S/L Sjøfalk

Survey Report

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REPORT

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ABSTRACT

In May 2004, a dual EM3000 system was mounted on S/L Sjøfalk. This report describes the establishment of the vessel coordinate system, the determination of transducer orientation angles, and the determination of the attitude and heading sensor orientation angles.

The transducer orientation angles were determined from a survey conducted on May 13th and 14th 2004. The attitude sensor mounting angles were determined from surveys conducted on June 7th , 8th , 9th and 24th 2004.

KEY WORDS

Vessel coordinates

Transducer orientation

Attitude calibration

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Introduction

The Norwegian Hydrographic Service has carried out a survey of the Survey Launch (S/L) Sjøfalk. All the measurements were done while the vessel was located in Stavanger during May and June 2004.

Main tasks:

1. Establishment of vessel coordinate system
2. Determination of the orientation of the two EM3000D echo sounder transducers relative to the vessel coordinate system.
3. Determination of the orientation angles of the attitude and heading sensors

A measuring tool, developed at The Norwegian Hydrographic Service, was mounted directly on to the transducer and utilized to obtain the transducer orientation (see chapter 2). To prepare for the motion sensor calibration, six mounting brackets for GPS-antennas were also established, and related to the vessel coordinate system. The motion sensor calibration was based on comparing the motion sensor output with GPS-achieved motion parameters.

1. Establishment of vessel coordinate system

Definition of the vessel coordinate system

The vessel coordinates system is a left-handed coordinate system with the X-axis alongside and directed fore, the Y-axis transverse and directed starboard and the Z-axis vertical and directed up. The origin is placed near to the centre of mass.

Fieldwork

Traditional land survey with total station was carried out May 13th and 14th 2004. A total of 21 benchmarks in the vessel coordinate system were surveyed. In order to determine the position and orientation of the transducers, a total of 32 points related to the transducer coordinate systems were surveyed also. All the benchmarks were observed from at least two of the 5 survey stations.

List of benchmark coordinates

This chapter gives benchmark coordinates in the vessel coordinate system.

Table 1 Final vessel coordinates

Bench-Mark	X-coordinate (m)	Y-coordinate (m)	Z-coordinate (m)	Description
1	-5.5553	-0.3684	-0.6334	Rudder (port)
2	-5.5601	0.3850	-0.6265	Rudder (starboard)
3	4.2992	-0.0015	-0.3184	Keel (fore)
4	5.1698	0.0293	2.5429	GPS-bar at bow
5	-4.7548	1.4704	1.5948	GPS-bar starboard stern
6	-3.9920	1.0407	3.0285	GPS-bar wheelhouse roof (starboard, aft)
7	-3.9802	-1.0473	3.0266	GPS-bar wheelhouse roof (port, aft)
8	-0.5856	1.0530	3.4032	GPS-bar wheelhouse roof (starboard, fore)
9	-0.5937	-1.0498	3.4026	GPS-bar wheelhouse roof (port, fore)
10	-3.4528	0.9685	4.0044	Starboard Seapath antenna fitting
11	-3.4435	-0.9430	4.0034	Port Seapath antenna fitting
12	-3.4494	0.0102	4.0023	GPS navigation antenna fitting
13	-4.0507	-1.6612	1.2273	Lift eye skrew (port, stern)
14	-4.0772	1.6291	1.2335	Lift eye skrew (starboard, stern)
15	0.9310	-1.6941	1.3020	Lift eye skrew (port, fore)
16	0.9068	1.7009	1.2924	Lift eye skrew (starboard, fore)
17	-0.0027	-0.4233	-0.7169	Port centre laser tool
18	0.0027	0.4234	-0.7167	Starboard centre laser tool
21	-0.0048	-0.4214	-0.6714	Acoustic centre port transducer
22	0.0018	0.3821	-0.6977	Acoustic centre starboard transducer
23	-0.275	-0.025	-0.483	Reference point at the top centre MRU
30	-0.2706	0.4025	-0.1014	Preliminary mark in MRU cabin
31	-0.6044	0.4073	-0.1008	Preliminary mark in MRU cabin
32	0.3088	-0.2978	0.6529	Preliminary mark in MRU cabin

Benchmark overview

For all the benchmarks where a GPS-mounting bracket is utilized, the coordinates refer to the centre of a GPS-antenna mounted on top of the brass bracket, and having an antenna offset of 0.065m. Three different bracket sizes were used. The longest (1055 mm) was used for benchmark 4, a medium size (300 mm) for benchmark 5 and a smaller one (200 mm) for the rest. All lengths are measured between the two stopping edges of the brass bracket.

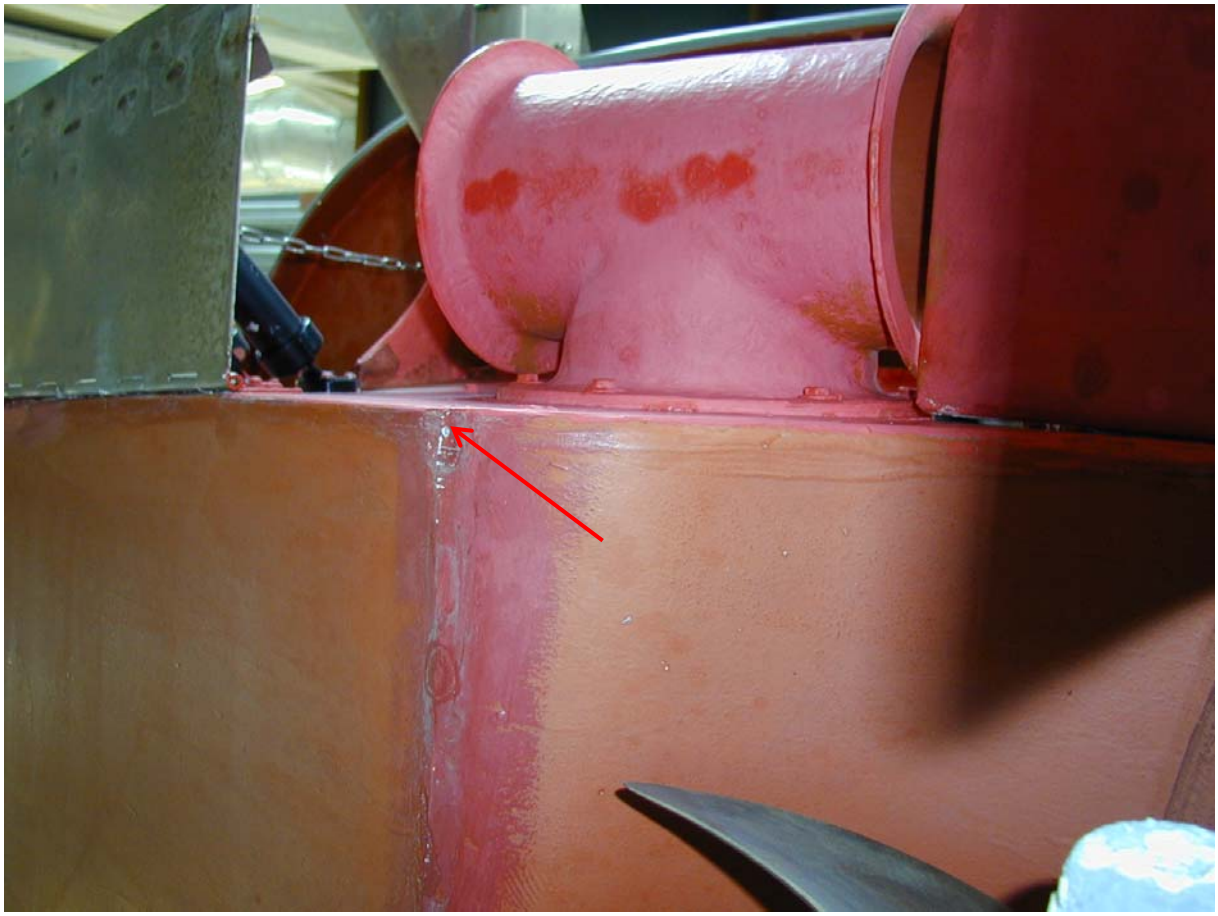

Figure 1 Benchmark P1

Figure 2 Benchmark P2

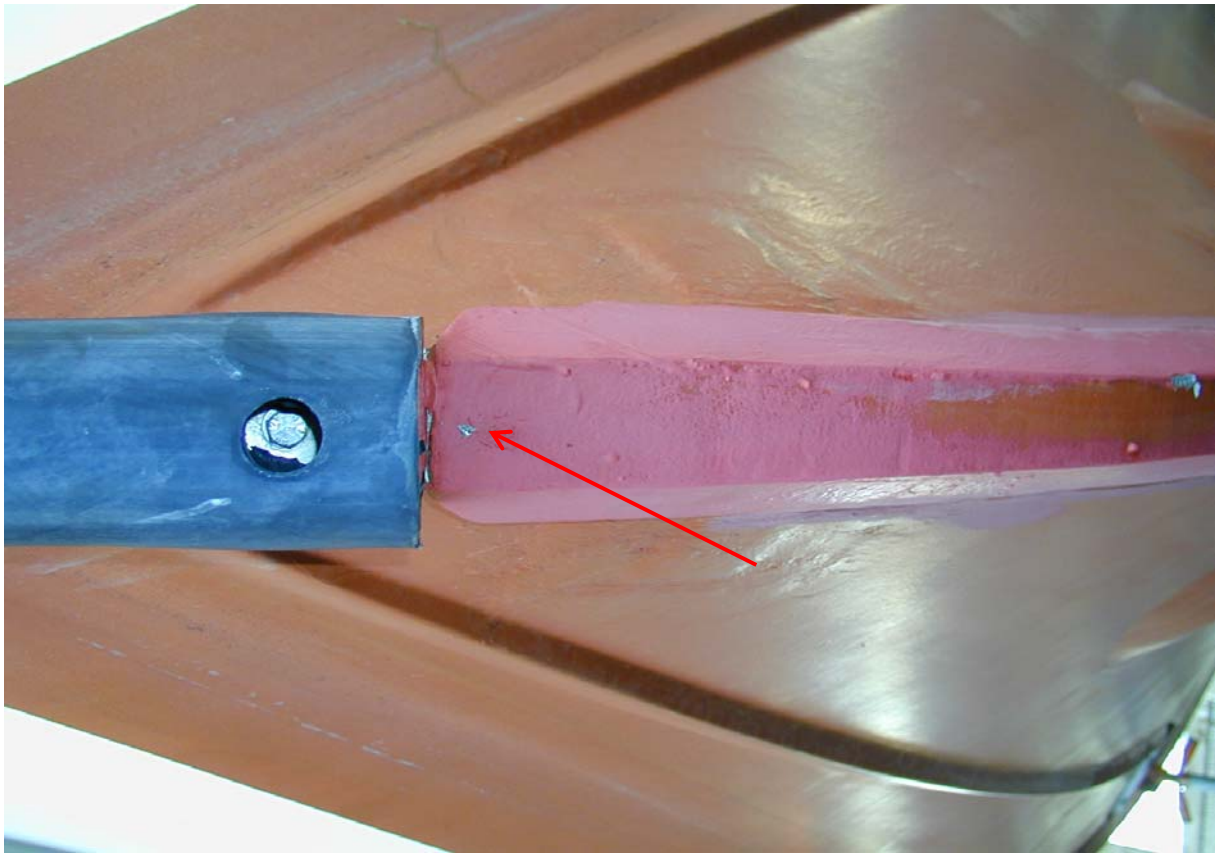

Figure 3 Benchmark P3

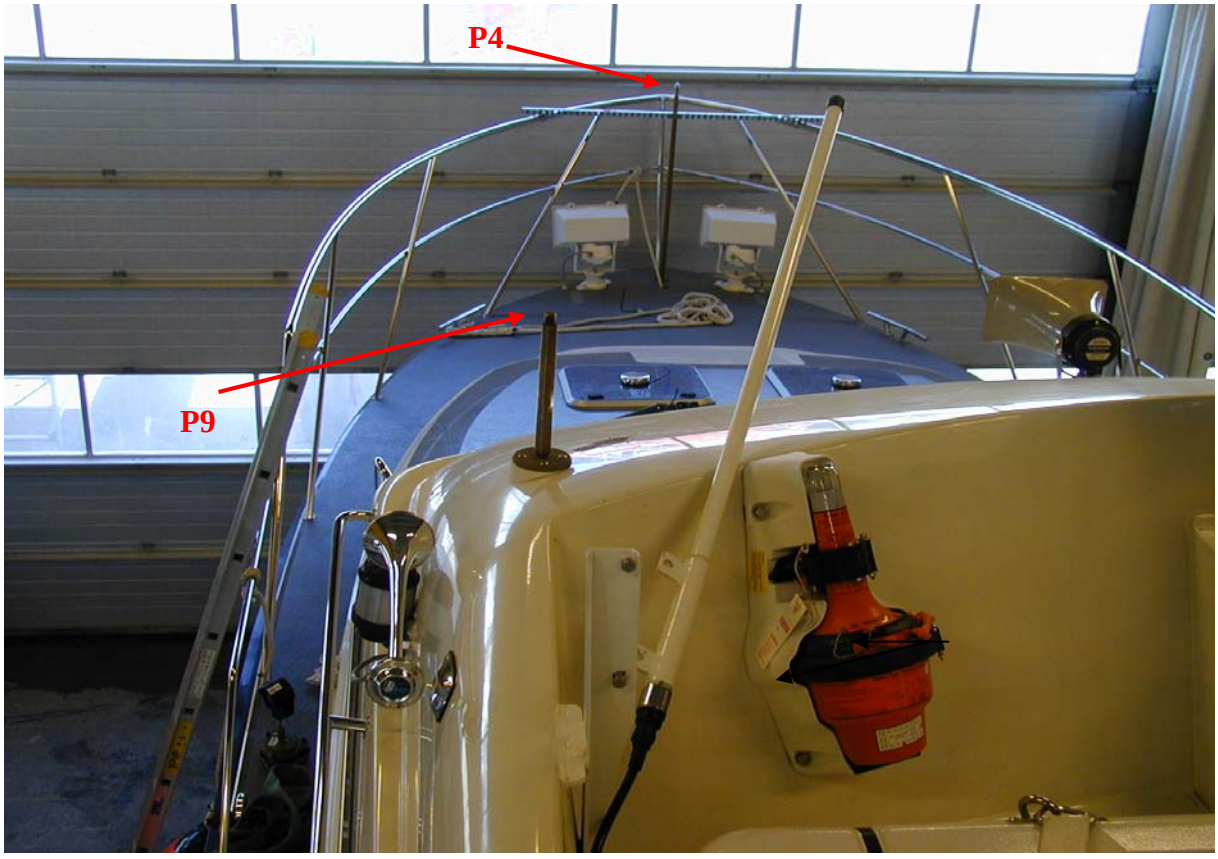

Figure 4 Benchmark 4 – GPS antenna mount on the bow. Benchmark 9 – GPS antenna mount on port front wheelhouse roof (the surveyed locations are near the antenna phase centres, above the top of the brass bar)

