Computational and Experimental Analysis of a Small Gap in an Integrated Electric Thruster

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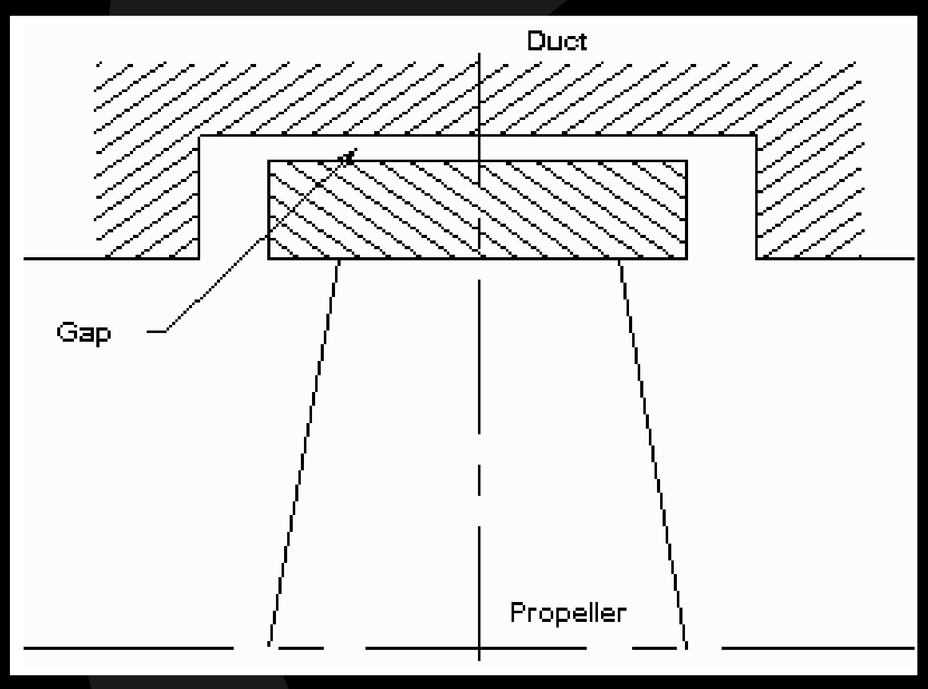
Introduction

The flow between two cylinders, with the inner cylinder rotating is of general interest in several naval engineering problems. Such rotating machinery includes motors, turbines, pumps and journal bearings. The particular problem under investigation is the development of a novel underwater integrated electrical thruster unit.

A source of power loss arises from the frictional resistance that occurs between two such concentric cylinders with partly enclosed ends and a pressure difference across the gap, see the schematic below.



Schematic of the gap in the tip driven thruster

The flow between concentric rotating cylinders has been studied since Taylor reported the formation of array of alternating laminar toroidal vortices at a particular speed dependent upon the geometry of the problem. This is known as the critical Taylor Number. As the Taylor number is further increased the flow changes through various wavy and chaotic states to turbulent flow. When the Taylor Number is around 1000 times the critical number, the flow is fully turbulent with uniform vortices. These vortices have a wavelength that is larger than the laminar case and are highly dependent upon the start-up conditions.

One of the most important issues in rotating machinery from an engineering point of view is the frictional torque required to drive the system. The most common methods of estimating the torque between infinite cylinders is to use empirical equations usually based on the Reynolds number and radius ratio. These predictions take no account of the effects of the finite cylinder and associated end effects, which are present in most rotating engineering devices.

