INFLUENCE OF TURBOMACHINERY SURFACE QUALITY ON TRANSONIC HUMID-AIR FLOW: HIGH-SPEED OPTICAL AND PRESSURE MEASUREMENTS OF CONDENSATION AND DROPLET FIELDS

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ABSTRACT

This paper presents experimental results on the influence of surface quality on transonic internal flows of humid air undergoing spontaneous condensation. A dedicated test facility equipped with interchangeable convergent–divergent channels of identical nominal geometry but varying surface roughness was employed. The flow field was investigated using high-speed schlieren imaging, unsteady wall pressure measurements with high-frequency transducers, and optical droplet diagnostics based on light extinction and laser diffraction. The results demonstrate how surface quality affects boundary layer development and modifies the interaction between pressure waves and the boundary layer in condensing transonic flows.

INTRODUCTION

In numerous energy and aerospace applications, internal flow passages such as turbomachine channels, stator blade rows, and compressor ducts operate under transonic conditions with humid air, where spontaneous condensation of water vapor may occur [1, 2]. In practice, these internal surfaces are rarely hydraulically smooth [3]. Manufacturing tolerances, operational wear, and surface deposits lead to varying levels of roughness and complex surface topographies. Such features can significantly influence boundary layer behavior, local thermodynamic conditions, and shock–boundary layer interactions, thereby affecting both the onset of condensation and the structure and stability of condensation waves.

Existing experimental studies on spontaneous condensation in steam and humid air flows have predominantly focused on nominally smooth nozzles and cascades, while systematic investigations addressing controlled variations in surface quality remain scarce. Meanwhile, recent numerical and experimental studies suggest that surface roughness and topography influence not only aerodynamic losses, but also nucleation rates, droplet growth, and spatial moisture distribution. Consequently, there is a clear need for well-controlled experimental data quantifying the impact of defined roughness characteristics on coupled pressure fields, density gradients, and the condensed phase in transonic humid air flows.

Figure 1 presents the experimental facility used in this study, including the air supply system, the test section with interchangeable convergent–divergent channels, and the measurement instrumentation. Representative schlieren images illustrate high-speed humid air flow through the nozzle, revealing shock structures, condensation regions, and associated density gradients under selected operating conditions. To address the identified research gap, the present study employs channels with identical nominal contours but systematically varied internal surface quality, ranging from optically smooth walls to controlled micro- and macro-scale roughness.

RESULTS AND DISCUSSION

The results indicate that, even under identical global operating conditions, variations in surface quality lead to measurable changes in boundary layer behavior, shock system topology, and the position and stability of the condensation front. High-speed schlieren imaging shows that increased roughness intensifies near-wall disturbances and alters the dynamics of condensation waves, as reflected in the amplitude and frequency of shock-related oscillations. Synchronized wall pressure measurements reveal roughness-dependent shifts in the locations of pressure peaks associated with shocks and condensation waves, along with modifications in the spectra of unsteady pressure fluctuations. Optical diagnostics further indicate that surface quality affects not only the axial location of condensation onset but also droplet size distributions and local liquid volume fractions.

The combined dataset provides a consistent basis for assessing the role of surface quality in shaping condensation onset, unsteady flow structures, and droplet dynamics in transonic humid air flows. It also offers valuable reference data for the validation of CFD models of condensing flows.

Figure 1. The view of the air system for the nozzle tests and the exemplary Schlieren photographs of the moist air flow through the nozzle

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