A COMPARISON OF INERTIAL VERSUS CONVENTIONAL ACOUSTIC METROLOGY

DATA COMPARED IS FROM REPRESENTATIVE FIELD SURVEY OPERATIONS IN WEST AFRICA

ZUPT LLC

COMPARISON REPORT – ZCR09-003

March 15th, 2009

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1	Issue for Approval	J Gillet	K. Vickery	15th March 2009
Rev	Description	Prepared	Approved	Date

Executive Summary

As part of an existing field survey contract Zupt are required to demonstrate the performance and time savings of an inertial positioning technique (C-PINS), versus a conventional acoustic metrology technique used commonly for non line of sight metrology measurements. This report contains a field survey data set for comparative purposes

Time savings - Inertial method ~ 25% of the time needed for conventional techniques

Field operations of the Zupt metrology system clearly demonstrate the following:

> Inertial metrology data acquisition takes less than a quarter of the time taken for conventional measurements:

Distance measurements agree within 26mm

Inertial metrology distance measurements compare to acoustic horizontal (L) distance measurements within ~26mm

Report example –

Conventional method	L = 15044mm
Inertial method	L = 15070mm

Pitch and Roll data agree within the noise of the tooling

The PGB Well and Manifold receptacle pitch and roll data all agree within the measurement noise of the tooling and accepted practice technique:

Report example –

	PGB Well Pitch	PGB Well Roll	Manifold Pitch	Manifold Roll
Conventional	-0.62°	-0.28°	+0.56°	+0.37°
Inertial	-0.82°	-0.24°	+0.55°	+0.37°
Difference	0.2°	0.04°	0.01°	0.00°

Relative heading agrees within 0.06°

The PGB Well and Manifold relative heading data agree within 0.06°. A fixed offset of ~0.3 degrees existed between the conventional based heading data and the C-PINS heading data. Again this was due to a tooling (mounting bracket assembly) fixed offset that will be removed in future through an onshore alignment calibration to a known fixed baseline.

	PGB Well Heading (G)	Manifold Heading (G)	Difference
Conventional	27.39°	20.93°	6.46°
Inertial	27.70°	21.30°	6.40°
Difference	0.31°	0.37°	0.06°

All deliverable parameters are well within the required client contractual tolerances

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1. Introduction

A fundamental requirement of a metrology survey services contract awarded to Zupt is that Zupt would introduce and use the C-PINS inertial metrology tool in parallel with conventional acoustic techniques to demonstrate to the client the following:

The maturity of the inertial technique
The achievable precision of the inertial method
The time savings associated with inertial versus acoustics measurements

Zupt is now approximately 9 months into the operations of this two year contract. This report details a single representative comparison data set.

** the route survey bathymetry (depth and altitude) data is not discussed or included within this report – due to the reduced accuracy requirements.*

1.1 Scope of Work

As with conventional metrology data acquisition the required results, to be documented and reported for the jumper construction are as follows:

Horizontal Distance L between stab receptacle reference points
Difference in relative depth ΔZ between the two receptacle reference points

Manifold receptacle # 1 pitch:	Rotation around X1
Manifold receptacle # 1 roll:	Rotation around Y1
PGB well receptacle # 2 pitch:	Rotation around X2
PGB well receptacle # 2 roll:	Rotation around Y2

Horizontal angle α between the Y1 axis and a direct line L between receptacle reference points
Horizontal angle β between the Y2 axis and a direct line L between receptacle reference points
Vertical profile of seabed along design jumper route referenced to absolute depth (referenced to Lowest Astronomical Tide, LAT).

1.2 Required Metrology Tolerances

The table below shows the required accuracy of this contract.

Point	X	Y	Z	Rx	Ry	Rz
Unit	mm	mm	mm	°	°	°
PGB Well Receptacle	0	0	0	0	0	0
MSS Receptacle	+/- 75	+/- 75	+/- 75	+/- 1	+/- 1	+/- 1

