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Influence of the Dump Gap on the Performance of Dump Diffusers

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Abstract: In order to study factors that influences the dump diffuser performance, numerical simulation of flow structure is performed in a 3D single-dome combustor with a dump diffuser. Realizable $k-\varepsilon$ model is chosen for the simulation with the same inlet condition for the diffuser under different dump gaps and flow splits. The numerical results show a great correspondence with experimental pressure results and PIV measurements. Based on this the numerical solution can be used to analyze the influence of flow split and dump gaps on dump diffuser performance. The results show that small dump gaps increase the static pressure recovery of the pre-diffuser and decrease its total pressure loss. The total pressure loss coefficient of the combustors reaches a minimum at a certain relative dump gap, which is around 1.7 when mass-flow split between outer and inner annuli is 1.73.

1. Introduction

Aircraft combustion chamber flow field is mainly decided by the performance of the diffuser. The main purpose of a combustor diffuser is to decrease the velocity and increase the static pressure of the flow [1]. Under the requirements of modern aircraft combustor, faired diffuser is no longer suitable due to its sensitivity to different inlet flow conditions, while dump diffuser can assure the stability of the diffusion process under a wild range of inlet flow conditions. The performance of dump diffusers depends on a variety of parameters such as dump gap, dome depth, area ratios of the annuli, inclination of the combustor walls, flow split between the annuli [2]. In the past a lot of experimental and numerical studies [3-12] have been reported on the design and optimization of the dump diffuser. Owing to the complexity of flow field inside the dump diffuser, the design optimization of the dump diffuser remains an elusive task. In this paper 3D numerical simulation is performed in the dump diffuser with a real dome and swirler, the diffuser performances are compared under different dump gaps.

2. Numerical Methodology

2.1 Model geometry and computational grids

The combustor model studied in this paper is shown in figure 1. Before the pre-diffuser an approach section with the length of 65mm is added. The pre-diffuser is designed with a hybrid curvature (constant pressure gradient and constant velocity gradient). The inlet height of the pre-diffuser is 27.5mm and its length is 59mm with a constant area ratio 1.6.

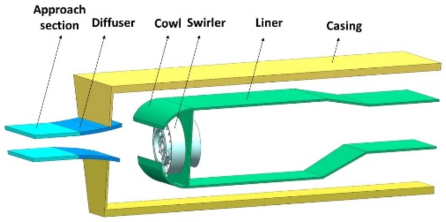


Figure.1 Single-dome combustor with a dump diffuser

Figure 2 shows the computational grids of the combustor model. The hybrid meshing is performed with hexahedron in the approach section and pre-diffuser and tetrahedron in the liner and the annuli. Inside the pre-diffuser the wall y+ is kept between the interval $30 < y^+ < 70$. Mesh refinement is performed in the dump region to capture detailed flow pattern inside this region. The total cell number is around 10 million.

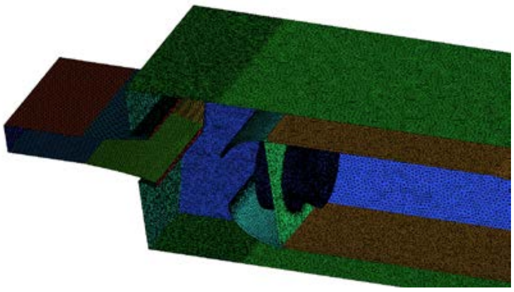


Fig.2 Computational grids

2.2 Solution methods and boundary conditions

In this paper numerical simulation is performed with ANSYS Fluent. The realizable $\mathrm{k}-\varepsilon$ model is chosen with standard wall function. SIMPLE scheme is used to solve the pressure velocity coupling problem.

The operating pressure and temperature are $\mathrm{p} = 113100\mathrm{Pa}$, $\mathrm{T} = 283\mathrm{K}$. The Velocity-inlet condition is given and a constant velocity $V_{in} = 98.8m/s$ is set at the approach section inlet. The outlets of the liner and the annuli is all Outflow. Other surfaces are set with Wall.

