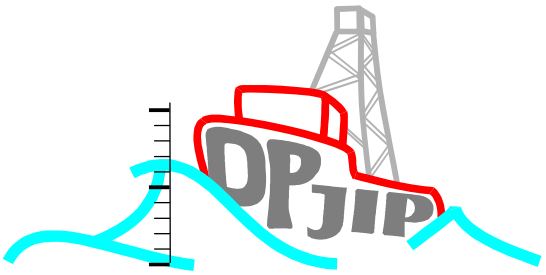

Publishable Synthesis Report DP-JIP

Contract No.: ENK6-CT-2000-00104

Acronym: DP-JIP

Title: Improved Dynamic Positioning for Large Vessels to Increase Safety and Effectivity in Offshore Operations and Exploration and Exploitation of Marine Resources

Project Coordinator: MARIN

Partners: BP
Kongsberg Simrad
IZAR (new name of Astano after merger with Bazan)
IHC Caland

Reporting period 1 december 2000 – 30 november 2003

Project start date: 1 December 2000

Duration: 34 months

Project funded by the European Community under the 'Energy, Environment and Sustainable Development' Programme (1998-2002)

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1. Executive Summary

The DP JIP consortium

The Joint Industry Project carries out an investigation to develop and make available against economically justifyable cost a method for “Improved Dynamic Positioning for Large Vessels to Increase Safety and Effectivity in Offshore Operations and Exploration and Exploitation of Marine Resources”. The consortium exists of the following companies:

Project Coordinator:	MARIN
Partners:	BP Kongsberg Simrad IZAR (new name of Astano after merger with Bazan) IHC Caland

Application

The project results will be useful in DP applications for deep water drilling, floating production, offshore offloading of oil and/or gas (LNG), dredging, cable laying and pipe laying.

Technical results

In the project, industry and MARIN have been working together to develop and test a method for improved dynamic positioning.The improvement method is based on the notion that positioning of a large ship in open sea by use of thrusters will become more effective if the environmental forces are known in “real time”. In feed back control such real time information is called “Feed Forward”.

An example of feed forward which is common practice in DP systems is measurement of wind speed and direction, and the use of wind force coefficients to estimate the wind force on the ship. For large ships the so-called “wave drift forces”, which are second order effects in a seaway, are dominant forces.

The estimation of wave drift forces, which cannot be directly measured, has to make use of physical relations between observables and these second order forces. It has been found that the relative water motion at the bow, stern and sides of the ship is a good observable: it is a measurement with a good signal to noise ratio and it contains the physical information to estimate the wave drift forces in various ways.

Two different methods were used to estimate the wave drift forces from the relative motions. Only a limited number of relative motions sensors (i.e. 6) was needed to get an estimate with sufficient accuracy, and even have some redundancy left. One method is the “waterline integral method”, first described by J.A. Pinkster and the other method is the “modulator method” first described by A.B. Aalbers and U. Nienhuis.

The project comprised three stages:

- Technology and Software development for the Real Time Environmental Force Estimator (RTEFE)
- Full scale measurement campaign on the “Loch Rannoch”,a BP operated shuttle tanker for the Schiehallion Field, in which data was collected for correlation with model tests and real “life” data to test the software on.
- Model scale closed loop DP tests in which the RTEFE technology was tested, followed by DP simulations to finalise the technology and evaluate powering effects.

In the present summary report the result of the investigations is presented, and the general conclusion drawn. It could be concluded that the RTEFE caused a significant improvement in positioning accuracy. This is useful in higher sea states because it extends the operating envelope of the DP vessel. In more or less unidirectional wave systems the positioning improvement can exceed 40%. In very directional seas improvements up to 25% have been established.
The effect on power use is relatively small: upto 5 % improvement may directly be obtained. Greater fuel savings can be achieved from a more efficient operation: e.g. by using RTEFE’s increased positioning capability as well as the decision support to the DP operator.
Simulations for a North Sea Shuttle tanker show a 10% reduction in average annual loading time, mainly obtained from 20% improvement in the winter half year.

The results of the DP-JIP project have been delivered in reports and software source code of the RTEFE. A follow-up is planned, using the Loch Rannoch for a full scale demonstration of the technology.

2. Objectives and Strategic Aspects

Technical Objectives
With the development of the Real Time Environmental Force Estimator (RTEFE), the following objectives were envisiged:

- Reduction of fuel consumption on DP vessels of at least 20 %
- Significantly increased positioning accuracy and less downtime
- More reliable positioning in harsh weather and increased limit sea state.