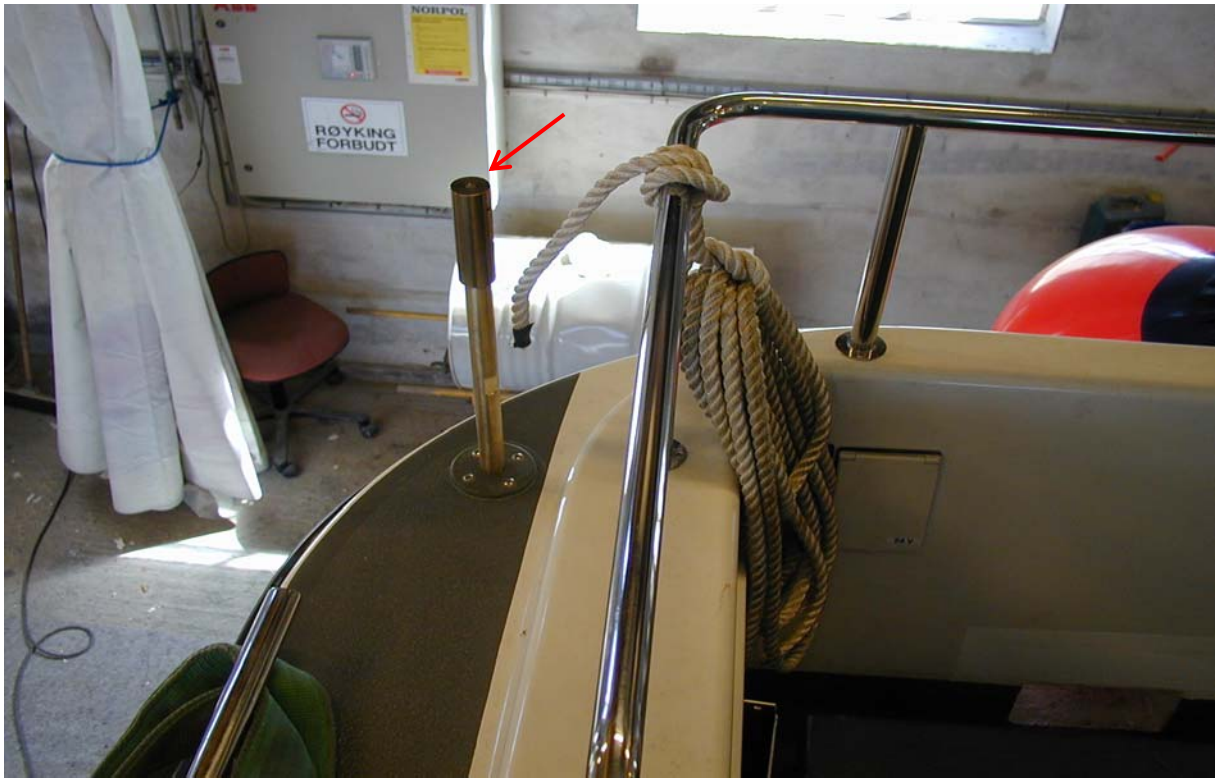

Figure 5 Benchmark P5 – GPS antenna mount rear starboard

Figure 6 Benchmark P6, P7, P10, P11and P12. P6 (starboard) and P7 (port) – GPS antenna mount on rear wheelhouse roof. P10 (starboard) and P 11 (port) are at the top of the centre of the drilled hole of the Seapath bar. P12 is for the Abspos antenna.

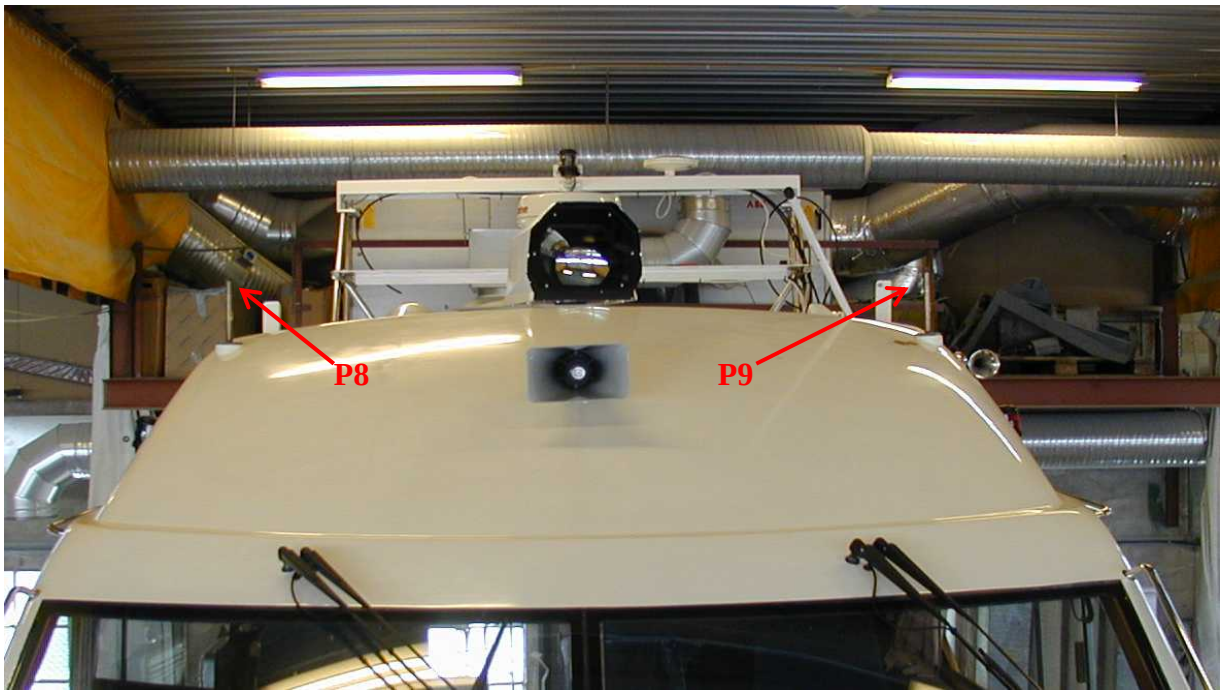

Figure 7 Benchmark P8 (starboard) and P9 (port) – GPS antenna mount on front wheelhouse roof.

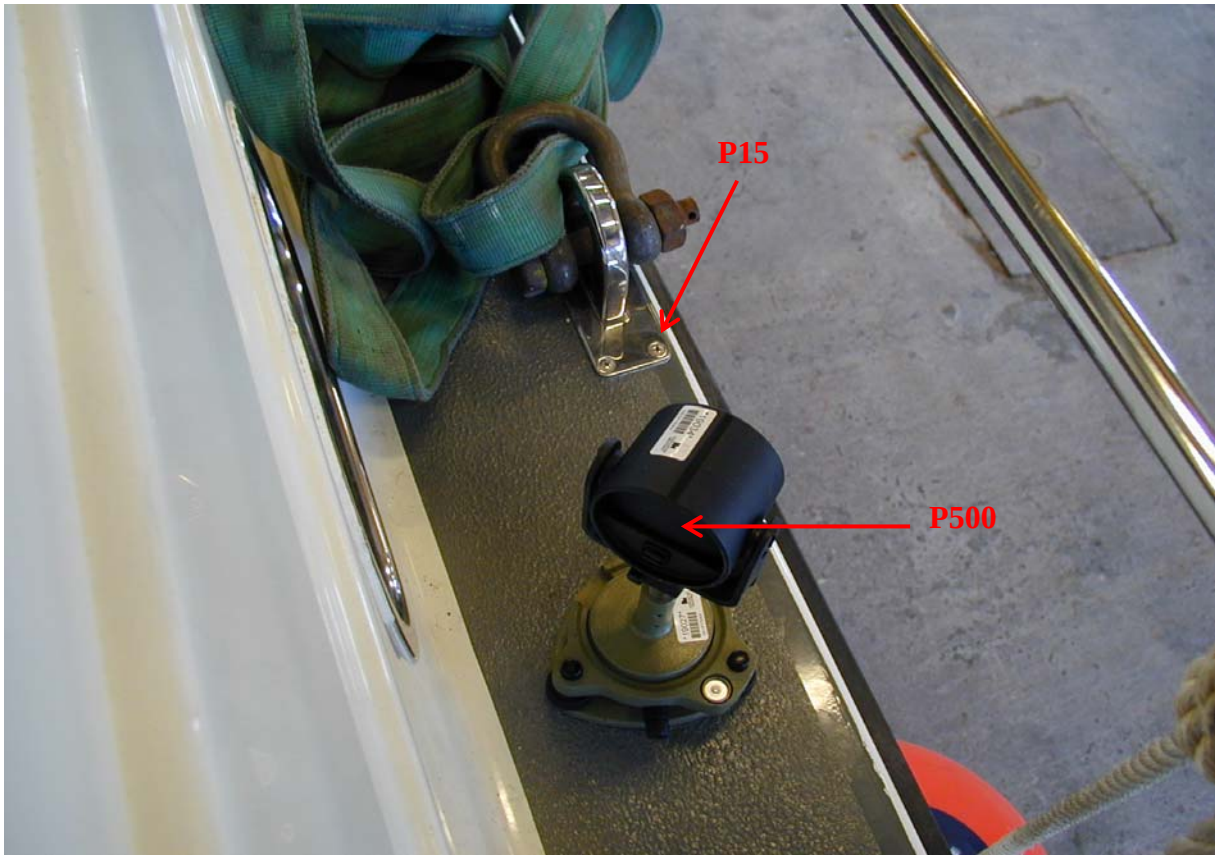

Figure 8 Benchmark 15 – Lift eye screw (port, fore). Survey station P500.

Figure 9 Benchmark 16 – Lift eye screw (starboard, fore)

Figure 10 Benchmark 17 – Port centre laser tool

Figure 11 Starboard transducer with laser measuring tool mounted on it

2. Determination of transducer orientation angles

To utilize the data collected by the EM3000 transducers, it is essential to know how the transducers are placed in the vessel coordinate system. The rotation of the transducers compared to the axes of the coordinate system must be found. Secondly the position of the transducer acoustic center must be found in terms of coordinates in the vessel system.

The measuring tool

To be able to achieve the accuracy specified in the EM3000 installation manual, the Norwegian Hydrographic Service has developed a measuring tool *(Ofstad –2001)*. This tool is mounted directly on to the surface of the EM3000 transducer and carries two lasers. One laser is mounted parallel to, and prolongs the transducer axes. The laser beam defines a point wherever it hits. The position of the laser beam points and the position of the centre of the transducer are utilized in the determination of the transducer orientation relative to the vessel coordinate system. In addition to the laser parallel to the transducer axes, the laser cage has a laser beam pointing backward, inclined about 43° from the other laser beam. This laser beam is used whenever the parallel laser beam is obstructed. Figure 10 and 11 shows the measuring tool mounted on the transducers on Sjøfalk.

Orientation parameters for EM3000 transducers

Surveyed benchmarks, laying on the prolonged transducer axis, with coordinates determined in the vessel coordinate system, are used as a base for transducer orientation determination. The transducer orientation is determined by transforming these benchmarks to the vessel coordinate system in such a way that the transducer axis coincides with the vessel coordinate system axis. The rotational parameters of this conform transformation reflects the transducer orientation angles relative to the vessel coordinate system (i.e. the transducer installation angles). This is a simple principle, but the method presupposes the surveyed benchmarks to be positioned exactly on the prolongation of the “real” transducer axis (as they are defined within the transducer). Since this is not true, a few corrections must be applied:

1. *Correction for the misalignment of the measuring tool axis*. This is an instrument correction for the measuring tool. Even though the measuring tool is produced with strict precision requirements, the instrument has to be calibrated. A thorough calibration was set up as a traditional survey (utilizing a precision theodolite and an EDM), and the calibration values were determined by a mathematical exercise (*Ofstad-2001*). This calibration should be repeated after some time as a verification of the stability of the calibration values. A simple calibration of the laser beam alignment is performed every time the measuring tool is used.
2. *Correction for the orientation of the transducer outer rubber surface relative to the titanium back surface*. It is assumed that the titanium back surface of the transducer coincides with the acoustic transducer axis. No measurements were made on the transducers to determine the orientation angle between the outer rubber surface and the titanium back surface. Experiences from earlier calibrations of other transducers have shown surface rotations up to 0.2°. The largest errors are found in the rotation about the transducer z-axis. 0.2° may be extreme, but values larger than 0.1° are common.
3. *Corrections for the orientation of the transducer acoustic axis relative to the mechanical surface of the transducer*. This correction cannot be determined by this procedure, and we

regard this as a task for the equipment manufacturer. In the current situation, the misalignment of the acoustic axis is assumed to be negligible.

