

单孔复合角射流的流场实验研究

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【摘要】在回流式传热风洞中,用五孔针对单气膜孔射流下游的流场进行了三维测量,观察到了一对具有明显强度和大小差别的流向耦合双涡结构,并发现 $\gamma=15$ 的扇形孔较圆孔具有较弱的射流穿透能力和旋涡强度,其射流冷气可更利于贴近壁面。

主题词: 射流 流场 实验

分类号: TK124

1 实验装置与条件

实验在回流式传热风洞中进行^[1],坐标系、喷射角及试验件的结构与尺寸以及参数定义均与文献[1]中完全一致。 β 是喷孔向负 z 方向旋转后其轴线在 $x-z$ 平面上的投影与 x 方向间的夹角。射流雷诺数 $Re = \rho_j U_j D / \mu_j$ 均为20000;对应吹风比 $M = \rho_j U_j / \rho_\infty U_\infty$ 为1.0和2.0,主流速度 U_∞ 分别为 $12.1 \pm 0.10 \text{ m/s}$, $6.6 \pm 0.12 \text{ m/s}$ 。在所有对应无射流工况下,主流湍流度均为 $0.24 \pm 0.03\%$,喷孔中心位置在对应两个主流速度的边界层动量厚度雷诺数分别为720和540.6。本文采用旋转五孔针的方法进行测量。

2 边界层中流向速度 U/U_∞ 等值线的一般特征和流向涡的结构、强度

图1(a)~(c)为圆孔射流时 U/U_∞ 的等值线分别在 $x/D = 1.0, 2.0$ 和 4.35 截面上分布,此图较突出地代表了复合角射流时沿流向 U 分布的4个典型特征:(1)射流向负 z 方向偏移,整体分布不对称;(2)在射流后尾迹区的上方,射流核心区域呈不对称腰子形,具有 $U/U_\infty > 1.0$ 的超越速度,其最大值偏向正 z 一侧,且这个超越速度区域沿流向逐渐消失;(3)在尾迹区中速度严重“亏损”,并存在一个沿流向逐渐扩大的尾迹流动核心区域;(4)在射流两侧,边界层变得很薄,且正 z 侧比负 z 侧更薄。图1(a)~(d)中, $\alpha = 60^\circ, \beta = 30^\circ, M = 1.0, Re = 20000$ 。

图1(b)和(d)反映了 γ 对 U 分布的影响。当 γ 从图1(b)中的0扩张为图1(d)中的15时,射流穿透主流的能力明显减弱,超越速度消失,射流后的尾迹区域明显减小,射流两侧的边界层明显增厚。这表明由于扇形喷孔出口截面面积的增大,导致了该截面上吹风比和动量比的减小,从而使得射流冷气能够较好地贴附在壁面上起到保护作用。

图2(a~b)和图2(c~d)分别是圆孔和 $\gamma=15$ 的扇形孔射流下游 $x/D = 1.0$ 和 4.35 截面上的 v 和 w 速度矢量分布(图2(a~d)中, $\alpha = 60^\circ, \beta = 45^\circ, M = 2.0, Re = 20000$),从图中可发现,在复合角射流工况下,产生了一对明显的流向耦合涡,但由于喷孔轴线向负 z 方向偏转,因

