Target to reduce friction drag by roughness elements: Doable or Not?

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Abstract: Drag is the force by which a fluid resists the relative motion of a solid. The fluid can be external or internal to the wall boundaries which can be rigid or compliant. Flow control aims at minimising the drag force.
In this talk, we will discuss about the challenging of deploying flow control strategies to achieve friction drag reduction for wall-bounded flowsand how to investigate the potential problems in validating the strategies precisely. Generally, the drag consists of three categories: profile drag, induced drag and wave drag. Here, we will not discuss induced drag and wave drag since theyare respectively related to vorticity and supersonic flows.The talk will be focused onthe skin frictiondrag which is categized into the profile drag and related to two kinds of strategies: laminar flow control and turbulent drag reduction. These two strategies are clearly proposed for two kinds of flows: laminar and turbulent flows.We either need to delay laminar-turbulent transition or enhance turbulence.
The classical process of the laminar–turbulent transition is subdivided into threestages: receptivity, linear eigenmode growth and nonlinear breakdown to turbulence. Along-standing goal of laminar flow control (LFC) is the development of drag-reductionmechanisms by delaying the onset of transition. The process of laminar to turbulenttransition has been shown to be influenced by many factors, such as surfaceroughness elements, slits, surface waviness and steps. These surface imperfections cansignificantly influence the laminar–turbulent transition by influencing the growth of TSwaves inaccordance with linear stability theory and then nonlinear breakdown alongwith 3D effects (Kachanov 1994). Since the existence of TS waves was confirmed bySchubauer&Skramstad (1948), numerous studies aiming to stabilise or destabilisethe TS modes have been carried out in order to explore and explain different pathsto transition. If the growth of the TS waves is reduced or completely suppressed,and providing no other instability mechanism comes into play, it has been suggestedtransition could be postponed or even eliminated (Davies & Carpenter 1996). Despiteroughness elements being traditionally seen as an impediment to the stability of theflat plate boundary layer, recent research has shown this might not always be the case.Reibert et al. (1996) used spanwise-periodic discreteroughness elements to excite themost unstable wave and found unstable

waves occur only at integer multiples of theprimary disturbance wavenumber and no subharmonicdisturbances are destabilised.Following this research, Saric, Carrillo &Reibert (1998) continued to investigate theeffect of spanwise-periodic discrete roughness whose primary disturbance wavenumberdid not contain a harmonic at _s D12 mm (the most unstable wavelength according tolinear theory, where _s denotes the crossflow disturbance wavelength in the spanwisedirection). By changing the forced fundamental disturbance wavelength to 18 mm,the 18, 9 and 6 mm wavelengths were present. Saric et al. (1998) found the linearlymost unstable disturbance (12 mm) was completely suppressed. Shahinfar et al. (2012)showed that classical vortex generators, known for their efficiency in delaying, or eveninhibiting, boundary layer separation can be equally effective in delaying transition.An array of miniature vortex generator (MVGs) was shown experimentally to stronglydamp TS waves. However, the MVGs might induce bypass transition due to large amplitude of disturbances. It is needed to mention that any localised irregularity, impurity, etc. occurs on the surface, this may cause a local wedge of a turbulent boundary layer. Therefore, for laminar-turbulent transition, we have problems or obstacles: attachment line contamination (fuselage boundary layer) and crossflow instabilities (boundary layer crossflow vortices); effects of steps, gaps, waviness, structural deformations in flight; bypass transition (3-D roughness, indentations, bumps, rivets), insects, dirt, erosion, rain, ice crystals and so on, which makes laminar-flow control challenging in deployment. In Fig 1, we illustrate the pathway to turbulent by a shallow surface indentation.

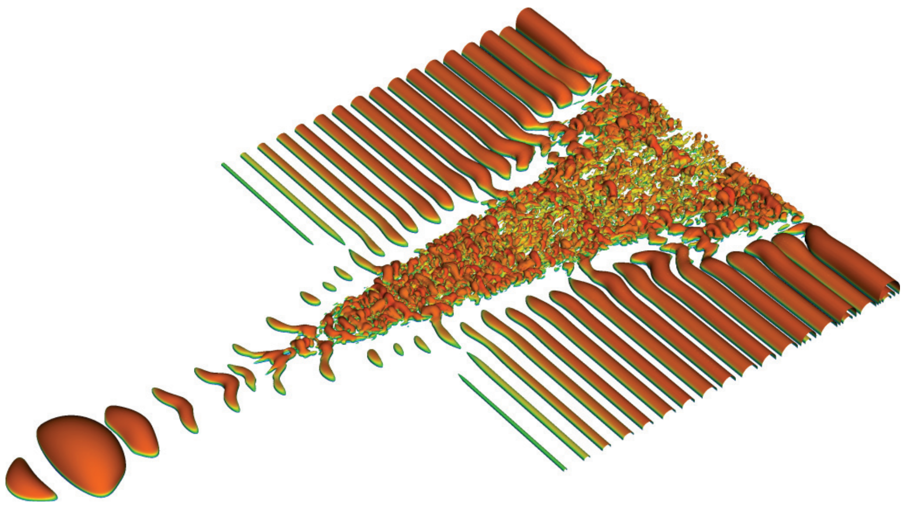

Figure 1. Transition induced by a shallow dimple

Further, a turbulent boundary layer is able to deal with flow separation. We know thatthedimples on a golf ball, which are increasing the skin-friction drag, give rise to improvedperformance because the increased surface roughness trips the boundary layer andsignificantly lowers the dominant pressure drag.To reduce the turbulent skin-friction drag, by using riblets, a modest skin-friction drag reduction can be achieved. The selective suction technique, which combines suction to gain an asymptotic turbulent boundary layer and riblet to fix the location of low-speed streaks, is able to get a drag reduction. In this talk, we will not discuss the turbulent boundary layer drag reduction which gives a largest drag reduction up to 60% of the corresponding drag and will focus on delay transition since it is about to achieve an order of magnitude lower skin-friction drag.

Reference

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