STUDY OF THE PRESSURE DROP FOR RADIAL INFLOW BETWEEN CO-ROTATING DISCS

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Abstract

A basic theoretical analysis and experimental study of the pressure drop for radial inflow between co-rating discs are reported in this paper. It was shown that, with the influence of the centrifugal force and Coriolis force, the circumferential component of the absolute velocity can be very high resulting in pronounced total pressure drop in rotating cavity with radial inflow. At the same time, the total pressure drop of rotating cavity with radial inflow was investigated experimentally. Conclusions are drawn as following; the main influencing factors of the total pressure drop are the nondimensional mass flowrate and rotating Reynolds number. The total pressure drop is increased with rotating Reynolds number. At low rotating Reynolds number, the total pressure drop is increased with nondimensional mass flowrate; and at high rotating Reynolds, with the increase of nondimensional mass flowrate, the total pressure drop is increased at first and then decreased.

1 Introduction

In modern aero engine, internal air system is defined as those airflows which do not directly contribute to the engine thrust, which system has several important functions to perform for the safe and efficient operation of the engine. These functions include internal engine and accessory unit cooling, bearing chamber sealing, prevention of hot gas ingestion into the turbine disc cavities, control of bearing axial loads, control of turbine blade tip clearances and engine anti-icing.

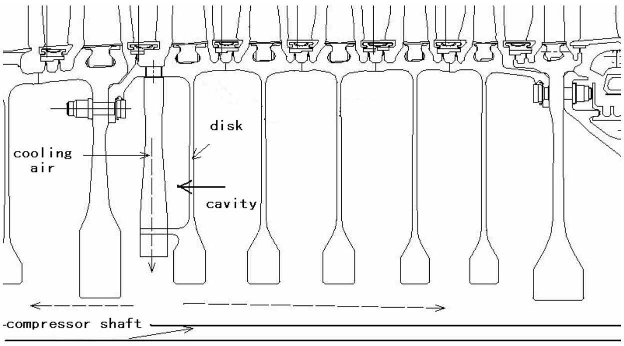

Figure 1. Cooling air flow in engine

As shown in Figure 1, the cooling air is bled from the main gas path in the compressor and radial flows inwards through the rotating cavity, then some flow backwards for cooling purposes.The flow for radial inflow between co-rotating discs(sometimes it could be called as flow in a rotating cavity with a radial inflow, a rotating cylindrical cavity provides a simple model to study the flow and heat transfer between co-rotating turbine or compressor discs,) was called as source-sink flow by Hide[1] in 1968, there are four different flow regions in the rotating cavity: a source region, a sink region, Ekman-layers on each disc and core region between the Ekman-layers, the source region and the sink layer is an interior core of inviscid rotating fluid in which the radial and

axial components of velocity are zero, as shown in Figure 2.
And then, the most importance of this study is perhaps that of Owen[2,3] [1985], Chew[4,5] [1988], Pincombe [1984] and Firouzian[6,7] [1985], they obtained solutions of the linear and the nonlinear Ekman layer equations using integral momentum techniques; Summarizing the prior studies, because the complexity of both the geometries and aero-thermal phenomena involved, the total pressure drop is very difficult to predict and catch.
The study of the flow and heat transfer in this bleeding cavity between two co-rotating discs is very important for designing the internal cooling system. In author's formerly paper[8,9,10], the spatial distribution of the velocity of a rotating cavity with a radial inflow was obtained. In this paper, a basic theoretical analysis and experimental study are reported to explain the total pressure drop. At the same time the experimental apparatus is described.

