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DYNAMIC POSITIONING CONFERENCE

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SENSOR SESSION

The Development and Use of an Inertial Navigation System as a DP Position Reference Sensor (IPRS)

Keith Vickery

Sonardyne, Inc.

Abstract

This paper discusses the expected benefits of adding an inertial sensor to the suite of position reference sensors associated with DP drilling operations. Once the benefits are described the process of technology selection, evaluation and field testing are also described.

The conclusions from the testing and evaluation program are discussed and the concept of a Partnership for IPRS Technology Advancement is introduced for continuing field development leading, eventually to product introduction.

Introduction

It has long been suggested that the integration of an inertial sensor into the suite of position reference sensors for DP application would add reliability to DP operations as well as providing additional benefits.

Sonardyne started to review the available technology in this sector late in 1997 and is currently running a staged program, in parallel with offshore trials, to develop an Inertial Position Reference System (IPRS).

The development/evaluation has progressed to a stage that requires access to vessels and "joint" development partners (operator and drilling contractors). Sonardyne is looking for collaborative partners and so invites comment and cooperation from both the drilling and operating community.

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The block diagram below shows how such a basic system might be configured.

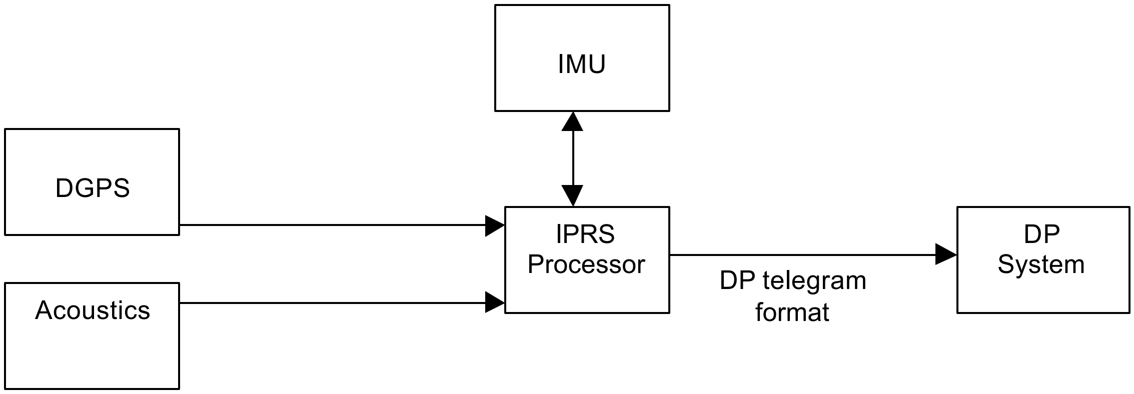

Fig. 1 Block diagram of simple Inertial Position Reference System

Some details of the system development/evaluation may not be described, to the level required by some, within this paper. This is due to the commercial nature of such a product development/evaluation. If this paper does not provide enough detail please contact the author or Sonardyne directly for a more detailed discussion.

Definition of System Benefits

The addition of a high update rate, very repeatable inertial positioning sensor to the DP system offers the following potential benefits:

- Graceful disconnect/shut down of operations
- Short term DGPS outage cover (Due to system failure or Scintillation)
- To slow down acoustic update rate
    - Assist the "Multi-user" problem
    - (Many vessels in small area using same frequencies)
    - Extend battery Life
- Additional position reference sensor
- DP model "smoothing"
    - Less fuel consumption (possibly – who cares)
    - Less "wear and tear" lowers maintenance demands
    - Quieter acoustic operations
- Provides very accurate heading, pitch, roll and heave

As each benefit is reviewed the requirements of a relevant Inertial Measurement Unit (IMU) can be defined and hence the specification for the required sensors or INS can be established.

Graceful disconnect/shut down of operations

The cost of a disconnect for deepwater drilling operations is on the order of $2,000,000. This cost is split in most cases 50/50 between the drilling contractor and the field operator. The possibilities of damage to both life and the environment if such a decision is not made by far exceed this.

The opportunity to extend the period of time needed to make the decision to disconnect and to allow for a graceful disconnect is seen as one of the benefits the introduction of inertial technology to the DP drilling market.

In the event that all other "external" position reference systems fail an inertial based system will provide a period to allow a graceful disconnect, or recovery of one of the other position reference systems.

The system maintains a position telegram into the DP desk long enough to complete a preliminary disconnect, including hanging the drill string off. The final disconnect decision can be made under control, rather than in a hurried state of confusion, if none of the other external reference sensors can be recovered. This decision period would be substantially weather independent.

Short term DGPS outage cover (Due to system failure or Scintillation)

We are currently moving into a period of significant sun spot activity that may, in turn, cause periods of degradation and potential loss of either GPS observations or communications of differential corrections. This subject is described in a previous paper in this section (ref 1.).