Strategic aspects and EU policy needs
DP-technology and manufacturing of DP-systems have always been a typical European activity, and most DP-vessel owners and builders are European. The field of application of large DP vessels is world wide, and concerns activities beyond private, regional and even national level, such as:
For Energy Resources

- Search and exploratory drilling for oil and gas
- Production of offshore oil and gas from floating equipment, and installation of well infrastructure (e.g. satellite pipelines, control cables)
- Export of oil and liquified gas from such floating production equipment to shore
- Maintenance drilling and field extension/upgrading

For Mineral resources or Land Suppletion

- Deep water dredging to collect minerals or fill material for artificial islands, coastal reinforcement etc.

For International Infrastructure

- Dredging and maintenance of harbour entries, for which DP vessels are used which deploy their DP system to follow a pre-defined track

- Pipeline laying, for oil and gas transport, for which DP vessels are used, also following tracks
- Cable laying for national and international coastal networking and transocean telecommunications

3. Scientific and Technical Description of the Results

3.1 Description

The project work commenced in December 2000, after the formal 'go' of the EC was received.

Desk studies (Work Package No. 1)

The desk study #1 on the interface definition of the RTEFE to DP control systems has been completed and used for the definition of the scope of work of a follow up project with a full scale demonstration of the system.

The desk study on design requirements Part 1 has been cmpleted. Part 2 concerns the effect of the RTEFE on the design and has still to be completed.
In concerns a re-design of the thruster layout and sizing of the shuttle tanker and simulations with the new configuration to demonstrate the impact on ship design and thruster layout/sizing. This part of the work has been delayed and will be completed outside the reporting period deadline of 30 November 2003.

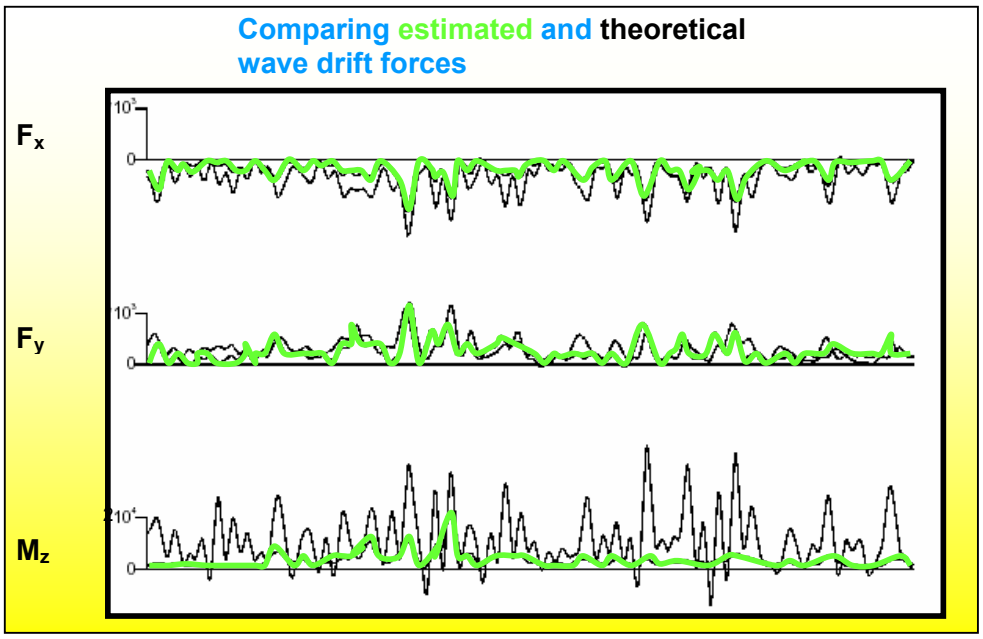
The desk study to investigate thruster wear as a possible consequence of use of the RTEFE methd has been carriedout by RollsRoyce Marine in a sub-contract to the JIP Co-ordinator. The report is completed and was presented at the final reporting JIP meeting in Cap d'Ail, France.

Theoretical developments (Work Package No. 2)

The theory which was used in a 1991 pilot project to estimate the wave drift forces from relative water motions at the side of the vessel, was evaluated and improved. In the Mid-Term Progress Report was described that a better estimate of wave drift forces could be obtained if the ship was considered as a forward and aft part. However, practical reasons brought forward by the participants (i.e. unavailability in the industry of methods to calculate wave drift forces on fore and aft body separately) lead to the decision to additionally develop an estimating method for the wave drift forces on fore and aft body from calculations for the whole ship. The method has been tested and implemented in the RTEFE method.

