

6th European Postgraduate Fluid Dynamics Conference  
Imperial College, London  
10-12 July 2012

## On the frequency of hydrodynamic perturbations. Early and intermediate transients.

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We present recent findings concerning the frequency in the transient evolution of three-dimensional perturbations in sheared flows. We adopt the initial-value problem formulation, proposed by Criminale and Drazin [1], that was recently used to carry out exploratory studies on the perturbation transient dynamics [2,3]. We consider two typical shear flows: the plane Poiseuille flow, as the archetype of wall flows, and the bluff-body wake flow, as an example of unbounded flow.

We show evidence of a discontinuous behavior in the frequency inside the transient life of three-dimensional traveling perturbation waves in two typical sheared flows. In the wall flow case, the presence of the discontinuity is barely influenced by the symmetry of the initial condition or by the obliquity angle of the perturbation wave. In the free flow, the wake, the jumps are more marked for antisymmetric perturbations, either aligned with the basic flow or oblique to it. The discontinuity appears after many eddy turn over times have elapsed and last from 10% to 50% of the global transient length. We interpret this phenomenon as the signature of both the end of the early transient, the part of the evolution must affected by the initial condition, and the beginning of the intermediate term, where the accomplishment of the final values of the wave characteristics take place in accordance with the modal theory. In general, these sudden variations are preceded by a modulation of the constant frequency value observed in the early transient and followed by higher values with a modulation that progressively extinguishes as the asymptotic state is approached. The investigation of the dispersion relation in the asymptotic regime reveals that longitudinal long waves and all the perturbations not aligned with the base flow present a dispersive behavior, while only longitudinal short waves are non-dispersive.

This work contains also a numerical investigation of the frequency dependence on the obliquity angle, which indicates that purely orthogonal waves, always stable in the long-term, are standing waves. Since any of these waves arriving in the system will have a zero phase velocity and since during the early transient orthogonal waves can present intense algebraic growth, the system in this condition faces a situation where, in principle, instability can be incentivated.

[1] Criminale W. O., Drazin P. G., *Stud. Applied Math.* 83:123-157, 1990.

[2] Scarsoglio S., Tordella D., Criminale W. O., *Stud. Applied Math.* 123:153-173, 2009.

[3] Scarsoglio S., Tordella D., Criminale W. O., *Phys. Rev. E* 81:036326, 2010.