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PLANING CRAFT IN WAVES - FULL SCALE MEASUREMENTS

Hans Jørgen B. Mørch
Faculty of Engineering and Science, Agder University College
Grooseveien 36, 4876 Grimstad, Norway

Ole A. Hermundstad
Centre for Ships and Ocean Structures, Norwegian University of Science and Technology
Marine Technology Centre, 7491 Trondheim, Norway

ABSTRACT

Results from full scale measurements on a 21 foot planing pleasure craft in waves are presented. The measurements were performed as part the project "Regional innovation in the boatbuilding industry", financed by the Norwegian Research Council.

In order to gain better understanding of design loads the instrumentation consisted of pressure transducers for slamming pressures, and strain gages for hull response. On one panel, also hull deflections were measured. Vertical accelerations were measured.

INTRODUCTION

Full scale measurements were performed on a planing craft, "Nidelv 610", during the period November-December 1999. The tests were a part of innovation project supported by the Norwegian Research Council, where several of the leading boat builders in Norway participated. The object of the tests was to get a better understanding of the loads of a planing craft in a seaway for better to dimension the hull and also facilitate the use of more exotic materials.

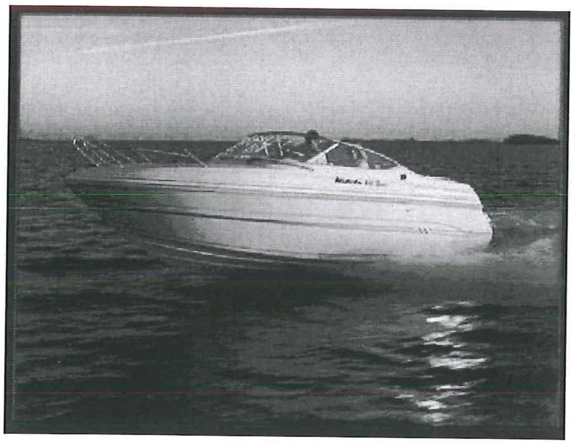

Fig. 1: *Nidelv 610, courtesy of Nidelv Boats.*

1. FULL SCALE TESTS

1.1 Hull particulars of test craft

Hull lines are given in figure 2.

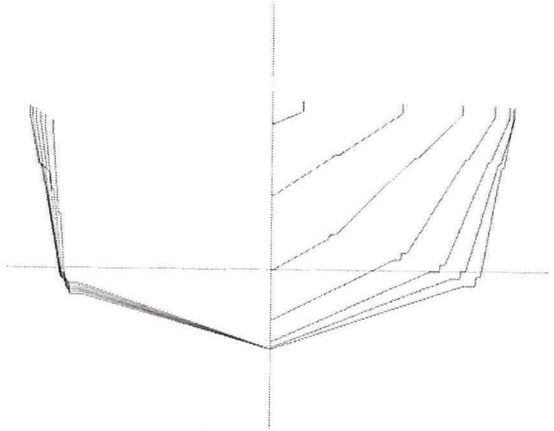

Fig. 2: *Hull lines*

Hull particulars:

Engine	Volvo Penta 190 hp
L_{oa}	6.10 m
L_{pp}	4.75 m
$B_{max\ chine}$	1.9 m
Deadrise	19.5°
Displacement during tests	1550 kg

1.2 Instrumentation

The instrumentation is shown in figures 3-5. It consisted of the following:

- 14 pressure transducers flush with the bottom. The pressure transducers were placed in a three row grid pattern, parallel to the keel in the area of the stagnation line from keel to chine. Longitudinal spacing 0.4 m and transverse spacing 0.2-0.25 m.

- 1 displacement transducer, LVDT, for measurements of panel deflection.
- 6 strain gauges
- 3 vertical accelerometers

Speed was recorded using GPS. One accelerometer was mounted on a piece of PVC foam and used as wave buoy prior and after the test, see figure 6.

In order to get adequate information from slamming load logging frequency was set to 750 Hz. All measurements are filtered using running averages. Accelerations are averaged over 30 data samples, whereas measurements with pressure transducers, strain gauges and LVDT are averaged over 5 data samples.

