SSSU 92
ISSN 0140 3818

EXPERIMENTAL MEASUREMENTS OF HULL PRESSURES ON FAST DISPLACEMENT CATAMARANS DURING MOTIONS IN LONG-CRESTED HEAD-SEAS

J.F. Wellicome, P. Temarel, A.F. Molland and P.R. Couser

Ship Science Report 92
December 1995

UNIVERSITY
OF
SOUTHAMPTON

DEPARTMENT OF SHIP SCIENCE

FACULTY OF ENGINEERING
AND APPLIED SCIENCE

SSSU 92
ISSN 0140 3818

UNIVERSITY
OF
SOUTHAMPTON

DEPARTMENT OF SHIP SCIENCE

FACULTY OF ENGINEERING

AND APPLIED SCIENCE

EXPERIMENTAL MEASUREMENTS OF HULL PRESSURES ON FAST DISPLACEMENT CATAMARANS DURING MOTIONS IN LONG-CRESTED HEAD-SEAS

J.F. Wellicome, P. Temarel, A.F. Molland and P.R. Couser

Ship Science Report 92
December 1995

Ship Science Report No. 92
Experimental Measurements of Hull Pressures on Fast Displacement Catamarans During Motions in Long-Crested Head-Seas

Dr J.F. Wellicome, Dr P. Temarel, Dr A.F. Molland and Mr P.R. Couser

December 1995

Abstract

Piezoresistive pressure transducers have been used to measure the pressure variations at six points on a catamaran hull moving in regular, long-crested, head-seas. Preliminary results demonstrate the feasibility of this experimental approach although a more refined experimental procedure may be required to obtain greater accuracy in the pressure measurements.

The pressure measurements were carried out for one demihull spacing at two speeds in calm water and also in regular waves of differing wave periods. The mean pressures from both calm water and regular wave tests are presented along with the RMS variation from the mean during the tests in regular waves.

Contents

List of Tables

List of Figures

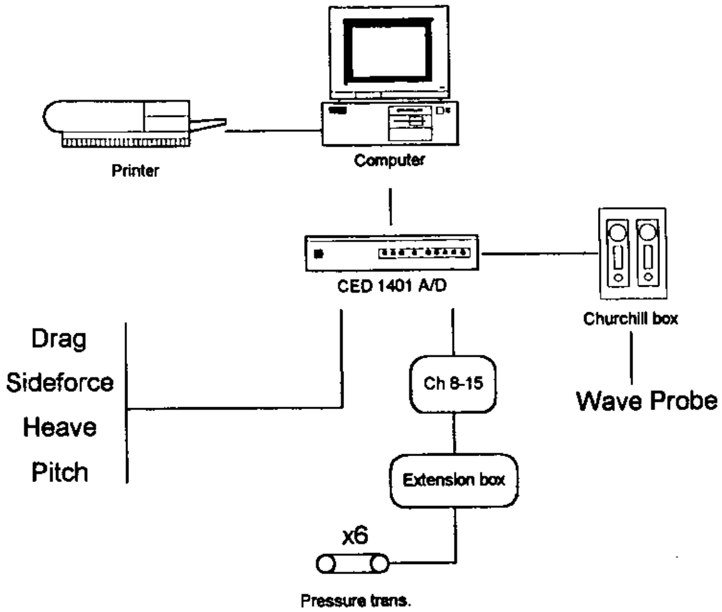

Figure 1: Experimental apparatus

1 Introduction

An investigation into the motions of catamarans in long-crested head-seas has been carried out Ref [3]. This report describes the measurements of the pressure variations along the hull as the vessel responds to the wave system. (The measurements were made in regular waves at a number of positions on the demihull.) The pressures are used to provide data for verification of the numerical models used to calculate catamaran motions Ref [4].

2 Experimental procedure

2.1 Test tank

The model experiments were carried out in the Southampton Institute test tank, the principal particulars of which are given in Table 1, below:

The tank has a manned carriage which is equipped with a dynamometer for measuring model total resistance together with various computer and instrumentation facilities for automated data acquisition. The equipment and set up is shown in Figure 1.

