

六喷管超音速引射器性能 的理论分析和实验研究

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【摘要】 对某一定尺寸的六喷管超音速引射器进行气动性能的实验研究。结果表明: 随着主次流压比 P_p^*/P_s^* 增加, 引射系数及修正引射系数下降; 当引射系数增加时, 混合管动量修正系数 K_m 下降, 但主喷管流量系数 μ 变化不大。对上述工况进行理论计算的结果与实验数据符合良好。

主题词: 喷管 引射器 超音速 性能分析

分类号: V 231.3 O 345.3 TK05

海湾战争以来, 直升机发动机的进气防砂问题日益受到重视。利用进气粒子分离器排除进气中的砂尘时, 必须使用抽气装置。前人的研究表明, 在同一较短的混合管长径比下, 单喷管引射器的引射系数很小, 而多喷管引射器的引射系数则大得多, 可以满足砂尘引射排出的要求。本文进行了一项六喷管超音速引射器的气动性能试验, 取得了与理论分析一致的结果。并对有无扩压器的情况作了比较试验。

1 实验测试

实验系统包括主流气源、主流管路、引射器实验段及测试仪表。每个子喷管的喉部直径为

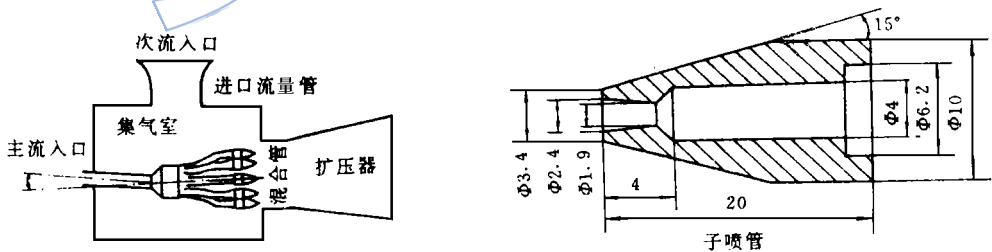


图 1 实验段结构简图

1.9 mm, 出口直径为 2.40 mm, 混合管内径为 67.5 mm, 长度为 54 mm, 扩压器出口直径为 92 mm, 长 193 mm。六喷管连接管道内径为 4.3 mm, 其中一个子喷管位于混合管轴线上, 其余 5 个子喷管围绕混合管轴线均布于直径为 45 mm 的圆周上。引射器实验段次流系统由内径为 80 mm 的标准进口流量管及内径为 320 mm, 长为 300 mm 的集气室组成。以上尺寸是由粒子分离器研制要求而定。实验段结构如图 1 所示(图中中心喷管与另一子喷管重影)。主流喷管

前管路中有测温表、压力计、标准孔板流量计用于气动参数的测量。次流流量由标准进口流量管测得。为了测量混合管出口处主次流混合均匀程度,用多管测压耙测量该处的速度分布,由此求得动量修正系数 K_m 。并根据主流参数和实验测得的主流量,求得主喷管的流量系数 μ_0 。

2 理论分析

对图 1 所示的多喷管引射系统,在下列假设条件下,建立超音速多喷管引射器性能特性的数学模型。(1)主流与被引射次流均视为完全气体;(2)气流流动是稳定的;(3)混合管为等截面圆柱形,在其始端主次流的静压力、速度、温度分布是均匀的,并在混合管末端静压力也是均匀的;(4)忽略流动势能,主次流在混合管中混合的不均匀程度,用动量修正系数来考虑。

引射系数 x 的计算式是通过主喷管出口截面与混合管出口截面之间的动量方程、连续性方程、能量方程以及气动函数、状态方程求得的。

$$x \sqrt{\frac{T_s^*}{T_p^*}} = \frac{\lambda_{p2} - \lambda_2 - \frac{1}{k\mu\pi b_{cr}} \left\{ \left[\frac{A_{p2}}{A_t} - \frac{A_m}{A_t} \right] \pi(\lambda_2) + \frac{P_m}{P_s^*} \cdot \frac{A_m}{A_t} \frac{P_s^*}{P_p^*} - \pi(\lambda_{p2}) \frac{A_{p2}}{A_t} \right\}}{(K_m + 0.5fL_m/D_m)\lambda_n - \lambda_2} - 1.0$$

