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喷管激波贴口压比计算

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【摘要】 本文根据试验数据，利用多元线性回归分析方法建立了轴对称收敛－扩散喷管激波贴口时落压比与面积比，收敛半角，扩张半角，无量纲喉道曲率半径之间关系的数学模型。计算结果为喷管试验研究和跨音速流计算提供了依据。

关键词：多元线性回归分析 轴对称收－扩喷管 激波 压比计算

1 前 言

根据一维流理论，在收敛－扩散喷管中，当落压比 π_c 达到某一值 p_{2r}^* 时，正激波贴口。然而在实际的收敛－扩散喷管流动中，由于气体粘性和多维流动效应的影响，该激波不再是一道正激波，而是一 λ 形波。本文通过对一系列不同几何参数的收敛－扩散喷管的试验证明，该激波的中间部分很近似正激波，靠近壁面部分呈 λ 形。且试验值 p_{2r}^*（p_{2r}^* 的值根据距喷管出口 5mm 处壁面压力突跃而取值的）与一维流动的计算值 p_{2c}^* 相差很多。

当 π_c 大于 p_{2r}^* 时，激波被推出管外，气体在出口截面上是超音速的，背压变化造成的扰动不会传到喷管内部，此时喷管流场内各点的无量纲参数，例如马赫数，压力比，温度比等，仍对应于设计压比状态。大量的试验数据也证实了这一点[1-2]。而当 π_c 小于 p_{2r}^* 时，激波将移向管内，激波位置随 π_c 的大小而改变。因此激波贴口压比 p_{2r}^* 的确定，对喷管试验和跨音速流计算都是很有意义的。

由于目前对 p_{2r}^* 的准确计算尚有很多困难。本文根据试验数据，采用多元线性回归分析方法建立轴对称收敛—扩散喷管激波贴口压比与几何参数的数学模型，为喷管研究提供依据。

2 数学模型

采用多元线性回归分析建立轴对称收敛—扩散喷管激波贴口压比与几何参数的数学模型，对于有 m 个变量的线性回归方程为：

$$p_{2r}^* = b_0 + b_1X_1 + b_2X_2 + \cdots + b_mX_m \qquad (1)$$

式中：b_0、b_1、b_2、…，b_m 为回归系数。有 4 个变量（面积比 X_1、收敛半角 X_2、扩张半角 X_3、无量纲喉道曲率半径 X_4（喉道曲率半径与喉道半径之比）的方程(1)共有 5 个回归系数。

试验是在燃气涡轮研究所引射喷管试验器上进行的[2]。试验中对 4 组不同几何参数的 24 个模型喷管进行了吹风试验，获取了各个喷管在不同落压比条件下，喷管壁面压力，流量特性和推力特性的曲线。几何参数 X_1、X_2、X_3、X_4 的变化范围为：$X_1=1.21\sim2.44$，$X_2=8°\sim24°$，$X_3=4°\sim20°$，$X_4=0.31\sim2.0$。

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将 24 组试验数据代入方程(1),采用最小二乘法就可求得各个回归系数。为了提高解的精度,采用全主元消去法求解正规方程组,将回归系数代入方程(1),模型建立即完成。

3 检验和分析

为检验本文所建立的数学模型是否正确,必须确定 p_{2T}^* 与 X_1、X_2、X_3、X_4 之间是否存在线性相关关系,以及为将回归方程中对 p_{2T}^* 影响不大的参数剔除,还需对回归方程(1)和回归系数 b_0,b_j($j=1,4$)进行显著性检验。根据概率统计理论[3],很容易求得此回归方程的复相关系数 $R\approx 0.97$,由此可见 p_{2T}^* 与 X_1、X_2、X_3、X_4 之间有很强的线性关系。

5 个回归系数的显著性检验分别为:$F_0=17.29$,$F_1=211.75$,$F_2=0.37$,$F_3=0.28$,$F_4=0.45$。若取检验水平 $\alpha=0.01$,从 F^- 分布表中可查出自由度 $n_1=1$,$n_2=(24-4-1)$ 的临界值 $F(1,19)=8.18$,可见,X_1 的变化对 p_{2T}^* 影响最显著($F_1>>8.18$),而 X_2,X_3,X_4 的影响则很弱,可忽略。因此,多元回归方程(1)可简化成 p_{2T}^* 与 X_1 之间的一元线性回归方程

$$p_{2T}^* = b_0 + b_1 X_1 \qquad (2)$$

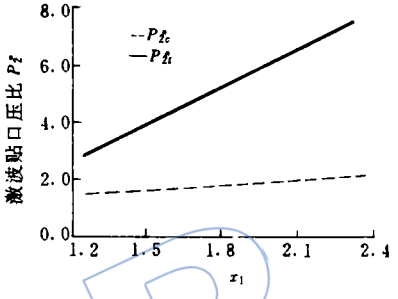

图 1 p_2^* 与 X_1 之间的关系

p_{2T}^* 与 X_1 的关系如图 1 所示,图中同时给出了一维流的计算值 P_{2C}^*,以便比较。由图可见,P_{2C}^* 较 p_{2T}^* 低,这主要是由于气体粘性和多维流动效应造成的。

