IIB Project Summary:
A Study of the Possible Instabilities in the Cores of Tornadoes
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1 Introduction

Tornadoes are formidable natural phenomena and are a significant area of interest among a range of fields, including geography, meteorology and fluid mechanics due to their interesting and complicated underlying mechanics. There is no shortage of images and videos available of tornadoes, however the challenge with their study lies with the difficulty and potential danger of data collection. Therefore, the ability to simulate a realistic tornado within a laboratory setting is very desirable so that experimentation can be carried out at a smaller, safer and less destructive scale. The destructive potential of tornadoes can not be understated, leading to destroyed infrastructure, serious injury and death. Any experimental data may aid towards understanding these phenomena, possibly leading to better understanding on how to cope with or reduce the damage of tornadoes.

Experimental apparatus that can model tornadoes provides the opportunity to study the many interesting aspects of the phenomena that remain rather poorly understood. A particularly interesting aspect of tornadoes is that they may exhibit vortex breakdown (see later), which may be a cause of tornado dissipation. If the breakdown, and the factors governing it, are better understood, a link may be made between the breakdown and the lifetime of a tornado. Vortex breakdown was therefore another focus of this project.

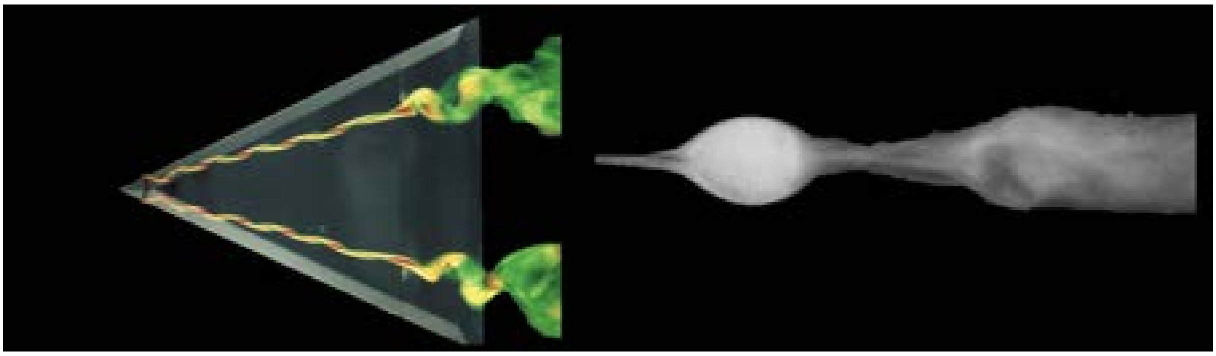
1.1 Aim and Objectives

The **aim** of the project was to visualise the flow around laboratory simulated small-scale tornadoes and possibly observe *vortex breakdown*. To achieve this aim, the objectives of the project were to:

1. develop experimental apparatus that can form tornadoes in the laboratory and;
2. visualise the tornado flow using flow visualisation techniques.

2 Theory: Introduction to vortex breakdown

Vortex breakdown was defined as '*the abrupt and drastic change of structure which sometimes occurs in a swirling flow*' by Brooke Benjamin (1962) [1]. The first observations of breakdown were on delta wings, with the breakdown resulting in a loss of lift and control of the aircraft. The breakdown was observed to occur in the 'spiral' form, visualised by Henri Werlé [2] in figure 1a. The spiral breakdown is one of two main types of breakdown, with the other type being the 'axisymmetric bubble' breakdown. The axisymmetric bubble breakdown appears as the fluid seeming to diverge around a non-existent obstacle in the flow, as shown in Harvey's flow visualisation [3], presented in figure 1b. There is anecdotal evidence of vortex breakdown occurring in tornadoes and therefore it was expected that it may be observed during this project.



(a) Spiral (Source: [2]) (b) Axisymmetric Bubble (Source: [3])

Figure 1: The two main types of vortex breakdown

3 Development of the experiment

The first objective of the project was to develop an experiment that could simulate small-scale tornadoes. The main component of the apparatus was the vortex chamber, within which the tornado (or the vortex) formed. The chamber is shown in figure 2. A pump drives flow out the top of the chamber and into the chamber at the bottom. The flow at the bottom passes through a foam ring which aims to give flow uniformity around the circumference. The flow then passes blades that introduce the tangential velocity (or the swirl) required to form the central vortex. The flow path at entrance to the chamber is shown more clearly in figure 3.

