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NEW APPLICATIONS WITH UNSTEADY FLOW SEPARATION ANALYSIS

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New applications have arisen relatively recently in which unsteady flow separation and its analysis can play important roles. The applications considered are both medical and industrial and they will be considered in the presentation together with comparisons between analytical results and direct numerical simulations and /or experiments in every case, at various typical flow rates or Reynolds numbers.

The first project presented concerns the influence of vessel wall flexibility in multiple vascular dynamics, specifically for the unsteady flow of blood through the cerebrovascular system and particularly through an abnormality such as an arterio-venous malformation where the effect of and on the network of vessels present is crucial.

- The flow properties at branch junctions have a central determining role here and in the many other networks of real interest.
- Unsteadiness tends to be less prominent in the cerebrovascular system than elsewhere in the human body but it is still a contributory factor to be taken into account.
- In one analytical limit the long-scale temporal and spatial behaviour dominates, which is more the conventional scenario applying for the rest of the body than relevant to the Brain scenario. In another limit short-scale dynamics dominate particularly at the branch junctions and then the resulting short-scale properties drive the elastic wave response in the rest of the network. This mechanism appears to be more allied to the haemodynamics within the within the brain, especially where there are localised nonlinear effects within the network such as in the case of a vascular abnormality. Agreement with direct numerical simulations is found for medium flow rates [1]. In between the above two extremes there is long-scale /short-scale interaction of course directly connecting all parts of the unsteady pulsating network.
- The effect of viscosity leads to unsteady separation either over the longer length scale or over the shorter local one, similar to that described below.
- Only 2D theory has been addressed seriously so far in such studies.

Second, the project of [2] and subsequent studies is on side branching from a single mother vessel to one or more comparatively small daughter vessels. The flow field consists essentially of Euler regions at the branch junctions and unsteady interactive boundary layer regions along the individual vessels, with pressure jumps involved between them.

- Unsteady separation here tends to be associated first with the longer length scale over which the unsteady interactive boundary layer equations apply in full across the entire daughter vessel.
- Separation can nevertheless be a feature of the shorter scale Euler flow region where it appears as an unsteady classical form initially at least, as the flow pulsates.
- Again agreement with direct numerical simulations is found for medium flow rates.
- Both 2D and 3D theory has been advanced in principle here.

The third project here addresses the complete three-dimensional motion through a slender mother-and-daughters arrangement [3]. The behaviour near the carina, the division at a 3D branch junction, is especially significant because of deposition of drugs or glues.

- The dynamics involved is necessarily 3D even near the carina. The near-carina flow can readily oppose the main axial flow.
- The fully three-dimensional nature of the flow persists in terms of the global interaction between the core of the flow and the thin near-carina behaviour and in terms of the local carina flow response itself.
- Qualitative agreement is found with earlier direct simulations on 3D branching motions at moderate flow rates.

Fourth is a project (or projects) from an industrial setting concerned with fluid-fluid or solid-fluid impact problems at high velocity and in particular for water with air. Small-time analysis is addressed in [4] for water effects alone, concerning the spray jet dynamics especially, while air-water interactions are studied in [5].

- Both settings are subject to the possibility of unsteady separation occurring through the unsteady interactive systems present, depending on the effective Reynolds number.
- Qualitative agreement with experiments is apparent in the context of [4].
- Oblique impact is a main issue in the setting of [5]. Similar agreement with experiments is found here, along with favourable agreement with direct simulations.
- Only 2D analyses and associated computations have been studied productively so far.

Fifth, project [6] concerns liquid crystals, again from an industrial application. Full zone theory and analysis are carried through for an axisymmetric geometrical configuration but with a view to understanding the non-axisymmetric flow and thermal responses that occur in practice.

- The onset of completely 3D non-axisymmetric behaviour within an axisymmetric configuration is crucial in practice for manufacturing reasons.
- The theory in effect points to the setting up of internal jet-like motions and thence to violent short scale instability appearing for a certain critical parameter.
- The criterion for this is found to be close to the results obtained in huge direct numerical simulations over a range of operating conditions.

These new areas of study involve various collaborations with Edward Green, Peter Franke, Denis Doorly, Robert Bowles, Richard Purvis, Jim Oliver, John Ockendon, Sam Howison, Dominic Davis, among others, and are supported by EPSRC, The Lighthill Institute, The Smith Institute, The Medical Modelling Group, The Weierstrass Institute, among others. Clearly we cannot cover each and every detail of the above summarised areas in the associated presentation. Instead the focus will be on the major aspects involved.

References

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