PHOTOGRAMMETRIC WAVE PROFILE DETERMINATION

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1. Introduction

In order to carry out a project of determining the water resistance of a ship, the Laboratory of Hydrodynamics of NTU of Athens needed firstly to determine experimentally the wave pattern around certain type of cargo ship (M0047). The above Laboratory have at their disposal a 91x4.5 metres towing tank equipped with a towing bridge capable of moving at variable speeds while at the same time towing a model of a vessel. In addition there are also five electronic probes, which can register the wave height at discrete points, thus producing wave profiles. However these recordings were not considered adequate for the experiment, as it was impossible for the probes to record the wave height over the whole area of interest and especially close to the ship. A different methodology was sought, in order to obtain information about the wave pattern over the whole water surface around the ship model.

Based on previous experience (Calisal et al. 1968, Inui 1981) a photographic method was thought to be more favourable and thus the assistance of our Laboratory was asked. The wave heights were to be determined with an accuracy of 1 mm and only along one side of the model as the wave pattern is considered symmetric for the specific ship moving forward and on a straight line as it was the case in this experiment.

2. The photogrammetric setup

The room under the towing bridge is quite limited (Fig.1) and this fact excluded the use of any metric camera available, which would be the obvious solution for the above accuracy requirements. Moreover steroscopic photography had to be used as we had to deal with a dynamic phenomenon as difficult as the water surface. Further difficulties that had to be overcome were the poor lighting conditions, the lack of any detail points on the water surface, the obvious inability to provide adequate control on the water or the model surface for the orientations and finally the fact that several models had to be processed in order to maintain an adequately large photo scale for the 1 mm accuracy required. A thorough search of the related bibliography proved that such a problem had not been tackled before, in the sense, that up to now, wave patterns
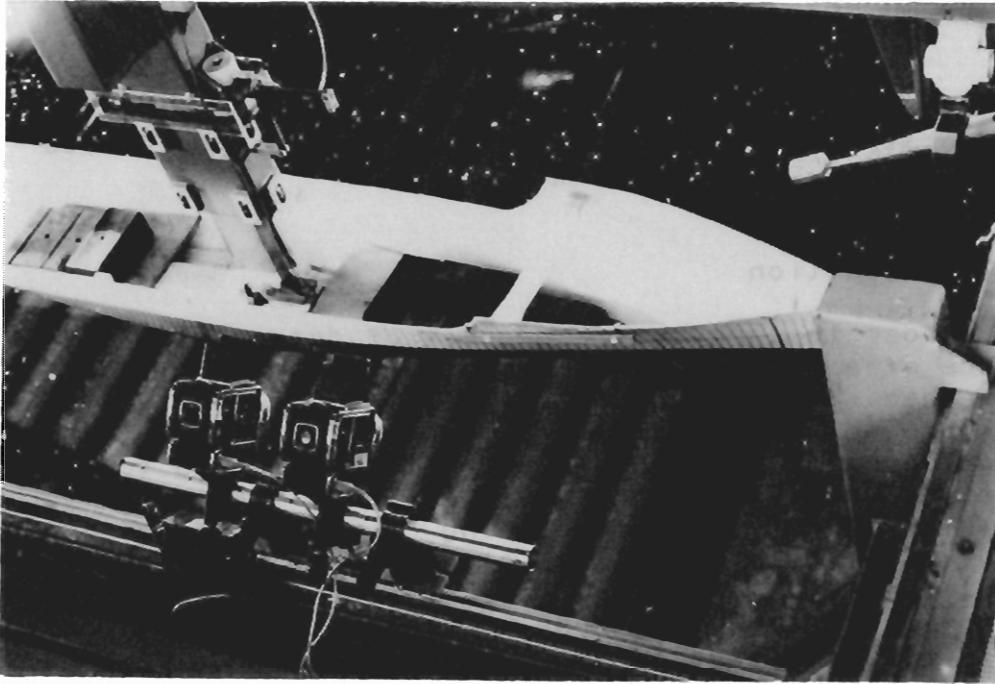
(a) the photogrammetric setup
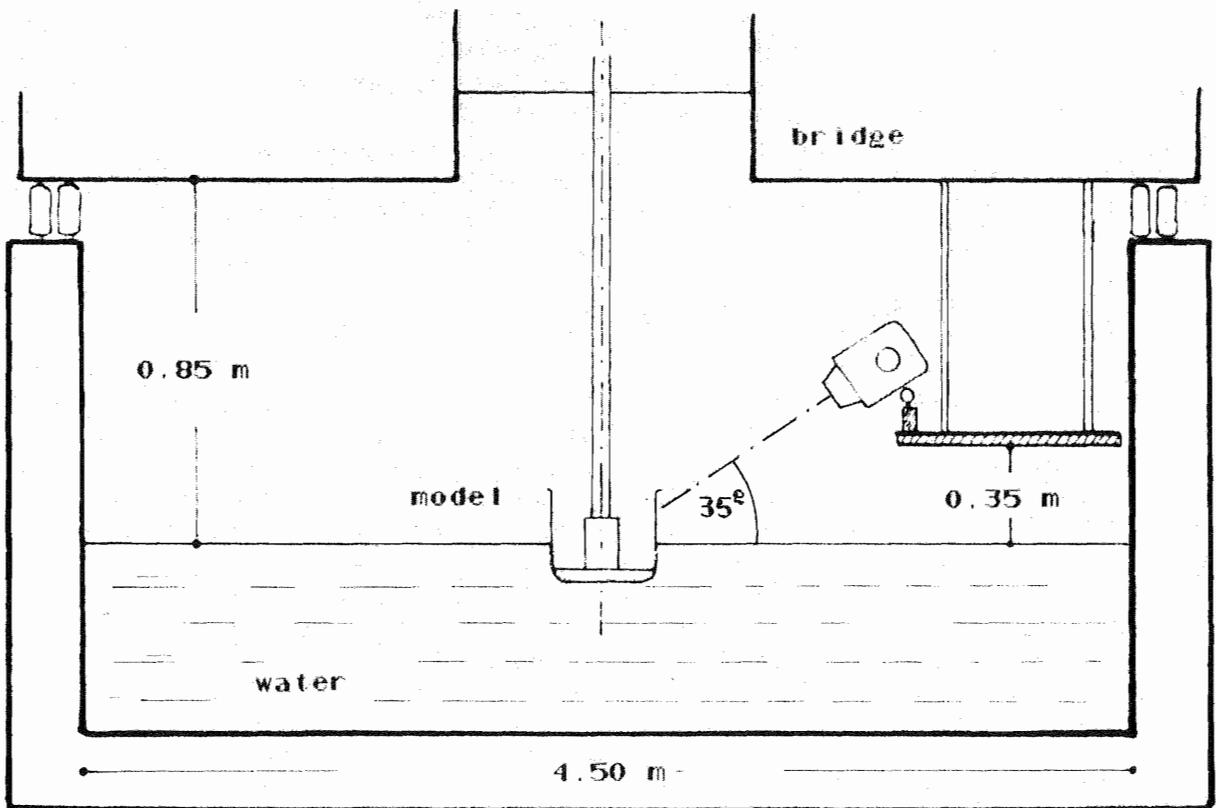
(b) dimensions under the bridge

