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Experimental Thermal and Fluid Science 22 (2000) 183–195
Experimental Thermal and Fluid Science
www.elsevier.nl/locate/etfs

Experimental performance analysis of an annular diffuser with and without struts

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Received 8 May 2000; received in revised form 15 July 2000

Abstract

In this paper, the performance analysis of an annular diffuser is presented. In a typical industrial gas turbine diffuser, a certain number of structural members, called struts, serve both as load bearings support and as passages for cooling air and lubricant oil. Measurements were made in a 35% scaled down model of a PGT10 gas turbine exhaust diffuser with and without struts in order to determine the total and static pressure development and the effect of struts on both the local phenomena and the overall performance. More realistic flow conditions are made available by a ring of 24 axial guide vanes at inlet, which represent the last turbine rotor. The model has been tested on a wind tunnel facility developed at the University of Perugia with inlet speed around 80 m/s, allowing satisfactory accuracy for flow measurements and similarity with the PGT10 diffuser in terms of Reynolds number. Static pressure taps located at various streamwise positions on the hub and the casing allowed the estimation of pressure recovery development. A Pitot tube and a hot split-film anemometer were used to determine static and total pressure inside the diffuser at different axial positions. The comparison between the two cases, with and without the struts, was made also by the use of global parameters, which correlate static and total pressure.

In a previous paper, a detailed three-dimensional analysis of the flow path inside the diffuser was presented and the detrimental effect of the struts, in terms of flow separation and unsteadiness, was discussed. The stationary flow measurements and the investigation of the diffuser without the struts are presented in this paper. The whole research project represent a complete diffuser investigation available to develop an optimal design and to advance the computational and design tools for gas turbine exhaust diffusers. © 2000 Elsevier Science Inc. All rights reserved.

1. Introduction

The exhaust diffuser of an industrial gas turbine recovers the static pressure by decelerating the turbine discharge flow. This allows an exhaust pressure lower than the atmospheric one, thus increasing the turbine work. The Mach number at the modern turbine exhaust is around 0.4–0.45, with a resulting velocity of about 250 m/s and a kinetic energy of about 30 kJ/kg. Considering that the energy produced by a gas turbine is around 350 kJ/kg, the exhaust flow kinetic energy can be 10% of the entire turbine work. It is thus clear that the exhaust diffuser is a critical element in turbomachine environment in terms of efficiency and stability.

A considerable amount of experimental and numerical investigations on simple diffusers [1,2] can be found in literature and the factors influencing their performance are predominantly the area ratio and the length of the flow path over which diffusion occurs. Global parameters, relationships between static and total pressure and performance maps are generally used to determine diffusers' performance [3,4].

In diffusers situated downstream a turbomachine, the inlet flow presents a swirl component and a high level of turbulence. Therefore, the diffuser cannot be treated as an isolated element but it has to be seen as a component of the whole system, included the turbomachine. The increased turbulent mixing at inlet, which result in a later onset of flow separation, can sometimes improve diffusers' performance [5]. Dominy et al. [6] showed that in a S-shaped duct, the wakes created by the upstream turbine lead to total pressure distortion and significant local yaw and pitch angles. Moreover diffusers behind a turbomachine have struts supporting loads and passages

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Nomenclature

A_1	cross-surface at inlet, m^2
A_2	cross-surface at outlet, m^2
C_p	pressure recovery coefficient, dimensionless parameter
C_{pi}	ideal pressure recovery coefficient, dimensionless parameter
P_{st1}	static pressure at inlet, kPa
P_{st2}	static pressure at outlet, kPa
P_{t1}	total pressure at inlet, kPa
P_{t2}	total pressure at outlet, kPa
K	pressure losses coefficient, dimensionless parameter
R_{20}	electric resistance at 20°C, Ω
α_{20}	temperature coefficient at 20°C, °C^{-1}
η	diffuser efficiency, dimensionless parameter

for engine cooling and lubrication systems and these structural members, that extends radially from the inner to the outer annulus wall, act as bluff bodies and consequently cause unsteady wakes [7]. As is well known, within diffusers, which are characterized by strong adverse pressure gradients, boundary layers grow rapidly and tend to separate. To avoid unacceptable weight penalties, the diffusion must occur in the shortest possible length, while preventing flow separation requires small divergence angles. The presence of a row of struts inevitably causes a blockage and an acceleration of the flow, thus reducing the diffusion achieved. Ubertini and Desideri [8] showed how the interaction between the last turbine rotor and the struts, supporting the shaft, produce the onset of flow separation. Experimental and numerical investigations in a diffusing S-shaped duct made by Norris et al. [9] showed a 28% efficiency reduction, an almost doubled pressure loss coefficient and a significant rise of the separation bubble size when a row of struts are present in the duct.

Anyway very few examples of experimental analysis concerning annular diffusers downstream a turbine [10,11] or a compressor [12,13] can be found in the literature survey. In a previous paper [8], the authors presented a detailed three-dimensional investigation of a scaled down model of an annular exhaust diffuser, showing the turbulent flow field, the growing and the separation of the boundary layer and the evolution of the struts' wakes along the duct. The aim of this paper is to determine the overall performance of the diffuser and how it is achieved by local and detailed measurements of static and total pressure. The analysis has also been made in the diffuser without struts in order to understand and quantify their detrimental effect.

2. Experimental apparatus

Measurement were made in a diffuser model built by Nuovo Pignone S.p.A. reducing in 0.35:1 scale the annular exhaust diffuser of the gas turbine PGT10 (Fig. 1). The model was designed to operate in geometric and Reynolds number similarity with the PGT10 exhaust diffuser. The GT diffuser operates with a Reynolds number exceeding 10^6 and the model's Reynolds number is higher than 6×10^5, that is high enough to assume similar flow conditions with the real diffuser.

A funnel-shaped inlet prevents flow separation from the walls in the first part of the diffuser. The inlet section features 24 axial guide vanes, which provide both as a means of introducing swirl into the test section as well as of producing wakes representative of those produced by the last turbine rotor of the real PGT gas turbine. The diffuser length is 450 mm and the inlet and outer diameters are 190 and 320 mm, respectively. To keep

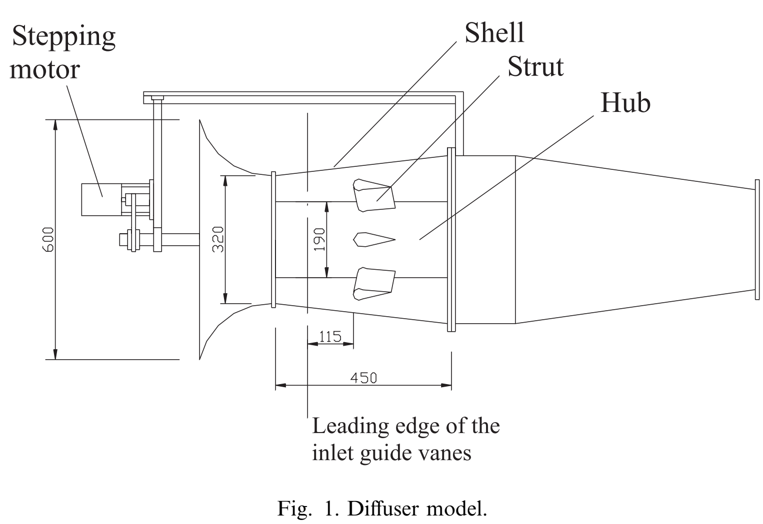

Fig. 1. Diffuser model.