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NOAA Ship Okeanos Explorer
2009 Mapping Systems Readiness Report

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Table of Contents

Purpose

The purpose of this document is to describe NOAA Ship Okeanos Explorer mapping system and the performance evaluation undertaken in September 2008. The intent of this report is to provide a comprehensive listing of all system components, configuration, calibrations and system performance evaluations.

Background

NOAA Ship Okeanos Explorer, R 337 (WTDH) is NOAA's only ship dedicated exclusively for ocean exploration. Okeanos Explorer is one of the five former U.S. Navy T-AGOS ships acquired and converted by NOAA for use as a scientific research ships. Originally built for anti-submarine warfare, former USNS Capable was commissioned as NOAA Ship Okeanos Explorer on August 13, 2008. The vessel went extensive refurbishment adding mission space for ROV hanger, bow and stern thrusters, fairings for mapping sensors, bridge up-gradation by Todd Pacific Shipyards Corporation 2005-2008. The ship has been outfitted with a multibeam echo sounder (MBES), single beam echo sounder (SBES) and sub bottom profiler (SBP) along with host of ancillary equipments. For detailed lay-out of the all the new, modified and re-located equipment consult NOAA ship Okeanos Explorer general arrangement plans [1] and Appendix A. Videos of the NOAA Okeanos Explorer conversion can be accessed at http://oceanexplorer.noaa.gov/okeanos/welcome.html

Vessel Specifications

Vessel Specifications			
Hull Number	337	Cruising speed	10 knots
Call letters	WTDH	Mapping speed	8 Kts
Builder	VT Halter Marine, Inc., Moss Point, MS	Berthing	46
Launched	Oct 28, 1988	Commissioned officers	6
Delivered to NOAA	Sept 10, 2004	Licensed engineers	3
Commissioned	Aug 14, 2008	Crew	18
Length (LOA)	68.3 m (224 feet)	Scientists	19
Breadth	13.1 m (43 feet)	Ambar RHIB	
Draft	5.18 m (17 feet)	Full Load displacement	2312 LT
Range	9600 nm	Light ship displacement	1616 LT
Endurance	40 days		
Main propulsion	2800 hp General electric DC drive motors	Power	4 Caterpillar D398 12 cylinder 800 HP diesel generators produce 240,000 watts at 600 vac.

Table 1: Vessel specifications (September, 2008) based on http://www.moc.noaa.gov/oe/Specs/General%20Specifications.pdf

Hardware

Equipment Name	Install Date	Manufacturer	Ser. No.
30 kHz Multibeam Echo Sounder EM 302	2006/2007	Kongsberg	101
POS MV V4 Heading sensor	2007/2008	Applanix	2572
POS MV motion sensor	2007/2008	Applanix	564
Navigation system C Nav	Feb 9,2007	C&C Technology	5164
CTD 9/11 + [1 Pressure sensor, 2 conductivity sensors, 2 temperature sensors]	2007/2008	Sea Bird	SBE3 5017 (T) SBE3 5001 (T) 09P47490-0905 (P) SBE4C 3449 (C) SBE4C 3451 (C)
Surface Sound Velocity (SBE 45 Thermosalinograh)	2007/2008	Sea Bird	3845414-0317
Water sampler	2007/2008	General Oceanic 2.5 L	
Fluorometer 10-AU Filed flurometer	Not operational (In repairs as of June, 2009)		
Single beam echo sounder (12 kHz) EA 600	2006/2007	Kongsberg	GPT cabinet 385
Sub bottom profiler	2006/2007	Knudsen	K2K-07-0910
Net Apps Storage	2007	NetApps	#1: 0135019575 & #2: 0135019506

Table 2: Mapping hardware inventory

Additional deck equipment used during mapping operations includes:

- J-Frame (3,500 lbs. safe working load) used for vertical CTD casts and a towing capacity of 3,000 lbs. up to 45 degrees from vertical.
- CTD Winch (3,500 lbs safe working load using a 0.375 inch electromechanical cable) with 8,000 m of cable for CTD
- A-Frame (20,000 lbs. safe working load) used for deployment of ROV

Figure 1: J frame located on starboard side is designed for CTD casts (left). CTD Winch (right).

Figure 2: View of A-Frame looking aft. The A-Frame is presently configured to handle the ROV.

Multibeam Echo Sounder (MBES)

Okeanos Explorer is equipped with Kongsberg Maritime EM 302 multibeam sonar system. The sonar system was hull mounted by Todd Shipyard in Seattle during 2006/2007 and was accepted after field tests in September, 2008 [5]. The EM 302 receiver and transmit array are arranged in a transducer fairing installed between frame 15 and 42 (Figure 3). The top side electronics for EM 302 are located in Ship's library (trans-receiver unit – PU unit) and EM 302 control software SIS (Seafloor Information System) station is located in main mission space (control center). A remote on/off switch is also located in the control center.

The nominal frequency of EM 302 is 30 kHz. The system can be operated in two modes – CW or FM mode. The distinctive advantage of FM mode is that larger swath coverage can be realized as compared to traditional deep water multibeam systems. The sonar also utilizes multi-ping technology where two pings are simultaneously sent into water thereby increasing the data density.

Figure 3: (Clockwise from left) EM 302 TRU unit, Transducer fairing, Elements of EM 302 being installed inside the fairing, TRU remote on / off switch, EM 302 EM 302 SIS control computer.

Positioning and Orientation equipment

Applanix TSS Positioning and Orientation system for Marine Vehicles (POS/MV) estimates position, heading, attitude and heave of the vessel. The system includes POS computer system (PCS), an Inertial measurement unit (IMU) and two GPS antennas. The IMU is located in the fan room in front of Ship's library (between frames 35-40).

Figure 4: (Left) POS IMU located in fan room (right) DGPS (02) antennas mounted on the forward rails on the platform above bridge (view from starboard side looking port).