Experimental

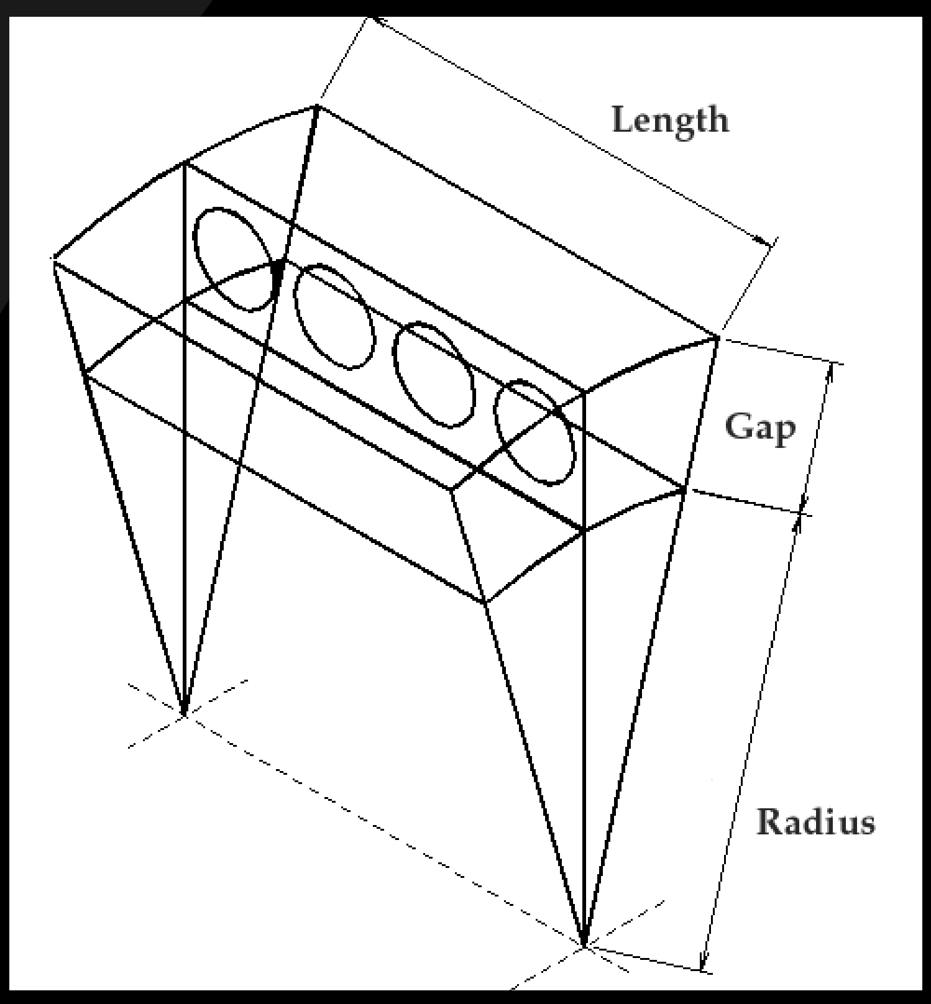
An experimental rig has been designed and is now in the latter stages of construction. This will shortly be commissioned for test work. This experimental rig has been designed to be dynamically similar to the integrated electrical thruster unit, which has a radius ratio of 0.986 and operates at Reynolds number of 2,000 based on the gap width. This meant that to be able to visualise the flow in the rig the inner radius had to be scaled to 704mm to give a 10mm working gap.

The test rig consists of an inner cylinder mounted vertically on a shaft in a water tank enclosed by a clear outer cylinder. The inner cylinder is connected to the motor, on a separate framework to minimise vibrations, by a timing belt drive. The outer cylinder is suspended from the framework by a dynamometer cage working in contra-flexure.