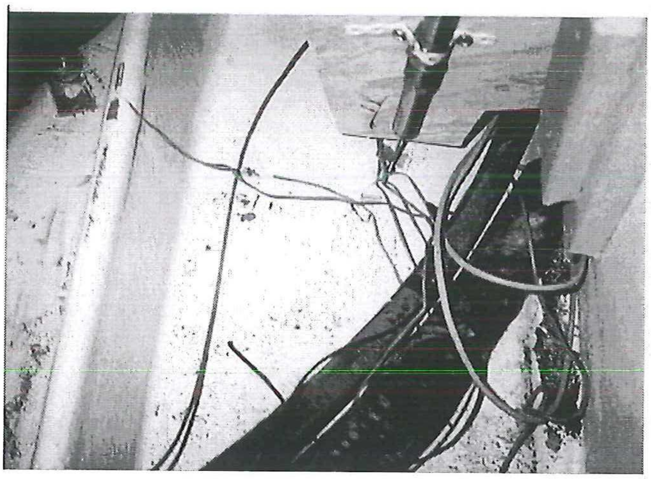

Fig. 3: Instrumentation of aft bottom panel. The displacement transducer (LVDT) is in the upper middle part of the picture. Hidden behind it is a pressure transducer. A pressure transducer is also seen to the left of the longitudinal stiffener. Three strain gauges are seen in the picture, in front of the LVDT, closer to the stiffener, and on top of the stiffener.

1.3 Performed tests

The tests were done with the intention of finding design loads. The boat was therefore run as roughly as possible within reasonable safety, way beyond the limits of comfortable boating. In the most moderate sea condition, significant wave height 0.32 m, it was possible to run the boat at full speed 40 knots. At the higher sea states, significant wave height 0.55 m, the average speed was in excess of 30 knots.

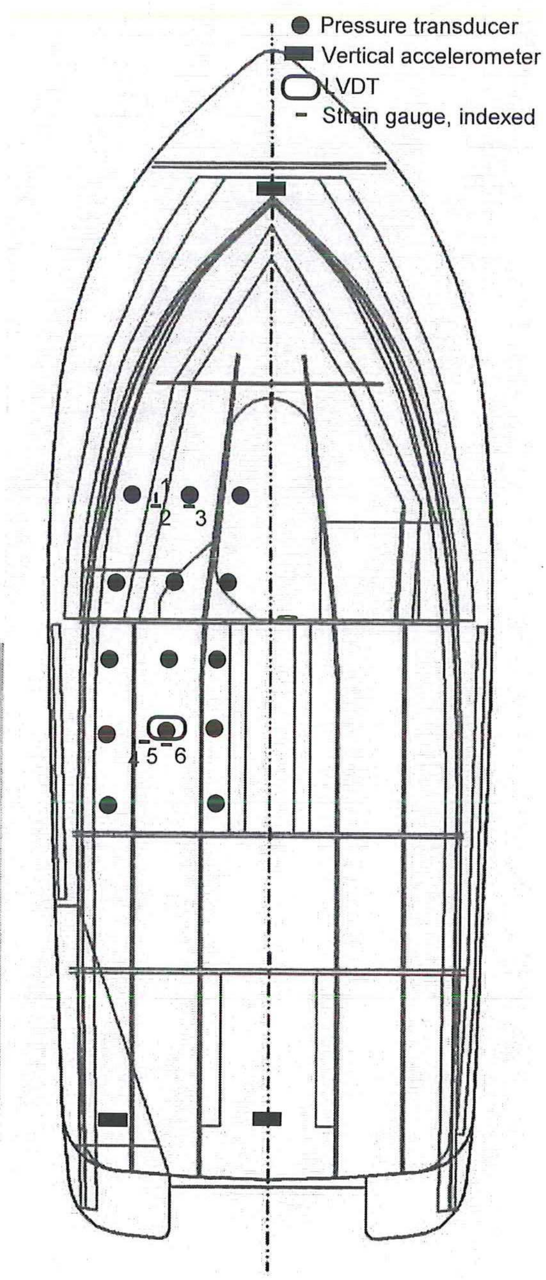

Fig. 4: Instrumentation

Test runs were mainly done in head seas and in following seas. Some runs were done in oblique head waves and in side waves. Most of the tests were performed with displacement 1550 kg. To investigate effect of displacement on hull loads, a full loaded condition of 1870 kg displacement

