

# EXPERIMENTAL MEASUREMENT OF SIDEFORCE AND INDUCED DRAG ON CATAMARAN DEMIHULLS

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*A catamaran comprises two demihulls and although the flow about the catamaran centre line is symmetric the flow about the centre lines of the individual demihulls is not. The asymmetric nature of the fluid crossflow around the demihulls causes sideforce and hence induced drag to be experienced on the demihulls. The sideforces generated by each demihull act in opposition and cancel whereas the induced drags of both demihulls act together to resist the forward motion of the vessel.*

*Experimental procedures used to estimate the sideforce and induced drag are presented together with results for one hullform at two demihull separations ( $S/L = 0.225$  and  $S/L = 0.329$ ) and at several Froude Numbers.*

*It is shown that the induced drag generated by the demihulls is negligible despite the generation of significant sideforce. The sideforce produced was found to reduce rapidly with increasing demihull separation.*

## 1 Introduction

In order to understand better the calm water resistance characteristics of catamarans a study into the effects of the asymmetric flow around the individual catamaran demihulls has been made.

A catamaran is made up of two demihulls, and the presence of one demihull modifies the flow such that the other demihull is effectively operating at an angle of incidence (or yaw) to the free stream. The demihull acts as a low aspect ratio lifting surface experiencing both side force and induced drag.

The calm water resistance of catamarans has been investigated over a number of years at the University of Southampton [1, 2, 3]. This research has led to the experimental determination of total and wave pattern resistance for a large geometric series of catamarans with systematically varied design parameters. These experimental results were used to calculate form factors for the demihulls in both catamaran and monohull (isolated) conditions.

Form factors were calculated by examining the  $C_T - C_{WP}$  curve at high Froude number and assuming that the other possible components of resistance (wave breaking, spray, induced drag, etc.) were small at these Froude numbers. The form factors were then calculated by fitting the curve  $(1+k)C_F^1$  to these data. Whence  $C_{WP} + (1+k)C_F = C_T$  at high speeds.

The form factors thus derived were found to be substantially greater than unity, and this is somewhat greater than might be expected for these slender hullforms. From observations made during the tests, spray sheet formation and wave breaking were not thought to be significant, especially for the more slender models. Thus, an attempt to quantify the induced drag due to the asymmetric flow around the individual demihulls has been made in order to assess its contribution to  $C_T - C_{WP}$ . If a significant induced drag were present, form factors would be less than previously estimated.

## 2 Experimental procedure

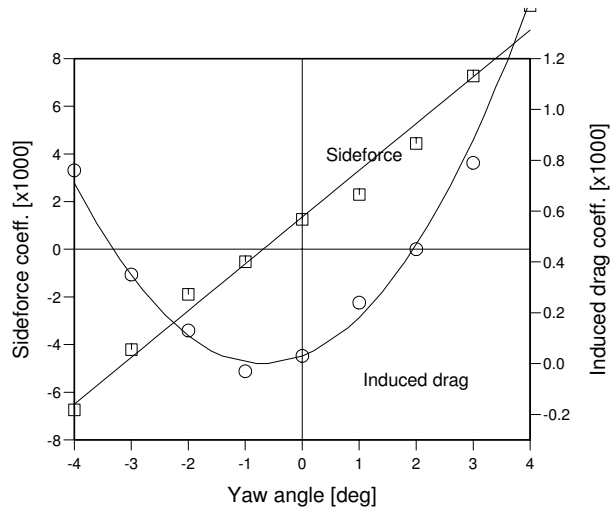
Experiments were carried out at the Southampton Institute test facility, details of which are given by Molland et al.[1]. The hullform tested was Model 5b in the notation of Molland et al.[1] (C5 in the

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<sup>1</sup>The form factor  $(1+\beta k)C_F$  is used in the case of the catamarans, where  $\beta$  is introduced to take account of the viscous interaction between the demihulls

Table 1: Details of models (5b)

$L/\nabla^{1/3}$	8.5
$L/B$	11.0
$B/T$	2.0
$L$	1.6m
WSA	0.276 m <sup>2</sup>

Figure 1: Sideforce and induced drag at  $F_n = 0.74$ , showing yaw offset

notation of Insel[2, 3]). The hull was of round bilge, transom stern form and based on the NPL round bilge series [4], and its principal particulars are given in Table 1.

