Off-axis Vortex Ring Collisions

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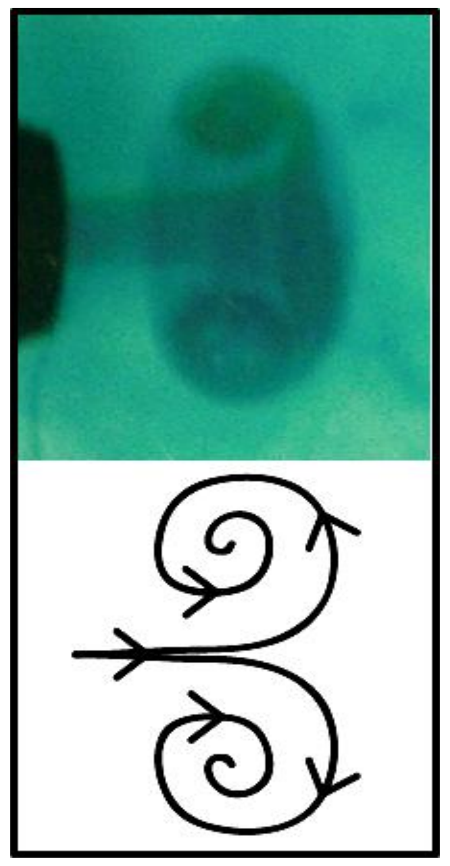
Introduction

Vortex Rings provide an interesting look into fluid dynamics. These rings are self propelling axisymmetric flow. Their remarkable stability allows the rings to maintain motion without generating turbulence. Any instability is transferred quickly throughout the ring. Momentum from the ring is conserved through circulation.



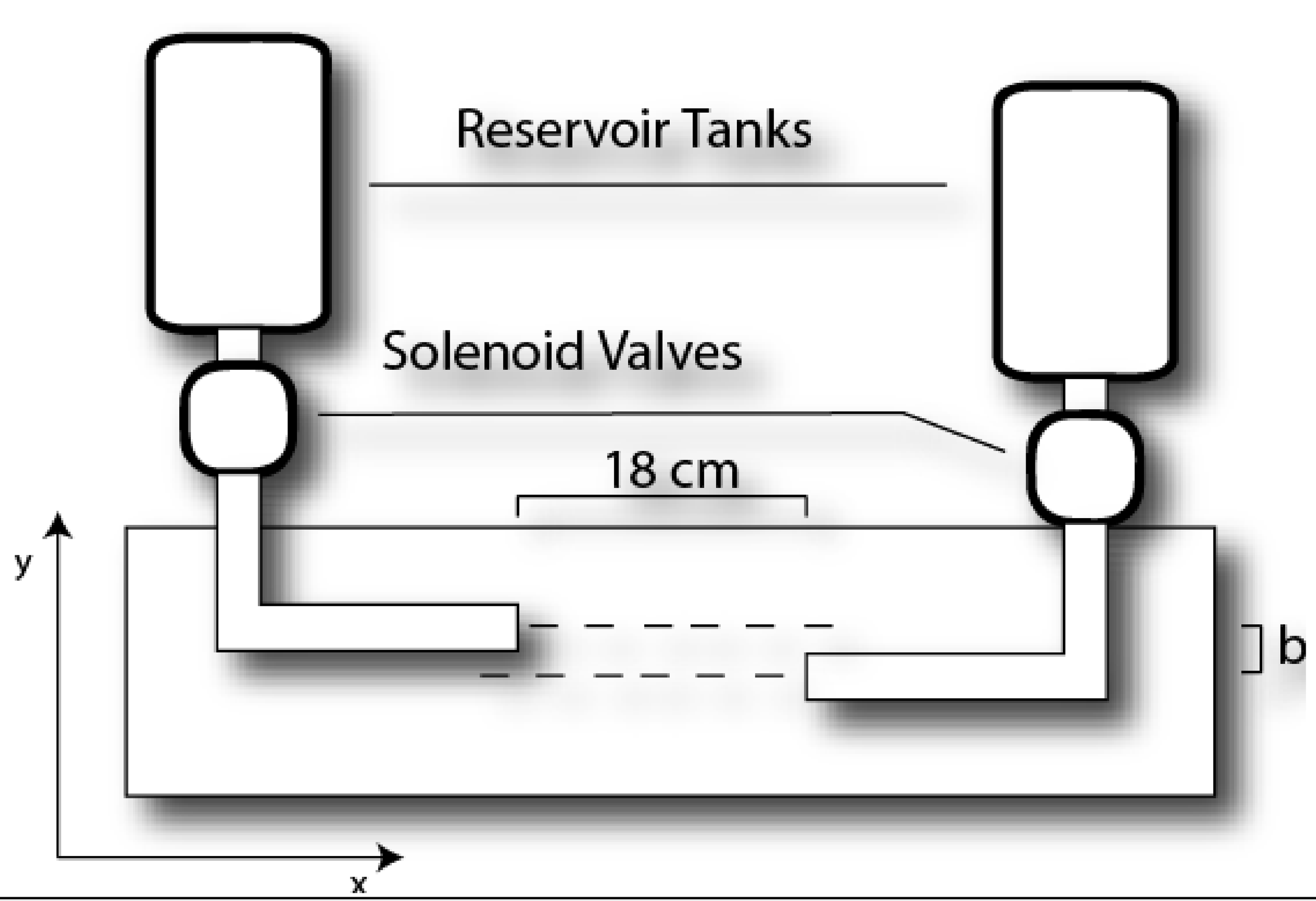
Vortex rings are characterized by their Reynolds Number, a dimensionless quantity which expresses the ratio of inertial and viscous forces. A ring with a Reynolds Number under 1000 is considered completely laminar.