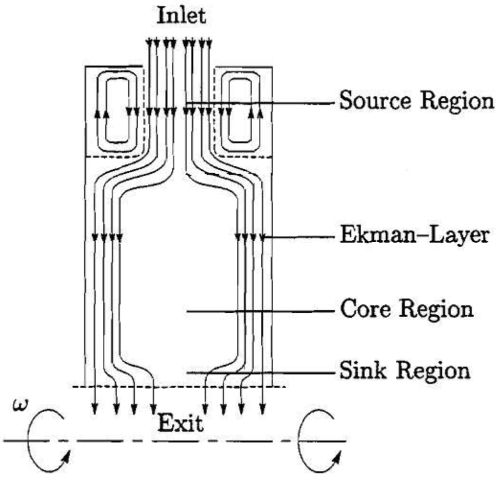

Figure 2. Source-Sink flow

2 Basic Theory

For radial inflow between co-rotating discs the centrifugal force and Coriolis force are the main influencing factors on the total pressure drop, the combined effects of the centrifugal force and Coriolis force could result in pronounced total pressure drop, so it is the main method to analysis the force of the flow in the rotating cavity, Figure 3 shows the details.

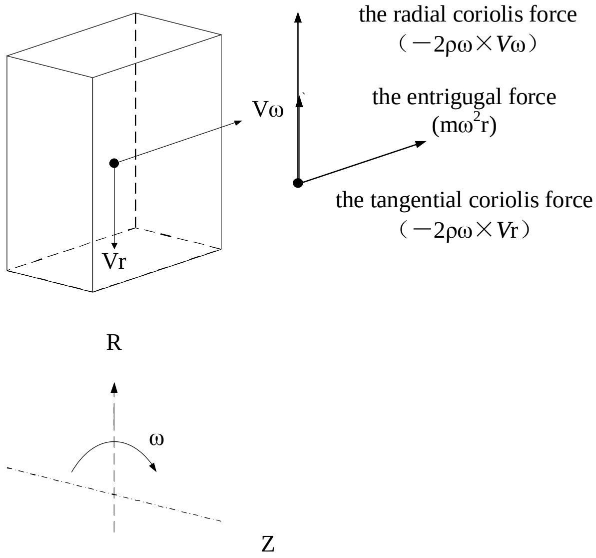

Figure3 influence of Carioles force and Centrifugal force

At non-inertial reference system (rotating coordinate), the great velocity for radial inflow (V_r)could result in the great tangential Coriolis force($-2rw \times V_r$), the tangential Coriolis force causes a further increase of the circumferential component of the absolute velocity (V_w), the increasing circumferential component of the absolute velocity(V_w) could lead to the pronounced radial Coriolis force. The radial Coriolis force would prevent radial inflow.
As shown in Figure 3, the radial Coriolis force and centrifugal force are contrary with radial inflow, So Which would prevent radial inflow and result in pronounced total pressure drop in rotating cavity with radial inflow.

3 Experimental Apparatus

3.1 Test Rig

The experiment was finished on the multifunctional rotating facility in National Key Laboratory on Aero-engines of BUAA. Figure 4 shows a simplified diagram of the multifunctional rotating facility. The whole housing is 1 meter in diameter and 3 meters long and the design rotating speed is 3000 r/min.

Three-stage screw compressor could compress the air into a pressurize tank, which could supply stably experimental air. A thermal flow meter measures the mass flow rate. Through 20 holes the air flows into the test section and then enters the cavity.

In this rig, the whole assembly (that is, the two discs, the shroud, and drive-shift) is rotated by a variable-speed electric motor. Seals are used to minimize leakage between the stationary and rotating components.

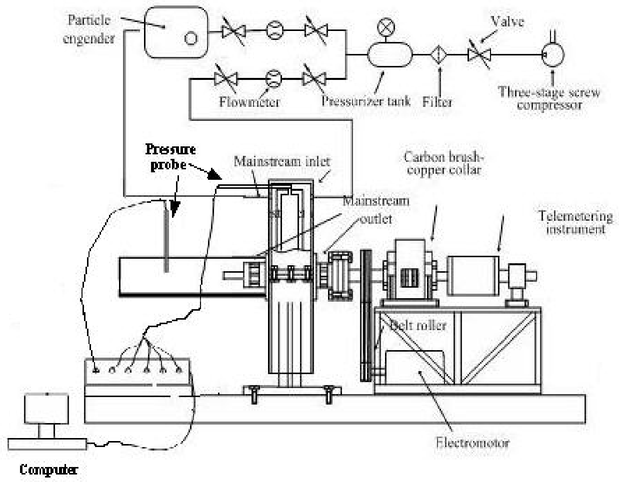

Figure 4. Test rig

3.2 Test Model and Experimental Conditions

The cavity comprised two polycarbonate disks of 670 mm in diameter and a peripheral shroud of 10 mm in thickness (shown in Fig.5). The distance between the two co-rotating disks is 60 mm and the inflow gap is 10 mm. In this experiment, air is introduced into the cavity at R2, and withdrawn at R_1,