2.2 Models

Experiments have been carried out on one of the catamaran hulls from the Southampton Catamaran Series Ref [3, 2]. The hull form tested was based on the NPL round bilge series Ref [1] and was Model 4b in the notation of Ref [3]. The hulls used were the same as those used in the experiments of Ref [3]. These were constructed using a vacuum bagged foam sandwich shell. This method of production gave excellent rigidity for a minimum of weight and also facilitated the insertion of the pressure transducer mounting points.

Table 1: Details of Southampton Institute Tank

Length	60m
Breadth	3.7m
Water depth	1.8m
Max carriage speed	4.2 ms^{-1}

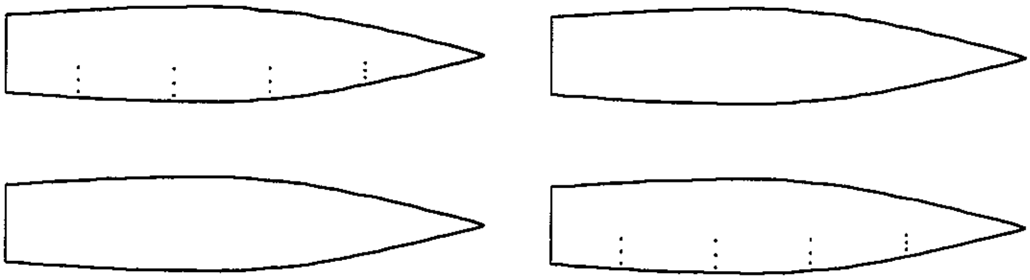

Figure 2a: Inside

Figure 2b: Outside

Figure 2: Mounting Positions

2.3 Measurements, equipment and instrumentation

All measurements were recorded via the carriage data acquisition system which consisted of a CED1401 A/D (analogue to digital converter) and a PC. Wolfson Unit MTIA software was used to drive the system and to provide preliminary data analysis. Wolfson Unit MTIA also provided software to drive the tank wave maker.

Drag and sideforce were measured in the usual manner on the dynamometer. Data was passed to the CED1401 A/D through a 10Hz low-pass filter.

Heave and pitch were measured at the centre of gravity using linear and angular potentiometers respectively. Data was filtered using a 10Hz low-pass filter.

Wave trace was recorded using a resistance wave probe mounted on the carriage. A stiff sword type probe was used. The correlation of this probe with shore based measurements had been made in previous experiments; again data was filtered (10Hz low-pass) before being acquired by the CED1401 A/D.

Pressure transducers and mounting: Pressure measurements were made using piezoresistive pressure transducers with a 2psi range (Endevco Model 8500). These transducers have a 2mm silicon diaphragm in their head onto which a strain gauge Wheatstone bridge has been etched. It was noted that *this diaphragm is relatively delicate and should not be subjected to point loads such as a pen tip. Generally, the pressure transducers have to be treated with much care.* These devices also have temperature compensation built into the barrels of the transducer. A Fylde box was used as power supply, bridge balance and amplification for the pressure transducers. The transducers were connected to the Flyde box via extension cables. To record the time varying pressures measured by the transducers it was necessary to amplify the bridge output by a factor of 200-500 to provide the ±5.0v input to the CED1401 A/D which was used to acquire the data which was then recorded on a PC.

Six pressure transducers were available. However, to enable a greater number of pressure measurements over the hull surface to be made, a total of twelve pressure transducer mounts were glued into one of the model demihulls. At any one time six of these mounts were occupied by pressure transducers and the other six by blanks, the blanks being of the same dimensions as the pressure transducers and made from brass rod. The mounts were positioned on the starboard side of the model only. This would enable up to twenty-four pressure measurements to be made. Measurements of pressures both inside the tunnel between the catamaran demihulls and on the outside of the catamaran could be carried out by moving the pressure tapped demihull from the starboard side of the catamaran to port, see Figure 2. The pressure transducer mounts were positioned at four equally spaced stations along the hull with three mounts at each station equally spaced around the girth (from centre line to water line). Details of the mount positions and nomenclature are given in Table 2.

