Comparison of motion measurement devices : ADIS and MotionPak II
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SUMMARY

This report describes the processes involved in comparing two inertial motion sensors, the MotionPak II and ADIS, used in model testing in the Offshore Engineering Basin (OEB) at the Institute for Ocean Technology (IOT). Seakeeping trials carried out in 2004 on the Roberts Sisters II fishing vessel were duplicated at model scale in the summer of 2009. Analysis was performed on the model data using a series of Generalized Experiment Control and Data Acquisition Package (GEDAP) command procedures to generate plots comparing the motions tracked by each device. Included in this report is a discussion of the results as well as recommendations regarding the feasibility of replacing the MotionPak II with the ADIS.

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This report describes the processes involved in comparing two inertial motion sensors, the MotionPak II and ADIS, used in model testing in the Offshore Engineering Basin (OEB) at the Institute for Ocean Technology (IOT). Seakeeping trials carried out in 2004 on the Roberts Sisters II fishing vessel were duplicated at model scale in the summer of 2009. Analysis was performed on the model data using a series of Generalized Experiment Control and Data Acquisition Package (GEDAP) command procedures to generate plots comparing the motions tracked by each device. Included in this report is a discussion of the results as well as recommendations regarding the feasibility of replacing the MotionPak II with the ADIS.

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1.0 INTRODUCTION

This report details an analysis of data collected in the Offshore Engineering Basin in the summer of 2009. Seakeeping trials were run on a 10.667 scale model, IOT761, in an attempt to correlate with full scale tests run in 2004 on the Roberts Sisters II fishing vessel. Specifically, a comparison of two inertial motions sensors, the Analog Devices Inertial Sensor (ADIS) and the MotionPak II, located aboard the model scale vessel. The purpose of this report is to offer a recommendation on the possibility of replacing the MotionPak II with the ADIS module. Detailed descriptions of the analysis procedure as well as results in each direction of motion are included as well.

2.0 PROJECT BACKGROUND

The Fishing Vessel Safety Project is a part SafetyNet Initiative designed to understand risks and dangers involved with workers in a marine environment. It encompasses five seakeeping trials and three model tests. This report will cover specifically one seakeeping trial and one model test. Safety is a growing concern in the offshore industry, especially in Newfoundland and Labrador, and this initiative aims to recommend viable practises and policies to prevent injury or fatalities. In 2004 seakeeping trials were carried out 10 nm east of St. John's on the Roberts Sisters II fishing vessel. A model was constructed at a 10.667 scale of the RSII and tested in an attempt to simulate the seakeeping trials in the Offshore Engineering Basin (OEB).

3.0 DESCRIPTION OF DEVICES

The sensors used for testing on the model are forms of micro electrical mechanical systems (MEMS) and both have the capability for six degrees of freedom (6DoF) motion sensing. They use different types of measurement devices to track the yaw pitch, and roll rates as well as heave, surge, and sway accelerations. While the MotionPak II may be a sturdier, longer lasting, sensor the ADIS module is roughly 10 times cheaper. If the ADIS could track similar motions to the MotionPak II it could prove a viable and economical replacement.

	ADIS	MotionPak II
Dimensions	23mm x 23mm x 23mm	127mmx112.5mmx116mm
Operating Temp. Range	- 40 to 105°C	- 40 to 85°C
Rate Range	±300 deg/sec	±75 deg/sec
Acceleration Range*	±5g	±2.7g
Shock*	2000g	200g

*Where g=9.81m/s ²

3.1 Description of MotionPak II

The MotionPak II inertial sensor by Systron Donner contains three orthogonally mounted mircomachined quartz angular rate sensors and three silicon based accelerometers. These components contain no moving parts, which make the entire sensor “solid-state”. This adds to the sturdiness and reliability of the device. It has applications in many industries such as torpedo guidance, automotive testing, and antennae stabilization.

Figure 1: MotionPak II Module

3.2 Description of Analog Devices Inertial Sensor (ADIS)

The Analog Devices Inertial Sensor (ADIS) is composed of a triple axis gyroscope to track angular rates and a triple axis accelerometer. As the device collects data, it automatically conditions in input signal in order to give a smoother plot for easier viewing graphically. In model testing, the ADIS was used with the autopilot system that guided the model through the OEB on the desired path for each run. The ADIS collected real time data so that the steering module could autocorrect the model heading if necessary.

Figure 2: ADIS Module

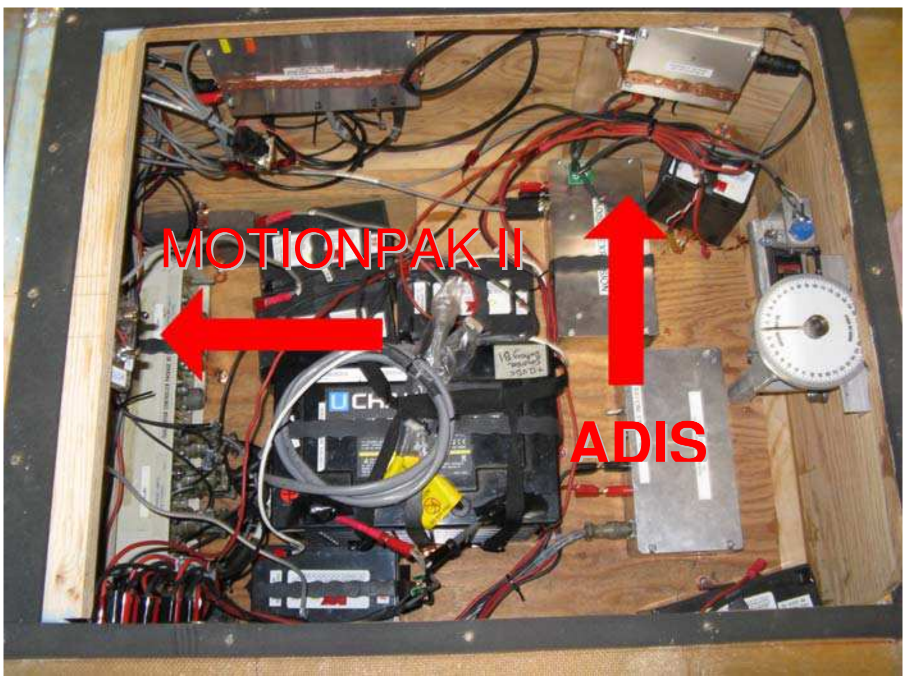

Figure 3: Locations of MotionPak and ADIS Inside of Model

4.0 ANALYSIS PROCEDURE

The analysis procedure consists of several command procedures which compare results obtained from the two different motion capture devices for 23 different combinations of parameters:

Speeds:	Trawling (4 Knots) / Cruising (8 Knots)
Sea Directions:	Bow / Beam / Quartering / Following
Wave Patterns:	Regular / Irregular
Anti-Roll Tank:	Filled / Empty

- The raw data from tests (.DAC file format) is split into the different channels required for analysis and converts data into full scale, (factor = 10.667)
- The MotionPak II Heave Acceleration channels as well as the ADIS Pitch Rate, Yaw Rate, and Surge Acceleration channels were multiplied by -1 in order to get a more accurate comparison of the MotionPak II and ADIS motions.
- Because the model is fixed, rotational speeds would differ at different areas on the model. In order to authentically compare the motions, the channels that track MotionPak II were translated to the position of the ADIS. Measurements were taken on the model to find the relative distances between the center of the MotionPak II and the center of the ADIS sensor inside of a housing. The dimensions of the ADIS sensor were taken from a data sheet. The calculations used are as follows:

