第 6 卷　第 3 期　　航空动力学报　　Vol. 6　No. 3
1991 年　7 月　　Journal of Aerospace Power　　July　1991

供气管孔流量系数的实验和计算研究

西北工业大学　吴丁毅[* *]　许都纯　刘松龄　邓劲松

一、单孔实验及分析

由于供气管外气流速度较低，流过冲击孔的气流主要受管内气流轴向流动的影响。因此本实验仅研究管内有横向流动时单孔的流量系数和多孔管内轴向静压分布。

单孔实验中（图 1）测量来流的总温 T^*、总压 P^* 和静压 P_d，并测量主管道流量 $\dot{m}$ 和小孔出口气流静压 P_j 和流量 $\dot{m}_j$。研究了孔径 d 与壁厚 t 之比 t/d 分别为 1.032、0.754、0.624 三种不同的实验器。

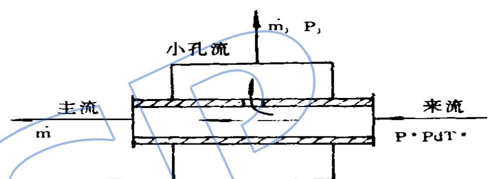

图 1　单孔实验示意图

根据分析，选择无因次参数 $\overline{\Delta P}$ 为变量，整理实验结果。$\overline{\Delta P}=(P^*-P_j)/(P^*-P_d)$，为小孔气流速度头与主流速度头之比，它在一定程度上描述了主流对小孔流动的影响。实验结果见图 2。由图可以看出，随着 $\overline{\Delta P}$ 增大 C_d 也增大，并逐渐趋向定值。$\overline{\Delta P}$ 越大意味着横向流动的影响越小，则流量系数增大。当 $\overline{\Delta P}$ 超过 100 以后 C_d 趋向定值，即横向流动的影响消失。由图 2 还可以看到，当 t/d 从 0.642 增加到 1.032 时流量系数是增大的。即在此范围里增加管壁厚度可以提高流量系数。无横向流动时，实验表明 $t/d=2$ 时流量系数最大。对于有横向流动的情况，不同 t/d 的流量系数是否存在极值还有待实验验证。不过实际应用的冲击冷却供气管壁厚都很小，t/d 不超过本实验的范围。

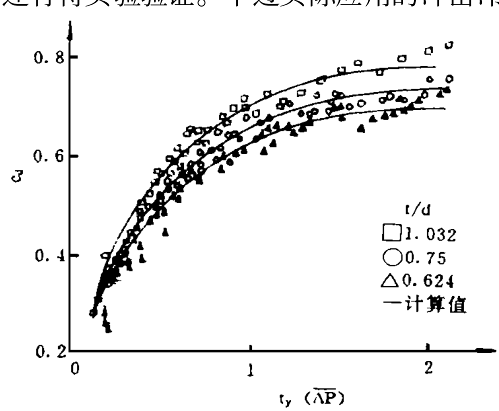

图 2　单孔流量系数的实验和计算值

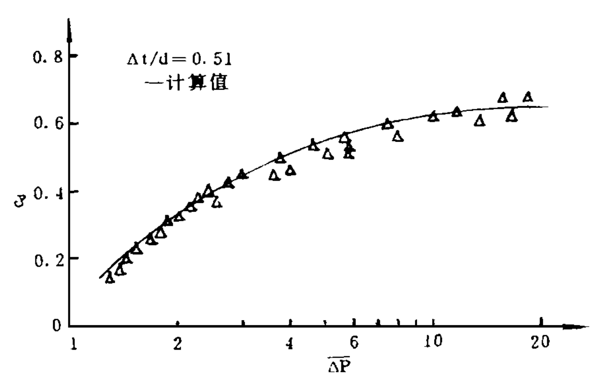

图 3　计算值与文献［2］实验结果的比较

本文于 1989 年 12 月收到。　* * 西安西北工业大学 706 教研室　710072

对实验结果进行数值拟合，得到管内有横向（轴向）流动时小孔流量系数的计算公式：

$$C_d = 0.779(t/d)^{0.266}\left[e^{-0.397/(\lg(\overline{\Delta P})+0.057)} + 0.212\right] \qquad (1)$$

适用于 $\overline{\Delta P} = 2\sim 120$，$t/d = 0.5\sim 1.05$ 的范围。计算结果与实验数据的对比见图 2 和图 3。

二、多孔管实验和计算

因条件限制，多孔管实验中仅测量了沿管轴向的静向分布，并用式（1）计算通过各个小孔的流量。由于在供气管中静压分布受通过各孔的流量的影响很大，若式（1）计算得到的相应的管内静压分布与实验值一致，则表明式（1）对多孔管也是适用的。