Fig. 1

were only determined with the cameras stationary (Adams & Pos 1984, Gutu et al. 1984, Szczechowski & Orzechowski 1984).

Two non-metric motor driven cameras, Hasselblad EL/M with normal angle lenses of 80 mm principal distance, were used. The cameras were positioned on a rigid base, which could slide along a specially constructed guiding rail bolted on the towing bridge. In this way the relative position of the cameras remained undisturbed and the coverage of the ship model with stereoscopic models became possible . The two cameras were electronically synchronised and a powerful flash was also attached to the system in order to take care of the poor lighting conditions under the bridge. The cameras were positioned approximately 200 mm apart, at a distance of 1 m from the water line and with an inclination angle of approximately 35 grad. In this way a favourable base-to-distance ratio was ensured, while at the same time maximum possible coverage of the object was obtained. Considering that the photography would be processed analytically on a ZEISS Stereocord G2, the above setup would theoretically provide a sub-millimetre accuracy for the wave heights.
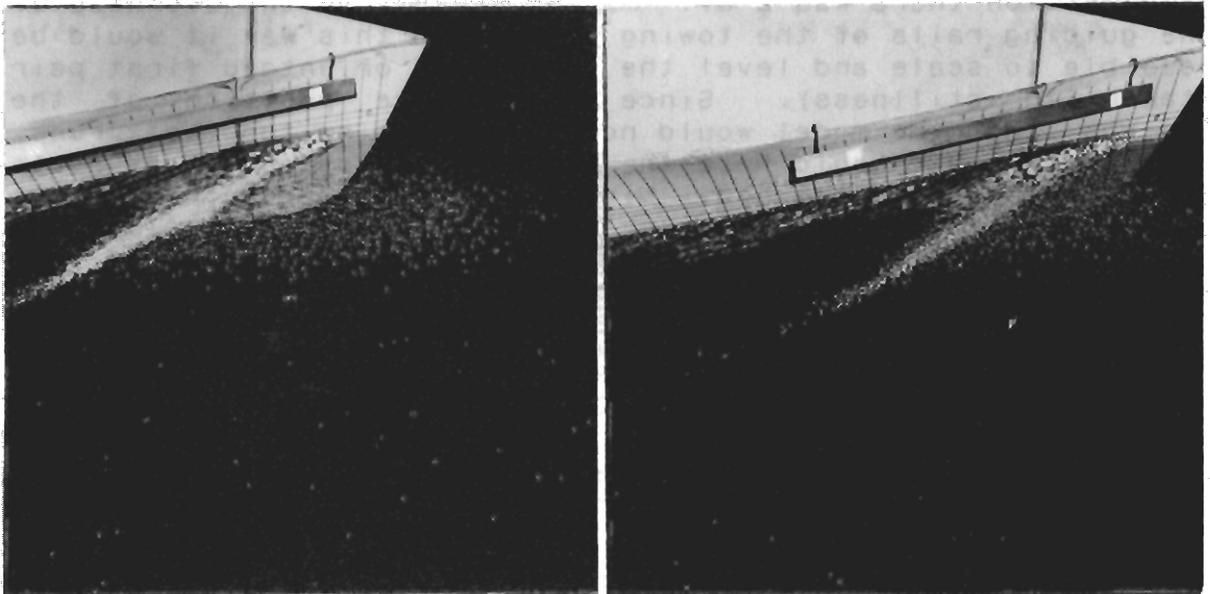

Fig. 2 The first stereopair

The problem of providing detail points on the water surface was solved by spraying, just before the shutters were fired, yellow paper-tape punch of 1 mm diameter on the water surface. As for the basic control for the orientations, a light aluminium bar, bearing two self-adhesive retro-targets at a precisely measured distance of 283 mm, was simply hung on the ship model (Fig.2) in order to provide scale information. Besides a precisely drawn grid on the outer surface of the ship model proved later to be very useful. for connecting the models and for bringing them to the same system to the same system. Several tests were carried out in order to determine the optimum shutter speed and relative aperture combination, as well as the correct timing of the 'detail point' spraying.

