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再入钝锥体烧蚀热防护内部热响应的数值仿真

Numerical simulation of internal thermal response of ablative thermal protection for reentry spacecraft

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作者	单位
张涛	中国空气动力研究与发展中心 超高速空气动力学研究所, 四川 绵阳 621000
陈德江	中国空气动力研究与发展中心 超高速空气动力学研究所, 四川 绵阳 621000

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中文摘要:

研究了烧蚀热防护系统内部热响应的计算模型和计算方法. 采用碳化层-热解面-原始材料层模型, 建立碳基材料内部热响应物理模型和数学模型, 利用有限元法分析和计算再入目标热防护系统轴对称内部热响应. 着重研究和分析了轴对称烧蚀过程中热解气体质量流率计算方法和传热机制. 将热解气体与碳化层之间的对流换热处理为源项, 通过保证刚度矩阵和形函数矩阵的正定对称性可以加速温度场计算收敛. 计算表明: 热解气体的质量流量主要由厚度方向构成, 占80%以上; 头部驻点附近最大烧蚀厚度接近10mm, 需要采用抗烧蚀能力强的碳-碳材料, 身部烧蚀量小于2mm, 可以采用密度较小的碳-酚醛材料.

英文摘要:

The thermal response simulation model and method of ablation thermal protection system were studied. Charred layer-pyrolysis surface-original material layer model was applied to establish physical and mathematical model of thermal response and the axis-symmetrical thermal response of thermal protection system of spacecraft was computed by finite element method. The calculational formulas of pyrolysis gas mass flux and mechanism of heat transfer during ablation course were studied and analyzed deeply. Convection heat transfer between pyrolysis gas and charred layer was treated as heat source and it could speed up convergence of temperature field calculation by keeping the conductance matrix and capacitance matrix positive definite symmetric. The calculation results demonstrate that the mass flow of pyrolysis gas in the direction of thickness is over 80%, and side direction part is very small. The ablation scale is approximately 10mm, so the carbon-carbon material with good anti-ablation performance must be used in the tip of target; the ablation scale of body is less than 2mm, so the carbon-phenolic aldehyde of small density can be used in thermal protection system of body.

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