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Visualization of the flow past a Frisbee

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Abstract. The flow past a Frisbee is visualized in a low-speed wind tunnel using smoke to identify the mechanism of lift generation in forward flight. It is found that as the air flow passes over a Frisbee, a pair of longitudinal vortices is formed just behind it. The vortex pair induces substantial downwash in the downstream flow, and as a result, a lift force can act on a Frisbee. The rotation of a Frisbee greatly strengthens the vortex pair, thereby enhancing the downwash and hence the lift force.

1. Introduction

The flying disc called a Frisbee (see Walker, 1977) is a popular outdoor plaything. As is illustrated in fig. 1, it is a circular disc with a curved rim. The inner disc is 180 mm in diameter and 1 mm thick, and the outer rim is 240 mm in diameter and 6 mm thick. It is made of light plastic, and weighs ≈ 100 gr.

We tried throwing a Frisbee outdoors, and obtained a forward speed of ≈ 6 m/s and a rate of rotation of ≈ 6 rotations/s. Therefore, the ratio of peripheral to forward speed was equal to ≈ 0.75 .

In the study reported in this paper, visualization of the flow past a Frisbee was attempted in a low-speed wind tunnel. An improved version of the smoke-wire method (Fukamachi, Ohya

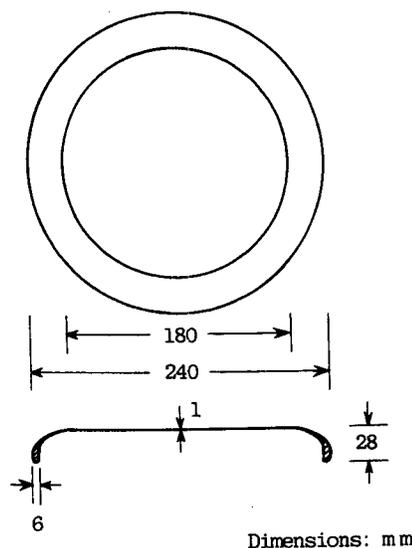


Fig. 1. Schematic diagram of a Frisbee.

and Nakamura, 1991) was adopted in the experiment. Emphasis was placed on the mechanism of lift generation in the forward flight of a Frisbee.

2. Experimental arrangement

The experiment was conducted in a low-speed wind tunnel with a rectangular working section 2 m high, 4 m wide and 6 m long. The tunnel could provide a reasonably uniform flow with a turbulence intensity of $\approx 0.12\%$.

The experimental arrangements are illustrated in fig. 2. As can be seen, a Frisbee was connected to an electric motor with a metal rod 9 mm in diameter and 230 mm in length to give a uniform rotation about the model centre. The assembly was mounted on a table in the working section with the flat upper surface of the model aligned with the flow.

The smoke-wire method was used in the experiment to visualize the flow past the model. Liquid paraffin mixed with iron powder 100 meshes in size was used to generate smoke of long duration (Fukamachi et al. 1991). A nichrome wire 0.3 mm in diameter and 1.5 m in length was stretched horizontally upstream of the model to generate smoke to obtain the top and side views of the flow. The height of the wire was adjusted so that the smoke would pass just around the model. A gridiron, which could generate a continuous grid of smoke, was also used in place of a single wire. It was placed ≈ 10 cm upstream of the model's front edge. The horizontal and vertical wires of the gridiron were slightly detached to ensure electric insulation. The smoke grid was perturbed near the model as it moved downstream. Using a slit for illumination, the perturbed smoke grid on the lateral plane at any streamwise position could be visualized. Thus, the new smoke-wire method can be a good substitute for the currently used tuft-grid method. A Nikon F camera with a 55 mm standard lens was used for photography. A National Maclord (AG-410) video camera was also used in the experiment to shed more light on the time-variant nature of the flow.

The experimental flow speed was 1 m/s, and the rate of rotation of the model was less than 3 rotations/s. Accordingly, the range of the ratio of peripheral to free-stream speed was 0 to 2.26.

