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EXPERIMENTAL STUDY OF FLAT BAFFLE INLET TOTAL-PRESSURE DISTORTION IN A THREE-STAGE FAN

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Abstract

The effect of relative depth of flat baffle on distortion descriptor characteristics, distortion sensitivity, and pressure field distribution of the three-stage fan was experimentally studied. Through the analysis of the inlet and outlet flow fields, the influence of relative depth of flat baffle on the circumference angle range of the low total pressure area and transmission characteristics of the distortion descriptor were obtained, under the condition of 24%, 29% and 34% relative depths of flat baffle. The results show that complex total-pressure distortion descriptor increase near-linearly with the increase in inlet average axial Mach number. With relative depths of flat baffle increasing, the growth rate of the steady-state distortion descriptor is greater than that of the time-variant distortion descriptor. The ratio of steady-state distortion descriptor to time-variant distortion descriptor increases from 0.919 to 1.847, when relative depth of flat baffle increases from 24% to 34%. The pressure distortion sensitivity increases first and later decreases with increase in the ratio of steady-state distortion descriptor to time-variant distortion descriptor

Keywords: fan; inlet total-pressure distortion; flat baffle experiment; stability margin loss; distortion sensitivity

1. Introduction

With the development of modern aviation, the future advanced engine has the characteristic of high performance, high mobility and high stability, which puts forward higher requirements for the aerodynamic stability of the engine. Internal flow field of the fan/compressor will become very unstable, in case of inlet total-pressure distortion, which will has a significantly effect on the operation of the engine. In order to effectively evaluate the law and magnitude of the influence of inlet total-pressure distortion on fan/compressor stability, a large number of engine stability evaluations have been carried out. The influence of inlet total-pressure distortion on the fan/compressor is very complex, which needs further research. Flat baffle inlet total-pressure distortion experiment is a method to evaluate the influence of total-pressure distortion on the aerodynamic stability of fan / compressor. Foreign scholars have conducted a large number of experimental studies in this regard. However, due to the complexity of the internal flow of the engine and the limitations of test conditions, there are few experimental studies on inlet total-pressure distortion in China. Therefore, it is very necessary to carry out experimental research on aero-engine inlet total-pressure distortion and obtain detailed flow field parameters.

Cheng B Q et al. conducted a total inlet total-pressure distortion test on a turbofan engine using a movable plug-in plate distortion generator, and analyzed the impact of total inlet pressure distortion on the aerodynamic stability of a turbofan engine. Li L et al. compared and analyzed the complex total-pressure distortion descriptors characteristics of four kinds of insert plates on a two-stage low-speed axial compressor tester. Jiang Y et al. tested the aerodynamic stability of the engine by using a movable spoiler plug plate, and obtained the steady-state inlet total-pressure field of the engine. On the whole, there are few studies on inlet total-pressure distortion and few test data on inlet total-pressure distortion in China.

This paper focused on studying the effect of relative depth of flat baffle on distortion descriptors characteristics, distortion sensitivity, and pressure field distribution of the three-stage fan. Results from an experimental research on performance and flow field of a three-stage fan are reported under the condition of inlet total-pressure distortion. The inlet total-pressure is distorted by means of flat baffle with 24%, 29% and 34% relative depths. The overall performance and stability of the three-stage fan were studied under variable speed, and detailed measurements were carried out at inlet and outlet using steady-state and dynamic measurement points.

2. Test equipment and test scheme

2.1 Test equipment

The test was carried out on a high speed compressor test rig (Figure 1), which composed of power system, intake system, exhaust system, lubricating oil system, operating system, electrical system, etc.

During the test, the gas flows through the inlet flow pipe, front diffuser section, intake throttle, diffuser section, honeycomb and rectifier network into the pressure stabilization box, and then enters the test piece after passing through the double button bell mouth.

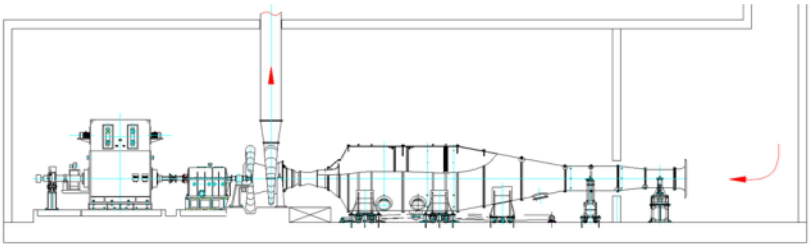

Figure 1 – High speed compressor test rig

Flat baffle installs at the inlet of the test fan. The distance between flat baffle and the aerodynamic interface plane is 2.5 times the inlet diameter of the test fan. The relative depths of flat baffle are 24%, 29%, 34% respectively. Relative depth of flat baffle is show in Figure 3.