The transducer orientation is calculated from all available observations of laser beam hits. Both the direct laser and the inclined laser beams of the measurement tool are utilized. The procedure is to utilize the direct laser observations for a preliminary calculation of laser hit positions. These preliminary coordinates are used to calculate the ranges from the transducer origin to the laser hit positions. Based on this input, some special software is used to calculate the final coordinates (in the vessel coordinate system) of the laser hit positions. This software corrects the observations according to the laser tool calibration values.

EM3000 orientation angles and transducer coordinates

Table 2 shows the calculated EM3000D transducer installation angles. Table 3 shows the vessel coordinates for the transducer acoustic centers.

Table 2 Transducer installation angles – all install angles are given with the same sign as required by Kongsberg Simrad

	Starboard transducer		Port transducer	
	Installation angle	Standard deviation	Installation angle	Standard deviation
Roll	**-33.972°**	**0.011°**	**32.217°**	**0.012°**
Pitch	**2.317°**	**0.007°**	**2.207°**	**0.008°**
Heading	**-0.337°**	**0.007°**	**-0.089°**	**0.007°**

Table 3 Coordinates for the transducer acoustic centres. The sign of the transducer Z-coordinates must be changed before the values are entered into the Simrad MBE.

	X (Foreward)	Y (Starboard)	Z (Up)
Starboard Transducer	**0.002**	**0.382**	**-0.698**
Port Transducer	**-0.005**	**-0.421**	**-0.671**

3. Attitude calibration

Equipment

The GPS observations onboard the vessel were made with eight separate Trimble 4000 SSE GPS receivers.

A separate Trimble 4000 SSE GPS receiver was mounted on an onshore benchmark to provide reference station data.

The vessel attitude sensor was the Seapath 200 from Kongsberg Seatex.

Fieldwork

The attitude calibration took place in Stavanger in June 2004. In order to achieve a satisfactory verification of the calibration results, four days of logged data were analysed, i.e. 7th, 8th, 9th and 24th of June. One GPS-reference station was etablished on Kalvøy, and eight GPS receivers were mounted on the vessel. Data from all the receivers was logged to PC's for post processing. The initial Seapath installation angles were set according to Table 4 prior to the first calibration survey (June 7th). Attitude data from the Seapath was logged on the EM3000 computer and transferred to the PC for comparison with the GPS data. After logging of all the GPS receivers were started, the vessel cruised for 2-3 hours within a few kilometres from the reference station. Then the logging was stopped and the GPS-data from the onboard receivers were brought to the office for post processing. Utilizing the Geogenius GPS processing software, the onboard data was processed relative to the onshore reference station. The GPS positions were used to calculate attitude values, which were compared to the Seapath attitude data to determine preliminary Seapath installation angles. These values were entered into the Seapath. Next day (June 8th) a second period of data logging was carried out. The new GPS-data was processed and corrections to the preliminary installation angles were calculated and entered into the Seapath. Two more days of surveying were used to verify the calculated installation angles, and some small corrections were entered into the Seapath after the last survey. The solutions presented in this report are based on the following principle for the calculations.

Each individual antenna was positioned relative to a reference station on the shore close to the survey area. Eight GPS receivers, logging at 1 Hz, were utilized on Sjøfalk. The GPS benchmarks set up a geometrical figure, which is used to calculate the vessel orientation (i.e. pitch, roll and heading) in a terrestrial coordinate system. For each epoch, the position of the vessel coordinate system origin is calculated and used to calculate an estimate of the vessel heave. Before comparing the MRU heave to the GPS heave, the GPS heights were corrected for the geoid height, observed tides and for vessel draft changes (settlement) due to different velocity during the survey.

Strategy for installation angle determination

The installation angles are determined from observed differences between GPS-derived attitude angles and attitude angles from the vessel motion sensor.

The determination of GPS-attitude angles is described in Appendix 2.

The angular differences are put into a least squares adjustment where roll, pitch and heading offsets are determined. For a system utilizing separate heading sensors (e.g. Seapath and Pos-MV), the motion sensor rotation angle about the vertical axis (e.g. MRU Yaw) can be determined independent from the attitude sensor heading. There is also a possibility to solve for timing offsets between the systems.

A very simple observation model is used:

$$\begin{bmatrix} \omega_{GPS} \\ \phi_{GPS} \\ \kappa_{GPS} \end{bmatrix} = \begin{bmatrix} \Delta\omega \\ \Lambda\phi \\ \Delta\kappa \end{bmatrix} + \begin{bmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \omega_{MS} \\ \phi_{MS} \\ \kappa_{MS} \end{bmatrix}$$

Where ω = roll, ϕ = pitch and κ = heading. γ = motion sensor yaw rotation. ***MS*** denotes Motion sensor determined values and ***GPS*** denotes GPS determined values. Installation angles are $\Delta\omega$, $\Delta\phi$, $\Delta\kappa$ and γ.

Orientation angles of attitude and heading sensor

Table 4 shows the calculated corrections to the motion sensors and Table 5 the resulting installation angles.

Table 4 Calculated corrections to installation angles for motion sensors on Sjøfalk. * The corrections calculated on 9. June were never entered into the Seapath system.

	Entered corrections to installation angles (°)				Final correction to installation angle
	7. June	8. June	9. June	24. June	
Roll	**0.12**	**-0.11**	**-0.03***	**-0.02**	**-0.01**
Pitch	**5.71**	**0.03**	**-0.03***	**-0.02**	**5.72**
Seapath heading	**-0.63**	**0.33**	**-0.03***	**-0.01**	**-0.31**
MRU heading	**-0.84**	**-0.19**	**-0.92***	**0.10**	**-0.93**

Table 5 Calculated installation angles for motion sensors on Sjøfalk

	Initial installation angles	Calculated installation angles after corrections are applied (°)				Final installation angle
		7. June	8. June	9. June	24. June	
Roll	**180**	**-179.88**	**-179.99**	**179.98***	**179.99**	**179.99**
Pitch	**0**	**5.71**	**5.74**	**5.71***	**5.72**	**5.72**
Seapath heading	**-90**	**-90.63**	**-90.30**	**-90.33***	**-90.31**	**-90.31**
MRU heading	**0**	**-0.84**	**-1.03**	**-1.95***	**-0.93**	**-0.93**

Graphical verification of results

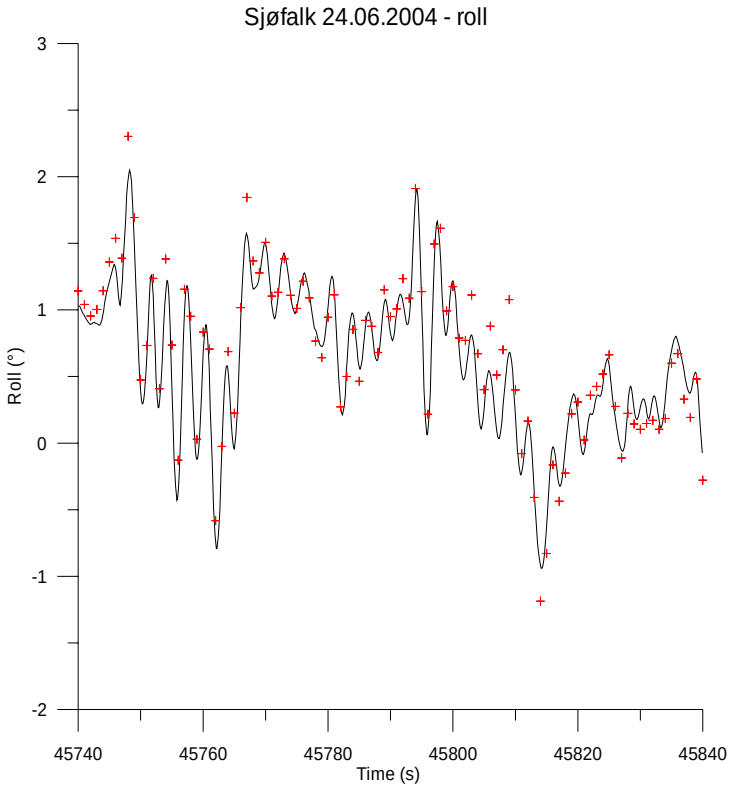

Figure 12 Seapath roll (black curve) and GPS roll (red marks) show a rather good agreement after the attitude calibration

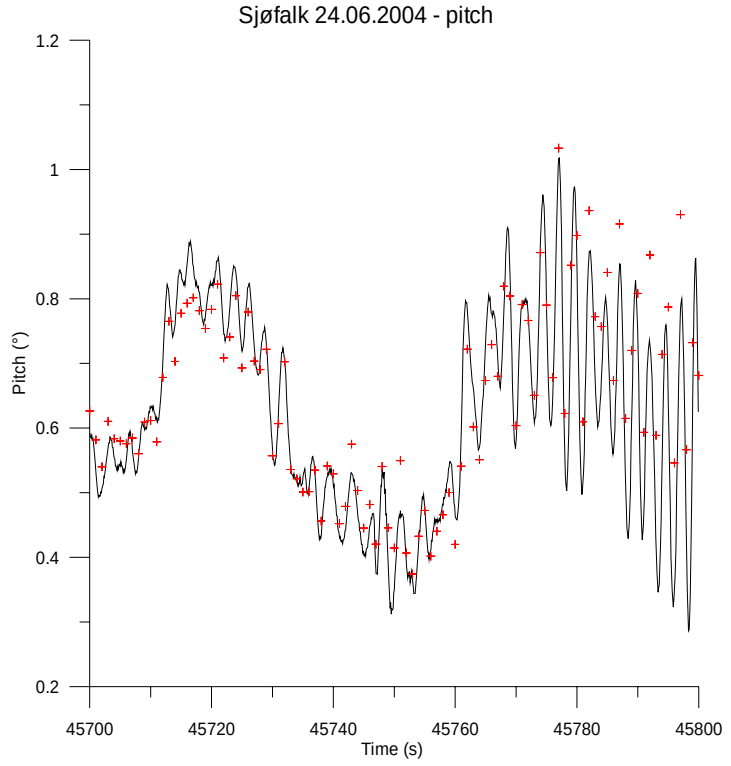

Figure 13 Seapath pitch (black curve) and GPS calculated pitch (red marks) does not fit as good as the roll and heading values

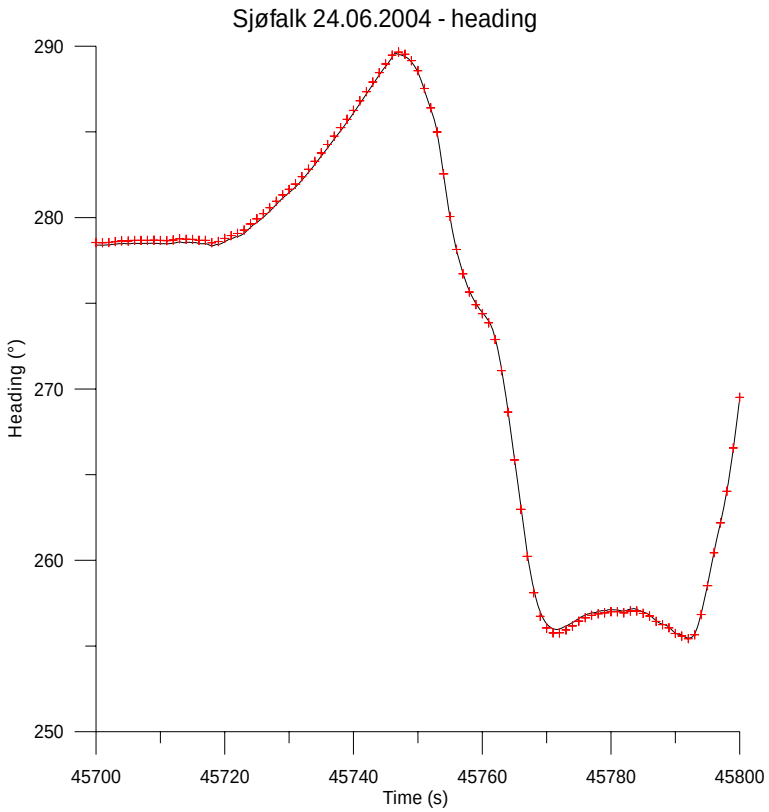

Figure 14 seapath heading (black curve) and GPS roll (red marks) show a good agreement after the attitude calibration

Heave is not yet analysed because the MRU unit utilised is an old one which is going to be replaced.

