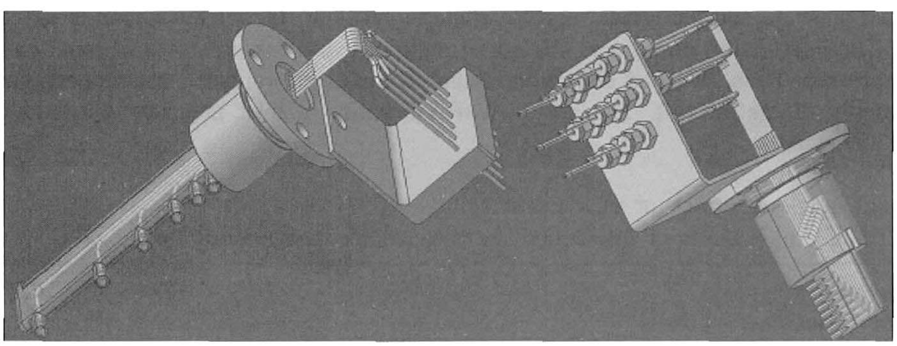

Fig. 1. Rakes installed in front of inlet distortion simulating device (temperature and boundary layer rake)

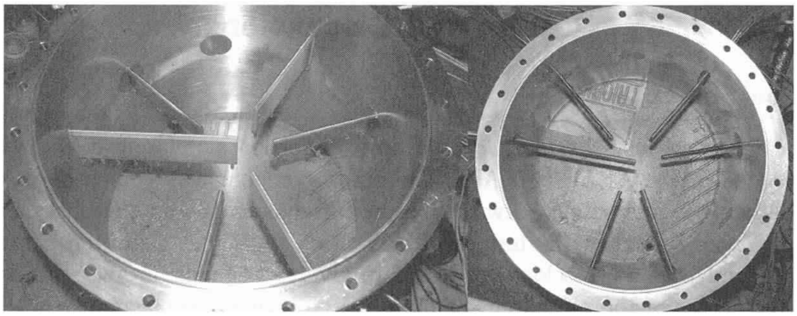

Fig. 2. Picture of installed Rakes

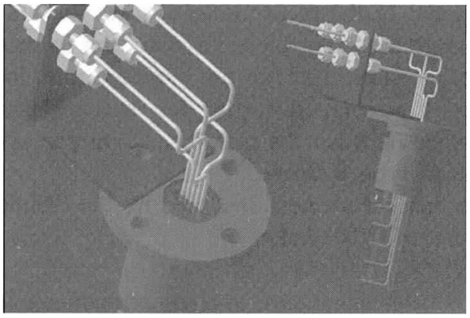

Fig. 3. Rake installed in the rear of the inlet distortion simulating device (Total pressure rake)

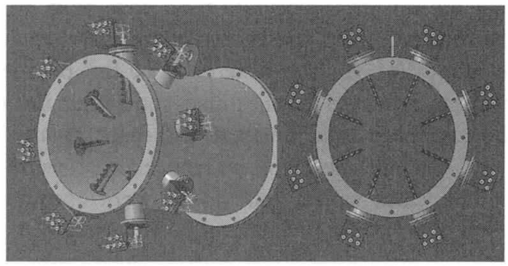

Fig. 4. Schematic of installed rake

At the rear of the inlet distortion simulating device, 8 total pressure rakes were installed and each rake was equipped with 5 total pressure probes. In the design of the location and length of rakes, the location of the engine inlet nose-cone was considered. The static pressure was measured by static taps on the duct surface. Figures 3 and 4 show the rake installed in the rear of inlet distortion simulating device and the schematic of rake installation, respectively.

Inlet Distortion Simulating Device

Figure 5 shows block shape inlet distortion simulating device. The blockage ratios of the device were 20%, 30%, and 40% of the engine inlet area, respectively. This type of inlet distortion simulating device is easy to manufacture and install, however, it can simulate limited degree or shape of inlet distortion condition and various block shape devices are required in order to simulate other degree or shape of inlet distortion condition.

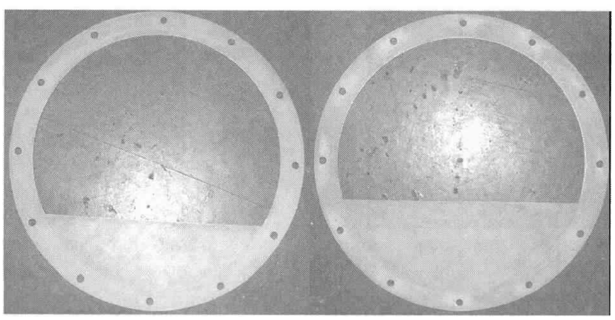

Fig. 5. Block shape inlet distortion simulating devices

Results and Discussions

Inlet Distortion Simulating Test

The inlet distortion tests by block type of inlet distortion simulating device were conducted with dummy engine in the AETF of KARI. The dummy engine was equipped with a nose-cone in order to simulate the interaction between measuring equipment and the nose-cone of engine.