The details of the pressure transducer mounts are shown in Figure 4. They consist of a barrel into which the pressure transducer can be inserted. The barrel is glued into the foam sandwich of the model skin and is flush with the outer skin of the model. When the pressure transducer is fitted, it too is flush

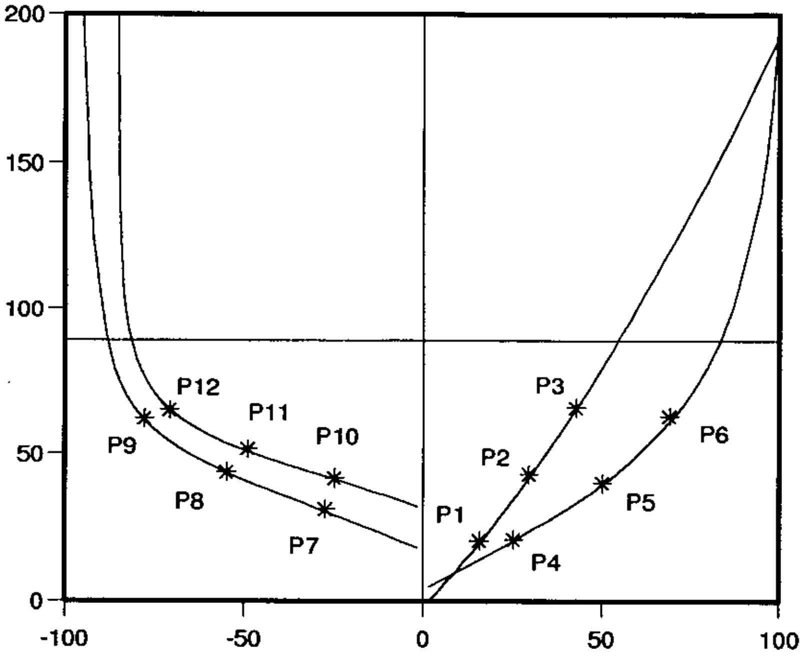

Figure 3: Pressure transducer mounting positions

Table 2: Pressure transducer mounting positions

No.	Stn.	Girth (from keel) mm	Beam mm	Height (from keel) mm
P1	7.5	26.0	15.5	20.5
P2	7.5	52.0	29.5	43.0
P3	7.5	78.0	42.5	66.0
P4	5.5	30.5	25.0	21.0
P5	5.5	61.0	50.0	40.0
P6	5.5	91.5	69.0	63.0
P7	3.5	30.0	27.5	31.0
P8	3.5	60.0	55.0	43.5
P9	3.5	90.0	78.0	62.0
P10	1.5	26.0	25.0	41.5
P11	1.5	52.0	49.0	51.5
P12	1.5	78.0	71.0	65.0

