Role of Detuning in the Final Stage of Subharmonic Mode Transition in Boundary Layers

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This work involves mechanisms for transition to turbulence in a Blasius boundary layer through resonant interactions between a plane Tollmien-Schlichting Wave and pairs of oblique waves with equal-but-opposite wave angles. When the frequency of the TS wave is exactly twice that of the oblique waves, we have a "tuned" subharmonic resonance. This leads to the enhanced growth of the oblique modes. Following this, other nonlinear interactions lead to the the growth of other 3-D modes which are harmonically based, along with a 3-D mean flow distortion (for example see Corke and Mangano [1]). In the final stage of this process, a gradual spectral filling occurs which we have traced to the growth of fundamental and subharmonic side-band modes. To simulate this with controlled inputs, we introduced the oblique wave pairs at the same conditions, but shifted the frequency of the plane TS mode (by as much as 12%) so that it was not exactly twice that of the 3-D modes. These "detuned" conditions also lead to the enhanced growth of the oblique modes, as well as discrete side-band modes which come about through sum and difference interactions. Other interactions quickly lead to a broad band of discrete modes. Of particular importance is the lowest difference frequency which produces a low frequency modulation similar to what has been seen in past experiments with natural 3-D mode input (Kachanov and Levchenko [2]). Cross-bispectral analysis of time series allow us to trace the origin and development of the different modes. Following these leads to a scenario which we believe is more relevant to conditions of "natural" transition, where low amplitude background disturbances either lead to the gradual detuning of exact fundamental/subharmonic resonance, or in which 3-D mode resonance is detuned from the onset. The results contrast the two conditions, and document the propensity of the 2-D/3-D mode interactions to become detuned.

[1] *J. Fluid Mech.*, 209, 93-150.

[2] *J. Fluid Mech.*, 138, 209.