The major problem remaining to be solved was that of levelling the stereoscopic models, since there was no information whatsoever as to the exact position of the horizontal water surface. This was tackled as follows: For every stereoscopic model two pairs were taken consecutively. The first one with the bridge, the ship model and the water surface in complete stillness. After that and without changing the position of the cameras the second one was taken while the towing bridge had reached its predetermined speed of approximately 1.346 m/s. It should be noted that, by its construction there was a 0.1 mm uncertainty of the evenness of the guiding rails of the towing bridge. In this way it would be possible to scale and level the relatively orientaed first pair (taken in stillness). Since the relative position of the cameras and the model would not change during the test runs, the second pair would have the same attributes as far as scale and levelling is concerned. Nine pairs of stereoscopic models were needed in order to cover the area of interest alongside the whole model, including the water surface just behind the vessel (Fig.3).
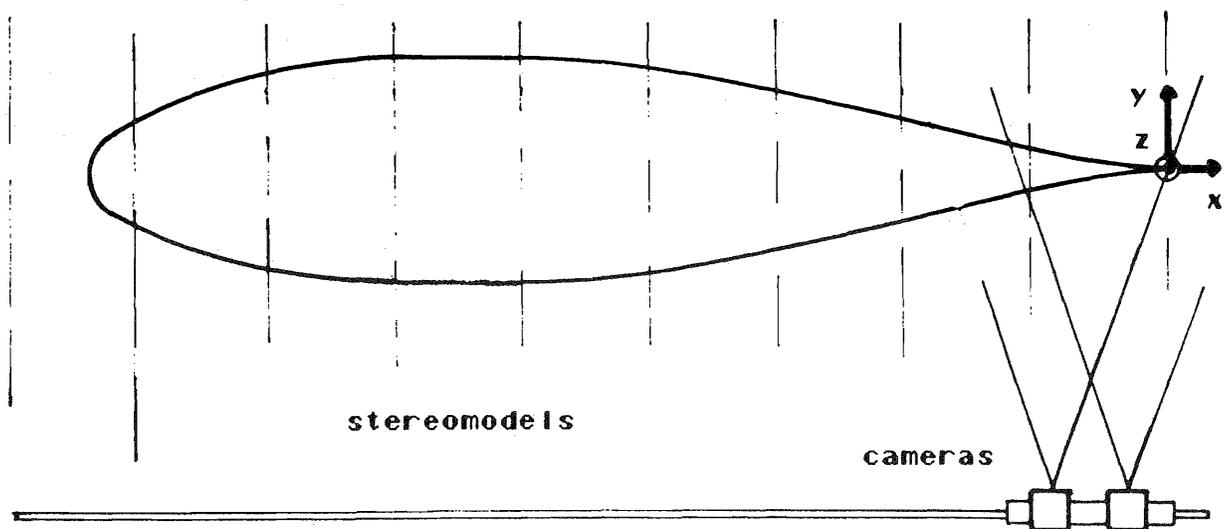

Fig. 3 Stereo coverage and the reference system

3. Processing of the data

The photogrammetric processing of the photography was carried out on a ZEISS Stereocord G2 connected via a DIREC 1 unit to a Hewlett Packard 9845S desktop computer (Fig. 4). As this instrument uses photographic prints the negatives were printed on paper with a 2x magnification in such a way that the frame of the negative appeared on the prints. In this way any shrinkage could be accommodated using the mean values of the dimensions of the negatives, several of which were previously measured on a Heyde monocomparator. Moreover the centre of the frame was also determined analytically, in order to provide an origin for the plate co-ordinates. The scale of the prints was approximately 1:6.5. The two cameras were also calibrated for very close focal settings (Scott & Georgopoulos, 1980) and the Stereocord measurements were corrected accordingly.
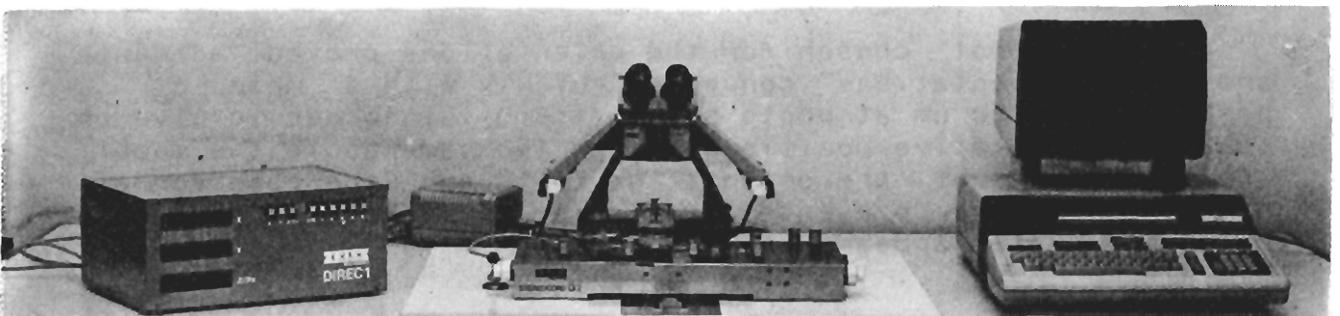

Fig. 4 The instrumentation

The plate co-ordinates of the first of the two pairs for each model, corrected as described above and produced by the Stereocord measurements, were used as input to an aerial triangulation programme (Ioannidis & Badekas 1986). This programme used as observation equations, apart from the collinearity equations, the known distance and an arbitrary set direction with an increased weight. The co-ordinates of the origin of the system were also used as pseudo-observations. The a priori uncertainties used were 0.1 mm for the known distance (283 mm) and the plate co-ordinates and 0.0001 grad for the direction. For this procedure the points observed were (a) the two targets on the aluminium bar for the scale, (b) two points on the grid of the ship model for the direction and for the connection of the models later and (c) eight points on the water surface to provide information about the horizontal plane. The triangulation program was run off-line on a CDC

Cyber 171 mainframe computer connected to the HP 9845S (Fig.5).
The resulting exterior orientation elements from this program
were fed to the HP 9845S and the orientation was confirmed with
the help of the already observed points. Further checks were
provided by observing all grid points on the ship, the two
targets on the aluminium bar and several points on the still
water surface.