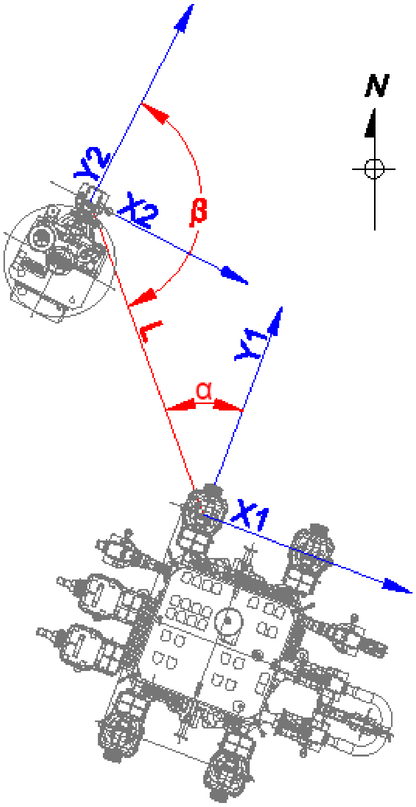


Figure1: Examples of Values to be reported

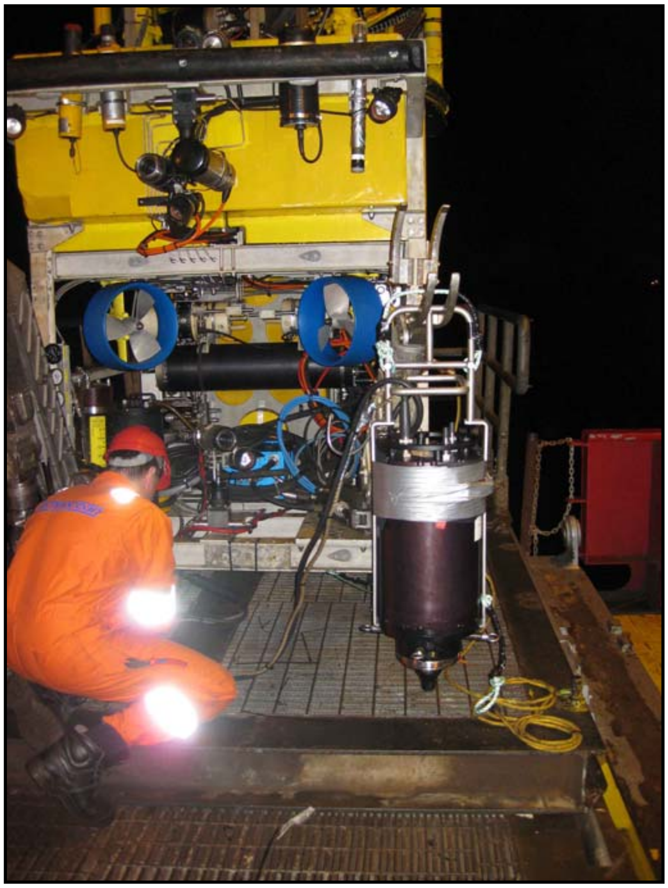


Figure 2: ROV with C-PINS installed

2. RESOURCES

2.1 Personnel

The contract requirement for conventional 24hr operations require that Zupt provide 4 personnel. To enable the running of the C-PINS system in parallel Zupt provided a fifth person (at no cost to the client) – an inertial surveyor:

Party Chief / Surveyor
Acoustic Engineer
Acoustic Surveyor
Acoustic Surveyor/ AutoCAD operator
Inertial Surveyor

2.2 Inertial Equipment Summary

The following inertial equipment was used during this work:

C-PINS system – Ser No. 2 1,000m rated including:
- SSTT surface software running on a PC
- Test cabling
- ROV lifting tool
- Stab tool attachment plates (qty 2)

Figure 3: C-PINS installed as deployed in 5 function manip.

2.3 Equipment Details

C-PINS system

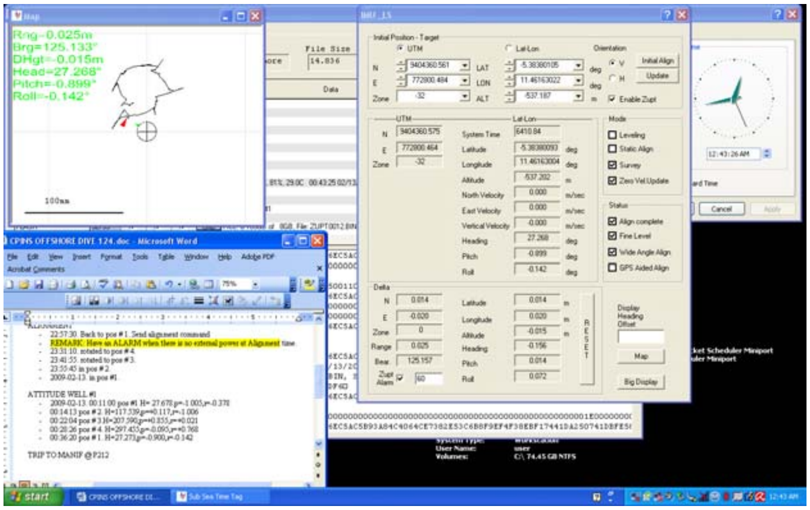
The C-PINS subsea housing contains the following sub systems:

- Inertial sub assembly (ISA)
- Subsea data processing
- Power supply conditioning and isolation
- Back up battery (30 mins)
- On-board data storage (48 hours continuous operations)
- Internal Digiquartz unit (not fitted in Ser No. 2 unit)
- Time Tag Unit that includes multi port data acquisition for the following fully isolated interconnections:
  - Surface communications (RS232 or RS422)
  - Data storage dump (USB)
  - External Digiquartz (RS232)
  - Mini SVS (RS232)
  - Altimeter (RS232)
  - Barometer – through surface PC

The C-PINS system is a fully self contained inertial navigation system that also allows for external sensors data to be collected and tagged with system time to allow for the route survey data to be acquired by the same system as is used for the primary metrology measurements.

Surface Software

The surface software application “SSTT” provides for all of the initialization, external sensor interfacing, data logging (both at the surface and in the subsea unit) and control of the subsea system. Many standard type navigation and depth displays are available within SSTT.


Rng=0.025m
Brg=125.133°
DHgt=-0.015m
Head=27.268°
Pitch=-0.899°
Roll=-0.142°

Initial Position - Target: ● UTM ○ Lat-Lon
N 9404360.561 LAT -5.38380105 deg
E 772800.484 LON 11.46163022 deg
Zone -32 ALT -537.187 m
Orientation: ● V ○ H
☑ Enable Zupt

UTM: N 9404360.575, E 772800.464, Zone -32
System Time 6410.84
Latitude -5.38380093 deg
Longitude 11.46163004 deg
Altitude -537.202 m
North Velocity 0.000 m/sec
East Velocity 0.000 m/sec
Vertical Velocity -0.000 m/sec
Heading 27.268 deg
Pitch -0.899 deg
Roll -0.142 deg

Mode: ☐ Leveling ☐ Static Align ☑ Survey ☑ Zero Vel Update
Status: ☑ Align complete ☑ Fine Level ☑ Wide Angle Align ☐ GPS Aided Align

Delta: N 0.014, E -0.020, Zone 0, Range 0.025, Bear. 125.157, Zupt Alarm ☑ 60
Latitude 0.014 m, Longitude 0.020 m, Altitude -0.015 m, Heading -0.156, Pitch 0.014, Roll 0.072

- 22:57:30 Back to pos #1. Send alignment command
- REMARK: Have an ALARM when there is no external power at Alignment time
- 23:31:10 rotated to pos #4
- 23:41:55 rotated to pos #3
- 23:55:45 in pos #2
- 2009-02-13 in pos #1

ATTITUDE WELL #1
- 2009-02-13 00:11:00 pos #1 H= 27.678,p=-1.005,r=-0.378
- 00:14:13 pos #2 H=117.539,p=0.117,r=-1.006
- 00:22:04 pos #3 H=207.590,p=0.355,r=0.021
- 00:28:26 pos #4 H=297.455,p=-0.095,r=0.768
- 00:36:20 pos #1 H=27.273,p=-0.900,r=-0.142