  [Distance To Center of ADIS Box (Measured)]
  \+ [1/2 Length of ADIS Box (Measured)]
  \- [1/2 Length of ADIS Sensor (Data Sheet)]
  ____
  [Distance from Center of MPII to Center of ADIS Sensor]

- Values were then multiplied by the full-scale factor, 10.667 yielding:

-6.4901m	in the X Direction (Positive towards Bow)
+2.586 m	in the Y Direction (Positive towards Starboard)
+3.081 m	in the Z Direction (Positive towards Bottom)

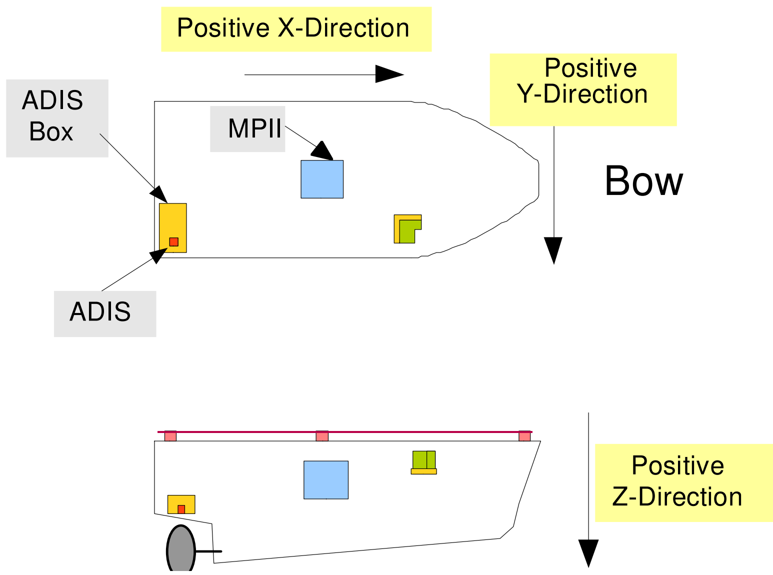

Figure 4: Relative Positions of MotionPak II and ADIS

The National Research Council utilizes a software system called the Generalized Experiment Control and Data Acquisition Package **(**GEDAP) to manage and analyze data collected experimentally. A command procedure located in this system called MOTIONPAK was used to derive total of 18 motion characteristics from the accelerations and rotational speeds measured by the sensors. Fast Fourier Transform (FFT) routines were used to integrate the linear accelerations and angular rates measured by both sensors. The procedure outputs displacements, velocities, and accelerations for surge, sway, heave, roll, pitch, and yaw. These results were combined with several other channels to return a total of 30 characteristics:

1.	MotionPak II Surge Displacement	(m)
2.	MotionPak II Surge Acceleration	(m/s^2)
3.	MotionPak II Sway Displacement	(m)
4.	MotionPak II Sway Acceleration	(m/s^2)
5.	MotionPak II Heave Displacement	(m)
6.	MotionPak II Heave Acceleration	(m/s^2)
7.	MotionPak II Yaw Angle	(deg.)
8.	MotionPak II Yaw Rate	(deg./s)
9.	MotionPak II Pitch Angle	(deg.)
10.	MotionPak II Pitch Rate	(deg./s)
11.	MotionPak II Roll Angle	(deg.)
12.	MotionPak II Roll Rate	(deg./s)
13.	Shaft Speed	(RPS)
14.	Rudder Angle	(deg)
15.	QUALSYS Pitch Angle	(deg)
16.	QUALSYS Roll Angle	(deg)
17.	Forward Speed	(knots)
18.	South Center Wave Probe	(m)
19.	ADIS Surge Displacement	(m)
20.	ADIS Surge Acceleration	(m/s^2)
21.	ADIS Sway Displacement	(m)
22.	ADIS Sway Acceleration	(m/s^2)
23.	ADIS Heave Displacement	(m)
24.	ADIS Heave Acceleration	(m/s^2)
25.	ADIS Yaw Angle	(deg.)
26.	ADIS Yaw Rate	(deg./s)
27.	ADIS Pitch Angle	(deg.)
28.	ADIS Pitch Rate	(deg./s)
29.	ADIS Roll Angle	(deg.)
30.	ADIS Roll Rate	(deg./s)

- Channels 1-12 (MotionPak II) were plotted against channels 19-30 (ADIS) and cropped to a reasonable time frame for analysis.
- Some plots required tarring in order to get the most precise data curves for comparison. Tarring was required when all the values for ADIS were either lower or higher than the values for MotionPak II. This process involved using a GEDAP procedure STAT1 to obtain the mean values from the channels for ADIS and MotionPak II. Next, another command procedure, TRANSFORM1 was used to translate the data by the negative

value of the mean. This made the mean value zero for both data curves and yielded a much closer comparison for cases where tarring was applicable.

5.0 RESULTS

The analysis procedure led to some varying results. Comparisons in certain motion directions yielded very different results than comparisons carried out with other directions. This is possibly due to several sources of error in both the model testing and analysis procedure. Because of the automatic filtering by the ADIS module, it was more difficult to compare the accelerations tracked by both devices. The raw data from the MotionPak II signal was very noisy in comparison to the signal conditioned ADIS. However, when the plots were cropped to a suitable time frame, the line created by ADIS follows the general motion of the MotionPak II curve. For the purposes of this report, each motion characteristic is compared separately. Results of every run carried out in model testing are included in appendix A.

5.1 Comparison of Heave Motions

The MotionPak II and ADIS tracked both the frequency and amplitude of displacement near perfectly. ADIS amplitudes were slightly smaller than MotionPak II in runs at trawling speed (4 knots) as well as cruising (8 knots) in regular wave patterns. Amplitudes in irregular waves at the same speeds had no particular pattern for inconsistencies; at some points ADIS was smaller in amplitude than MotionPak II and at some points it was higher. This is illustrated in Figure A 1-2 of appendix A These discrepancies were very small however and almost negligible. The filtered ADIS data plotted well against the noisy MotionPak II data in heave accelerations. As shown in Figure A3 for regular waves and Figure A 4 for irregular, the general line created by the MotionPak II data is followed fairly well by the ADIS data.

5.2 Comparison of Surge Motions

The comparisons for surge displacements returned results with some major discrepancies. For some cases, such as Figure A 5 both the frequency and amplitude of displacement were the same in both devices. In most other runs the ADIS amplitude was lower than MotionPak II. As shown in Figure A 6 the frequency of displacement in regular wave patterns matches very well, but the amplitudes of the motions are lower in ADIS. Results with irregular wave patterns (Figure A 7) were similar, but not as extreme as those in regular patterns. A few runs had issues with mismatched frequencies, however in most runs the ADIS amplitudes were not as large as those in MotionPak II. Illustrated in Figure A 8-9, ADIS and MotionPak II tracked accelerations in surge similarly for both regular and irregular wave patterns. The conditioned ADIS signal follows the basic pattern created by the MotionPak channel.

5.3 Comparison of Sway Motions

The sway plots are very similar to the comparisons done in the surge direction with certain exceptions. Most runs resulted in matched frequencies but ADIS amplitudes smaller than MotionPak (Figure A 11) The exception was found in some runs with regular wave patterns. As shown in Figure A 12, the amplitudes of the sway displacement in these cases were larger in ADIS than in MotionPak. Much like surge, the accelerations in this motion characteristic matched well between both devices.

