Leakage and Thermal Characterizations of Canted Labyrinth Seals

Mohana Rao

Received: 8 December 2016 Accepted: 5 January 2017 Published: 15 January 2017

Abstract

Labyrinth seals are the simple and most commonly used rotating seal in cold (compressor) and hot (turbine) regions of gas turbine engines. In order to achieve successful engine design estimating accurate leakage flow rates, windage heating and heat transfer coefficients are critical for rotor dynamic stability. The windage effect inside the flow creates direct loss of power also increase fluid temperature. In this paper numerical simulation of a canted stepped labyrinth seal is performed using commercial Fluent CFD code with 2D axisymmetric is used to study leakage flow and windage heating for various seal clearances for solid (smooth) stator land geometry. The 2D model is subsequently used to determine average heat transfer coefficients on the rotor and stator for heating and cooling situations.

Index terms— CFD, labyrinth seal, windage effect, gas turbine.

1 Leakage and Thermal Characterizations of

Canted Labyrinth Seals R Mohana Rao ? & Dr. Manzoor Husain ? -Labyrinth seals are the simple and most commonly used rotating seal in cold (compressor) and hot (turbine) regions of gas turbine engines. In order to achieve successful engine design estimating accurate leakage flow rates, windage heating and heat transfer coefficients are critical for rotor dynamic stability. The windage effect inside the flow creates direct loss of power also increase fluid temperature. In this paper numerical simulation of a canted stepped labyrinth seal is performed using commercial Fluent CFD code with 2D axisymmetric is used to study leakage flow and windage heating for various seal clearances for solid (smooth) stator land geometry. The 2D model is subsequently used to determine average heat transfer coefficients on the rotor and stator for heating and cooling situations.

2 I. Introduction

s the airline industry is growing OEMs are working improved and efficient Aero Engine Technologies to offer to their customers. As per ACARE 2020 norms Fuel burn, Noise and NOx emissions are to be improved significantly, in order to achieve this either new technologies that radically improve performance or identify the current design leakages so that gaps can be filled & improved.

In this paper the leakage & windage thermal characterization behaviors of Lab seals are worked, the ability to accurately model lab seals leakage flows is extremely important, as leakages can significantly affect latter stages of compressor and turbine efficiencies that cause undesirable hot gas ingestion. In order to meet the stringent norms the component material durability studies in heat generated boundary conditions by viscous dissipation or windage flow environment. Lab seals are exposed to high flow velocities contributing to elevated temperatures further enhance heat transfer coefficients.

3 II.

4 Literature Review

5 A Abstract

6 Global

Journal of Researches in Engineering ( ) Volume XVII Issue VII Version I A Tipton [8]conducted test that resulted temperature profile by variable factors of pressure ratio, clearance and rotor speed. He measured the total temperature increase in the seal and reported that the total Lab seals windage heating effect was performed initially with experimental methods subsequently correlations are derived. The first of this experiment was prepared by Stocker H[3] subsequently temperature difference between the seal outlet and inlet total can reach upto 19.4K. McGeehan and Ko [4] experimented to investigate the windage heating effect and derived a correlation equation to predict the windage power loss in the labyrinth seal. The influence of the mass flow rate, rotor speed, inlet preswirl, and friction factor, the wall surface has taken into consideration in their equation.

7 III.

8 Present Work

In this work, combination of parameters to improve the seal design, the experimental case of seal configuration reported by J. Denecke, K. Dullenkopf, S. Witting and H.-J. Bauer in [1] is considered as baseline case for smooth land. In the present work, the authors conducted a CFD investigation on different configurations of canted teeth as Design 1, canted with Wavy surface as Design 2 and canted with hat step and way surface as Design 3.The design evolved while conducting a parametric study on teeth height, teeth tip thickness, stepped teeth, inclined teeth etc. The baseline configuration is a simple sharp teeth labyrinth seal. The results obtained for the baseline configurations using this methodology were validated by comparing against 2D and 3D experimental data with smooth land. Wróblewski [6] analyzed radiation affects that intensifies heat transfer leading temperature differences in the casing elements caused by radiation, are much smaller than those resulting from different thermal conductivity coefficient much greater than the one resulting from convection. Piotr et al [9] investigated tip leakage off-design conditions the effect of tip leakage flow rate and the tip leakage swirl angle was found to bring up to a 1.5% decrease in enthalpy losses. D. Fr?czek et al [11] worked out geometry for rubbing effect by modifying the fin tip inclination geometry resulted by mass flow reduction of 13%.

9 a) Baseline Geometry: Sharp Teeth

Denecke et al. [1]used scaling & dimensional methods to analyze the leakage and windage heating of rotating seals. By adopting the Buckingham-theorem, they found that the discharge behavior, exit swirl, and windage heating in the contact less seal can be uniquely expressed by several non-dimensional numbers. They also presented a rule to scale the engine seal to the laboratory conditions .Moreover; they measured the total temperature increase in as tepped lab yrinth seal with smooth stator. The performance of a seal can be described by the relation between the pressure ratio and a flow parameter. The most common flow parameter is the following flow function:??T o,in A c P o,in C d = ? ? id

The discharge coefficient depends on the pressure ratio, number of used seals, leakage mass flow rate. The flow through an ideal labyrinth seal.

10 Windage Heating:

The total temperature increase due to the internal losses in adiabatic flow is called windage heating,

11 H = C p ??T total

The windage heating number ? is defined as IV.

12 Analysis a) Numerical Analysis

Computational Fluid Dynamics (CFD) is extensively used because its capability to analyze a large number of design configurations and parameters in a relatively short period of time. Therefore, with the development of commercial codes, the use of CFD analysis has been increasing rapidly in recent years in 2 or 3 dimensional analysis. The test cases adopted in this work are two-dimensional with number of different operating conditions are analyzed.

13 b) Boundary Conditions

A commercial finite volume code, Ansys Workbench with Fluent 16.1v [10] is used. This commercial tool has wave linking geometry that eliminates loss of geometry while importing from CAD model to Fluent, manages entire problem in project charter. It was assumed that air was an incompressible ideal gas and the flow was steady and adiabatic. Various turbulence models available in Fluent [10] were considered for the current simulations. The flow in the labyrinth seal is mainly dominated by pressure difference in the axial direction.