TRIP TO MANIF @P212

Figure 4: SSTT Software Interface

3. OPERATIONAL TIME DIFFERENCES BETWEEN CONVENTIONAL AND INERTIAL

3.1 Clarification of metrology methodologies

This report discusses the data acquisition and processing associated with a “West African metrology operation” where potentially no “line of sight” exists between the hub at the well and manifold. For clarity we describe the three primary acoustic metrology techniques that may be in use today:

3.1.1 Acoustic tape measure

When a clear line of sight exists between the two hubs some clients are comfortable accepting a single set of acoustic ranges – reduced to distance to define the horizontal range between the two hubs. This is primarily used with vertical jumpers – where the relative orientation of the two hubs is not critical. In some instances the acoustic beacons are also used to collect pitch and roll data for the two hubs. Probably the two transponders will have precise pressure transducers fitted to allow for relative depth measurement (not absolute) to be made. No over-determination is available for this method as the technique used results in a single measurement. Two way acoustic ranges will be measured from A to B and B to A so some multipath mitigation will be available when reducing this data.

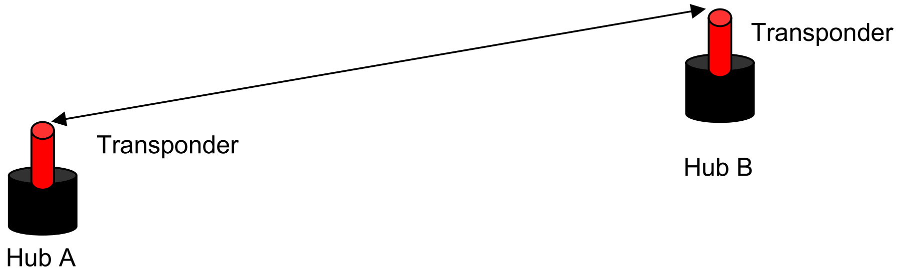


Figure 5: Acoustic Tape Measure Diag.

3.1.2 Braced Quadrilateral

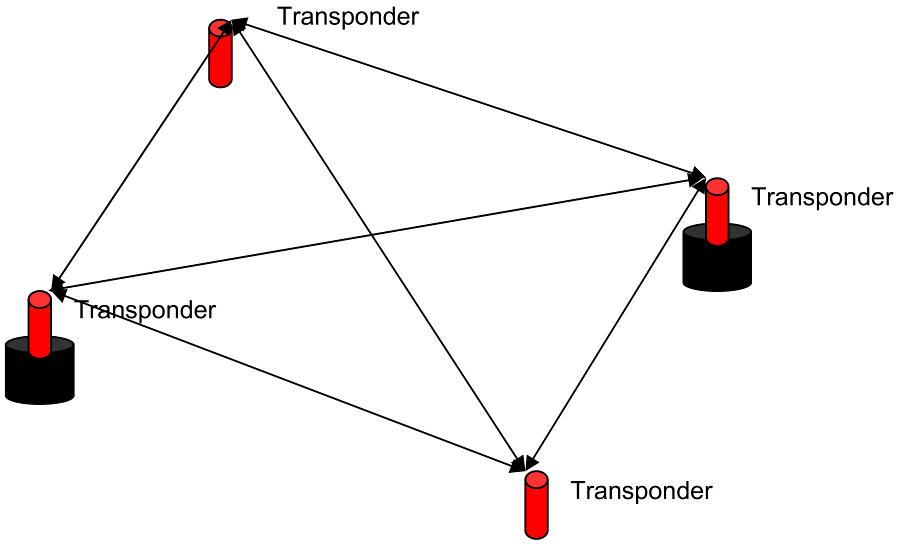


Figure 6: Braced Quadrilateral Diag.

In the instance of vertical jumpers where the client requires some additional redundancy from the measurement method then a braced quadrilateral technique may be used. This is a classic method for metrology data acquisition in the US Gulf of Mexico.

In this case the two beacons will be deployed on the two hub points as sown in the first instance, but also an additional 2 beacons will be deployed within frames to form a braced quadrilateral minimal LBL array. The array will be calibrated and an over determined solution provided with some quality metric showing the missclosure of the (probably) least squares adjustment (either 2 dimensional or 3 dimensional).

Again – with this technique both precise pressure transducers and standard inclinometers will be included within the hub transponders to provide a facility for measuring relative depth and hub attitude data.

This technique requires a clear (non multipath or reverberant) line of sight between the two transponder transducers placed on the structures (hubs).