5.4 Comparison of Roll Motions

The plots for all roll angle comparisons underwent tarring (described in Analysis Procedure) in order to get an accurate comparison of the sensor data. The angles tracked by both the MotionPak and ADIS matched nearly identically on all runs. As shown in Figure A 16-17 the two curves plot almost exactly identical for both regular and irregular waves. There was considerably more MotionPak noise in the rates for this comparison than in other angular motion but the ADIS curve follows the general MotionPak curve consistently. (Figures A 18-19)

5.5 Comparison of Pitch Motions

With ADIS and MotionPak, both the angle and angular rate matched very well. As illustrated in Figure A 20, the motions tracked very similarly in both regular and irregular wave patterns, with little discrepancy between the two. Several data curves had to be translated to a mean to of zero in order to get a more accurate comparison. This tarring led to a very small difference in the pitch angle curves between the two modules. The angular rate in this motion characteristic (Figure A 22-23) did not have the noise in MotionPak data that the accelerations in linear motions did.

5.6 Comparison of Yaw Motions

Some errors occurred when comparing the angles measured by both devices. Yaw angle comparisons seemed to vary between runs. For the most part, the yaw angle comparisons were very close. (Figure A 24). In several cases with regular waves there was slight mismatching with amplitude and positioning. Figure A 26 illustrates an example of a comparison where the ADIS read angles slightly lower than the MotionPak. Normally this error would be fixed with tarring but it was not effective in this situation. Yaw rates (Figure A 26-27) were plotted with little difference in amplitude or frequency between both devices.

6.0 CONCLUSIONS/RECOMMENDATIONS

For the most part, the ADIS measured very similar motions to the MotionPak II. Comparisons in heave, pitch, roll, and yaw resulted in very consistent motion curves while comparisons in the surge and sway directions yielded varying results. These results may be due to the signal conditioning that the ADIS module carries out as it collects data. The MotionPak data is completely raw and unfiltered so perhaps the consistent discrepancy in amplitude for surge and sway could be due to errors in filtering. Another possible source of error could be in the placing of the ADIS module. The propeller is located very close to the position of the ADIS module. Vibrations originating from the spinning propeller may have added noise to the ADIS reading which, when conditioned, may have caused the discrepancies in surge and sway displacement.

With further analysis in correcting sources of error occurred in this comparison, the ADIS could prove an economical and worthwhile replacement for the MotionPak II.

APPENDIX A

Figures Referenced in Report

APPENDIX A: FIGURES REFERENCED IN REPORT

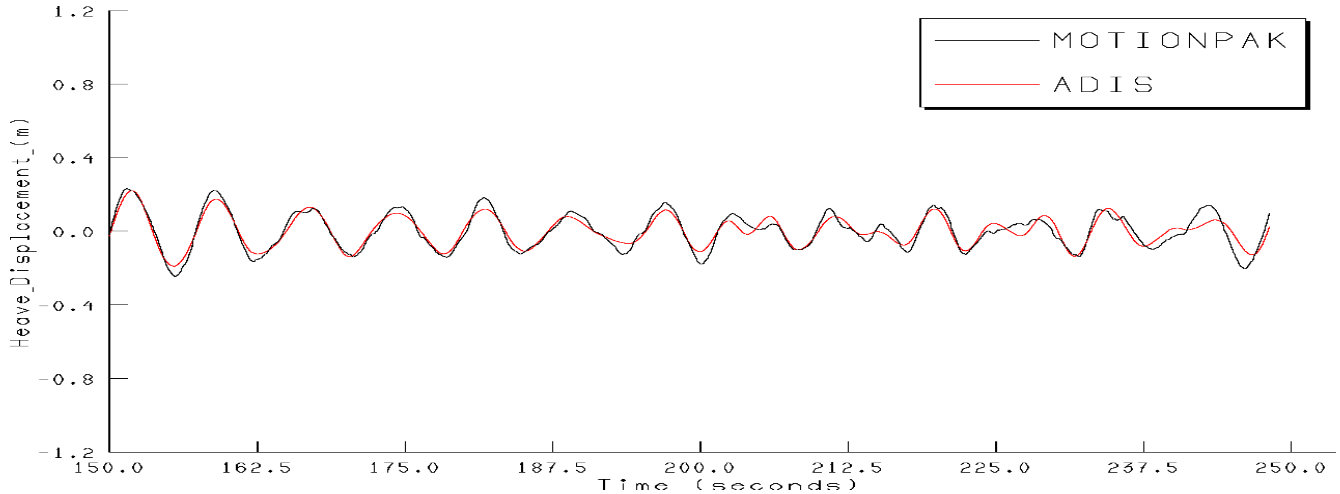

Figure A 1: Heave Displacement, Regular Wave Patterns, Quartering Waves, Cruising Speed, ART Filled

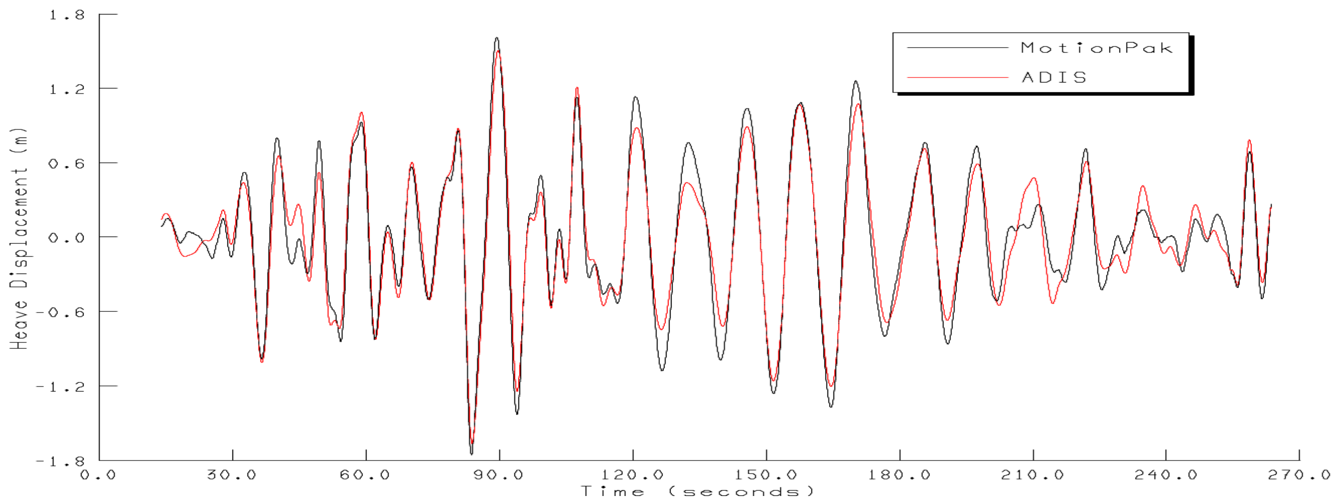

Figure A 2: Heave Displacement, Irregular Wave Patterns, Quartering Waves, Cruising Speed