Appendix 1. Documentation

Corrections for eccentric observations

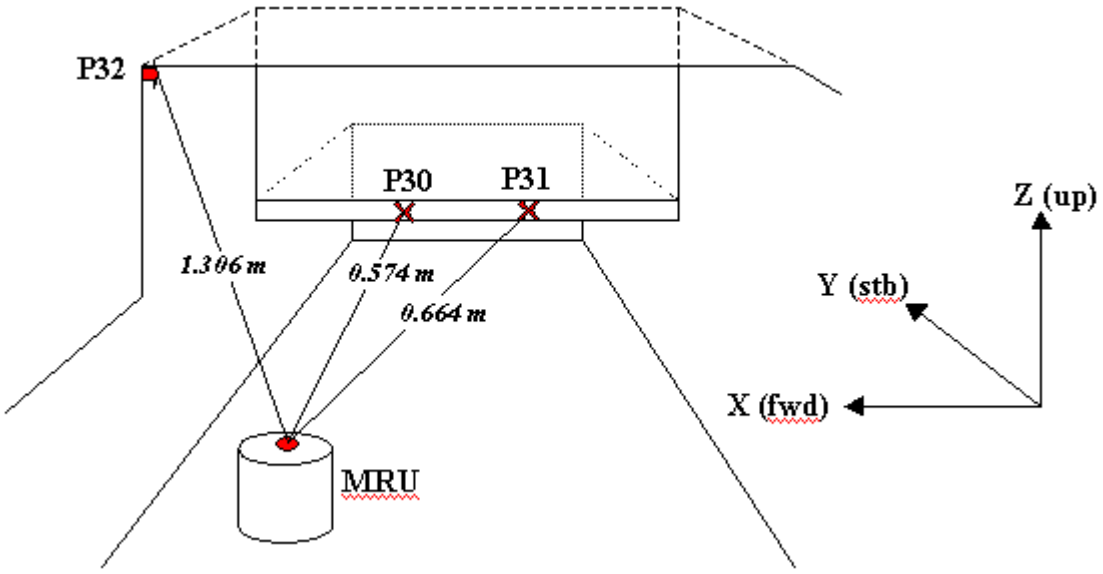

Figure 15 The distances from the surveyed benchmarks P30, P31 and P32 to the MRU reference point (top centre MRU cylinder) were measured with measuring tape and are given in this figure. From these measurements it was possible to calculate the coordinates of the MRU reference point.

Survey calculations

The vessel coordinate system was calculated utilizing the Gemini software.

```
Utjevning                    2004.05.19

KJENTE PUNKT

PunktID       Tema     N-koord.   Ø-koord.    Høyde
100           1000      0,000      0,000      0,000
200           1000      7,448      0,000      0,208

NYBEREGNA PUNKT:

Punkt Tema      N       Ø         H    Std. N  Std. Ø  Std. H
300   1000   -2,706 -16,406    0,351    0,000   0,000   0,000
500   1000    3,776 -10,146    1,445    0,000   0,000   0,000
400   1000   -2,255 -11,149   -0,131    0,000   0,000   0,000
2            -2,797  -7,604   -0,547    0,000   0,000   0,000
3             6,996  -8,847   -0,514    0,000   0,000   0,000
4             7,949  -8,869    2,321    0,000   0,000   0,000
5            -1,836  -6,575    1,639    0,000   0,000   0,000
6            -1,072  -7,058    3,055    0,000   0,000   0,000
8             2,332  -7,340    3,333    0,000   0,000   0,000
10           -0,513  -7,169    4,016    0,000   0,000   0,000
14           -1,158  -6,479    1,257    0,000   0,000   0,000
16            3,813  -6,842    1,174    0,000   0,000   0,000
18            2,743  -8,052   -0,795    0,000   0,000   0,000
19           -1,666  -6,513    0,038    0,000   0,000   0,000
20            4,665  -7,311   -0,140    0,000   0,000   0,000
1000          2,671  -8,898   -1,380    0,000   0,000   0,000
1002          3,402  -7,566   -0,457    0,000   0,000   0,000
1003          3,031  -4,957   -1,388    0,000   0,000   0,000
1004          2,203  -7,480   -0,484    0,000   0,000   0,000
2000          8,562  -8,585   -0,746    0,000   0,000   0,000
2002          2,137  -7,453   -0,476    0,000   0,000   0,000
2003          2,107  -7,622   -1,370    0,000   0,000   0,000
2004          1,644  -8,775   -1,369    0,000   0,000   0,000
```

3000	2,786	-7,548	-0,489	0,000	0,000	0,000
3002	1,731	-8,771	-1,369	0,000	0,000	0,000
3003	2,741	-8,168	-1,378	0,000	0,000	0,000
3004	3,695	-9,031	-1,389	0,000	0,000	0,000
4002	3,771	-9,028	-1,391	0,000	0,000	0,000
4003	3,505	-7,727	-1,384	0,000	0,000	0,000
4004	3,430	-7,587	-0,464	0,000	0,000	0,000
5002	3,800	-8,086	-1,391	0,000	0,000	0,000
5003	2,679	-8,771	-1,380	0,000	0,000	0,000
5004	1,764	-7,959	-1,367	0,000	0,000	0,000
6000	8,488	-9,429	-0,741	0,000	0,000	0,000
6002	1,701	-7,971	-1,365	0,000	0,000	0,000
6003	1,944	-9,208	-1,373	0,000	0,000	0,000
7000	2,749	-8,019	-1,379	0,000	0,000	0,000
8003	3,360	-9,346	-1,386	0,000	0,000	0,000
8004	3,898	-8,081	-1,387	0,000	0,000	0,000
9	2,141	-9,434	3,355	0,000	0,000	0,000
11	-0,670	-9,074	4,035	0,000	0,000	0,000
12	-0,593	-8,124	4,024	0,000	0,000	0,000
4000	-4,867	-7,328	-0,901	0,000	0,000	0,000
8000	-4,943	-8,223	-0,886	0,000	0,000	0,000
1	-2,858	-8,355	-0,546	0,000	0,000	0,000
7	-1,242	-9,139	3,075	0,000	0,000	0,000
13	-1,418	-9,759	1,285	0,000	0,000	0,000
15	3,542	-10,226	1,219	0,000	0,000	0,000
17	2,664	-8,895	-0,786	0,000	0,000	0,000
5000	2,606	-9,485	-0,429	0,000	0,000	0,000
6004	1,887	-9,422	-0,433	0,000	0,000	0,000
7002	1,916	-9,447	-0,424	0,000	0,000	0,000
7003	2,413	-11,860	-1,382	0,000	0,000	0,000
30	2,487	-8,044	-0,172	0,000	0,000	0,000
31	2,155	-8,010	-0,162	0,000	0,000	0,000
32	3,025	-8,786	0,573	0,000	0,000	0,000
7004	3,326	-9,599	-0,386	0,000	0,000	0,000
8002	3,360	-9,589	-0,401	0,000	0,000	0,000

Antall ukjente	58	Antall konvensjonelle stasjoner	416
		Antall hor. vinkler	416
		Antall vertikalvinkler	416
		Antall avstander	416
Antall ukjente	190	Antall observasjoner	1248

Sum PVV	0,000047152929058
Antatte standardavvik på vektsenhet	0,0005000
Antall overskytende målinger	1058
K-tall (ant. overbest./ant. obs.)	0,85

Transformation to the vessel coordinate system

This is a printout of the transformation from the local terrain coordinate system to the vessel coordinate system. The utilized transformation is a 7-parameter conform transformation (the scale is fixed, so only 6 unknowns are solved for).

```
SENSORMAAL
  ----------

  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Wed May 19 12:06:52 2004

  Input "FROM" file : S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\terrengsystem.txt
  Input "TO" file   : S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\tilsystem_baat.txt
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0008
    Standard deviation of unit weight (S0) =          0.0115

    Estimated parameter         Standard deviation     95% Significant?

    DX =      -3.453972              0.012886               YES
    DY =       8.197304              0.005054               YES
    DZ =       0.063494              0.021377               YES
    WX =       0.010642              0.002850               YES
    WY =      -0.028312              0.002555               YES
```

```
    WZ =      -0.087418             0.001195               YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :   -3.453972 m                0.000000 m           0.012886 m
    DY :    8.197304 m                0.000000 m           0.005054 m
    DZ :    0.063494 m                0.000000 m           0.021377 m
    WX :    0.609748 deg (roll)       0.000000 deg         0.163322 deg
    WY :   -1.622152 deg (pitch)      0.000000 deg         0.146374 deg
    WZ :   -5.008686 deg (yaw)        0.000000 deg         0.068457 deg

  Q-matrix (lower triangle)
  -------------------------
      1.26517
      0.12317      0.19458
      0.08034      0.36200      3.48171
     -0.00267      0.05380      0.41317      0.06191
      0.03779     -0.00222      0.08843     -0.00236      0.04973
      0.08949      0.01520      0.00232     -0.00013      0.00041      0.01088


  VERIFICATION OF TRANSFORMATION:
```

Point	X_from	Y_from	Z_from	X_to	Y_to	Z_to	DX	DY	DZ
1	-2.8580	-8.3550	-0.5460	-5.5553	-0.3684	-0.6334	0.0017	0.0083	0.0266
2	-2.7970	-7.6040	-0.5470	-5.5601	0.3850	-0.6265	-0.0031	0.0083	0.0335
3	6.9960	-8.8470	-0.5140	4.2992	-0.0015	-0.3184	0.0002	-0.0015	0.0116
12	-0.5930	-8.1240	4.0240	-3.4494	0.0102	4.0023	-0.0013	0.0102	0.0103
13	-1.4180	-9.7590	1.2850	-4.0507	-1.6612	1.2273	0.0073	-0.0161	0.0273
14	-1.1580	-6.4790	1.2570	-4.0772	1.6291	1.2335	-0.0192	-0.0160	0.0335
15	3.5420	-10.2260	1.2190	0.9310	-1.6941	1.3020	0.0080	0.0034	0.0220
16	3.8130	-6.8420	1.1740	0.9068	1.7009	1.2924	-0.0162	0.0034	0.0124
17	2.6640	-8.8950	-0.7860	-0.0027	-0.4233	-0.7169	-0.0027	0.0767	0.0131
18	2.7430	-8.0520	-0.7950	0.0027	0.4234	-0.7167	0.0027	-0.0766	0.0133
19	-1.6660	-6.5130	0.0380	-4.5456	1.5640	0.0000	0.0056	-0.0360	0.0000
20	4.6650	-7.3110	-0.1400	1.8334	1.3218	0.0000	-0.0066	-0.0082	0.0000

```
   Standard deviation of transformation fit :     0.0459 m
   Maximum error at station id     17   :         0.0778 m


  TRANSFORMATION OF SELECTED INPUT FILE
(S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\terrengsystem.txt)
  -------------------------------------
```

Point	X_to	Y_to	Z_to	sigma X	sigma Y	sigma Z
1	-5.5553	-0.3684	-0.6334	0.0001	0.0001	0.0001
2	-5.5601	0.3850	-0.6265	0.0001	0.0001	0.0001
3	4.2992	-0.0015	-0.3184	0.0001	0.0001	0.0001
4	5.1698	0.0293	2.5429	0.0001	0.0001	0.0001
5	-4.7548	1.4704	1.5948	0.0001	0.0001	0.0001
6	-3.9920	1.0407	3.0285	0.0001	0.0001	0.0001
7	-3.9802	-1.0473	3.0266	0.0001	0.0001	0.0001
8	-0.5856	1.0530	3.4032	0.0001	0.0001	0.0001
9	-0.5937	-1.0498	3.4026	0.0001	0.0001	0.0001
10	-3.4528	0.9685	4.0044	0.0001	0.0001	0.0001
11	-3.4435	-0.9430	4.0034	0.0001	0.0001	0.0001
12	-3.4494	0.0102	4.0023	0.0001	0.0001	0.0001
13	-4.0507	-1.6612	1.2273	0.0001	0.0001	0.0001
14	-4.0772	1.6291	1.2335	0.0001	0.0001	0.0001
15	0.9310	-1.6941	1.3020	0.0001	0.0001	0.0001
16	0.9068	1.7009	1.2924	0.0001	0.0001	0.0001
17	-0.0027	-0.4233	-0.7169	0.0001	0.0001	0.0001
18	0.0027	0.4234	-0.7167	0.0001	0.0001	0.0001
19	-4.5456	1.5640	0.0000	0.0001	0.0001	0.0001
20	1.8334	1.3218	0.0000	0.0001	0.0001	0.0001
30	-0.2706	0.4025	-0.1014	0.0001	0.0001	0.0001
31	-0.6044	0.4073	-0.1008	0.0001	0.0001	0.0001
32	0.3088	-0.2978	0.6529	0.0001	0.0001	0.0001
1000	0.0214	-0.4194	-1.3104	0.0001	0.0001	0.0001
1002	0.6069	0.9613	-0.3557	0.0001	0.0001	0.0001
1003	0.0361	3.5378	-1.2759	0.0001	0.0001	0.0001
1004	-0.5938	0.9429	-0.4169	0.0001	0.0001	0.0001
2000	5.8423	0.3982	-0.5026	0.0001	0.0001	0.0001
2002	-0.6621	0.9640	-0.4106	0.0001	0.0001	0.0001
2003	-0.6519	0.8025	-1.3065	0.0001	0.0001	0.0001
2004	-1.0123	-0.3863	-1.3283	0.0001	0.0001	0.0001
3000	-0.0072	0.9259	-0.4055	0.0001	0.0001	0.0001
3002	-0.9261	-0.3748	-1.3258	0.0001	0.0001	0.0001
3003	0.0273	0.3139	-1.3004	0.0001	0.0001	0.0001
3004	1.0529	-0.4627	-1.2907	0.0001	0.0001	0.0001

```
   4000   -7.6354    0.4837   -1.0384   0.0001   0.0001   0.0001
   4002    1.1284   -0.4531   -1.2904   0.0001   0.0001   0.0001
   4003    0.7498    0.8197   -1.2806   0.0001   0.0001   0.0001
   4004    0.6368    0.9429   -0.3621   0.0001   0.0001   0.0001
   5000   -0.0190   -1.0199   -0.3665   0.0001   0.0001   0.0001
   5002    1.0751    0.4878   -1.2819   0.0001   0.0001   0.0001
   5003    0.0183   -0.2922   -1.3091   0.0001   0.0001   0.0001
   5004   -0.9641    0.4369   -1.3162   0.0001   0.0001   0.0001
   6000    5.8421   -0.4491   -0.5066   0.0001   0.0001   0.0001
   6002   -1.0259    0.4195   -1.3161   0.0001   0.0001   0.0001
   6003   -0.6757   -0.7915   -1.3271   0.0001   0.0001   0.0001
   6004   -0.7404   -1.0197   -0.3909   0.0001   0.0001   0.0001
   7000    0.0223    0.4630   -1.3000   0.0001   0.0001   0.0001
   7002   -0.7096   -1.0421   -0.3813   0.0001   0.0001   0.0001
   7003    0.0230   -3.3924   -1.3440   0.0001   0.0001   0.0001
   7004    0.7066   -1.0713   -0.3035   0.0001   0.0001   0.0001
   8000   -7.6334   -0.4147   -1.0329   0.0001   0.0001   0.0001
   8002    0.7401   -1.0582   -0.3174   0.0001   0.0001   0.0001
   8003    0.7467   -0.8057   -1.3000   0.0001   0.0001   0.0001
   8004    1.1721    0.5013   -1.2750   0.0001   0.0001   0.0001
```