3.1.2 Non – "Line of sight" metrology – or full array based metrology

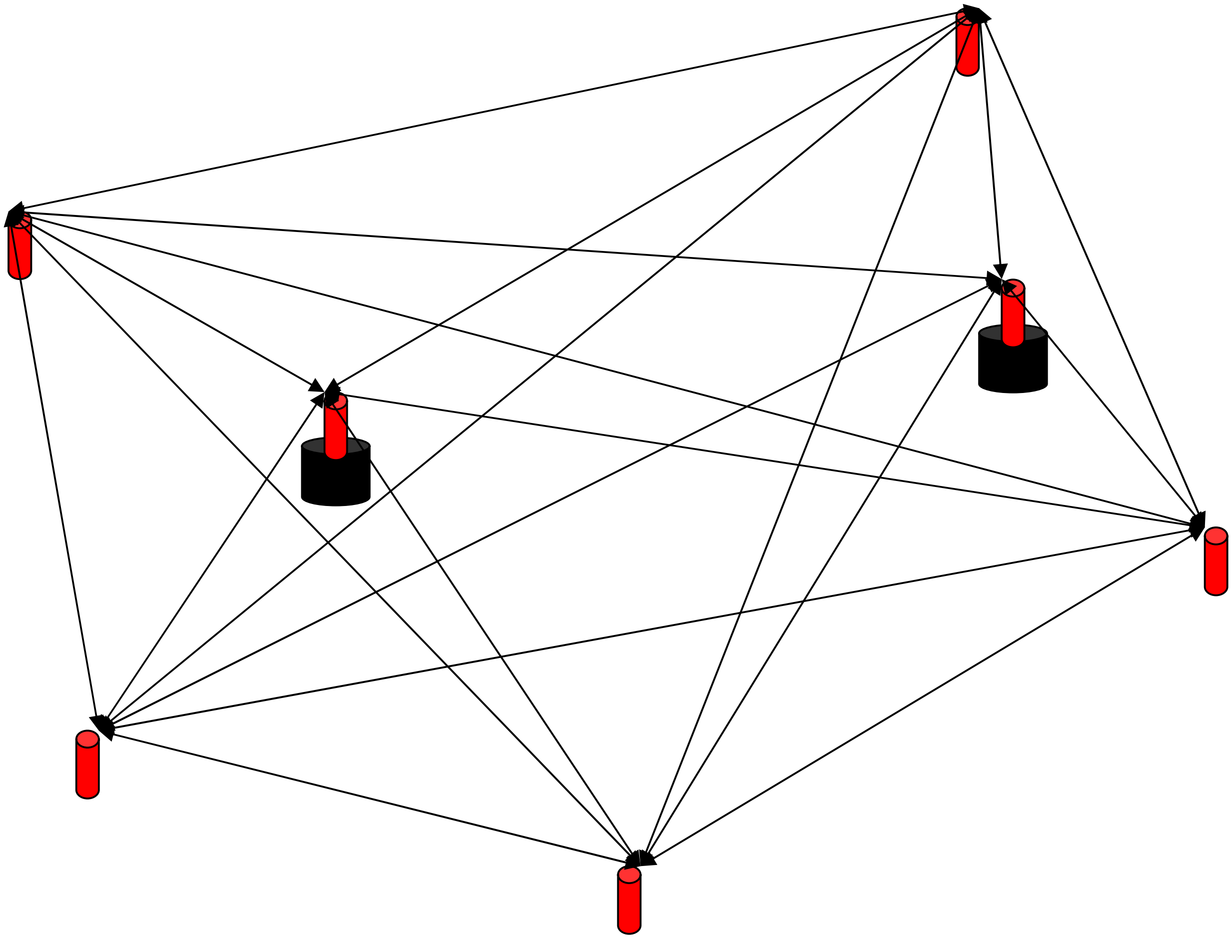


Figure 7: Non "Line of Sight" full array Diag.

In the case above an acoustic transducer on a transponder placed on the hubs will not have a clear line of sight between them. In many cases the subsea hardware is large enough such that transponders located on the hubs will not be able to measure a direct range. In these cases the previous two methods will not work to define the horizontal distance between the two hubs. To overcome this lack of visibility a full LBL array is deployed to allow a position solution to be derived for both hubs independently of each other. These array based independent positions are then used to work out the grid horizontal distance between the two hubs. The array may contain either 4 or 5 beacons (as shown in this instance).

This is often the case when horizontal jumpers are used for sparse field developments in West Africa.

In the case of horizontal jumper metrology a requirement also exists for the collection of precise heading of the hubs. In these cases jumper manufacturer specific ROV tooling is used (examples - stabbing plates located within the hub or stabbing tooling fixed to a face of the hub structure) to allow for precise heading measurements at both hubs.

This tooling is then used to make successive measurements, in some cases with repetitive sampling at multiple orientations to derive quality indicators of the heading of the hubs. Current generation subsea gyros will also deliver attitude data when this heading data is collected.

This report compares the time taken for this **non “line of sight”** type of metrology – **not** the braced quadrilateral method, or the acoustic tape measure method.

3.2 Duration for Conventional Non “Line of Sight” Technique

Zupt have completed six sets of metrology measurements within this contract to date. The data below shows the average times that the vessel has been solely used for each of the elements from these six metrology data collections:

The average “total vessel days for metrology” is 5.67 days from the conventional work to date.

The actual data acquisition and ROV trip times just associated with metrology operations are significantly less than this “total vessel days for metrology” time ~2.7 days. Many issues cause this variance. These are the normal types of disturbance to operations that are encountered during offshore ROV and simultaneous field operations. Some of the issues that have caused this variance are:

ROV in TMS waiting on visibility – as drilling vessel jetting a well nearby
Moving off location as rig moving
Waiting off location as rig flaring
ROV lights failed
ROV sim ops issue with rig ROV, survey ROV waits in TMS
Deployment rigging issues – recover and re-deploy tripod frames
Winch wire swap out – vessel issue
Stop operations for crew change
Excessive time for cleaning well as cleaning tool not serviceable
ROV tether re-termination
Etc, etc.

3.3 Duration for Inertial Technique

The inertial system has been mobilized in parallel with the conventional spread due to operations being conducted from a dual work class ROV vessel. The primary ROV was conducting the conventional work and the secondary ROV was used for the inertial data collection.

Two representative example of dive durations and data collection are detailed below:

Dive Example A		
	Start time	06:20
	End Time	19:55

Dive A contained:

Alignment	70 mins
Position/Attitude PGB	35 mins
PGB Remove and re-stab test into the well (x2)	10 mins
Seabed stab test	15 mins
Traverse to manifold	20 mins
Manifold position, P/R/H	35 mins
Traverse to PGB	6 mins
PGB position, P/R/H	35 mins
Traverse to manifold	8 mins
Manifold position, P/R/H	32 mins
Traverse to PGB	4 mins
PGB position	13 mins
Traverse to manifold	6 mins
Manifold position, P/R/H	9 mins
Traverse to PGB	9 mins
PGB position	10 mins
Traverse to manifold	10 mins
Manifold position	7 mins
Traverse to PGB	7 mins
PGB position, P/R/H	8 mins
Traverse to manifold	6 mins
Manifold position, P/R/H	3 mins
Traverse to Manifold spare slot	13 mins
Spare Manifold slot position	7 mins
Traverse to manifold	6 mins
Manifold position, P/R/H	4 mins
Traverse to PGB	9 mins
PGB position	5 mins
Traverse to Manifold	6 mins
Vertical offset to seabed at manifold	8 mins
Route survey Out	66 mins
Route survey Back	55 mins
Traverse to PGB	11 mins
PGB position	15 mins
Recover to surface – download data	
	~600 mins (10 hours)

Data download at the surface took approximately 45 minutes.