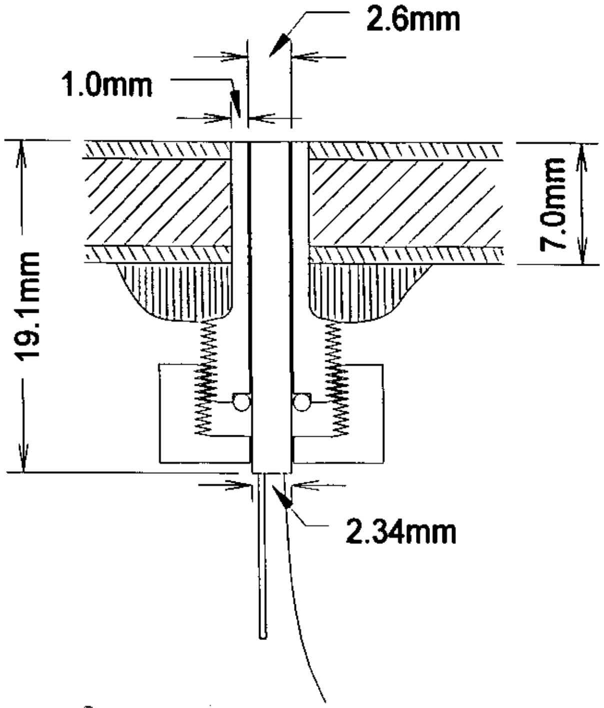

Figure 4: Construction of pressure transducer mounts

with the outer skin of the hull. The inner end of the barrel extends into the model and has an external thread. When the pressure transducer is inserted it protrudes from the barrel inside the model, an o-ring fits over the pressure transducer and is clamped in place by a threaded cup which screws onto the barrel of the transducer mount to give a water tight seal. This method of attaching the pressure transducers to the model was found to provide a simple, yet effective means of mounting the transducers in the hull, enabling the transducers and blanks to be interchanged relatively quickly.

Pressure transducer bridge balance and amplification: As described above, a Fylde box was used to provide the power supply and bridge balance required by the pressure transducers as well as the amplification necessary to bring the output to ±5v. A supply voltage of 10v is recommended for these transducers, although they will operate with a lower supply voltage (and also with a supply voltage of up to 15v). The pressure transducer output is approximately 25mv/Psi/volt excitation or 0.036mv/ mmH_2O /volt excitation. (Noting that 1 Psi = 6894.4 Pa = 703 mmH_2O .)

The pressure transducers were found to operate well in air at the recommended excitation voltage of 10v. Although it was not possible to check the response to exact pressure changes (no suitable apparatus was available, but certified calibration had been provided by the manufacturer), the dynamic response could be checked by blowing on the face of the transducers. The zero values were found to be very stable showing virtually no drift over a period of several hours. No drift was found either in the output from the bridge or in the amplified signal.

The performance of the pressure transducers in water was inferior to that in air. Initially, the specified excitation voltage of 10v was used but this was reduced since excessive drift occurred, possibly due to heating effects or earth leakages. Operating at reduced excitation voltages (around 5v) showed some improvements but repeatability and zero value drift were still much greater than in air. A significant decrease in the rate of zero drift could be achieved if the transducers were allowed to warm up for several hours. Some of these discrepancies can be attributed to the small pressure changes being measured, being typically up to 50 mmH_2O . This corresponds to 3.5%fsd (full scale deflection). The specification of the pressure transducers gives a repeatability of within 0.5%fsd which is up to about 14% of the values being measured. Improvements in the accuracy of the pressure measurements in water are being pursued. In particular, heating and earth leakage effect are being investigated.

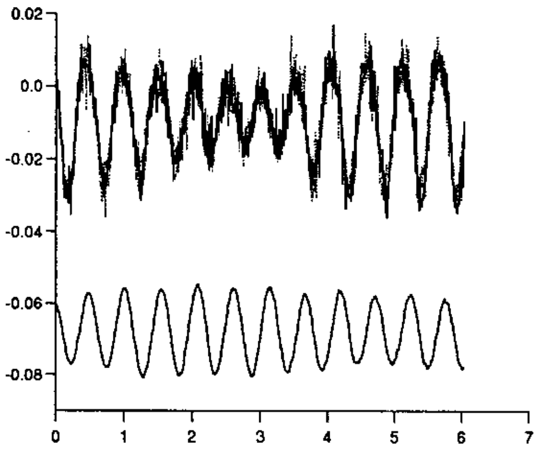

Figure 5: Typical pressure measurement trace

Table 3: Average wave and pressure measurements, Model 4b, $S/L = 0.2$, $F_n = 0.2$, outside pressure mounts 1–6

T_0 s	ω_e rad/s	Ave. Wave mm	Ave. Heave mm	Ave. Pitch deg	Ave. P1 mmH_2O	Ave. P2 mmH_2O	Ave. P3 mmH_2O	Ave. P4 mmH_2O	Ave. P5 mmH_2O	Ave. P6 mmH_2O
calm water		-0.88	-1.63	0.00	-1.50	-3.78	-2.86	-6.28	-3.03	-2.50
0.962	10.00	-4.86	-1.90	0.17	-2.92	-3.35	-3.49	-3.63	-2.12	-2.13
0.841	12.00	-1.05	-1.61	0.18	-1.95	-1.55	-1.32	-3.50	-2.22	-2.23