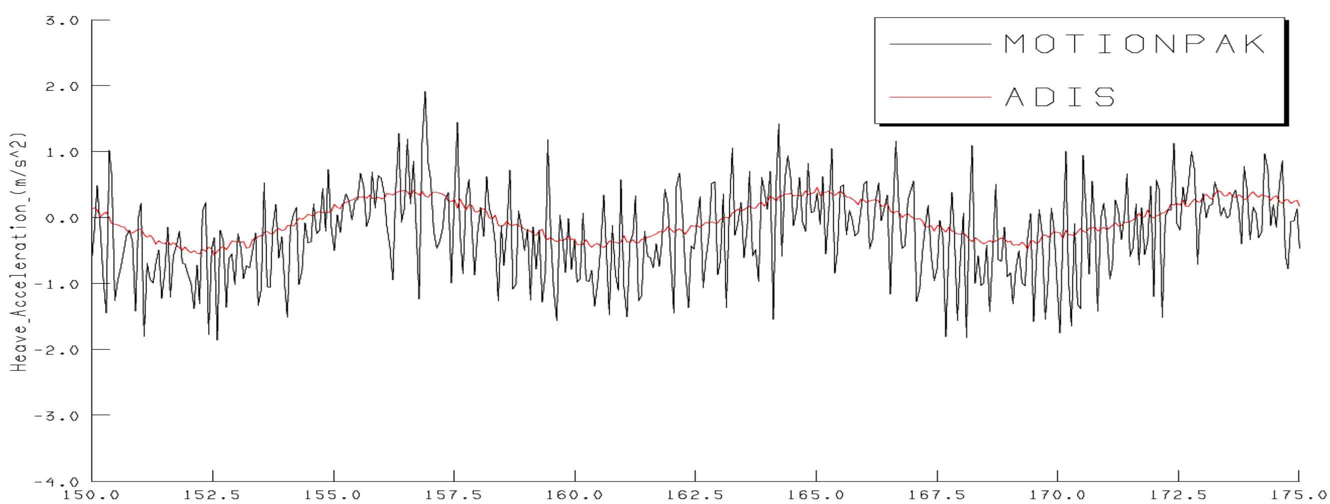

Figure A 3: Heave Acceleration, Regular Wave Patterns, Quartering Waves, Cruising Speed, ART Filled

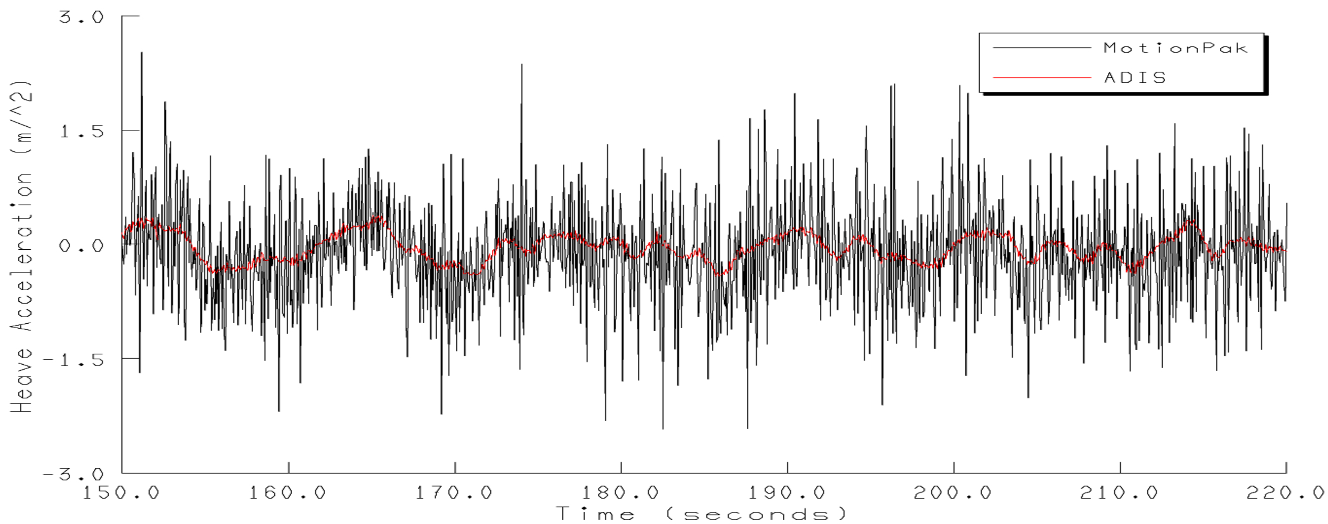

Figure A 4: Heave Displacement, Irregular Wave Patterns, Quartering Waves, Cruising Speed

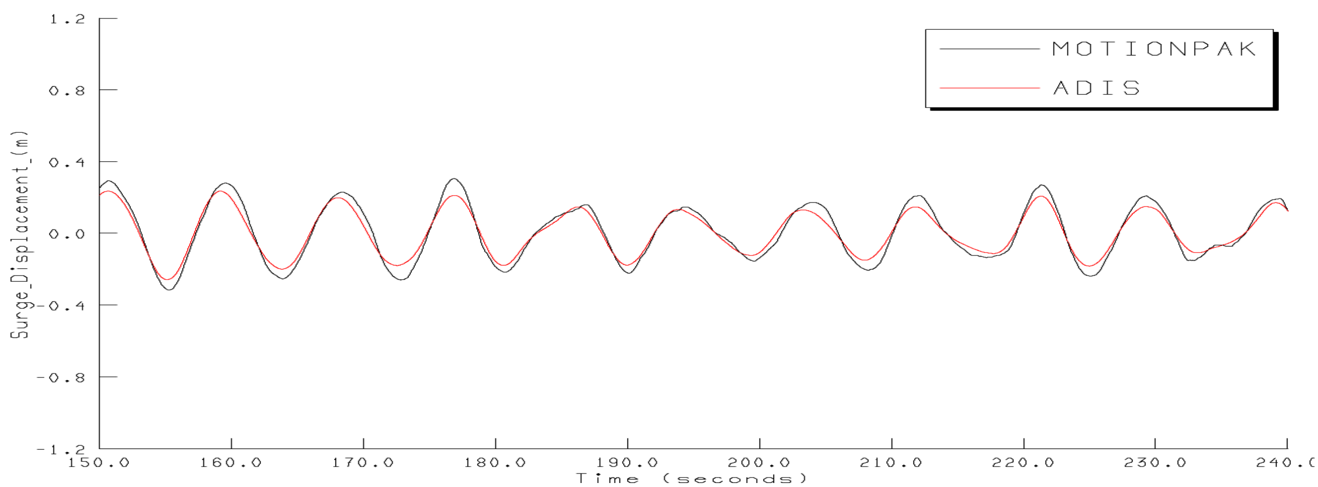

Figure A 5: Surge Displacement, Regular Wave Patterns, Quartering Seas, Cruising Speed, ART Empty