Sound Speed measurements

Okeanos Explorer is outfitted with a Sea-bird electronics, Inc. (SBE) 9/11plus CTD with dual temperature and conductivity sensors and 8,000m of cable. The surface sound speed sensor is a SBE45 Micro-TSG with SBE 38 remote temperature probe. Expendable bathy thermograph (XBT) casts are conducted while the ship is surveying at full cruising speed. The sound speed profiles (from CTD and XBT) are recovered in real time. The sound speed computed by the TSG is fed into the multibeam software. During the shake down cruise, due to different format issues sound speed from TSG was not available for continuous feed into EM 302 multibeam sonar. Issues with inputting surface sound speed EM 302 in real time are now resolved with an installation of two junction boxes in the dry lab that split the continuous surface data into respective formats for EM302 and SCS. Sound speed profile obtained from CTD / XBT cast can be converted to EM 302 compliant data format using Velociwin (a NOAA in-house tool).

During May 2009 CTD and XBT cast comparable results were obtained using the two systems with maximum difference of 1-2 m/s (Figure 5)

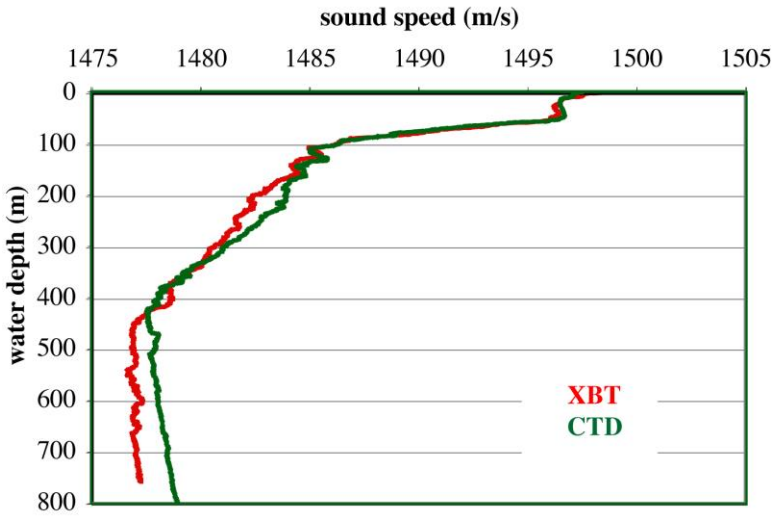


Figure 5: Comparison of sound speed calculated from an XBT and CTD cast at the May 2009 patch test.

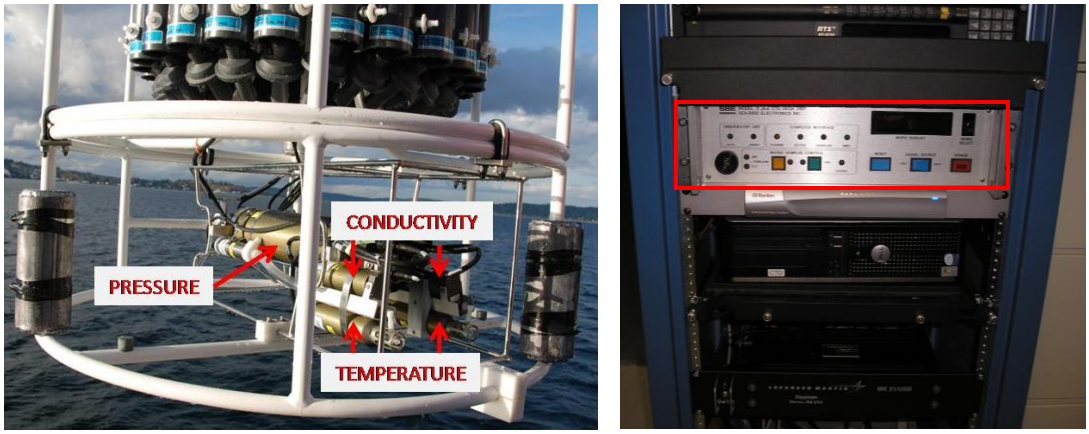


Figure 6: (Left) SBE 9plus CTD with dual temperature and conductivity sensors. The CTD is connected to an SBE 32 Carousel for collecting water samples with up to 24 2.5L Niskin bottles. (Right) SBE 11 plus CTD Deck Unit located in the dry lab.

Figure 7: (Left) XBT launch from the aft deck (Right) Thermo-salinograph (TSG) is mounted at the aft bulk head of wet lab, which continuously measures temperature and salinity of water pumped in through the bow thruster room.

Water sampler

Seabird 911Plus CTD and deck unit combined with a Seabird 32 Carousel with 24 General Oceanics 2.5L water sampling bottles. See figure 6 above.

Fluorometer

At present this system is not being used for mapping and it is under repair.

Figure 8: Turner designs 10-AU installed in wetlab.

Bridge DP system

Okeanos Explorer has been equipped with Kongsberg Dynamic position (DP) that has been integrated with the navigation system to help Okeanos Explorer maintain her position with in few meters during ROV operations. The DP system uses the unique set of bow and aft thrusters to maintain ship's position. The DP system is also capable of accepting predefined track lines which are run with DP system with minimal supervision.

During performance evaluation of bridge DP system the system was found to be working satisfactorily as for maintaining the position and following the track lines. The bridge DP system accepts the track lines in a specific format in form of a series of way points. It was found problematic during shake down cruise to convert MapInfo (or Hypack) generated track lines into DP system compliant format. Also the DP system at present is not connected to ship's net work and therefore files containing way points need to be manually fed to the DP system through local USB port. As a turn around solution the way points can also be manually entered into DP system through key pad.

Example of DP system compliant way point table is provided in Appendix B.

Figure 9: Bridge DP system installed on *Okeanos Explorer* showing different controls and the USB drive for feeding the way point table.

