Mass of an Air Cannon Vortex

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Introduction

In 2005 Paul McKeag, conducted a series of experiments on vortex rings in air. Video of an air vortex traveling through air over a distance of four meters was analyzed using Logger Pro to find the velocity of the vortex as a function of the distance traveled. In a separate series of measurements, the impulse delivered to a force plate by a vortex at different distances was measured and the result was used (with the velocity-distance data) to find the mass of the vortex as a function of distance.

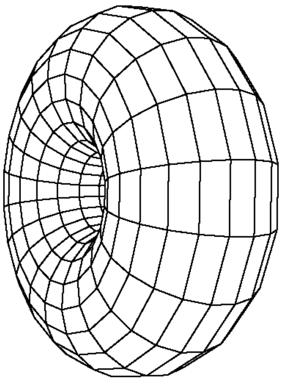


Fig 1 - A toroid.

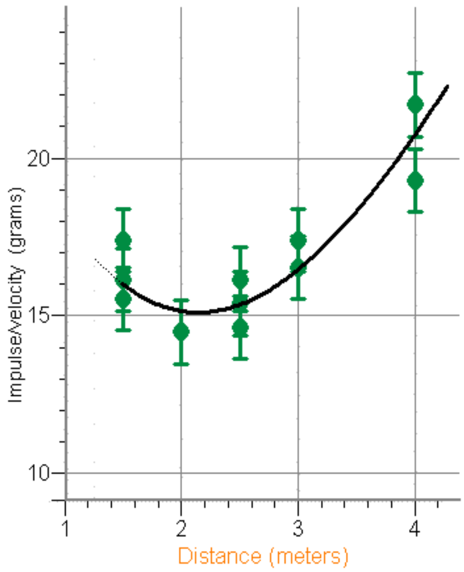


Fig 2 - Mass (impulse/velocity) of vortices as a function of distance traveled.

McKeag's mass-distance plot is reproduced as figure 2. The mass appears to reach a minimum at two meters. This could have resulted from the shedding of an initial non-spinning mass of air under the influence of friction from the surrounding air, the same friction force that initiates the spinning of the air mass, and forms the vortex.

McKeag first analyzed video to find the velocity of one particular vortex as a function of distance traveled, and assumed that the velocity was the same at a given distance for all subsequent firings. Examination of different videos using Logger Pro does not support this assumption. In this work the relationship between the mass of an air vortex and the distance traveled will be found by measuring the velocity of the vortex just before the impulse measurement.

Procedure

The body of the air cannon was a **cylindrical, plastic trash-can**. The opening of the trash-can was covered with a sheet of plastic, fixed around the opening with a large, thick rubber band.

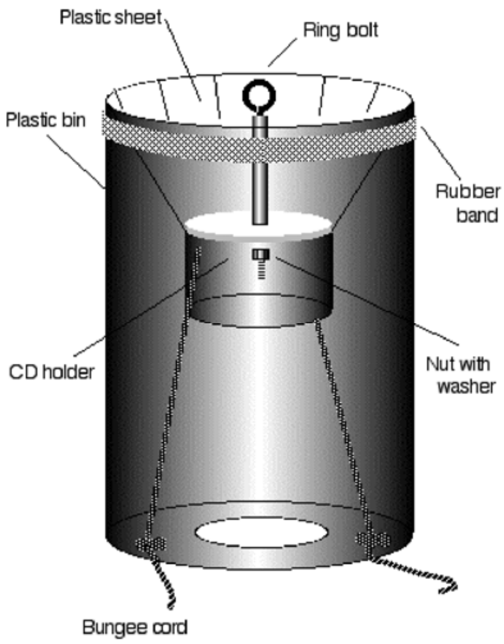


Fig 3 - The air cannon

Fig 4 - The cannon mounted on a wheeled cart

A CD holder was mounted on the plastic sheet with an eye-bolt and a washer. The CD holder was tied to the base of the trash can using bungee cords so that when the eye bolt was pulled back and released the plastic sheet returned suddenly to its original position, ejecting a known volume of air through a circular opening with a diameter of 15 cm cut in the base of the trash can. The completed cannon was secured on a cart.

Force Plate

Four Vernier dual-range force probes were connected were calibrated using a one Newton weight**.** Four small holes were drilled in a light plastic board. The four dual-range force probes were fixed to the board and attached to clamp stands as shown in figure 5.

Fig 5 - The finished force plate.