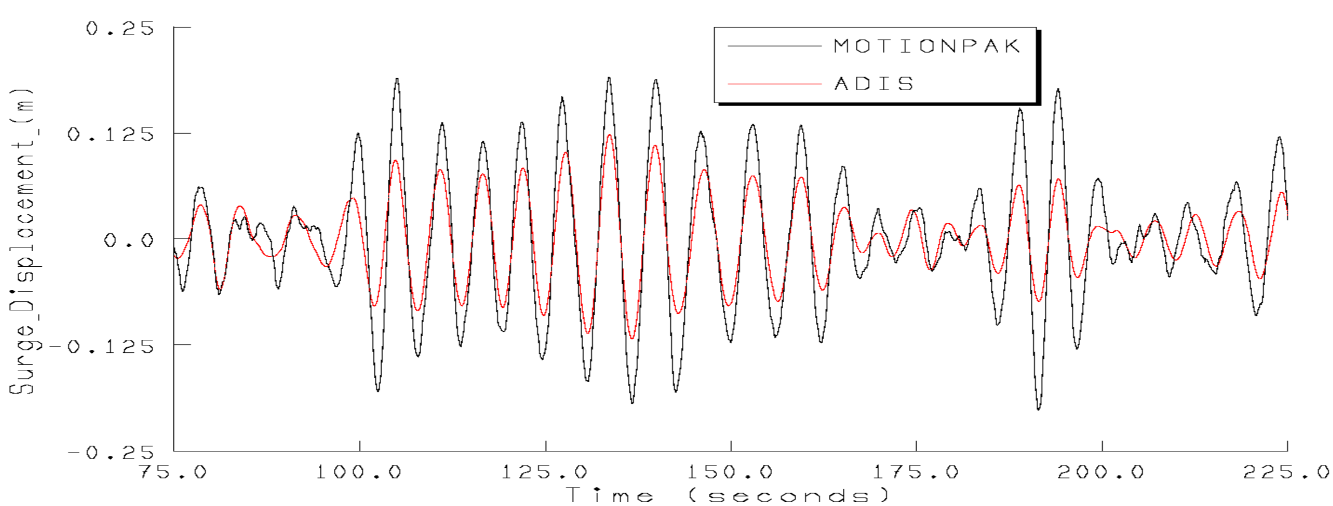

Figure A 6: Surge Displacement, Regular Wave Patterns, Beam Seas, Trawling Speed, ART Empty

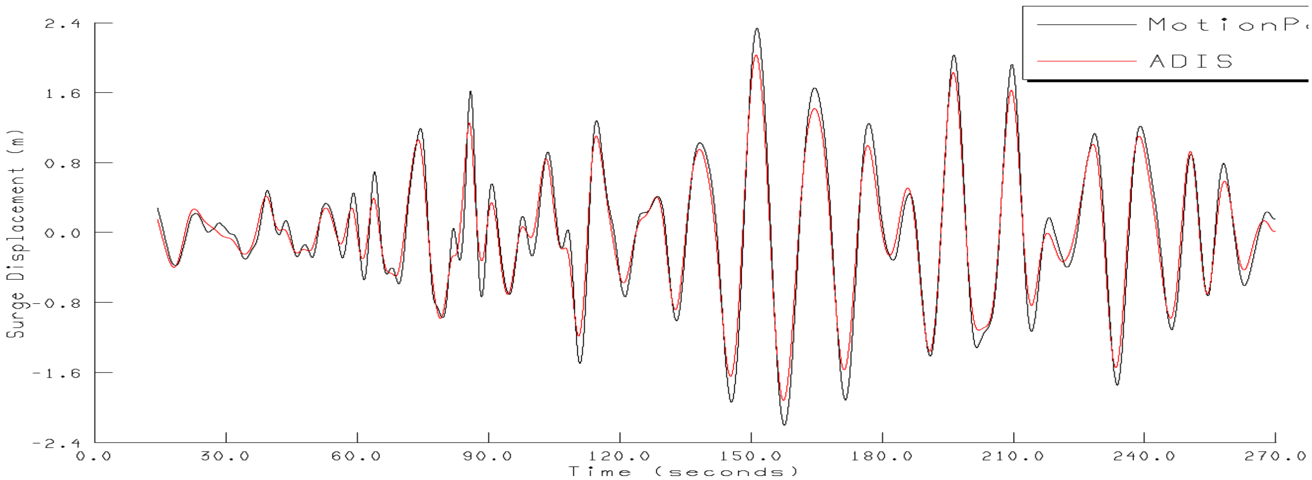

Figure A 7: Surge Displacement, Irregular Wave Patterns, Following Waves, Trawling Speed

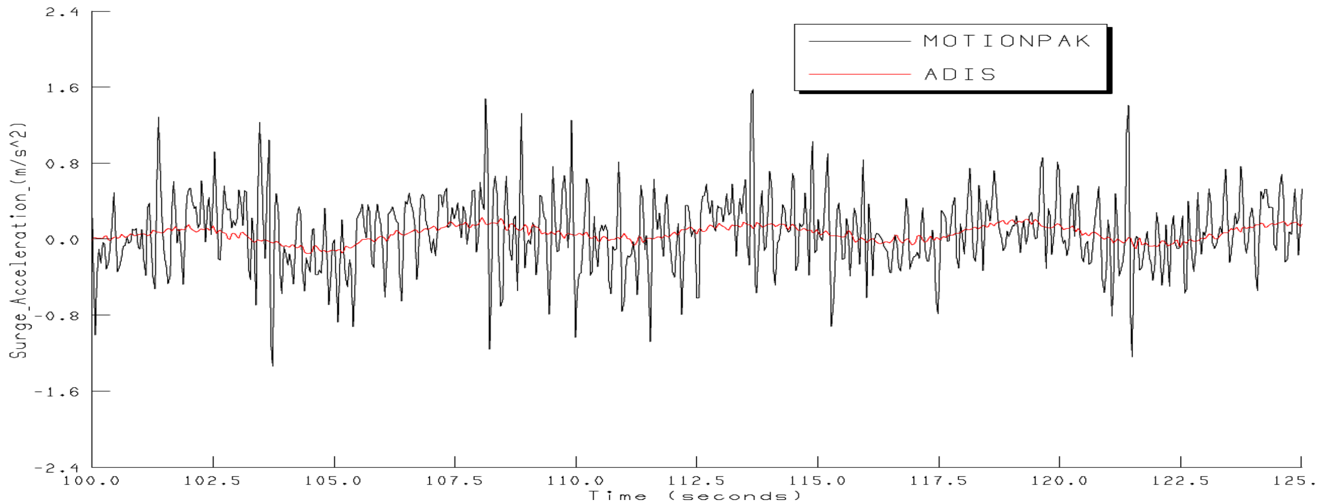

Figure A 8: Surge Acceleration, Regular Wave Patterns, Quartering Seas, Cruising Speed, ART Empty