Experiments were conducted with a rotational Reynolds number of 9.4×10^5 and the nondimensional mass flowrate $5.48 \times 10^{4.}$

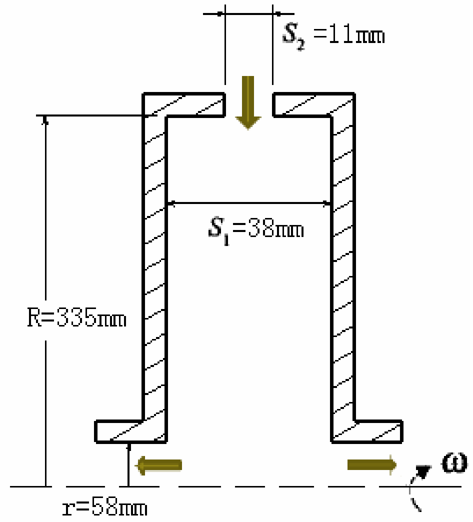

Figure 5. Test model.

3.3 Pressure Measure Apparatus

Total pressure probes (at inlet an outlet) were used to measure the pressure drop in the rotating cavity (shown in figure 4).

4 Results

The circumferential component of the absolute velocity(V_w) is shown in figure 6, the influence of the circumferential component of the absolute velocity with the radial Coriolis force (in section 2) is proved.

