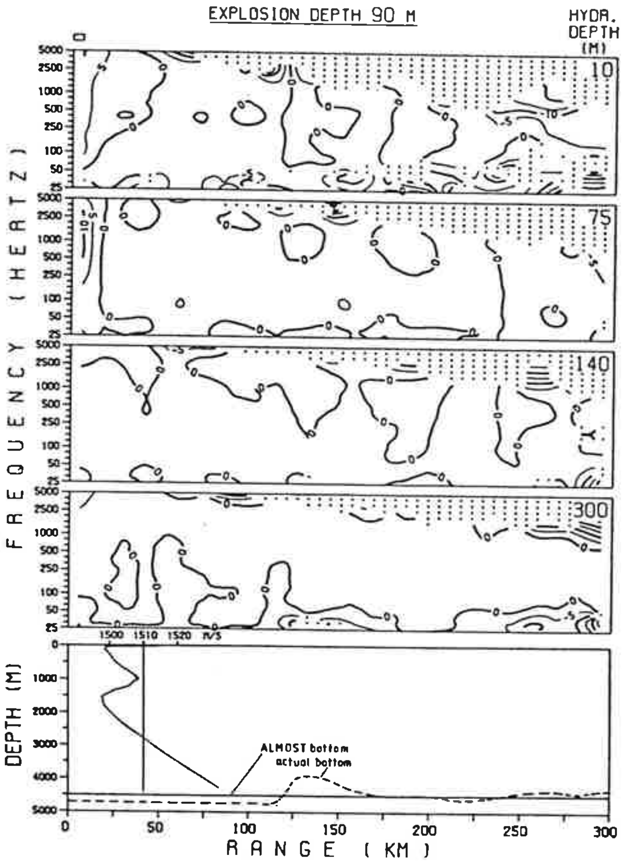

Figuur 5 Propagatieverliesverschil (dB) tussen de gemeten data en die van ALMOST.

REFERENTIE

[1] Urick, R.J., *Principles of underwater sound*, McGraw-Hill Book Company. New York, 2nd ed., 1975.

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AKOESTISCHE VORM- EN STANDMETINGEN VAN GESLEEPTE SONAR ARRAYS

dr.ir. E.C. van Ballegooijen
Fysisch en Elektronisch Laboratorium TNO
Postbus 96864, 2509 JG 's-Gravenhage

MEASUREMENT OF POSITION, SHAPE AND ATTITUDE OF A TOWED ARRAY

Summary: A brief introduction is presented of the so-called 'shot-firing' method that is used for the three-dimensional determination of the position, shape and attitude of a hydrophone array towed from a surface vessel. The method employs the travel time differences of impulsive waves measured across the array and a reference hydrophone aboard the tow ship. The waves are generated by two small explosive charges dropped from two consorts. The method is not for operational use and is intended as an alternative to the use of fixed test ranges and provides results suitable for validating computer models of array motion. It allows making snapshots of the array at regular time intervals at a maximum rate of about 3 snapshots per minute.
A measurement concerning the position, shape and attitude of a towed array during manoeuvres is discussed as an illustrative example. The tow configuration consisted of a tow cable of about 800 m, a vibration isolation section (VIM) of about 300 m, followed by an acoustic section of about 300 m and again about 100 m of VIM's. An error analysis is carried out in order to find the accuracy of the results obtained. It can be shown that the hydrophone positions can be determined within decimeter range.

1 INTRODUCTION

A towed array consists of a neutrally buoyant acoustically transparent hose of a length of tens to hundreds of meters and containing a line of hydrophones. The array is usually equipped with auxiliary instruments such as heading and depth sensors. The array is towed from a ship by an electric strain cable. Towed arrays are widely used in military sonar systems and for seismic subsurface exploration.