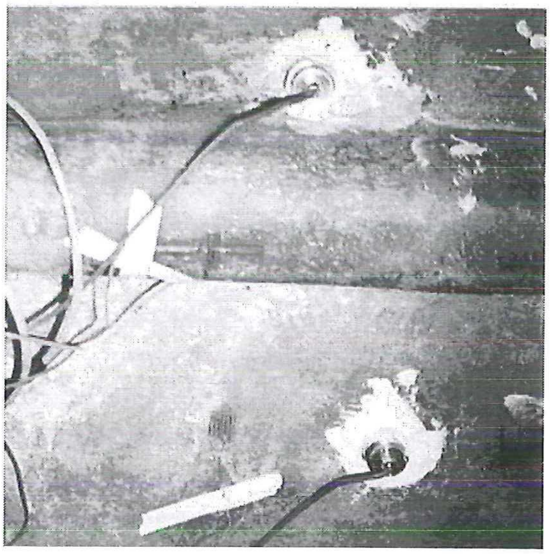

Fig. 5: Forward pressure tranducers. Strain gauges on panel and on the stiffener can also be seen.

using sand bags, was tried on some test runs. In general, the full loaded conditions gave reduced accelerations and pressures and structural response. For full details on performed tests, see [1].

Each recording on a set course and speed lasted 1 and a half to 2 minutes, in order to get enough data for statistics. The boat encountered a wave typically every second.

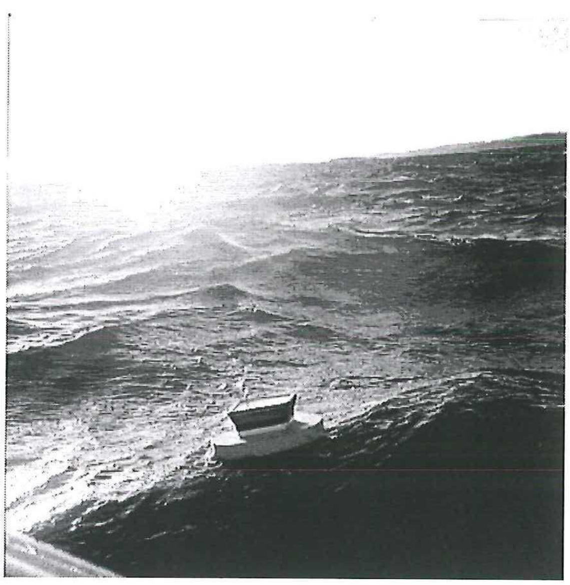

Fig. 6: Wave conditions during tests.

2. TESTS RESULTS

2.1 General remarks

Given here are results from one typical test run in one of the rougher sea states, head waves, significant wave height of 0.55 m and zero up-crossing wave period 2.9 s. Maintained speed was around 30 knots.

2.2 Time series

Plot of vertical accelerations fore and aft are given in figure 7. The boat is typically in the air and free falling for up to half a second. When landing, the aft part of the boat hits the waves first, gets an upward vertical acceleration. This results in a bow down pitch acceleration, so at the same time the forward accelerometer experiences a downward acceleration of up to 3 g. At the next instant the bow hits the water and is accelerated upwards with 5-8 g. This can be seen in the figure for time equal to for example 58, 59 and 64 seconds.