Data Collection

The force probes were zeroed. The air cannon was aimed at the force plate. The distance between the opening of the air cannon and the force plate was measured using a tape measure, and the distance was recorded. A meter stick was placed on the floor parallel to the firing direction for distance calculation in the video analysis function of Logger Pro.

The force probes were set to collect 1000 data points per second for 3 seconds. A smoke bomb was lit and placed in a beaker, and the beaker was put inside the air cannon. A board was used to temporarily block the opening of the air cannon so that the smoke generated would not escape. A vortex was fired by pulling back the eye bolt as far as possible every time and releasing after approximately three seconds to minimize the effects of air flow within the cannon. The distance between the air cannon and the force plate was varied six times, obtaining three trials each time.

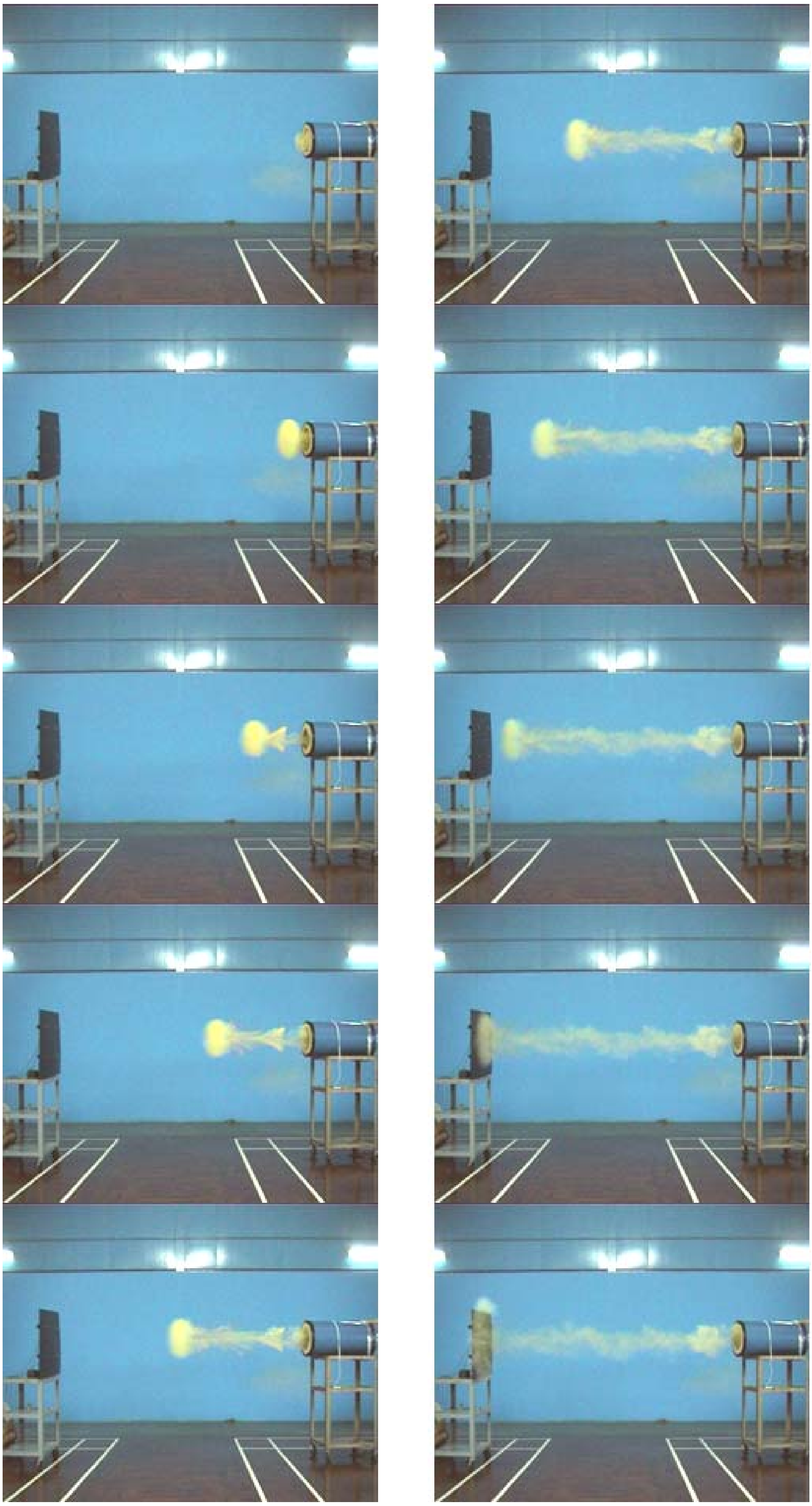
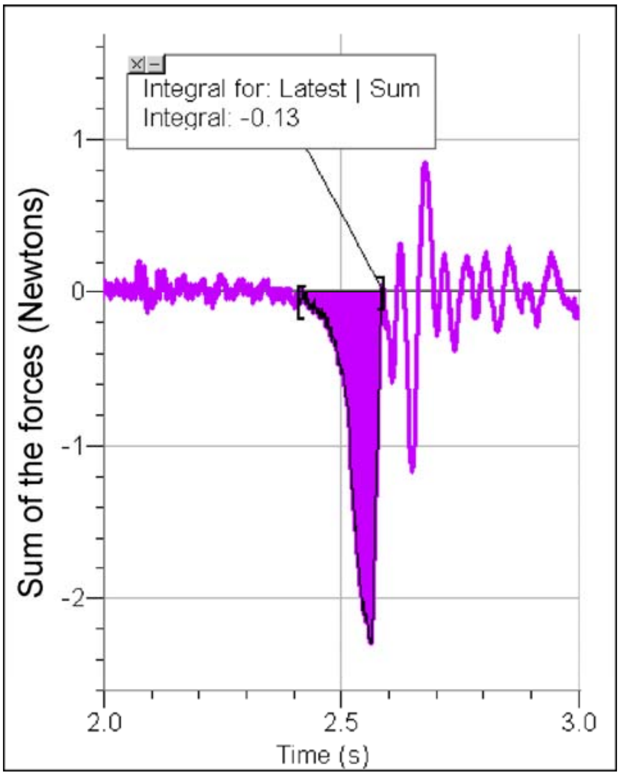


