我校能源与动力学院黄国平教授在流体力学国际顶级期刊JFM发表论文

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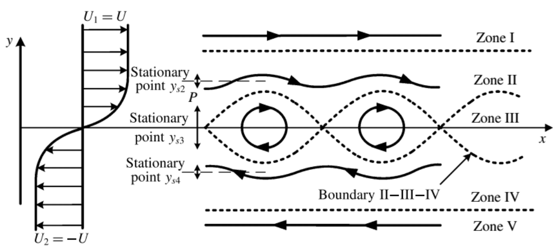
近日，我校能源与动力学院黄国平教授及其团队其他成员共同撰写的学术论文“A nonlinear dynamic model for unsteady separated flow control and its mechanism analysis”在流体力学国际顶级SCI期刊Journal of Fluid Mechanics（简称JFM, IF=2.821, 流体领域投稿期刊国际排名第一)发表。

流体脱离固体表面运动的流动分离现象往往产生极大的流动阻力或流动损失，导致流体机械产生严重的后果，如飞机机翼或压气机叶片的失速现象。为此，人们常采用某种手段来消除或削弱流动分离，即流动控制，这在航空航天流动问题中一直是具有重要科研价值的热点问题。近年来，研究人员发现，像脉冲射流和振动表面等非定常激励措施，能在耗费较小能量的前提下更有效地控制流动分离，产生所谓“四两拨千斤”的效果，但对其动力学机理的理解仍不清楚。因此，关注分离流动的动态拟序结构、并力图通过非定常激励措施更有效地控制流动分离成为了流体力学的研究前沿。黄国平教授团队在国家自然科学基金项目（51176072、51306089）和航空发动机AXXX计划项目的支持下，提出了一个创新性的研究思路：从常见的分离流动提炼出拟序分离流的特征，建立反映其特征的简化动力学模型，在简化模型层面研究内在本质机理，进而揭示非定常激励抑制分离的动力学机理。当前，因为拟序流动结构复杂、非线性很强，一般的流场计算或实验研究难于把握这类问题；这个新思路有助于突破困局，达到“去除枝叶、留下主干”的效果。

此次在JFM上发表的论文，从N-S方程出发基于分离区剪切流近似、Stuart涡列模型及拉格朗日方法（流动图画如下图所示），对典型拟序分离流动结构建立了反映混沌非定常分离流的简化模型（SCDM模型）：

$$\frac{d^2y}{dt^2}=\varepsilon\omega_0^2 y-\frac{\varepsilon\omega_0^2}{y_s^2}y^3-K_d\frac{dy}{dt}+(A+\eta\cos(\omega t+\varphi))\sin(\omega_0 t+\varphi_0)$$



该模型发现的非定常激励的频率依赖性、混沌分离流有序化机制及激励信号与分离涡团自同步现象已得到数值模拟与实验的证实。成果能为今后进一步研究非定常激励控制分离的机理、指导设计更有效的流动控制方案，提供了一个有效的新手段。

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A nonlinear dynamic model for unsteady separated flow control and its mechanism analysis

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In the analysis of the interaction between external periodic excitation and unsteady separated flow in controlling the flow separation, a new nonlinear approximate model has been established. This model is used to describe the typical chaotic and coherent characteristics of a separated flow such as small- or large-scale vortices, the injection, and the dissipation of the kinetic energy based on a simulation of a simplified cross-direction motion of free shear flows. This study presents an appropriate treatment to simulate the external periodic excitation and uses the maximum Lyapunov exponent to evaluate the degree of flow ordering in the different control states. The results of the nonlinear model are compared with experimental and numerical results, showing that the nonlinear model could be used to effectively explain the behaviours of chaotic flows and investigate the rules for controlling separated flows. In addition, as shown in the nonlinear approximate model, the self-synchronization of unsteady flow separation and periodic excitation has been analysed. Initially, the research provided an explanation of the self-synchronization mechanism, which cites that the effects of the separated flow control are independent of the phase difference between the periodic excitation and the unsteady flow. The characteristics of unsteady separated flow control have also been presented in this model, where the corresponding large eddy simulation (LES) was used for separated flows in a curved diffuser. The proper orthogonal decomposition (POD) method was used to analyse the difference between separated vortical structures with or without periodic excitation. The results showed that the model and the simulation had the same mechanism of flow control as for the separated flows. The periodic excitation transforms the original chaotic flow into a relatively ordered flow and decreases the magnitude of the chaotic unstable vortices, rather than completely eliminating the vortices, while flow mixing is reduced, inducing less energy loss.