The study of interest is on reverse flow direction. The Models of basic design and Design 1 to 3 are run through by varying mass flow with boundary condition as per table 1.

14 Fig. 12: Basic Design velocity contours

The Wall shape change introduced in the fixed wall refer design 1 to design 3 , two things will happen either wall shear increase or decrease and second one will be flow circulations. Design 1 will be canted shape and fixed wall is straight. Design 2 the seal shape is canted and fixed wall is having 2 dimple shapes. Design 3 is having canted seal with fixed wall having dimple shape with hat projection.

The analysis is run with Table 1 boundary condition and the mass flow is varied with .1 to .25 kg/s for basic design and design 1 to 3 with fow direction as shown in figs 12 to 15. The jet stream in design1 continues its full contact with fixed wall at exit. In Design 2, the jet stream slides over the concave surface of fixed wall , the velocity vectors hits down ward path by not sliding over the remaining straight surface of fixed wall as shown in Fig. 14. In Design 3, the velocity vectors hit the walls of stationery surface of concave with double step creating static current that obstruct the main jet shown in Fig. 11, at the exit the jet diffuse compared to Design 2.

In design 3 the jet stream hits the concave surface of fixed wall and reflects back to downwards their by losing its velocity. In this the jet is like jig jag pattern. The hat shape cavity at fixed wall creates a seal lock hence reduce leakage. Refer figures 16 to 19, as the flow rate increases the pressure ratios is also increased thus linear in nature for all the 3 designs. Its observed that the design 1 is having higher pressure ratios then other two designs. The temperature rise in Design 1 is higher than the other two designs. Design 3 shows that less swirl velocity compared to two other designs. Design 1 and 2 are starting with same swirl velocity but as it progresses design 2 has steep increase. The windage heat power is higher in design 1 compared to two other designs.

The seals can further be studied with honeycomb fixed wall by various speed parameters. It may further studied by introducing air injection between knife edges and swirl interrupting steps thatwould create turbulence flow in the flow path that restricts movement.

15 VI. Conclusions

A new model of canted teeth with different wall shapes for labyrinth seals has been studied numerically and compared to base line sharp teeth with smooth land. The temperature rise and windage heat power is high in Design 1. Analyses indicate that the design 3 is capable of reducing overall seal leakage by generating more turbulence and friction flow.

2D axisymmetric analysis of the Labyrinth Seal geometry (with rotation speed of 20,000 rpm) was first carried out. The objective was to establish baseline capability to run lab seal CFD analysis using Fluent and validate the experimental results.

16 Global

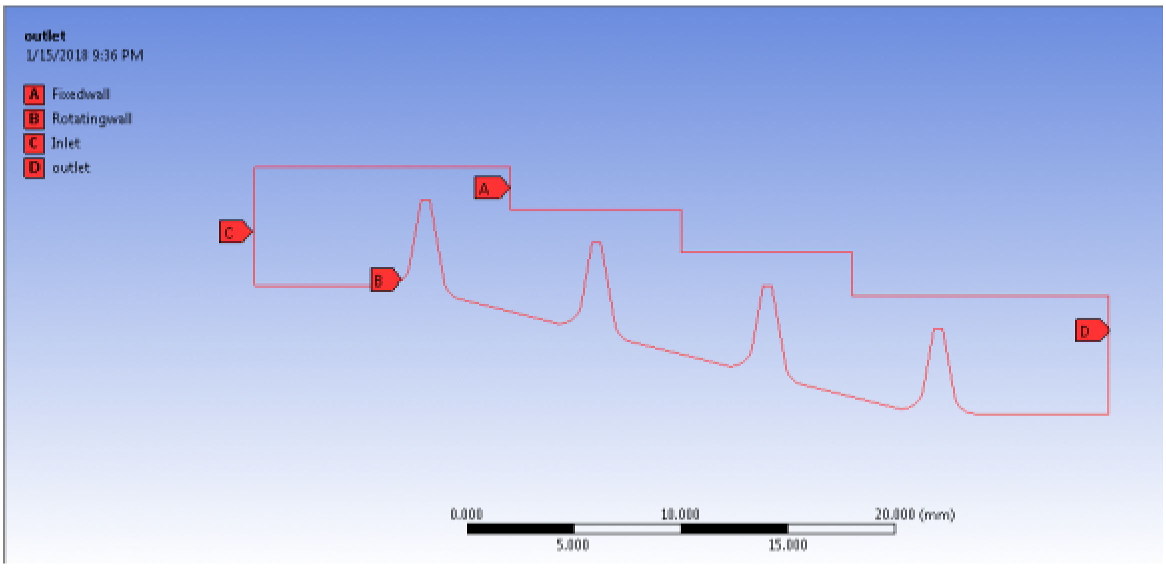


Figure 1:

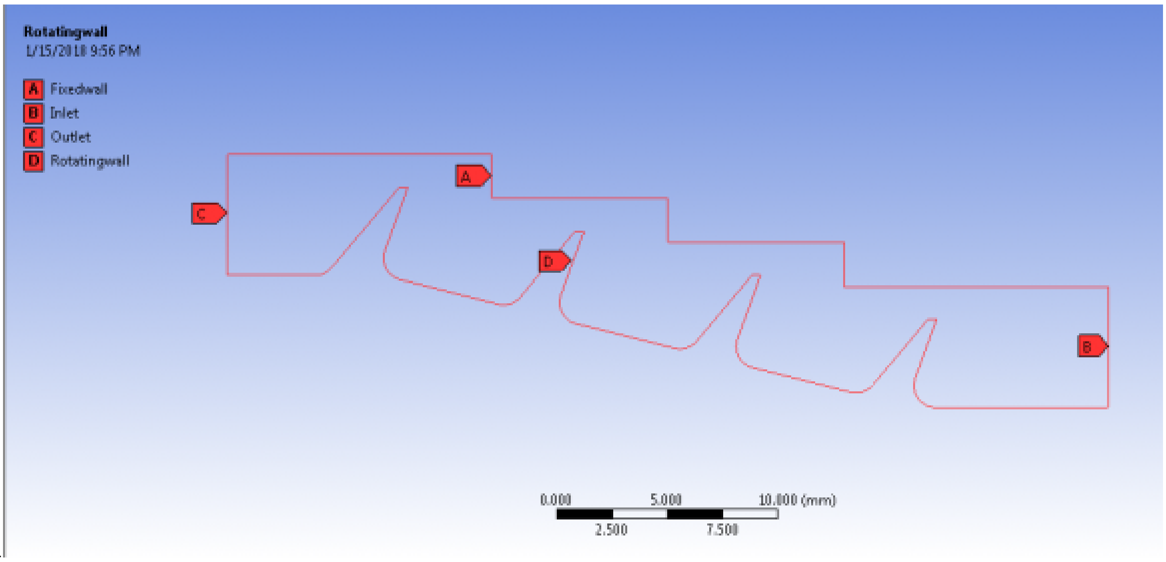
1 

Figure 2: Fig. 1

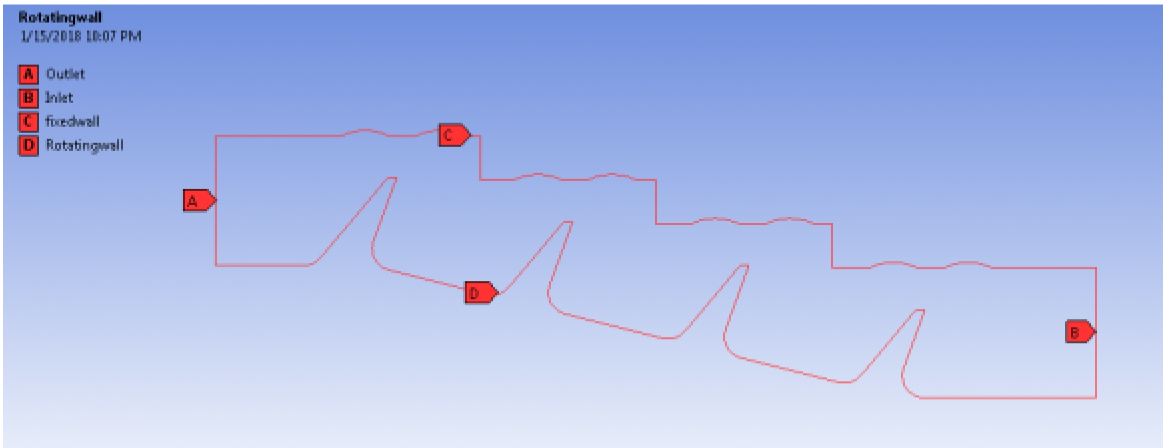
1 

Figure 3: Fig. 1 :

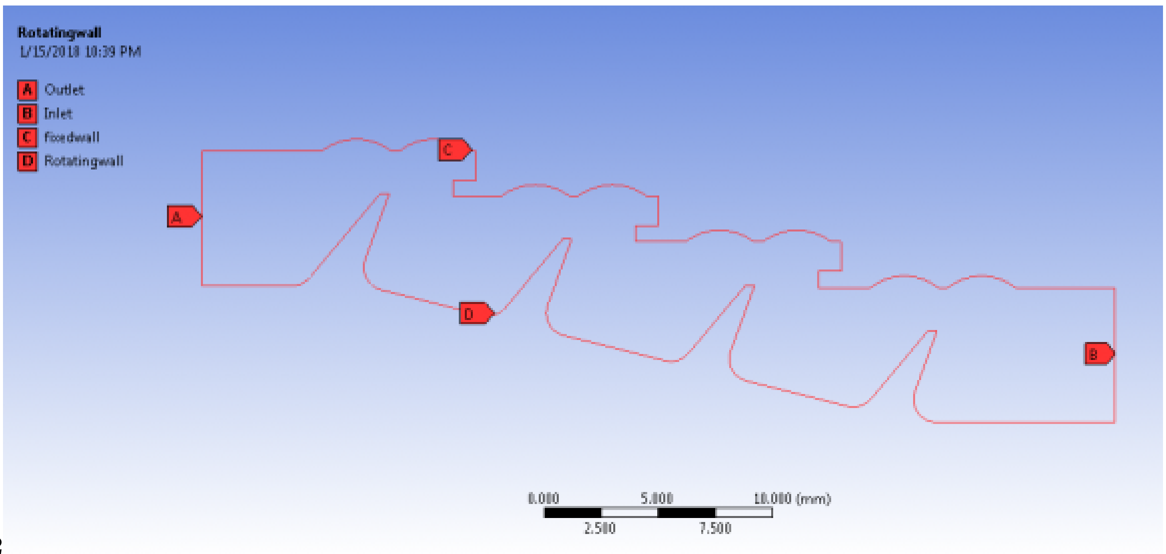
2 

Figure 4: Fig. 2 :

