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INFLUENCE OF GROUND EFFECT ON THE AERODYNAMIC CHARACTERISTICS OF A HIGH ASPECT-RATIO CATAMARAN VESSEL

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ABSTRACT

The influence of ground effect on a high aspect ratio catamaran model with an aerofoil shaped superstructure was experimentally tested. Lift, drag and pitching moment were measured as a function of ground clearance. Data were obtained from surface pressure tappings at several spanwise positions and a 2-axis force balance connected to the model hulls through the test-section floor. Optimum lift/drag ratio was observed at value of surface clearance slightly greater than those used in current high speed ferry designs.

INTRODUCTION

With increasing operating speeds of catamaran ferries, the aerodynamic forces on the superstructure are becoming significant compared to the hydrodynamic forces and can no longer be overlooked. The present study investigates the effect of transforming the superstructure of these vessels from a conventional profile to a more aerofoil shaped design in order to obtain aerodynamic lift and reduce the total drag of the vessel.

The principal aim of this study was to lower the total drag by introducing an aerofoil shaped superstructure so that higher speed may be achieved for the same power requirement. Besides the obvious advantage gained by streamlining, an additional benefit is possible through using the superstructure to generate aerodynamic lift and partly support the weight of the vessel. The vessel displacement and hydrodynamic drag is thereby reduced. Provided that the incremental aerodynamic drag associated with the lift generation is less than the hydrodynamic drag reduction, the total vessel drag will be lowered.

Fast catamaran ferries typically operate with a hull to surface clearance around 5% of the vessel length. This is in the range where ground effect is very significant. The literature contains numerous studies of aerofoils operating in ground effect (e.g. Chawla et al., 1990; Fink and Lastinger, 1961). These all relate to conventional aircraft operating close to the ground, or to special purpose "WIG" craft which are totally airborne. The present study differs in that the catamaran is principally water-borne, and the hulls extending right to the surface act as endplates which significantly enhance ground proximity effects.

CATAMARAN MODEL AND APPARATUS

The catamaran superstructure geometry is detailed in Table 1. The span of 340 mm was chosen to limit interference with the side walls of the wind tunnel test section, which was 610 mm square with corner fillets.

Profile	NACA 4415
Aspect Ratio	1.5
Span	340 mm
Chord	227 mm

Table 1: Catamaran model superstructure geometry

For simplicity at this preliminary stage, a constant chord unswept aerofoil without flaps or other control surfaces was used. The NACA 4415 aerofoil profile was chosen due to its relatively flat under surface and its large internal volume, which make it practical for both ease of construction and load carrying capacity in a commercial vessel.

The aspect ratio of 1.5 is significantly greater than the values of about 0.3 typical of current fast ferry designs. The current study represents the first stage of a more extensive program in which the influence of aspect ratio will be examined.

The model was manufactured from high strength aluminium on a CNC milling machine. A total of 30 internal pressure tubes were tapped at 5 different spanwise positions from the plane of symmetry to the tip of the model. The pressure tubes were connected to a Scanivalve with internal pressure transducer. This arrangement permits the determination of surface pressure contours to facilitate comparison with CFD predictions. The estimated uncertainty in measured values of the static pressure coefficient, Cp, was ± 0.006.

Vertical endplates made of 6 mm aluminium plate were attached to the model to simulate the catamaran hulls. The leading edges were rounded and the trailing edges were chamfered to avoid local flow separations.

The experimental set up is presented in Figure 1. The model mounting arrangement on the 2-axis force balance permitted independent adjustment of the pitch angle (α) and the ground clearance (h). The force balance consisted of two vertical and one horizontal strain gauge load cells. Surface pressures and force balance data could be obtained simultaneously.