The objective of the R&D was to obtain a real time estimate with an accuracy better than 20% in the wave drift forces and in Figure 1 is shown that this objective could be met for the longitudinal (Fx) and transverse drift force (Fy). For the moment the desired accuracy was not achievable. But, further evaluation (see WP5) learned that the moment has a change of sign during passage of a wave group which is of too high frequency for the ship inertia to follow, so that it is not relevant for DP control.

Figure 1: Comparison of RTEFE result with theoretical wave drift forces



Instrumentation of the Loch Rannoch (Work Package No. 3)

The instrumentation has been installed and put to work as described in the Mid Term Progress Report. The monitoring period has started on January 1, 2002 and completed in October 2002, after a damage to the ship. Together with the specific trial of 22 dec 2001 the dataset contained sufficient DP offloading and full DP cases to be able to select a proper range of sea states for in-depth analysis and correlation with model tests. The selection process has been described in detail in the DP JIP Summary Report of Model Scale and Full Scale Tests (Ref 4).

The monitoring data had to be cross checked with help of redundant data records and it was concluded that the log data of the DP system provided incorrect values for the main propeller thrust. Propeller pitch settings were measured as redundant signals and re-analysis of the full scale measurements has to be carried out, using Pitch-Thrust relations provided by Rolls Royce Marine. This part of work caused a significant delay in the evaluation and reporting of the model test correlation with full scale data and is the main reason that the WP1 Desk Studies #2 and #4 have not yet been completed.

Scale model tests for correlation and evaluation of the RTEFE (Work Package No. 4)

A comprehensive series of scale model tests was carried out in the Offshore Basin of MARIN. It concerned tests with a conventional DP control method to establish the correlation between scale model tests and full scale measurements, and it concerned tests with and without RTEFE to assess the effectiveness of the wave feed forward technique, in positioning accuracy and in power consumption.

In Figures 2 and 3 is shown how the use of the RTEFE improves positioning with about the same or slightly less effort of the thrusters. Positioning provements in the order of 25% to 40% could be obtained, mainly because the large excursions were ‘topped off’. This effect means that in harsh environment the vessel lies more stable and hence workability is improved.

In terms of fuel saving two aspects could be derived:

1. The power consumption was estimated from the thrust measurement, using the relation $P \sim T^{1.5}$. This estimation resulted in a small power reduction (upto 4%) for the higher sea states, but this magnitude is within the overall accuracy bandwidth.
2. The improved positioning is worthwhile to use for increased efficiency of the vessel 's operation, creating additional options to save fuel.

These aspects were furhter investigated in WP5.

Figure 2: Result of using RTEFE in a 4.5 m sea state (compared with conventional DP)