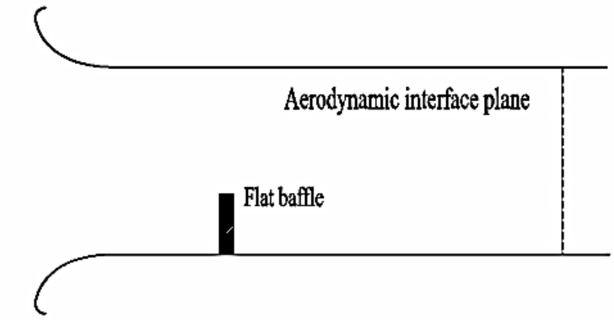

Figure 2 – Flat baffle scheme

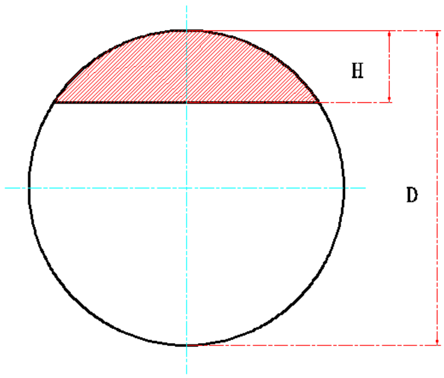

Figure 3 – Relative depths of flat baffle

2.2 Test scheme

Figure 4 shows measurement scheme of the compressor. 36 total-pressure measuring points and 6 dynamic pressure measuring points arrange at the inlet of compressor. 36 total-pressure measuring points and 6 dynamic pressure measuring points arrange at the outlet of compressor. The flat baffle installs directly below the flow channel.

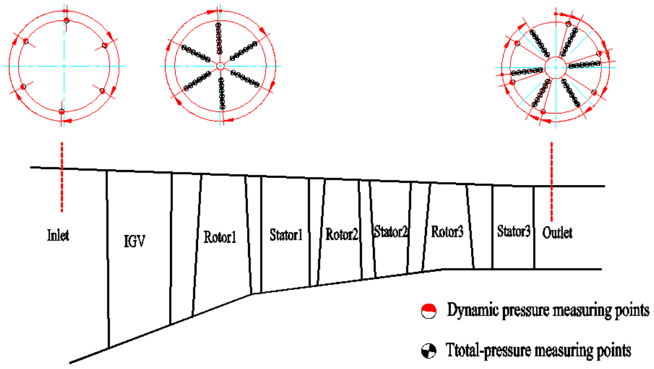

Figure 4 – Measurement scheme of inlet and outlet of the three-stage fan

3. Results and analysis

3.1 Effect of relative depth of flat baffle on distortion descriptor

Complex total-pressure distortion descriptor is defined as：

$$W = \Delta\sigma_0 + \varepsilon \tag{1}$$

The steady-state distortion descriptor is defined as:

$$\Delta\sigma_0 = (1 - \sigma_0/\sigma_{cp}) \tag{2}$$

σ_0 -average value obtained by measuring the radial and circumferential integrals of the total pressure along the low total-pressure zone of the cross-section;

σ_{cp} -measures the average of all pressure gauge points on the cross-section.

The time-variant distortion descriptor is defined as:

$$\varepsilon = \frac{\sum_{1}^{m} \frac{\sqrt{\frac{1}{t}\int_0^t \left[P_{cp}^* - P_i^*\right]^2 \cdot dt}}{P_{cp}^*}}{m} \tag{3}$$

t - time interval;

m - total number of dynamic instruments;

P_{cp}^* - average value of total pressure at a certain measuring point in time;

P_i^* - instantaneous value of total pressure at a measuring point in time.

The distortion sensitivity coefficient is defined as:

$$\alpha_W = \Delta SM / W \tag{4}$$

W -the distortion descriptor near the operating point；

ΔSM - the loss of stall margin.

The distortion intensity of the compressor inlet flow field is measured by complex total-pressure distortion descriptor. First, under the conditions of three different relative depths of flat baffle, the complex total-pressure distortion descriptor of the fan is given.