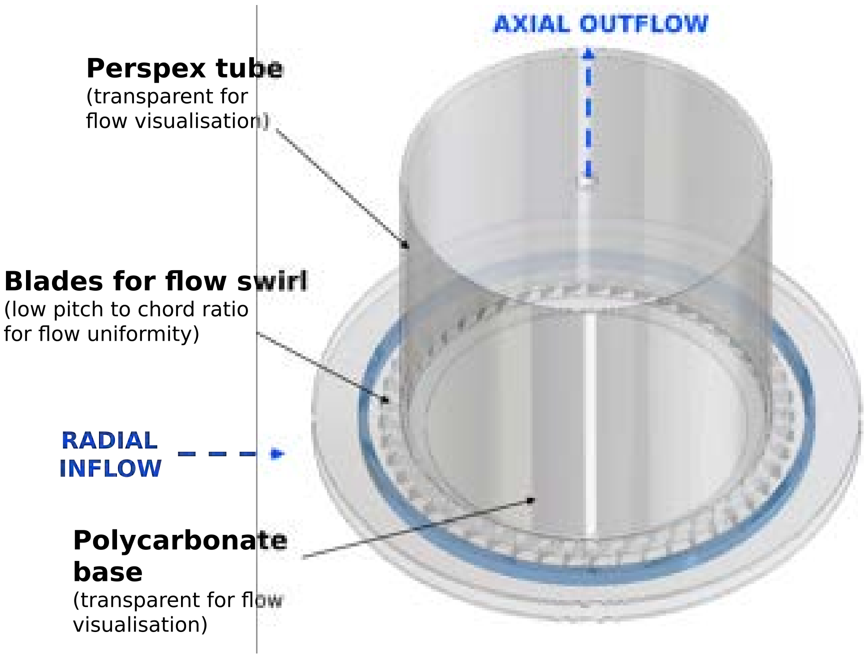


Figure 2: 3D CAD model of the vortex chamber

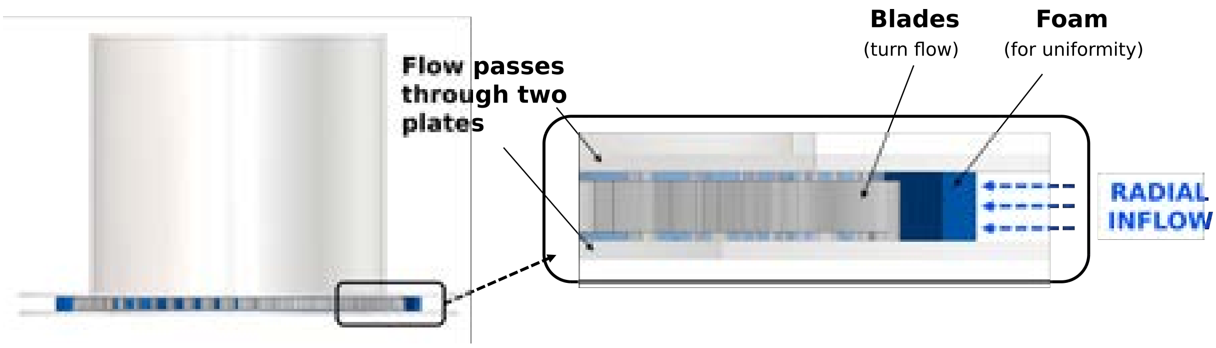


Figure 3: Flow path at entry to the chamber

The independent variables of the experiment were the flow rate (meaning the volume of water passing through the cylinder per second) and the flow swirl (meaning how much the flow has been turned by the blades at the entrance of the chamber). The flow rate was controlled by a pump which drove the water around the system and the flow swirl was set by the turning angle of the blades.