The balance was sealed in a plenum chamber which prevented any net flow in or out of the working section through the gaps around the catamaran hulls. These gaps were minimised by using sealing strips taped to the tunnel floor. Henderson (1997) provides a detailed discussion of the sealing arrangements and their

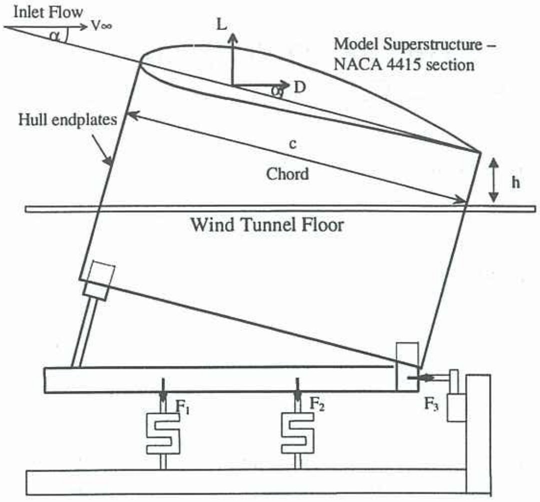

Figure 1 : Schematic of the test rig.

importance in obtaining reliable results. The estimated uncertainty in values of lift coefficient obtained from the balance data was 0.8%. The uncertainly in drag coefficient varied from ± 2% at h/c = 0.6 to ± 5% at h/c = 0.1. The principal source of uncertainty in the drag measurement was repeatability in separate trials of the experiment. It is thought this arose mainly from the aerodynamic effects of changing seals clearance or through the seal contacting the model in some cases.

The ground plane was provided by the wind tunnel floor. No attempt was made to remove the boundary layer which had naturally developed on this surface. Roberts (1998) measured the displacement and total thicknesses of the boundary layer to be approximately 2 mm and 15 mm respectively.

Data were obtained through an incidence range from 0^o to 12^o at heights of the aerofoil trailing edge above the test-section floor corresponding to ground clearance/chord (h/c) values from 0.05 to 0.6.

RESULTS AND DISCUSSION

Surface Pressure Distribution

The effect of ground proximity on the mid-span surface pressure distribution at an incidence $\alpha = 4^o$ is presented in Figure 2. The increasing pressure on the underside of the aerofoil as the ground is approached explains the variations in lift coefficient seen in Figure 5. The upper surface pressure distribution changes very little with ground proximity; a small undulation in the upper pressure gradient around mid-chord is thought to indicate a transition to turbulent flow through a laminar separation bubble for $h/c \geq 0.1$. The suction peak moves forward slightly with decreasing h/c as a consequence of the increasing circulation around the model; incipient trailing edge separation is evident for h/c = 0.05. These results are typical of the pressure profiles obtained at other test conditions.

The variation of surface pressure distribution with incidence at a fixed ground clearance h/c = 0.1 is shown in Figure 3. A sharp upper surface suction peak develops close to the leading edge around $\alpha = 6^o$. This is responsible for the significant increase in drag at high incidence seen in Figure 6. A much broader suction peak is evident on the lower surface at $\alpha = 0^o$. This causes both reduced lift and increased drag as indicated by Figures 5 and 6.

The spanwise variation of the aerofoil surface pressure distribution at h/c = 0.05 and $\alpha = 12^o$ is shown in Figure 4. Curves are plotted for different ratios of distance z from the aerofoil tip to the aerofoil span b. Significant pressure variations on the upper surface are confined to the tip region $z/b < 1/4$. Here the peak suction steadily decreases as the tip is approached; there is a decrease in pressure over the rearward part of the upper surface, indicating the local effect of tip vortex. The lower surface pressure distribution remains almost constant along the span, indicating that the aerofoil lift distribution has been increased by the endplates producing a more 2-dimensional flow behaviour on the lower surface. This phenomenon was observed at all tested h/c values.