The lengths of these "outages" are unpredictable but can be up to 4 hours. During DGPS (or acoustic) short-term outages, or complete system failures, the inertial based system will provide a relative position, as an additional position reference, derived from the movement of the vessel. The processing within the IPRS recognizes degradation in either, or both, the DGPS and acoustics while continuing to generate an output based on the inertial sensors.

To slow down acoustic update rate:

Assist the "Multi-User" problem
(Many vessels in small area using same frequencies)

In a similar manner the "Multi-User" problem of congested offshore areas where many vessels are working within "earshot" of each other using the same acoustic bandwidth can be addressed with the use of inertial "in-fill" fixes. Very accurate GPS timing is easily available today to synchronize the clocks on all vessels operating offshore. With synchronized clocks and the "in-fill" capabilities of an inertial system each vessel could be given a time slot to be using the available bandwidth of the water column. This technique will allow many vessels (>6) to work in the same area and in some cases use the same array of transponders.

Extend Battery Life

A small but real part of the cost of operations for acoustic positioning systems is the annual cost of batteries consumed in subsea transponders. The expected update rate of most DP desks is one positioning telegram per second from each external position reference system. When this update rate is reduced, depending on DP system manufacturer, the accurate position available from an LBL system is un-weighted within the Kalman filter in the DP system due to the extended time period between fixes. To this end some acoustic positioning systems generate repeated "fill in" fixes and some generate "filtered" fixes. In most cases, once the update rate extends beyond 10 to 12 seconds, the DP desk totally rejects the acoustic data provided. To date this has required as regular an update as the acoustic positioning system and the water depth would allow.

Some large deepwater DP vessels of today are very acoustically noisy and as a result require very high source level, long life, transponders to provide reliable positioning. These transponders normally have Lithium battery packs to ensure maximum energy density. These large Lithium packs cost in the order of $2,500 each (New build Sonardyne Type 7800 Lithium pack). The disposal of spent Lithium cells also adds additional cost due to the legislated disposal requirements. Any method of slowing down the acoustic update rate has an impact on the life of such battery packs.

An example for a noisy vessel in 4,000 fsw, with an update rate of 3 seconds, a standard transponder would operate for apx 112 days prior to requiring a battery replacement. If we assume 5 beacons deployed at each drilling location and an average well location period of 90 days then the average annual cost of batteries will be roughly $50,000. Many efforts are made not to change batteries early as in the above example. Also the transponders spend some of their time in a quiescent state for part of a year. But just this simple example shows that by reducing the update rate from 3 seconds to 30 seconds reduces an estimated annual battery cost from $50,000 to $5,000 in addition to removing the shipping and handling issues associated with Lithium battery packs.

Providing inertial based "in-fill" fixes with a slow acoustic update rate will provide the savings shown above.

Additional position reference sensor

The International Maritime Organization (IMO) (ref 2.) provides guidelines with respect to required Position Reference Systems for DP drilling operations. These recommendations are commonly referred to as Class 2 and Class 3 certification.
The requirement for positioning systems can be defined as:"3 independent position reference sensors operating from 2 separate principles"

The commonly used deep water positioning principles today are DGPS and Acoustics in some form. Once one of these systems fails the alternates in deep water operations are minimal. Some may suggest the use of riser angle data. Rarely is Electrical Riser Angle (ERA) used as a real time, interfaced reference sensor. DP operators (DPO's) often use changes in the ERA as a guide to positioning performance.

Taut wire and radar or laser range and bearing systems cannot be used in deep water remote or floating infrastructure locations.

The possibility to use a position generated from sensors monitoring the movement of the vessel with respect to the earth may add an additional "principle of operation ". The argument against this is the need for any inertial system to be aligned and aided or bound by one of the other absolute or seabed relative positioning systems. The main demand for the "other principles of operation " is to provide levels of redundancy, temporary or otherwise, when one of the systems fail. This level of redundancy can be provided by such an inertial based position reference system. This debate will continue.

DP model "smoothing"

Less fuel consumption (possibly)
Less "wear and tear" lower maintenance demands
Quieter acoustic operations (dependent upon thruster type)