In order to obtain maximum benefit of a towed array it is necessary to know its shape and attitude. This enables processing of acoustic data even in the case of a bent array, for example during manoeuvres of the tow vessel. Consequently the array is equipped with auxiliary sensors which measure array heading and depth continuously and hence enable a continuous estimate of array shape and attitude to be found [1]. However, such an estimation must be validated by comparison with an alternative and independent method. Results obtained by means of this method are therefore compared with corresponding results of array shape and attitude estimation. The technique for shape estimation using auxiliary sensor measurements is not subject of this paper and will not be discussed. It uses a hydrodynamic model in conjunction with the measurements to derive the best shape estimate.

A 'shot-firing' method, introduced in 1988, has been used to examine the 3D dynamic motion of an array towed from a surface vessel [2]. For a more comprehensive description of this method the reader is referred to Van Ballegooijen et al. [3]. The method requires no modifications to the array and allows measurement of dynamic motion under operational conditions. It employs travel time differences measured between hydrophones in the array and a reference hydrophone aboard the tow vessel. These differences are obtained from various signal arrivals. The impulsive signal arrivals are generated by two small charges dropped from two well-positioned consort vessels. The signals are digitally recorded, using a sampling frequency of 5 kHz. Using the measured arrival times, the position of the explosion points and some additional data on the vertical sound speed profile, course and speed of the tow vessel etc, a set of 6 non-linear equations can be found that can be solved for the location of an array hydrophone relative to the reference hydrophone aboard the tow vessel [3]. If certain conditions are met snapshots of the array position, shape and attitude can be provided at a maximum rate of about 3 per minute. Here, we will present the results of an experiment that can be considered as an illustrative example of the 'shot-firing' method.

2 TOW CONFIGURATION

The tow configuration is as follows: a tow cable of about 800 m, Vibration Isolation Modules (VIM's) with a total length of 320 m, an acoustic section of about 300 m, finally followed by about 100 m of VIM's. The array is equipped with 4 heading (H) and depth (D) sensors. The positions are indicated in figure 1. A total of 28 hydrophones in the acoustic section is selected to measure shape.

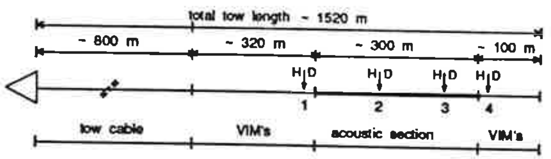

Figure 1 The tow configuration.

3 ARRAY POSITION AND SHAPE

Results are presented for a 90° turn to port at 10 knots with turning radius of 500 m. During this run 33 snapshots were taken at time intervals of 20 s, except for snapshots 1 through 8 and 29 through 33, where the time interval was 1 minute, giving a total duration of 18 minutes. First the results concerning the position of the array throughout the manoeuvre are presented, followed by some detailed array shapes.

Figure 2 gives the position of the array relative to the tow vessel. Two snapshots, snapshots 5 and 9, are missing due to misfires. It is clear that the array cuts the corner and array depth will therefore increase during the manoeuvre. This effect is depicted in the insert, where the depth of the first hydrophone is plotted. The position and orientation of each individual snapshot in figure 2 is determined by the observed speed and gyro course of the tow vessel. Because the describing coordinate system, in which the position of the array is measured, is related to the gyro course of the tow vessel [3] uncertainties in the gyro course of the tow vessel will cause orientation errors of about 1° between the successive snapshots in the position of array. This effect becomes more pronounced during the turning of the tow vessel, because gyro course is then changing very rapidly and the error in the observed gyro course will increase. However, these errors will hardly influence the array shape. The problem can be largely overcome by increasing the sampling frequency of gyro course and by smoothing the data. At the end of the run the array shows a drift angle of about 6° with the track of the tow vessel, which is consistent with the prevailing wind direction.

Such a measurement of the behaviour of the overall position of the array during a manoeuvre can be very well used as an independent check for the results of models on hydrodynamic array modelling.

In figures 3a, 3b and 3c the detailed array shapes in the horizontal xy-plane (like an air-photo), are shown for the snapshots 1, 29 and 33, respectively. The crosses refer to the measured hydrophone positions.