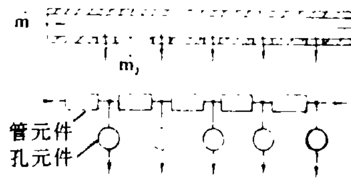

图 4 计算网格

为了计算多孔管中压力和流量分布，将多孔管试验模型表示成相应的计算网络，如图 4 所示。该网络由代表壁面摩阻影响的管元件和代表孔的元件组成。应用作者研究的通用空气网络计算程序[3]以及式（1）便可以算出管内静压分布和通过各个孔的流量。图 5 为本文实测的静压与计算值的对比和文献［1］测量的静压与本文计算值的对比；表 1 是文献［1］流量分配实验值与本文所做计算值的对比，符合程度较好。可以看出由于有空气自孔流出，沿管流动方向压力逐步升高，孔的流量不断增大。

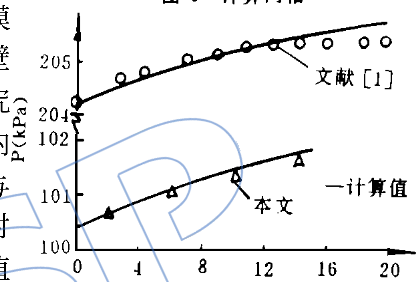

图 5 多孔管静压分布

表 1 多孔管流量分配计算值与文献［1］结果对比

	$\dot{m}$ (kg/s)	$\dot{m}_{j1}/\dot{m}$	$\dot{m}_{j2}/\dot{m}$	$\dot{m}_{j3}/\dot{m}$	$\dot{m}_{j4}/\dot{m}$	$\dot{m}_{j5}/\dot{m}$
实验值[1]	0.1723	0.172	0.194	0.213	0.208	0.213
计算值	0.17226	0.175	0.193	0.205	0.210	0.217

供气管的这种流量分配特性表明，若冲击孔孔径相同，则在涡轮动叶根部或导叶缘板附近冲击孔气量将偏小，有可能影响冷却效果。在设计供气管和计算冷却流量时应予以考虑。

三、结　　论

1. 供气管内气体的横向流动对孔的流量系数有重要影响。在本文给出的参数范围内可用式（1）计算流量系数。当 $\overline{\Delta P} > 100$ 后可以忽略横向流动的影响。

2. 沿供气管轴向孔的流量有明显增加。在管进口附近的孔流量较小，设计涡轮叶片冲击冷却供气管时应注意这一点。

参 考 文 献

[1] Damerow, W. P. et al., "Experimental and Analytic Investigation of the Coolant Flow Characteristics in Cooled Turbin Airfoils", NT2-27290, June, 1972.

[2] Robde, J. E. et al., "Discharge Coefficients for Thick Plate Orifices with Approach Flow Perpendicular and Inclined to the Orifice Axis", NASA TN D-5467, 1969.

[3] 吴丁毅、刘松龄，"关于冷气系统的一种通用计算方法"，1989 年中国工程热物理学术会。

RESEARCH ON DISCHARGE COEFFICIENT OF COOLING HOLES ON FEEDER TUBE

Wu Dingyi, Xu Duchuen, Liu Songling, Deng Jinsong
(Northwestern Polytechnical University)

ABSTRACT The main air flow supplied in the feeder tube is delivered to cooling holes with axis perpendicular to the main flow. This crossflow pattern exerts a significant influence on the hole discharge coefficient. The experimental investigation of the hole discharge coefficients and the measurement of static pressure distribution along the tube axis have been completed. It is shown that the discharge coefficient increases as the ratio of the orifice thickness to diameter and the velocity head ratio between orifice flow and tube flow increase. But the discharge coefficient approaches to a constant when the velocity head ratio is greater than 100. Empirical formulas have been dedueed from the experimental data. The static pressure distribution along the tube and the air flow rate allocation for the holes have been calculated by using the general air system computer program developed by author. The results ageree with the experimental data well.

COORDINATION OF α、β COEFFICIENTS WITH *k* COMPLEXES FOR VARYING SPECIFIC HEAT SOLUTIONS

Cui Jiya *(Beijing University of Aeronautics and Astronautics)*

ABSTRACT Three complexes ε_T, ε, ε_v of k are introduced to simplify the original expressions of gasdynamic functions with k of varying specific heats and their analytical solutions, and to unite two other forms of gasdynamic functions using coefficients α of β so that the calculations and applications at higher temperatures could be more convenient. It is clarified that the effect of varying specific heats reflected through k is the essence of these functions. The different sets of formulae are also briefly compared and analysed for reference in engineering applications.

NUMERICAL STUDY OF VISCOUS FLOWS IN COMPLEX GEOMETRIES

Shi Feng, Xu Zhong, Miao Yongmiao *(Xi′an Jiaotong University)*

ABSTRACT The program SIMPLEC has been adopted to calculate the viscous flows at all Mach numbers inside a plane cascad and nozzle. In order to tread both incompressible and compressible flows, pressure is chosen as a primary dependent variable in preference to density. The effect of the pressure on the density is implicitly included in the pressure correction equation. Further, the covariant velocity components are chosen as the dependent variables in the momentum equations, which makes the pressure-velocity coupling relatively easy to handle. Comparison of the calculated results with the experimental data show that the present method exibits much better stability and covergence behavior, and is applicable to a variety of the incompressible and compressible flows, ranging from subsonic to supersonic.