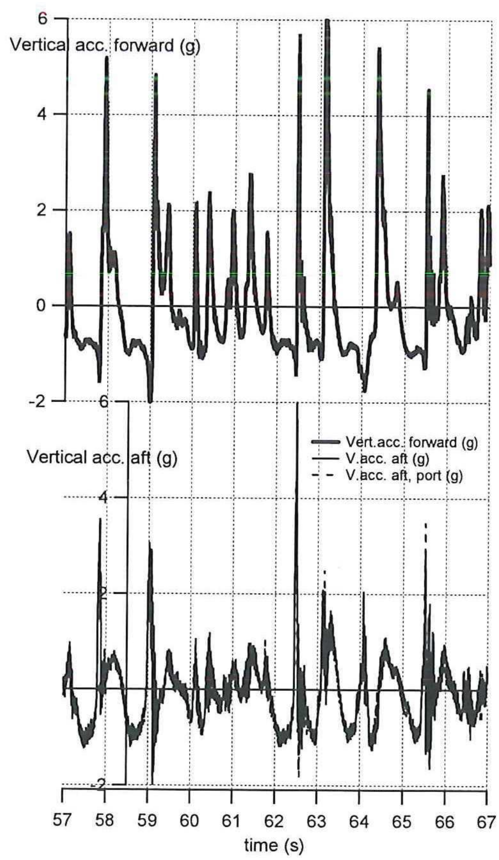

Fig. 7: Vertical accelerations

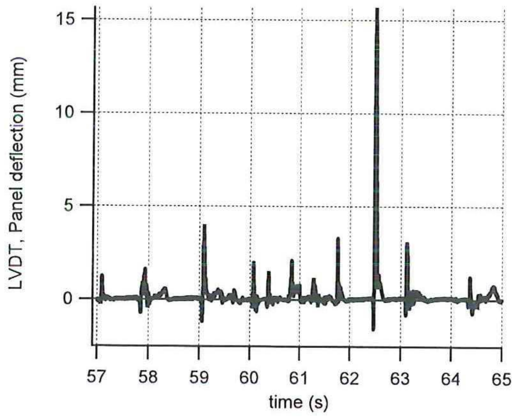

Fig. 8: Panel deflection, LVDT (mm)

This behaviour leads to moderate hull loads in the instrumented area of the hull, with panel deflections about 2-4 mm, figure 8, and 500-1000 micro strain, (0.05-0.1 % elongation) figure 10. Position of maximum loading can be seen to vary between the fore and aft set of strain gauges.

More extreme loads are observed when the hull hits a wave in a certain area. In figure 9, the correlation between average panel pressure, panel deflection and local tension of the inside of the bottom laminate is illustrated. At t=62.5 s, a large hull load is observed for the aft panel. From figure 8, it can be seen that vertical accelerations fore and aft are similar. This indicates that the boat lands on a wave mid-ship, in the vicinity of the aft panel. The panel pressure in figure 9, is the average of the two aft pressure transducers in the middle row, see figure 4.

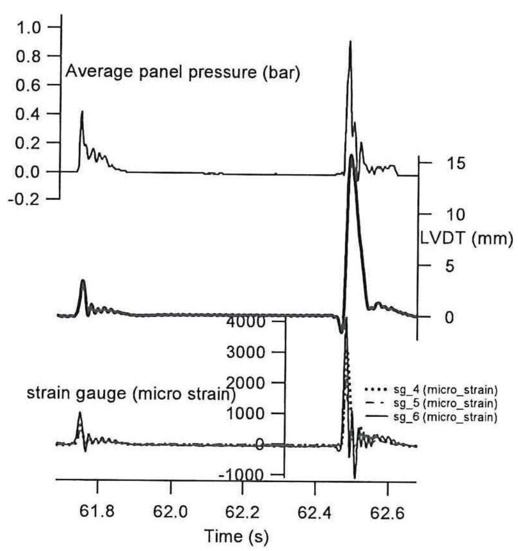

Fig. 9: Average panel pressure, panel deflection and strain gauges on aft panel

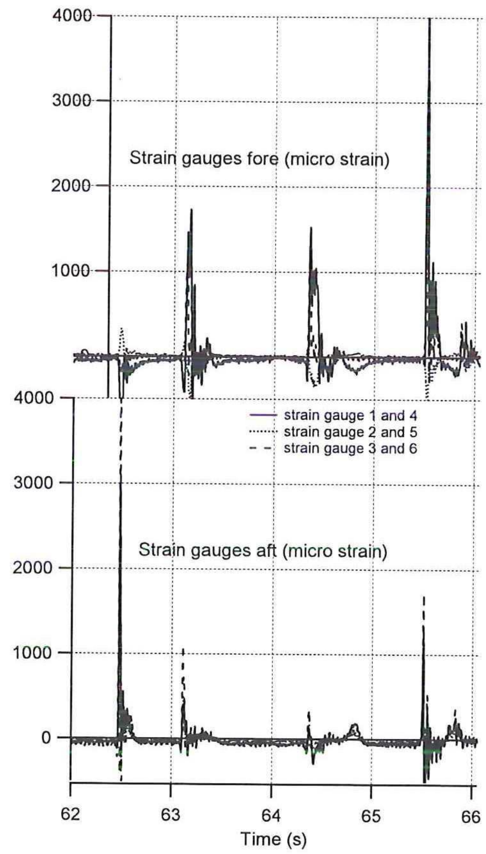

Fig. 10: Strain gauges. Positive values when in tension (micro strain)

2.3 Amplitude distributions

Cumulative probability distributions of positive amplitudes of vertical accelerations and hull structural loads are given in figures 11-14 for the test run.

It can be seen that the incident in figure 10 is rare. From figure 11 it can be seen that 90 % of the panel deflections are less than 8 mm.