Starboard transducer

Preliminary “to” coordinates for the transducer

```
Point     X        Y        Z      σX      σY      σZ   Comment
  18   0.0000   0.0000   0.0221  0.0001  0.0051  0.0051 Senter styrbord laserkors
1000   0.0000  -1.0306   0.0000  0.0001 10.0001  0.0001
2000   5.8436   0.0000   0.0000 10.0001  0.0001  0.0001
3000   0.0000   0.5910   0.0000  0.0001 10.0001  0.0001
4000  -7.6450   0.0000   0.0000 10.0001  0.0001  0.0001
```

Each across-axis coordinate component is given a 0.1 mm accuracy, whereas the along-axis coordinate components are given a 10 m accuracy. The Z-coordinate of the laser cross origin is determined from the laser tool design.

Transformation from vessel coordinates to transducer coordinates

```
SENSORMAAL
  ----------

  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Wed May 19 12:53:43 2004

  Input "FROM" file :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\Frasystem_styrbord.xyz
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\tilsystem_styrbord.xyz
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0001
    Standard deviation of unit weight (S0) =          0.0033

    Estimated parameter         Standard deviation     95% Significant?

    DX =       0.028542              0.000274               YES
    DY =       0.049078              0.000479               YES
    DZ =       0.852405              0.000244               YES
    WX =      -0.592693              0.000402               YES
    WY =       0.039733              0.000049               YES
    WZ =      -0.006332              0.000049               YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :    0.028542 m               0.000000 m           0.000274 m
    DY :    0.049078 m               0.000000 m           0.000479 m
    DZ :    0.852405 m               0.000000 m           0.000244 m
    WX :  -33.958787 deg (roll)      0.000000 deg         0.023043 deg
    WY :    2.276541 deg (pitch)     0.000000 deg         0.002805 deg
    WZ :   -0.362791 deg (yaw)       0.000000 deg         0.002804 deg
```

```
  Q-matrix (lower triangle)
  -------------------------
    0.00683
   -0.00002   0.02084
   -0.00009  -0.00200  0.00542
   -0.00003  -0.01251  0.00235  0.01468
    0.00018  -0.00009 -0.00009 -0.00003  0.00022
   -0.00007  -0.00018  0.00006  0.00003  0.00000  0.00022


  VERIFICATION OF TRANSFORMATION:
  -------------------------------
  Point   X_from   Y_from   Z_from  X_to   Y_to   Z_to  DX    DY    DZ
     18   0.0027   0.4234  -0.7167   0.0001   0.0002   0.0219  0.0001  0.0002 -0.0002
   1000   0.0214  -0.4194  -1.3104   0.0005  -1.0306  -0.0002  0.0005  0.0000 -0.0002
   2000   5.8423   0.3982  -0.5026   5.8436  -0.0001   0.0004  0.0000 -0.0001  0.0004
   3000  -0.0072   0.9259  -0.4055  -0.0006   0.5910  -0.0004 -0.0006  0.0000 -0.0004
   4000  -7.6354   0.4837  -1.0384  -7.6450   0.0001   0.0003  0.0000  0.0001  0.0003

    Standard deviation of transformation fit :       0.0007 m
    Maximum error at station id      3000    :       0.0007 m


  TRANSFORMATION OF SELECTED INPUT FILE
  (S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\Frasystem_styrbord.xyz)
  -------------------------------------

Point     X_to      Y_to      Z_to   sigma X  sigma Y  sigma Z Text
   18    0.0001    0.0002    0.0219   0.0001   0.0001   0.0001 Starboard center laser tool
 1000    0.0005   -1.0306   -0.0002   0.0001   0.0001   0.0001 aa d
 1002    0.6147    0.6377   -0.0013   0.0001   0.0001   0.0001 a2 s
 1003   -0.0085    2.2711   -2.1818   0.0001   0.0001   0.0001 a3 s
 1004   -0.5873    0.6086    0.0021   0.0001   0.0001   0.0001 a4 s
 2000    5.8436   -0.0001    0.0004   0.0001   0.0001   0.0001 bb d
 2002   -0.6554    0.6308   -0.0020   0.0001   0.0001   0.0001 b2 s
 2003   -0.6798   -0.0034   -0.6547   0.0001   0.0001   0.0001 b3 s
 2004   -1.0333   -0.9956    0.0042   0.0001   0.0001   0.0001 b4 s
 3000   -0.0006    0.5910   -0.0004   0.0001   0.0001   0.0001 cc d
 3002   -0.9471   -0.9862   -0.0033   0.0001   0.0001   0.0001 c2 s
 3003    0.0022   -0.4168   -0.4016   0.0001   0.0001   0.0001 c3 s
 3004    1.0322   -1.0730    0.0026   0.0001   0.0001   0.0001 c4 s
 4000   -7.6450    0.0001    0.0003   0.0001   0.0001   0.0001 dd d
 4002    1.1076   -1.0662   -0.0052   0.0001   0.0001   0.0001 d2 s
 4003    0.7217    0.0016   -0.6940   0.0001   0.0001   0.0001 d3 s
 4004    0.6445    0.6184    0.0026   0.0001   0.0001   0.0001 d4 s


 Coordinates converted to range (used for calculation of laser system coordinates)
 ---------------------------------------------------------------------------------
       18      0.0219 0.001 0.001 0.0002
     1000      1.0306 0.001 0.001 0.0002
     1002      0.8858 0.001 0.001 0.0002
     1003      3.1493 0.001 0.001 0.0002
     1004      0.8458 0.001 0.001 0.0002
     2000      5.8436 0.001 0.001 0.0002
     2002      0.9097 0.001 0.001 0.0002
     2003      0.9438 0.001 0.001 0.0002
     2004      1.4349 0.001 0.001 0.0002
     3000      0.5910 0.001 0.001 0.0002
     3002      1.3673 0.001 0.001 0.0002
     3003      0.5788 0.001 0.001 0.0002
     3004      1.4889 0.001 0.001 0.0002
     4000      7.6450 0.001 0.001 0.0002
     4002      1.5374 0.001 0.001 0.0002
     4003      1.0012 0.001 0.001 0.0002
     4004      0.8932 0.001 0.001 0.0002
```

The last part of this program output gives the distances between the laser cross origin and the laser hit marks. The three last columns indicate the a-priori standard deviation for the distance, the standard deviation in the across direction at the laser origin, and the distant dependant scale factor for the across accuracy.

This list is expanded with a column containing a code describing which of the laser cross axis (A-D) and which of the laser cage sides (1-4) the individual observation is based on. This is used as input data for a program that converts the observations to coordinates.

Input data for the conversion between directions and coordinates

```
1000      1.0306 0.001 0.001 0.0002 aa_d
1002      0.8858 0.001 0.001 0.0002 a2_s
1003      3.1493 0.001 0.001 0.0002 a3_s
1004      0.8458 0.001 0.001 0.0002 a4_s
2000      5.8436 0.001 0.001 0.0002 bb_d
2002      0.9097 0.001 0.001 0.0002 b2_s
2003      0.9438 0.001 0.001 0.0002 b3_s
2004      1.4349 0.001 0.001 0.0002 b4_s
3000      0.5910 0.001 0.001 0.0002 cc_d
3002      1.3673 0.001 0.001 0.0002 c2_s
3003      0.5788 0.001 0.001 0.0002 c3_s
3004      1.4889 0.001 0.001 0.0002 c4_s
4000      7.6450 0.001 0.001 0.0002 dd_d
4002      1.5374 0.001 0.001 0.0002 d2_s
4003      1.0012 0.001 0.001 0.0002 d3_s
4004      0.8932 0.001 0.001 0.0002 d4_s
```

Calculated coordinates (“To”-coordinates used as input for the final calculation)

```
Transducer misalignments
  ------------------------
  Roll           -0.0047 degrees
  Pitch           0.0192 degrees
  Yaw             0.0378 degrees

  18      0.0000     0.0000     0.0221     0.0015     0.0015     0.0015 Senter stb laserkors
1000     -0.0008    -1.0306     0.0001     0.0012     0.0010     0.0012 aa_d
1002      0.6141     0.6384    -0.0028     0.0011     0.0011     0.0012 a2_s
1003     -0.0083     2.2711    -2.1818     0.0016     0.0013     0.0014 a3_s
1004     -0.5855     0.6104     0.0025     0.0011     0.0011     0.0012 a4_s
2000      5.8436    -0.0041    -0.0020     0.0010     0.0022     0.0022 bb_d
2002     -0.6556     0.6306    -0.0024     0.0011     0.0011     0.0012 b2_s
2003     -0.6809    -0.0023    -0.6536     0.0011     0.0012     0.0011 b3_s
2004     -1.0356    -0.9933     0.0045     0.0011     0.0012     0.0013 b4_s
3000      0.0004     0.5910     0.0000     0.0011     0.0010     0.0011 cc_d
3002     -0.9479    -0.9854    -0.0035     0.0012     0.0011     0.0013 c2_s
3003      0.0013    -0.4175    -0.4009     0.0011     0.0011     0.0011 c3_s
3004      1.0306    -1.0745     0.0039     0.0012     0.0012     0.0013 c4_s
4000     -7.6450     0.0060     0.0026     0.0010     0.0025     0.0025 dd_d
4002      1.1079    -1.0659    -0.0047     0.0012     0.0012     0.0013 d2_s
4003      0.7218     0.0023    -0.6938     0.0011     0.0012     0.0011 d3_s
     4004      0.6447     0.6182     0.0022     0.0011     0.0011     0.0012 d4_s

  Number of transformed points = 16
```

This software also corrects the observations for transducer misalignment, which is determined by a check of the transducer in a precision coordinate measuring machine.

Final transducer orientation

```
SENSORMAAL
  ----------

  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Tue Jun  8 14:48:38 2004

  Input "FROM" file :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\baatsystem.txt
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\styrbord_sjofalk.inp2
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0000
    Standard deviation of unit weight (S0) =          0.0006

    Estimated parameter         Standard deviation     95% Significant?

    DX =       0.028637              0.000220               YES
    DY =       0.049646              0.000276               YES
    DZ =       0.852585              0.000194               YES
    WX =      -0.592927              0.000194               YES
    WY =       0.040433              0.000130               YES
    WZ =      -0.005874              0.000117               YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :    0.028637 m                0.000000 m          0.000220 m
    DY :    0.049646 m                0.000000 m          0.000276 m
    DZ :    0.852585 m                0.000000 m          0.000194 m
    WX :  -33.972196 deg (roll)       0.000000 deg        0.011138 deg
    WY :    2.316619 deg (pitch)      0.000000 deg        0.007472 deg
    WZ :   -0.336541 deg (yaw)        0.000000 deg        0.006701 deg

  Q-matrix (lower triangle)
  -------------------------
      0.12412
      0.00071      0.19526
     -0.00083     -0.00628      0.09656
     -0.00164     -0.10310      0.00590      0.09657
      0.04086      0.00007     -0.00069     -0.00076      0.04346
     -0.01995     -0.00131      0.00041      0.00192     -0.00296      0.03495


  VERIFICATION OF TRANSFORMATION:
  -------------------------------
   Point    X_from    Y_from    Z_from    X_to      Y_to      Z_to     DX       DY       DZ
    18     0.0027    0.4234   -0.7167   -0.0001    0.0006    0.0221  -0.0001   0.0006   0.0000
  1000     0.0214   -0.4194   -1.3104   -0.0005   -1.0302    0.0002   0.0003   0.0004   0.0001
  1002     0.6069    0.9613   -0.3557    0.6150    0.6376   -0.0015   0.0009  -0.0008   0.0013
  1003     0.0361    3.5378   -1.2759   -0.0076    2.2710   -2.1822   0.0007  -0.0001  -0.0004
  1004    -0.5938    0.9429   -0.4169   -0.5871    0.6095    0.0023  -0.0016  -0.0009  -0.0002
  2000     5.8423    0.3982   -0.5026    5.8434   -0.0042   -0.0013  -0.0002  -0.0001   0.0007
  2002    -0.6621    0.9640   -0.4106   -0.6552    0.6317   -0.0018   0.0004   0.0011   0.0006
  2003    -0.6519    0.8025   -1.3065   -0.6802   -0.0027   -0.6543   0.0007  -0.0004  -0.0007
  2004    -1.0123   -0.3863   -1.3283   -1.0342   -0.9945    0.0050   0.0014  -0.0012   0.0005
  3000    -0.0072    0.9259   -0.4055   -0.0004    0.5913   -0.0004  -0.0008   0.0003  -0.0004
  3002    -0.9261   -0.3748   -1.3258   -0.9481   -0.9851   -0.0026  -0.0002   0.0003   0.0009
  3003     0.0273    0.3139   -1.3004    0.0015   -0.4165   -0.4013   0.0002   0.0010  -0.0004
  3004     1.0529   -0.4627   -1.2907    1.0312   -1.0734    0.0028   0.0006   0.0011  -0.0011
  4000    -7.6354    0.4837   -1.0384   -7.6452    0.0063    0.0030  -0.0002   0.0003   0.0004
  4002     1.1284   -0.4531   -1.2904    1.1066   -1.0666   -0.0051  -0.0013  -0.0007  -0.0004
  4003     0.7498    0.8197   -1.2806    0.7212    0.0012   -0.6940  -0.0006  -0.0011  -0.0002
  4004     0.6368    0.9429   -0.3621    0.6447    0.6183    0.0024   0.0000   0.0001   0.0002

    Standard deviation of transformation fit :       0.0013 m
    Maximum error at station id      2004    :       0.0018 m
```