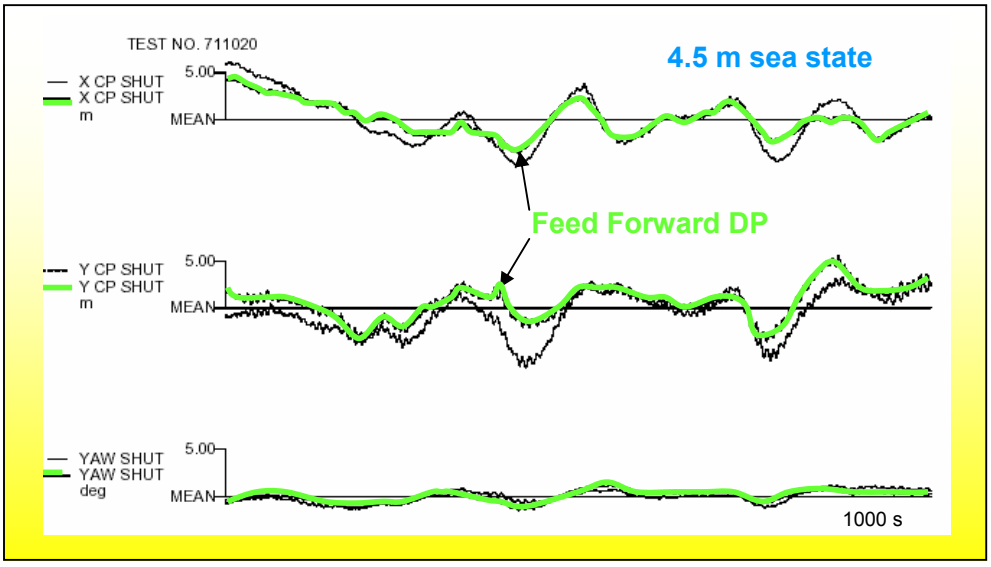
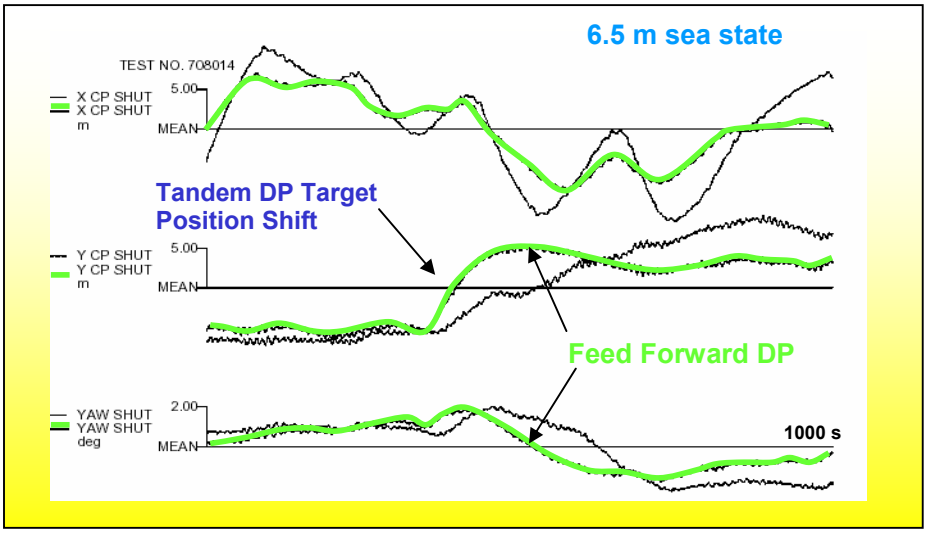


Figure 3: Result of using RTEFE for Offloading DP in a 6.5 m sea state (comp'd with conventional DP)



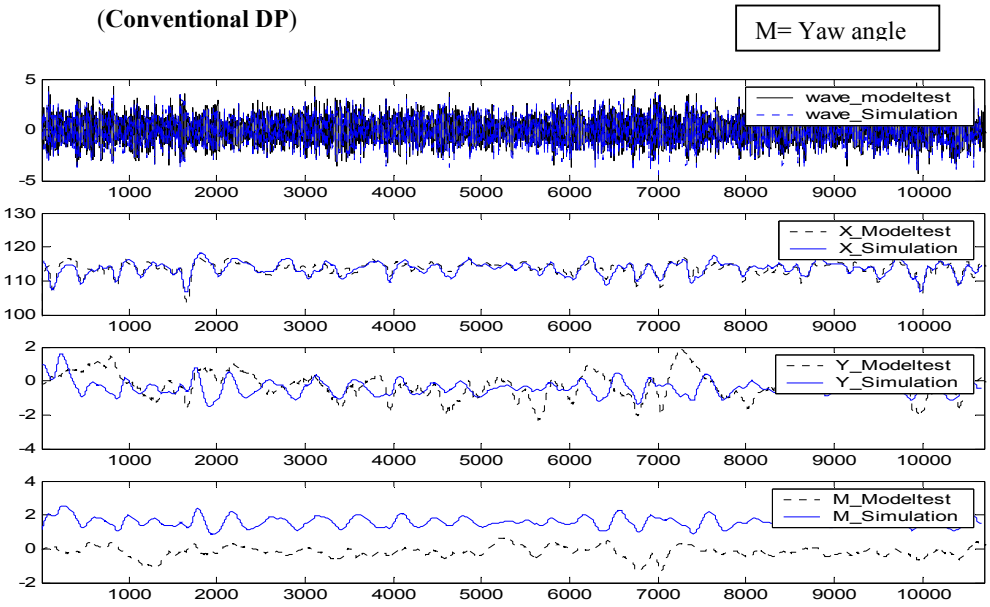
Finalisation of the software and RTEFE interfacing (Work Package No. 5)

Time domain simulations were used to investigate an improved method of wave drift moment estimation and of optimisation of the feed back in combination with RTEFE.
The simulation method, using the MARIN program DP-Master was validated against the model tests, and a typical example of correspondence is shown in Figure 4.