2.3 Performance parameters

The relative dump gap, in this paper, is defined as the ration between the dump gap and the pre-diffuser inlet height. Typical sections of the combustor are numbered in figure 3 and performance parameters are defined as follows:

Static pressure recovery of the pre-diffuser:

$$C_{p1-2} = \frac{\overline{p}_2 - \overline{p}_1}{1/2\rho V_{in}^2} \tag{1}$$

Total pressure loss of the pre-diffuser:

$$\lambda_{1-2} = \frac{\overline{p}_{t2} - \overline{p}_{t1}}{1/2\rho V_{in}^2} \tag{2}$$

Average total pressure at the combustor outlet:

$$\overline{p}_{t4} = \frac{m_{3i}\overline{p}_{t3i} + m_{3l}\overline{p}_{t3l} + m_{3o}\overline{p}_{t3o}}{m_0} \tag{3}$$

Total pressure loss of the dump diffuser:

$$\lambda_{1-4} = \frac{\overline{p}_{t4} - \overline{p}_{t1}}{1/2\rho V_{in}^2} \tag{4}$$

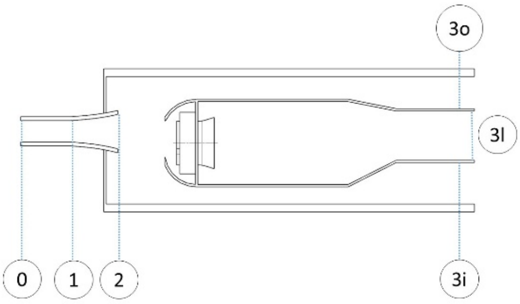


Figure 3. Dump diffuser model

3. Numerical Results

In order to verify the accuracy of numerical simulation, experiments are performed with dump gap D=60mm.The absolute static pressure along the cowl surface in measured. Figure 4 shows the comparison between the calculated results and experimental results, both results show a great match.

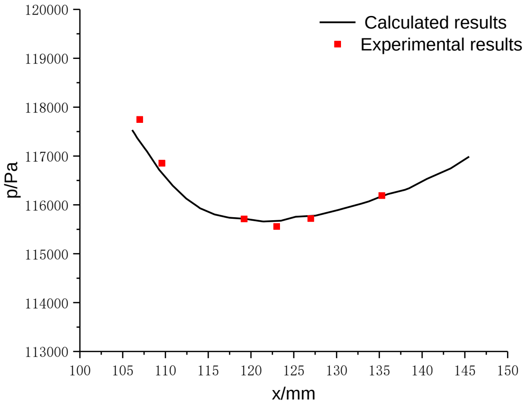
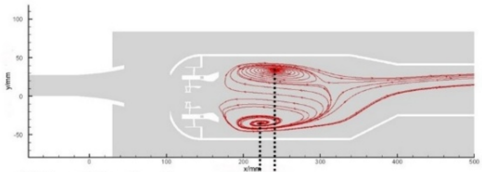
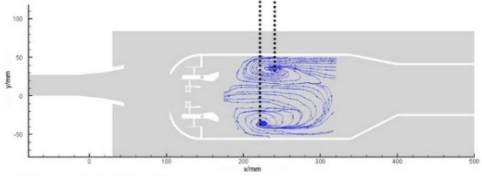


Figure 4. Static pressure distribution along outer cowl



(a) Computational results



(b) Experimental results

Figure 5. Vortice centers in combustor liner

The flow fields inside the liner are also compared numerically and experimentally, shown in figure 5. The centers of vortices are in the same places and the streamlines are similar, proving the accuracy of the numerical results.

3.1 Pre-diffuser Performance

In this paper the flow split between the liner and the annuli remains constant ($m_l = 46.2\%, m_o = 34.1\%, m_i = 19.7\%$). Figure 6 shows the influence of relative dump gap on pre-diffuser static pressure recovery and total pressure loss. The static pressure recovery decreases while total pressure loss increases when the diffuser has bigger dump gap, showing that a small dump gap has a favorable effect on pre-diffuser performance. This is because at small dump gaps the air flow will be induced into the inner and outer annuli by the cowl, creating a relatively uniform pre-diffuser outlet profile, hence the high pressure region before the dome is closer to the pre-diffuser outlet. Figure 7 is the velocity contour at the pre-diffuser outlet with different dump gaps, from this figure we can conclude that under the same velocity level the velocity at the center of the outlet increases when the dump gap increases, creating a lower static pressure recovery at pre-diffuser outlet.