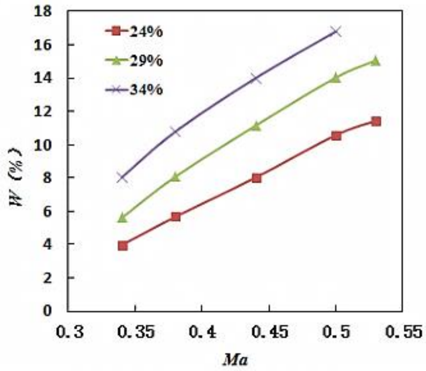

Figure 5 – Relationship between complex total-pressure distortion descriptor and inlet average axial Mach number

Figure 5 shows the change of the complex total-pressure distortion descriptors with inlet average axial Mach number under the condition of 24%, 29% and 34% relative depths of flat baffle. The abscissa is the inlet average axial Mach number and the ordinate is the complex total-pressure distortion descriptor. It can be seen from the figure that the change between the complex total-pressure distortion descriptors and the inlet average axial Mach number is basically linear that the complex total-pressure distortion descriptor increases with the increase in inlet average axial Mach number.

This is mainly because as the shielding area increases, the total pressure loss in the pipeline increases, and the total pressure field non-uniformity of the airflow at inlet also increases. For Mach 0.5, when relative depth of flat baffle increases from 24% to 34%, the complex total-pressure distortion descriptor of the compressor inlet increases from 11% to 16.6%.

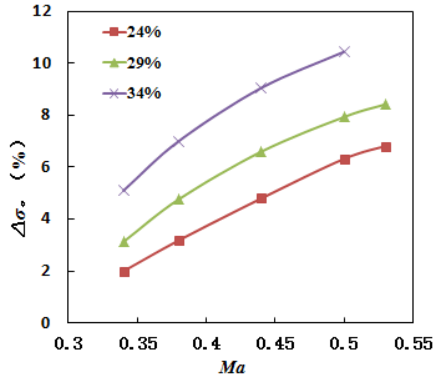

Figure 6 – Relationship between steady-state total-pressure distortion descriptor and inlet average axial Mach number

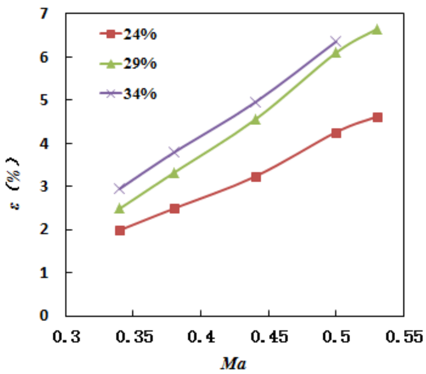

Figure 7 – Relationship between dynamic total-pressure distortion descriptor and inlet average axial Mach number

Figure 6 and Figure 7 show the steady-state distortion descriptor and time-variant distortion descriptor as a function of the inlet average axial Mach number. The changes in the steady-state distortion descriptors, time-variant distortion descriptors and inlet average axial Mach number in the figure are basically linear. However, it can be seen from the figure, as the inlet average axial Mach number increases, the growth slope of the steady-state distortion descriptor is greater than that of the time-variant distortion descriptor. This means that relative depths of flat baffle and inlet axial Mach number will affect the ratio of steady-state distortion descriptor to time-variant distortion descriptor.

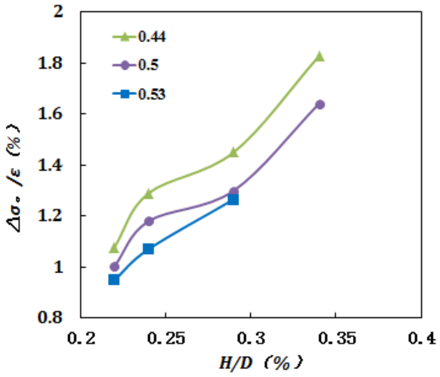

Figure 8 – Relationship between proportion of complex total-pressure distortion descriptor and relative depth of flat baffle

Figure 8 shows the change in ratio of the steady-state distortion descriptor to the time-variant distortion descriptor versus the inlet average Mach number. The abscissa in the figure is the relative depth of flat baffle .It can be seen from Fig. 8 that the ratio of steady-state to time-variant distortion descriptors is basically linear with the relative depth of flat baffle, under the condition of different inlet axial Mach numbers.