Before going into the turn the array may be considered as straight (fig. 3a), in the middle of the turn the array is clearly bent (fig. 3b), while at the end of the manoeuvre the array becomes straight again (fig. 3c). Since the orientation of the array is taken out of these plots the drift angle of the array at the end of the manoeuvre is not observable from these plots.

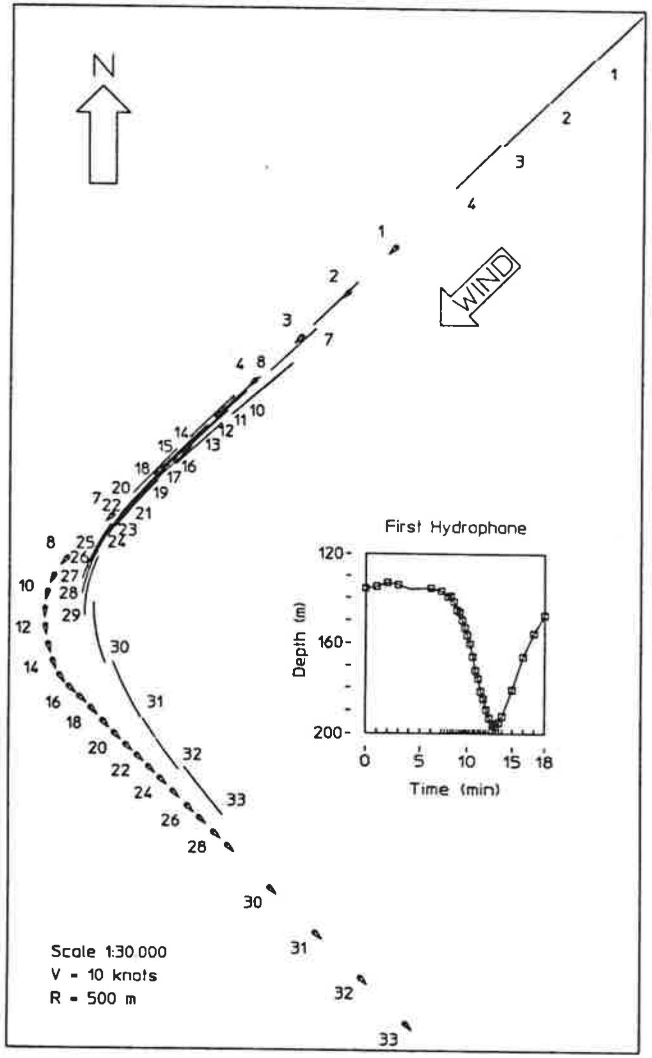

Figure 2 The position of a towed array throughout the 90° turn with radius 500 m.