Single Beam Echo Sound (SBES)

SBES system consists of 12 kHz transducer (Kongsberg 12-16/60) with 2 KW transmit power that can collect depths up to 7000 m of water depths. The tranreceiver unit is connected to EA-RDS that provides the user interface to control the system settings. The tranreceiver unit is located in ship's library with top side electronics including controlling computer are located in dry lab. Figure (10) provides an example of EA 600 interface. The sonar has been tested to date to a depth of 4500 m. Acceptance report of EA 600 is included [6].

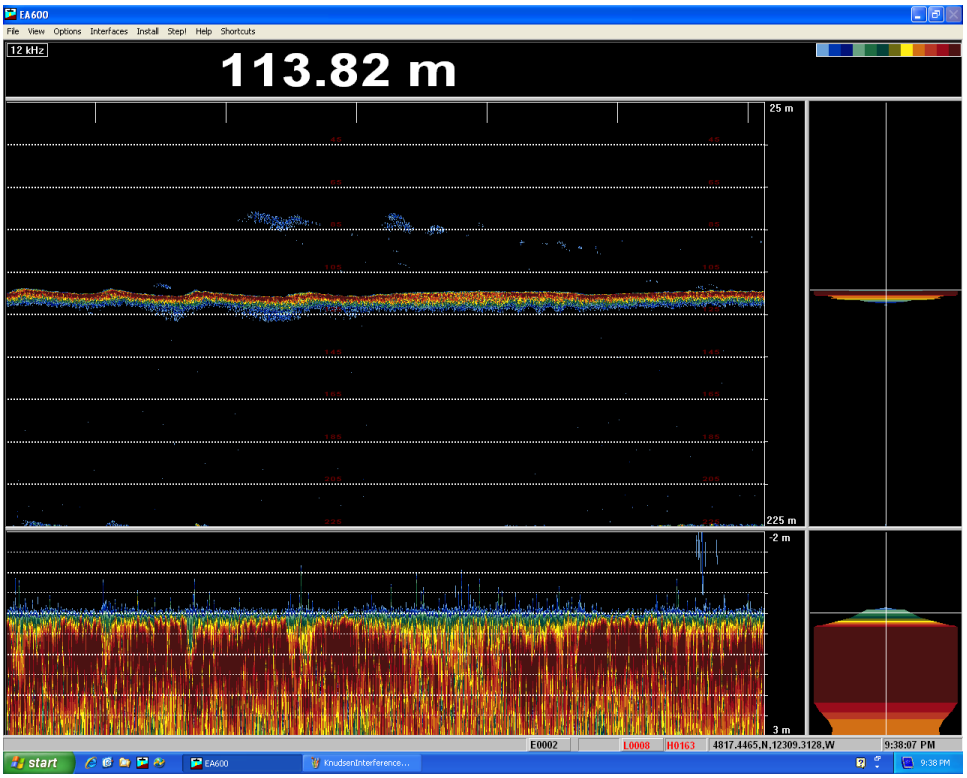


Figure 10: EA 600 RDS controller.

Sub Bottom profiler (SBP)

NOAA Ship *Okeanos Explorer* is outfitted with 3.5 kHz Knudsen chirp 3260 sub-bottom profiler. The system was accepted by ship in Nov 2008 after some initial checks [2] on the system using simulator mode. However, the system was not configured to receive navigation and heave input at that time. During March 2009 sea trials the system was configured to collect some data. The data has been sent to Knudsen for evaluation.

Also during evaluation it was observed that there is a strong interference between SBP and EM302 / EA 600. The SBP profiler has been reported to accept external trigger from EM 302 but this option has not been tested yet pending delivery of additional electronic board from Kongsberg, Inc which will enable additional external trigger. Presently the external trigger port from EM 302 is used for remote ON/OFF switch and there fore further trouble shooting has to wait till Kongsberg, Inc deliver the required parts (accepted delivery July, 2009)