In order to measure the induced drag of the demihull two tests were carried out:

**Demihull at incidence:** Firstly, a single isolated demihull was tested on the force dynamometer. The model was fixed in all six degrees of freedom. The variation in sideforce and drag with yaw angle was measured at several speeds. It has been assumed that the change in drag was purely due to induced drag. In practice the resistance associated with an asymmetric wave pattern may be different to that of the symmetric case. Due to the constraints on time and equipment, measurements of the asymmetric wave pattern were not made. It was noted during the tests that up to a yaw angle of 1°–2° the visible changes in the wave patterns were small. At higher yaw angles variations of the wave pattern became apparent.

These tests provided the variation of lift and drag with incidence and speed for the isolated demihull. Typical results are presented in Figure 1. (Note that total resistance is made up of two components  $C_D = C_{D_0} + C_{D_i}$ , and only the induced drag component  $C_{D_i}$  is plotted in the results presented.) The sideforce is assumed to be proportional to incidence angle and a straight line fit has been made. In practice, for low aspect ratio lifting surfaces, the lift curve slope increases slightly with increasing incidence until stall occurs. The induced drag is assumed proportional to the square of the sideforce and hence, in this case, to the square of the incidence angle and a parabolic fit has been made to these data.

Although care was taken to align the model at zero incidence it was found that the sideforce zero crossing point showed a 0.5° offset. The demihull was accurately aligned in the tank, taking into account this correction, before continuing with the second stage of the experiment.

**Demihull sideforce in catamaran mode:** The second stage of the experimentation involved adding the second demihull to produce the normal catamaran configuration. As in the previous experiment, both demihulls were fixed in trim and sinkage. The second demihull was fitted directly to the carriage leaving the original demihull on the force dynamometer. No connections were made between the two demihulls but the second demihull was carefully aligned parallel with the original. The models were run at various speeds and a note was made of the sideforce generated by the demihull attached to the dynamometer. This was repeated for two demihull separations.

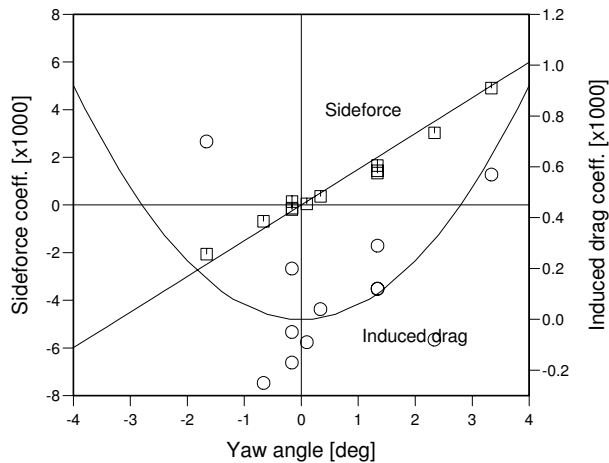


Figure 2: Sideforce and induced drag at  $F_n = 0.35$ ,  $C_{D_0} = 6.37 \times 10^{-3}$