4 结 论

本文利用多元线性回归分析技术,建立了轴对称收敛－扩散喷管激波贴口时落压比与面积比,收敛半角,扩张半角,无量纲喉道曲率半径之间关系的数学模型。面积比为影响激波贴口压比的主要参数,且两者呈现线性关系。收敛半角,扩张半角,无量纲喉道曲率半径对激波贴口压比影响很小。

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and ejctor ramjet modes, ejector ramjet and rocket modes.

VISCOUS FLOW FIELD PREDICTION IN AXISYMMETRIC PASSAGES

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ABSTRACT The viscous flow fields in the inflow axisymmetric passages of centrifugal compressors are predicted with vorticity-stream function (ω-ψ) method. The expressions of q-τ turbulence model equations in orthogonal curvilinear coordinate system are derived here, and they are used to predict the turbulent flow fields. The q-τ turbulence model has an advantage in capability of treating the boundary conditions. The unsteady terms are introduced in the ω-equation and q, τ equations, and the time-marching method is applied to solution of these equations. In the case of turbulent flow prediction the wall function is used in the near-wall region. Several numerical examples of laminar and turbulent flows in a 2D channel and axisymmetric passages with complex boundaries show that their solutions obtained with the present method is in good agreeement with their exact solution or their experimental data.

DIGITAL SIMULATION OF TRANSONIC FLOW FIELDS IN A PLANAR NOZZLE

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ABSTRACT This paper presents a method for simulation of transonic flow fields in a planar nozzle. For this purpose, the Jumeson-type Runge-Kutta finite volume method is applied to solving Euler equation with the aid of local time stepping and impicit residuals averaging techniques. In such a manner the convergence rate is sped up in planar nozzle flow solution, so that the steady state can be obtained in less than a hundred iterations. An adaptive dissipation term is added to the equations to eliminate the fluctuation of the flow parameters and the vibrations in front of and behind the shock. The results of the calculations are in good agreement with the test data and the results of calculations with other numerical methods.

CALCULATION OF PRESSURE RATIO AT NOZZLE EXIT WITH SHOCK

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ABSTRACT A mathematical model of a axisymmetric convergent-divengent nozzle is set up by multivariant linear regression analysis method. The relationships of pressure ratio at nozzle exit with shock to four geometric parameters, i. e. area ratio, half-convergent angle, half-divergent angle and radius ratio of throat curvature to throat, are considered. The pressure ratio only depends on

the area ratio. Other parameters have little effect on it. The results provide the basis for testing and transonic calculation of the axsiymmetric convergent-divergent nozzle.

ELIMINATION OF OVERTEMPERATURE IN TURBOJET

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ABSTRACT This paper analyzes the reasons of the overtemperature in a turbojet and provides the available measures to eliminate it, such as the strict requirements for the engine overhaul at the repair factory and the reasonable engine adjustment in the field maintenance. It is essential for the field maintenance to adjust properly the relationship between the turbine pressure ratio and the exhaust nozzle area, so that the turbine gas temperature comes down without afterburning temperature drop. In this way, the influence of the above problem on the operational performance of the engine can be minimized on condition that the engine reliability is guaranteed.

DYNAMIC CHARACTERISTICS OF TWO NEW VIBRATION MODES OF THE DISK-SHELL SHAPED GEAR

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ABSTRACT Two new vibration modes of the disk-shell shaped big medium gears placed on the three separate medium shafts of a turboprop engine have been found. They have the same nodal diameters as the conventional ones but their frequencies are higher. The tooth ring vibrates both radially and axially and has greater deflection than the gear hub. The resonance of these two new nodal diameter modes is much more dangerous than that of the conventional nodal diameter modes. Moreover they occur just nearly at the upper and lower bounds of the gear operating speed range. A special detuning method is developed for removing the resonance of these two new modes out of the upper and lower bounds respectively and the effectiveness of the damping rings in this case has been researched. The vibration responses measured on the reductor casing have been then reduced to a quite low level after the damping rings were applied to the three big medium gears.

CALCULATION OF FLASH TEMPERATURE ON TOOTH SURFACE OF INTERNAL HELICAL GEARS

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ABSTRACT An accurate calculating approach for flash temperature of internal helical gears is presented. Firstly, the load distribution on tooth surface is obtained by using 3-D finite element method and loaded tooth contact analysis technique. Then, the relative velocities and curvature radii