Figures 12 and 13 give cumulative amplitude distributions for average pressures. In figure 12, the average for all pressure transducers is seen to exceed 0.4 bar during the test run. In the same figures average pressure amplitudes for the three rows of pressure transducers are given. It can be seen that the inner and outer row are quite similar. The middle row with only four pressure transducer show higher pressures, and even higher for average of the last two transducers. For the middle row a fitted Weibull model is also shown.

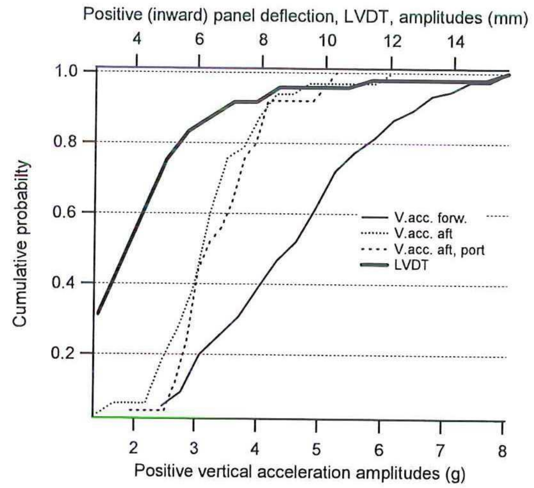

Fig. 11: Cumulative probability of amplitudes of vertical accelerations and panel deflections.

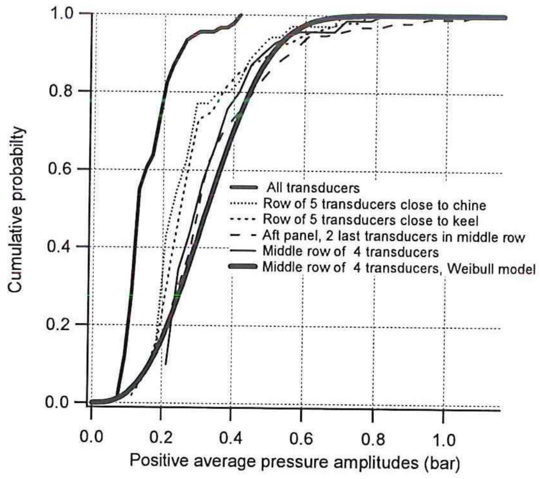

Fig. 12: Cumulative probability of amplitudes of average pressures

In figure 13, the distributions for average pressures depending on longitudinal positions are given. It can be seen that pressure amplitudes are quite evenly distributed, except for the aft two transducers where pressures are lower.

Figure 14 gives cumulative amplitude distributions for the strain gauges 3 and 6 together with fitted Weibull models. Strain gauge 3 was mounted on the bottom panel close to the forward pressure transducer, and strain gauge 6 close to the aft transducer. The results indicate higher hull deflections in the forward panel.

Amplitudes of average pressures and hull deflections have been fitted to a Weibull

probability density distribution, by method of moment.

$$f(x) = \frac{m}{\theta}\left(\frac{m}{\theta}\right)^{m-1} e^{-\left(\frac{m}{\theta}\right)^{m}}$$

