University of Warwick

End of Year Progress Report:

Simulation of Vortex Rings

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1. Introduction & Background

This report provides a short synopsis of my current and future research.

The simplest model of a vortex filament is the vortex ring. In a reference frame moving with the vortex ring, a region of fluid called a bubble is carried with the vortex ring. Inside the bubble is the core proper, in which the vorticity has a maximum value. The remaining region inside the bubble has little vorticity. Inside the core is the inner-core region, next to the core axis, which is effectively laminar [1]. Vorticial involvement in a turbulent flow field is proved by the existence of actual large scale and coherent structures when they cluster or lump together, the fluid accommodates to changing and interacting forces, and new flow patterns are created in the process. This can result in the generation of vortices in the laminar or turbulent form. Turbulent vortex rings are much more complicated than turbulent line vortices due to curvature effects. This kind of transition is due to instability of flow. Vortices viscosity and self rotation property have a major effect on vortex filaments merging, splitting and reconnecting. The slower growth of the turbulent vortex ring, compared to that of the laminar ring is reflected in the slightly slower decrease of its transitional velocity. The rate of decay is faster in turbulent motion than in laminar flow. The detailed structure of a vortex ring depends to a large extent on how it was generated. Vortex shedding can be triggered by instability, by the acceleration / deceleration of bodies. The mechanism is applied to the generation of a vortex pair by means of flapping or by means of an abrupt expulsion of fluid from a slit [2]. In both cases the vorticity sheets are generated while rolling up into individual vortices. The axisymetric analogy is the generation of a vortex ring at any opening such as the end of a pipe. Acceleration and subsequent deceleration of a blunt body or a plate perpendicular to the movement can create a pair of rings which detaches its self from the body. Periodic movement of a body can create periodic vortex configurations. The vortices acting on the boundary layer create a discontinuous surface and then these surfaces unite to form a vortex surface, if the boundary layer is sucked off at the opening, no vortex ring can develop, the detached vortex ring induces a secondary vortex with vorticity of opposite sign. The life time of a vortex ring consists of the creation of turbulent motion during roll-up of the ring while fluid is expelled from the wake section. A turbulent line vortex is an isolated turbulent vortex in the sense that, outside the vortex from a certain radius, the flow field is turbulence free. The mechanism of entrainment from the surrounding flow into the vortex ring differs decisively between laminar and turbulent. A laminar ring grows by acquiring fluid over the whole surface through molecular diffusion and carries the fluid into the wake. While the growth of a turbulent ring is governed by macroscopic entrainment of fluid pockets into the core. Most of the fluid entrained is ejected into the wake. These periodic losses of fluid from the bubble appear in the wake in the form of distinct small vortex rings and hairpin vortices. The generation of these discrete vortices can be explained by azimuthal waves which occur during instability. The wavy filaments stretch to hairpins and eventually are shed as small vortex rings. These complex flow patterns have a great impact on quantities of technical interest. Vortex control comes in methods of avoidance of noise and combustion enhancement in engines.

2. Results

In turbulent flows, the conservation equations for mass and momentum are applied which result in the continuity and Navier-Stokes system of equations. Spectral methods are used in solving the resulting partial and ordinary differential equations having in mind smoothness of solution as an objective, with mostly periodic boundary conditions taken into account. Spectral methods are a class of spatial discretization for differential equations. The key components for their formulation are the trial functions and the test functions [3]. Trial functions provide approximate representation of the solution while test functions ensure that the differential equations and boundary conditions are satisfied as closely as possible by the truncated series expansion. This is achieved by minimizing, with respect to a suitable norm, the residual produced by using the truncated expansion instead of the exact solution. The residual accounts for the differential equation and sometimes the boundary conditions with respect to each of the test functions. The trial basis functions in spectral methods on a single tensor-product domain are global, infinitely differentiable and nearly orthogonal. Fourth order Runge-Kutta method is favoured for time stepping. My starting point will be based on research conducted at the university of Southampton by Dr Gary Coleman [5], and later using the experimental data of PhD student David Hunter at the Warwick school of engineering for validating my code data output.

3. Thesis Outline

Table of Contents

4. References:

1- H.J.Lugt (1995): Introduction to Vortex Theory , (Vortex Flow Press , Potomac , Maryland) [479].
2- P.G .Saffman (2001): Vortex Dynamics , (Cambridge Monographs on Mechanics and Applied Mathematics) [107].
3- C.Canuto, M.Y.Hussaini, A.Quarteroni,T.A. Zang, (2006): Spectral Methods : Fundamentals in single Domains, (Springer verlag , Germany).
4- P.J. Archer, T.G. Thomas, G.N. Coleman, Direct Numerical Simulation of Vortex Ring Evolution from the Laminar to the Early Turbulent Regime.

Activities (Current Academic Year):

Learning programming and using programming Packages:

- Matlab
- Fortran90

Demonstrating Duties:

- ES174 Design for Function (Term 1).
- ES180 Technological Science 1.
- ES3D3 Civil Engineering Materials and Structural Analysis.
- ES174 Design for Function (Term 2).
- ES440 / ES911Computational Fluid Dynamics.
- ES174 Fluid Flow PC Lab.

Attended various lectures and seminars at Warwick University:

- EPSRC Symposium Workshop on Computational Fluid Dynamics ,Computational Fluid Dynamics, Tuesday 1 – Thursday 3 September 2009.
- Regular Seminars held by the Fluid Dynamics Research Centre, University of Warwick.

Literature Review:

- Literature search through relevant books/journals/thesis/publications.
- Reading and writing notes on relevant literature.