上式中 k 为比热比,即 c_p/c_v , 计算过程可按下列程序进行。首先假设一个引射系数的初值 $x^{(1)}$, 且由主次流总压 P_p^*, P_s^* 、总温 T_p^*, T_s^* 、六喷管的流量系数 μ 、喉部面积 A_t 确定主流流量 m_p , 由此得一个次流流量的初值 $m_s^{(1)}$ 。由次流入口阻力系数 C_{fs0} 根据下式求次流总压 $P_s^* = P_{si}^* - 0.5C_{fs0}m_s^2R^*T_s^*/(P_{si}^*A_{s2})$ 。由 $x = m_s/m_p = [(P_s^*/\sqrt{T_s^*})A_{s2}q(\lambda_2)]/[(P_p^*\sqrt{T_p^*})A_t\mu]$ 得 $q(\lambda_2) = P_p^*/P_s^* \sqrt{T_s^*/T_p^*} \mu x A_t/A_{s2}$ 。由 $q(\lambda_2)$ 直接求得 λ_2 (一般上式可求得两个 λ_2 , 因次流一般为亚音速流, 故取 $\lambda_2 \leq 1.0$), 得到 λ_2 后可直接计算压力函数 $\pi(\lambda_2)$ 。

由 $m_p T_p^* + m_s T_s^* = m_m T_m^*$ 求得 T_m^* , 由此计算混合管临界音速 a_{mcr} 。假设速度系数 λ_n 的一个初值 $\lambda_n^{(1)}$ 求得混合管流速 V_m , 由扩压器效率 η 得到混合管出口压力 P_m 。因为: (1) $m_m/m_p = 1 + x = P_m^* A_m q(\lambda_n^{(1)}) \sqrt{T_p^*/T_m^*} / (\mu P_p^* A_t)$; (2) $y(\lambda_n^{(1)}) = q(\lambda_n^{(1)}) / \pi(\lambda_n^{(1)})$; (3) $\pi(\lambda_n^{(1)}) = P_m / P_m^*$, 则由文献[1] $\sqrt{T_m^*/T_p^*} = (1 + x \sqrt{T_s^*/T_p^*}) / (1 + x)$ 得 (4) $y(\lambda_n^{(1)}) = P_p^*/P_m^* \cdot A_t/A_m \cdot \mu (1 + x \sqrt{T_s^*/T_p^*})$, 根据 (5) $\lambda_n = [2/(k+1)]^{1/(k-1)} [1 - (k-1)(\lambda_n^{(1)})^2/(k+1)] y(\lambda_n^{(1)})$ 可算得 $\lambda_n^{(1)}$ 。如此迭代可求得最终 λ_n , 并计算 V_m 、 P_m 及雷诺数 Re_m , 根据 $Re_m \leq 10^5, f = 0.316 Re_m^{-0.25}$, $Re_m > 10^5, f = 0.0032 + 0.221 Re_m^{-0.237}$, 求得 f 。

由 $q(\lambda_{p2}) = A_t/A_{p2}$ 求得 λ_{p2} (主流为超音速流, 取 $\lambda_{p2} \geq 1.0$)。将 L_m/D_m 及 K_m 等值代入 $x \sqrt{T_s^*/T_p^*}$ 的表达式即可计算 $x^{(II)}$, 比较 $x^{(II)}$ 与 $x^{(I)}$, 满足精度要求可终止迭代计算, 否则以 $x^{(II)}$ 代替 $x^{(I)}$, 重复上述计算过程。

3 理论计算与实验结果的比较分析

图 2 表示理论计算与实验结果的对比 (图中 $P_s^* = 0.1 \text{ MPa}$, $T_s^* = 299 \text{ K}$, $0.971 \leq T_p^*/T_s^* \leq 1.02$), 两者符合良好。说明利用实测的动量修正系数主喷管流量系数, 运用气体动力学原理进行理论计算, 其方法可行。

