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Results for the Blasius boundary layer:

In Healey (1993), reproducible disturbances were excited in Gaster's low-freestream-turbulence wind-tunnel, and hot-wire measurements were taken at a sequence of positions downstream of the source to determine their spatio-temporal evolution. This work recognises that a single time-series measurement can not give a full description of the dynamics of disturbances in the boundary layer because the evolution seen at one point in the flow depends on the evolution further upstream. Therefore, nonlinear maps were fitted to the data that transform, point by point, the phase portrait at one streamwise location onto the phase portrait at the neighbouring downstream position. These maps were found to reproduce known linear stability characteristics of the Blasius boundary layer, and also to show 'horse-shoe' characteristics that could generate spatio-temporal chaos.

It had been observed by Gaster and co-workers that modulated wavetrains in the Blasius boundary layer undergo a breakdown in which spikes appear in measured time series at lower amplitudes than for unmodulated wavetrains. These spikes evolve into turbulent spots. Low levels of freestream turbulence typically produce modulated disturbances in boundary layers, so this observation is important in understanding laminar-turbulent transition. In Healey (1994b and 1995c) experimental results were presented for a particular type of modulation in which the effects of increasing and decreasing amplitudes and strength of modulation could be studied independently. It was found that decaying sections preferentially undergo breakdown to spikes as the modulation strengthens. The phenomenon is very sensitive to the relative phase between the carrier wave and its envelope, suggesting that quadratic nonlinearity is crucial to the process (generic amplitude equations with cubic nonlinearity display phase-invariance). Amplitude equations with quadratic nonlinearity arise when linear waves with wavelengths and frequencies in 2:1 ratios interact. Weakly nonlinear theory was used to derive the coefficients in quadratic amplitude equations where modulation was modelled by allowing frequencies to become complex. These coefficients become larger for decaying modulations, and it was suggested that this might cause the preferred breakdown of sections of decaying modulation in the experiments. Healey (1996) identified the underlying properties of dispersion relations that generate resonances with integer ratios and used them to locate higher order resonances in the Blasius boundary layer.

However, in Healey (2000a), examination of further wind-tunnel experiments indicated that the resonant interactions were more likely to involve Craik resonant triads. Another mechanism that could produce preferential spike formation for either decaying or growing sections of modulation was also introduced in this paper, in which a progressive envelope steepening occurs (such behaviour is also predicted by higher-order Ginzburg-Landau equations). The experimental data supported this hypothesis, and direct numerical simulations are being carried out by Chris Davies' group in Cardiff University to investigate these ideas further.

Asymptotic theories for instabilities in the Blasius boundary layer are either based on the Reynolds number scalings associated with the lower branch of the neutral curve, or on its upper branch. Near the upper branch there are distinct critical layers (where a wave's phase velocity coincides with the local mean flow velocity, and unsteady and inertial terms balance) and viscous wall-layers (where viscous and unsteady terms balance), but near the lower branch these layers overlap giving a triple-decked structure. A difficulty for experimentalists wishing to compare experimental (or numerical) results with these theories is that the two theories make conflicting quantitative predictions at Reynolds numbers used in laminar-turbulent boundary layer experiments. A detailed comparison between the asymptotic theories and numerical stability results is presented in Healey (1995b) over a wide range of Reynolds numbers. A kink on the upper branch of the neutral curve is found to correspond to where the critical layer and viscous wall-layer merge to give a triple-decked structure, even on the upper branch. The kink therefore indicates where a qualitative change in disturbance structure, and where a change in balances between different physical effects, takes place. The kink persists in the presence of pressure gradients, and for adverse pressure gradients it marks the change between essentially inviscid dynamics and viscous dynamics, as shown in Healey (1998).

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