Experimental Study on Loss Characteristics of High-Speed High-Loading Compressor Cascades: Postprint

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Abstract

The experiment measured the downstream flow field of a high-speed, high-load compressor cascade at two Mach numbers (0.5884 and 0.5) across eight incidence angles of -8°, -6°, -4°, -1.69°, 0°, 2°, 4°, and 8°, and analyzed the variation of its loss characteristics with incidence angle. The results show that at the design Mach number of 0.5884, the incidence range corresponding to low total pressure loss coefficients for this cascade is narrow; as the incidence deviates from the optimal incidence toward both extremes, the cascade loss increases rapidly and sharply. From 2° to 4° incidence, the flow field structure changes: the near-midspan region also begins to experience significant separation, while the corner separation in the near-endwall region actually decreases, causing the total pressure loss to not increase rapidly but remain essentially constant. As the incidence further increases to 8°, the flow develops into a large-scale separated flow across the full blade span, the wake velocity deficit increases sharply, and the total pressure loss also increases sharply.

Full Text

Preamble

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1. Experimental Setup

1.1 Wind Tunnel and Test Cascade

The experiments were conducted in a linear cascade wind tunnel facility designed for compressor aerodynamic research. The wind tunnel system, illustrated in [Figure 1: see original paper], provides controlled flow conditions for cascade testing. The test section accommodates a linear cascade with adjustable incidence angles to investigate flow behavior under various operating conditions, as shown in [Figure 2: see original paper].

The cascade geometry is detailed in [Figure 3: see original paper] and the primary geometric parameters are summarized in . The cascade consists of highly loaded compressor blades with specific profiles optimized for aerodynamic performance studies.

1.2 Test Conditions

The experimental program covered a range of Mach numbers and incidence angles to characterize cascade performance across different operating regimes. The reference Mach number was maintained at Ma = 0.5884. Additional test conditions included Mach numbers ranging from low-speed to high-subsonic conditions: Ma = 0.4, 0.6, 0.8, and 1.69. The incidence angle was systematically varied to investigate its effect on flow separation and loss generation.

1.3 Measurement Plane Location

All aerodynamic measurements were performed at a plane located 1.2 axial chord lengths downstream of the cascade trailing edge. This measurement plane allowed comprehensive survey of the exit flow field, including total pressure losses and secondary flow structures.

2. Measurement System and Data Processing

2.1 Instrumentation and Measurement Technique

The measurement system comprised multiple pressure probes and instrumentation arrays to capture the three-dimensional flow field downstream of the cascade. The arrangement of measuring instruments is shown in [Figure 4: see original paper] and [Figure 5: see original paper]. Total pressure measurements were acquired using a multi-hole probe traverse system with high spatial resolution.

The total pressure loss coefficient was calculated based on area-averaged values across the measurement plane. The average total pressure at the exit plane was determined using:

$$P_{s,avg} = \frac{\sum_{i=1}^{N} P_{s,i} \cdot A_i}{\sum_{i=1}^{N} A_i}$$

where $P_{s,i}$ represents the static pressure at measurement point i, and A_i is the corresponding area element. The total pressure loss coefficient was then computed as:

$$C_{pt} = \frac{P_{t,in} - P_{t,avg}}{P_{t,in} - P_{s,in}}$$

where $P_{t,in}$ and $P_{s,in}$ are the inlet total and static pressures, respectively, and $P_{t,avg}$ is the mass-averaged total pressure at the exit plane.

2.2 Data Reduction and Uncertainty Analysis

The entropy generation through the cascade was evaluated to quantify flow losses. The entropy change was calculated using:

$$\Delta S = -R \ln\left(\frac{P_{t,exit}}{P_{t,in}}\right) + c_p \ln\left(\frac{T_{t,exit}}{T_{t,in}}\right)$$

where R is the specific gas constant and c_p is the specific heat at constant pressure. For incompressible flow conditions, this simplifies to:

$$\Delta S \approx -R \ln\left(\frac{P_{t,exit}}{P_{t,in}}\right)$$

The measurement uncertainty was estimated to be within ±2% for total pressure measurements and ±1.5% for flow angle measurements, based on probe calibration data and repeatability tests.

2.4 Flow Field Analysis

The exit flow field was analyzed through contour plots of total pressure loss coefficient and velocity distributions. [Figure 6: see original paper] presents the variation of the overall total pressure loss coefficient with incidence angle, showing the sensitivity of cascade performance to operating condition changes. The spanwise distribution of pitchwise-averaged total pressure loss coefficient, depicted in [Figure 7: see original paper], reveals the development of secondary flows and endwall losses.

Detailed flow structures were examined through contour maps of exit total pressure loss coefficient under different incidence conditions, as shown in [Figure 9: see original paper]. These contours highlight the formation and evolution of corner separation regions near the endwall. The pitchwise velocity profile at mid-span, presented in [Figure 11: see original paper], provides insight into the blade wake characteristics and mixing losses.

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Note: Figure translations are in progress. See original paper for figures.