

数值分析紊流燃烧模型*

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【摘要】 本文通过二元模型加力室流场计算和燃烧效率测定,对 $k-\epsilon-g$ 紊流燃烧模型中模型系数 C_R 、 C_{g1} 、 C_{g2} 的选定和计算浓度脉动均方值 g 的不同方法进行数值研究。通过计算结果与实验数据比较,可认为:模型系数值的选定直接与化学反应速率有关,而其中 C_R 影响最大。 g 的计算虽然可有不同方法,而其中微分方程求解最佳。

关键词: 流场计算 燃烧效率 紊流 燃烧模型

计算机模拟技术是否能正确预测燃烧流场的关键是紊流燃烧模型是否合理? 目前国内外广泛应用的紊流燃烧模型是 Spalding 提出的旋流破碎模型:

$$R_{fu} = C_R \rho g^{1/2} \epsilon k \quad (1)$$

式中 C_R 为模型系数, k 为紊流动能, ϵ 为紊流动能耗散率, g 为浓度脉动均方值, 利用式 (1) 计算化学反应速率 R_{fu} 必须求解是 k , ϵ , g 。所以式 (1) 又称为 $k-\epsilon-g$ 模型。 g 的求解可用微分方程^[1,2]:

$$\frac{\partial}{\partial x_j} (\rho u_j g) = \frac{\partial}{\partial x_j} \left(\Gamma_g \frac{\partial g}{\partial x_j} \right) + C_{g1} \left(\frac{\partial m_{fu}}{\partial x_j} \right) - C_{g2} \rho g \frac{\epsilon}{k} \quad (2)$$

在使用 $k-\epsilon-g$ 模型时众人所使用的模型系数 C_{g1} 、 C_{g2} 和 C_R 也很不一致。为此, 本文在二元模型加力室进行紊流模型数值研究。气流为完全发展紊流的均匀可燃混气(煤油+ 空气), 并假设满足简化反应系统和快速反应的条件, 在采用 $k-\epsilon$ 双方程紊流模型、 $k-\epsilon-g$ 紊流燃烧模型和热通量辐射模型情况下, 经 Favre 平均的流场控制方程可写成下列通用形式:

$$\frac{\partial}{\partial x_j} (\bar{\rho} u_j \Phi) = \frac{\partial}{\partial x_j} \left(\Gamma_{g,eff} \frac{\partial \Phi}{\partial x_j} \right) + S_\Phi \quad (j = 1, 2) \quad (3)$$

式中, Φ 分别为速度 u 和 v , 总焓 H , 燃料成分 m_{fu} , 混合分数 f , 紊流动能 k , 紊流动能耗散率 ϵ , 燃料浓度脉动均方值 g , 辐射通量 R_x 和 R_y 等 10 个参数。将偏微分方程 (3) 在控制容积内积分并将源项线性化, 可得下列离散方程^[1,2]:

$$\bar{\Phi}_p = (\sum A_i \bar{\Phi}_i + S_u) / (\sum A_i - S_p) \quad (4)$$

式中, $\bar{\Phi}$ 和 $\bar{\Phi}_p$ 分别代表各变量 Φ 在网格内 p 点和其相邻的四个网格点上的值。按 SIMPLE 算法对离散方程 (4) 迭代法求得温度。本文工况的进口气流参数为: $u_{in} = 30 \text{ m/s}$, $T_{in} = 600 \text{ K}$, 余气系数 $\alpha = 1.25$ 。计算结果表明: 不同模型系数和 g 的表达式所得的燃烧室各气流参数分布是不相同的。为了确定模型系数和选定 g 的表达式, 在带圆板稳定器的模型加力室进行数值试验, 研究不同的 C_R 、 C_{g1} 和 C_{g2} 以及 g 的表达式对气流温度, 速度成分燃烧效率化学反应速率, 回流量和回流区长度的影响。为了验证计算结果是否可靠和合理, 在二元模型加力室进行燃烧效率

实验研究把实验数据与计算加以比较,可以认为:(1) 众人使用 C_R 值为 0.53~6.0, 文献[2] 用概率密度方法估计。实际燃烧过程化学反应速率不仅与紊流参数有关,而且还与化学动力因素有关,为了考虑温度的影响, C_R 可用下式估算:

$$C_R = (\Delta T^* / 1000)^2 g^{1/2} / g_{\max}^{1/2} \ln(1 + 2g_{\max}^{1/2} / g^{1/2}) \quad (5)$$