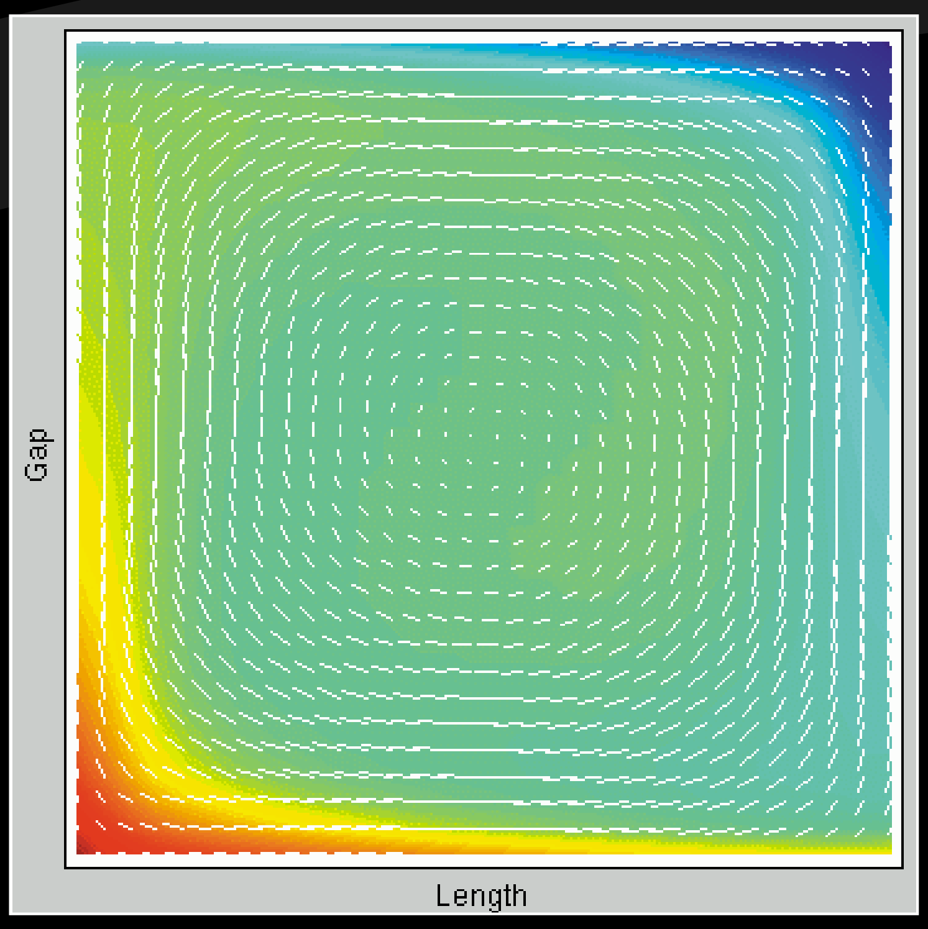
The inner cylinder has been split in two to allow calibration of the end losses and special consideration during the construction is taking place to assure the cylinders are true and concentric for the experiments.

Computational

The flow between two cylinders has been studied computationally using the finite volume method. The flow has been modelled using RANS equations with the turbulence kinetic energy and dissipation determined from both the standard k-e model and a Reynolds Stress Model. To date both QUICK and TVD discretization schemes have been employed in conjunction with the SIMPELC pressure corrections for steady calculations along with transient calculations using the PISO algorithm.



The computational Geometry, showing the domain and postion of two pairs of vortices.



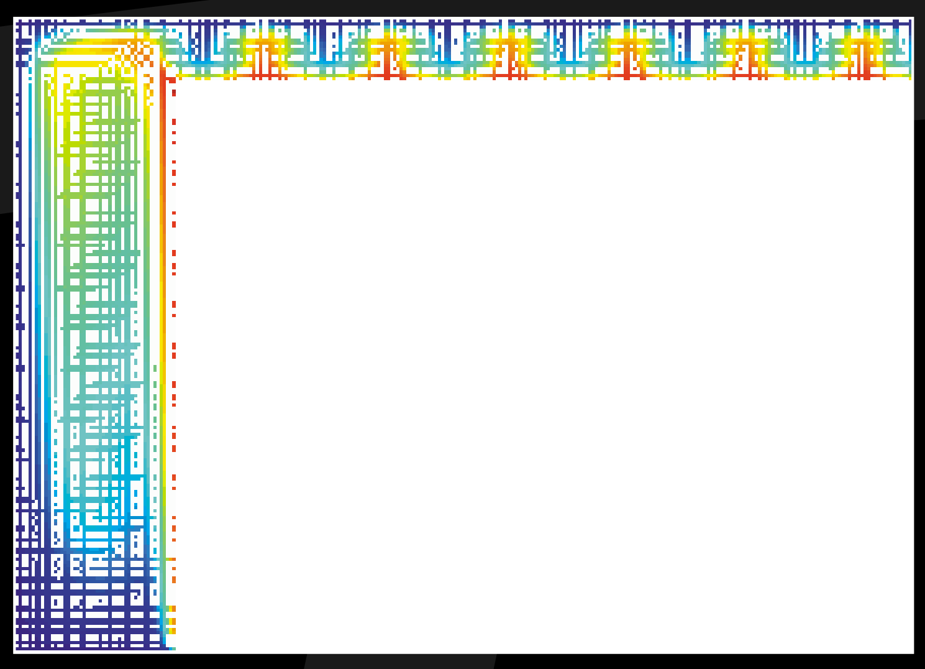
One Taylor Vortex, modeled between two mirror boundaries.

