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VORTEX CELL SHAPE OPTIMISATION FOR SEPARATION CONTROL

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ABSTRACT

The present study is a part of the FP6 VortexCell2050 project. The overall goal of the project consists in developing a technology for mitigating unfavourable effects of large-scale separation from a bluff body by confining the recirculation eddy to a vortex cell that is a special cavity in the body surface. To prevent the vortex leaving the cell due to instability, an active, preferably closed-loop control is to be used. Theoretical studies of laminar flow in a vortex cell show that in order to avoid secondary separation inside the cell the shape of the cavity has to be very carefully chosen. Secondary separation is likely to increase the number of unstable degrees of freedom of the flow in the cell, thus making the closed-loop control more difficult. Therefore, it has to be avoided.

At realistic flow conditions the flow in the cavity will be turbulent. For the purpose of shape optimisation an efficient flow model can be obtained by replicating the structure of laminar high-Reynolds-number flow in a vortex cell [1] and replacing laminar viscosity with effective turbulent viscosity. The resulting model is illustrated in figure 1. It is a combination of an inviscid Batchelor-model flow and a cyclic boundary layer.

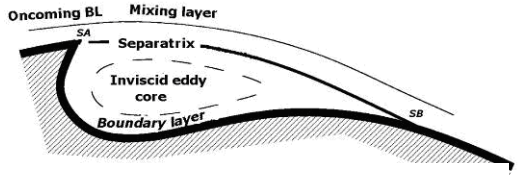

Fig. 1. Batchelor model and cyclic boundary layer structure.

Comparisons of the calculations within this model and experimental results obtained with a specially designed facility show a moderate quality of agreement. The geometry of the facility ensures that there is no vortex shedding from the cell even though there is

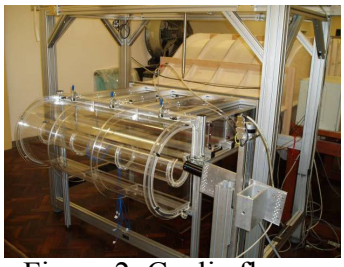

Figure 2. Cyclic flow facility

no closed-loop control (figure 2). The Cebeci-Smith and the Baldwin-Lomax turbulence model are implemented in various variants for the calculation of the wall-bounded parts of the boundary layer and the Wilcox model combined with the Prandtl model is used in the mixing layer. The Batchelor model flow is calculated using the FreeFem++ [2] package.

For the optimisation we used algorithm [3]. This is a multi-objective optimization algorithm for continuous problems that uses the Parzen method to build a probabilistic representation of Pareto solutions, with multivariate dependencies among variables. Some techniques of NSGA-II [4] are used to classify promising solutions in the objective space, while new individuals are obtained by sampling from the Parzen model.

The shape optimisation is applied to the shape of an interchangable section of a special test-bed facility (figure 3). The shape of the cavity is parametrised using about 30 parameters. The objective functions are the total length of the secondary separation in the cavity and the distance from the separation point downstream from the cavity to the trailing edge. An intermediate shape is shown in figure 4.

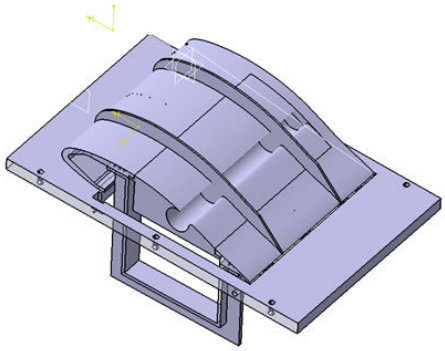

Figure 3. Test-bed facility

At the time of writing the optimisation calculations were still running. It may, however, be concluded that the entire approach is self-consistent.

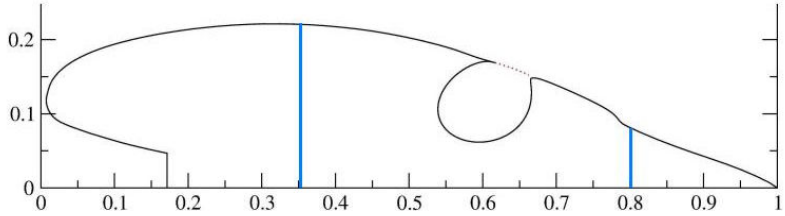

Figure 4. Test-bed and cavity shape being optimised

The next stage of research should concentrate on the validation of the developed tool by conducting experimental research.

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