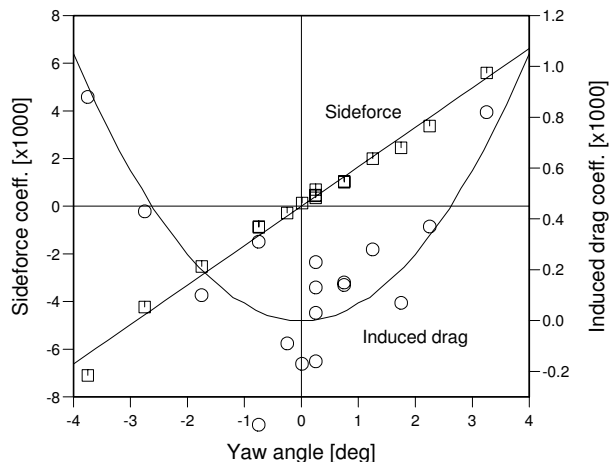


Figure 3: Sideforce and induced drag at  $F_n = 0.61$ ,  $C_{D_0} = 6.04 \times 10^{-3}$

### 3 Results

**Results — Demihull at incidence:** Figures 2 to 6 show the results to the first part of the experiment. Sideforce and induced drag coefficients against yaw angle for the isolated demihulls at various speeds are presented. The definitions of the non-dimensional coefficients used are given in Equations 1 and 2, noting that the wetted surface area used is that of a single demihull.

$$\text{Sideforce Coeff. } C_L = \frac{\text{Sideforce}}{\frac{1}{2} \rho W S A U_0^2} \quad (1)$$

$$\text{Induced drag Coeff. } C_{D_i} = \frac{\text{Drag at incidence} - \text{Drag at zero incidence}}{\frac{1}{2} \rho W S A U_0^2} \quad (2)$$

For clarity, the results have been corrected for the angular offset noted in Section 2; hence zero sideforce and induced drag are achieved at zero yaw angle.

In all cases the results for sideforce show a good correlation with the straight line fit, although some non-linearity can be observed. The lift (sideforce) curve slope increases slightly with increasing incidence angle and this is as expected for low aspect ratio bodies such as these.

Results for induced drag show reasonable correlation with the parabolic fit, especially at the higher speeds tested (Figures 4 to 6). At the lower speeds there is more scatter in the results and this is due to the lower forces being measured (Figures 2 and 3). The scatter in the induced drag results at these lower speeds may also be due to the more chaotic nature of the wake when the transom is not quite releasing cleanly, especially for the slowest speed,  $F_n = 0.35$  (Figure 2). The results are summarised in Table 2.

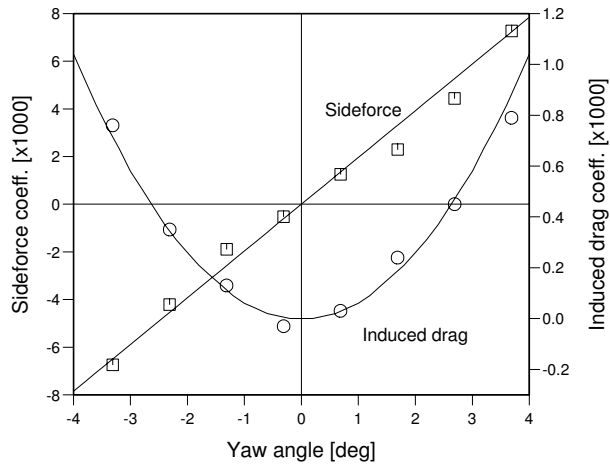


Figure 4: Sideforce and induced drag at  $F_n = 0.74$ ,  $C_{D_0} = 5.34 \times 10^{-3}$

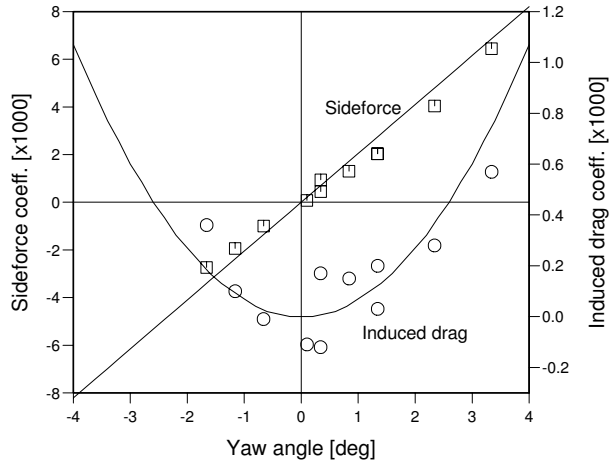


Figure 5: Sideforce and induced drag at  $F_n = 0.87$ ,  $C_{D_0} = 5.13 \times 10^{-3}$