Coordinates of the transducer accustic centre

The previous table is expanded with one row containing the transducer coordinates of the transducer acoustic centre.

```
Point   X_to      Y_to       Z_to     sigma X   sigma Y   sigma Z  Text
22     0.0000   -0.0230     0.0610    0.0001    0.0001    0.0001   Acoustic centre transducer
```

Simrad has determined the acoustic centre to be offset by 23 mm in the transducer Y-axis. The Z-coordinate of 0.061 m reflects the distance between the laser beams and the outer surface of the transducer.

This file is now transformed back to the vessel coordinate system to obtain the vessel coordinates of the transducer acoustic centre

```
SENSORMAAL
  ----------

  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Wed May 19 14:56:22 2004

  Input "FROM" file :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\Frasystem_styrbord_origo.xyz
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\Frasystem_styrbord.xyz
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ............................ =          0.0000
    Standard deviation of unit weight (S0) =          0.0002

    Estimated parameter         Standard deviation     95% Significant?

    DX =       0.003650              0.000006                YES
    DY =       0.435227              0.000006                YES
    DZ =      -0.735373              0.000006                YES
    WX =       0.593029              0.000006                YES
    WY =      -0.036466              0.000003                YES
    WZ =      -0.017063              0.000002                YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :    0.003650 m                0.000000 m           0.000006 m
    DY :    0.435227 m                0.000000 m           0.000006 m
    DZ :   -0.735373 m                0.000000 m           0.000006 m
    WX :   33.978061 deg (roll)       0.000000 deg         0.000358 deg
    WY :   -2.089343 deg (pitch)      0.000000 deg         0.000147 deg
    WZ :   -0.977620 deg (yaw)        0.000000 deg         0.000142 deg

  Q-matrix (lower triangle)
  -------------------------
      0.00119
      0.00000      0.00122
      0.00000      0.00003      0.00119
      0.00000     -0.00023     -0.00014      0.00115
      0.00004      0.00001     -0.00002      0.00001      0.00019
      0.00000     -0.00001     -0.00001     -0.00004      0.00001      0.00018


  VERIFICATION OF TRANSFORMATION:
  -------------------------------
   Point  X_from   Y_from   Z_from    X_to     Y_to     Z_to     DX      DY      DZ
     18  -0.0001   0.0006   0.0221   0.0027   0.4234  -0.7167  0.0000  0.0000  0.0000
   1000   0.0002  -1.0302   0.0001   0.0214  -0.4194  -1.3104  0.0000  0.0000  0.0000
   1002   0.6146   0.6380  -0.0012   0.6069   0.9613  -0.3557  0.0000  0.0000  0.0000
   1003  -0.0084   2.2712  -2.1819   0.0361   3.5378  -1.2759  0.0000  0.0000  0.0000
   1004  -0.5875   0.6091   0.0022  -0.5938   0.9429  -0.4169  0.0000  0.0000  0.0000
   2000   5.8434  -0.0003   0.0007   5.8423   0.3982  -0.5026  0.0000  0.0000  0.0000
   2002  -0.6556   0.6313  -0.0019  -0.6621   0.9640  -0.4106  0.0000  0.0000  0.0000
   2003  -0.6800  -0.0030  -0.6545  -0.6519   0.8025  -1.3065  0.0000  0.0000  0.0000
```

```
   2004  -1.0336  -0.9951   0.0045  -1.0123  -0.3863  -1.3283  0.0000  0.0000  0.0000
   3000  -0.0008   0.5913  -0.0003  -0.0072   0.9259  -0.4055  0.0000  0.0000  0.0000
   3002  -0.9474  -0.9857  -0.0030  -0.9261  -0.3748  -1.3258  0.0000  0.0000  0.0000
   3003   0.0019  -0.4165  -0.4013   0.0273   0.3139  -1.3004  0.0000  0.0000  0.0000
   3004   1.0319  -1.0727   0.0031   1.0529  -0.4627  -1.2906  0.0000  0.0000  0.0001
   4000  -7.6452   0.0013   0.0003  -7.6354   0.4837  -1.0384  0.0000  0.0000  0.0000
   4002   1.1073  -1.0659  -0.0048   1.1284  -0.4531  -1.2904  0.0000  0.0000  0.0000
   4003   0.7215   0.0018  -0.6938   0.7498   0.8197  -1.2806  0.0000  0.0000  0.0000
   4004   0.6443   0.6187   0.0027   0.6368   0.9429  -0.3621  0.0000  0.0000  0.0000

   Standard deviation of transformation fit :     0.0000 m
   Maximum error at station id    3004   :        0.0001 m


  TRANSFORMATION OF SELECTED INPUT FILE
(S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Styrbord_svinger\Frasystem_styrbord_origo.xyz)
  -------------------------------------

   Point    X_to     Y_to     Z_to    sigma X  sigma Y  sigma Z Text
      18    0.0027    0.4234   -0.7167   0.0001   0.0001   0.0001 Starboard center laser tool
      22    0.0018    0.3821   -0.6977   0.0001   0.0001   0.0001 Acoustic centre transducer
    1000    0.0214   -0.4194   -1.3104   0.0001   0.0001   0.0001 aa d
    1002    0.6069    0.9613   -0.3557   0.0001   0.0001   0.0001 a2 s
    1003    0.0361    3.5378   -1.2759   0.0001   0.0001   0.0001 a3 s
    1004   -0.5938    0.9429   -0.4169   0.0001   0.0001   0.0001 a4 s
    2000    5.8423    0.3982   -0.5026   0.0001   0.0001   0.0001 bb d
    2002   -0.6621    0.9640   -0.4106   0.0001   0.0001   0.0001 b2 s
    2003   -0.6519    0.8025   -1.3065   0.0001   0.0001   0.0001 b3 s
    2004   -1.0123   -0.3863   -1.3283   0.0001   0.0001   0.0001 b4 s
    3000   -0.0072    0.9259   -0.4055   0.0001   0.0001   0.0001 cc d
    3002   -0.9261   -0.3748   -1.3258   0.0001   0.0001   0.0001 c2 s
    3003    0.0273    0.3139   -1.3004   0.0001   0.0001   0.0001 c3 s
    3004    1.0529   -0.4627   -1.2906   0.0001   0.0001   0.0001 c4 s
    4000   -7.6354    0.4837   -1.0384   0.0001   0.0001   0.0001 dd d
    4002    1.1284   -0.4531   -1.2904   0.0001   0.0001   0.0001 d2 s
    4003    0.7498    0.8197   -1.2806   0.0001   0.0001   0.0001 d3 s
    4004    0.6368    0.9429   -0.3621   0.0001   0.0001   0.0001 d4 s
```

Port transducer

Preliminary “to” coordinates for the transducer

```
  17    0.0000    0.0000    0.0221   0.0001   0.0001   0.0001 Senter babord laserkors
5000    0.0000   -0.6920    0.0000   0.0001  10.0001   0.0001
6000    5.8490    0.0000    0.0000  10.0001   0.0001   0.0001
7000    0.0000    1.0608    0.0000   0.0001  10.0001   0.0001
8000   -7.6368    0.0000    0.0000  10.0001   0.0001   0.0001
```

Each across-axis coordinate component is given a 0.1 mm accuracy, whereas the along-axis coordinate components are given a 10 m accuracy. The Z-coordinate of the laser cross origin is determined from the laser tool design.

Transformation from vessel coordinates to transducer coordinates

```
SENSORMAAL
  ----------

  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Wed May 19 14:22:51 2004

  Input "FROM" file :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\Frasystem_babord.txt
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\tilsystem_babord.xyz
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0001
    Standard deviation of unit weight (S0) =          0.0041
```

Estimated parameter		Standard deviation	95% Significant?
DX =	0.029968	0.000337	YES
DY =	-0.023866	0.000513	YES
DZ =	0.853023	0.000263	YES
WX =	0.562153	0.000459	YES
WY =	0.039037	0.000060	YES
WZ =	-0.002566	0.000060	YES

Transformation parameters		Adj. correction	Standard deviation
DX :	0.029968 m	0.000000 m	0.000337 m
DY :	-0.023866 m	0.000000 m	0.000513 m
DZ :	0.853023 m	0.000000 m	0.000263 m
WX :	32.209008 deg (roll)	0.000000 deg	0.026296 deg
WY :	2.236634 deg (pitch)	0.000000 deg	0.003439 deg
WZ :	-0.147027 deg (yaw)	0.000000 deg	0.003432 deg

Q-matrix (lower triangle)

0.00683					
0.00001	0.01582				
-0.00007	0.00105	0.00415			
0.00002	-0.01073	-0.00125	0.01268		
0.00017	0.00006	-0.00007	0.00002	0.00022	
0.00007	-0.00012	-0.00005	0.00002	0.00000	0.00022

VERIFICATION OF TRANSFORMATION:

Point	X_from	Y_from	Z_from	X_to	Y_to	Z_to	DX	DY	DZ
17	-0.0027	-0.4233	-0.7169	0.0004	-0.0002	0.0213	0.0004	-0.0002	-0.0008
5000	-0.0190	-1.0199	-0.3665	-0.0007	-0.6920	0.0001	-0.0007	0.0000	0.0001
6000	5.8421	-0.4491	-0.5066	5.8490	0.0002	0.0004	0.0000	0.0002	0.0004
7000	0.0223	0.4630	-1.3000	0.0003	1.0608	0.0000	0.0003	0.0000	0.0000
8000	-7.6334	-0.4147	-1.0329	-7.6368	0.0000	0.0003	0.0000	0.0000	0.0003

Standard deviation of transformation fit : 0.0008 m
Maximum error at station id 17 : 0.0009 m

TRANSFORMATION OF SELECTED INPUT FILE
(S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\Frasystem_babord.txt)

Point	X_to	Y_to	Z_to	sigma X	sigma Y	sigma Z	Text
17	0.0004	-0.0002	0.0213	0.0001	0.0001	0.0001	Port center laser tool
5000	-0.0007	-0.6920	0.0001	0.0001	0.0001	0.0001	aa d
5002	1.0530	1.0963	-0.0048	0.0001	0.0001	0.0001	a2 s
5003	-0.0021	0.4266	-0.4101	0.0001	0.0001	0.0001	a3 s
5004	-0.9859	1.0246	0.0036	0.0001	0.0001	0.0001	a4 s
6000	5.8490	0.0002	0.0004	0.0001	0.0001	0.0001	bb d
6002	-1.0476	1.0084	-0.0036	0.0001	0.0001	0.0001	b2 s
6003	-0.6950	-0.0022	-0.6695	0.0001	0.0001	0.0001	b3 s
6004	-0.7225	-0.6954	0.0024	0.0001	0.0001	0.0001	b4 s
7000	0.0003	1.0608	0.0000	0.0001	0.0001	0.0001	cc d
7002	-0.6913	-0.7188	-0.0024	0.0001	0.0001	0.0001	c2 s
7003	0.0092	-2.1777	-2.0925	0.0001	0.0001	0.0001	c3 s
7004	0.7269	-0.7524	0.0030	0.0001	0.0001	0.0001	c4 s
8000	-7.6368	0.0000	0.0003	0.0001	0.0001	0.0001	dd d
8002	0.7598	-0.7331	-0.0029	0.0001	0.0001	0.0001	d2 s
8003	0.7274	0.0040	-0.6992	0.0001	0.0001	0.0001	d3 s
8004	1.1501	1.1063	0.0052	0.0001	0.0001	0.0001	d4 s

Coordinates converted to range (used for calculation of laser system coordinates)

17	0.0213	0.001	0.001	0.0002
5000	0.6920	0.001	0.001	0.0002
5002	1.5201	0.001	0.001	0.0002
5003	0.5917	0.001	0.001	0.0002
5004	1.4219	0.001	0.001	0.0002
6000	5.8490	0.001	0.001	0.0002
6002	1.4541	0.001	0.001	0.0002
6003	0.9650	0.001	0.001	0.0002
6004	1.0028	0.001	0.001	0.0002
7000	1.0608	0.001	0.001	0.0002
7002	0.9973	0.001	0.001	0.0002
7003	3.0201	0.001	0.001	0.0002
7004	1.0462	0.001	0.001	0.0002
8000	7.6368	0.001	0.001	0.0002

```
8002      1.0558 0.001 0.001 0.0002
8003      1.0090 0.001 0.001 0.0002
8004      1.5958 0.001 0.001 0.0002
```

The last part of this program output gives the distances between the laser cross origin and the laser hit marks. The three last columns indicate the a-priori standard deviation for the distance, the standard deviation in the across direction at the laser origin, and the distant dependant scale factor for the across accuracy.