而在负 z 的一侧, 流向涡受到了抑制, 范围很小, 非常靠近壁面, 其强度较弱, 而正 z 一侧的流

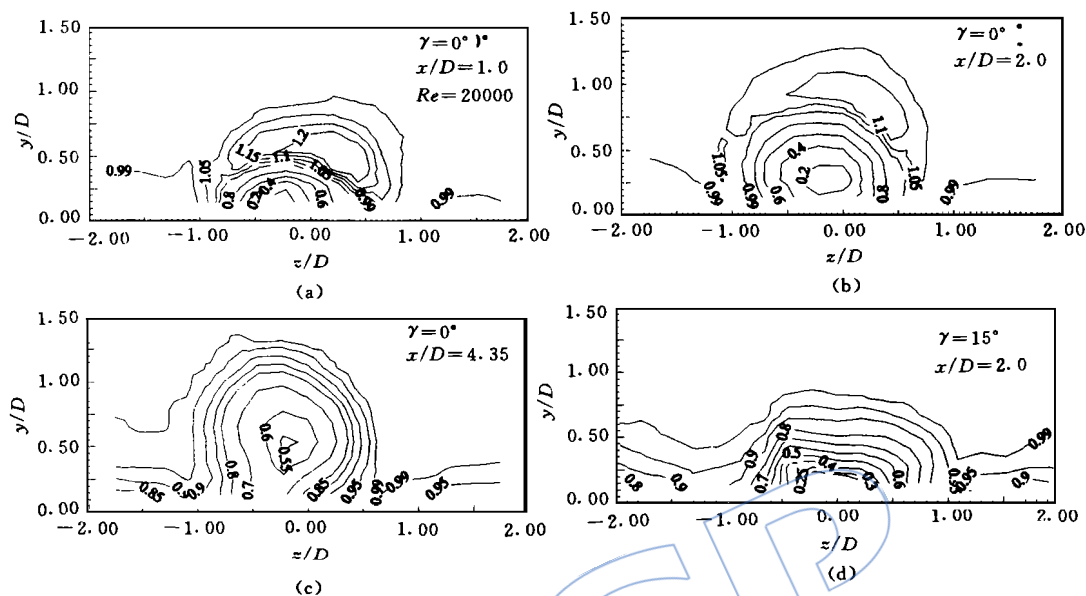


图1 复合角射流时 U 分布的一般特征

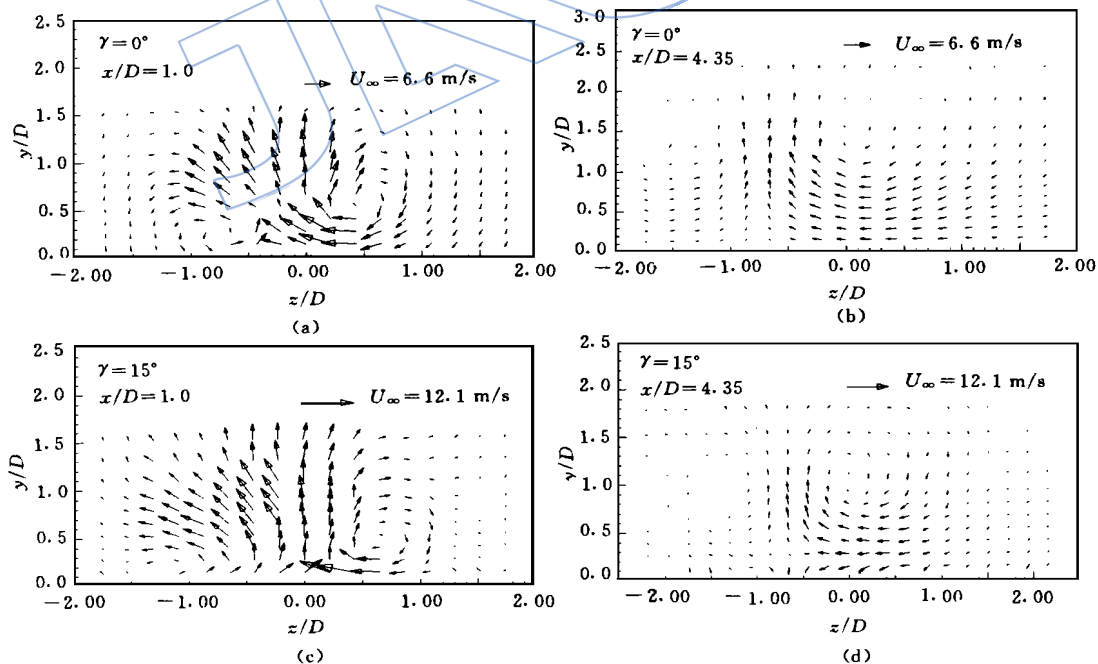


图2 V, W 速度矢量

向大涡则同喷孔未偏转前的情形差不多。此前的研究^[1-4]表明, 在 $\beta = 0$ 的对称射流的下游均

会产生一对对称流向耦合涡,但这一 $\beta \neq 0$ 时产生的,一对具有明显强度和大小差别的流向耦合双涡结构,是本文作者在实验中观察到的。

Compton 和 Johnston^[5]在与本文近似的实验条件下没有观察到流向小涡,作者认为可能是以下 3 方面的原因: (1) 测点设置离壁面太远。他们测量的最靠近壁面的点为 $y/D \approx 0.79$,而在本文所进行的实验中, y/D 的最小值可达 0.13; (2) 流向测量截面离喷孔太远。他们设置的离喷孔最近的截面的 $x/D \approx 20.4$, 这样远的距离, 流向小涡完全有可能在流程中破裂和消失; (3) 吹风比 M 不够大。

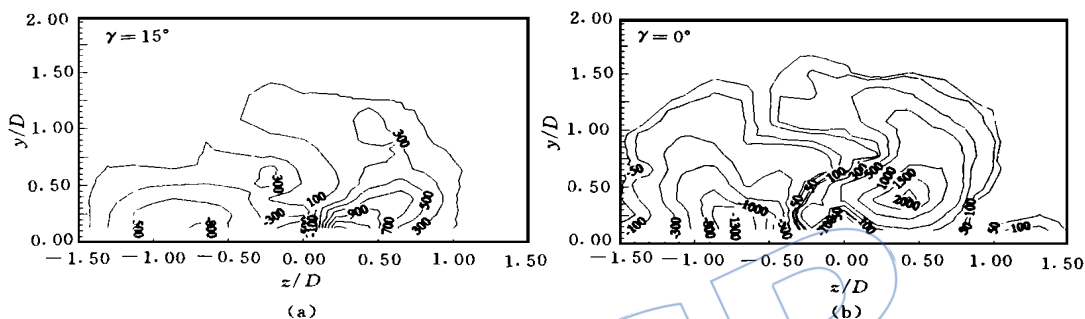


图 3 圆孔和扇形孔流向涡度 Ω_x 的分布比较

图 2(a~b) 和图 2(c~d) 反映了 γ 对流向涡结构的影响。随着扇形角从 0 增大为 15° , 可以发现涡心更靠近壁面, 旋涡强度得到了显著的减弱, 其 $x/D = 1.0$ 截面上的流向涡度 Ω_x ($\Omega_x = \partial w / \partial y - \partial v / \partial z$) 的等值线分布如图 3(a) 和 (b) 所示 (图中, $\alpha = 60^\circ$; $\beta = 45^\circ$; $M = 2.0$, $x/D = 1.0$, $Re = 20000$)。这表明扇形角的增大, 将显著减小速度梯度 $\partial w / \partial y - \partial v / \partial z$, 无论是流向大涡还是流向小涡, 其强度都将明显下降。因此, 复合角射流时, $\gamma = 15^\circ$ 的扇形孔具有显著降低流向耦合涡强度的作用。

结论 (1) 作者在实验测量中发现, 复合角射流时产生一对具有明显强度和大小差别的流向耦合双涡结构; (2) $\gamma = 15^\circ$ 的扇形孔较圆孔具有较弱的射流穿透能力和旋涡强度, 其射流冷气可更利于贴近壁面从而起到保护作用。

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factors of discharge coefficients are considered. The results show that the momentum ratio L and Reynolds numbers of little holes have important effect on discharge coefficients but momentum ratio L has no influence. Parameters of the geometrical configuration P/D , S/D , α , β and L/D have great influence, but the rows of holes has little effect on discharge coefficients.