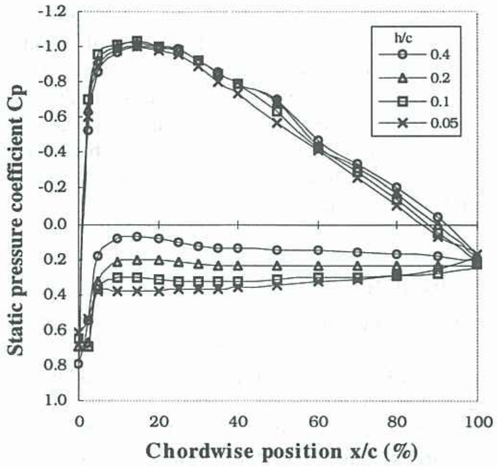

Figure 2 : Influence on ground clearance ratio h/c on mid-span surface pressure distribution at incidence $\alpha = 4^o$

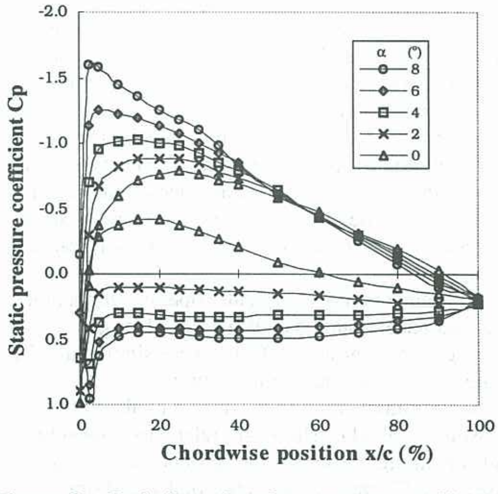

Figure 3 : Variation of surface pressure coefficient Cp with incidence α at h/c = 0.1.

Lift and Drag

Lift and drag coefficients were defined by

$$C_L = L/(0.5\,\rho\,V^2\,S)$$
$$C_D = D/(0.5\,\rho\,V^2\,S)$$

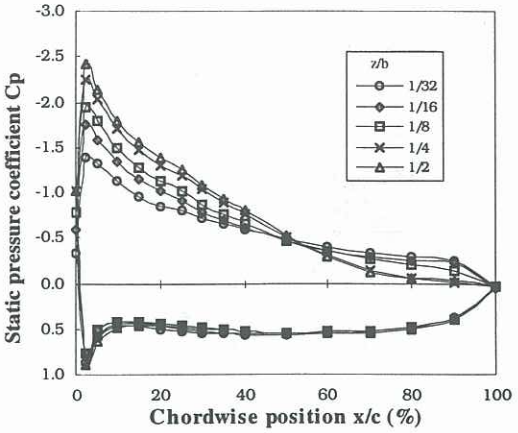

Figure 4 : Variation of surface pressure distribution with spanwise position z/b at incidence $\alpha = 12^o$ and clearance h/c = 0.05.

where S = plan superstructure area (m^2)
V = effective stream velocity in the plane of the model (m/s)

The variation of lift coefficient with ground clearance is shown in Figure 5. The two sets of curves $C_{L,Total}$ and $C_{L,mid-span}$ relate to the total lift force obtained from the balance and the local lift value obtained from integration of the mid-span surface pressure distribution, respectively. The lift coefficient increases significantly as h/c reduces until maximum lift is achieved at values of h/c between 0.1 and 0.2 depending on incidence. The decrease in lift as h/c is reduced below these values is thought to arisen from a combination of developing upper surface stall and reduced lower surface pressures arising from the flow acceleration at low ground clearance. Lift increased monotonically with incidence α in the range 0^o to 8^o for all of the ground clearance values tested.

