DISC-WING AERODYNAMICS

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Abstract

An experimental investigation into the aerodynamics of a rotating disc-wing has been carried out in an open-circuit wind tunnel. The disc-wing considered has an axi-symmetric, approximately elliptic cross-section and hollowed out underside cavity. The forces and moments were measured for various flow speeds, spin rates over the incidence range -10° to 30°. Observations from fluorescent paint patterns and smoke filaments (flow visualisation techniques) have revealed the surface flow regime and flow field, respectively. The upper surface flow is characterised by separation at a line (arc) of constant radius on the leading edge rim, followed by reattachment at a line of similar geometry. Trailing vortices detach from the trailing edge rim. The cavity flow is characterised by separation at the leading edge lip, followed by straight-line reattachment. The aim of this research was to gain an understanding of the complex three-dimensional flow structures, which will enable the effective implementation of a flow control method, contributing towards the development of an unmanned air-vehicle or projectile.

1 Introduction

The rotating disc-wing is most commonly encountered as a Frisbee™ sports disc. The disc considered in this study has an approximate elliptical cross-section and hollowed out underside cavity. The centre of pressure, COP, of this configuration is ahead of the centre of the disc, COG, see Fig 1. This results in a destabilising nose up pitching moment, C_M, at typical flight angles of attack. If the disc is rotating, gyroscopic effects dictate that a pitching moment results in a precessional rolling motion. This provides pitch stabilisation at the expense of roll stability.

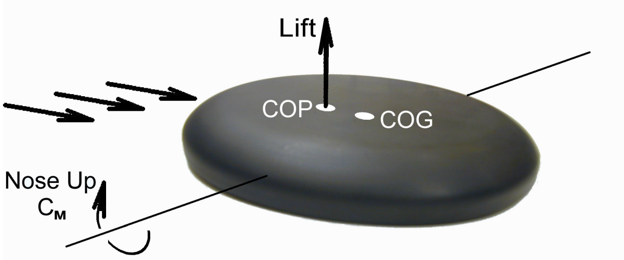

Figure 1. Disc-wing flight dynamics.

2 Experimental Details

The disc was tested in a low speed wind tunnel, mounted with it's planform vertical, on an L shaped arm, which consisted of a horizontal axle supported by a vertical strut.

A number of aluminium disc-wing models were tested, turned on a lathe to the desired profile. The diameter is the characteristic length which gives an aspect ratio, $AR = 4/\pi \approx 1.27$, constant for all disc-wings. To compare circular wings the thickness to diameter ratio, T/D, is used. The dimensions of the disc profiles are given in [1] and have T/D ~ 0.14.

3 Results and Discussion

3.1 Force Data

The force and moment data is presented and discussed by Potts and Crowther [1].

The loads were measured for the range of conditions that the disc-wing will experience in free flight. The lift and drag trends are shown in Fig 2 for Reynolds number, $Re = 2.84\times10^5$, equivalent to a flow speed of 15m/s, and advance ratio (rim speed to flow speed), AdvR = 0.46, equivalent to a spin rate of 8 rev/sec. The lift curve has slope 0.05 between 5° to 27° incidence. The drag curve shows a minimum, C_{Do}, of 0.09 at the zero lift angle, -4° incidence.

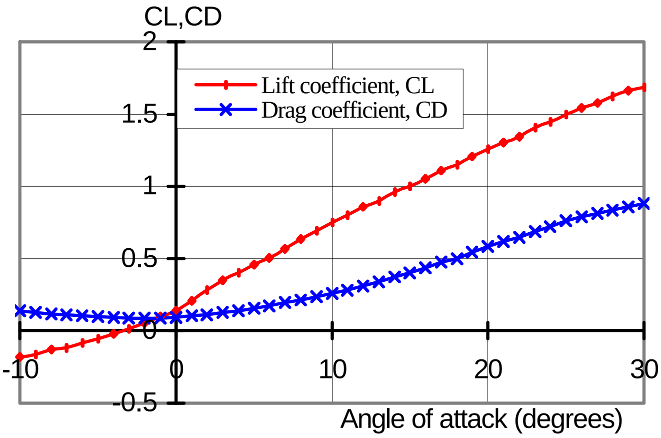

Figure 2. Lift and Drag characteristics for AdvR = 0.46, Re = 2.84 ´10^5.