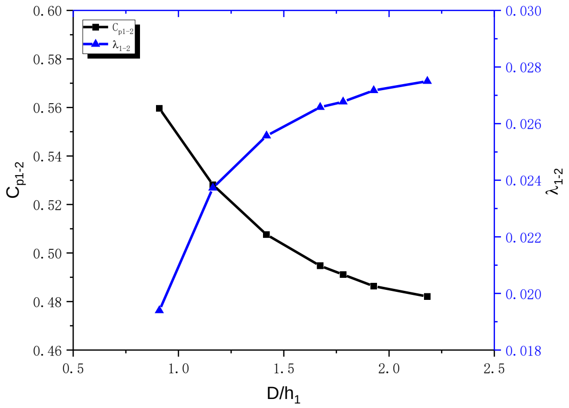
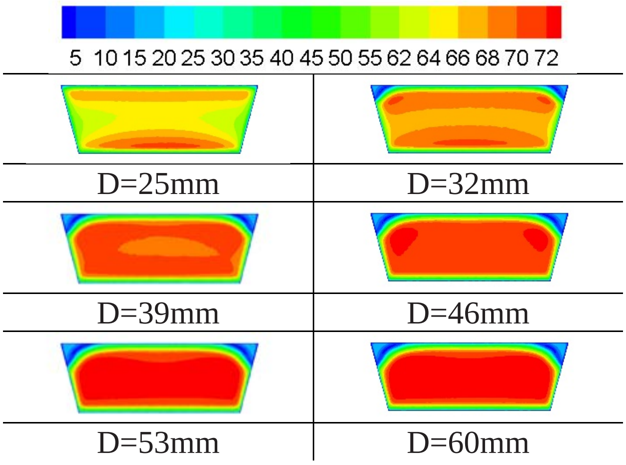


Figure 6. Static pressure recovery and total pressure loss of the pre-diffuser with different dump gaps



D=25mm D=32mm

D=39mm D=46mm

D=53mm D=60mm

Figure 7. Velocity contour at pre-diffuser outlet

3.2 Dump Diffuser Performance

Figure 8 fives the static contour at the central section of the combustor (z=0mm). Figure 9 is the static pressure coefficient at the casing wall of both outer and inner annuli. Under the same dump gap, the static pressure at the outer annulus increases along the axial direction while the static pressure at the inner annulus firstly hits a maximum value then decreases. The pressure difference between annuli decreases with bigger dump gaps.

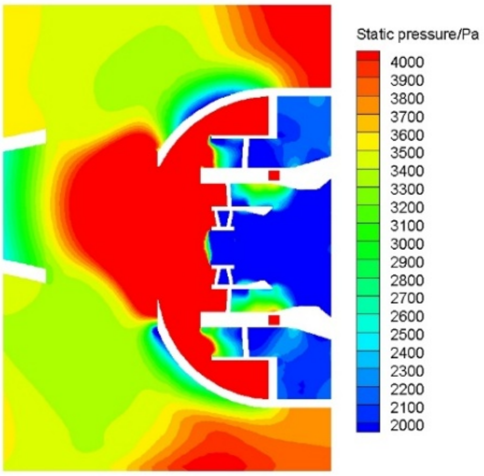


Figure 8. Static pressure contour on face z=0 at D=39mm

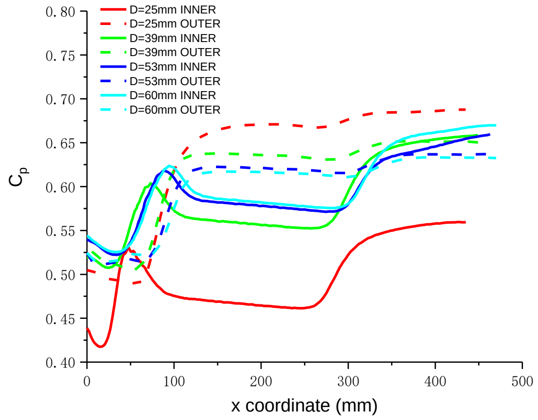
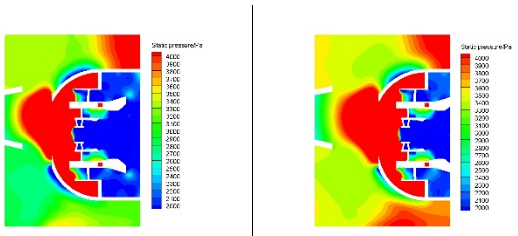
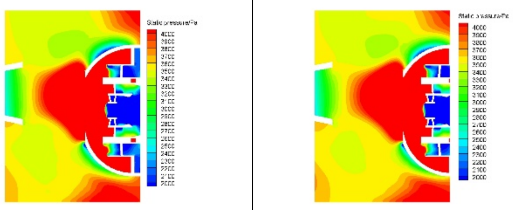