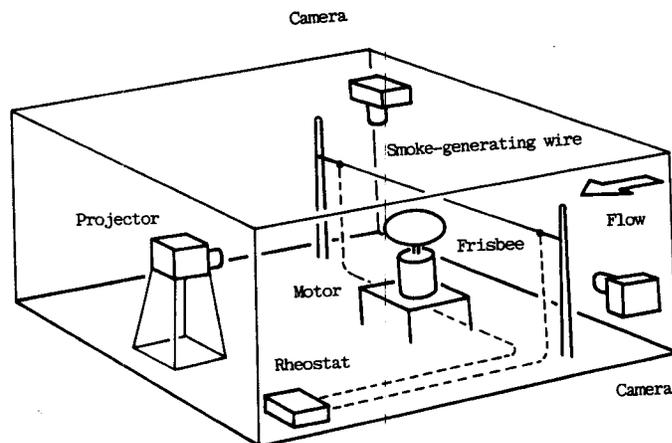


Fig. 2. Experimental arrangement.

3. Experimental results and discussion

All the figures shown below compare the flow patterns between the model at rest and that which was rotating at the maximal rate of 3 rotations/s. The case for a rate of 1 rotation/s was also tested, but we found that qualitatively the flow patterns were not much different from those obtained for the maximal rotation rate.

Fig. 3 shows the top view of the flow past the model. We see from fig. 3a that for the model at rest the flow perturbation was confined to the downstream area of the model with no appreciable lateral extent. This is because a Frisbee is essentially a disc-shaped object. Fig. 3b, showing the flow pattern for the model with a clockwise rotation, indicates that the model's rotation certainly increased the flow perturbation, but still with a relatively small lateral extent. It also suggests that no clear trace of the Magnus force on a spinning body could be detected.

Fig. 4 shows the side view of the flow past the model. We see from fig. 4a that the model at rest did produce substantial downwash behind it as the air flow passed over it. It is obvious that the flow should, in turn, exert an appreciable lift force on the model. Fig. 4b also indicates that the model's rotation greatly enhanced the downwash.

Fig. 5 shows the perturbed smoke grid, viewed from downstream, on a lateral plane just behind the downstream edge of the Frisbee model. The direction of rotation for fig. 5b is such that the right edge of the model is moving out of the photograph. It is very interesting to see

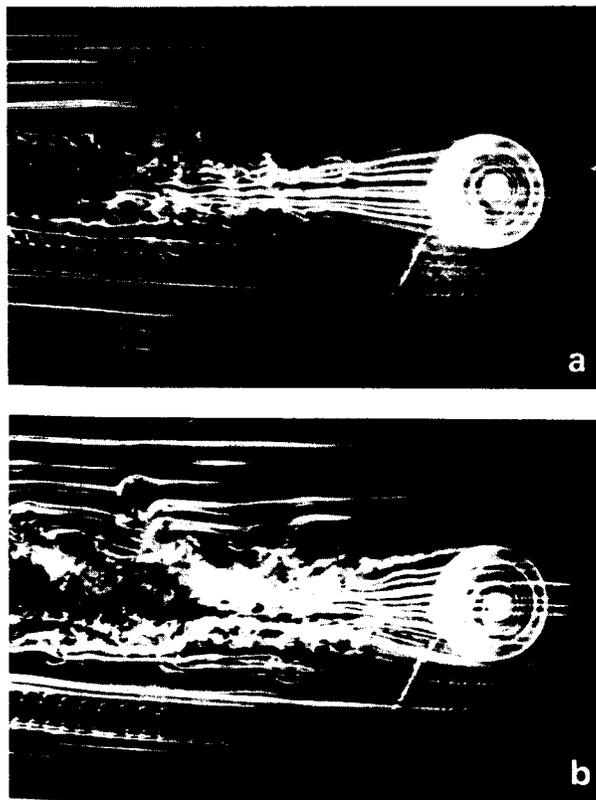


Fig. 3. Top view of the flow past a Frisbee. Flow speed, 1 m/s, (a) model at rest, (b) model at a constant rotation of 3 rotations/s. The direction of the rotation is clockwise.

