

DISC-WING AERODYNAMICS

1 Introduction

An experimental investigation into the flow characteristics of a disc-wing has been carried out in a low speed wind tunnel over a flow speed range of 0 to 20 m/s. In its simplest form a disc-wing can be described as an axisymmetric wing. The disc considered in this study was a Frisbee-like configuration, cross-sectional profile seen in Fig. 1.

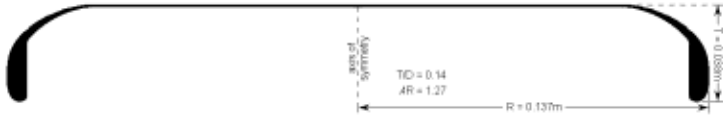


Figure 1. Cross-sectional disc-wing profile.

As an introduction to the dynamics of disc-wing flight consider Fig. 2. The centre of pressure cp of the disc-wing is ahead of the disc centre of gravity cg . This results in a destabilising nose up pitching moment. If the disc is rotating, gyroscopic effects dictate that this pitching moment M results in a precessional rolling rate p . Thus spin provides enhanced pitch stiffness at the expense of roll stability.

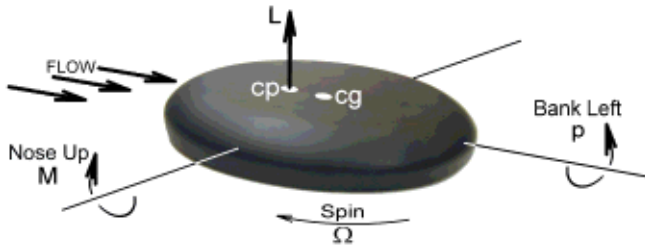


Figure 2. Disc-wing flight dynamics.

2 Experimental Methods

Load Measurement - The aerodynamic loads acting on the disc-wing were measured using a six component overhead balance.

Pressure Measurement - The surface pressures were measured through a number of pressure tapings using a U-tube manometer.

Surface Paint Flow Visualisation - Fluorescent paint was applied to the disc-wing, which was mounted in the tunnel until the time-averaged surface flow patterns were revealed.

Smoke Wire Flow Visualisation - The smoke is generated by the resistive heating of a wire causing the vaporisation of oil droplets. As the flow passes the wire it creates a smoke filled wake behind it producing clearly defined smoke filaments. The cross-sections of the separation and vortex structures were illuminated using a laser light sheet.

5 Surface Paint Flow Visualisation

The **upper surface** flow (Fig. 5a) is characterised by separation at an arc of constant radius (L_1), followed by reattachment at a line of similar geometry (L_2). A separation bubble is formed (B) and the reattached boundary layer (C) separates off the surface at L_3 . Trailing vortices detach from the upper surface at two symmetrical positions (V_1, V_2).

The **cavity surface** pattern (Fig. 5b) indicates that the boundary layer separates off the leading edge lip and impinges on the inside of the trailing edge rim. Reversed flow (F) exists from the trailing edge towards the stagnation line L_4 . The shear layer encloses a weakly circulating separation bubble (E).

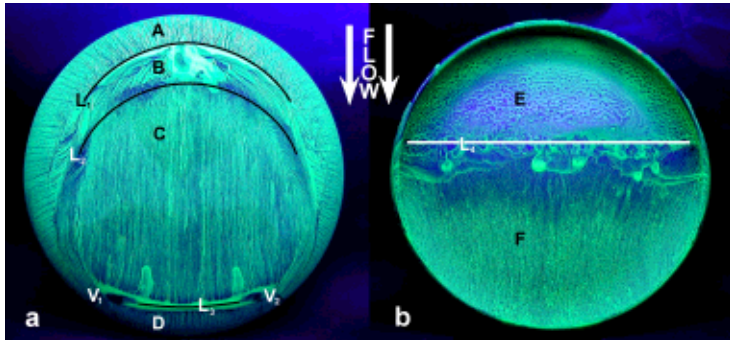


Figure 5. (a) Upper and (b) cavity surface paint patterns at 5° incidence, 15m/s.

6 Smoke Wire Flow Visualisation

Smoke wire flow visualisation has revealed the separation and vortex flow structures (Fig. 6). The separation bubble and cavity separation cross-sections (Fig. 6a) reveal laminar separation and the formation of an unstable shear layer. The counter rotating trailing vortices (Fig. 6b) show strong central downwash.

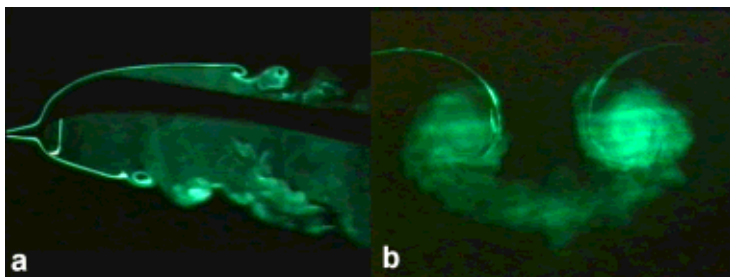


Figure 6. (a) Upper surface & cavity separated shear layer cross-sections and (b) cross-section of the trailing vortices at 10° incidence, AdvR = 0, 3m/s.