Figure 9. Static pressure coefficient along casing walls with different dump gaps

In this paper the central line of the pre-diffuser is closer to the outer annulus, making the high pressure region before the dome closer to outer dump region. The static pressure at the outer dump region is higher than the static pressure at the inner dump region, which is more obvious at small dump gaps. Figure 10 shows this phenomenon by comparing static pressure contour at the dump region with different dump gaps. It can be easily concluded that small dump gaps induce high static pressure recovery at the pre-diffuser outlet. Air flow diffuses at the dump region, a bigger dump region helps the diffusion process, resulting a more uniform static pressure distribution in the dump region.



D=25mm D=39mm



D=53mm D=60mm

Figure 10. Static pressure contour on face z=0 at different dump gaps

Small dump gaps improve the performance of pre-diffuser by increasing its static pressure recovery and decreasing its total pressure loss. One might assure, therefore, that small dump gaps produce high performance of the entire dump diffuser. This is not, however, necessarily true. Figure 11 gives the influence of the relative dump gaps on the total loss of the dump diffuser. When the relative dump gap is reduced blow a certain value, losses of the dump diffuser starts to increase. The reason is found in the increased flow curvature downstream off the pre-diffuser outlet, which is induced by small dump gaps. Flow loss is therefore rapidly increases due to excessive local acceleration and flow curvature. Figure 12 shows the flow curvature at different dump gaps.

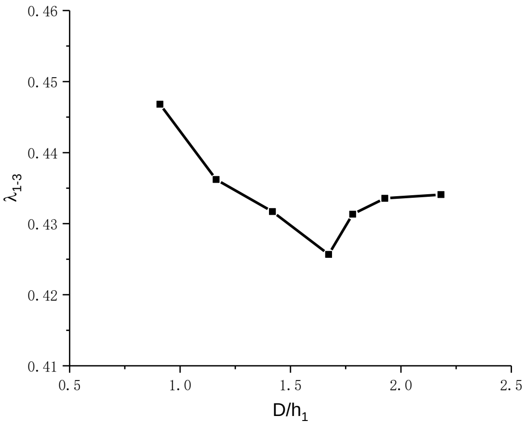


Figure 11. Total pressure loss of the dump diffuser with different dump gaps

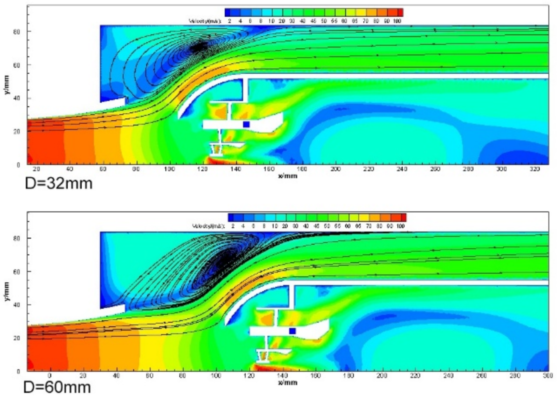


Figure 12. Streamlines at the dump diffuser with different dump gaps

The loss caused by air diffusion increases with bigger dump gaps, therefore there exists an optimal relative dump gap, which gives a smallest total pressure loss of the dump diffuser, and its value depends on the amount of pre-diffuser amd on the flow split. In this paper, when the flow split remains $m_l = 46.2\%, m_o = 34.1\%, m_i = 19.7\%$, the optimal relative damp gap is about 1.7.

4. Conclusion

In the present contribution, a 3D numerical simulation is conducted on the dump diffuser of the aircraft combustor. The influence of the dump gap on the pre-diffuser and the entire dump diffuser performances is analyzed. Based on the model and parameters used in this paper, the following conclusions can be drawn:

(1) Numerical results match well with the experimental pressure measurements and PIV measurements, CFD method can be used to analyze the influence of dump gap on dump diffusers.

(2) When flow split between the liner and the annuli remains unchanged, small dump gap will improve the performance of the pre-diffuser.

(3) Small dump gaps induce the increased flow curvature on the dome, resulting a greater flow loss, while big dump gaps cause a larger diffusion loss. There exist an optimal relative dump gap under the flow split in this paper, which is about 1.7.

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