Figure 6 presents similar plots for the drag data. There is a general decrease in drag as ground clearance is reduced. The overall model drag coefficient from the balance data, $C_{D,Total}$, is higher than the pressure drag coefficient for the mid-span element, $C_{D,mid-span}$, which does not include the effects of viscous friction. The total drag data shows greater irregularity, with fluctuations of around 10%. This is thought to have arisen from the lower precision of drag balance measurement, as irregularities due to separation phenomena are not evident in the pressure drag results. The total drag continues to fall from h/c = 0.6 to 0.05 over the whole incidence range investigated, despite the adverse effects of increasing upper surface diffusion noted above. However, an increase in mid-span pressure drag is evident at h/c = 0.05 for $\alpha = 8^o$.

Centre of pressure

An accurate knowledge of the centre of pressure is needed in order to predict the pitch stability of a vessel. The influence of ground proximity on the location of centre of pressure is shown in Figure 7. The effect of increasing incidence is quite marked, causing both the overall x_{cp} (from balance data) and x_{cp} for the mid-span element (from pressure data) to move forward by about 20% chord, over the range tested.

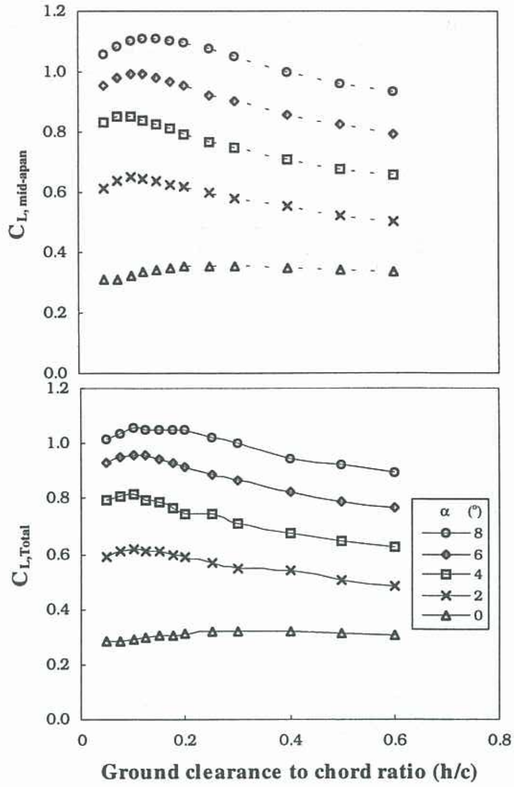

Figure 5 : Effect of ground clearance ratio h/c on lift coefficient for mid-span element, $C_{L, mid-span}$ and total lift coefficient, $C_{L, Total}$

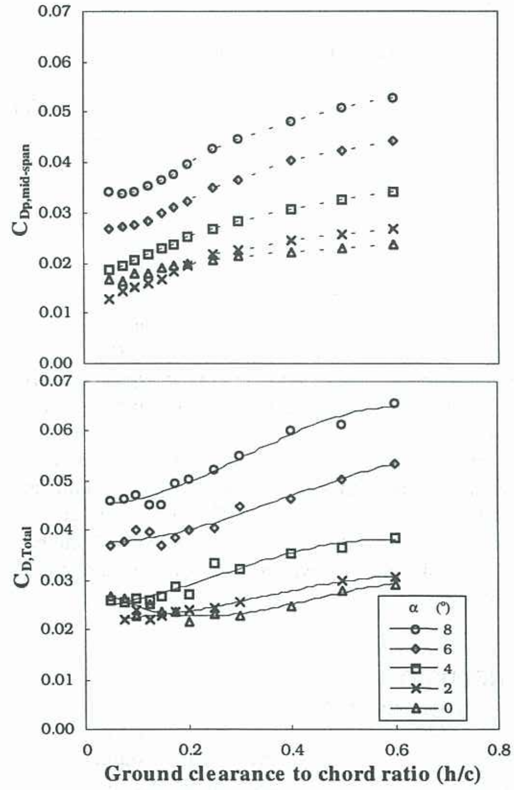

Figure 6 : Effect of ground clearance ratio h/c on total drag coefficient, $C_{D, Total}$ and pressure drag coefficient for mid-span element, $C_{Dp, mid-span}$

Decreasing ground clearance generally produced only slight forward movement of x_{cp} at low incidence, and a slight rearward movement of x_{cp} at high incidence.