3.2 Surface Flow Visualisation

Fluorescent paint patterns for a non-spinning disc-wing are presented and discussed by Potts and Crowther [1,2].

With reference to Fig 3, flow direction from top to bottom: The flow over the upper surface of a non-spinning disc is characterised by separation at an arc of constant radius on the leading edge rim, followed by reattachment at a line of similar geometry. Trailing vortices detach from the upper surface at two symmetrical positions on the trailing edge rim.

The cavity flow is characterised by separation at the leading edge lip, followed by straight-line attachment close to the centre.

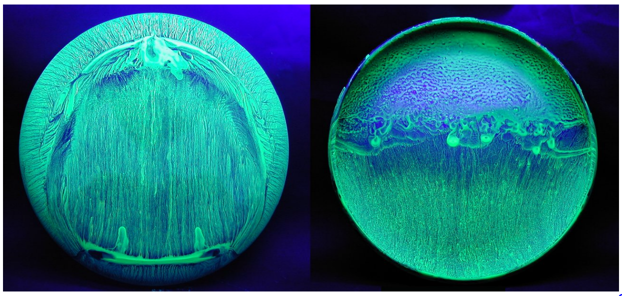

Figure 3. The surface paint patterns at 5° incidence, Re = 2.84 ´10^5.
(Left) Upper surface. (Right) Cavity surface.

3.3 Flow Field Visualisation

Smoke filament cross-sections of the disc-wing flow field are presented and discussed by Potts and Crowther [2].

A plane of smoke filaments can be seen in Fig 4 over the upper surface of a non-spinning disc-wing for Re =1.49×10^4, equivalent to 2m/s. The narrowing of the wake can be seen aft of the disc and the filaments become turbulent at around D/2 downstream from the trailing edge.

Figure 5. Smoke filaments over the upper surface at 10° incidence, Re = 1.49 ´10^4.

3.4 Proposed Disc-wing Flow Topology

The two-dimensional flow cross-section shown in Fig 5 depicts many of the flow structures that have been previously discussed. In addition, Fig 5 shows a small separation bubble on the inside of the trailing edge rim and a turbulent wake with associated downwash.

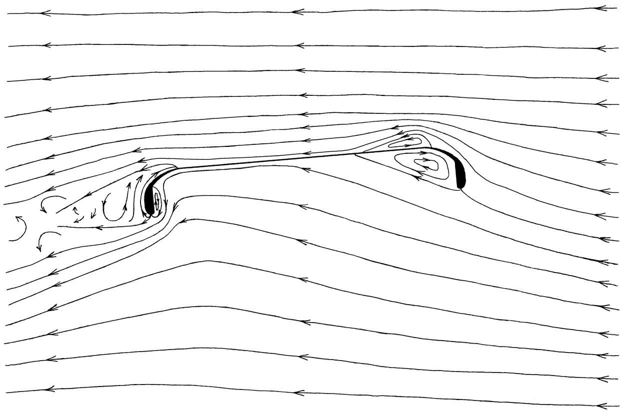

Figure 5. 2D cross-sectional flow topology for a non-rotating disc-wing, 5° incidence.

References

[1] Potts J.R. and Crowther W.J.: The flow over a rotating disc-wing. *RAeS Aerodynamics Research Conference Proc.*, London, U.K., Apr. 2000.

[2] Potts J.R. and Crowther W.J.: Visualisation of the flow over a rotating disc-wing. *Proc. of the Ninth International Symposium on Flow Visualization*, Edinburgh, Scotland, U.K., Aug. 2000.