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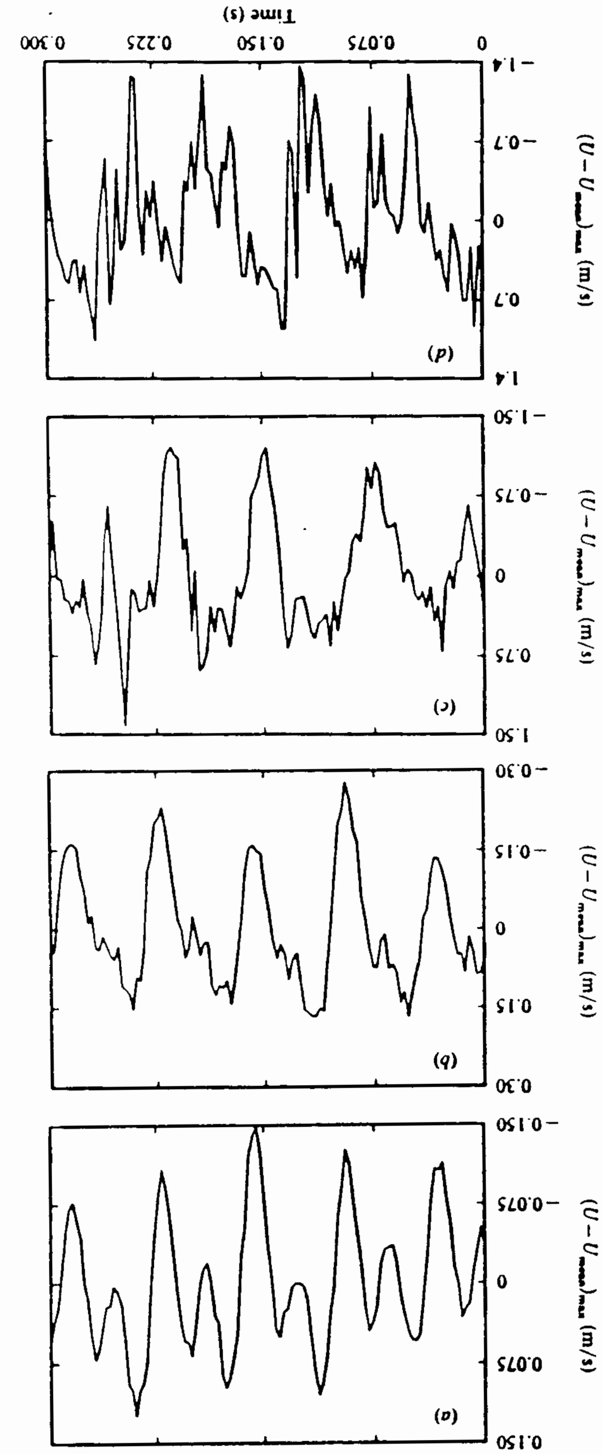
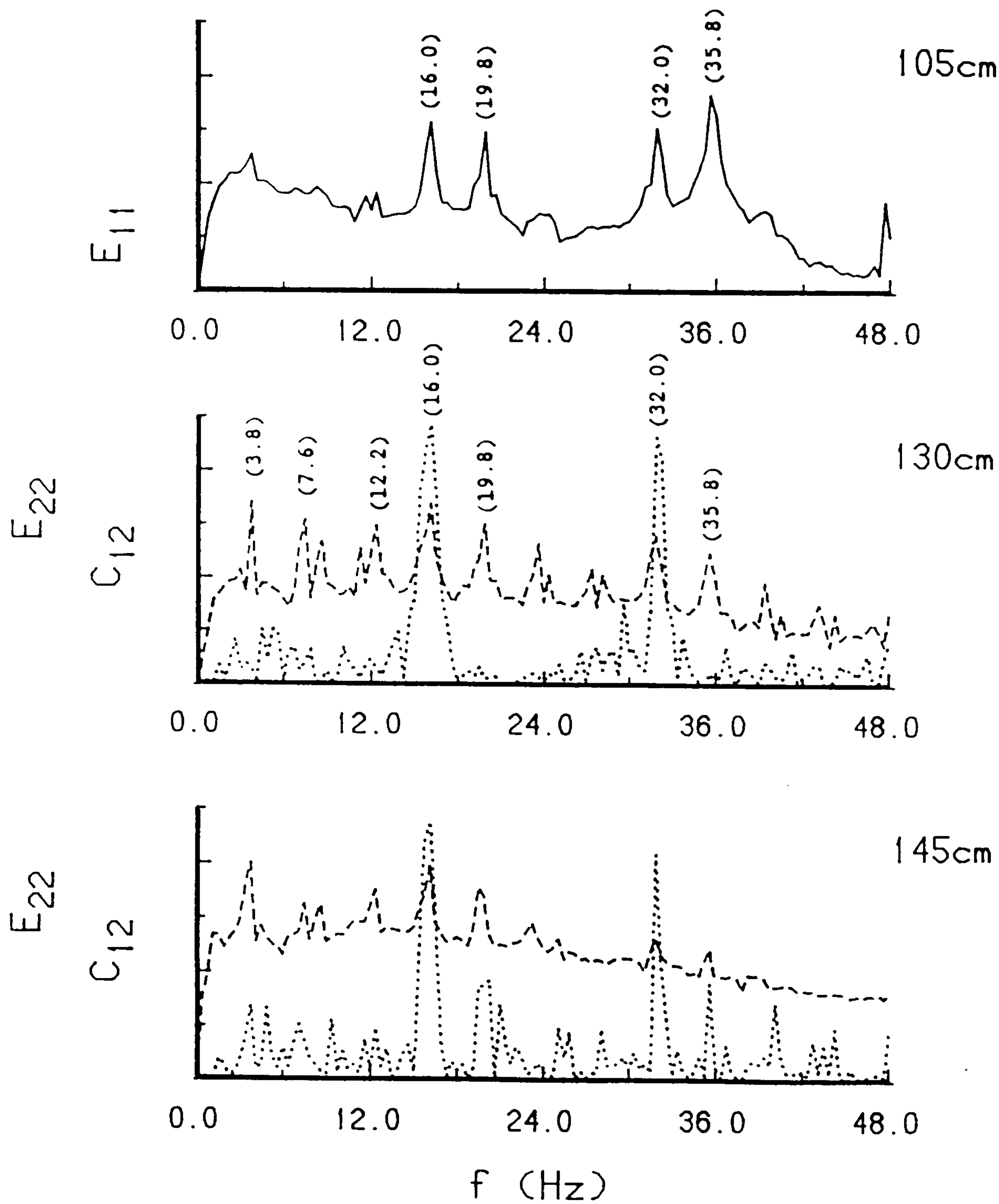

(a)
(b)
(c)
(d)
Time (s)
0
0.075
0.150
0.225
0.300
(U − U_mean)_rms (m/s)
−0.150
−0.075
0
0.075
0.150
−0.30
−0.15
0.15
0.30
−1.50
−0.75
0.75
1.50
−1.4
−0.7
0.7
1.4

Downstream evolution of u-spectra for 16/35.8 detuning



Summary:

- We observe a scenario in which 3-D modes develop by an interaction with an amplified plane TS mode through a "**tuned**" or "**detuned**" fundamental/ subharmonic resonance.

- With increased detuning (up to 13%), we observed **an increased sensitivity** of 3-D mode growth to the 2-D mode initial amplitude, consisting of:

  1. A decrease in the 2-D threshold amplitude necessary for resonance.

  2. An increase in the output response of the 3-D mode to the 2-D amplitude.

  3. Combined, there is a **propensity to detune.**

- Mankbadi (1993) performed a critical layer asymptotic analysis for a fully nonlinear interaction of frequency detuned modes in a 2-D bl.
  He shows that:
  - Contrary to a "tuned" parametric growth, with "detuning" the parametric growth rate is dependent not only on the initial amplitude of the plane wave, but also on the initial amplitudes of both 3-D wave pairs.
  - For a given frequency detuning, there is an *optimum angle* of oblique modes, **which is dependent on the amount of detuning and initial amplitudes**, at which the parametric growth rate equals that of the "tuned" resonance.
  - In an adverse p-grad, "detuning" could result in higher growth than with a "tuned" resonance.
- In a limited investigation, these results are consistent with those from PSE calculations by Bertolotti at ICASE.