式中 ΔT^* 为理论温升, 当 $g = g_{\max}$ 时本计算工况 $C_R = 3$ 。由图 1 可知 C_R 大小对气流温度影响较

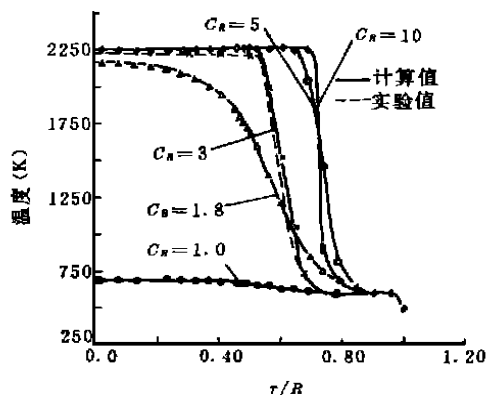


图 1 C_R 对温度径向分布的影响

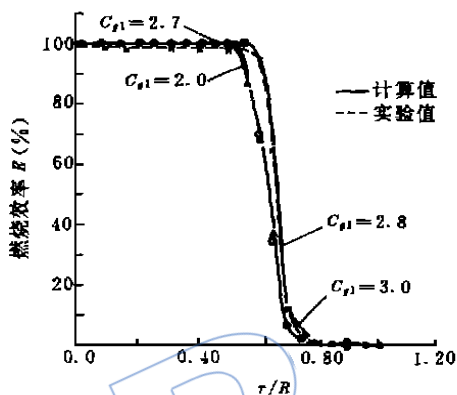


图 2 C_{g1} 对燃烧效率径向分布的影响

大, $C_R < 3$ 温度偏低, $C_R > 3$ 温度偏高, 只有 $C_R \approx 3$ 时温度分布才与实验数据吻合较好。(2) 由于 C_{g1} 为 g 方程中源项的产生项系数, C_{g1} 增大可使 g 增大, 从而使 R_{fu} 增加。各学者所用的 C_{g1} 为 2.0~3.0。按照燃料浓度时均值与脉动值微分方程之间关系可得出 $C_{g1} = 2/\sigma$, 当 $\sigma = 0.7$ 时 $C_{g1} = 2.8$ 。图 2 表明 C_{g1} 按 $C_{g1} < 2.8$ 和 $C_{g1} > 2.8$ 分成二组 C_{g1} 小于 2.8, 所得燃烧效率偏低, 这是因为 R_{fu} 太低。 $C_{g1} = 2.8$ 时与实验数据符合较好, 而 $C_{g1} > 2.8$ 时, C_{g1} 加大对效率影响不大。(3) C_{g2} 是 g 方程源项中消耗项系数, 它的增大可使 R_{fu} 降低。目前工程上所用 C_{g2} 为 0.134~2.0。图 3 表明, 只有 $C_{g2} = 2.0$ 时, 才与实验结果相符合。(4) 本计算表明 g 的各种代数表达式可作为 g 的初值用, 而 g 的求解用微分方程(2)较好。

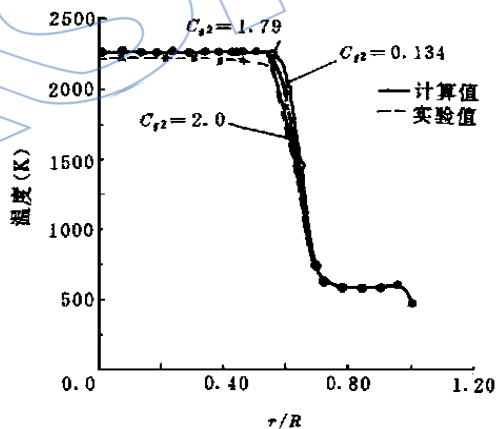


图 3 C_{g2} 对温度径向分布的影响

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EXPERIMENTAL STUDY ON PROPELLER FENCE FOR EFFICIENCY ENHANCEMENT AND NOISE REDUCTION

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ABSTRACT

Three-blades scale-model propellers with and without propeller fence along the chord direction at 88% tip blade radius are compared experimentally in the wind tunnel in respect of aerodynamic and acoustic characteristics. Their rotational speeds vary between 1500rpm to 3000rpm. Experimental results indicate that under conditions of identical advance ratio J the efficiency of the propeller with propeller fence is enhanced 1.9% ~ 4.9% and its lower noise level is reduced 13~20dB. It is shown that the propeller fence is one of effective measures to increase efficiency and to decrease noise of propellers.