Therefore, for a fixed inlet axial Mach number, the ratio of steady-state to time-variant distortion descriptors at the inlet will change under the condition of different relative depths of flat baffle. For Mach number 0.5, the relative depth of flat baffle increases from 24% to 34%, and the ratio of steady-state to time-variant distortion descriptor increases from 1.559 to 1.647.

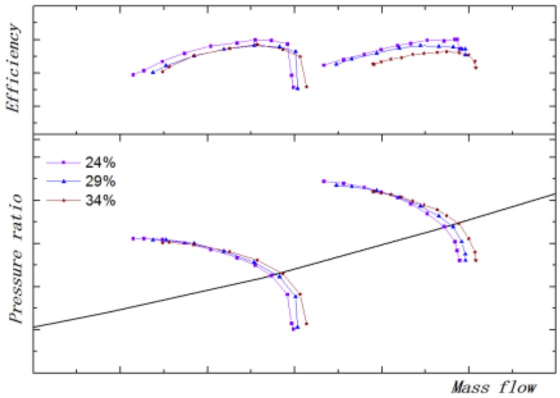

Figure 9 – The overall characteristic of three-stage fan with different relative depths of flat baffle

Figure 9 shows characteristic of the three-stage fan under the condition of flat baffle with relative depth 24%, 29% and 34%. With increase in relative depth of flat baffle, stall margin and efficiency of the three-stage fan are decreasing.

3.2 Effect of relative depth of flat baffle on transmission characteristic of total-pressure distortion descriptor

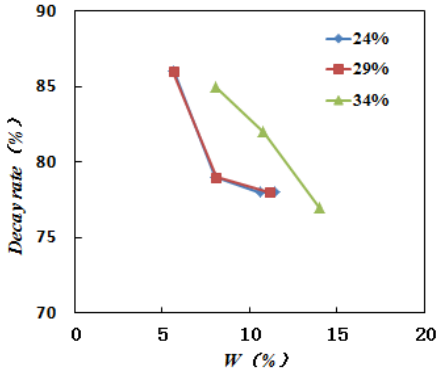

Figure 10 – Decay rate of steady-state distortion descriptor

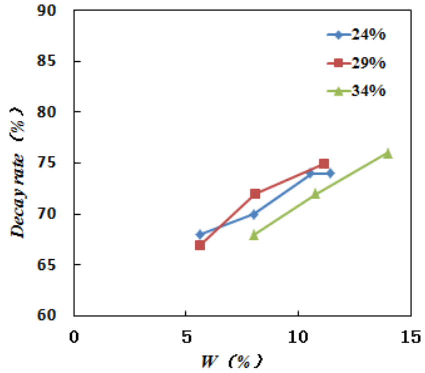

Figure 11 – Decay rate of time-variant distortion descriptor

Figure 10 and Figure 11 show the variation of decay rate of steady-state and time-variant distortion descriptors with the complex total-pressure distortion descriptor at different relative depths. It can be seen from Figure 10 that the decay rate decreases with the increase in the complex total-pressure distortion descriptors. For 34% relative depth of flat baffle, the complex total-pressure distortion descriptors increases from 8% to 14%, while the decay rate of steady-state distortion descriptors decreases from 85% to 77%.

As can be seen from Figure 11, the relationship between decay rate of the time-variant distortion descriptor and the complex total-pressure distortion is linear, that the decay rate gradually increases with the increase in complex total-pressure distortion descriptor. For 29% relative depth of flat baffle, the complex total-pressure distortion descriptor increases from 5.6% to 15%, and the decay rate of the time-variant distortion descriptor increases from 67% to 76%.

For small relative depths of flat baffle, the decay rate of the time-variant distortion descriptor is greater than that of the steady-state distortion descriptor, while for the larger relative depths of flat baffle, the decay rate of the steady-state distortion descriptor is equivalent to that of the time-variant distortion descriptor.

3.3 Effect of relative depth of flat baffle on flow field at inlet and outlet of fan

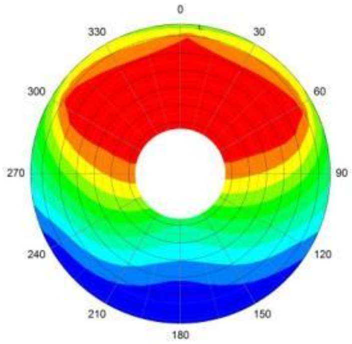

Figure 12 – Total-pressure contours with 24% relative depth of flat baffle

Figure 12 shows total-pressure contour with 24% relative depth of flat baffle. The influence of relative depths of flat baffle on the total-pressure field at the inlet and outlet of the fan at the inlet

Mach number of 0.35 is given below. The abscissa in the figure is the circumferential angle, and the ordinate is the dimensionless total-pressure at different radial heights.