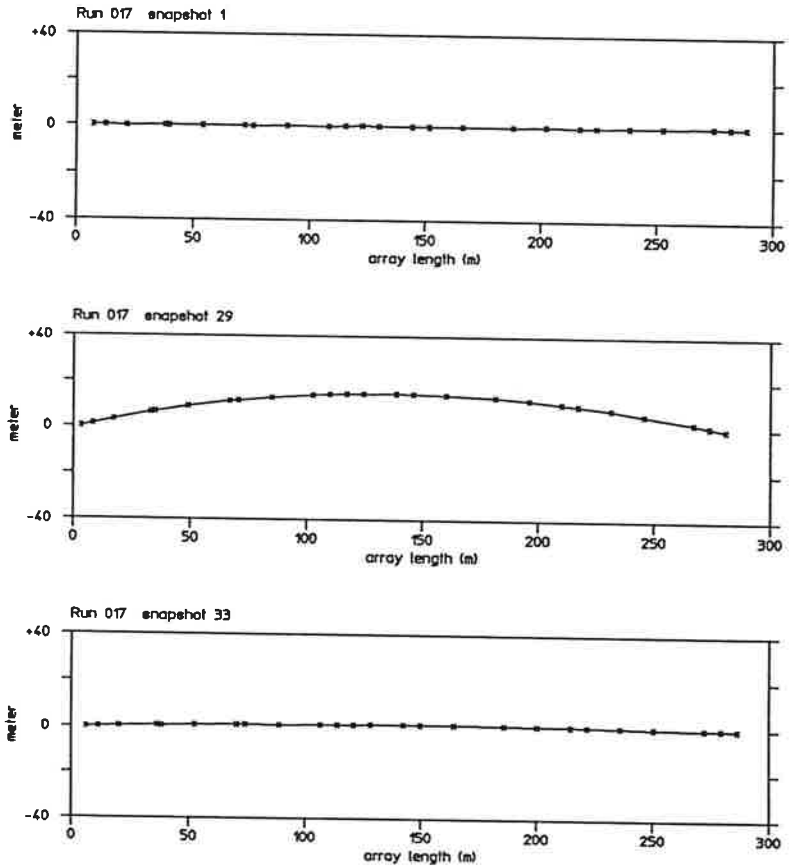

Figure 3 The detailed array shapes in the horizontal plane for the snapshots 1 (a), 29 (b) and 33 (c), respectively.

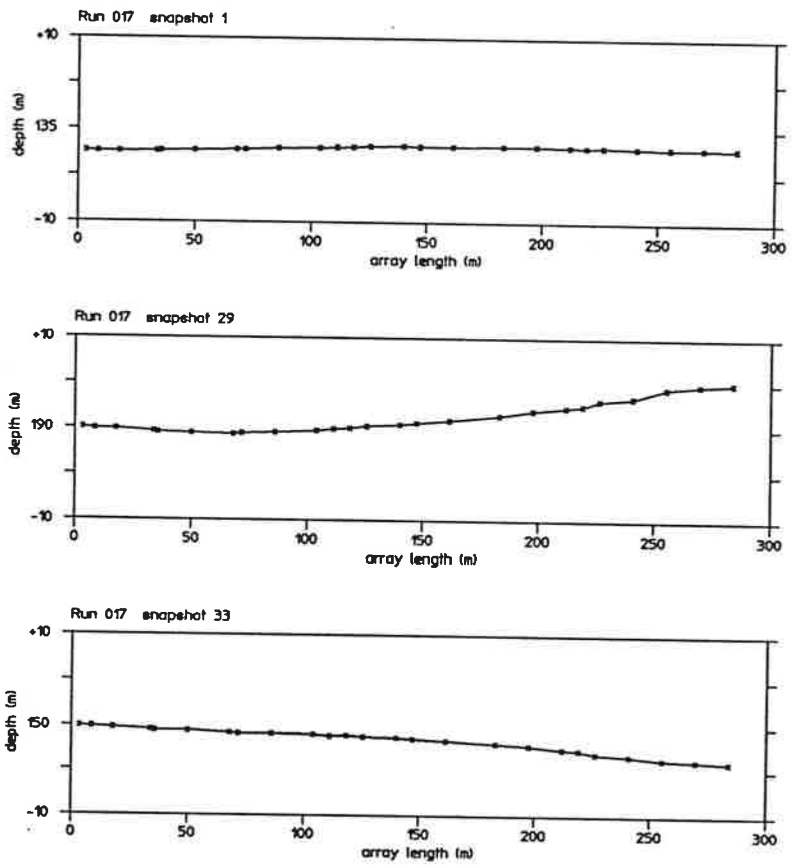

Figure 4 The detailed depth profiles in the vertical plane for the snapshots 1 (a), 29 (b) and 33 (c), respectively.

The detailed depth profiles show quite clearly that since the array cuts the corner, it sinks during the turn. The depth of the first hydrophone, varies from about 135 m to 190 m and back to 150 m, as is shown in figure 4a, 4b and 4c, respectively.

These detailed snapshots are used to compare with the results following from the shape estimation methods, based on the in-hose auxiliary sensors (heading and depth) [1].