3 Results

Despite the problems mentioned above several reasonably successful runs were made and the results are presented. To date, pressure measurements have been carried out on the outboard side only, at positions P1 to P6. The measurements were carried out at two Froude numbers ($F_n = 0.2$ and 0.53) and at several encounter frequencies. The results are presented in Table 3 ($F_n = 0.20$) to Table 6 ($F_n = 0.53$). The pressure transducers were zeroed with the model at rest and at zero trim and sinkage, thus the pressures given in these tables include three components: the hydrostatic pressure due to the changes in trim and sinkage, the hydrodynamic pressure and pressure due to the stationary wave system which occurs from the steady forward speed, and the unsteady pressure fluctuation due to the encountered wave system and consequent model motions. Table 3 and Table 4 give the average pressures measured during the runs due to the first two pressure effects mentioned above. Table 5 and Table 6 give the RMS value of the oscillating pressure about this mean, which corresponds to the effects of the unsteady response and encountered wave system.

An example of a typical set of traces is given in Figure 5.

3.1 Discussion of results

Two of the measurements of mean wave height in Table 4 (at $T_0 = 1.141$s and 1.033s) are not present. The wave trace suggested that a zero shift had occurred. However, the RMS values of the wave oscillation appeared to be reasonable and these values are include in Table 6.

In Tables 3 and 4 the mean values for the heave and pitch which were measured during the runs at the different encounter periods are reasonably consistent for both of the speeds tested. There appears to be no change in these values during test in waves, when compared with the calm water results; also there is no change of heave and pitch with changing wave period for the tests in regular waves.

It is also seen in these tables that the absolute mean pressures are reasonably consistent for each

Table 4: Average wave and pressure measurements, Model 4b, $S/L = 0.2$, $F_n = 0.53$, outside pressure mounts 1–6

T_0 s	ω_e rad/s	Ave. Wave mm	Ave. Heave mm	Ave. Pitch deg	Ave. P1 mmH_2O	Ave. P2 mmH_2O	Ave. P3 mmH_2O	Ave. P4 mmH_2O	Ave. P5 mmH_2O	Ave. P6 mmH_2O
calm water		2.16	-8.55	3.13	-7.53	-8.51	-9.16	-4.25	-1.52	-1.12
1.285	10.02	1.89	-8.40	3.14	-9.62	-10.50	-1.23	-6.12	-2.25	-1.54
1.141	12.00	—	-7.77	3.13	-9.02	-8.91	-8.83	-4.55	-2.02	-1.60
1.033	14.01	—	-7.43	3.11	-12.07	-7.73	-9.40	-5.27	-2.44	-1.88
0.949	16.00	1.28	-7.77	3.14	-3.29	-5.62	-5.71	-2.77	-1.79	-1.71
0.949	16.00	1.53	-8.59	3.09	-6.80	-8.68	-7.64	-3.88	-1.16	-1.20

Table 5: RMS wave elevation and pressure measurements, Model 4b, $S/L = 0.2$, $F_n = 0.2$, outside pressure mounts 1–6

T_0 s	ω_e rad/s	RMS Wave mm	RMS Heave mm	RMS Pitch deg	RMS P1 mmH_2O	RMS P2 mmH_2O	RMS P3 mmH_2O	RMS P4 mmH_2O	RMS P5 mmH_2O	RMS P6 mmH_2O
0.962	10.00	10.56	1.45	1.19	6.52	6.26	6.11	3.66	2.57	2.11
0.841	12.00	13.43	3.46	0.88	13.54	11.47	10.14	2.62	2.80	3.52

Table 6: RMS wave elevation and pressure measurements, Model 4b, $S/L = 0.2$, $F_n = 0.53$, outside pressure mounts 1–6