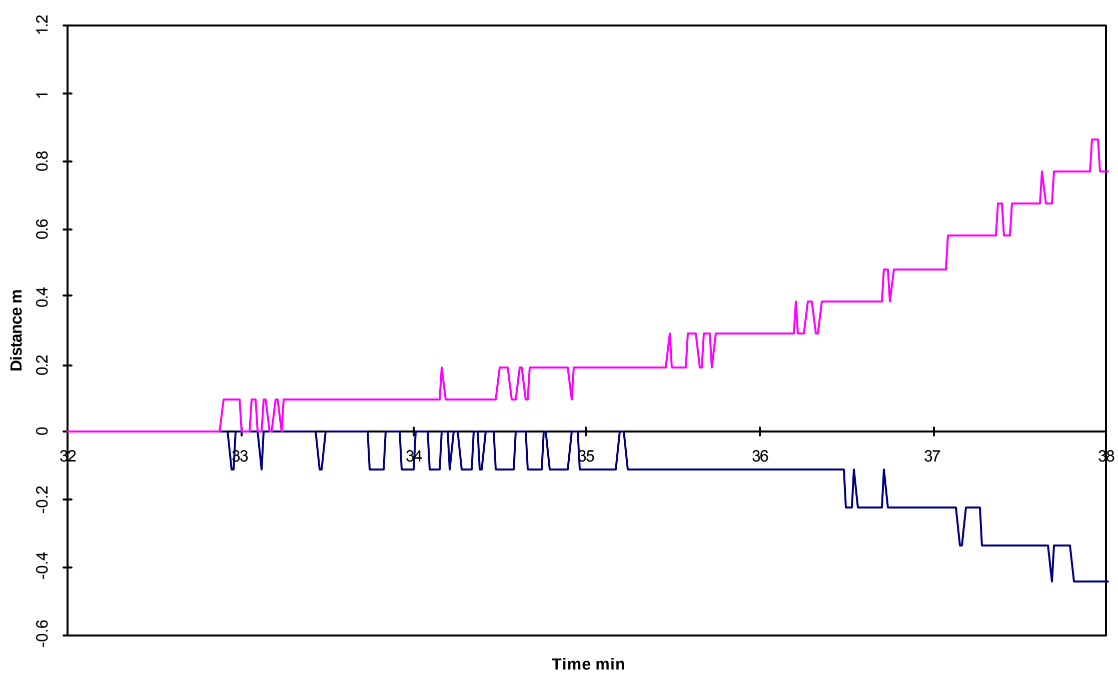

Fig 3. Example of short term drift of an IPRS

The short term drift characteristics of this type of sensors provides very repeatable, second to second relative positioning. By utilizing the velocity information available the DP model generated velocity can be tuned to demand less of the thrusters to maintain position. An inertial system may be a valid sensor to provide accurate data for "wave feed-forward" movement monitoring. All of these benefits are still to be quantified. It is true to state that any long term reduction in thruster loading and demand will increase operational life of thruster components. Fuel savings are suggested but very difficult to evaluate.

Any reduction in thruster load activity (refers to fixed pitch installations only) will reduce the acoustic noise surrounding the vessel and improve the operating environment for the acoustic positioning system.

Provides additional accurate heading, pitch, roll and heave

The quality of inertial sensors required to provide positioning, as defined above, also provide accurate attitude and heave data. The Heading and attitude data is significantly more accurate (0.05 degrees dynamic heading, 0.03 degrees dynamic pitch and roll) than data available from commonly used ships gyro's and vertical reference units (VRU's). This level of accuracy would allow for the inertial sensor to replace both a Gyro and VRU within the spread of the vessel's equipment.

It is felt that the addition of accurate real time heave data could assist with slip joint and general riser management logs and alarms.

Performance/Benefit Summary

The above benefits need to be put into the context of performance. Table 1 is one interpretation of the requirements that could be placed on the IPRS.

Positioning requirement *	Required positioning accuracy from IPRS	Duration of required accuracy
Graceful disconnect	<2% of water depth	15 minutes
Short term DGPS outage	<2% of water depth	As long as possible
Slower acoustics for battery savings	3m to 5m	60 seconds
Multi-user slower update	3m to 5m	120 seconds
Additional sensor	<2% of water depth	As long as possible
DP model smoothing	5cm	second to second

* Un-aided - in the event of total failure of both DGPS and acoustics.

Table 1. Required performance during various applications

As a single system is envisaged as providing all of the above benefits the most demanding requirement drives the specification of the system. If any single requirement can be defined for a simpler application then the specification for the inertial sensor may be reduced, which, in turn will impact overall system price.

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Technology Review

The significant change in the performance "3-4 orders of magnitude improvement in the last decade" (ref 3.), along with the reduction in cost for inertial sensors provides us with an array of affordable, different technologies from which we can select components to the required specification.

