航空学报
ACTA AERONAUTICA ET ASTRONAUTICA SINICA
ISSN 1000-6893
CN 11-1929/V

航空学报 » 2013, Vol. 34 » Issue (7) :1531-1537 DOI: 10.7527/S1000-6893.2013.0271

RANS/LES在超声速突起物绕流中的应用研究

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Study of Protuberances in Supersonic Flow with RANS/LES Method

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摘要

安装在超声速/高超声速飞行器表面的突起物如机翼、控制舵等通常会导致复杂的激波/边界层干扰,对突起物的局部气动特性甚至飞行器整体的气动特性产生较大的扰动。在采用计算流体力学(CFD)数值模拟此类问题时,传统的求解雷诺平均Navier-Stokes(RANS)方程方法由于不能准确预测湍流脉动流场并且精度有限,在应用上受到一定的限制。本文在研究B-L(Baldwin-Lomax)内层模型和Smagorinsky亚格子模型优缺点的基础上,提出了一种新型的RANS/LES(Large Eddy Simulation)混合模型,并进行了算例验证,证实了该方法的可行性。在此基础上,对火箭表面突起物的干扰流场进行了数值模拟研究,细致地刻画了突起物附近的激波/边界层干扰、剪切层失稳和底部分离涡形成的非定常过程,获得了突起物及火箭表面上的压力脉动历程并进行了频谱分析。研究发现,相对于突起物底部的非定常分离流动,突起物前缘的激波和边界层相互干扰的非定常过程是突起物周围压力脉动的主导因素,这种高频的压力脉动可能对火箭内设备的正常工作产生不利的影响。

关键词： RANS/LES方法 突起物 激波/边界层干扰 超声速流动 数值模拟

Abstract:

The protuberances fixed on a supersonic aircraft such as aerofoil or rudder may cause complex shock wave/boundary layer interactions which can greatly affect the aerodynamic characteristics around the protuberances or even in the whole aircraft. Traditional computational fluid dynamics (CFD) numerical methods solving Reynolds-averaged Navier-Stokes (RANS) equations cannot forecast the turbulence pulsating flow accurately. In this paper, a novel mixed RANS/LES (Large Eddy Simulation) model is developed based on the study of the merits and demerits of the B-L (Baldwin-Lomax) model and Smagorinsky model. Then it is applied to simulate the flow of the protuberances fixed on a rocket. Such flow phenomena as shock wave/boundary layer interaction, shear layer instability and separation vortex are depicted meticulously. The pressure pulsation process on the protuberance surface is obtained, and it is subsequently used to make a frequency spectrum analysis. Result indicates that the shock wave/boundary layer interaction rather than the bottom separation vortex is the main factor causing the pressure pulsation on the protuberance,. and this pressure vibration may affect badly the normal operation of the equipment in the rocket.

Keywords: RANS/LES method protuberance shock wave/boundary layer interaction supersonic flow numerical simulation

Received 2012-09-07; published 2012-12-07

Fund:

国家级项目

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引用本文:

陈琦, 司芳芳, 陈坚强, 袁先旭, 谢昱飞. RANS/LES在超声速突起物绕流中的应用研究[J]. 航空学报, 2013, 34(7): 1531-1537.DOI: 10.7527/S1000-6893.2013.0271

CHEN Qi, SI Fangfang, CHEN Jianqiang, YUAN Xianxu, XIE Yufei. Study of Protuberances in Supersonic Flow with RANS/LES Method[J]. Acta Aeronautica et Astronautica Sinica, 2013, 34(7): 1531-1537.DOI: 10.7527/S1000-6893.2013.0271