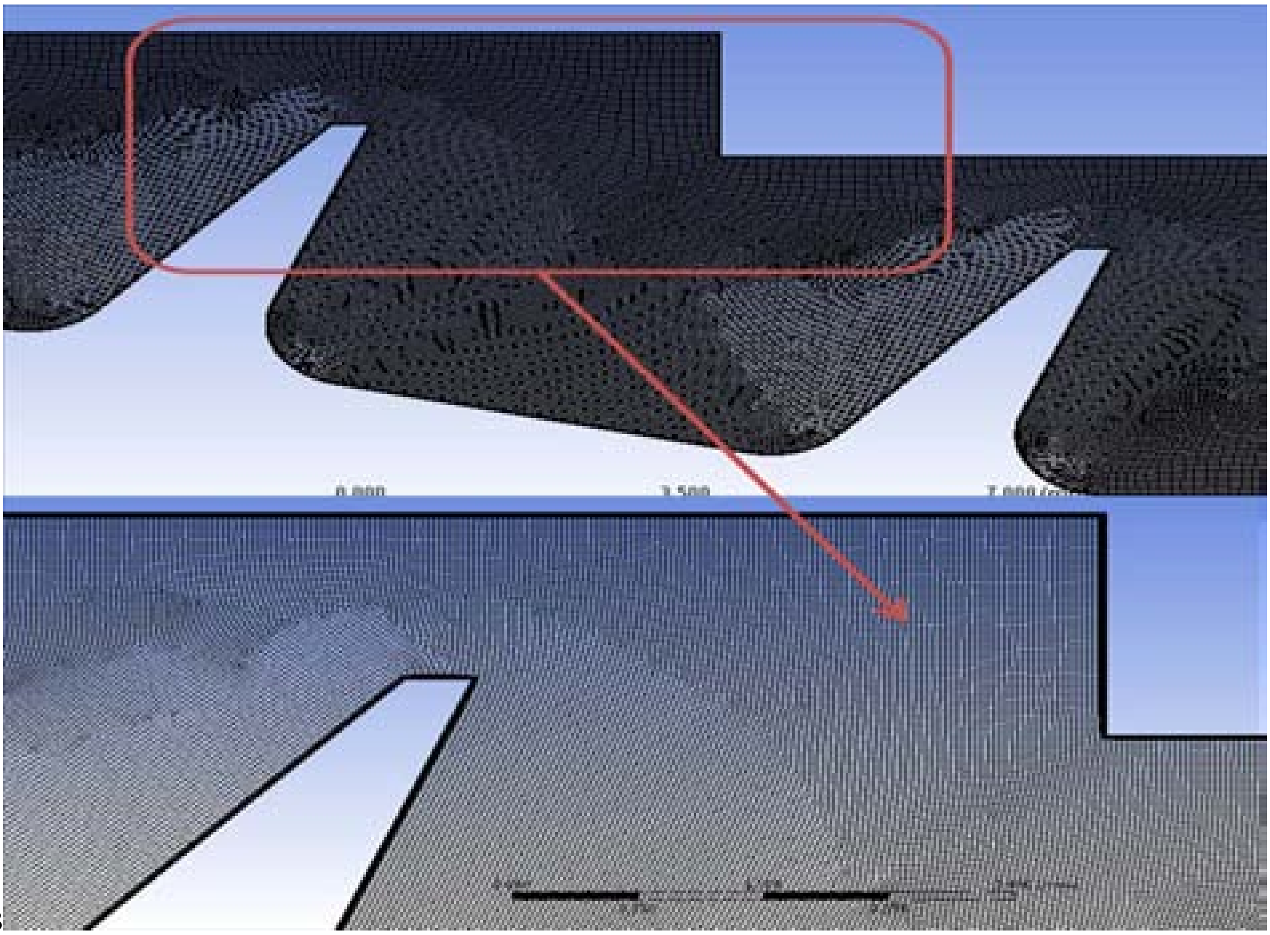
3 

Figure 5: Fig. 3 :

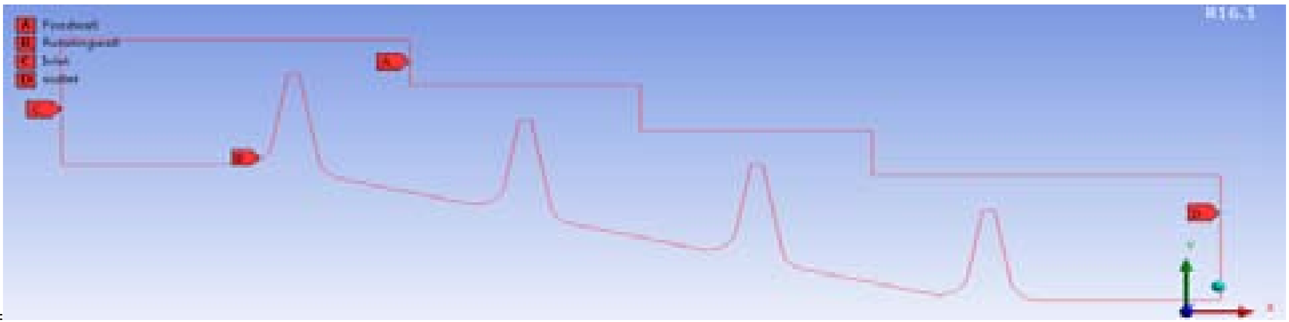
4 

Figure 6: Fig. 4 :

5252623

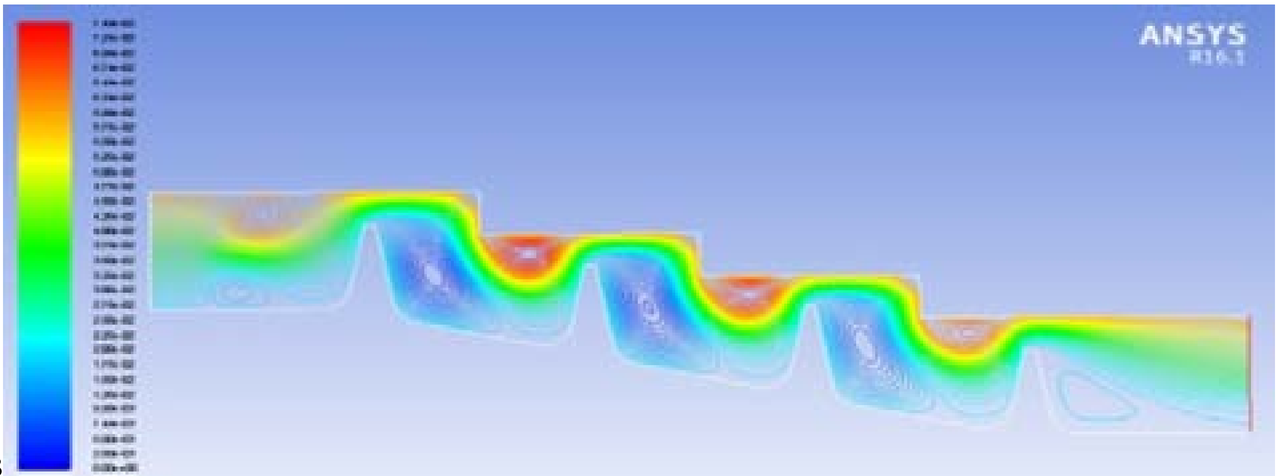


Figure 7: Fig. 5 , 2 Fig. 5 :Design 2 :Fig. 6 : 2 Design 3 :