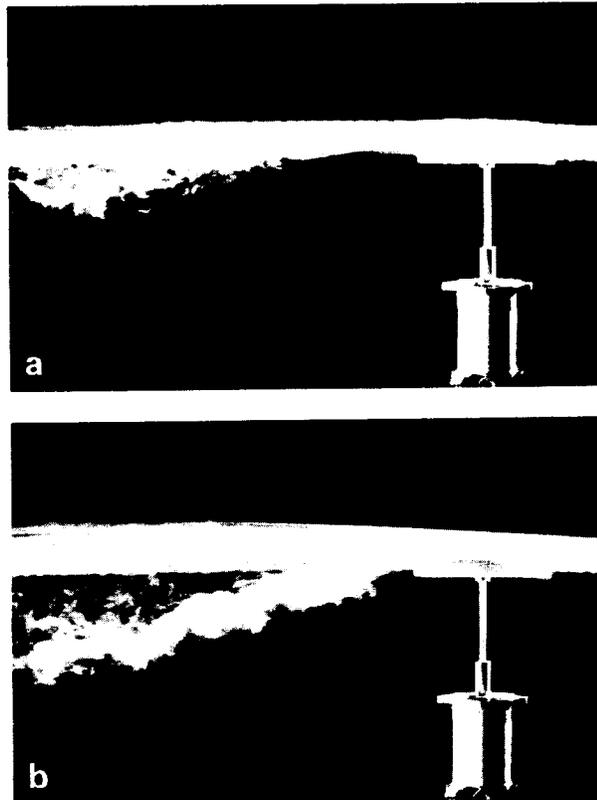


Fig. 4. Side view of the flow past a Frisbee. Flow speed, 1 m/s, (a) model at rest, (b) model at a constant rotation of 3 rotations/s.

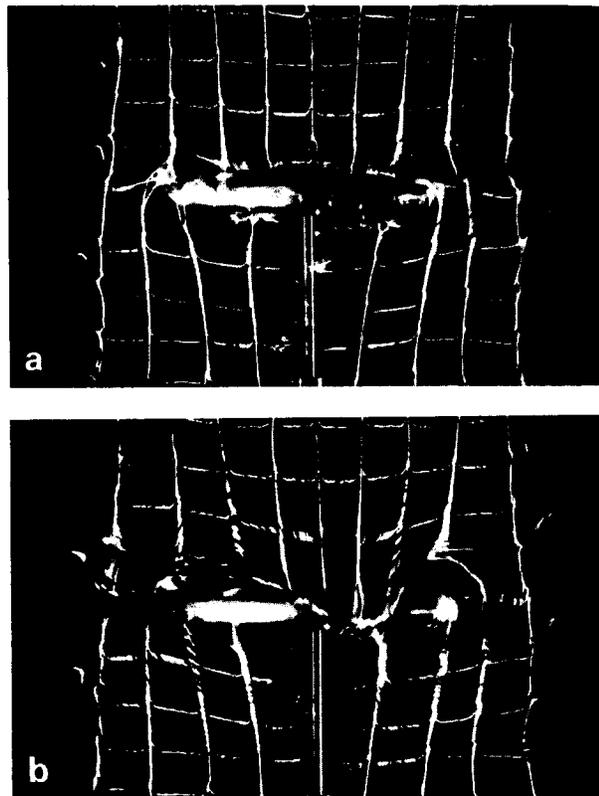


Fig. 5. Perturbed smoke grid showing the flow on a lateral plane just behind the downstream edge of a Frisbee. The smoke grid is viewed from downstream. Flow speed, 1 m/s, (a) model at rest, (b) model at a constant rotation of 3 rotations/s. The direction of the rotation is such that the right edge of the Frisbee is moving out of the photograph.

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from fig. 5a that a pair of longitudinal vortices was formed behind the model. Fig. 5b also shows that the vortex pair was greatly strengthened by the model's rotation. Clearly, it is this pair of longitudinal vortices that is responsible for the generation and enhancement of the downwash and hence of the lift force in the forward flight of a Frisbee. A closer examination of fig. 5b reveals that the formation of the vortex pair shifted slightly from the centre to the right. Fig. 3b also suggests that this flow asymmetry is caused by the model rotation. The video camera was particularly useful for capturing the successive formation of the vortex pair.

4. Conclusion

The flow past a Frisbee was visualized in a low-speed wind tunnel using smoke to identify the mechanism of lift generation in forward flight. The experiment, which was made on a Frisbee with the flat upper surface aligned with the flow, showed that a pair of longitudinal vortices was formed behind the Frisbee as the air flow passed over it. The vortex pair induced appreciable downwash downstream of the Frisbee. The rotation of the Frisbee greatly strengthened the vortex pair, thereby enhancing the downwash. It is concluded that the pair of longitudinal vortices thus observed is responsible for the generation and enhancement of lift force in the forward flight of a Frisbee.

References

- Fukamachi, N., Y. Ohya and Y. Nakamura (1991) An improvement of the smoke-wire method of flow visualization, *Fluid Dyn. Res.* 7, 23.
Walker, J. (1977) *The Flying Circus of Physics with Answers* (Wiley, New York) p. 84.

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