Dive B	Start time	21:19 Day 1
	End Time	03:46 Day 2

Dive B contained:

Alignment	33 mins
Alignment aborted due to power failure. Discovered that the C-PINS had not received power from the ROV (had not switched power to C-PINS on at start of dive) Inadvertently tested how long the battery lasts inside the unit in an operational scenario – 45 mins	
ROV power the C-PINS system	
Alignment	63 mins
PGB position P/R/H	25 mins
Traverse to manifold	18 mins
Manifold position, P/R/H	45 mins
Traverse to PGB	10 mins
PGB position, P/R/H	17 mins
Traverse to manifold	7 mins
Manifold position, P/R/H	10 mins
Traverse to PGB	7 mins
PGB position	5 mins
Traverse to manifold	3 mins
Manifold position	3 mins
Traverse to PGB	6 mins
PGB position	4 mins
Traverse to manifold	3 mins
Manifold position	3 mins
Traverse to PGB	6 mins
PGB position	2 mins
Route survey Out and Back	20 mins
Recover to surface	
	~260 mins (~4.4 hours)

Data download at the surface took approximately 35 minutes.

As can be seen from the above multiple data sets were collected during each dive. From our experience we believe that two operational dives of an average of 6 hours should allow for complete redundant data sets similar to the above to be collected. In addition to this we would assume that a test dive will be made at the start of the operation adding approximately 4 hours to the duration. The total time for inertial mobilization and data acquisition will be much less than 24 hours.

3.4 Operational Time Comparison

The final deliverable for metrology operations (CAD drawing of jumper layout, hub attitudes, headings and horizontal distance and bathymetry route survey) is required offshore at the end of data processing. In most cases a contractual period of 24 hours is provided after the final data acquisition prior to this deliverable being required. The total time numbers below allow for the processing of the data (18 to 24 hours) collected as well as an allowance for operational disruption due to one of the many factors discussed in paragraph 3.2.

Conventional metrology data acquisition and processing	~5.2 days
Inertial metrology data acquisition and processing	~1.5 days

4. DATA COMPARISONS AND DISCUSSION

The data below is representative data comparing inertial and acoustic data. These tables are summary data from detailed data processing. All data supporting these results (including raw data) is available for discussion if required.

Inertial Results				**Conventional Results (Acoustics)**		
	Easting	Northing	Depth			
WELL	**772800.48**	**9404360.56**	**-537.21**			
MANIFOLD	**772805.92**	**9404346.51**	**-537.24**			
S.d Obs	**0.08**	**0.12**	**0.09**			
Horizontal Distance (L)	**15.070**	**meters**		Horizontal Distance (L)	15.044	M
UTM Heading Well	**27.70**	deg		UTM Heading Well	27.39	deg
UTM Heading Manif.	**21.30**	deg		UTM Heading Manif.	20.93	deg
UTM Bearing M to W	**338.84**	deg		UTM Bearing M to W	340.29	deg
Angle Alpha	**317.54**	deg		Angle Alpha	319.36	deg
Angle Beta	**131.14**	deg		Angle Beta	132.90	deg
PGB/MANIFOLD Diff Depth	**-0.036**	**Manifold is deeper (m)**		PGB/MANIFOLD Diff Depth	-0.079	Manifold is deeper (m)

Difference between the Inertial and Conventional data			
Horizontal distance (L)		**0.026**	m
Heading PGB (G)		**0.31**	deg
Heading MANIFOLD (G)		**0.37**	deg
UTM Bearing M to W		**-1.45**	deg
Angle Alpha		**-1.82**	deg
Angle Beta		**-1.76**	deg
Depth between PGB and MANIFOLD		**0.043**	m

4.1 Horizontal distance (L)

The table above shows the primary horizontal distance having a difference of 26mm. In the development of the C-PINS solution and operational procedures the control of L has been the area of our greatest focus. The precision and accuracy of the heading and attitude data is relatively easy to achieve.

The resulting horizontal distance is derived from an inverse of our absolute co-ordinates for the PGB well and Manifold slot – derived from multiple navigation runs.

The client provided tolerance for L is 75mm. The standard deviation resulting from our multiple data sets are slightly higher than this (80mm in Easting and 120mm in Northing) but the repeatability and hence reliability of the derived solution is seen in the consistency of the of the raw and processed multiple data sets (a total of 10 traverse loops used to compute this distance).

4.2 Depth between PGB Well and Manifold

The depth differences in the table above are derived from the inertial navigation data – not the Paroscientific digiquartz depth data. Either are available from the C-PINS solution. Deriving this level of differential depth data from the navigation solution is highly demanding of the inertial solution and provides great confidence in the overall results.

The difference between the conventional (Digiquartz) and Inertial "depth difference" is 43mm. The tolerance required is 75mm.

4.3 Heading – PGB and Manifold

The differences between the headings for the PGB and Manifold have a fixed offset of (approximately) 0.3°. We are very confident that this fixed offset is due to the method used to attach the C-PINS system to the rotating stab. To accommodate the bolt pattern on the top of the rotating stab and the bottom of the C-PINS end cap we have to use two attachment plates – these plates were bolted up offshore and have some slack in the orientation.

Figure 8 C-PINS mounting

In future this "fixed" heading offset will be removed by calibrating an assembled C-PINS system with the two attachment plates. A normal gyro alignment and calibration. For permanent operations of this type we would suggest that a calibrated known baseline be installed in the shore facility so that such alignment checks can be easily achieved.

