Trajectories of windborne debris of the plate-type

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INTRODUCTION

Wind-borne debris is known as a major source of damage in strong wind events such as hurricanes. Using the generic classification scheme proposed by Wills *et al* [1], generic debris types can generally be classified as either 'compact', 'sheets/plates', or 'rods'. Although the types of test missile used in impact tests have traditionally been of the 'compact' or 'rod' type [2], there is also evidence of considerable damage produced by 'plate' type objects – for example, concrete roof tiles during Hurricane 'Charley' in Punta Gorda in 2004. This paper describes numerical solutions of the flight characteristics of square flat plates, following initiation of flight, and makes comparisons with experimental data.

AERODYNAMIC FORCES AND MOMENTS

The variation of the normal force coefficient, assumed for the numerical study, was based on data for a square flat plate given by Hoerner [3]; the following segmented linear form was assumed:

$C_N = 1.8\ (\alpha/40)$, for the angle of attack, $\alpha < 40$ degrees (1a)

$C_N = 1.2$, for $40 \leq \alpha \leq 140$ (1b)

$C_N = 1.8\ (180-\alpha)/40$, for $140 < \alpha \leq 180$ degrees (1c)

For angles of attack between about 30 and 40 degrees the plate 'stalls', and in some wind-tunnel tests, the normal force coefficient has shown a sharp peak, before falling to a near constant 'stalled' value of 1.2.

Lift and drag coefficients were then obtained by:

$C_D = 0.1 + C_N \sin(\alpha)$ and $C_L = C_N \cos(\alpha)$ (2)

The distance of the centre of pressure position, c, from the centre of the plate, determines the pitching moment on a plate. The following segmented form for c/ℓ was assumed, where ℓ is the plan dimension of the plate:

$(c/\ell) = 0.22 \cos(1.8\alpha)$, for the angle of attack, $\alpha \leq 38$ degrees (3a)

$(c/\ell) = 0.08 \cos[2(\alpha-38)]$, for $38^0 < \alpha < 82.5^0$ (3b)

$(c/\ell) = 0.0$, for $82.5^0 \leq \alpha < 97.5^0$ (3c)

$(c/\ell) = -0.08 \cos[2(142-\alpha)]$, for $97.5^0 < \alpha \leq 142^0$ (3d)

$(c/\ell) = -0.22 \cos[1.8(180-\alpha)]$, for $142^0 < \alpha \leq 180^0$ (3e)

Following Tachikawa [4], the following bilinear function was assumed for the component of lift coefficient due to the rotational velocity (Magnus Effect) :

$C_{Lr} = 0.42\ (2.5\ \omega/\omega_o)$, for $\omega/\omega_o < 0.2$ (4a)

$C_{Lr} = 0.42\ (0.375 + 0.625\omega/\omega_o)$, for $\omega/\omega_o \geq 0.2$ (4b)

where the steady-state angular velocity, ω_o, is given by [4]: $\omega_0 = \frac{0.64U}{\ell}$,where U is the wind speed.

COMPARISONS OF COMPUTED TRAJECTORIES WITH EXPERIMENTAL DATA

The equations of motion of a plate translating and rotating in one plane were given previously [5]. These were solved numerically on a time step basis.

A large number of experimental runs were made in the wind tunnel at Texas Tech University to determine flight trajectories of square plates. Most of these were released at an initial angle of attack, α_o, of 0 degrees. A range of wind speeds were used in each case. An example of the comparisons between experiment and calculations are shown in Figure 1, for a plate released at 0 degree angle of attack. Calculations were carried out with and without the Magnus Effect on lift forces included. From these figures, it can be seen that the Magnus Effect has a large influence on the computed vertical displacements, but that there is little influence on the calculated resultant plate velocity. It is clear that Magnus Effect lift forces should be included in the numerical calculations of plate trajectories. The agreement between the computed trajectory (Magnus Effect included) and the experimental data is good, although the measured resultant plate speed is slightly underestimated.

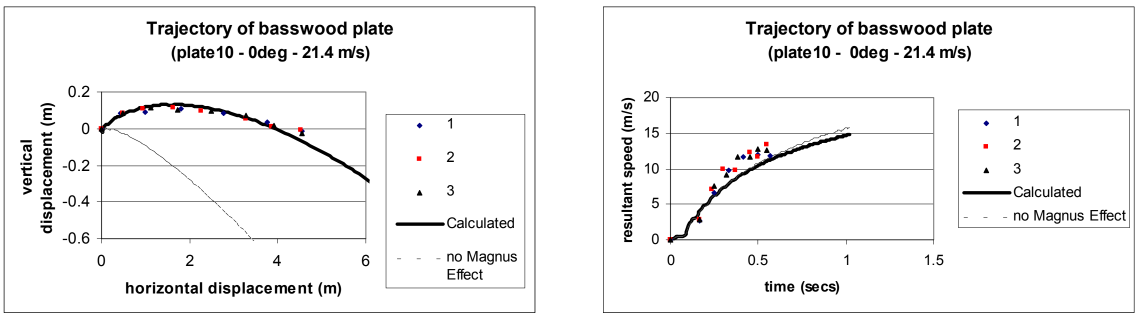

Figure 1. Comparison of experimental and computed trajectories with and without Magnus Effect lift

CONCLUSIONS

- Numerical calculations of the trajectories of square flat plates have been made, and compared with experimental data. Generally, good to excellent agreement has been shown.
- Simple segmented models of the aerodynamic forces and moments as a function of angle of attack, seem to be quite adequate for the numerical calculations.
- Magnus Effect lift needs to be incorporated to get good agreement.

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