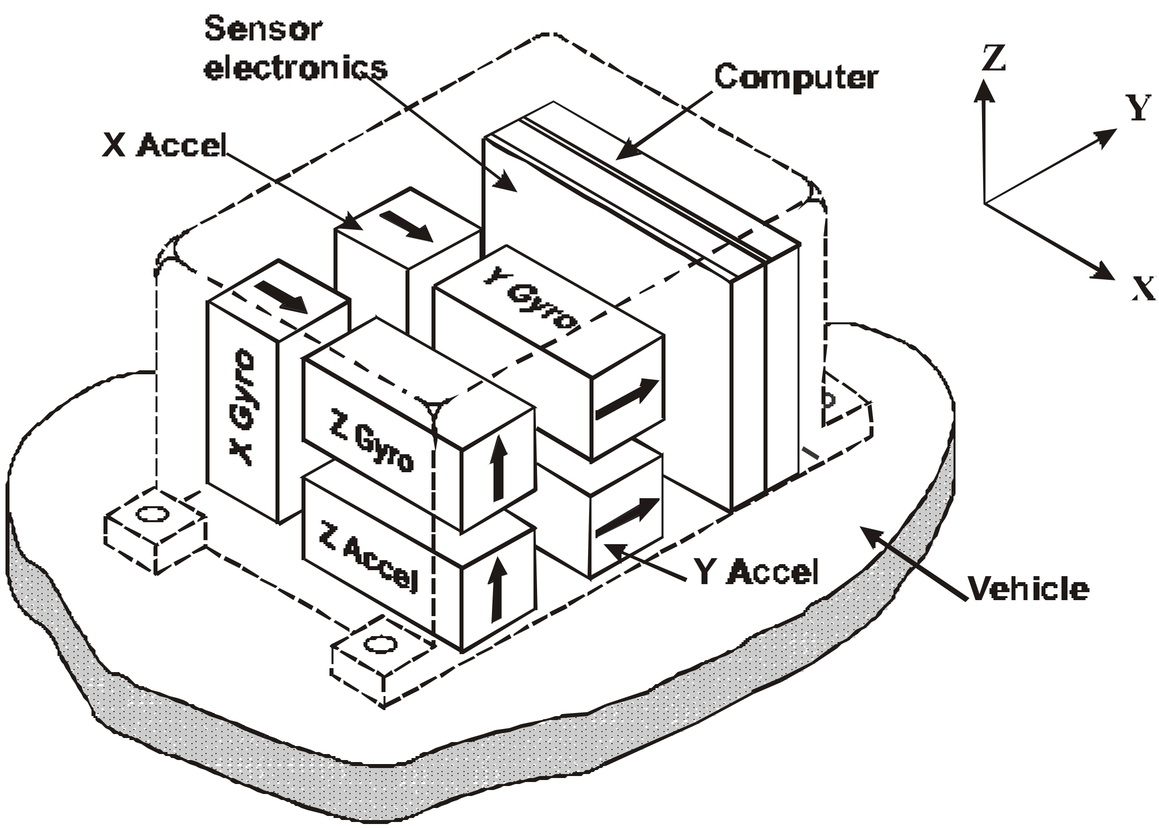


Fig 4. Basic Strapdown Inertial Navigation System

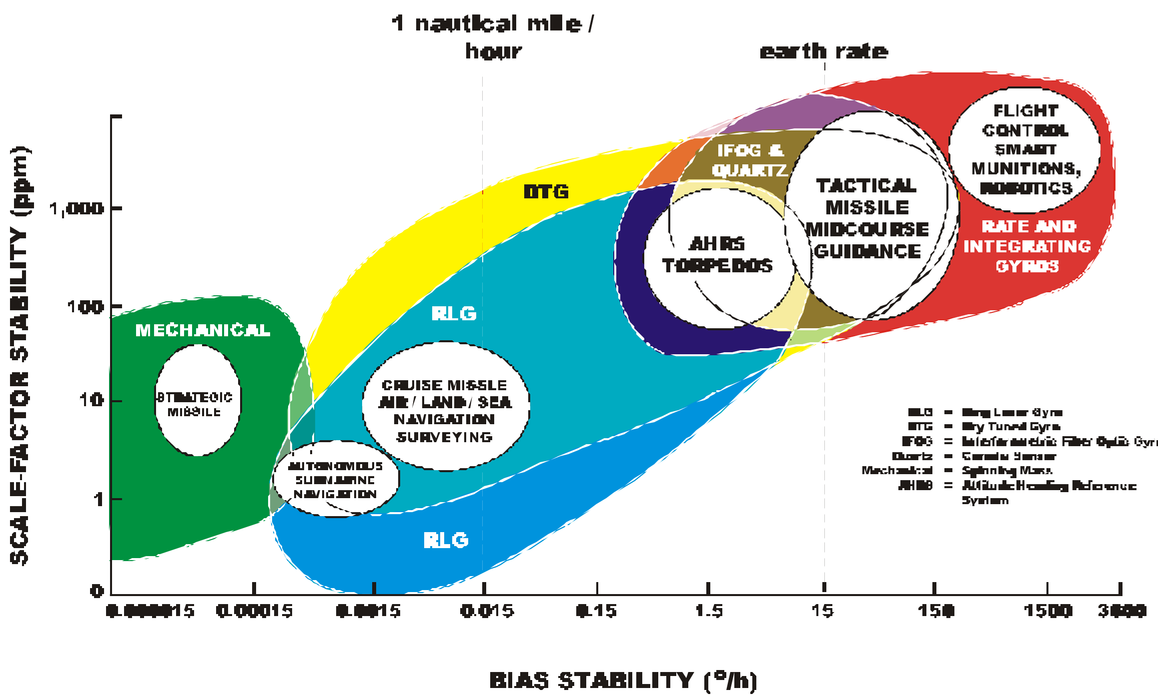
An inertial navigation system is constructed from an accelerometer and gyro in each of the x, y and z axis. The raw data from these sensors is used to solve for translation and rotation motion on the surface of a rotating ellipsoid (earth surface) to generate a position, relative velocity and attitude in all 3 axis - pitch, roll and yaw.