ON MODELLING CONDITIONS FOR COOLING EFFECTIVENESS EXPERIMENTS

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ABSTRACT

According to strict theory of similarity, the modelling conditions for model experiments on cooling blades or vanes of a gas turbine are obtained from a necessary set of differential equations and single-valued conditions. It is shown that when the pressure in modelling is lower than that in the actual turbine, the temperature in modelling must be lowered simultaneously in order to maintain the criterion on $pl/\mu \propto T$ for cooling air and for gas invariant. Therefore, it is necessary to increase the pressure and to decrease appropriately the temperature in modelling tests for the blades and vanes of high-pressure turbines with high pressure ratio.

SURFACE TEMPERATURE MEASUREMENT OF TURBINE DISKS

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ABSTRACT

A new method of temperature measurement with a single-wire thermocouple-slip ring system is first introduced to measure the surface temperature of the turbine disks in the turbojet engines and the accuracy of this method is considered in this paper. In this case the limited channels of the lip ring are fully utilized and the measured surface temperatures of the disk are actual and believable enough. The problems in its application such as the installation of the thermocouples, the cooling of the slip ring and the balance of the turbine rotor with this system are also discussed briefly.

NUMERICAL STUDY OF TURBULENT COMBUSTION MODEL

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ABSTRACT

Although the $k-\epsilon$ turbulent combustion model becomes widespread in engineering application, but the coefficients of the model C_R , C_{g1} , C_{g2} and expressions of the square of concentration fluctuations g used by researchers are different. In

fact, the effects of these coefficients and g expressions on reaction rate and temperature profiles are significant. This paper aims at providing optimal values of these coefficients and rational g expression. Numerical calculations were carried out for recirculating reacting flow behind a bluff-body burner. It is shown that C_R is given by $C_R = (\Delta T^* / 1000)^2 g^{1/2} / g_{\max}^{1/2} \ln(1 + 2g_{\max}^{1/2} / g^{1/2})$, C_{g1} is defined as $C_{g1} = 2 / \sigma_f$, C_{g2} is 2 in this prediction.

The prediction is in favourable agreement with the experimental measurements.

A CALCULATION RESEARCH ON BURNING RATE OF ALUMINIZED COMPOSITE PROPELLANT

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ABSTRACT

A research has been completed by applying PEM model to combustion simulation of aluminized propellants. The effects of aluminium particles on the surface energy of the propellant are taken into consideration so simply as the heat sink PEM model of J. P. Renie et al, but a new method to determine the pseudopropellant's formulations is presented in this paper, thereby an extended and modified PEM model is developed. According to this model, the burning rates and pressure exponents of aluminized propellants are calculated. The results show that our model makes the calculated results of burning rates and pressure exponents more approach to their experimental data as compared with the heat sink PEM model of J. P. Renie et al.

DESIGN PRINCIPLE OF CHANGE-SPEED INVOLUTE CONICAL GEAR TRAIN

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ABSTRACT

A theory of hobbing involute conical gears on a hobber with a horizontal feed motion is described in the light of the gear engagement principle. The relations among some important parameters of the imaginary rack-shaper cutter and the generated gear are analyzed, and the design method of a change-speed train mainly composed of intersected involute conical gears is considered in detail. It has many special advantages such as many speed degrees only with a few gears, adjustable gear clearance by changing position of the gear along with their axes respectively. Because in designing this kind of train it is very important how to minimize the volume and size and how to maximize the changeable speed degrees and the difference between the highest degree and the lowest degree. A practical method is provided to control some key parameters to reach these goals. The present theory is proved correct and the method is shown practical by tests of a sample change-speed train.

OPTIMAL TOOTH PROFILE MODIFICATION OF HELICAL GEARS FOR IMPROVING RESISTANCE TO SCUFFING

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ABSTRACT

An approach is presented to increase scuffing load capacity of helical gears. Firstly, the flash temperature distribution on tooth is evaluated by using 3-D