3 Force and Moment Data

The aerodynamic loads were measured for the range of conditions that the disc-wing will experience in free flight, see Fig. 3. The lift curve is linear whereas the drag curve is parabolic, expected for a typical low aspect ratio wing. The effect of spin is small but measurable, most significantly causing a non-zero 'Magnus rolling moment' at low incidence, see Fig. 3b.

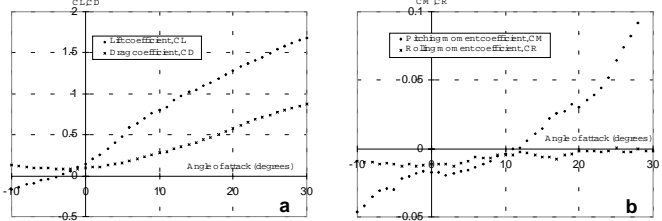


Figure 3. (a) Lift & drag and (b) Pitching & rolling moment characteristics, AdvR = 1, 20m/s.

4 Pressure Data

The surface pressure distribution for 0° incidence is presented below in Fig. 4 as colour weighted contour plots. **Upper Surface** - The highest pressure region occurs on the leading edge rim, see Fig. 4a. The flow separates thereafter under the influence of an adverse pressure gradient.

Cavity Surface - The shear layer separates off the trailing edge lip and deflects into the cavity reattaching inside the trailing edge rim. This causes the high pressure region seen in Fig. 4b.

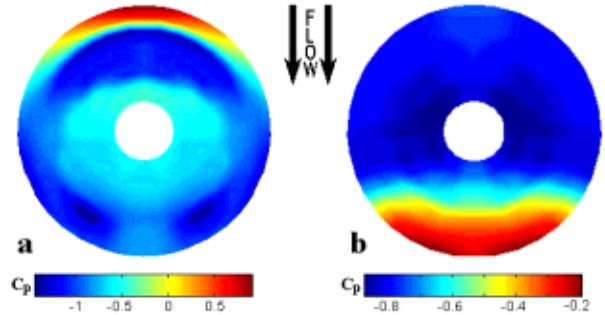


Figure 4. (a) Upper and (b) Cavity surface pressure distribution at 0° incidence, 14m/s.

7 Disc-wing Flow Topology

The proposed flow topology is given for 10° incidence based upon surface flow patterns and smoke filament flow visualisation. The two-dimensional flow cross-section (Fig. 7a) depicts the separation bubble, cavity flow and turbulent wake. The reversed flow within the cavity is turbulent with stagnant air enclosed behind the leading edge. The three-dimensional flow topology (Fig. 7b) shows the structure of the separation bubble and trailing

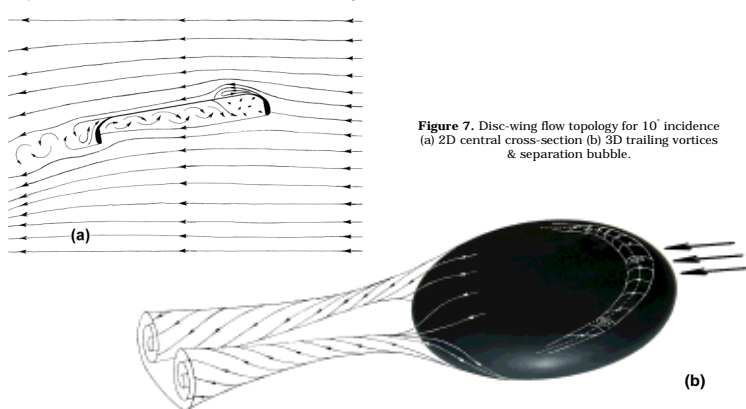


Figure 7. Disc-wing flow topology for 10° incidence (a) 2D central cross-section (b) 3D trailing vortices & separation bubble.

vortices.

Conclusions

- The aerodynamic load data is consistent with a typical low aspect ratio wing. The effect of spin is small, causing a non-zero rolling moment.
- The upper surface flow is characterised by an arc separation line, followed by reattachment. The cavity flow is characterised by reattachment inside the trailing edge rim and reversed flow within the cavity forming a straight stagnation line.
- The separation bubble is enclosed by an unstable laminar shear layer. The trailing vortices are close together creating a strong central downwash.
- Small flow asymmetries have been observed with rotation.

Further Reading

Potts J.R. & Crowther W.J.: The Flow Over a Rotating Disc-wing. RAEs Aerodynamics Research Conference Proc., London, U.K., Apr. 2000.
Potts J.R. & Crowther W.J.: Visualisation of the Flow Over a Disc-wing. Proc. of the Ninth International Symposium on Flow Visualization, Edinburgh, Scotland, U.K., Aug. 2000.



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