为了进一步了解六喷管引射器的性能, 对有无扩压器时引射器的气动性能进行了实验研究, 其实验结果由图 3 所示 ($P_s^* = 0.1 \text{ MPa}$, $T_s^* = 298 \text{ K}$, $0.99 \leq T_p^*/T_s^* \leq 1.0$)。由图可见, 有

扩压器时其引射系数是无扩压器时的 1.85- 2.47 倍, 且有无扩压器, m_s/m_p 均随 P_p^*/P_s^* 增加而下降, 这与文献[1, 2, 3]的结论相一致。

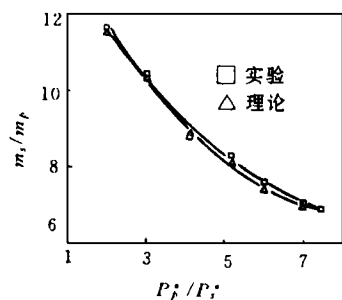


图 2 对比曲线

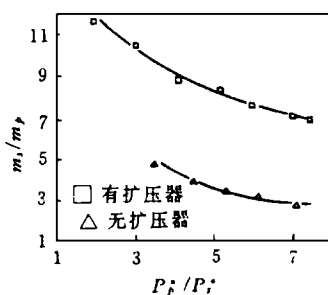


图 3 引射系数随压比的变化

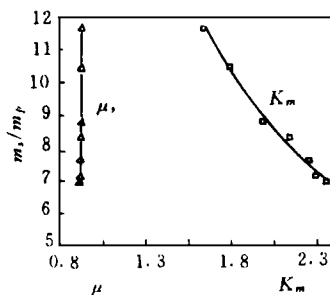
图 4 μ, K_m 随引射系数的变化

图 4 表示实验所测的主喷管流量系数 μ 和引射器混合管动量修正系数 K_m 与引射系数 (流量比) 的关系曲线 ($P_s^* = 0.1 \text{ MPa}$, $T_s^* = 299 \text{ K}$, $0.971 \leq T_p^*/T_s^* \leq 1.02$, $1.98 \leq P_p^*/P_s^* \leq 7.46$)。显然, 随 m_s/m_p 增大, K_m 逐渐变小, (由 2.35 变化至 1.64), 说明引射流量比增大混合效果渐趋良好。主喷管流量系数变化不大 (由 0.917 变化至 0.932)。

在实验过程中, 由于 $0.971 \leq T_p^*/T_s^* \leq 1.02$, 因此引入温度修正系数 $\sqrt{T_s^*/T_p^*}$ 后, 修正引射系数 $m_s/(m_p \sqrt{T_s^*/T_p^*})$ 变化不大。本文的工作就六喷管超音速引射器利用气体动力学原理进行理论计算, 限于实验条件, 仅文中的工况进行了实验研究。至于多喷管引射器性能的其他影响因素, 尚待进一步研究。

4 结 论

(1) 六喷管超音速引射器性能特性的理论计算和实验研究结果符合良好。(2) 带扩压器时的引射系数为不带扩压器时的引射系数的 1.85- 2.47 倍。(3) 随 m_s/m_p 增加, K_m 逐渐下降而 μ 变化不大。(4) 有无扩压器时, m_s/m_p 均随 P_p^*/P_s^* 的增加而下降。

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quations are applied to prediction. The experimental and predicted data of the outlet angle due to the secondary flow are presented for three cascades with end-bend blades and one with the corresponding unbended blades. The investigation shows that the change in outlet angle can be accurately predicted by the presented method. Reducing curvature of the blade rear part makes the averaged intensity of the stream line component of the outlet secondary vorticity decrease, but does not change the distance from the center of the vorticity to the end wall.

Key Words Blades Secondary flow Flow fields

*) A MODEL TO CORRELATE FLOW SEPARATION WITH FLOW LOSS IN A TRANSONIC ROTOR

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ABSTRACT A model correlating flow separation with flow loss is proposed for predicting the incipient location and size of the flow separation in a transonic rotor. The flow fields of several rotors have been investigated with the model. The results show that the flow separation mainly occurs in the tip area owing to strong shock boundary interaction, and the incipient separation point is behind the shock location. The tip leakage flow vortex has a strong effect on the interaction between shock wave and boundary layer.