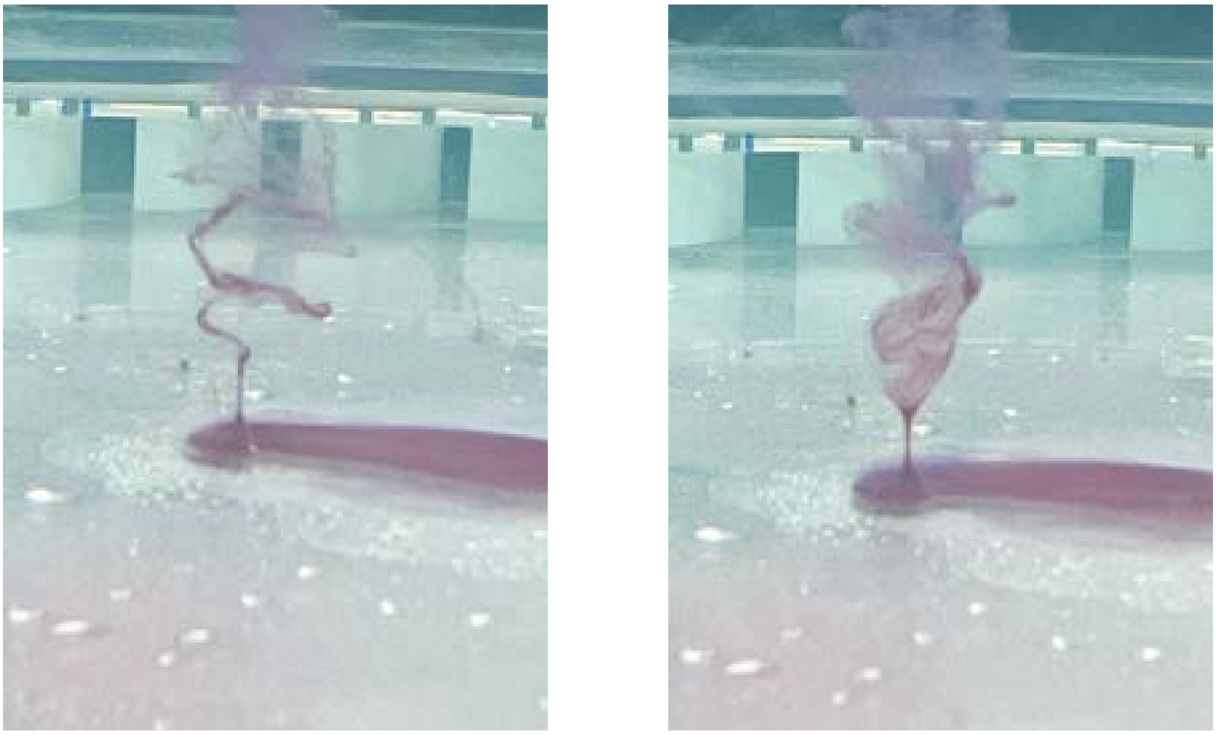
The following section will present results using flow visualisation. Flow visualisation is a broad term used to describe a variety of techniques used to visualise the local behaviour of the flow. A common technique, and the one used in this project, is to inject dye into the flow which will then follow the local trajectory to give a true representation of the flow's behaviour.

4 Results

For all the experiments in this project, the blade turning angle was set at 60°. Figure 4 shows vortex breakdown occurring a short vertical distance above the surface in its two main types, spiral and axisymmetric bubble. Note the similarities between the structures in figures 1 and 4. The vertical location of the breakdown varied significantly and the tornado circled the center of the chamber, never being stationary. As the flow rate (or flow speed) increased, there was little difference in the flow structures visualised. Both the spiral and axisymmetric bubble breakdown types were observed at all flow rates, however the tornado clearly became stronger as the flow rate increased. By comparing the images captured in this project (such as those in figure 4) with videos of real tornadoes, the experiment appears to be representative of real tornadoes and therefore vortex breakdown does seem to occur in tornadoes.

5 Conclusions

The main conclusions drawn from the project were that the project's experiment *was* representative of real tornado flow and that vortex breakdown does appear to occur in tornadoes. The nature of the vortex breakdown did not seem to change significantly with flow speed and future work will explore the effect of the second independent variable, the amount of flow turning by the blades. The experiment offers a range of exciting future projects and will hopefully result in some valuable insight into the nature of tornado flow in the future.



(a) Spiral breakdown

(b) Axisymmetric bubble breakdown

Figure 4: Two clear modes of vortex breakdown

References

[1] T. Brooke Benjamin. "Theory of the vortex breakdown phenomenon". *Journal of Fluid Mechanics*, 14:593–629, 1962.

[2] H. Werlé. "Sur l'éclatement des tourbillons d'apex d'une aile delta aux faibles vitesses". *La Rech. Aeronaut*, 74:25–30, 1960.

[3] J. K. Harvey. "Some observations of the vortex breakdown phenomenon". *Journal of Fluid Mechanics*, 14:585–592, 1962.