Next the second pair was inserted on the stage plates at
exactly the same positions as the first one. As the orientation
was the same and already determined a great number of points
were observed on the waves and their X, Y and Z co-ordinates
were determined. Observations to the targets, the same grid
points as in the first pair were used to confirm the precision
of the resection and intersection processes.

4. Practical results

The control chosen for the orientations proved adequate
and the orientations converged quickly with a mean σ_0 a
posteriori of 50 µm at photo scale (1:6.5). In order to give an
idea of the relative positions of the two cameras to the model,
the mean values of the orientation tilts and the base for all
nine models are presented in Table 1. The corresponding
reference system appears in Fig. 3.

ω = 35 grad   ranging   from 31.22 to 40.21 grad
ϕ = -2.5 grad   ranging   from -3.84 to 5.29 grad
κ = -3.3 grad   ranging   from -5.08 to 5.79 grad
B = 246 mm   ranging   from 222.0 to 279.0 mm

Table 1

As already mentioned before, the precision of the
orientations was confirmed with the help of observations to
points of known relative positions. Such points were all the
points on the grid of the ship model and points on the still
water surface. The discrepancies determined were 0.90 mm for
the plan position measured in 117 grid points and 1.30 mm for
the heights determined from 225 points, which was considered
just within the initial requirements. Check measurements were
also carried out on 126 grid points in the second pair of each
model, taken with the bridge moving. These resulted to a rms of
0.85 mm in X and 1.44 mm in Z, ie. practically the same results
as in the case of the pairs in stillness.

For the actual measurements a total of 1229 points were observed in all models ranging from 75 to 184 points for each one.Considering that the area covered was approximately 0.80m^2, this corresponds to 16 points per square decimeter or 1600 points in a square meter. The co-ordinates of these points were used as input to a contouring programme in the CDC Cyber 171 computer. The contours were plotted at a 1:1 scale with 1 mm interval for every model together with the plan position of the points observed. A careful editing of the plots was considered necessary in order to smooth 'noisy' areas and even the seams of the plots. Approximately 15% of the observed points were removed and the contouring programme was run again to produce final plots. This editing was considered necessary in order to get rid of points that (a) were situated outside the area of interest and disturbed the shape of the contours at the border of the plot (about 4%), (b) presented obvious gross errors (about 3%) and (c) presented a height difference of less than 2 mm from their neighbouring points and caused severe unevenness to the contours (about 8%).

In order to refer all measurements to the same co-ordinate system the following technique was used. From the 1:1 construction drawing of the ship model the corresponding grid points were digitised on a Calcomp 9100 digitiser. Thus the necessary information was obtained in order to transform the nine individual systems to a common one complying with the requirements set by the Laboratory of Hydrodynamics. This co-ordinate transformation involved the two translations and the rotation (ΔX, ΔY and K) that had been set arbitrarily at the stage where the model was absolutely oriented. As an example the corresponding contour plot for the first two models is presented in Fig. 6.

5. Discussion of the results

Despite the adverse conditions at the beginning of the project, the accuracy requirements have been successfully met. It has been proven, once more, that non-metric cameras with relatively large distortion values may well enable measurements of acceptable accuracy, provided analytical processing is used. The solutions adopted for this experiment are certainly not the best ones. For instance, the paper tape punch was rather big for accurate pointing and care should always be taken as to the exact positioning of the mark on the water surface nearby. The spraying of these points was also problematic, as it was done manually and it was rather impossible to time it and execute it perfectly for all test runs. This led to the decision to increase the number of photos and choose the best ones later.