Key Words Flow separation Losses Rotors

A PRELIMINARY INVESTIGATION ON CONTROLLING JET STRUCTURE BY HYDRODYNAMIC EXCITATION

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ABSTRACT Jets were excited by Kaman Vortex Streets under three conditions of Jet Mach Number 0.206, 0.361 and 0.831. Three vortex generators with different geometries were tested. Jet Velocity distributions with and without excitation were measured by stagnation pressure probe. The turbulent characteristics in the jet boundary layer were detected by a single hot wire probe. It is shown that excited jet velocity decay faster than that of unexcited jet, and turbulent energy in jet boundary layer is significantly increased by vortex excitation. Therefore, jet structure can be effectively controlled by hydrodynamic excitations.

Key Words Excitation Jets Boundary layer Kaman vortex Control

A STUDY ON SUPERSONIC 6- NOZZLE EJECTOR PERFORMANCE

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ABSTRACT The supersonic 6- nozzle ejector performance has been investigated experimentally for the given geometric dimensions. The experiment ranges over $1.98 \leq P_p^*/P_s^* \leq 7.46$, $0.971 \leq T_p^*/T_s^* \leq 1.02$ and $L_m/D_m = 0.80$. The entrainment ratio x varies from 6.96 to 11.66 for the ejector with a diffuser, and its corrected value $x \sqrt{T_s^*/T_p^*}$ varies from 6.88 to 11.62; on the other hand, the entrainment ratio varies from 2.82 to 6.28 for the ejector without the diffuser, and its corrected value varies from 2.78 to 6.24. The experimental results show that the entrainment ratio and its corrected value decrease with the increase

of P_p^*/P_s^* , but the corrected momentum coefficient K_m in the mixing pipe goes up. The mass flow rate coefficient μ of the primary nozzle increases slightly as the entrainment ratio goes up. The theoretical analysis has been done for the above conditions by application of aerodynamics. The comparison between the analysis and the experiment shows a good agreement.

Key Words Jet nozzles Ejectors Supersonic velocity Performance Analysis

SUBSTRUCTURE ITERATION FOR ANALYZING DYNAMIC BEHAVIOUR OF A CASING- SUPPORT- ROTOR SYSTEM

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ABSTRACT In order to investigate the dynamic behaviour of a casing- support - rotor system, an approach associated with substructure iteration and transfer matrix is developed. With help of the approach, the dynamic response analysis of a complex rotor system is simplified and the computation time is lessened. The convergence and stability of the approach are verified with a simple model.

Key Words Substructure Iteration methods Matrix method System architecture

STUDY ON REDUCTION FACTOR OF FATIGUE STRENGTH AND DISPERSION COEFFICIENT OF LIFE IN SEAM WELDED JOINTS

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ABSTRACT The purpose of this work is to study low cycle fatigue life of engine cases. A welded test piece has been designed according to reality of cases, using material of 1Cr18Ni9Ti in order to get fatigue function survey of seam welded joints. From tests S- N curve and P- S- N curve are obtained. Then the reduction factor of fatigue strength and dispersion coefficient of fatigue life for the seam welded joints are achieved with statistics analysis methods. Compared with a smooth test piece, the fatigue strength of the seam welded joints is obviously less than smooth test piece, but dispersion coefficient of fatigue life is better.

Key Words Welding joints Fatigue strength Life time

A BROKEN FILM CALIBRATION SYSTEM OF DYNAMIC PRESSURE MEASUREMENT

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ABSTRACT The investigated calibration system of dynamic pressure measurement with response frequency less than 1 kHz includes two parts: a broken- film dynamic pressure signal generator and an acquisition- analysis system. Many experiments were carried out for investigating frequency components produced by the signal generator of different lengths, which indicated that the signal generator, under first- order resonant frequency, can produce sufficient frequency components (0.5- 1.5 kHz) as exciting resources. Moreover, the calibration system was used for dynamic calibration of three pressure probes of different lengths with a pressure sensor respectively. Meanwhile a particular way is adopted to obtain precise frequency response characteristics only by measuring the pressure probe output. It is shown that the calibration system is simple, reliable, and applicable.