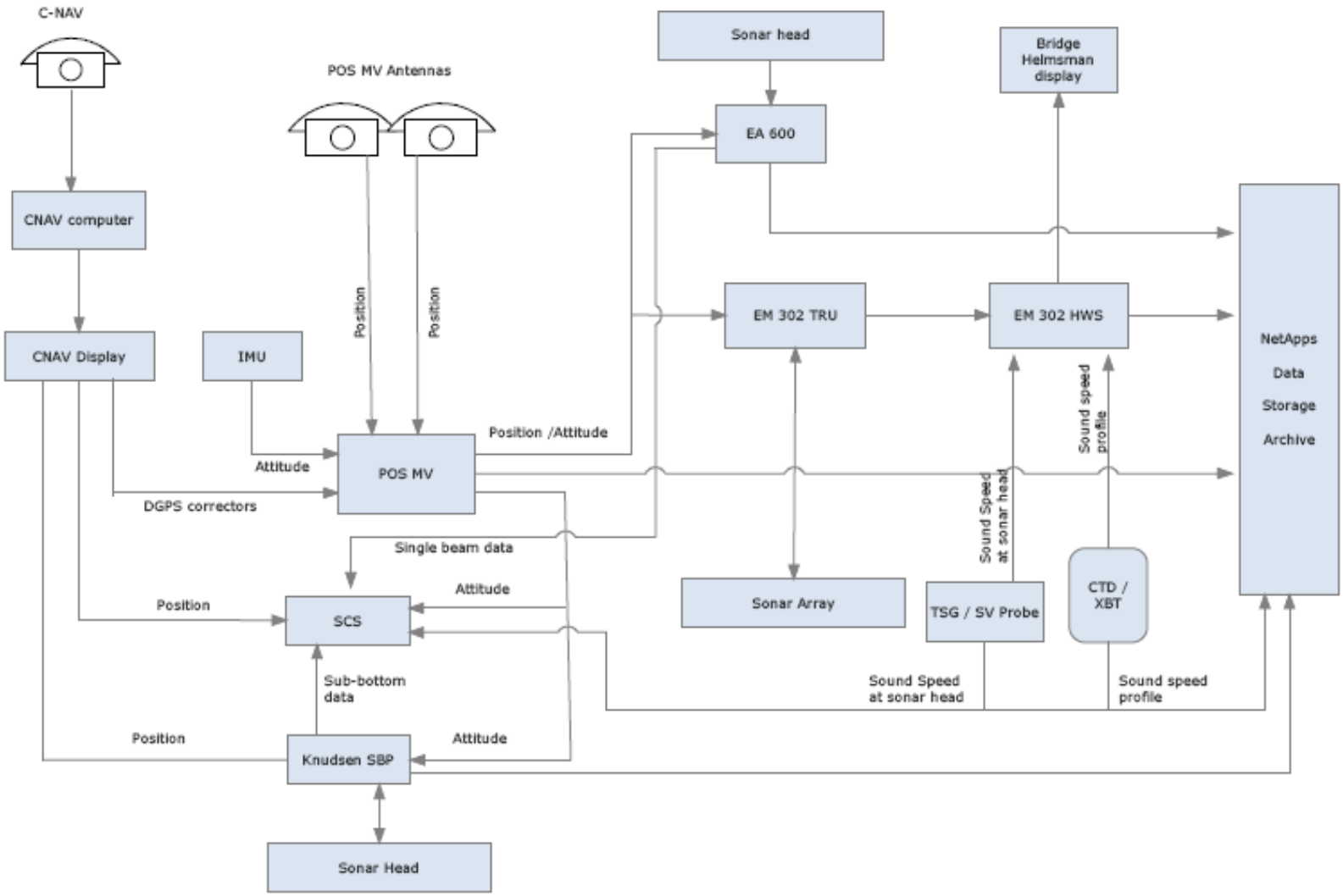


Figure 11: Schematic diagram of NOAA Ship *Okeanos Explorer* mapping system

Static Vessel offsets

The sensors (IMU and GPS antennas), the sonar system, and permanent benchmarks were measured with respect to the vessel's reference point (a granite block). The ship was surveyed by Westlake Consultants, Inc. The resultant preliminary report "Report of Sonar Systems and GPS Antennae as-builting on the NOAA Okeanos Explorer" March 18, 2008 [3] summarizes Westlake Consultant's survey methodology, defines the coordinate system and details the offsets measurements. All measurements described within the report are referred to the granite block and follow coordinate system all values STBD (Y), FWD (X) and down of the granite block (Z) as positive. Positive pitch is described as bow up and positive roll is described as STBD up.

Center of Roll and Pitch

As the position of center of gravity changes with ship loading conditions. The position of the center of the gravity was available from the records of the ship's inclining experiment done in 2008 [4]. For lever arm offsets, the center of gravity was assumed to be a reasonable approximation of the center of rotation. The position of the ship's center of gravity based on light conditions detailed in the Stability Test report [4], was measured to be 31.501 aft of the forward perpendicular (frame 0), 0.0 m starboard of the center line, and 5.514 m above the keel base line. These values were transformed into the POS/MV reference frame with reference to the Granite block (RP).

RP to center of rotation		
X	Y	Z
-7.896	2.487	0.825

Table: 3 Granite block (RP) to center of rotation offsets

Mapping sensor Specific offsets

The GPS antenna to reference point lever arm was accounted for in the POS/MV controller. The sonar specific offsets such as roll mounts and sonar locations were entered into Kongsberg seafloor information system (SIS) acquisition software. These figures referenced to the reference point (Granite block).

	Sonar coordinates (m)			Angular offsets (Degrees) after patch test		
	X	Y	Z	Roll	Pitch	Heading
EM 302 Transmit array	6.147	1.822	6.796	0.0	0.0	359.98
EM 302 Receiver array	2.497	2.481	6.790	0.0	0.0	0.03
EM 302 Water line	----	----	1.838	----	----	----
EA 600						
Knudsen SBP	3.967	3.500	6.746	----	----	----

Table 4: EM 302 specific offsets as entered in SIS.

IMU and Antenna Offsets

The offsets between the reference point and the GPS antenna were reference to the primary antenna. The port antenna is primary

POS /MV Coordinates			
	X	Y	Z
Primary GPS (Port Ant.)	8.265	1.335	-15.403
Ref to IMU	0.734	0.008	-0.022
Ref to Aux 1 GPS (C-NAV)	8.353	5.927	-15.396

Table 5: POS MV settings for offsets to primary GPS, aux GPS (C-NAV) and IMU.

Static draft measurement

The static draft is measured before the start of each cruise. The bow draft is directly read off draft marks on the hull and the stern draft is measured and then calculated from a specific frame on the fantail. These draft measurement are then compared to and verified with the results from the ship's stability calculations.

The nominal draft measurements before start of May 05 cruise (EX0903) were 4.81 m bow and 4.49 m stern.

System Calibrations and performance evaluations

Motion Reference Unit POS/MV GAMS calibration

EX GAMS calibration were done previously but we are unable to locate the records.

Measured distance between the antennas [3, Westlake report], is 2.3001. POS MV manual (section 4) describes that the distance between the antennas calculated in GAMS calibration should be within 5 mm to actual distance. The GAMS calibration resulted in a distance between the antennas to be 2.297 m therefore the difference between actual antennas separation and GAMS solution antennas separation is 4 mm (< 5mm). Therefore the GAMS calibration seems to be done correctly, however, we are unable to locate any records for this calibration.

EM 302 Patch test

EM 302 patch tests were conducted by Kongsberg field engineer Chuck Hohing as part of System Acceptance Test (SAT) for the EM 302 sonnar system [5]. NOAA personnel that assisted in sonar and POS/MV calibrations included Grant Frolick (PHB), Lt Cdr Jeremy Weirich and Mashkoor Malik.

Two separate tests were carried out during System acceptance trials. One shallow water patch test was conducted in the vicinity of Puget Sounds, WA on 8-10 September, 2008 in water depths < 120 m. During patch test acquisition, the seas were calm with less than a foot of sea. Offshore a test survey was conducted under supervision of Kongsberg engineers on 12 September, 2009 with water depths ranging between 1368-1863 m.