Moreover even the crude construction of the Stereocord G2 would not allow the accommodation of large height differences

in the model, thus not allowing the use of points on still water surface close to the cameras as check points or even as orientation points for the pairs taken with the model in movement. The use of paper prints, forced initially by the instrument, and although it was established later that diapositives could also be used under certain conditions, presented no special problems; to this aided the fact that a shrinkage correction was included in the calculations.
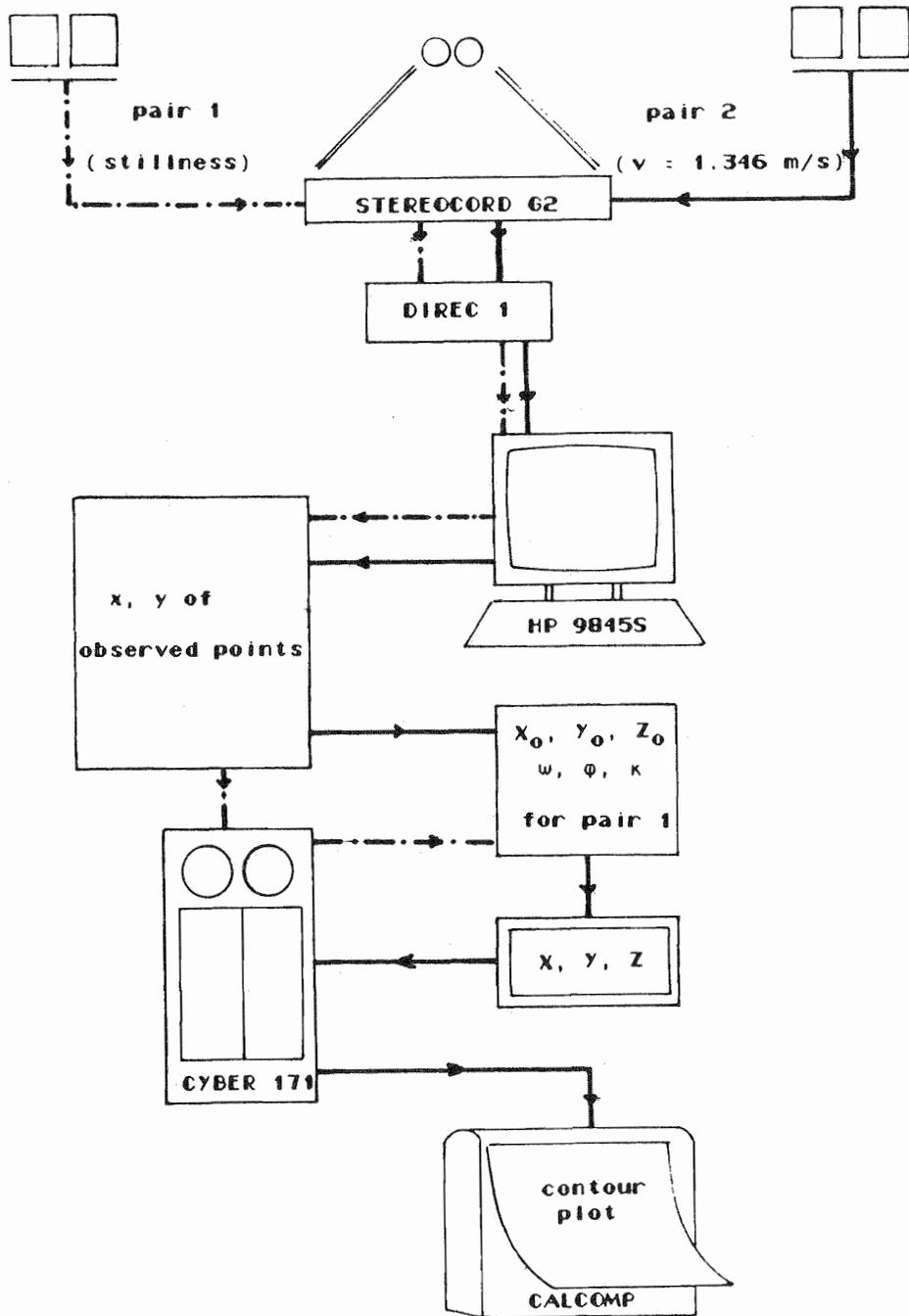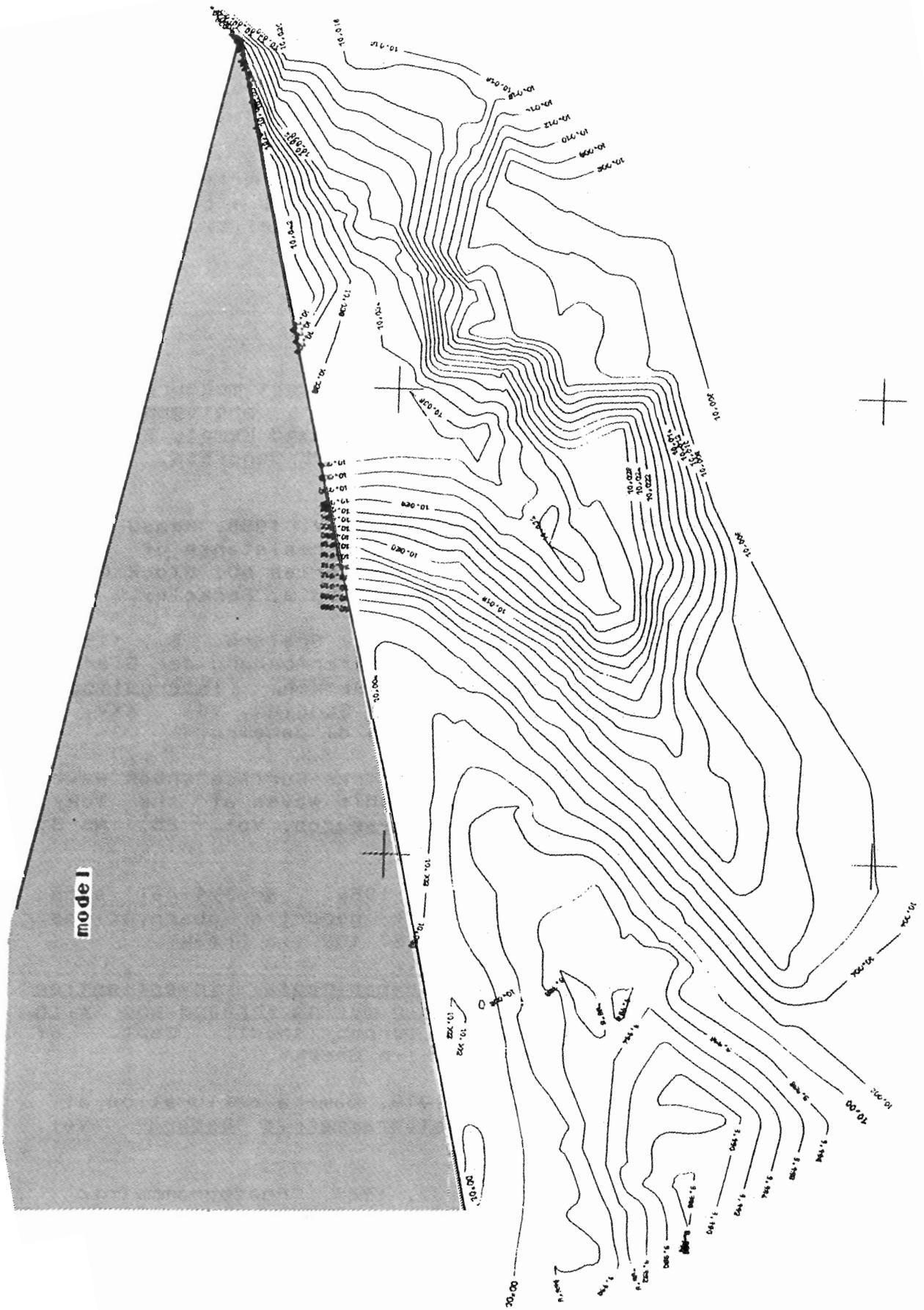
Fig. 5 Flow of the calculations

Fig. 6 Contour plot, scale 1:3.5

It is obvious that the aerotriangulation programme could not be used for all nine models, because there was no way to define the same co-ordinate system for the whole ship. The control provided was minimal, but the a posteriori σ_0 ensured the theoretical strength of the results. As already mentioned check pointings on known points proved this in practice as well.

Summarising, an accuracy of just over a millimetre was achieved for the wave heights and, consequently, a contour plot with a 2 mm interval is within the required fidelity.

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