T_0 s	ω_e rad/s	RMS Wave mm	RMS Heave mm	RMS Pitch deg	RMS P1 mmH_2O	RMS P2 mmH_2O	RMS P3 mmH_2O	RMS P4 mmH_2O	RMS P5 mmH_2O	RMS P6 mmH_2O
1.285	10.02	6.20	6.19	0.83	7.94	5.38	7.25	3.41	3.57	3.43
1.141	12.00	7.85	8.19	0.83	11.82	8.84	11.01	6.51	5.78	5.23
1.033	14.01	9.38	5.54	0.88	12.56	9.23	10.64	8.79	8.04	7.10
0.949	16.00	7.80	1.60	0.34	7.64	5.25	5.92	5.77	5.36	4.80
0.949	16.00	7.64	1.63	0.35	7.50	6.34	5.52	5.90	5.11	4.83

pressure transducer, but show more variation than the heave and pitch measurements. This could be more likely due to the zero drift mentioned earlier than an effect due to the changing wave encounter frequency.

The magnitudes of the suction pressures are greater near the bow, station 7.5, (P1–P3) than further aft, station 5.5 (P4–P6). This is to be expected since it is likely that the velocities at station 7.5 will be greater than at 5.5 leading to a greater negative pressure at station 7.5. This effect is most noticeable at higher Froude number (Table 4); at the lower speed (Table 3) pressures at both stations are approximately the same Again, this might be expected since the pressure change is proportional to the square of the velocity. The effect of draught, or position around the girth is less easy to determine although it would appear that the greatest magnitude pressures are found near the keel, P1 and P4. This effect is most noticeable when comparing P4–P6 at Froude number of 0.53, Table 4. It should be remembered that the pressures being measured are the differences from the pressures at rest, hence the hydrostatic pressure due to water depth is effectively removed. Thus one would not necessarily expect the pressure difference to increase with increasing depth.

In general the RMS pressures measured are of the same order of magnitude as the wave height. This relationship is to be expected. From the computational models Ref [4] the maximum pressure found on the body corresponded to the hydrostatic pressure due to the wave height. This pressure was found near the bow and stern of the model, with the pressure reducing at midships. These trends are to be found in the tests for both speeds (Table 5 and 6) where the RMS pressures at station 7.5 (P1–P3) are greater than at station 5.5 (P4–P6), these differences appearing to be greater at the slower speed. Again it is difficult to determine the effect of draught but the results suggest an increase in RMS pressure near the keel (P1, P4) when compared with the values near the waterline (P3, P6). This is contrary to what might be expected, since the orbital velocity and hence pressure changes due to the incident waves decrease with increasing depth.

4 Conclusions

Some reasonably successful tests were made and the pressure data recorded has been presented. These data reflect most of the trends that have been suggested by numerical models of this problem Ref [4].

The pressure transducers were found to operate to their specification in air but their performance in water was inferior, drift in the zero offset being the major problem. As a consequence, improvements in the behaviour of the transducers in water continue to be pursued, particularly concerning the influences of heating and earth leakage effects.

It should also be appreciated that extremely small pressures were being measured. The transducers have the smallest full scale range of all the standard transducers of this type that are available commercially. This range is 2Psi or 1400 mmH_2O . The pressure changes which might be expected during such experiments are of the order 50–100 mmH_2O or 3.6%–7.2% fsd. The quoted accuracy for these transducers is of the order of 0.5% fsd, thus measurement errors of the order of 7%–14% might occur.

Despite the current limitations discussed above, the use of such pressure transducers for these purposes has proved to be sufficiently promising as to be worth pursuing further.

References

[1] W.J. Marwood and D. Bailey. Design data for high-speed displacement hulls of round-bilge form. Ship Report 99, National Physical Laboratory, 1969.

[2] 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. Ship Science Report 71, Department of Ship Science, University of Southampton, March 1994.

[3] J.F. Wellicome, P.Temarel, A.F. Molland, and P.R. Couser. Experimental measurements of the seakeeping characteristics of fast displacement catamarans in long-crested head-seas. Ship Science Report 89, Department of Ship Science, University of Southampton, December 1995.

[4] J.F. Wellicome, P.Temarel, A.F. Molland, and D.Hudson. Theoretical prediction of the seakeeping characteristics of fast, displacement catamarans. Ship Science Report 93, Department of Ship Science, University of Southampton, December 1995.