If we look at the actual data that the jumper fabricator will use – the difference in heading between the PGB and the manifold – the difference between the Conventional and Inertial method is 0.06°

	PGB Heading (G)	Manifold Heading (G)	Difference PGB to MANIFOLD
Conventional	27.39°	20.93°	6.46°
Inertial	27.70°	21.30°	6.40°
Difference	0.31°	0.37°	0.06°

4.4 PGB and Manifold Pitch and Roll

PGB Attitude data		
Inertial data	Pitch	Roll
	-0.82	-0.24
S.d. Obs	0.11	0.11
Conventional data	Pitch	Roll
	-0.62	-0.28
S.d Obs	0.06	0.10
Difference to Reference	**Pitch**	**Roll**
(Ref is Conventional)	**-0.20**	**0.04**

MANIFOLD Attitude data		
Inertial data	Pitch	Roll
	0.55	0.37
S.d Obs	0.15	0.12
Conventional data	Pitch	Roll
MANIFOLD (P212)	0.56	0.37
S.d Obs	0.11	0.07
Difference to Dereference	**Pitch**	**Roll**
(Ref is Conventional	**0.00**	**0.00**

On this specific project the tooling that allows for the measurement of attitude to the reference surface within the Hub receptacle has the following interfaces:

Stab plate interface to receptacle
rotary stab interface to Stab plate
mounting plate/instrument interface to rotary stab
rotary stab contains two bearing surfaces to allow for rotation

From our experience over all work to date we believe the attitude repeatability of the tooling is on the order of +/- 0.1° This is the build up of error due to the multiple interfaces described above.

The accuracy of static sampled pitch and roll data from the C-PINS system is 0.02°. We believe, except from the difference in the PGB pitch data, the difference results are well within the “noise” of the tooling technique.

As the same assembly (was not disassembled and reassembled during the project) was used to measure the manifold and the well the PGB pitch data from the inertial system and the conventional system should be good.

During the collection of this specific data set some large stainless steel handles were removed from the stabbing plate. These had previously obscured access to the rotating stab for the ROV. These handles had been in place on all previous metrologies and had significantly increased the time taken for the ROV operators to rotate the stab due to manipulator access issues. The stainless handles did however add weight to the Stabbing plates.

Due to the very tight tolerances between the male stabbing tool and the female receptacle in the Stab plate the ROV lifted the plate several times during both the conventional and inertial metrology operations on this job.

To overcome the lightness of the Stab plates additional weights are now used to add weight to the stab plate.

The 0.2° difference in pitch on the PGB hub data is probably due to a slight difference in the seating of the Stab plate in the receptacle caused by the plate lifting when tools were recovered.

The client tolerance for attitude data is 1.0°. All of the inertial data has been well within this tolerance.

4.5 Manifold positioning and true values for the bearing of L, α and β

To understand this issue we need to discuss the method used within conventional metrology to position absolutely and orient the acoustic array.

Once the acoustic array is deployed and all baselines have been collected and the relative array has been calibrated this array is then translated and rotated to “fit” know data within the acoustic calibration software.

The array is calibrated with a beacon sitting at the center of the PGB hub receptacle and with a beacon in the manifold receptacle. Once the array is relatively calibrated, the final calibrated position of the beacon in the PGB hub receptacle is translated (moved laterally) into the actual coordinates provided by the client for the well.

Once this translation has been completed the position of the acoustic transponder at the Manifold location is rotated (in software) to best fit the field drawings provided by the client. The surveyor can easily rotate the array +/- 1 or more degrees and still see a very similar “fit” to the drawing.

In practical terms – the relative (with respect to each other) headings of the PGB and manifold are what matter to the jumper manufacturers, this is also true (as they are all connected) the relative relationship of angles α and β is critical to jumper manufacture.

The reason this is described here is that in the case of the inertial solution – we are not translating or rotating anything – the inertial solution is based purely on a navigation in a reference frame. So in this case we are navigating from the PGB hub to the Manifold hub and as such derive a grid referenced position for the manifold with respect to the PGB. The inverse of these two positions gives us a very accurate grid bearing of the line that intersects the PGB and manifold. No guess work to fit to drawings is involved. As such – we are also deriving a very precise, fully defined, grid referenced position for the manifold.

The grid referenced position (UTM Easting and Northing) derived by the acoustic system for the manifold receptacle can quite easily be wrong, although the relative horizontal distance L will be valid for the construction of the jumper.

With dimensional control drawings of the manifold the inertial solution can quickly confirm the precision of our solution by stabbing into a spare slot within the manifold.

	Inertial	Conventional	Difference between Inertial and Conventional
Grid Bearing MANIFOLD to PGB	338.84°	340.29°	**-1.45° or 0.00°**
Angle Alpha α	317.54°	319.36°	**-1.82° or 0.37°**
Angle Beta β	131.14°	132.90°	**-1.76° or 0.31°**

With an understanding of the above discussion you can see that the inertial system derived a grid orientation of line L with a difference of 1.45 from the orientation the acoustic surveyor selected as the best fit to the provided field drawings. Again – this will not make any difference to the jumper construction – but we strongly believe that the correct absolute value derived by the inertial solution will offer significant benefits for future field development activity.

If this 1.45° difference between the Inertial and Conventional orientation of L is removed from the above then the differences in α and β are the differences in the headings of the PGB and Manifold as discussed above (0.37° and 0.31°).

4.6 Data comparison conclusion

All deliverable parameters were within the required contractual tolerances

Deliverable Parameter	Difference	Client Tolerance
L	26mm	75mm
ΔZ	43mm	75mm
Manifold Pitch	0.00°	1.00°
Manifold Roll	0.00°	1.00°
PGB well Pitch	0.20°	1.00°
PGB well Roll	0.04°	1.00°
α	0.37°	1.00°
β	0.31°	1.00°

4.7 Quality Metric – Comfort factor during data acquisition and in the overall survey

As with any real time survey data acquisition we need to know that the data we are collecting is valid and that we are not progressing with the survey only to find at a later date that we had some major blunder or error in our processes or instruments. We define errors in positioning solutions as coming from one of three primary sources:

Mistake/Blunder – should be controlled by good operational procedures and training
Systematic errors/biases – should be removed by calibration of the system
Random errors/noise – solution should be designed to deliver tolerance within this noise

We used some of the techniques we have very successfully used over the past 2 years to provide some real time quality metrics that allowed us to have confidence in the data as this technique is relatively new to metrology measurement.