The primary error sources within an INS are:

> Calibration bias errors for both accelerometers and gyros
> Accelerometer measurement noise
> Gyro drift rate (eventually integrated into tilt error).

For most modern "medium" accuracy (ref 4.) 0.8nm/hr inertial systems the accelerometer noise errors are on the order of a few micro g's (µg's) while the gyro drift rate errors are in the order of a few thousandths of a degree per hour.

The following two charts (ref 3. reproduced with permission from the authors and Draper Laboratory, Cambridge, MA) clearly show the current technology with associated applications.



Current Gyro Technology Applications

Fig 5.

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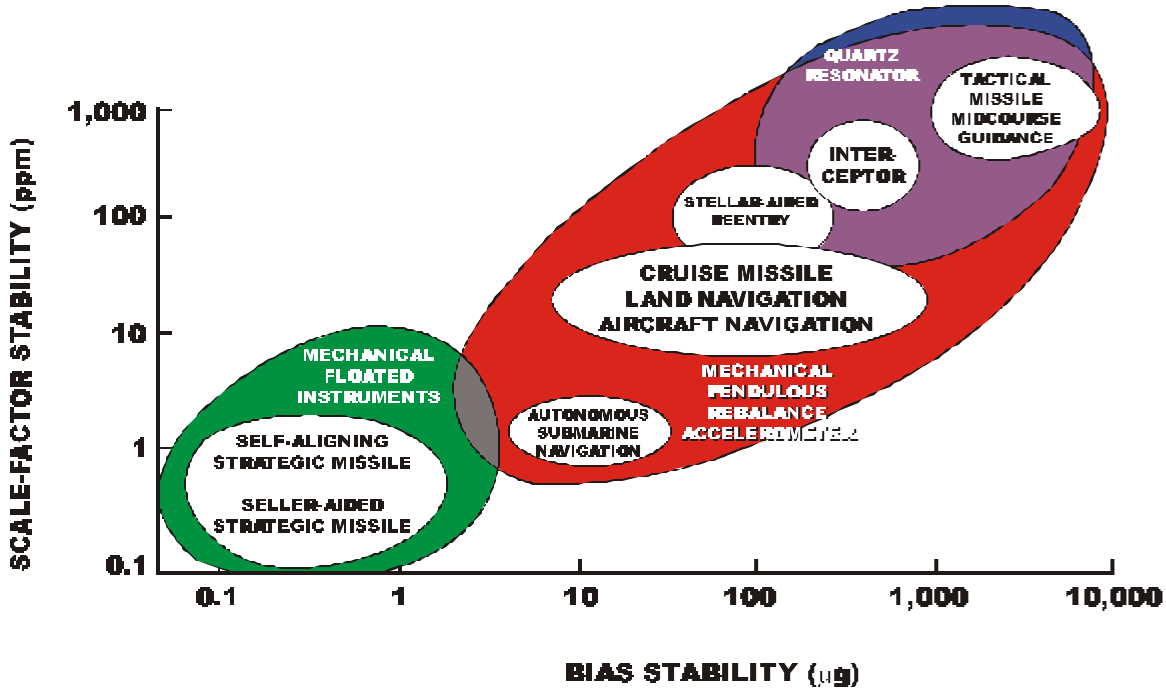