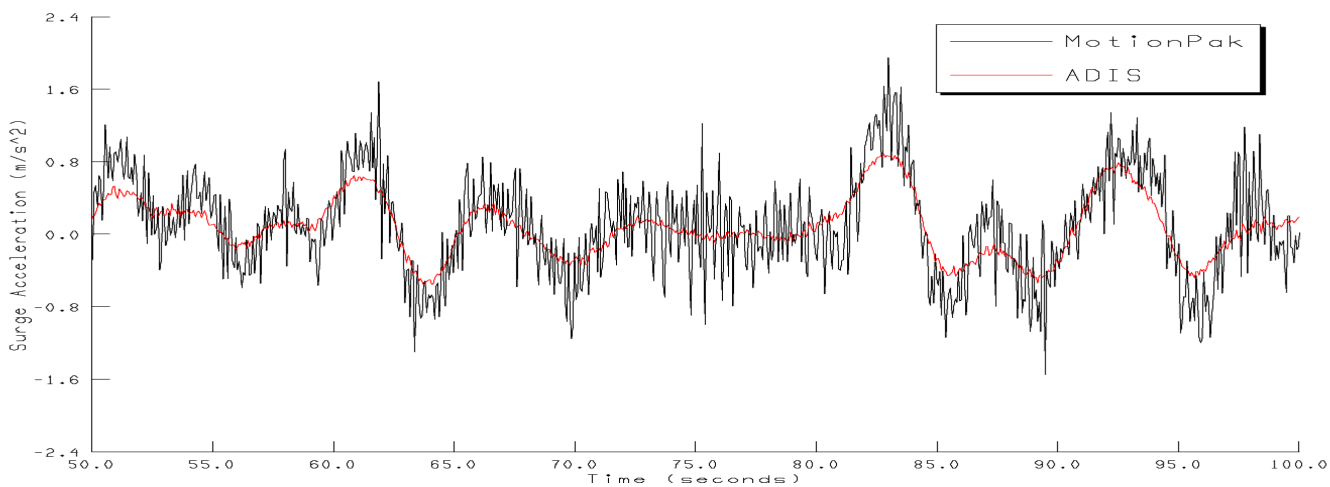

Figure A 9: Surge Displacement, Irregular Wave Patterns, Following Waves, Trawling Speed

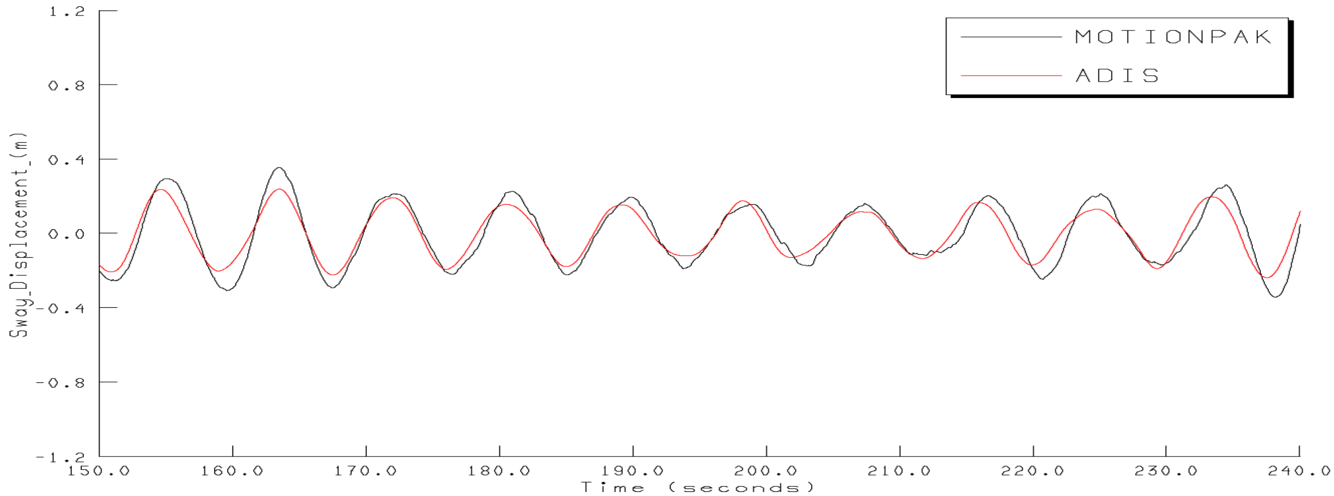

Figure A 10: Sway Displacement, Regular Wave Patterns, Beam Seas, Cruising Speed, ART Filled

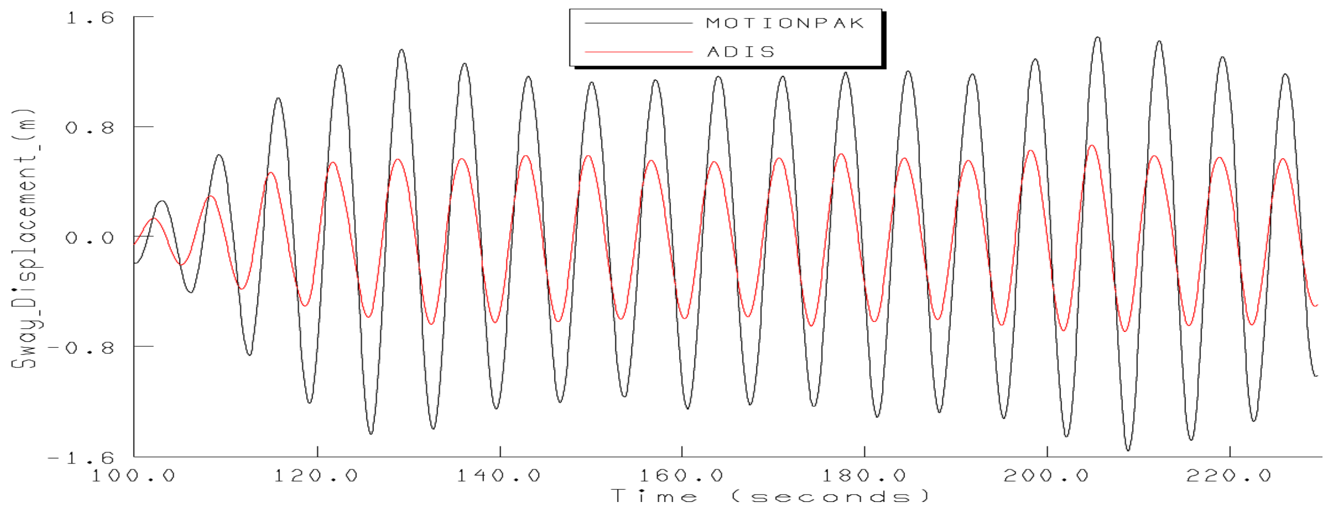

Figure A 11: Sway Displacement, Regular Wave Patterns, Beam Seas, Cruising Speed, ART Empty

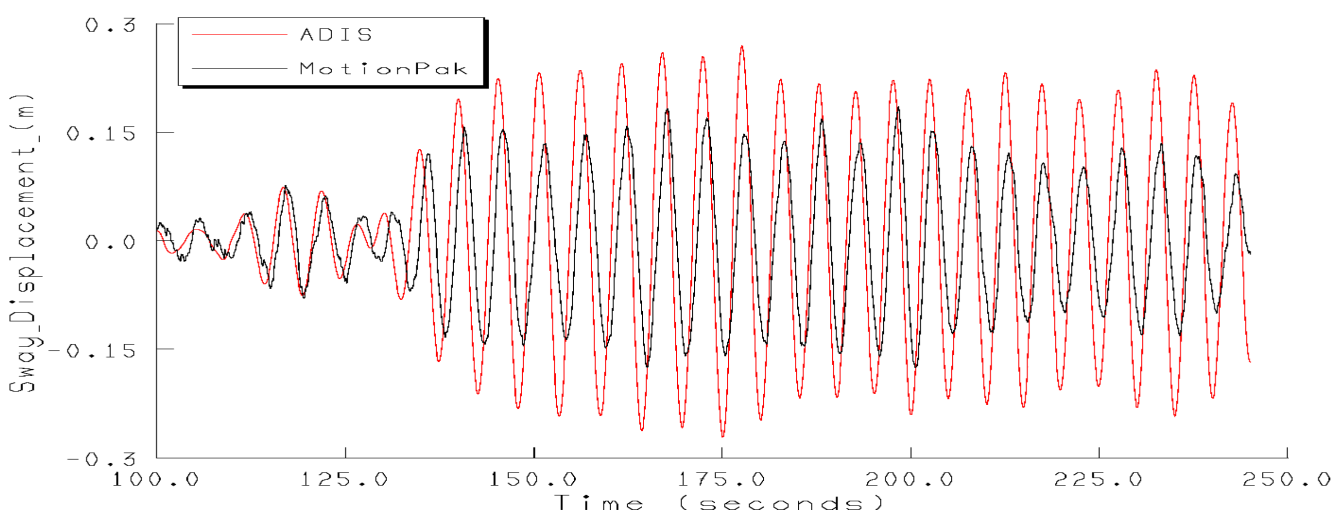

Figure A 12: Sway Displacement, Regular Wave Patterns, Beam Seas, ART Filled, Cruising Speed