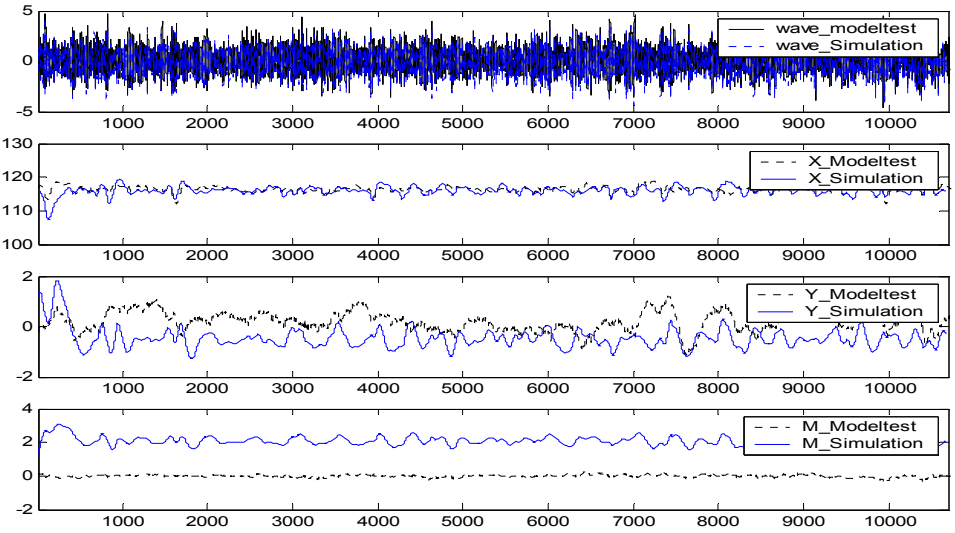
Figure 4: Comparison of DP model test with DP simulation

Note: The simulations and tests are for collinear conditions. Heading setpoint in the test is 0 degr (bow into the waves) and for the simulation 1.5 degr. (a small offset for stability, which explains the differences in Y and M)

(**Conventional DP**)



(**RTEFE DP**)



With the good correlation obtained a number of variations was investigated and it appeared that the use of a somewhat 'softened' feed forward output of the RTEFE improved positioning and power consumption. I.e an RTEFE output set to half the sum of the mean drift force plus the actual estimate gave good results by creating a smoother output to the thrusters (thereby reducing the increase in thruster wear that was reported by Rolls Royce Marine from abt 30% to less than 10%).

Additionally, the efficiency of the offloading operation of a North Sea Shuttle tanker was investigated by carrying out Monte Carlo simulations over a 4 year weather history. It showed that the increased position capability that may be achieved with the use of the RTEFE reduces average annual loading time by some 10%, mainly achieved in the winter half year.

Management (Work Package No. 6)

The tasks in this WP comprised Project Coordination and RTD management. The Coordination task consisted of regular Project Steering Committee meetings and the issueing of bi-monthly progress reports.
The RTD management comprised technical overview and progress control, within MARIN and between the participants. By keeping a constant and compact manpower allocation for the various tasks to be carried out, the scope and thereby the cost of RTD management coud be kept below the initial estimates.

3.2 List of deliverables

- Confidential Deliveries
  - Equipment installation Report WP2
  - Preliminary Measurement Report WP2
  - Design Method Report, Part 1 WP1
  - Thesis Mr O.J. Waals WP3
  - DP Interface Final WP1
  - Thruster blade bearing wear WP1
  - Full scale measurements dB WP2
  - Software code for 2 methods WP3
  - Specifications for Software WP3
  - Model test Data Report WP4
  - Final Summary Report of Model and Full Scale Tests WP5
  - Model test video WP4
- Further confidential deliverables March 2004
  - Gusto report on DP re-design WP1
  - DP FPSO evaluation WP1

- Publishable deliveries
  - Technological Implementation Plan WP6
  - Executive Publishable Summary WP6
  - Publishable Synthesis Report WP6
  - Various paper publications: see "*References"*

4. Assessment of Results and Conclusions

The work for the various Work Packages has satisfactorily been carried out. As shown in Table 1 a number of the originally described tasks has been slightly reduced due to the need to adapt the scope to the reduced budget available.