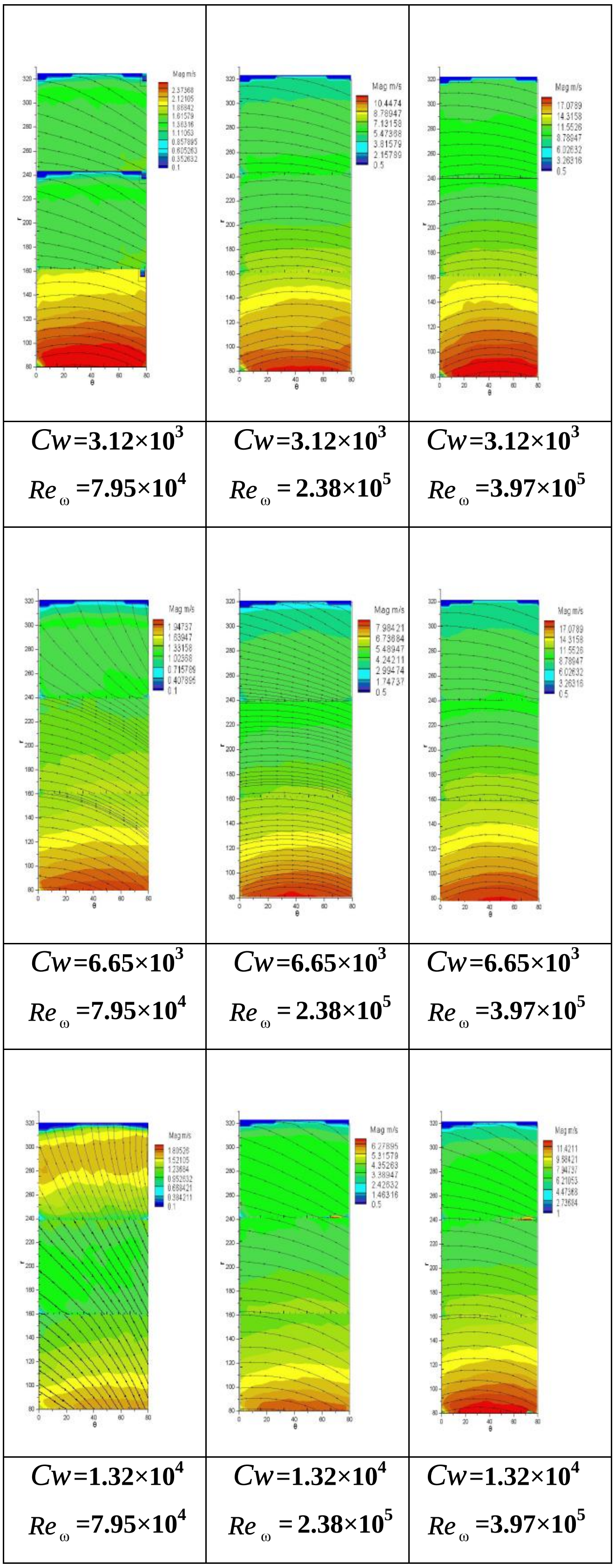

Figure6. the circumferential component of the absolute velocity

The total pressure drop with the change of nondimensional mass flowrate and rotating Reynolds number was investigated experimentally and was shown in figure 7 and figure8.

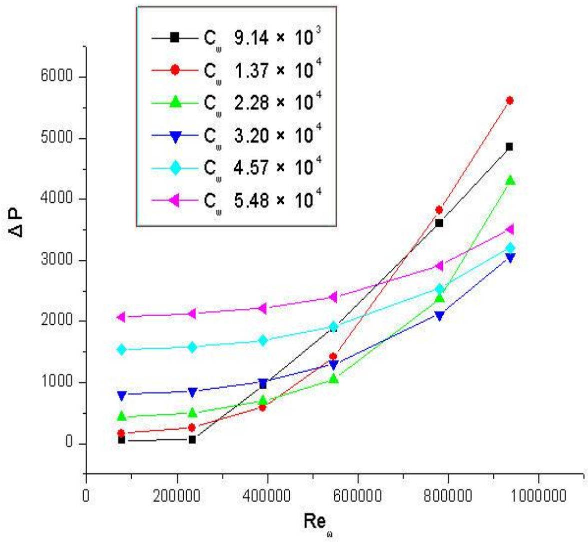

Figure 7 total pressure drop with different rotating Reynolds number

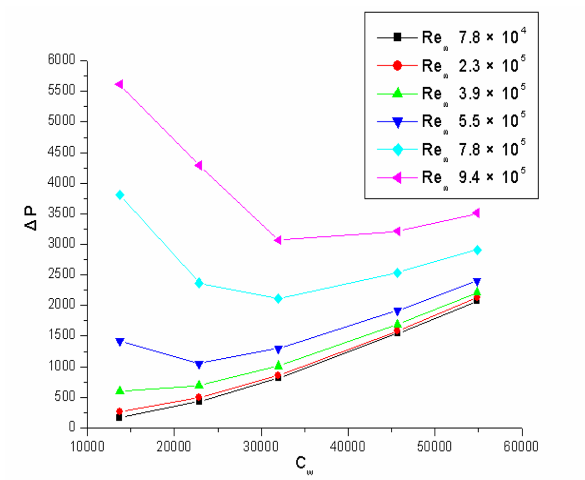

Figure 8 total pressure drop with different nondimensional mass flowrate

5 Conclusion

1) The centrifugal force and Coriolis force are the main influencing factors on the total pressure drop, so with the influence of the centrifugal force and Coriolis force, the circumferential component of the absolute velocity can be very high and can thus lead to

pronounced total pressure drop in rotating cavity with radial inflow.

2) The total pressure drop is increased with rotating Reynolds number. At low rotating Reynolds number, the total pressure drop is increased with nondimensional mass flowrate; and at high rotating Reynolds, with the increase of nondimensional mass flowrate, the total pressure drop is increased at first and then decreased.

Nomenclature

Notation	
R	Radius of hub
ω	Disk rotating speed and velocity
C_w	Flow rate coefficient $=Q/nR$
Q	Volumetric flow rate of fluid entering cavity
Re_ω	Rotational Reynolds number $=wR^2/n$
△P	the inlet and outlet pressure drop
Z	Axial coordinate
V_r	Radial velocity component
V_ω	Tangential velocity component
n	Kinematics viscosity
S	disc-to-disc spacing

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