4 ACCURACY

The 'intrinsic' accuracy of the 'shot-firing' method is determined by the sampling frequency. In this case a sampling frequency of 5 kHz was applied, giving a spatial resolution of about 0.30 m at an average sound speed of 1500 m/s, by which the arrivals can be determined. In practice this accuracy is increased to about 0.15 m, because the arrival times are obtained by interpolation. It is clear that increasing the sampling frequency allows a more accurate determination of the arrival times. However, the total throughput of data in the data acquisition system is limited and therefore either the number of recorded hydrophones or the sampling frequency has to be limited.

The accuracy in the hydrophone positions further depends largely on the accuracy by which the position of the explosion points can be determined as well as on the accuracy of the observed course and speed of the tow vessel. These positions are determined by measuring the consort positions and correcting for the displacement of the tow ship because of the delay between charge drop and detonation. Range and bearing of each consort is determined by triangulation over a fixed base-line (68.15 m) aboard the tow vessel using two laser rangefinders (LRF's). The ultimate bearing accuracy depends on the angle of view to the consorts. Accurate bearing measurements, say within 0.5°, require that this angle of view does not become too small. Also the angle between the two direct shock waves from the two charges may not become too small [3]. These demands limit the freedom to position the consorts relative to the tow vessel and the array (experimental geometry). The sensitivity of the shape/attitude results to errors in the position of the explosion points depends strongly on the experimental geometry. Since the position of the array is not known a priori it has to be estimated when designing the experiments. The accuracy of the measured array shapes is investigated using a numerical determination of the first and second order derivatives in the computed hydrophone locations as a result from variation of the explosion point positions using a fixed grid of 3 times 3 points in the horizontal plane and 2 points, above and below the centre point, for the depth variation. Estimates of the accuracy in the explosion positions, which may vary between snapshots due the changing experimental geometry during the run, are then used to compute the resulting variation in the array length. The observed stretch and its computed accuracy, indicated by the vertical bars, are plotted in figure 5. The different accuracies reflect the effects of the changing experimental geometry during the run. Load-extension curves of the array indicate that at speeds of about 10 knots the array will be stretched by about 0.4%. The observed average stretch at this speed of about 0.3% matches very well with the expected values. These figures indicate that the results of the calculations are expected to be good. In fact, this is a simple way of getting an impression of the quality of the measurements. A more comprehensive accuracy analysis confirms

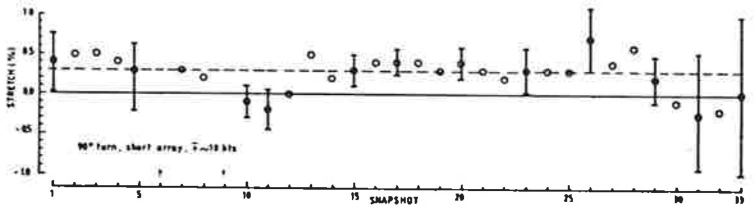

Figure 5 The observed stretch (%) of the array during the 90° turn. The vertical bars denote the accuracy range. The question marks indicate missing snapshots.

that the array position, shape and attitude results are very good and can be very well used to check with the results from shape estimation methods [4].

5 CONCLUSIONS

In general the 'shot-firing' method has proven its capability to measure position, shape and attitude of towed arrays during a number of trials and is now being used as a reference for shape estimation based on in-hose auxiliary sensors and hydrodynamic modelling of tow cable and arrays. However, the method requires careful design of the performance of the experiments to obtain maximum accuracy.

An important cause of inaccuracy in the 'shot-firing' method arises because of the laser range finder technique used. New instrumentation has been developed which provides direct bearing measurements of the consort positions to an accuracy better than 0.1° on all bearings. This overcomes one of the major constraints by permitting better experimental geometry and hence overall accuracy will be improved. Orientation errors can be reduced by the use of improved data-logging of ocean log data onboard the tow vessel. With these improvements the method is expected to determine the hydrophone positions within the 0.1 m range in all directions.

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