where

x- relevant amplitude
m - form parameter
θ - scaling parameter

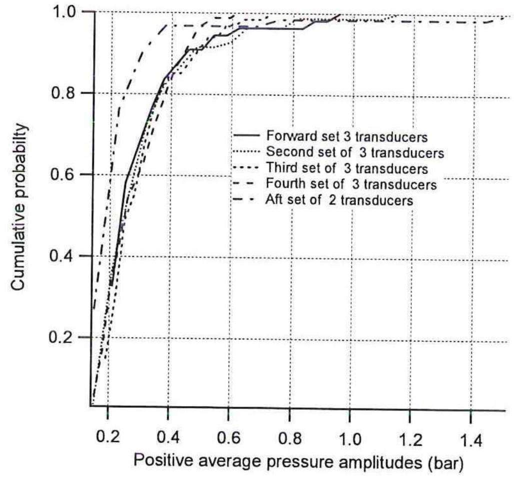

Fig. 13: Cumulative probability of amplitudes of average pressures

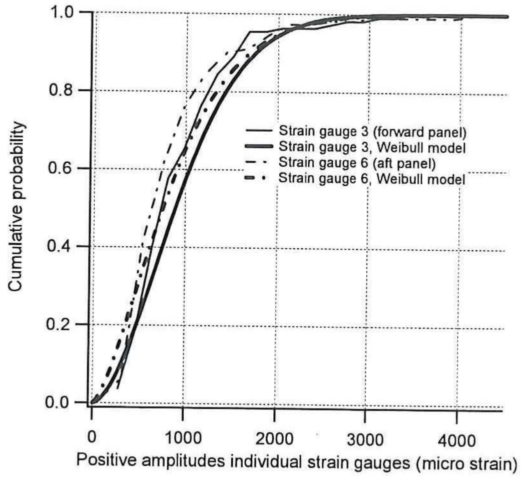

Fig. 14: Cumulative probability of amplitudes for strain gauges

The fitted Weibull model for the amplitude of average pressure for the four transducers in the middle row have, form parameter m=2.74, and scaling parameter θ=0.373. The probability density function is given in figure 15.

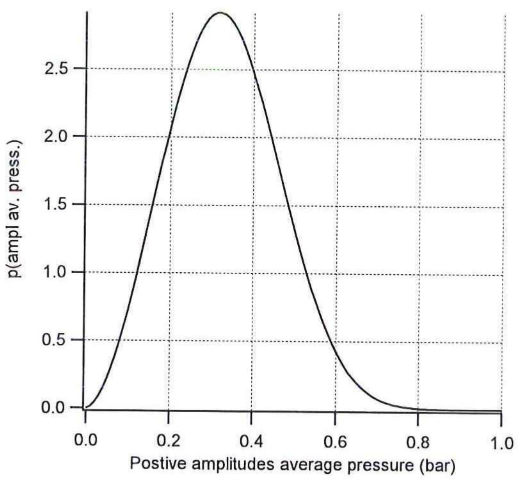

Fig. 15: Weibull probability distribution of amplitudes of average pressure, 4 transducers in middle row

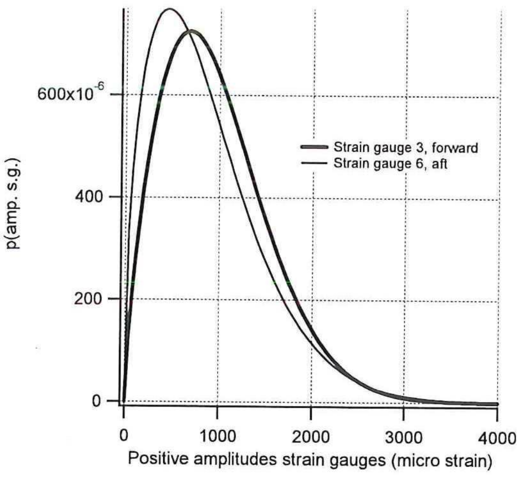

Fig. 16: Weibull probability distribution of amplitudes of strain gauge 3 forward, and 6 aft.

In figure 16 the probability density functions of amplitudes for strain gauges 3 and 6 are given. Values of m and θ are 1.76 / 1096 and 1.48 / 965, respectively.

2.4 Comparisons with design rules

Relevant values of design pressure and minimum laminate thickness are found in [2]. The design pressure for a bottom panel with b=0.33 m and l = 1.05 m, is 0.45 bar for the test craft. Assuming that the average pressure of the four transducers in the middle row represents the pressure on such a panel, it can be seen from figure 12 and 15 that about 15 % of the amplitudes exceeded this design value, during the test run.

Whether the strain gauge measurements indicate damaging hull deflections depend on the laminate properties. Using minimum values stated in [2] for required tensile strength and tensile modulus for GRP laminates, and Hooke's law, an elongation at failure of 1.14 % is obtained.

For a typical marine-type GRP laminate, initial damage, in form of fibre debonding and resin cracking, occurs at a tensile strain of 0.2 to 0.5 of the ultimate value [3]. Using a critical factor of 0.3, this leads to a critical value for elongation equal to 0.34 %, or 3400 micro strain, a value which was exceeded by 1-2 % of the amplitudes of the strain gauge measurements on the bottom panels. Assuming minimum required bending strength stated in [2], the test craft had a laminate thickness somewhat larger than that required. Correcting for this the design pressure is 0.48 bar, which still was exceeded by about 10% of the pressure amplitudes.

CONCLUSIONS

Results from the full scale test indicate that there is a large safety margin in existing rules for required laminate thickness based on design pressures. However, design pressures are too low.

The fitted Weibull models are conservative and can be used in design.

ACKNOWLEDGMENTS

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