Current Accelerometer Technology Applications
Fig 6

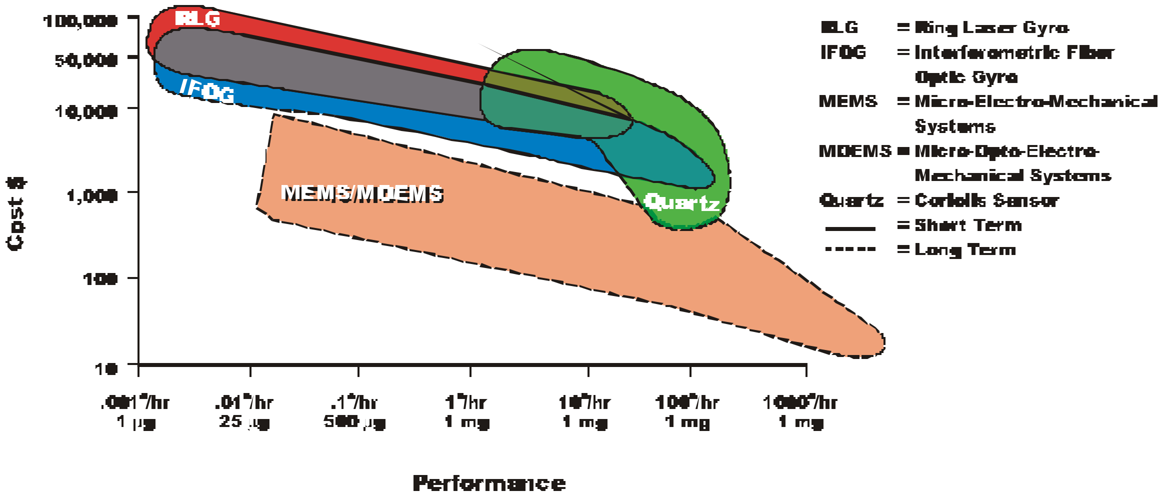
Sensor Technology Selection

From reviewing the above technology it can be seen that the best elements for the system as defined previously is a compromise of price and performance at the high end of commercially available technology.

The gyro bias stability requires ring laser gyro technology and the accelerometer specification falls into the mechanical pendulous rebalance accelerometer.

This performance specification falls in between what the U.S. Airforce (ref 4.) would specify as medium accuracy (0.8nm/hr) or a high accuracy (0.2nm/hr to 0.3nm/hr) inertial system.

As with any innovative use of technology we must be aware of what changes are planned. The reduction in the price with increased performance will continue and the chart below shows the direction this technology will take in the near future.



IMU Cost as a Function of Instrument Technology

Fig. 7

System Evaluation.

During the previous development/evaluation stages it became very clear that, although Sonardyne has a great deal of knowledge with respect to acoustics and positioning adjustments, we would need some expert help during the development of this product.

Working with consultants an evaluation plan was constructed based on three primary dynamic states:

Static

Dynamic – Onshore

Dynamic – Offshore

During each phase of the system evaluation we focused on alignment and navigation capabilities within that dynamic environment.

In all evaluation cases we were looking for any system failure modes that would undermine the required performance.

Static System Evaluation

The most fundamental test for the evaluation of the system performance has to ensure that the sensor type met the specification of the vendor and that the integration within the IPRS did not degrade this performance.

Static Alignment (calibration)

The static tests required static alignment of this units with various heading changes (with respect to the earth's rotation) at different stages of alignment. This ensures that both the x and y axis of the unit were fully aligned within the required alignment period.

This alignment period was initially set to 20 minutes to ensure optimal alignment but was quickly reduced to 5 minutes when it was realized that that unit would achieve complete alignment in this shortened period.

Static alignment was completed with both manually entered coordinates and with external (D)GPS as an alignment aid.

Static navigation was primarily just a test of the alignment and un-aided performance.

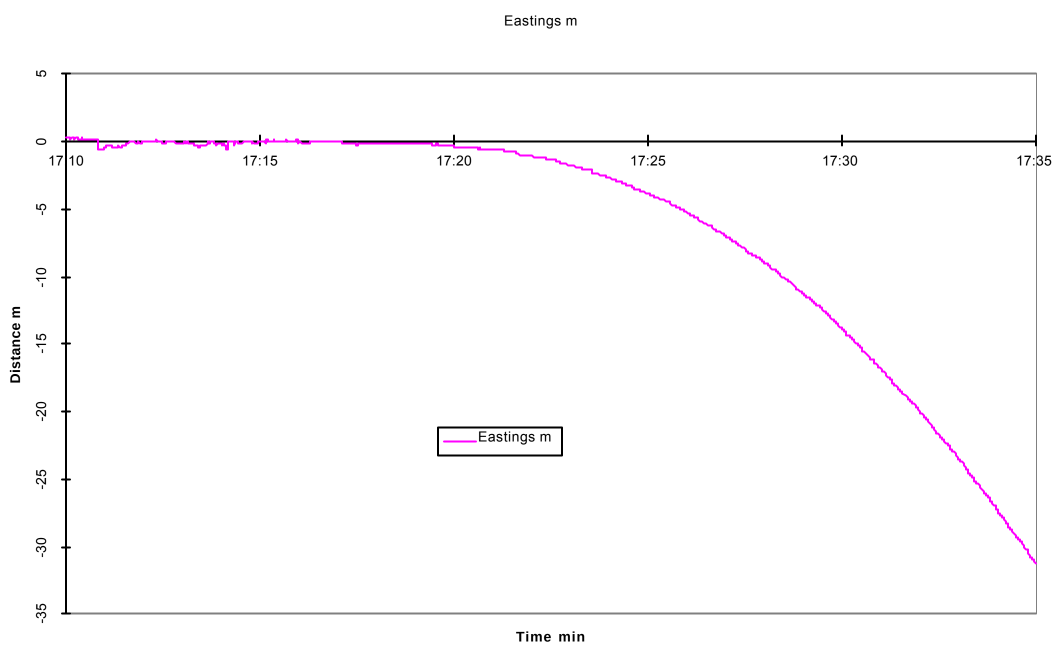


Fig. 8 Example of static un-aided performance – single axis

The conclusion from the static testing phase was that the system performance was achievable.