$$Re = \frac{v\, d_c}{\nu}$$

v : ring velocity
d_c : ring diameter
ν : dynamic viscosity

Experiment

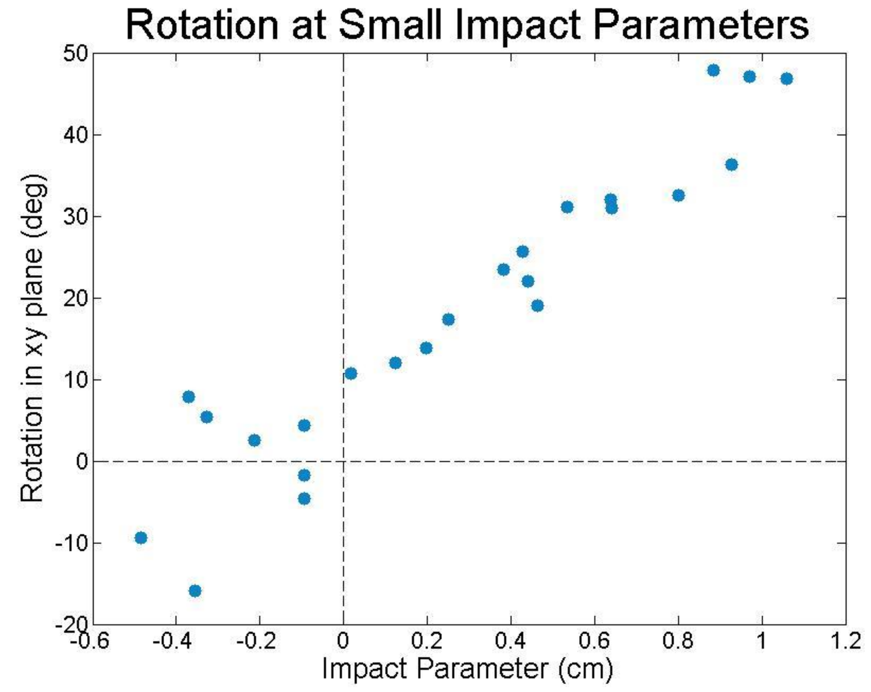
This experiment allows the observation of two colliding vortex rings with varying impact parameter, b (perpendicular distance of closest approach). Colliding rings are 1.4cm in diameter and have approximately the equal Reynolds Numbers of 1400. Measurements were taken by recording video of each collision and measuring one ring's velocity, trajectory, and geometry.