Navigation Time errors and Pitch Bias

The navigation time error was determined by running a pair of lines in the same direction at the two different speeds over a sloped area. One line was run up the slope at nominally 4 kts, and the other pair was run down slope at 8 kts. Each pair of lines was reviewed in SIS calibration mode as well as HIPS calibration utility.

Pitch bias was determined by running two pairs of lines at the same speed in opposite directions. Each line was run at 6 kts over a slope in Puget sounds. Each pair of lines was reviewed in SIS calibration mode.

The initial navigation time and pitch test showed large values (5 seconds for Navigation time error) and 4 degrees of pitch bias as shown in figures 12 and 13. After consultation with Kongsberg Engineers it was decided that these results are unexpectedly large and there might be a software bug in internal processing of EM 302. After a careful review of the internal processing of EM 302 and up gradation of the software version of the EM

302 another Navigation and pitch test was carried out which resulted in 0 seconds navigation time error and 0.7 degrees pitch bias. These results were independently verified in HIPS calibration utility and accepted as patch test values for navigation time and pitch bias.

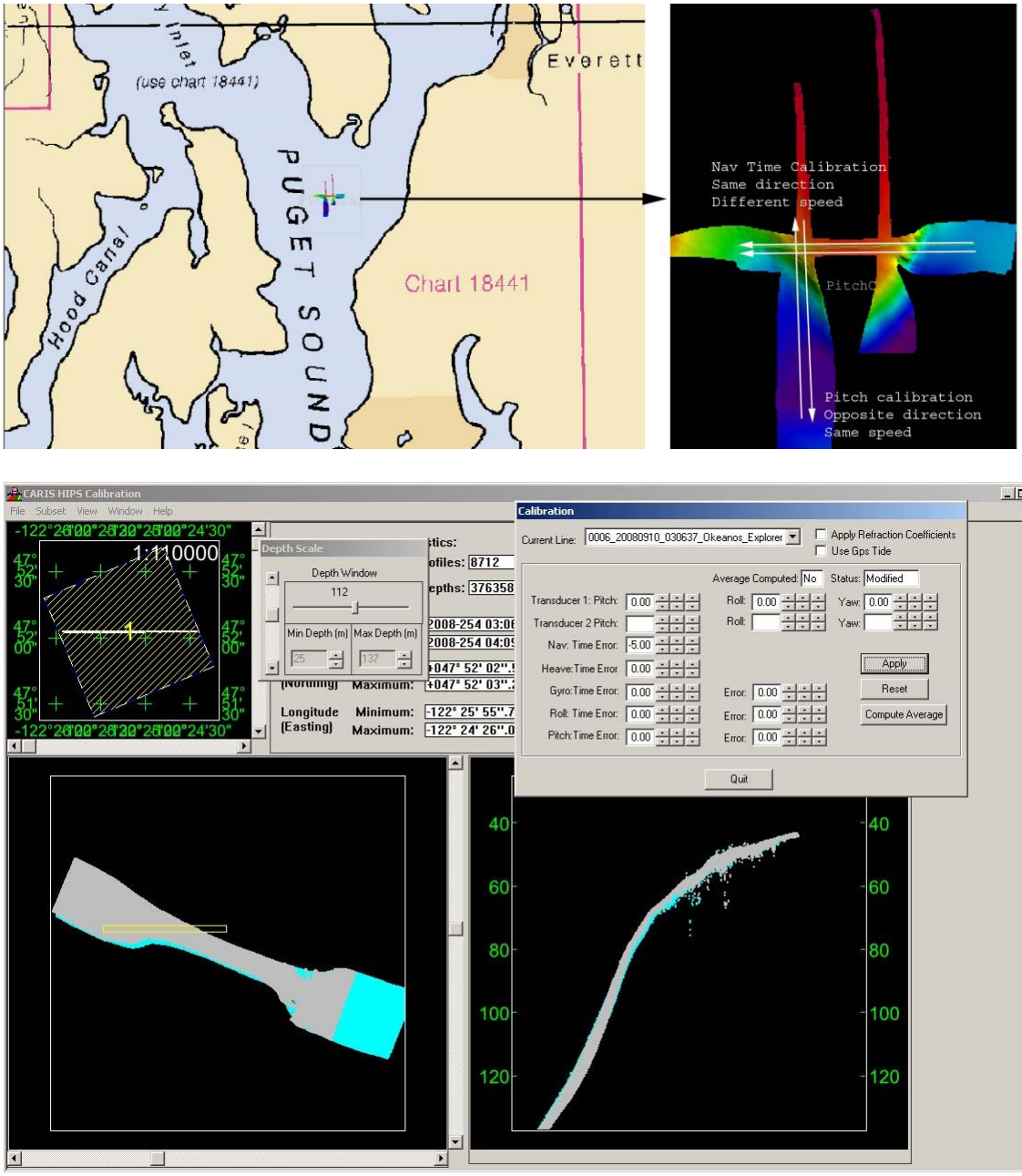


Figure 12: Location of navigation time bias and pitch patch test (Top). Screen grab of CARIS HIPS calibration utility to determine the navigation time bias (bottom). Note very high navigation time error was observed (-5 sec)