7

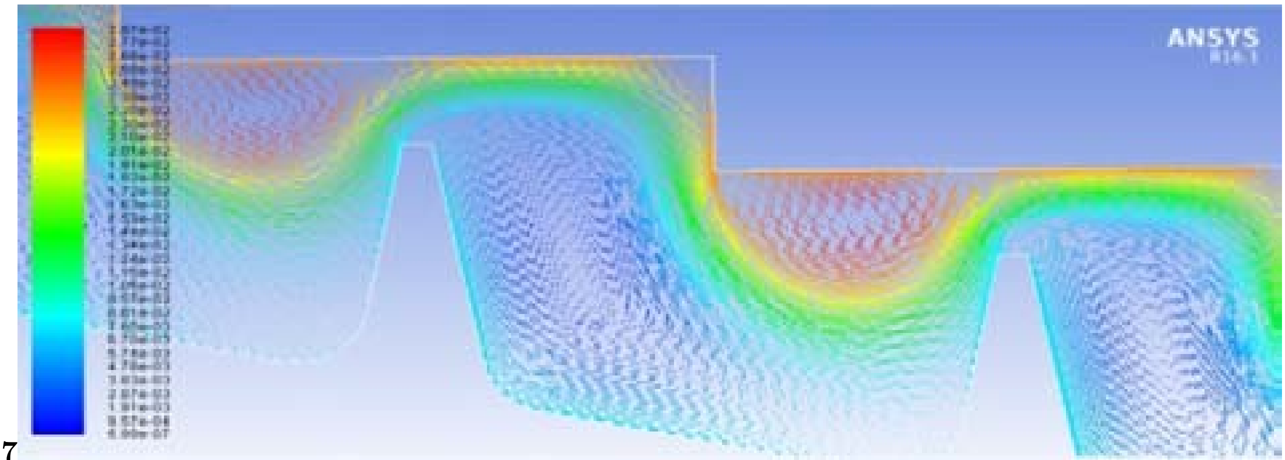


Figure 8: Fig. 7 :

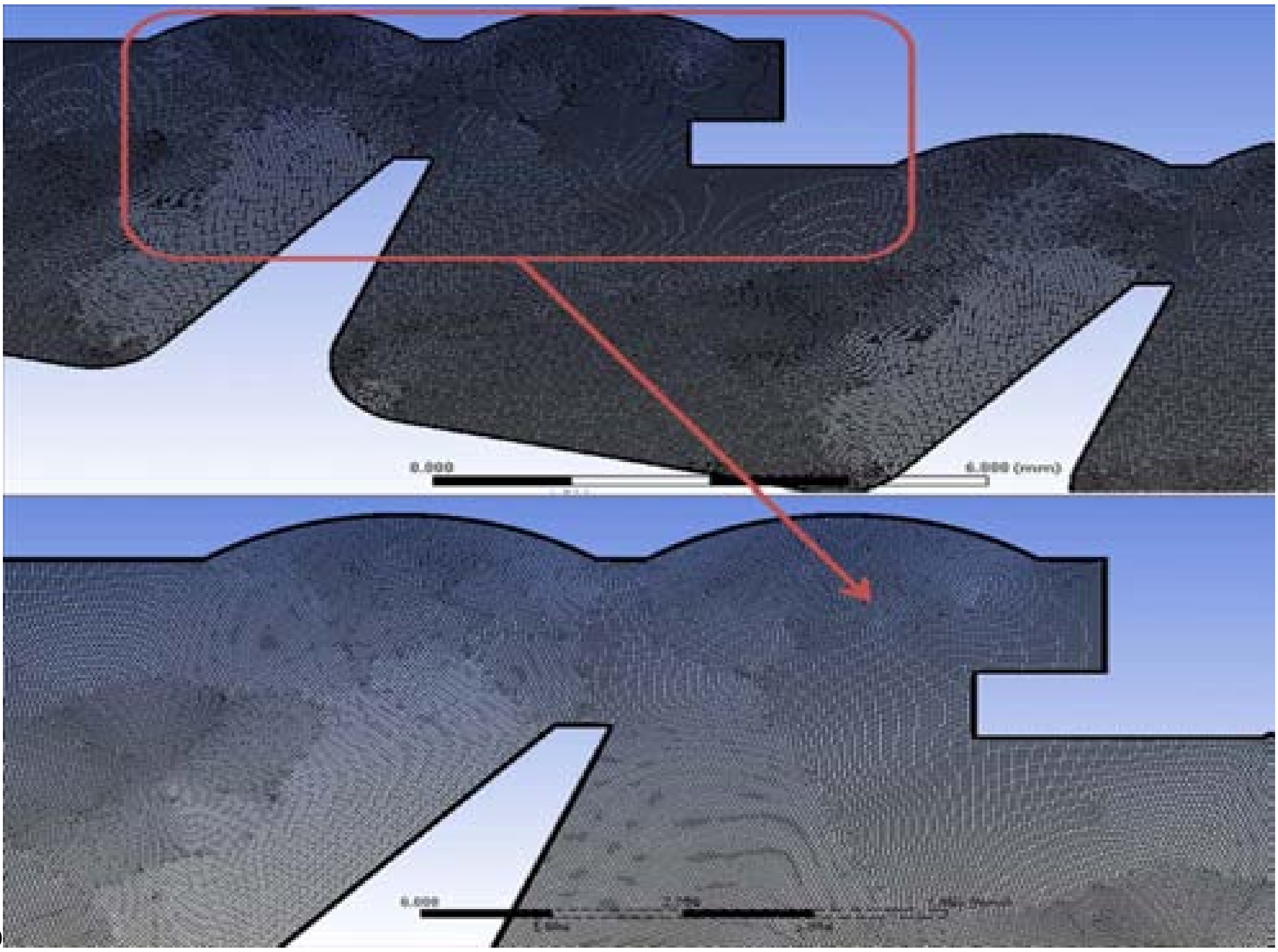
9 

Figure 9: Fig. 9 :