Key Words Combustion chambers Cooling Flow coefficients

AN EXPERIMENTAL INVESTIGATION OF ADIABATIC EFFECTIVENESS OF INCLINED MULTIHOLE WALL FULL- COVERAGE FILM COOLING WITH HEAT- MASS TRANSFER ANALOGY METHOD

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ABSTRACT Using the method of heat- mass transfer analogy, experimental research was carried on to investigate adiabatic film effectiveness of inclined multi- hole full-coverage film cooling. The hole configurations were regular patterns of staggered discrete circular holes, and holes inclined at an angle of 30 deg to the surface of experimental plate. Spanwise hole- to- hole spacing range is from 6.0 mm to 9.0 mm, streamwise row- to- row spacing from 4.5 mm to 18 mm, and hole diameter from 1.0 to 2.0 mm. Within the range of blowing ratio from 1.0 to 4.0, the experimental results of the adiabatic film effectiveness distribution for five plates were compared and analyzed. Finally, the optimum number of hole spacing and row spacing as well as the influences of blowing ratio on the adiabatic film effectiveness were obtained.

Key Words Airfilm cooling blades Adiabatic wall temperature
Heat and mass transfer theory Experiment

INVESTIGATION OF SINGLE FILM COOLING HOLE WITH COMPOUND- ANGLE ORIENTATION

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ABSTRACT The effects of blowing ratio at $M = 1.0$ and 2.0 on downstream flow field single film cooling hole with compound- angle orientations have been investigated experimentally. It is found that a pair of counterrotating vortices, one of which is strong and another is weak, were observed in the downstream region of jet exit. The hole with a fan-shaped angle of 0° or 15° was oriented so that its angles with respect to the test surface are 60° in a stream/normal plane projection, and 30° or 45° in a spanwise/normal plane projection. Contours of longitudinal velocity show asymmetric kidney shape. The fan- shaped hole effectively decreases the strength of longitudinal vortex and increases the spreading of jet so

that the film cooling effectiveness would be much greater than that found in the downstream of a circular hole

Key Words Jet Flow fields Experiment

A SURVEY ON PROPELLANT LEAK DETECTION TECHNIQUES FOR LIQUID ROCKET PROPULSION SYSTEM

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ABSTRACT The integrity test of Liquid Rocket Engine (LRE) must be carried out before its launch. The tests include the leak detection of liquid propellant and other liquid systems. It is necessary to set up an automated propellant leak detection system. This paper summarizes the leak detection techniques of LRE, which are classified into groups and considered in details. Finally, several prospects of the leak detection techniques are presented.

Key Words Liquid rocket engines Propellants Leakage Fault detection

“POWER- LAW ”AND “QUICK ”SCHEMES IN NUMERICAL STUDY OF NONSYMMETRY DIFFUSER

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ABSTRACT Speziale's nonlinear k - ϵ model is used to calculate the turbulent flow in nonsymmetry diffuser. Attention is focused on effect of the two typical convective difference schemes, “Power- Law ” and “QUICK ” schemes, on the performance of the models (the standard and nonlinear k - ϵ models). The results show that both convective difference schemes have little effect on the prediction of the models. So it is no longer to puzzle brain about choice of convective difference schemes, when applying to nonlinear k - ϵ models.

Key Words Diffusers Turbulent flow Mathematical models
Numerical computation

APPLICATION OF A SECOND- ORDER UPWIND SCHEME TO PISO ALGORITHM

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ABSTRACT Numerical simulation of spray combustion in liquid propellant rocket engine with PISO algorithm was implemented. A second- order upwind scheme developed by the authors was combined with the PISO algorithm to ensure the numerical accuracy. The Navier- Stokes equation in cylindrical coordinates was transferred into general curvilinear coordinate system and discretized by finite- volume method with non- staggered grid. The body- fitted grid generated by TTM method was used in the calculation. A stochastic spray model was employed to determine the drop let initial conditions, and the chemical reac-