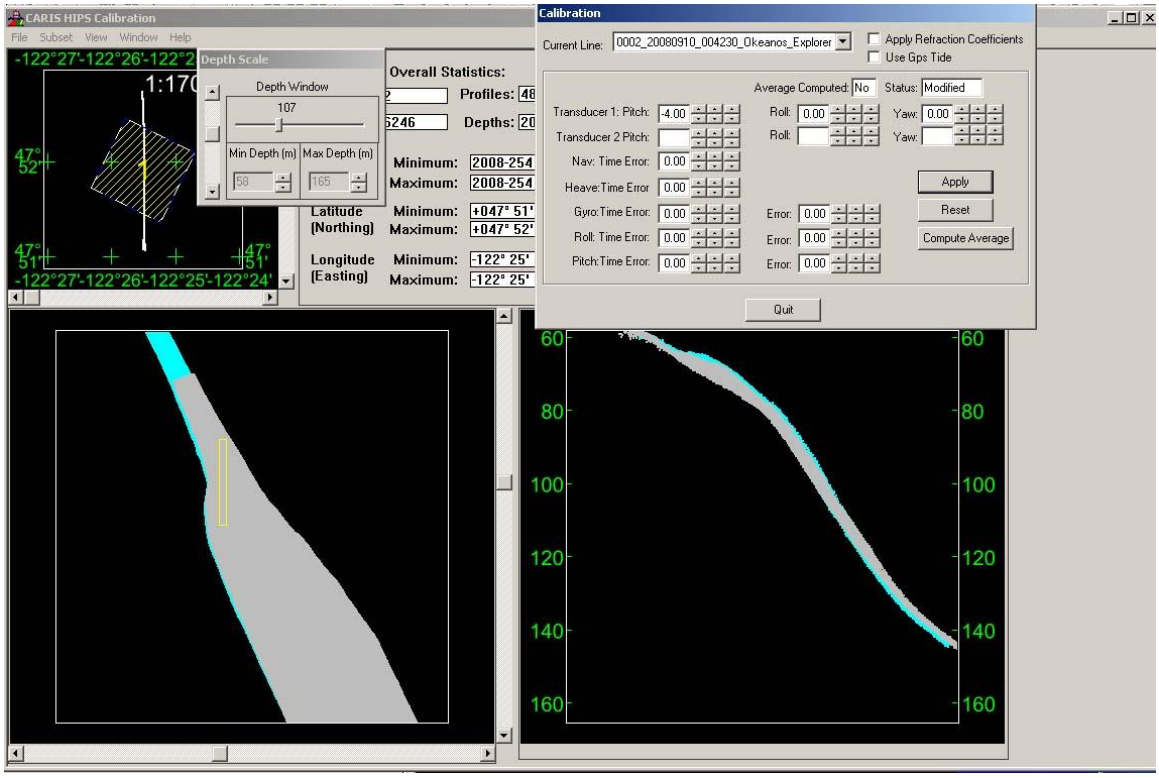


Figure 13: Screen grab of CARIS HIPS calibration utility to determine pitch offset. Note very high pitch offset was observed (4 deg)

Roll Bias

Roll bias was determined by running one pair of lines at the same speed in opposite directions. The lines were reviewed in SIS calibration mode. An independent verification of roll bias was conducted in CARIS calibration tool.

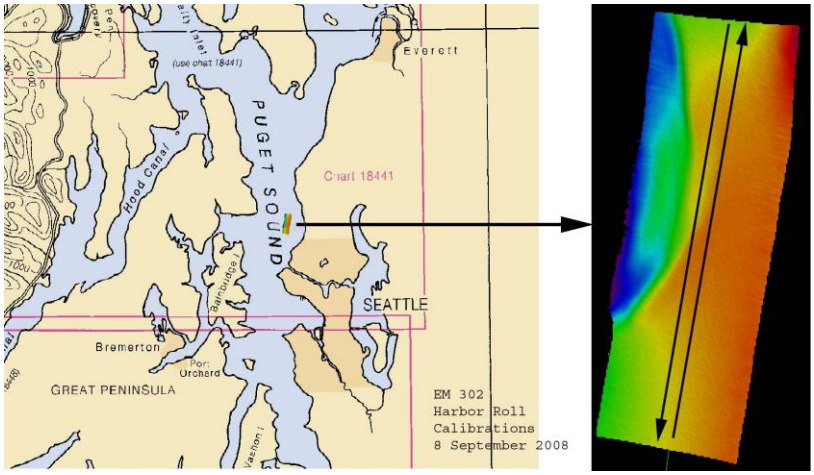


Figure 14: Location and data collected for roll bias pitch test in Puget Sound (shallow water case). The calibration analysis resulted in negligible roll bias offsets.

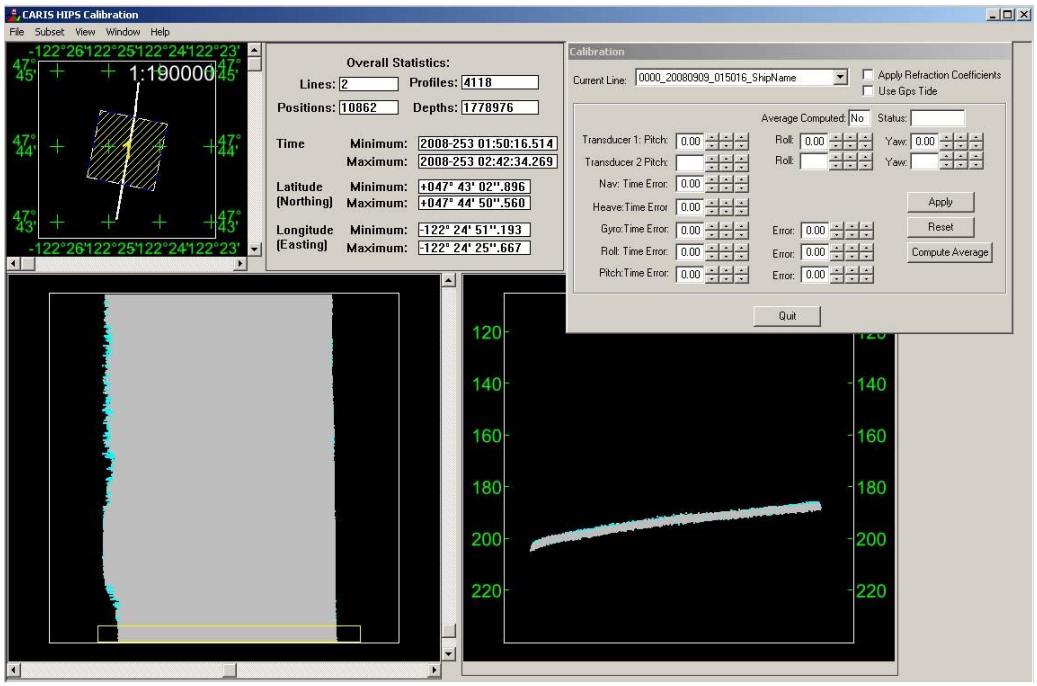


Figure 15: The HIPS calibration utility verified negligible roll bias results obtained from SIS calibration utility.

