Delaying transition in a Blasius boundary layer with finite compliant panels

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ABSTRACT

Compliant surfaces have been shown to be a promising passive control measure for controlling and delaying boundary layer transition in various theoretical studies [1-2]. In this paper, we report on a recent study we have done on the evolution of pulse-initiated disturbance wavepackets over one or more finite-length compliant panels. The broadband nature of a wavepacket offers a central advantage in permitting natural selection of most dominant waves to operate through the sum of its growth processes. This may be helpful in identifying the critical waves and key processes that are involved at the various stages in natural transition. The initiation, evolution and final breakdown of wavepackets into the incipient turbulent spots in a Blasius boundary layer was modelled by Direct Numerical Simulation (DNS) briefly described in [3]. The comparative evolution and transition performance of three cases are discussed here, namely the rigid-wall case, a single-panel wall and a two-panel wall.
In all cases, a fixed vertical-directed delta pulse of small amplitude was initiated at the point $x/\delta=$ 349.4, where $\delta = 2.3182\times10^{-3}$ m is the displacement thickness of the boundary layer at the initiation point.

The evolution and breakdown of the wavepacket in a Blasius boundary layer on a rigid wall has already been reported in [3]. For the single-panel case, a finite section of the wall from $x/\delta = 450$ to 762 was replaced by a tensioned membrane on a viscoelastic foundation, whose properties were designed to inhibit the development of compliant-wall modes. The simulation results showed that, the upstream intervention by the finite compliant panel effectively delayed the onset of the incipient turbulent spot by a distance of about 100 cm ($\Delta x/\delta = 430$). This represents an approximately 30% increase in the transition distance measured from the point of wavepacket initiation. Spectral study indicated that the relatively short membrane panel was able to effectively attenuate the primary 2-D Tollmien-Schlichting (TS) wave mode so that resultant wavepacket after the panel was dominated by a pair of oblique waves. Subharmonic secondary instabilities [4-5], which are responsible for nonlinear disturbance wave amplification on a rigid wall, were thus inhibited by the absence or near absence of the 2-D TS wave mode. Staggered Λ-structures and streamwise streaky structures similar to those found in the rigid wall case were observed for the single-panel case, but much further downstream. A second tensioned membrane panel of the same length was added at $x/\delta = 1359$-1658 to form the two-panel case. The last stage of the present simulation shows the wavepacket arriving the location $x/\delta \approx 2000$ in a perfectly laminar form ($|u|_{max}/U_\infty \approx 0.05$) – this already represents an increase in transition distance of about 50% over the corresponding rigid-wall case. The eventual breakdown location will be further downstream as the wavepacket has not displayed the usual structural features that signify imminent breakdown. This study has shown the efficacy of short compliant panel(s) in controlling and delaying transition.

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