Results

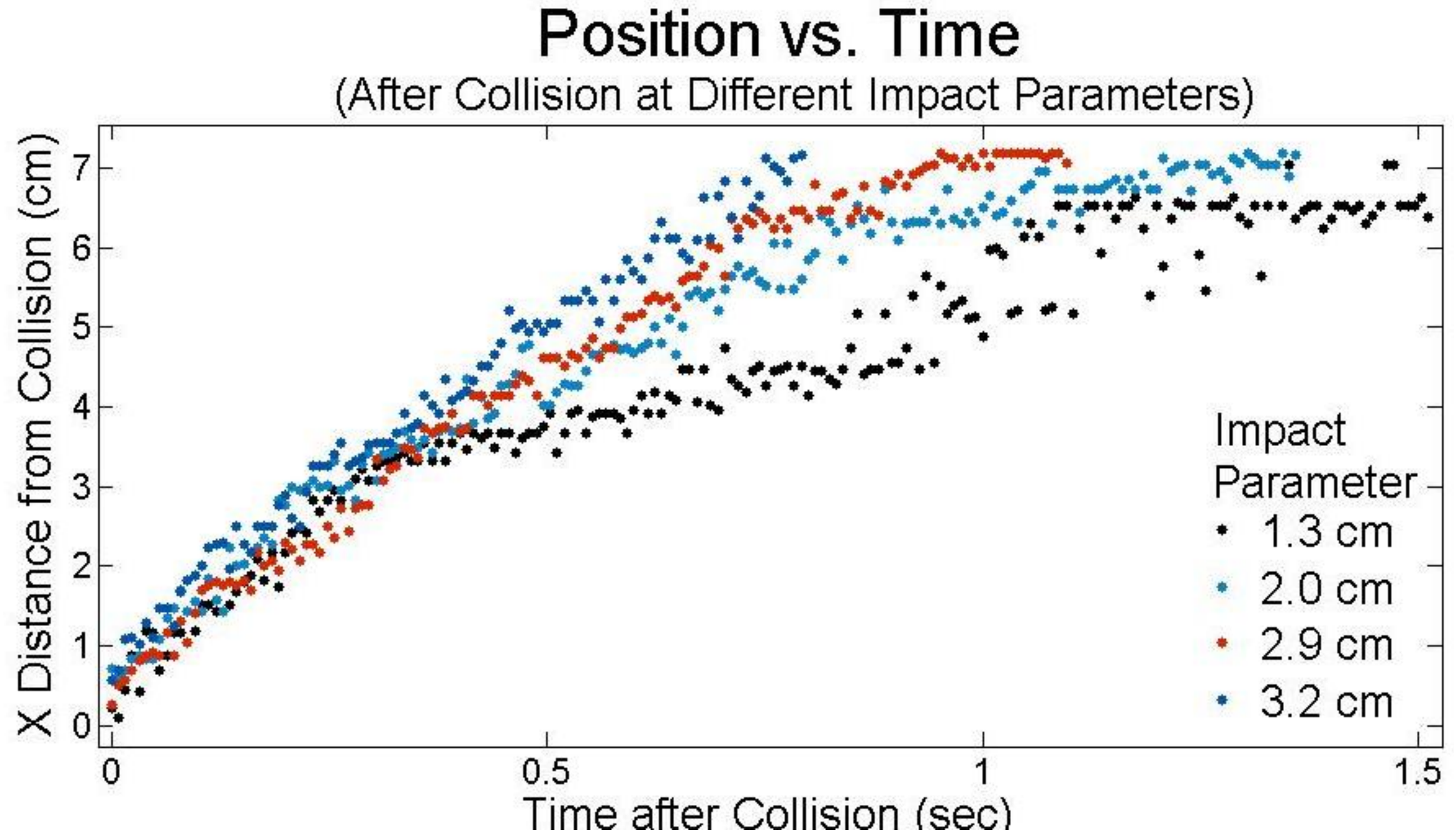
As the impact parameter, b, changes, the colliding vortex rings react in different ways. Observations show that a ring collision can exhibit one of three distinct behaviors depending on the impact parameter. These phases have attributes that are also dependent on the impact parameter.

b < 1.0 cm



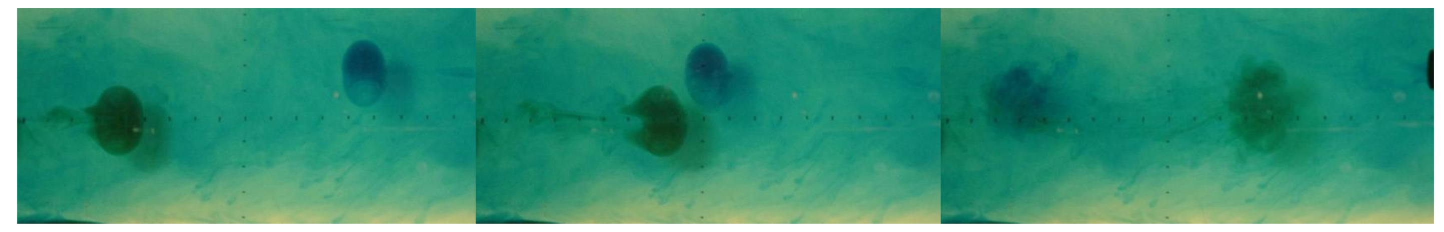
With zero impact parameter, the rings stop translational motion and expand rapidly before dissipation. With an impact parameter above zero but less than 1cm, the rings both expand and rotate. The angle of rotation shows a linear dependence on impact parameter.

b > 1.2 cm



When the impact parameter is above 1.2 cm, the rings pass by each other becoming unstable with varying amplitudes. Immediately after collision, tests showed that rings all traveled with similar speeds no matter the impact parameter. But at later times, speed changed drastically. This is most likely due to the amplitude of instability produced from each collision. Scattering can also be observed in this stage.