This list is expanded with a column containing a code for which of the laser cross axis (A-D) and which of the laser cage sides (1-4) the individual observation is based on. This is used as input data for a program, which converts the observations to coordinates.

Input data for the conversion between directions and coordinates

```
5000      0.6920 0.001 0.001 0.0002 aa_d
5002      1.5201 0.001 0.001 0.0002 a2_s
5003      0.5917 0.001 0.001 0.0002 a3_s
5004      1.4219 0.001 0.001 0.0002 a4_s
6000      5.8490 0.001 0.001 0.0002 bb_d
6002      1.4541 0.001 0.001 0.0002 b2_s
6003      0.9650 0.001 0.001 0.0002 b3_s
6004      1.0028 0.001 0.001 0.0002 b4_s
7000      1.0608 0.001 0.001 0.0002 cc_d
7002      0.9973 0.001 0.001 0.0002 c2_s
7003      3.0201 0.001 0.001 0.0002 c3_s
7004      1.0462 0.001 0.001 0.0002 c4_s
8000      7.6368 0.001 0.001 0.0002 dd_d
8002      1.0558 0.001 0.001 0.0002 d2_s
8003      1.0090 0.001 0.001 0.0002 d3_s
8004      1.5958 0.001 0.001 0.0002 d4_s
```

Calculated coordinates (“To”-coordinates used as input for the final calculation)

```
Transducer misalignments
  ------------------------
  Roll            0.0135 degrees
  Pitch           0.0029 degrees
  Yaw             0.0567 degrees

  17     0.0000     0.0000     0.0221     0.0015     0.0015     0.0015 Senter babord laserkors
5000    -0.0007    -0.6920    -0.0002     0.0011     0.0010     0.0011 aa_d
5002     1.0542     1.0952    -0.0041     0.0012     0.0012     0.0013 a2_s
5003    -0.0013     0.4268    -0.4098     0.0011     0.0011     0.0011 a3_s
5004    -0.9839     1.0265     0.0043     0.0012     0.0011     0.0013 a4_s
6000     5.8490    -0.0060    -0.0003     0.0010     0.0022     0.0022 bb_d
6002    -1.0477     1.0084    -0.0039     0.0011     0.0012     0.0013 b2_s
6003    -0.6960    -0.0019    -0.6684     0.0011     0.0012     0.0011 b3_s
6004    -0.7239    -0.6939     0.0027     0.0011     0.0011     0.0012 b4_s
7000     0.0011     1.0608     0.0002     0.0012     0.0010     0.0012 cc_d
7002    -0.6916    -0.7185    -0.0030     0.0011     0.0011     0.0012 c2_s
7003     0.0065    -2.1776    -2.0926     0.0016     0.0013     0.0013 c3_s
7004     0.7239    -0.7553     0.0027     0.0011     0.0011     0.0012 c4_s
8000    -7.6368     0.0085     0.0004     0.0010     0.0025     0.0025 dd_d
8002     0.7606    -0.7322    -0.0032     0.0011     0.0011     0.0012 d2_s
8003     0.7277     0.0023    -0.6990     0.0011     0.0012     0.0011 d3_s
8004     1.1521     1.1042     0.0047     0.0012     0.0012     0.0013 d4_s

  Number of transformed points = 16
```

This software also corrects the observations for transducer misalignment, which is determined by a check of the transducer in a precision coordinate measuring machine.

Final transducer orientation

```
SENSORMAAL
  ----------
```

```
  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Tue Jun  8 14:59:28 2004

  Input "FROM" file : S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\baatsystem.txt
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\tilsystem_babord3.xyz
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0000
    Standard deviation of unit weight (S0) =          0.0007

    Estimated parameter         Standard deviation     95% Significant?

    DX =       0.029979              0.000245               YES
    DY =      -0.024124              0.000303               YES
    DZ =       0.853133              0.000216               YES
    WX =       0.562296              0.000211               YES
    WY =       0.038513              0.000144               YES
    WZ =      -0.001562              0.000129               YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :    0.029979 m                0.000000 m           0.000245 m
    DY :   -0.024124 m                0.000000 m           0.000303 m
    DZ :    0.853133 m                0.000000 m           0.000216 m
    WX :   32.217208 deg (roll)       0.000000 deg         0.012076 deg
    WY :    2.206637 deg (pitch)      0.000000 deg         0.008232 deg
    WZ :   -0.089471 deg (yaw)        0.000000 deg         0.007376 deg

  Q-matrix (lower triangle)
  -------------------------
      0.12268
     -0.00040      0.18829
     -0.00062     -0.00020      0.09546
      0.00124     -0.09677      0.00018      0.09081
      0.03945      0.00010     -0.00053      0.00049      0.04220
      0.01997     -0.00098     -0.00029      0.00160      0.00320      0.03388


  VERIFICATION OF TRANSFORMATION:
  ------------------------------
   Point    X_from    Y_from    Z_from      X_to      Y_to      Z_to      DX        DY        DZ
     17    -0.0027   -0.4233   -0.7169    0.0003   -0.0004    0.0215    0.0003   -0.0004   -0.0006
   5000    -0.0190   -1.0199   -0.3665   -0.0015   -0.6921    0.0001   -0.0008   -0.0001    0.0003
   5002     1.0751    0.4878   -1.2819    1.0542    1.0950   -0.0046    0.0000   -0.0002   -0.0005
   5003     0.0183   -0.2922   -1.3091   -0.0017    0.4265   -0.4100   -0.0004   -0.0003   -0.0002
   5004    -0.9641    0.4369   -1.3162   -0.9848    1.0256    0.0040   -0.0009   -0.0009   -0.0003
   6000     5.8421   -0.4491   -0.5066    5.8489   -0.0065    0.0000   -0.0001   -0.0005    0.0003
   6002    -1.0259    0.4195   -1.3161   -1.0465    1.0095   -0.0033    0.0012    0.0011    0.0006
   6003    -0.6757   -0.7915   -1.3271   -0.6951   -0.0015   -0.6694    0.0009    0.0004   -0.0010
   6004    -0.7404   -1.0197   -0.3909   -0.7233   -0.6947    0.0025    0.0006   -0.0008   -0.0002
   7000     0.0223    0.4630   -1.3000    0.0015    1.0606    0.0003    0.0004   -0.0002    0.0001
   7002    -0.7096   -1.0421   -0.3813   -0.6921   -0.7181   -0.0023   -0.0005    0.0004    0.0007
   7003     0.0230   -3.3924   -1.3440    0.0065   -2.1776   -2.0926    0.0000    0.0000    0.0000
   7004     0.7066   -1.0713   -0.3035    0.7260   -0.7533    0.0029    0.0021    0.0020    0.0002
   8000    -7.6334   -0.4147   -1.0329   -7.6369    0.0085    0.0011   -0.0001    0.0000    0.0007
   8002     0.7401   -1.0582   -0.3174    0.7590   -0.7341   -0.0029   -0.0016   -0.0019    0.0003
   8003     0.7467   -0.8057   -1.3000    0.7273    0.0031   -0.6992   -0.0004    0.0008   -0.0002
   8004     1.1721    0.5013   -1.2750    1.1513    1.1048    0.0053   -0.0008    0.0006    0.0006

    Standard deviation of transformation fit :       0.0014 m
    Maximum error at station id      7004    :       0.0029 m
```

Coordinates of the transducer accustic centre

The previous table is expanded with one row containing the transducer coordinates of the transducer acoustic centre.

```
21     0.0000    -0.0230     0.0610    0.0001    0.0001    0.0001 Acoustic center transducer
```

Simrad has determined the acoustic centre to be offset by 23 mm in the transducer Y-axis. The Z-coordinate of 0.061 m reflects the distance between the laser beams and the outer surface of the transducer.

This file is now transformed back to the vessel coordinate system to obtain the vessel coordinates of the transducer acoustic centre

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  Calculation of transformation parameters
  Both input coordinate systems are supposed to be left handed
  All transformation angles are given as right handed rotations

  Wed May 19 14:52:03 2004

  Input "FROM" file :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\Frasystem_babord_origo.inp
  Input "TO" file   :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\frasystem_babord.TXT
  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0000
    Standard deviation of unit weight (S0) =          0.0002

    Estimated parameter         Standard deviation     95% Significant?

    DX =      -0.002320             0.000007               YES
    DY =      -0.434417             0.000007               YES
    DZ =      -0.735257             0.000007               YES
    WX =      -0.562449             0.000007               YES
    WY =      -0.031712             0.000003               YES
    WZ =       0.022836             0.000003               YES


  Transformation parameters       Adj. correction    Standard deviation
  -------------------------       ---------------    ------------------
    DX :   -0.002320 m                0.000000 m           0.000007 m
    DY :   -0.434417 m                0.000000 m           0.000007 m
    DZ :   -0.735257 m                0.000000 m           0.000007 m
    WX :  -32.225960 deg (roll)       0.000000 deg         0.000396 deg
    WY :   -1.816985 deg (pitch)      0.000000 deg         0.000163 deg
    WZ :    1.308434 deg (yaw)        0.000000 deg         0.000157 deg

  Q-matrix (lower triangle)
  -------------------------
      0.00119
      0.00000      0.00122
      0.00000     -0.00003      0.00119
      0.00000     -0.00021      0.00014      0.00113
      0.00004      0.00000     -0.00002     -0.00002      0.00019
      0.00000     -0.00001      0.00000     -0.00003     -0.00001      0.00018


  VERIFICATION OF TRANSFORMATION:
  -------------------------------
   Point    X_from    Y_from    Z_from    X_to     Y_to     Z_to    DX      DY      DZ
     17    0.0003   -0.0004    0.0215   -0.0027   -0.4233   -0.7169   0.0000   0.0000   0.0000
   5000   -0.0009   -0.6921    0.0003   -0.0190   -1.0199   -0.3665   0.0000   0.0000   0.0000
   5002    1.0531    1.0960   -0.0048    1.0751    0.4878   -1.2819   0.0000   0.0000   0.0000
   5003   -0.0021    0.4264   -0.4101    0.0183   -0.2922   -1.3092   0.0000   0.0000  -0.0001
   5004   -0.9858    1.0246    0.0037   -0.9641    0.4369   -1.3162   0.0000   0.0000   0.0000
   6000    5.8489   -0.0008    0.0002    5.8421   -0.4491   -0.5066   0.0000   0.0000   0.0000
   6002   -1.0475    1.0085   -0.0035   -1.0259    0.4196   -1.3161   0.0000   0.0001   0.0000
   6003   -0.6951   -0.0023   -0.6694   -0.6757   -0.7915   -1.3271   0.0000   0.0000   0.0000
   6004   -0.7227   -0.6954    0.0026   -0.7404   -1.0197   -0.3909   0.0000   0.0000   0.0000
   7000    0.0004    1.0606    0.0000    0.0223    0.4630   -1.3000   0.0000   0.0000   0.0000
   7002   -0.6915   -0.7188   -0.0022   -0.7096   -1.0421   -0.3813   0.0000   0.0000   0.0000
   7003    0.0087   -2.1781   -2.0921    0.0230   -3.3924   -1.3440   0.0000   0.0000   0.0000
   7004    0.7268   -0.7526    0.0031    0.7067   -1.0713   -0.3035   0.0001   0.0000   0.0000
   8000   -7.6369    0.0010    0.0008   -7.6334   -0.4147   -1.0329   0.0000   0.0000   0.0000
   8002    0.7597   -0.7334   -0.0027    0.7401   -1.0582   -0.3174   0.0000   0.0000   0.0000
   8003    0.7273    0.0037   -0.6991    0.7467   -0.8057   -1.3000   0.0000   0.0000   0.0000
   8004    1.1502    1.1059    0.0051    1.1721    0.5012   -1.2750   0.0000  -0.0001   0.0000

    Standard deviation of transformation fit :       0.0001 m
```

Til en hver tid er datafilen den gyldige versjonen av dette dokumentet.

Utskriftsdato:7. desember 2009

```
    Maximum error at station id      8002    :       0.0001 m


  TRANSFORMATION OF SELECTED INPUT FILE
(S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\Babord_svinger\Frasystem_babord_origo.inp)
  -----------------------------------

Point     X_to       Y_to       Z_to     sigma X   sigma Y   sigma Z Text
  17    -0.0027    -0.4233    -0.7169    0.0001    0.0001    0.0001 Port center laser tool
  21    -0.0048    -0.4214    -0.6714    0.0001    0.0001    0.0001 Acoustic center transducer
5000    -0.0190    -1.0199    -0.3665    0.0001    0.0001    0.0001 aa d
5002     1.0751     0.4878    -1.2819    0.0001    0.0001    0.0001 a2 s
5003     0.0183    -0.2922    -1.3092    0.0001    0.0001    0.0001 a3 s
5004    -0.9641     0.4369    -1.3162    0.0001    0.0001    0.0001 a4 s
6000     5.8421    -0.4491    -0.5066    0.0001    0.0001    0.0001 bb d
6002    -1.0259     0.4196    -1.3161    0.0001    0.0001    0.0001 b2 s
6003    -0.6757    -0.7915    -1.3271    0.0001    0.0001    0.0001 b3 s
6004    -0.7404    -1.0197    -0.3909    0.0001    0.0001    0.0001 b4 s
7000     0.0223     0.4630    -1.3000    0.0001    0.0001    0.0001 cc d
7002    -0.7096    -1.0421    -0.3813    0.0001    0.0001    0.0001 c2 s
7003     0.0230    -3.3924    -1.3440    0.0001    0.0001    0.0001 c3 s
7004     0.7067    -1.0713    -0.3035    0.0001    0.0001    0.0001 c4 s
8000    -7.6334    -0.4147    -1.0329    0.0001    0.0001    0.0001 dd d
8002     0.7401    -1.0582    -0.3174    0.0001    0.0001    0.0001 d2 s
8003     0.7467    -0.8057    -1.3000    0.0001    0.0001    0.0001 d3 s
8004     1.1721     0.5012    -1.2750    0.0001    0.0001    0.0001 d4 s
```

Attitude calibration

The numeric results from all four days of observations are listed. The calculation software was slightly modified after the calculation of the first day was done and the preliminary installation angles were set.

7th of June 2004

```
Attitude sensor calibration
  ---------------------------

  Calculate offset between the GPS derived attitude and attitude
  readings from an attitude sensor. All attitude angles are assumed to
  be given as right-handed rotations.