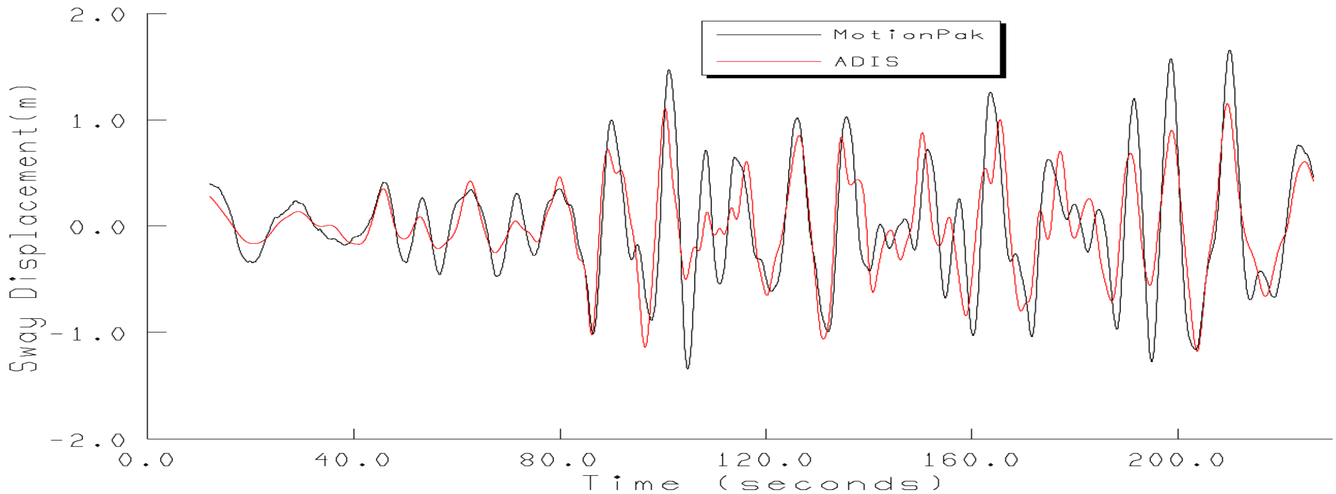

Figure A 13: Sway Displacement, Irregular Wave Patterns, Bow Seas, Cruising Speed

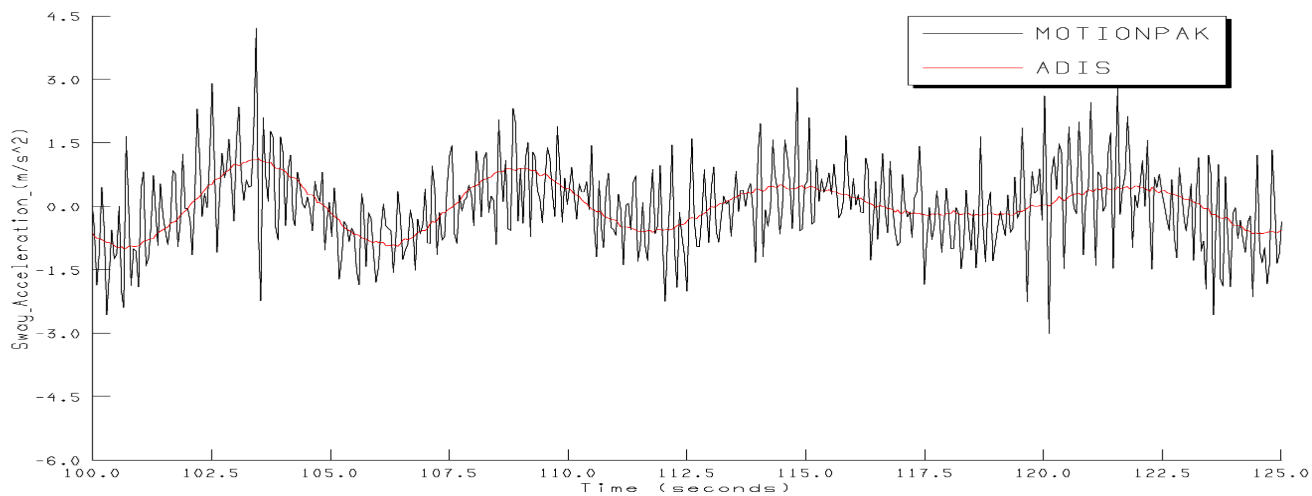

Figure A 14: Sway Acceleration, Regular Wave Patterns, Quartering Seas, Trawling Speed, ART Empty

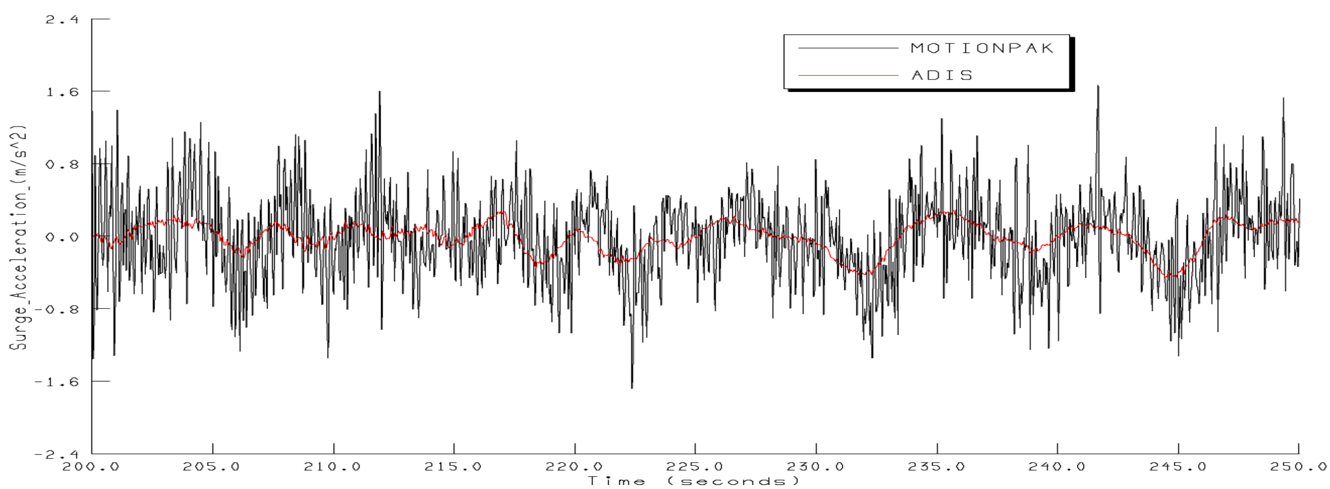

Figure A 15: Sway Acceleration, Irregular Wave Patterns, Beam Seas, Trawling Speed