1.0 cm < b < 1.2 cm

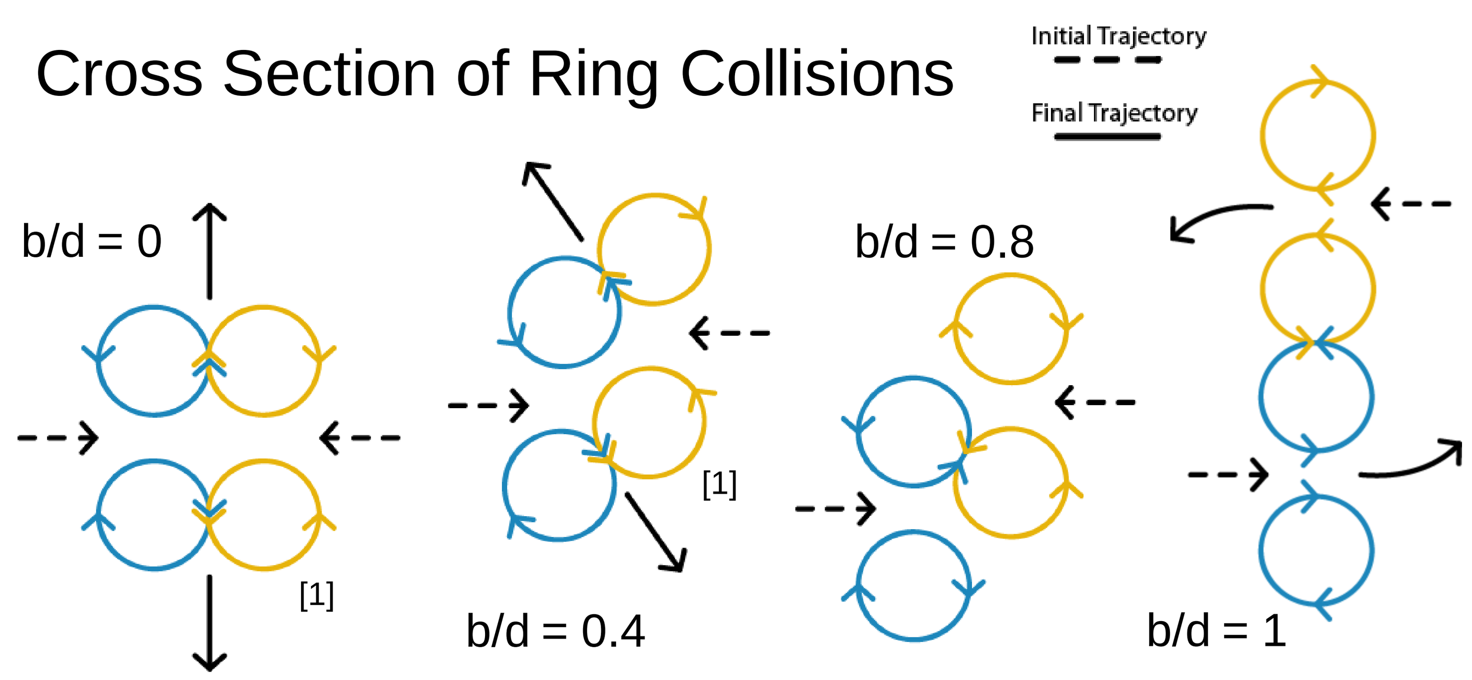


During this stage, interactions are transitioning from expansion and rotation to instability. Between these impact parameters, opposing vortices collide directly, causing ring annihilation. After the collision, dye and vorticity is diffused quickly.

Conclusion

Observations have shown that the impact parameter greatly affects the interaction between vortex rings. When different parts of each ring interact, drastic changes can occur in the ring's flow. These diagrams exhibit the interactions between colliding rings at various impact parameters. According to these results, it is reasonable to predict that behavior is dependent on the ratio of impact parameter and ring diameter, b/d.

Cross Section of Ring Collisions



Also, velocity calculations have shown that little momentum is transferred for collisions outside the ring's diameter. Instead these collisions produce instability in the ring causing eventual vortex shedding and loss of momentum due to viscosity.

[1] Smith, G. B. & Wei, T. 1994 Small-scale structure in colliding off-axis vortex rings. *J. Fluid Mech.* 259 , 281-290.