  Tue Jun  8 10:21:05 2004

  Input file with GPS attitude data .. :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att1\gps_att1.att
  Input file with attitude sensor data :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att1\0407jun.att

  T_gps_file-T_attitude_file =      0.000 s

  Number of unknowns:  4
  Number of observations:  7470

  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0008
    Standard deviation of unit weight (S0) =          0.0002


  Transformation parameters     Adj. correction     Standard deviation   95% Significant?
  -------------------------     ---------------     ------------------   ----------------
  D_roll    :   -0.121557 deg     0.000000 deg        0.006671 deg           YES
  D_pitch   :   -5.707778 deg     0.000000 deg        0.018217 deg           YES
  D_heading :   -0.629776 deg     0.000000 deg        0.006062 deg           YES
  MRU rot.  :    0.836924 deg     0.000000 deg        0.048118 deg           YES


  Q-matrix (lower triangle)
  -------------------------
```

```
     0.37544
    -0.14559      2.79969
     0.00000      0.00000      0.31004
    -2.63023      1.08120      0.00000     19.53302


  Input values to SEAPATH:
  ------------------------
  New roll     = Old roll        +0.12 deg.
  New pitch    = Old pitch       +5.71 deg.
  New heading  = Old heading     -0.63 deg.
  New MRU rot. = Old MRU rot.    -0.84 deg.
```

8th of June 2004

```
Attitude sensor calibration
  --------------------------

  Calculate offset between the GPS derived attitude and attitude
  readings from an attitude sensor. All attitude angles are assumed to
  be given as right-handed rotations.

  Wed Jun  9 10:00:26 2004

  Input file with GPS attitude data .. :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att2\gpsatt2.att
  Input file with attitude sensor data :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att2\0408jun.att

  T_gps_file-T_attitude_file =      0.000 s

  Number of unknowns:  4
  Number of observations:  7999

  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0003
    Standard deviation of unit weight (S0) =          0.0001


  Transformation parameters     Adj. correction     Standard deviation   95% Significant?
  -------------------------     ---------------     ------------------   ----------------
  D_roll    :    0.111293 deg     0.000000 deg        0.001692 deg           YES
  D_pitch   :   -0.027349 deg     0.000000 deg        0.009761 deg           YES
  D_heading :    0.328318 deg     0.000000 deg        0.003157 deg           YES
  MRU rot.  :    0.194556 deg     0.000000 deg        0.041144 deg           YES


  Q-matrix (lower triangle)
  -------------------------
     0.07367
    -0.08490      2.45187
     0.00000      0.00000      0.25650
    -1.22876      3.00987      0.00000     43.55979


  Input values to SEAPATH:
  ------------------------
  New roll     = Old roll        -0.11 deg.
  New pitch    = Old pitch       +0.03 deg.
  New heading  = Old heading     +0.33 deg.
  New MRU rot. = Old MRU rot.    -0.19 deg.
```

9th of June 2004

```
Attitude sensor calibration
  --------------------------

  Calculate offset between the GPS derived attitude and attitude
  readings from an attitude sensor. All attitude angles are assumed to
  be given as right-handed rotations.
```

```
  Thu Jun 10 12:56:35 2004

  Input file with GPS attitude data .. :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att3\gpsatt3.att
  Input file with attitude sensor data :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att3\0409jun.att

  T_gps_file-T_attitude_file =      0.000 s

  Number of unknowns:  4
  Number of observations:  7327

  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0008
    Standard deviation of unit weight (S0) =          0.0002


  Transformation parameters     Adj. correction     Standard deviation   95% Significant?
  -------------------------     ---------------     ------------------   ----------------
  D_roll    :    0.030143 deg     0.000000 deg        0.002855 deg           YES
  D_pitch   :    0.031114 deg     0.000000 deg        0.018357 deg           YES
  D_heading :   -0.027492 deg     0.000000 deg        0.006151 deg           YES
  MRU rot.  :    0.916021 deg     0.000000 deg        0.066626 deg           YES


  Q-matrix (lower triangle)
  -------------------------
      0.06653
     -0.08618      2.74935
      0.00000      0.00000      0.30867
     -1.30312      1.19951      0.00000     36.21813


  Input values to SEAPATH:
  ------------------------
  New roll     = Old roll        -0.03 deg.
  New pitch    = Old pitch       -0.03 deg.
  New heading  = Old heading     -0.03 deg.
  New MRU rot. = Old MRU rot.    -0.92 deg.
```

24th of June 2004

```
Attitude sensor calibration
  ---------------------------

  Calculate offset between the GPS derived attitude and attitude
  readings from an attitude sensor. All attitude angles are assumed to
  be given as right-handed rotations.

  Fri Jun 25 12:48:50 2004

  Input file with GPS attitude data .. :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att4\gpsatt4.att
  Input file with attitude sensor data :
S:\Grupper\Teknologi\Geodesi\Temp\sjofalk\att4\0424JUN.att

  T_gps_file-T_attitude_file =      0.000 s

  Number of unknowns:  4
  Number of observations:  8316

  CALCULATION OF TRANSFORMATION PARAMETERS -   Result from least squares adjustment
  ------------------------------------------------------------------------------

    SUM( pvv ) ........................... =          0.0008
    Standard deviation of unit weight (S0) =          0.0002


  Transformation parameters     Adj. correction     Standard deviation   95% Significant?
  -------------------------     ---------------     ------------------   ----------------
  D_roll    :    0.017265 deg     0.000000 deg        0.002163 deg           YES
  D_pitch   :    0.023051 deg     0.000000 deg        0.015497 deg           YES
  D_heading :   -0.007629 deg     0.000000 deg        0.005272 deg           YES
  MRU rot.  :   -0.102138 deg     0.000000 deg        0.036854 deg           YES
```

```
Q-matrix (lower triangle)
-------------------------
    0.04479
    0.00594      2.29989
    0.00000      0.00000      0.26619
   -0.59276     -0.04112      0.00000     13.00689


Input values to SEAPATH:
------------------------
New roll     = Old roll        -0.02 deg.
New pitch    = Old pitch       -0.02 deg.
New heading  = Old heading     -0.01 deg.
New MRU rot. = Old MRU rot.    +0.10 deg.
```

Appendix 2. GPS attitude angle determination

The GPS attitude angles are determined from the geodetic positions of the onboard antennas. Geodetic ITRF/Euref89 positions for the antennas are used to transform these coordinates to the local geodetic system. This is a left-handed topocentric coordinate system having the x-axis pointing towards north, the y-axis to the east and the z-axis up. The transformation formula is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{LG} = \begin{bmatrix} -\sin\varphi\cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi \\ -\sin\lambda & \cos\lambda & 0 \\ \cos\varphi\cos\lambda & \cos\varphi\sin\lambda & \sin\varphi \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{ITRF}$$

In this formula φ and λ denotes geodetic latitude and longitude. ***LG*** denotes the local geodetic coordinate system and ***ITRF*** denotes the geocentric ITRF coordinate system.

For each measurement epoch (in this case 1 Hz data was logged), the local geodetic coordinates of the four antennas are transformed to the vessel coordinate system. The transformation is calculated as a least squares fit between the two coordinate systems. The vessel attitude angles are described by the transformation parameters determined from the adjustment. The transformation equation:

$$\vec{X}_V = \vec{D}_X + s \cdot R \cdot \vec{X}_{LG}$$

Where $\vec{X}_{LG}$ are the local geodetic coordinates of the GPS antennas, and $\vec{X}_V$ are the vessel coordinates of the GPS antennas. The vessel coordinate system is defined as x pointing forward, y pointing starboard and z pointing down. $\vec{D}_X$ is a translation vector, *s* is a scale factor and ***R*** is a rotation matrix with the definition:

$$\begin{bmatrix} \cos\phi\cos\kappa & \cos\phi\sin\kappa & \sin\phi \\ \sin\omega\sin\phi\cos\kappa - \cos\omega\sin\kappa & \sin\omega\sin\phi\sin\kappa + \cos\omega\cos\kappa & -\sin\omega\cos\phi \\ \cos\omega\sin\phi\cos\kappa + \sin\omega\sin\kappa & \cos\omega\sin\phi\sin\kappa - \sin\omega\cos\kappa & -\cos\omega\cos\phi \end{bmatrix}$$

In this formula ω denotes roll, ϕ denotes pitch, and κ denotes heading. This rotation matrix is used for transformation from the left-handed local geodetic system to the right-handed vessel coordinate system. The rotations are determined as right-handed rotations in the vessel coordinate system.

The attitude angles determined from this transformation are relatively insensible to the positioning accuracy of the vessel (one nautical mile latitude error converts to one arc minute attitude angle error).

Only one data rejection criterion is used: Only epochs where the GPS positions can be transformed to the vessel coordinate system with no residual coordinate component errors larger than a user-defined limit (e.g. 3 cm) are accepted. No attitude angles are calculated for epochs with a misfit for one or more coordinate component.

Appendix 3. Vessel settlement

The settlement of S/L Sjøfalk is estimated from GPS position at 8 locations onboard the vessel. The GPS positions are corrected for observed tides at a location close to the area of operation. GPS positions from all the 8 locations are utilised to estimate the GPS position of the vessel coordinate system origin. The velocity is calculated from the positional change of the vessel coordinate system origin. The settlement describes the vertical displacement of the vessel due to velocity changes. The data set displayed below indicates that the height of the vessel coordinate system origin sinks when the boat starts moving and then rises as the speed increases until it reaches a velocity of approximately 10 m/s.

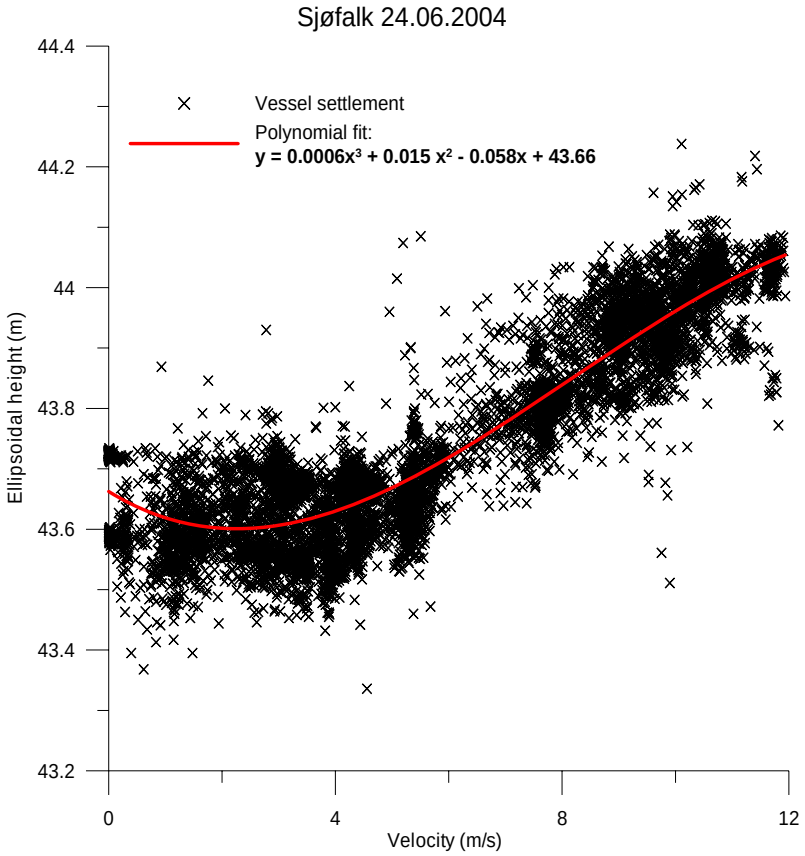

Figure 16 Settlement of S/L Sjøfalk.