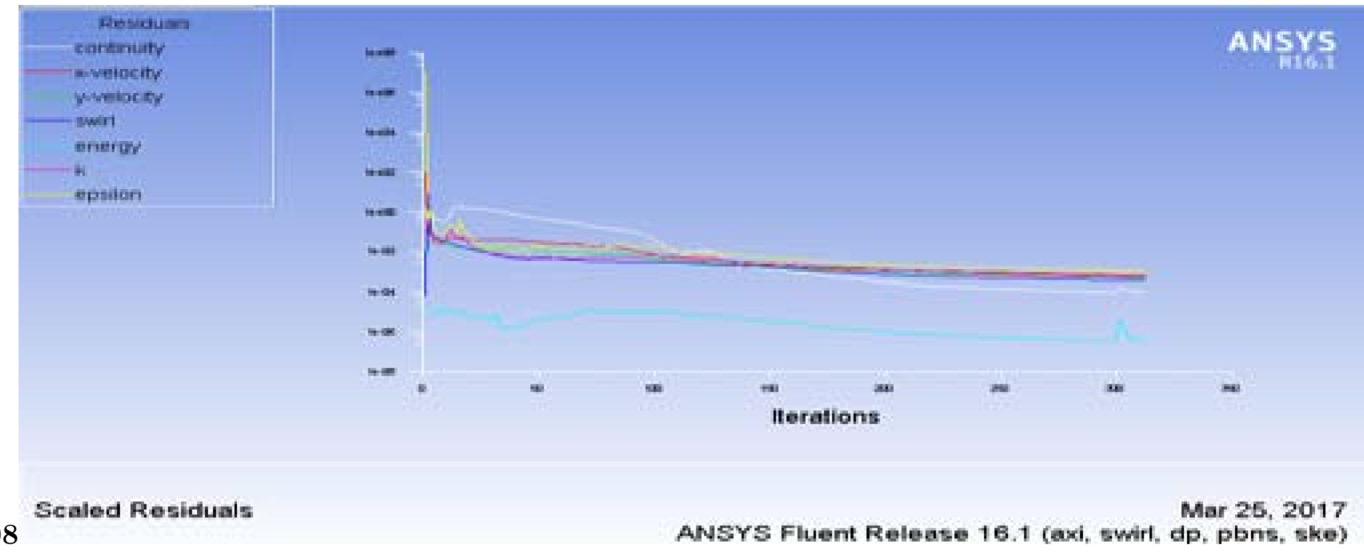
108 

Figure 10: Fig. 10 :Fig. 8 :

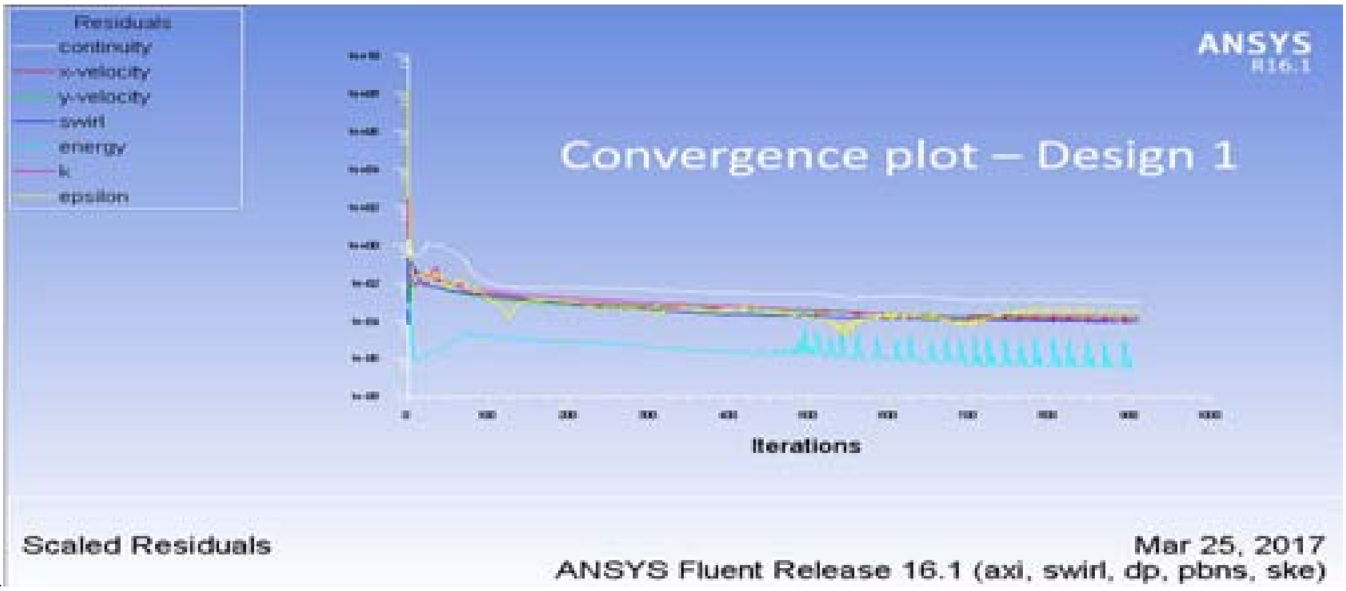
11 

Figure 11: Fig. 11 :