Figure 13 and Figure 14 show the circumferential average results of the total pressure at the inlet and outlet with relative depths of flat baffle. For the inlet total-pressure, it can be seen that the minimum circumferential pressure at the inlet is at 180 º area. For flat baffle with different relative depths, the range of the low total pressure area increases with the increase in relative depths.

For the total-pressure of outlet, from the perspective of circumferential distribution, the low total pressure area is also close to the lower part. With the increase in relative depths, the area occupied by the low total-pressure area increases, while the angle of the circumferential minimum total-pressure value shifts from 180 º to 171 º.

Figure 15 and Figure 16 show the circumferential distribution of the total-pressure at the inlet and outlet at the depth of 24%, 29% and 34% of the flat baffle. The total-pressure loss is greater near the casing at inlet.

For the total-pressure field at outlet, the total pressure area below 76% blade height changes significantly. The circumferential distribution of total-pressure near hub changes slightly, that the flow field near the hub is less affected by the total-pressure distortion.

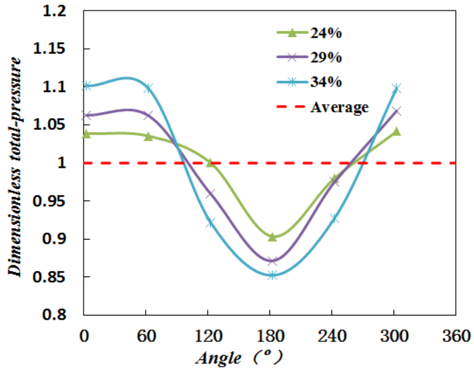

Figure 13 – Variation in the circumference of the low pressure zone with different relative depths of the flat baffle at inlet

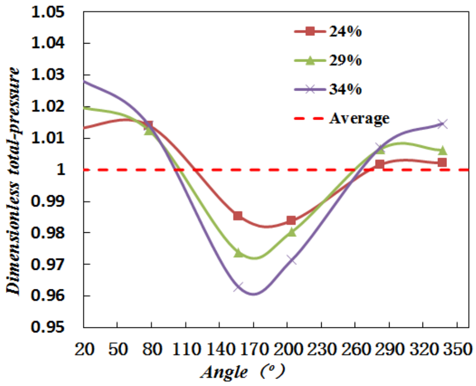

Figure 14 – Variation in the circumference of the low pressure zone with different relative depths of the flat baffle at outlet

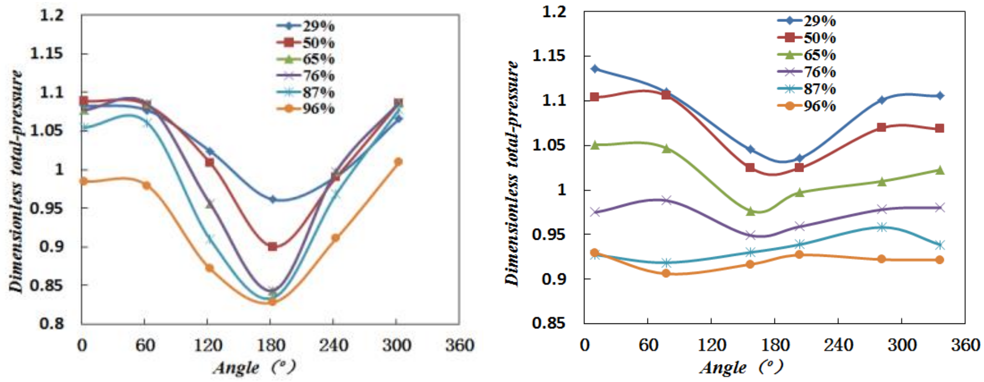

Figure 15 – Inlet and outlet total-pressure field with 29% relative depth of flat baffle