Dynamic Onshore Testing

The onshore dynamic testing was completed at the NASA's Michoud Assembly Facilities, University of New Orleans National Biodynamics Laboratory (NBDL) (formerly the Naval Biodynamics Laboratory).

This lab had facilities, through two pieces of test equipment, to generate representative dynamic motion for specific vessel size and weight, in a specific sea state.

For the purposes of our evaluation, two test platforms were used:

6 DOF (Degrees of Freedom) table

Ship Motion Simulator

Both the 6 degree of freedom table and the ship motion simulator are driven from wave tables generated from software developed at the Naval Surface Warfare Center, Carderock division, Bethesda, MD (ref 5.).

To minimize test time the high dynamics tests were completed on the smaller vessel and the low dynamic tests on the larger vessel size. Please note that in all of these onshore dynamic tests that the mean 3-axis displacement over time is zero. No twin hull (semi-submersible) simulation was completed at this stage.

Initially the 6DOF table was used to evaluate the following sea states operating on the following hull types.

Small class drillship	Length	490 feet to 530 feet
	Operating draft	20 feet to 30 feet
Large class drill ships	Length	730 feet to 800 feet
	Operating draft	35 feet to 45 feet

Sea states to be used for these tests were:

High sea state

Wind speeds of 60 knots (Beaufort 11)
Current of apx. 3 knots
Significant wave heights of 21 feet

Low sea state

Wind speeds of to 3 knots (Beaufort 1)
Current of 0.5 knots
Significant wave height of 2 feet

The wind was defined to be 5 degrees off the bow, and the bow towards the current. The wind to current offset was assumed to be apx. 40 degrees.

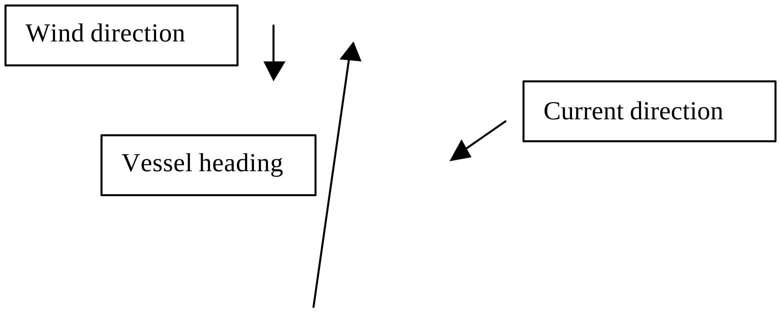


Fig. 9 Vessel heading with simultade wind and current direction.

Wave period was defined for the larger wave heights at 9 seconds and for the minimal dynamics tests periods of 13 seconds was assumed.

Due to design of the 6DOF table the heave component of the derived wave tables was actuated at 10% of actual due to table travel limits.

Results from the 6DOF tests supported the assumptions that the unit could be aligned, aided and navigated in an un-aided mode in accordance with the specification.

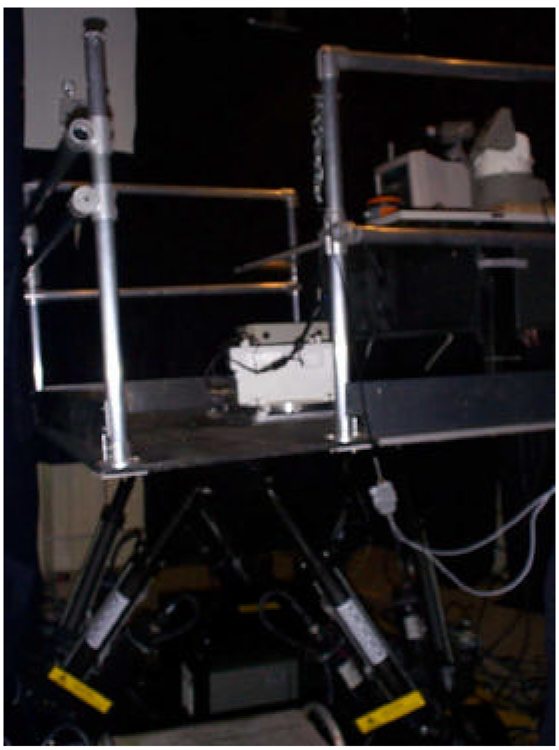


Fig. 10 6DOF Table set-up

Upon completion of the 6DOF tests the evaluation system was moved to the ship motion simulator (SMS).

The SMS, again driven by simulated wave tables, was used just for the high sea state, small drill ship, to evaluate the full effect of significant heave on the IPRS. The rates of heave motion were somewhat severe:

Heave	2m/s
Pitch/Roll	3degrees/s

The resultant performance of the IPRS was within specification, but purely operating in an un-aided condition.