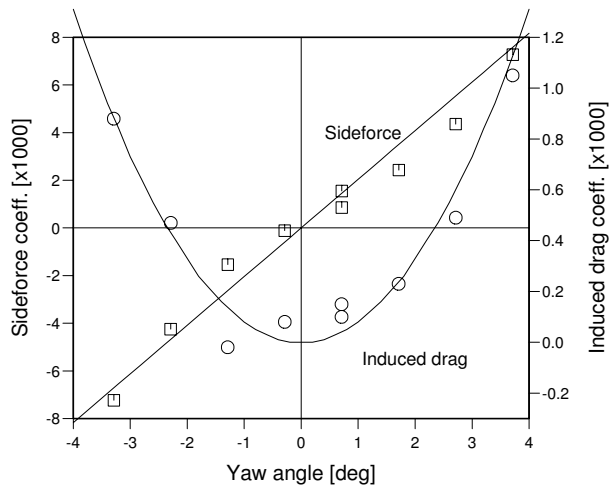


Figure 6: Sideforce and induced drag at  $F_n = 1.00$ ,  $C_{D_0} = 4.83 \times 10^{-3}$

Table 2: Regression coefficients for sideforce and induced drag results (isolated demihulls)

$F_n$	$C_L = m_1 \alpha$		$C_{D_i} = m_2 \alpha^2$		$C_{D_0}$
	$m_1$	$R^2$	$m_2$	$R^2$	
0.35	$1.499 \times 10^{-3}$	96.2%	$5.780 \times 10^{-5}$	62.7%	$6.37 \times 10^{-3}$
0.61	$1.656 \times 10^{-3}$	98.5%	$6.571 \times 10^{-5}$	68.4%	$6.04 \times 10^{-3}$
0.74	$1.962 \times 10^{-3}$	98.3%	$6.497 \times 10^{-5}$	98.9%	$5.34 \times 10^{-3}$
0.87	$2.052 \times 10^{-3}$	95.9%	$6.699 \times 10^{-5}$	90.0%	$5.13 \times 10^{-3}$
1.00	$2.042 \times 10^{-3}$	96.8%	$8.165 \times 10^{-5}$	97.5%	$4.83 \times 10^{-3}$

Where  $R^2$  is the coefficient of determination.

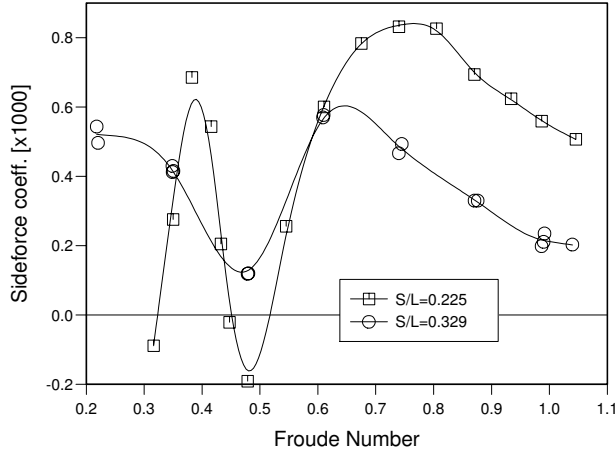


Figure 7: Sideforce experienced on a single catamaran demihull at  $S/L = 0.225$  and  $S/L = 0.329$ , non-dimensionalised with demihull (not catamaran) wetted surface area