Procedures

For the past several months we have been testing and modifying our procedures. Our procedures include strict methods for alignment, traversing and stabbing techniques as well as transit periods and update periods. We believe that our procedures are now complete and will allow for very repeatable inertial metrology surveys.

Quality control at the position level (blunder and bias removal)

One of the classic inertial guides to navigation accuracy is the “missclosure” – or “tie” to a know point. In this case the only known point we have is the PGB receptacle coordinate (offset from client provided well data). In all cases we completed a circular close to this coordinate for all of our “positioning” traverses between the PGB and the manifold. So all positioning traverses included PGB – manifold – PGB. As a result we achieved a missclosure (position error in E, N, Z) between our initial position and the position when we returned to the PGB. This data is available in real time to the operator.

Quality control at the observation level (noise)

In real time we also have parameters available from within the navigation adjustment that show the quality of the individual accelerometer and gyro observations. If we were to see an accelerometer or gyro start to fail or go out of specification or fail this would be immediately obvious within the innovation matrix within our navigation adjustment.

Quality control at the deliverable level

To ensure we do not have any assembly biases we will calibrate onshore, to ensure we do not have any offset blunders etc. we will check our missclosures. We will also repeat the traverses multiple times. We suggest at least 10 traverses at this stage, to provide some reliable statistical interpretation (SD or RMS etc.) for the quality of the overall solution.

APPENDIX 1

EXAMPLE OF EQUIPMENT SPREADS CONVENTIONAL – VERSUS INERTIAL

Conventional Equipment

The conventional equipment is currently housed within a 20’ container that is loaded onto the vessel for conventional metrology operations. The equipment within this container could be housed within a 10’ container – but this is still a significant amount of equipment. The tripods are stored outside of the container:

Conventional equipment list

3x Sonardyne Mk5 MF WB Compatt, standard end cap
5x Sonardyne Mk5 MF WB Compatt, Digiquartz / Inclinometer end cap
2x Sonardyne Mk5 MF WB RovNav c/w MF transducer + Spare
1x Sonardyne ANT/DTU Compatt test device
2x Sonardyne Fusion Engine WB portable LBL system

Miscellaneous
2x External Digiquartz pressure transducers
4x Tritech Altimeters (2x RS232, 2x RS485)
2x Valeport Mini SVS sound velocity probe
1 x Seabird logging CTD
1x PC c/w processing software (AutoCAD, Surfer) and software key (Dongle)
1x PC c/w for offline processing and as an operational spare for above
1x laptop for reporting
1x set calibration equipment
5x Sub-sea Tripods

Additional bathymetry equipment
1x subsea Octans FOG
2x Tritech Seaking bathymetry (CTD, altimeter) c/w SCU

Software

Sonardyne Fusion acoustic positioning software, Blue Marble, AutoCAD and Surfer software as well as various data collection and parsing software

Reporting / Data Processing

Inertial equipment list

The primary hardware for an inertial survey will be shipped within the cases shown below. Two complete C-PINS systems within the larger pelican cases and the bathy sensors (altimeter, pressure transducer, Seabird and Mini SVS) within the additional shipping case. In addition to this hardware ROV mounting, rotating stabs, brackets and stabbing plates will be needed. All of the equipment for an inertial survey could easily be stored within a 6’ container.

C-PINS system include:
- SSTT surface software running on a PC
- Test cabling
- ROV lifting tool
- Stab tool attachment plates (qty 2)

Spare C-PINS system as above

2	External Digiquartz pressure transducers
2	Tritech Altimeters
2	Valeport Mini SVS sound velocity probe
1	Seabird logging CTD
1	PC c/w processing software (AutoCAD, Surfer, Blue marble etc.) and all software keys

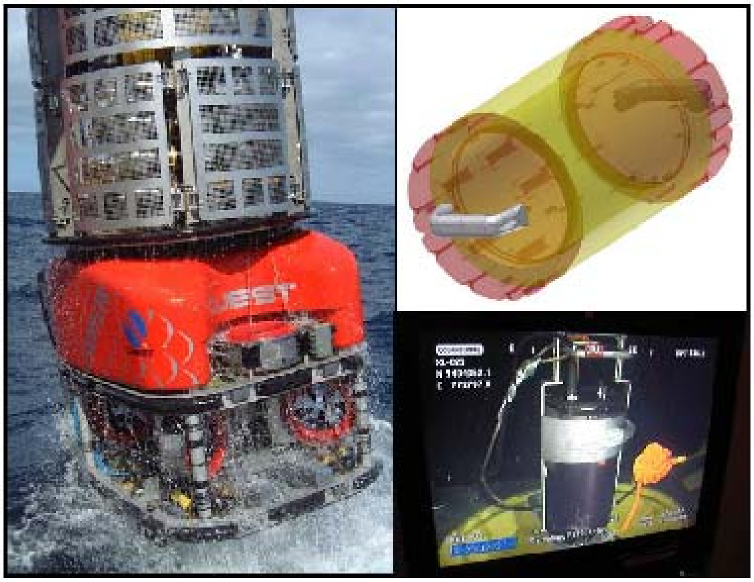
Assorted attachment hardware and brackets

APPENDIX 2

C-PINS Specification

Solutions - Service - Support

Subsea Precise Inertial Navigation System (C-PINS ROV)™



Zupt delivers operationally aware inertial technologies to improve the productivity associated with high cost operations for oil and gas exploration and field development. These capabilities are offered and supported worldwide.