Fig 6 – Video of a vortex hitting the force plate.

Results

The sum of the readings from the four force probes was graphed in Logger Pro. A force-time graph of each trial was obtained.

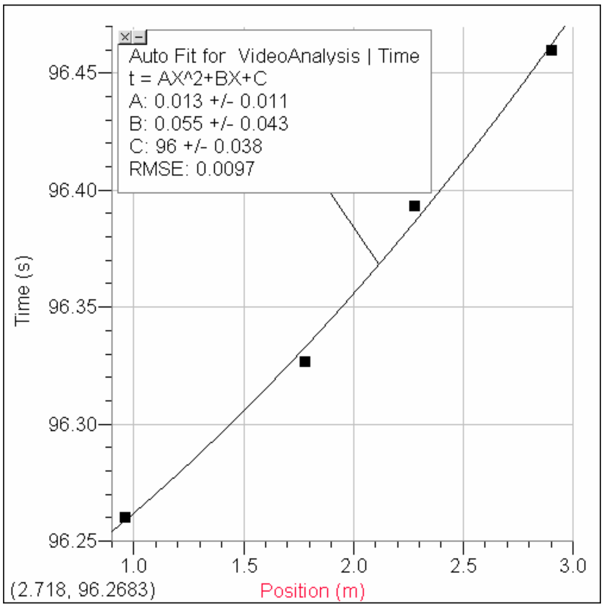
A typical force-time graph



Graph 1 – A typical force-time graph used for impulse determination.

The integral under the first peak on the force-time graph is the impulse applied to the plate by the vortex during the collision. Subsequent peaks were caused by the oscillation of the board after the impact.