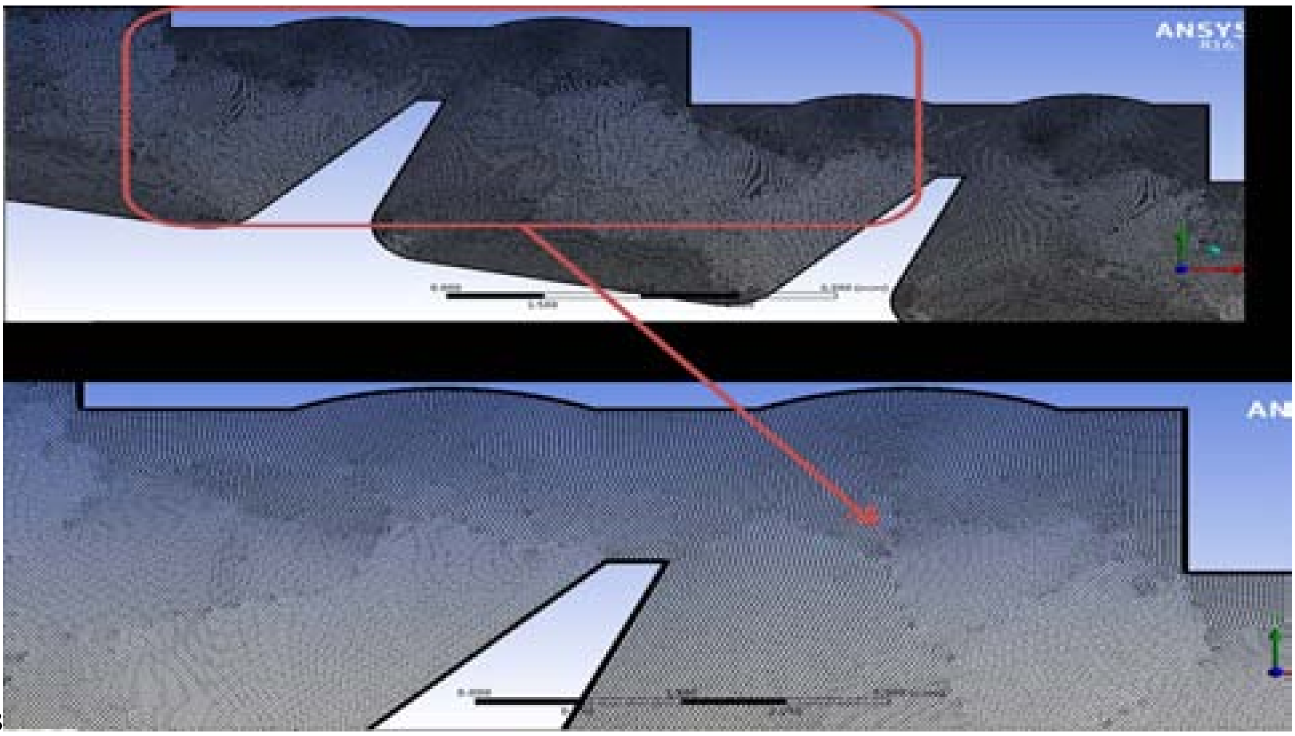
13 

Figure 12: Fig. 13 :

14

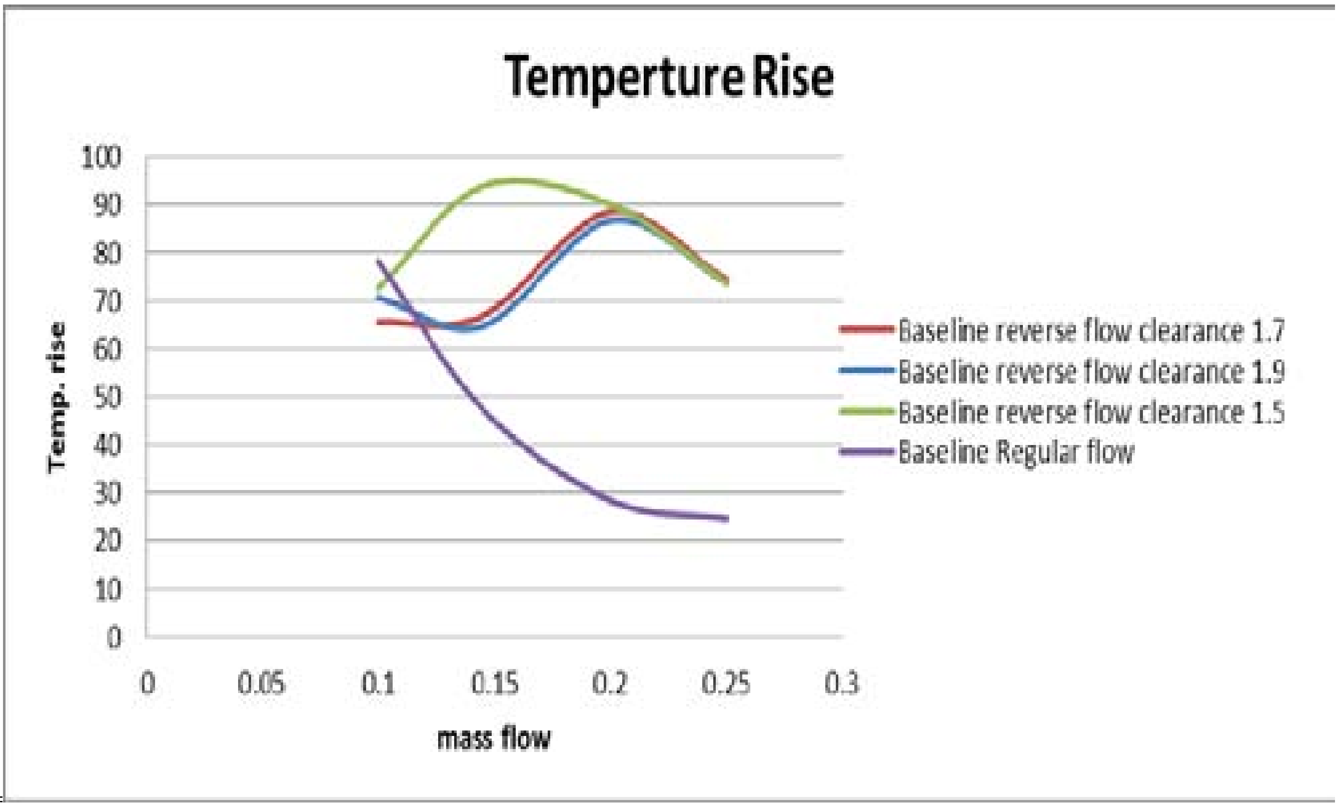


Figure 13: Fig. 14 :

