DESIGN AND REDUCED ORDER MODELING OF HIGH-SPEED CONTINUOUS WIND TUNNELS

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ABSTRACT

Open-return continuous wind tunnels have proven reliable experimental facilities for aerothermal studies at ambient pressures. Although their construction can be more cost-effective than the closed-return alternative, exhausting air to the atmosphere leads to lower efficiency. Thus, a reliable methodology to predict losses in the system is critical to informing the design and evaluating the operational costs. The present work aims to accurately characterize and predict the performance of a new high-speed continuous wind tunnel, PT3, at the Purdue Experimental Turbine Aerothermal Laboratory (PETAL). This novel facility, powered by a 300 HP fan, can achieve mass flows of 7.5 kg/s with Mach number 0.6 at the test section. Numerous experiments and CFD computations are performed to calibrate a one-dimensional model at different operating points. The study results in a valuable tool for quickly iterating between wind tunnel configurations and provides relevant design guidelines.

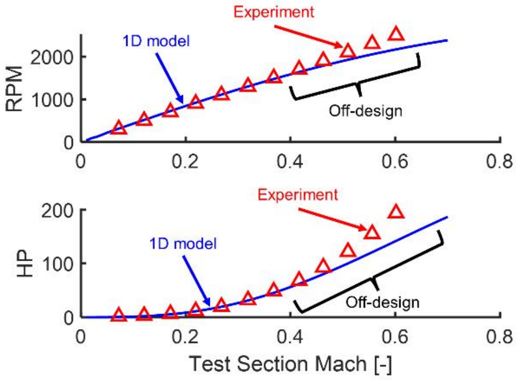
INTRODUCTION

Wind tunnel testing has been essential in aerodynamics development since the early 20th century when the first open-return wind tunnels were built [1]. Over a century of research has led to well-established design and operation guidelines [2–6]. While several of these references propose using correlations to estimate pressure losses, Eckert et al. [3] presented an experimentally validated systematic approach by compiling equations that model the different components together with simple compressible flow calculations. They found that the model overestimates the performance of facilities with flow problems (such as flow separation) or operating at off-design conditions. In the present paper, a solver based on these equations is coupled with the fan performance curves to investigate further the range of applicability at high speeds. The proposed model predicts the required fan speed and horsepower for a wide range of Mach numbers in the test section (0.05 to 0.6). Experimental validation tests are performed on the PT3 open-return wind tunnel, a new high-speed facility at the Purdue Experimental Turbine Aerothermal Laboratory (PETAL). A picture is shown in Figure 1a. These results and the effects of each wind tunnel component are discussed in detail.

RESULTS AND DISCUSSION

The predicted motor speed and power show good agreement at the investigated conditions. The comparison between the one-dimensional model and the experimental data is depicted in Figure 1b. The estimated RPMs for test section speeds below Mach 0.4 have errors under 4% with respect to the observed values. The error is less than 5% for the estimated power except for the low load operating points (less than 10 HP) and the tests at higher speeds, where flow peculiarities are present. In these off-design conditions, where the losses due to increased diffusion rates and sudden expansions become more relevant, the flow presents unsteadiness and higher losses. The experiments and CFD computations lead to refinements in the model and facility design modifications to improve the operating range.

a)



b)

Figure 1. a) Wind tunnel facility (PT3). b) One-dimensional model comparison with experimental data.

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