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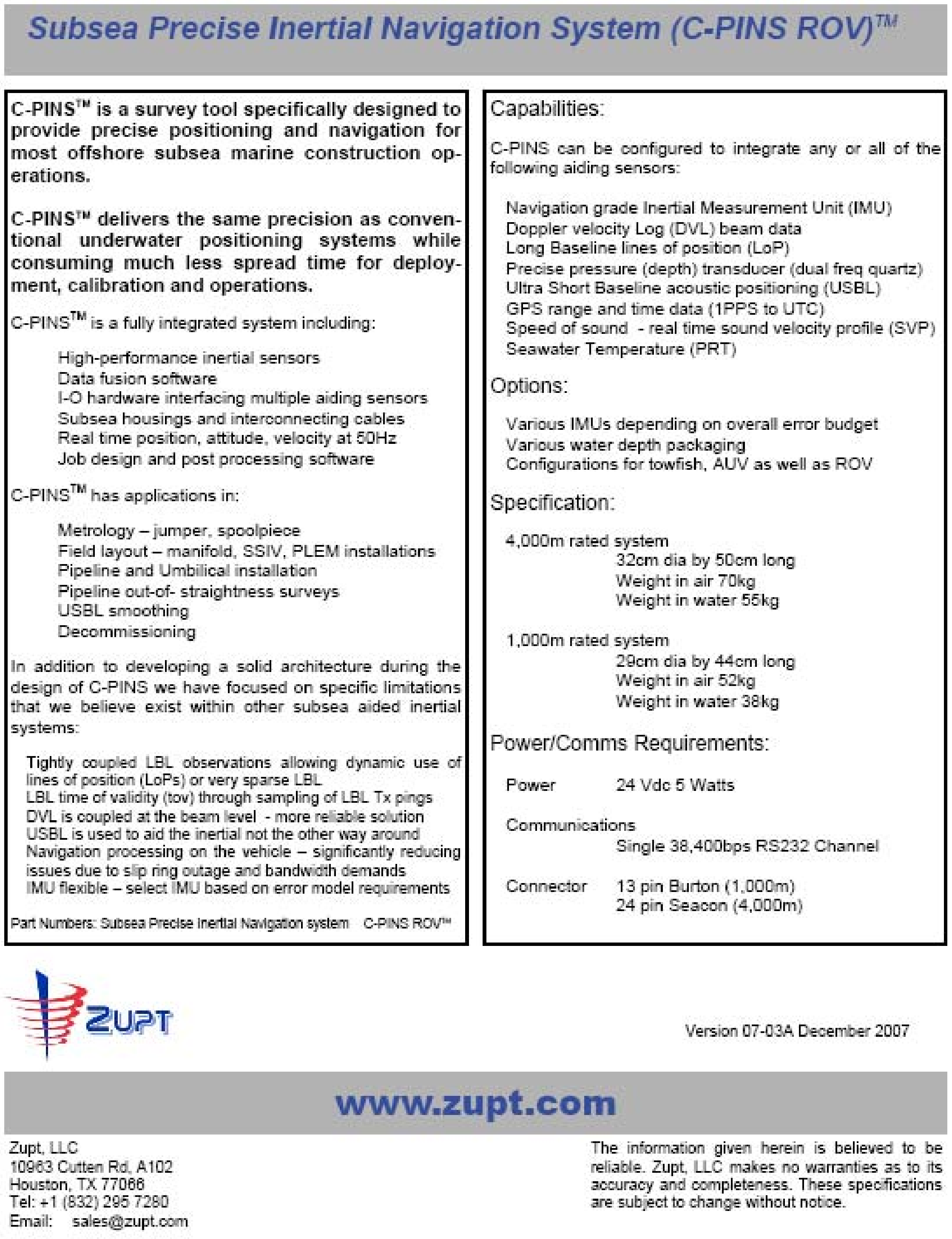

Subsea Precise Inertial Navigation System (C-PINS ROV)™

C-PINS™ is a survey tool specifically designed to provide precise positioning and navigation for most offshore subsea marine construction operations.

C-PINS™ delivers the same precision as conventional underwater positioning systems while consuming much less spread time for deployment, calibration and operations.

C-PINS™ is a fully integrated system including:

- High-performance inertial sensors
- Data fusion software
- I-O hardware interfacing multiple aiding sensors
- Subsea housings and interconnecting cables
- Real time position, attitude, velocity at 50Hz
- Job design and post processing software

C-PINS™ has applications in:

- Metrology – jumper, spoolpiece
- Field layout – manifold, SSIV, PLEM installations
- Pipeline and Umbilical installation
- Pipeline out-of- straightness surveys
- USBL smoothing
- Decommissioning

In addition to developing a solid architecture during the design of C-PINS we have focused on specific limitations that we believe exist within other subsea aided inertial systems:

- Tightly coupled LBL observations allowing dynamic use of lines of position (LoPs) or very sparse LBL
- LBL time of validity (tov) through sampling of LBL Tx pings
- DVL is coupled at the beam level - more reliable solution
- USBL is used to aid the inertial not the other way around
- Navigation processing on the vehicle – significantly reducing issues due to slip ring outage and bandwidth demands
- IMU flexible – select IMU based on error model requirements

Part Numbers: Subsea Precise Inertial Navigation system C-PINS ROV™

Capabilities:

C-PINS can be configured to integrate any or all of the following aiding sensors:

- Navigation grade Inertial Measurement Unit (IMU)
- Doppler velocity Log (DVL) beam data
- Long Baseline lines of position (LoP)
- Precise pressure (depth) transducer (dual freq quartz)
- Ultra Short Baseline acoustic positioning (USBL)
- GPS range and time data (1PPS to UTC)
- Speed of sound - real time sound velocity profile (SVP)
- Seawater Temperature (PRT)

Options:

- Various IMUs depending on overall error budget
- Various water depth packaging
- Configurations for towfish, AUV as well as ROV

Specification:

4,000m rated system
  32cm dia by 50cm long
  Weight in air 70kg
  Weight in water 55kg

1,000m rated system
  29cm dia by 44cm long
  Weight in air 52kg
  Weight in water 38kg

Power/Comms Requirements:

Power 24 Vdc 5 Watts

Communications
  Single 38,400bps RS232 Channel

Connector 13 pin Burton (1,000m)
  24 pin Seacon (4,000m)

Version 07-03A December 2007

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