Heading Bias

No heading tests were done for the system acceptance test for the EM 302. Kongsberg engineers stated that this offset was determined by measuring the physical offset angle while the vessel is in dry dock. For heading calibration in deep water, using a distinct object, the two lines run in opposite direction were compared and no heading discrepancy was found between them when viewed in subset editor of CARIS HIPS.

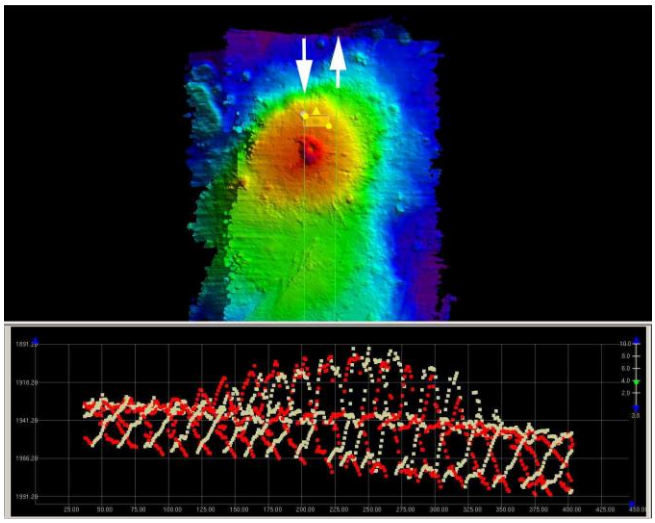


Figure 16: Two lines run in opposite direction over a distinct (an U/W volcano) when viewed in subset editor of CARIS HIPS showed no heading discrepancy.

EM 302 Patch Test results

EM 302 Patch Test Results				
	Depth	Heading	Pitch	Roll
EM 302 (Sep, 2008)	~ 1500 m	0	0.7	0
EM 302 (May, 2009)	~ 4000 m	0	0.7	0

Table 6: Results of patch tests conducted in September, 2008 and May, 2009.

Dynamic Draft

No dynamic draft measurements were made for EX this year.

Hips Vessel File

The Kongsberg SIS system accounts for all the static offsets and biases during real time acquisition. The motion data from POS MV is directly fed into SIS during data acquisition to account for ship motion (i.e. heave, roll, pitch, yaw). Also the real time sound speed at the sonar head is fed into SIS and the recently acquired sound speed profile is used in real time to correct soundings for sound speed corrections during data acquisition. Unless there are problems observed in the data, there is no requirement to apply these correction during post processing in CARIS HIPS. Therefore the vessel configuration file (VCF) for Okeanos Explorer contains zeros offsets and the motion data is also not applied during post processing. However, for the computation of uncertainty in CARIS HIPS, actual offsets are required along with standard deviations for miscellaneous sensors used. The HIPS VCF is provided as appendix C.

Mapping Software

Software	Version	License	Expiration Date	Agreements	Hot fix	Contract Duration
SIS EM 302	1.04	N/A	N/A	N/A	1.4.5	N/A
Velociwin	8.92 Plus	N/A	N/A	N/A	N/A	N/A
POS Controller	4	N/A	N/A	N/A	N/A	N/A
Caris HIPS	6.1	2 Dongle ID CW9605164 CW9605165	12/31/2008	Service pack 2: Upgrade Protection & Technical support	on order	5 years
Fledermaus	6.7.0 & 7.0	Dongle ID: 1181442213	N/A	N/A	N/A	?
Arc GIS	9.3	ArcView	N/A	N/A	N/A	?
Chart Reprojector	2.0.6	N/A	N/A	N/A	N/A	N/A
KAP Converter	5.7.2	N/A	N/A	N/A	N/A	N/A
MapInfo	9.5	(SN#) MINWEU0950038973 & MINWEU0950038974	2012	Upgrade protection & Technical support	Release Build 35	3 years
Pydro	9.4	Python22	1/1/2010	N/A	N/A	N/A
Hypack	8.0.0.10 (hypack admin) 9.0.0.22 (hypack admin) - 9.0.5.3 (survey)	USB #003681				
DP Line Conversion Utility (Matlab)	1.0	N/A	N/A	N/A	N/A	N/A
Seasave	7.18	N/A	N/A	N/A	www.seabird.com	N/A
SCS	4.3.4	N/A	N/A	N/A	N/A	N/A
Hydro_MI	8.3	N/A	N/A	N/A	N/A	N/A
C-NAV	C-Nav2050G S/N 5164	Code: B2643F-693598-0E5A5E-471498-50F093-30F128/ AFTER MAY: 0E4124-A427B8-B3B8BD-EA888C-34F1BB-3C1828	5/18/2010	Contract renewal with CC Technology every six months	N/A	6 Months
Snagit	9.1.2	CAWCM-QG4PF-MGYCA-34SNM-P4695 & D494F-5AKSZ-CQ8FV-CHA4U-S4F36	N/A	N/A	N/A	N/A
Knudson SBP, Sounder Suite Echo Control Server and Client	Software: V 2.07 Firmware: V.2.04	Part # D429-04216	N/A	N/A	N/A	N/A
SonarWiz	4004.0034	Dongle # Mfg 290 CTI 456	5/14/2012	EMA 05/14/12	N/A	3 Years