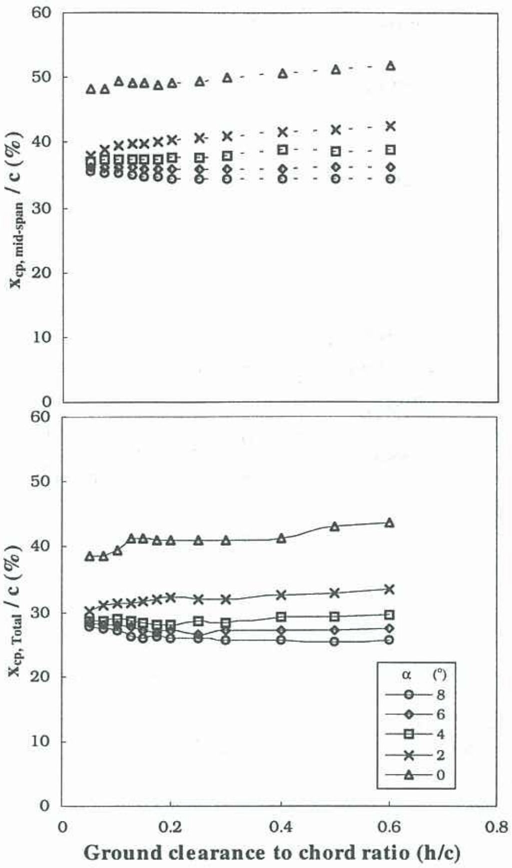

Figure 7 : Effect of ground clearance ratio h/c on centre of pressure for mid-span element, $x_{cp, \text{mid-span}}$ and overall model, $x_{cp, \text{Total}}$.

Lift to drag ratio

The influence of ground effect on overall lift-drag ratio (L/D) is shown in Figure 8. A sharp increase in L/D at h/c values less than 0.2 is observed for moderate incidence. This peak L/D is achieved at h/c around 0.1, which is somewhat greater than the value of 0.05 typical of current vessels. However, the reduction in L/D from h/c = 0.1 to 0.05 is only small.

The L/D curves indicate that optimum aerodynamic efficiency of the lifting superstructure will be achieved at incidence angles between 2^o to 4^o. There is a very large drop in L/D at $\alpha = 0^o$, which is associated with the broad suction peak and subsequent diffusion of the pressure surface flow.

CONCLUSION

The aerodynamic performance of a catamaran with a NACA 4415 aerofoil section superstructure was determined for various values of ground (surface) clearance to chord ratio and incidence. An optimum lift/drag ratio was observed around 2–4 degrees incidence. This provided lift coefficients around 0.8 with corresponding values of L/D about 25 to 30 for h/c around 0.1. These results encourage the belief that the design of fast catamaran vessels with partial aerodynamic support may be advantageous.

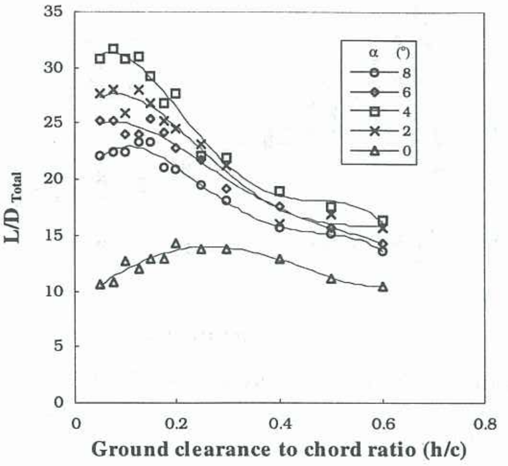

Figure 8 : Effect of ground clearance ratio h/c on overall lift to drag ratio L/D_{Total}.

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