Fig. 11. Ship Motion Simulator

Fig. 12 Heave Data from SMS

The conclusion of the onshore based dynamic (zero mean displacement) tests were that the system performed during both alignment and navigation as required and that dynamic thresholds could be defined to specify "minimum" system performance conditions.

During the New Orleans trials the impact of static aiding techniques being used with known dynamics were reviewed and tested. The results showed that, as expected, induced errors of the magnitude of the actual lateral velocity will be induced into the processed accelerometer bias causing false biases and incorrect position error growth.

Offshore Dynamic Testing

Dynamic tests were carried out offshore on a Dynamically Positioned multi-role support vessel. These tests confirmed the results of the onshore tests.

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Fig. 13 Dual IMU set up for offshore testing

The offshore results showed that the system could be aligned in the offshore environment with the use of an external reference aid. When the system was aided with an external reference sensor the system performance was within the required specification. The un-aided performance was also within the specification.

As expected the static aiding technique evaluated in New Orleans did not perform when tested offshore in the real world.

The example shown below illustrates the instant re-alignment to an external (DGPS) reference when that external reference is valid and available.

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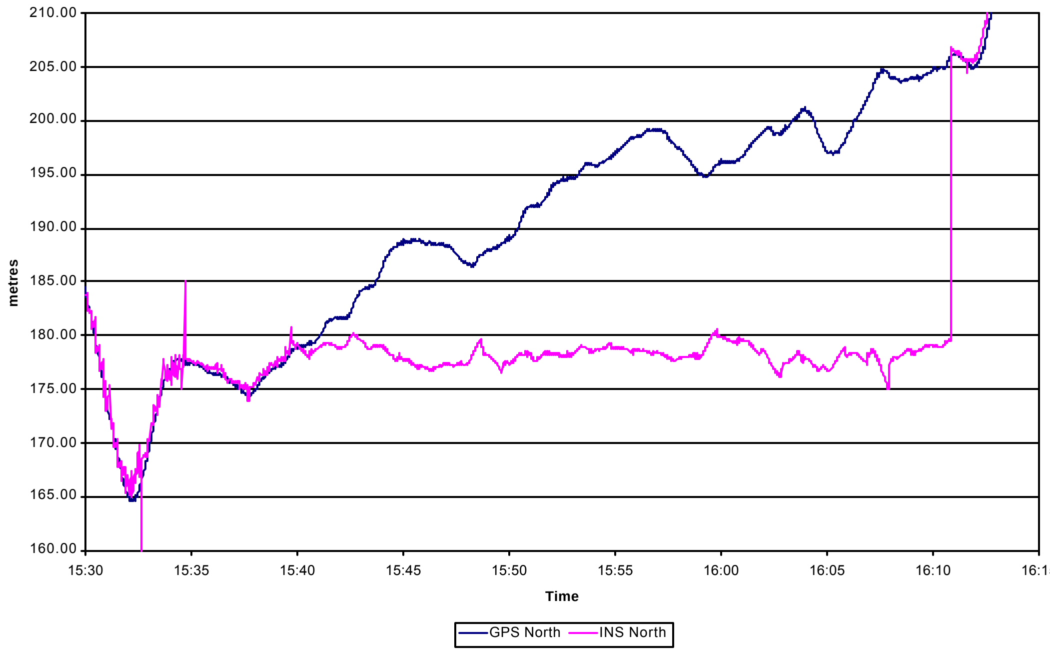

Fig. 14 Instant re-alignment after simulated DGPS outage period

Conclusions from the Testing Program

The conclusions from the extensive testing program are that the system is ready for long term evaluation by prospective users prior to being offered as a product.

In order to ensure that every facet of possible system failure modes have been evaluated we plan an extended period of system evaluations. This technology has not been used in this application previously and we have to be sure that we have not overlooked any issues that may significantly impact future operations. These long term trials will give us much more dynamic, weather and operational exposure to ensure that we have not missed anything during this development/evaluation process. The trials program is currently being structured so that both Sonardyne and the potential customer for this technology are involved in its introduction into actual applications.

The trial platforms currently being sought, or already planned for these trials are;

Large Semi-Submersible
Small (accommodation) Semi-Submersible

Large Drill Ship
Small Drill Ship

Construction barge
Large Offshore Supply Vessel/ROV/DSV

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We intend to complete the above trials offshore Brazil, offshore West Africa and the Gulf of Mexico. Initially the system will be run alongside the DP operations. Data from the external position reference sensors (PRS) and the data from the IPRS will be logged for evaluation.

The conclusion of these vessel installations will be to interface the system into the DP desk and operationally run with the system as one of the PRS.

Where do we go in the next 6-12 months?

The trials partnerships we are now discussing, and will continue to make over the next three to six months will allow us access to real additional operational conditions. Once the above evaluation program is complete and assuming no major hurdles are discovered the system will go through a rigorous Sea Acceptance Test (SAT) so that we have documented capability for prospective users.

In addition to the trials program additional capabilities are being discussed to expand the systems capabilities beyond those discussed within this document.

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