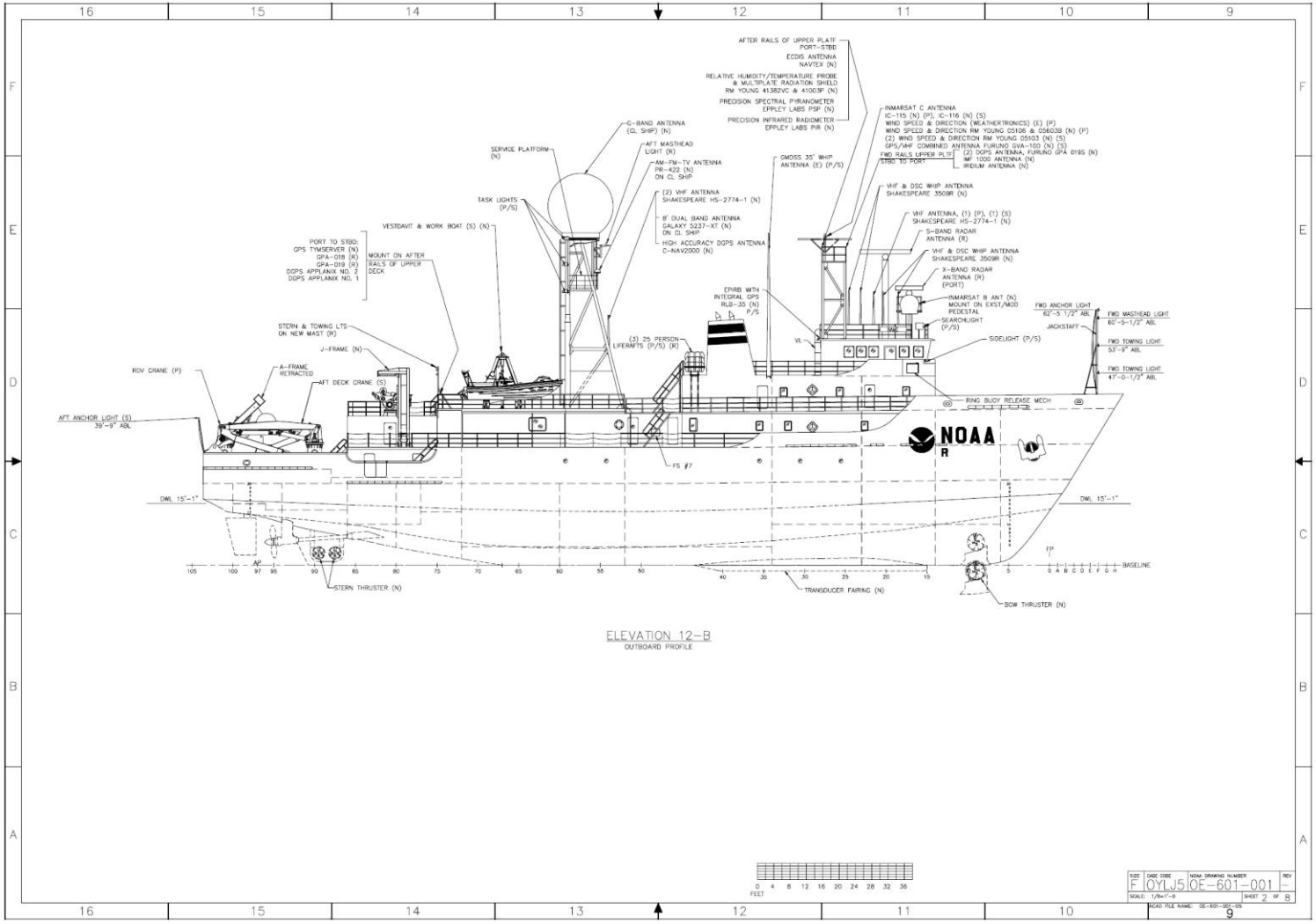
Appendices

Appendix A: Arrangement and location of deck hard ware and transducer fairing after the completion of Okeanos Explorer conversion

Appendix B: Format of bridge DP system compliant way point table

Appendix C: CARIS HIPS vessel configuration file

Appendix A: Arrangement and location of deck hard ware and transducer fairing after the completion of Okeanos Explorer conversion (Source: AMSEC LLC Naval Architect and Marine Engineers, Bremerton, Oakland, San Diego drawings 2005).



Appendix B: Example of DP system compliant way point table

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CreateDate (UTC),Sunday, September 28, 2008 20:20:20
Version,4
TrackName,
NoOfWp,7
Datum,WGS84
WPFormat,WPId,WPHemisNS,WPLatDeg,WPLatMin,WPHemisEW,WPLonDeg,WPLonMin,WPLegType,WPHead,WPSpeed,WPT
urnRad
WP,1,N,43,3.5609,W,126,40.3078,0,180,1.5433,200
WP,2,N,42,46.1603,W,126,49.2321,0,180,1.5433,200
WP,3,N,42,21.5328,W,127,15.5262,0,180,1.5433,200
WP,4,N,42,0.65965,W,127,14.6833,0,180,1.5433,200
WP,5,N,41,42.5906,W,127,22.0253,0,180,1.5433,200
WP,6,N,42,2.684,W,127,31.3482,0,180,1.5433,200
WP,7,N,42,16.7337,W,127,20.7283,0,180,1.5433,200
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Appendix C: CARIS HIPS Vessel Configuration File (VCF) for NOAA Okeanos Explorer April, 2009.

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  </TPEConfiguration>
</HIPSVesselConfig>
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References

[1] NOAA ship Okeanos Explorer general arrangement plans and profiles, 2005. NOAA drawing number OE - 601-001, 2005.

[2] Knudsen chirp 3260 acceptance test report, 2008. D101-04819-Rev 1.

[3] Westlake Consultant report of Sonar Systems and GPS Antennae as-builting on the NOAA Okeanos Explorer. March 18, 2008.

[4] Ship inclining experiment report, 2008.

[5] Sea Acceptance Test (SAT) report from Kongsberg EM 302

[6] Sea Acceptance Test (SAT) report from Kongsberg EA 600