**Results — Demihull sideforce in catamaran mode:** The results for the second part of the experiment, with the demihulls in catamaran configuration, are presented in Figure 7, here sideforce coefficient is plotted against Froude number. (Note that demihull sideforce has been non-dimensionalised with demihull *not* catamaran wetted surface area.) It should also be noted that, in the notation used here, a positive sideforce indicates a repelling force between the demihulls and a negative sideforce indicates that the demihulls are being drawn together. It can be seen that both curves display similar features with large variations in sideforce coefficient at low to moderate Froude numbers and a maximum at  $F_n \approx 0.7-0.8$  which reduces as Froude number is further increased. The variations of measured sideforce for the greater separation ( $S/L = 0.329$ ) are approximately half those measured at the closer separation ( $S/L = 0.225$ ).

These curves indicate that there is considerable interaction between the demihulls and that it is heavily speed dependant. It is perhaps surprising to note that at some speeds the sideforce is very small. Indeed, for the closest separation the demihulls attract one another at  $F_n \approx 0.3$  and  $0.48$ . As the separation is increased to  $S/L = 0.329$  the suction due to the venturi effect is reduced and although the sideforce is greatly reduced around  $F_n = 0.45$  the force is always outward. At speeds where the sideforce becomes negative the attraction force due to the venturi effect is greater than the repulsion forces from the impinging bow wave system.

In Figure 7, it can be seen that an outward force is experienced at virtually all Froude numbers. This demonstrates that the cross flow caused by the impinging bow wave system is greater than that due to the venturi suction.

**Results — Combined:** Combining the results from both parts of the experiment it is possible to estimate the induced drag of the demihull thus:

1. The sideforce for a given speed is read from Figure 7 (choosing the appropriate curve depending on the separation).

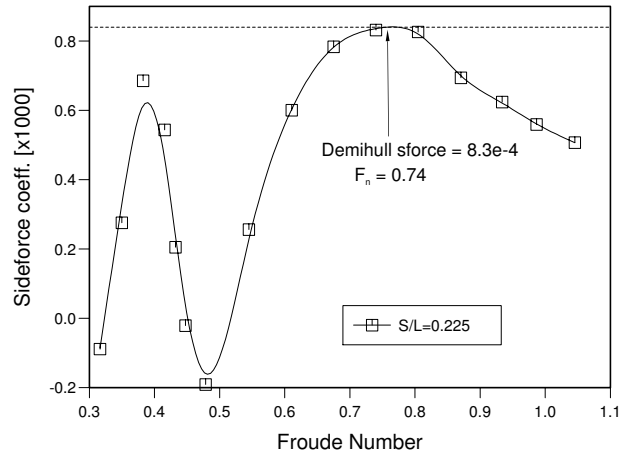


Figure 8: Example calculation of induced drag — Demihull sideforce in catamaran configuration

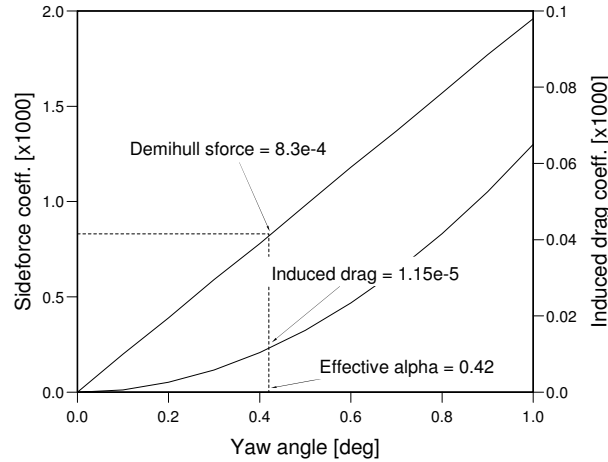


Figure 9: Example calculation of induced drag — Isolated demihull induced drag

2. The yaw angle required for the isolated demihull to achieve this sideforce may then be read from Figures 2 to 6, or calculated from Table 2, choosing the appropriate speed or interpolating between speeds if required.
3. The induced drag generated at this yaw angle may also be read from the same graph, or again, calculated from Table 2.