151719

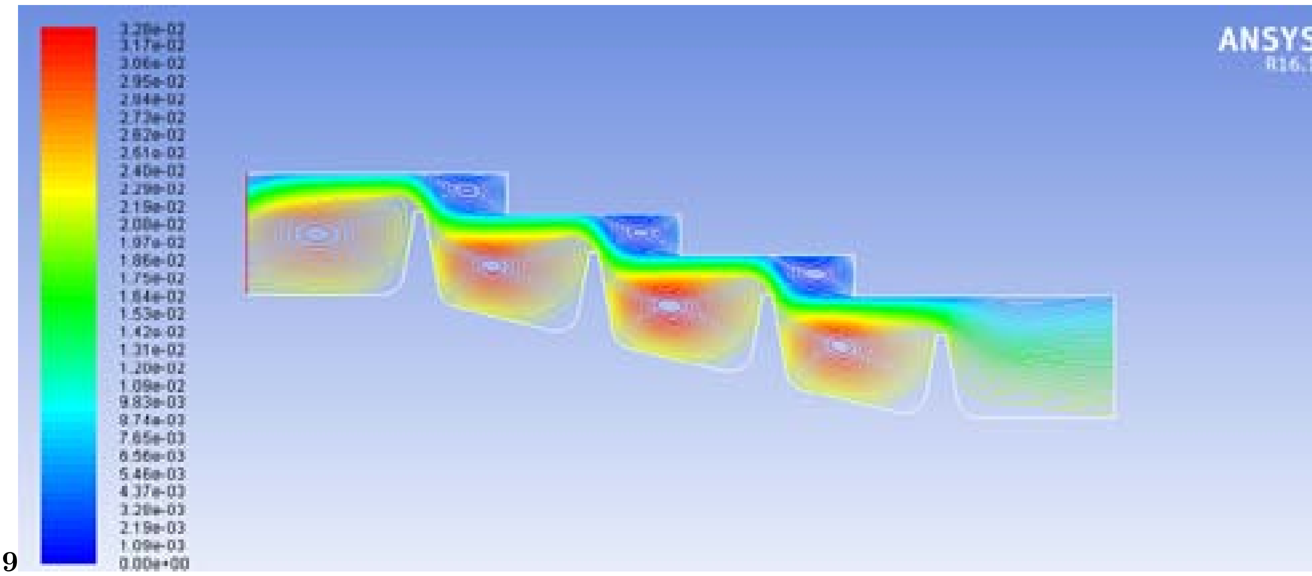


Figure 14: Fig. 15 :Fig. 17 :Fig. 19 :

1

Average rotor radius	0.253m
Inlet total temperature	300K
Outlet static pressure	200,000Pa
Turbulence model	Realizable k-epsilon,
Fluid	Air (ideal gas)
Wall Properties	Adiabatic, smooth surface

Figure 15: Table 1

123 [1]

.1 Acknowledgment

The authors wish to thank kondala Rao N and Suresh B for his guidance during case studies.

[Tipton et al. ()] ‘Analytical and Experimental Development of a Design Model for Labyrinth Seals’. Donald L Tipton , Thomas E Scott , Rodney E Vogel . 3810.2478/pomr-2013-0038. *POLISH MARITIME RESEARCH* 2013. 4 (80) .

[Cieslewicz and Jozwik (2004)] *CFD-Simulation for advanced Turbo machinery Sealing Technologies-Brush seals*, Stanislaw Michal Cieslewicz , Krzysztof Jozwik . December 2004. (Institute of Turbo machinery-Vienna)

[Wroblewski and Bochon ()] ‘Conjugate heat transfer analysis of the tip seal in the counter rotating low pressure turbine’. W Wroblewski , K Bochon . *Arch. Mech* 2015. 67 p. .

[Buggeln and Mcdonald (2008)] ‘Development of Navire-strokes analysis for Labyrinth seals’. R C Buggeln , H Mcdonald . AFWAL-TR-85-2103. *Aero Propulsion Laboratory* Jan 2008.

[Denecke et al. (2005)] ‘Experimental Investigation of the total Temperature increase and Swirl development in rotating Labyrinth Seals’. J Denecke , K Dullenkopf , S Witting , H.-J Bauer . GT2005-68677. *Proceedings of GT2005 ASME Turbo Expo*, (GT2005 ASME Turbo ExpoReno-Tahoe, Nevada, USA) 2005. June 6-9. Power of Land. (Sea and Air)

[Fr?czek et al. ()] ‘INFLUENCE OF HONEYCOMB RUBBING ON TIP SEALPERFORMANCE OF TURBINE ROTOR’. D Fr?czek , W Wróblewski , T Chmielniak . *Proceedings of 11thEuropean Conference on Turbo machinery Fluid dynamics & Thermodynamics ETC11*, (11thEuropean Conference on Turbo machinery Fluid dynamics & Thermodynamics ETC11Madrid, Spain) March 23-27, 2015.

[Ilieva (2016)] ‘Labyrinth Seals -A Promising and Effective Design’. Galina Ilieva . ID: NOV162352 1702. *International Journal of Science and Research* April 2016. 5 (4) .

[Mcgeehan and Ko ()] *Power dissipation in smooth and Honeycomb Labyrinth Seals” 89-GT-220, Gas Turbine and Aero engine congress and exposition*, W F Mcgeehan , S H Ko . June 4-8, 1989. Toronto, Ontario, Canada.

[Lampart et al. (2004)] *Tip leakage / Main flow interactions in multi-stage HP Turbines with shortheight blading” Proceeding s of ASME Turbo Expo*, Piotr Lampart , Sergey Yershov , Andrey Rusanov , Mariusz Szymaniak . 2004. June 14-17, 2004. Austria: Power for Land, Sea and Air. (Ansys workbench V 16.0)

[Millward and Edwards ()] ‘Windage heating of air passing through labyrinth seals’. J Millward , M Edwards . *ASME Journal of Turbo machinery* 1996. 118 p. .