Table 1: Comparison of planned activities and actual work accomplished as per 30 november 2003

Task ID and description	Completion % and cost %		Remark
1. Desk studies	100	80	Not on critical path
2. RTEFE development	100	100	
3. Full Scale measurements	80	80	Delayed start, but duration has been reduced to maintain the critical path and save cost
4. Model tests	100	100	
5. Finalisation	100	90	
6. Management	90	90	Scope of RTD management was reduced to save cost

In the DP-JIP the following **objectives** were set:

1. Develop an effective and reliable method to estimate in real time the wave drift forces acting on a vessel, with an accuracy of +/- 20%
2. Test the estimation method and validate against model tests and simulations
3. Obtain with the use of the estimate an improved positioning control method (RTEFE) that provides significant positioning improvement
4. Obtain through the use of the RTEFE some 20% reduction in fuel consumption

The investigations allowed to draw conclusions about the improvements in vessel positioning that can be achieved and preliminary conclusions could be drawn on potential for fuel saving and enhanced efficiency of operation.

1. A reliable estimate of the longitudinal and transverse drift forces could be obtained, which generally met the 20% accuray bandwidth target
2. The moment estimate was generally too low, but in view of the oscillatory character of the yaw moments on passage of a wave group, the low estimate was better for DP station-keeping than trying to follow the oscillation peaks
3. The correlation between model tests and full scale measurements was investigated and although quantitative differences were found –most of which could be explained- the qualitative agreement was good. So, predicted improvements from the use of the RTEFE at model scale may be expected to also apply for full scale conditions.
4. Positioning improvements between 25% and 40% on standard deviation of position error could be obtained, the smaller improvements applying to sea conditions with significant directional spreading. More important though is the significant reduction that is achieved in the large excursion events. Together with the decision support that can be provided to the DP operator from the use of RTEFE (i.e. improved heading setpoints and better information about DP capability in the prevailing conditions), this would imply a higher station keeping limit in harsh weather.
5. A thruster bearing wear investigation showed that increased thurster activity leads to proportionally increased wear, i.e in the order of 10-15%
6. Power consumption from the use of the RTEFE method could be estimated from measured thrust in the model tests and was calculated in time domain simulations. The model tests suggested at most a minor 4-5% improvement in a North Sea climate.
7. In the simulations, optimised use of the RTEFE was investigated. The results were that:
   - A peak limited and ‘softened’ RTEFE output to the DP controller resulted in good positioning improvements and comparable power consumption to conventional DP
   - The thruster activity was much less than in the original RTEFE, which means that the wear in thruster bearings increases less than 5% with respect to conventional DP, which has no operational consequences.
8. For an offloading tanker in a harsh area, the operational benefits due to the RTEFE positioning improvement could be estimated by carrying out Monte Carlo Simulations in historic weather. An average annual reduction of loading time of 10% was found, largely obtained in the winter season.
9. The total DP power consumption of a North Sea Shuttle tanker could attain a reduction of 5-10%, given the direct and indirect improvements due the use of the RTEFE.

So, it may be concluded that the objectives have reasonably been met. For the effect on fuel consumption further investigations are being carried out, using an energy flow simulation package. In this model the energy consumers in the vessel are being modeled and the simulated operation includes the power management system of the vessel.

In connection with the Technological Implementation Plan, the consortium members and the sponsoring companies are presently preparing a follow-up demonstration project.

Glossary

DP = Dynamic Positioning: a method to keep ships on station in wind, waves and current by using a position reference sytem and feed-back control of thrusters, propellers and rudders.

Thruster= Propulsion unit on a ship, generating force in a controllable way as to direction and magnitude

Feed-Forward= Method to use measurement of wind, wave or current force to steer the thrusters

References

A number of publications has been prepared or is in preparation in which the DP-JIP project is announced and/or in which –with consent of the Project Steering Committee- partial results are made public. In extentio:

Ref 1: A.B. Aalbers, R.F. Tap and J.A. Pinkster: “An Application of Dynamic positioning Control using Wave Feed Forward”. International Journal of Robust and Non-linear Control 2001; Vol. 11, pp 1207-1237. J. Wiley & Sons

Ref 2: R.R.Th. van Dijk and A.B. Aalbers: “What happens in Water:The use of Hydrodynamics to Improve DP”. Dynamic Positioning Conference, Marine Technology Society, Sept 2001, Houston

Ref 3: O.J. Waals, A.B. Aalbers and J.A. Pinkster: “Maximum Likelihood Method as a means to estimate the directional wave spectrum and the mean wave drift force on a dynamically positioned vessel”. 21st Offshore Mechanics and Arctic Engineering Conference (OMAE), June 2002, Oslo