An example of this procedure is shown in Figures 8 and 9. The case chosen corresponds to the speed at which maximum sideforce coefficient was measured, which occurred at a separation  $S/L = 0.225$ . Calculations of effective angle of attack ( $\alpha_e$ ) and induced drag have been made for the speeds tested and are presented in Table 3.

## 4 Conclusions

- Results for the isolated demihull (monohull) show reasonable correlation with what might be expected from low aspect ratio foils. Lift (sideforce) can be adequately regressed to a straight line for small angles of attack. Similarly, induced drag may be regressed to a parabolic variation with angle of attack. Only the results for the two slowest speeds show poor values for  $R^2$ , and this is probably due to the scatter in the experimental results rather than the parabolic model being inappropriate.
- Results for the demihull sideforce measured in catamaran configuration showed good repeatability. Sideforce showed considerable variation with Froude number for the separations tested. The vari-

Table 3: Calculated effective angle of attack and induced drag (for each demihull)

$F_n$	$C_L$	$\alpha_e$	$C_{D_i}$	$C_{D_i}/C_{D_0}$
0.35	$2.8 \times 10^{-4}$	$0.18^\circ$	$0.19 \times 10^{-5}$	0.29%
0.61	$6.0 \times 10^{-4}$	$0.36^\circ$	$0.85 \times 10^{-5}$	0.14%
0.74	$8.3 \times 10^{-4}$	$0.42^\circ$	$1.15 \times 10^{-5}$	0.22%
0.87	$6.9 \times 10^{-4}$	$0.34^\circ$	$0.77 \times 10^{-5}$	0.16%
1.00	$5.4 \times 10^{-4}$	$0.26^\circ$	$0.55 \times 10^{-5}$	0.11%

ation was found to reduce as separation was increased. At most speeds the sideforce was outward from the catamaran centre line, however, at certain speeds the demihulls were found to attract one another. The variation of sideforce with speed is due to the changes in relative magnitude of the outward force of the radiated wave system and the inward force due to the venturi effect. The venturi effect is reduced with increasing separation and this may be observed in the results.

- The sideforce measured was found to be reasonably large, being 4%–16% of the monohull resistance ( $C_{D_0}$ ) for the closest separation.
- The method described above has provided an experimental method for determining the sideforce generated by a catamaran demihull. It has been shown that an estimate of the induced drag can be made given a knowledge of the lift and drag variation with incidence of the demihull.
- The effective angle of attack at which the demihull is operating in catamaran configuration is small, typically less than  $0.5^\circ$ . This results in virtually insignificant induced drag despite the low aspect ratio of the demihulls. The induced drag coefficient is of the order  $1 \times 10^{-5}$  which is less than 0.3% of the monohull resistance ( $C_{D_0}$ ), again for the closest separation.
- The above results and analysis have shown that the induced drag due to the asymmetric flow around catamaran demihulls may be ignored for practical purposes. The measurements of sideforce may be of interest from a structural perspective but do not directly affect the resistance characteristics.

## References

- [1] A.F. Molland, J.F. Wellicome, and P.R. Couser. Resistance experiments on a systematic series of high speed displacement catamaran forms: Variation of length-displacement ratio and breadth-draught ratio. *Paper presented to the Royal Institution of Naval Architects*, November 1995.
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- [3] M. Insel. *An Investigation into the Resistance Components of High Speed Displacement Catamarans*. PhD thesis, University of Southampton, 1990.
- [4] D. Bailey. The NPL high speed round bilge displacement hull series. Maritime Technology Monograph 4, Royal Institution of Naval Architects, 1976.