A typical time-position graph



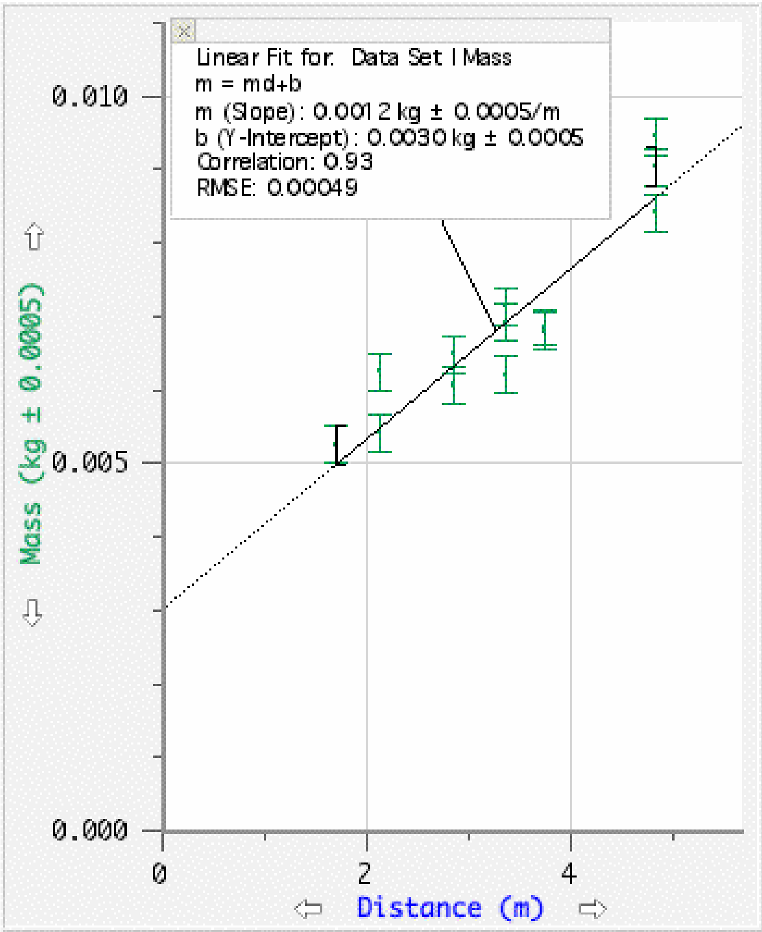
Graph 2 – A quadratic function has been fitted to the points.

A curve was fitted to the data. The derivative of the equation (*dt/dx*) was calculated so that the velocity of the vortex at impact could be found. The mass of each impacting vortex was then determined by dividing the impulse by the respective velocity.

Table 1 – Vortex velocity, impulse applied to the force plate and the mass of the vortex.

Velocity (m/s ± 0.3)	Impulse (N s ± 0.003)	Distance (m)	Mass (kg ± 0.0005)
9.7	0.051	1.70	0.0053
8.0	0.050	2.13	0.0063
8.5	0.046	2.13	0.0054
8.4	0.051	2.86	0.0061
7.1	0.046	2.86	0.0065
7.6	0.046	2.86	0.0061
7.9	0.049	3.36	0.0062
9.1	0.063	3.36	0.0069
7.0	0.050	3.36	0.0071
7.3	0.050	3.75	0.0068
7.8	0.053	3.75	0.0068
7.3	0.066	4.83	0.0090
6.9	0.058	4.83	0.0084
7.2	0.068	4.83	0.0094

Vortex mass potted against distance from 2.0 - 4.5 meters



Graph 3 – the mass-distance relationship is linear to within ±10%.

Discussion

The mass of the vortex increases with distance from the cannon. It appears that once the vortex has fully formed at 2.0 meters, it is enlarged by winding in still air as it travels. McKeag's data suggested that there is a minimum mass at two meters. Close examination of figure 5 shows that a trumpet shaped cloud is shed from the developing vortex soon after it leaves the cannon. The data here shows that once the vortex has fully formed at 2.0 meters there is an approximately linear increase in vortex mass with distance, up to 4.5 meters.

The mass of the vortex, from 5 to 10 grams, gives a vortex volume of from ~4000 to ~8000 cc, taking the density of air to be 1.20 kg per cubic meter at 20°C.

Evaluation

The mass of each vortex was determined to within ±10% (Table 1). Because the vortex path was not always a straight line, some impacts were not on the center of the plate. Trials for which the four force probes did not give similar readings were therefore rejected. The force plate and the camera were secured in position but the cannon was mounted on a wheeled trolley. In future it is suggested that the cannon be mounted on a fixed platform and a mechanism that does not involve pulling by hand should be utilized to move the eye-bolt.

The data is more reliable than earlier work because the velocity of each vortex as it hit the plate was determined at the same time that the impulse was measured. The approximately linear increase in the mass of the vortex at distances greater that 2.0 meters has been confirmed. Trials at distances of less than 2.0 meters should now be conducted to determine whether McKeag's suggestion of a minimum mass at 2.0 meters is correct.

References

Vortex ring - http://en.wikipedia.org/wiki/Vortex_ring

Fig 1 - http://www.mathematik.uni-marburg.de/~databionics/de/images/esom_top_toroid.png