The background colour represents the change in azmithual velocity across the gap and the vector plot shows the postion of the vortex. The results for this test case at a Reynolds number of 5,000 with different Radius Ratios are shown in the table These results, while clearly overestimating the moment coefficient, are consistent with other computations.

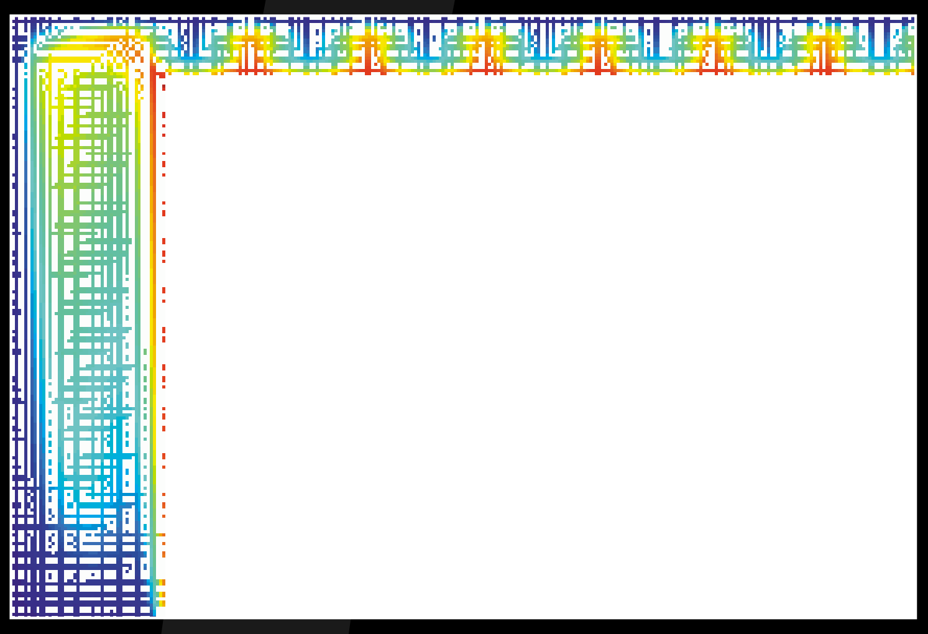
Radius Ratio	*Bilgen & Bilgous*	*Reynolds Stress*	κ–ε
0.985	0.0021	0.0042	0.0030
0.970	0.0026	0.0047	0.0033
0.941	0.0032	0.0058	0.0037

Their experimental results for a radius ratio of 0.94 showed results of the order of 10 percent higher than the empirical equations while the k-e model gave between 25 and 27 percent higher. With the resultant torque, from the Reynolds stress model a further 40 percent higher than the k-e model. The results are currently indicating that for larger radius ratios the models are either over predicting the frictional resistance or that the empirical equations are not valid for such high radius ratios, hence the need for new experimental data.

The domain has been extended further to include the end effects of the thruster as shown in figures below. These results show the effect of end vortices on the vortices distribution and the increase in vortex size is demonstrated between the laminar solution and the turbulent solution.



Laminar Taylor vortices in the thruster unit



Turbulent Taylor vortices in the thruster unit

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