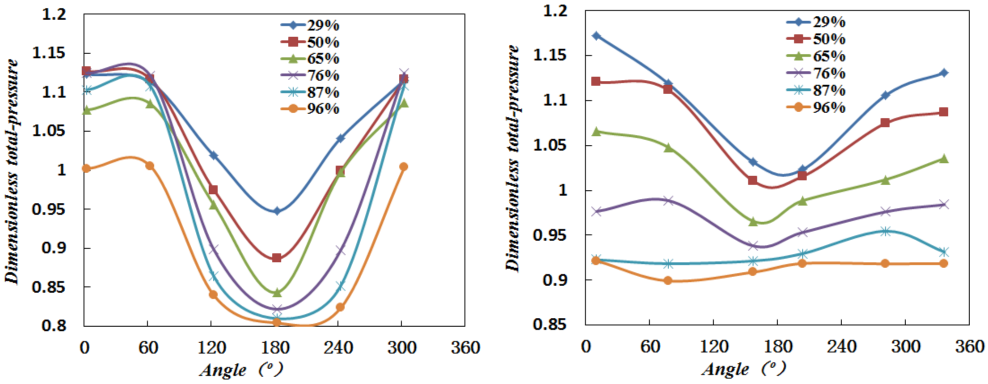

Figure 16 – Inlet and outlet total-pressure field with 34% relative depth of flat baffle

3.4 Effect of relative depths of flat baffle on fan distortion sensitivity

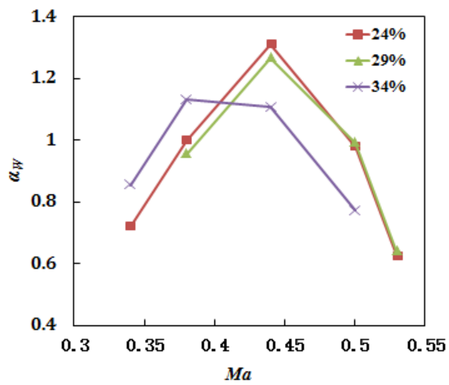

Figure 17 – Relationship between pressure distortion sensitivity and inlet average axial Mach number

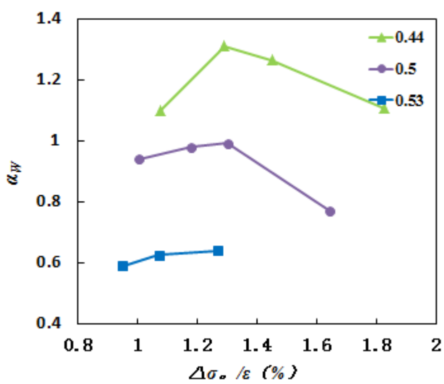

Figure 18 – Relationship between pressure distortion sensitivity and ratio of steady-state descriptor to time-variant distortion descriptor

For the distortion sensitivity coefficient, it can be seen that distortion sensitivity of the three-stage fan is different under the condition of same inlet Mach number and different relative depths of flat baffle.

According to Fig.17, for the same inlet Mach number, different relative depths of flat baffle affect the operating point and surge point position of the characteristic line, thus affecting the distortion sensitivity. The variation of relative depths of flat baffle has a great influence on the distortion sensitivity of low inlet Mach number. For inlet Mach number 0.44, distortion sensitivity changes from 1.107 to 1.31. And for inlet Mach number 0.53, the distortion sensitivity changes from 0.59 to 0.64.

For the same inlet Mach number, the distortion sensitivity increases first and then decreases with the increase in ratio of steady-state to time-variant distortion descriptors. For the same ratio of steady-state to time-variant distortion descriptors, the inlet Mach number increases with the decrease in distortion sensitivity.

4. Conclusion

Based on the experimental study, the following conclusions can be drawn:

- In general, the complex total-pressure distortion descriptors increase near-linearly with the increase in inlet average axial Mach number.
- With relative depth of flat baffle increasing, the growth rate of the steady-state distortion descriptor is greater than that of the time-variant distortion descriptor. The ratio of steady-state distortion descriptor to time-variant distortion descriptor increases from 0.919 to 1.847, when relative depth of flat baffle increases from 24% to 34%.
- At the condition of lower relative depth of flat baffle, the decay rate of time-variant distortion descriptor is greater than that of steady-state distortion descriptor.
- The relative depth of flat baffle has a great influence on the pressure distortion sensitivity at lower inlet Mach number. The pressure distortion sensitivity increases first and later decreases with increase in the ratio of steady-state distortion descriptor to time-variant distortion descriptor.

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6. Copyright Statement

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