Figures 6, 7 and 8 present the test results by block type inlet distortion simulating devices with 20%, 30%, and 40% of blockage ratio, respectively. Legends in the figures indicate the distance from the center of the measurement plane to the measurement point. Also, in the figures, x axis presents clockwise angle measured from the top perpendicular centerline of the measurement plane and y axis presents a dimensionless pressure of total pressure at the measurement point divided by averaged static pressure of the measurement plane. Results show that for the 20% blockage ratio case (Fig. 6), the degree of inlet pressure distortion increases as the distance from the center of measurement plane increases. And, as the blockage ratio increase to 40% (Fig. 8), the difference of the degree of inlet pressure distortion for each measurement plane is reduced. Results also show that the difference between the maximum total pressure and the minimum total pressure increases as the blockage ratio increases.

For all cases, the highest inlet pressure distortion occurs near 180° and by the definition of DC(90), data within 180° ± 45° were used to calculate DC(90) value.

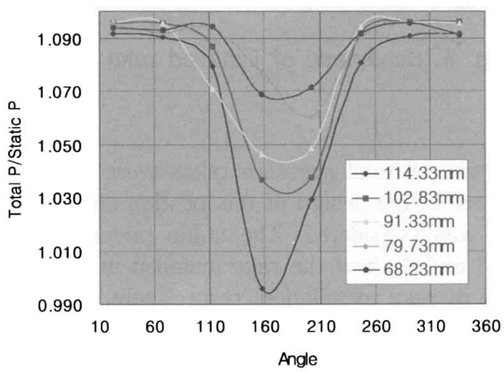

Fig. 6. Inlet pressure distortion by block type device with 20% blockage ratio

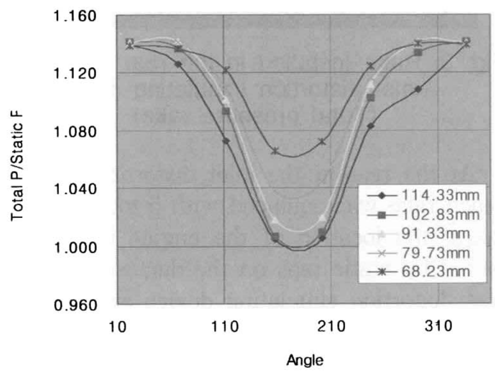

Fig. 7. Inlet pressure distortion by block type device with 30% blockage ratio

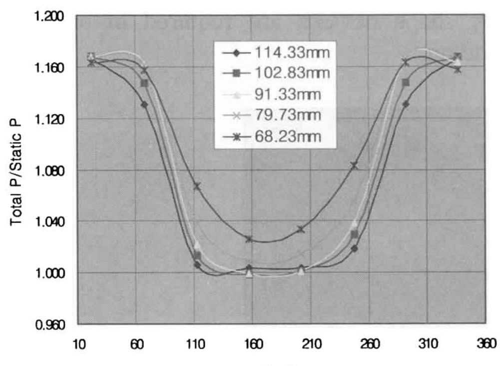

Fig. 8. Inlet pressure distortion by block type device with 40% blockage ratio

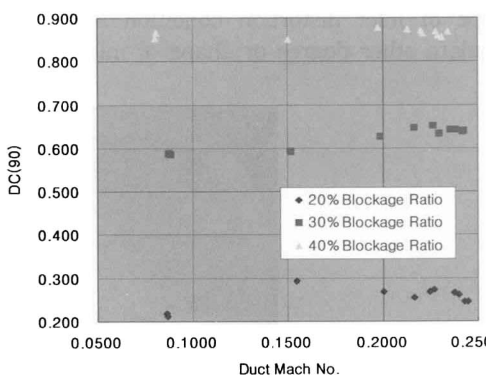

Fig. 9. DC(90) for block type inlet distortion simulating devices

Figure 9 presents the calculated DC(90) value for the block type inlet distortion simulating devices for varying Mach number. Results show that the value of DC(90) decreases as the blockage ratio decreases and the value of DC(90) is more dependent on the velocity of the air for lower blockage ratio. Results also show that the DC(90) value increases as the blockage ratio increases. That is caused by the increased inlet pressure distortion with increased blockage ratio as shown in Figures 6, 7 and 8.

Block type of inlet distortion simulating device was tested in order to simulate the inlet distortion caused by pressure non-uniformity at engine intake. Results showed that the device successfully created non-uniform pressure field. The results in this paper will be used as a database for the inlet distortion test for a gas turbine engine. In future, more research will be conducted in order to relate the variation of DC(90) value with test conditions.

Conclusions

In this study, inlet distortion simulating device was designed and tested in AETF of KARI with DC(90). In the tests, block type inlet distortion simulating device was used with a dummy engine equipped with a nose-cone. Results showed that the degree of inlet distortion by the block type device increased as the blockage ratio increased. Also, the degree of inlet distortion increased as the distance from the center of measurement plane increased. For all cases, the degree of total pressure distortion is most severe near 180°.

Based on the results presented in this paper, inlet distortion test with other inlet distortion simulating device will be conducted and the effect of inlet distortion on the engine performance will be estimated in near future.

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