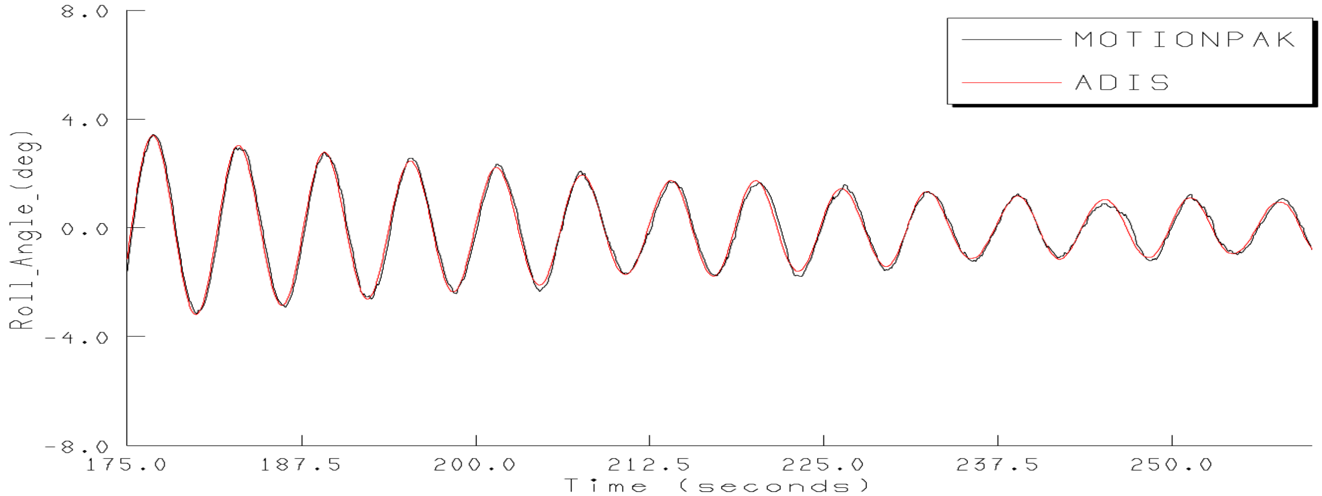

Figure A 16: Roll Angle (Tarred) , Regular Wave Patterns, Quartering Seas, ART Empty, Cruising Speed

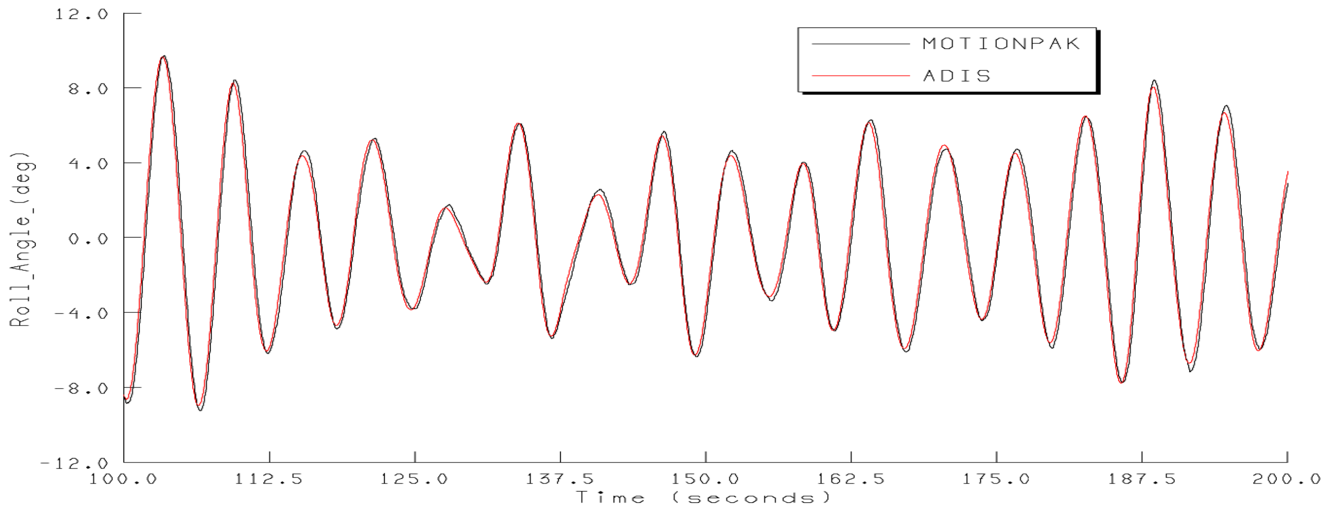

Figure A 17: Roll Angle (Tarred), Irregular Wave Patterns, Head Seas, Cruising Speed

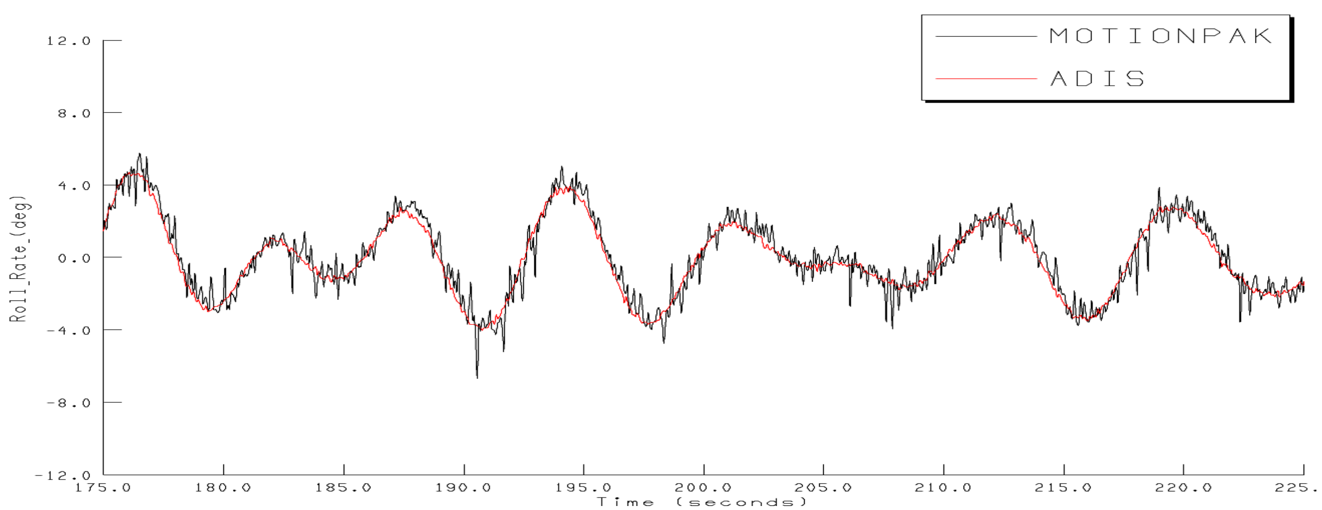

Figure A 18: Roll Rate, Regular Wave Patterns, Quartering Seas, ART Empty, Cruising Speed

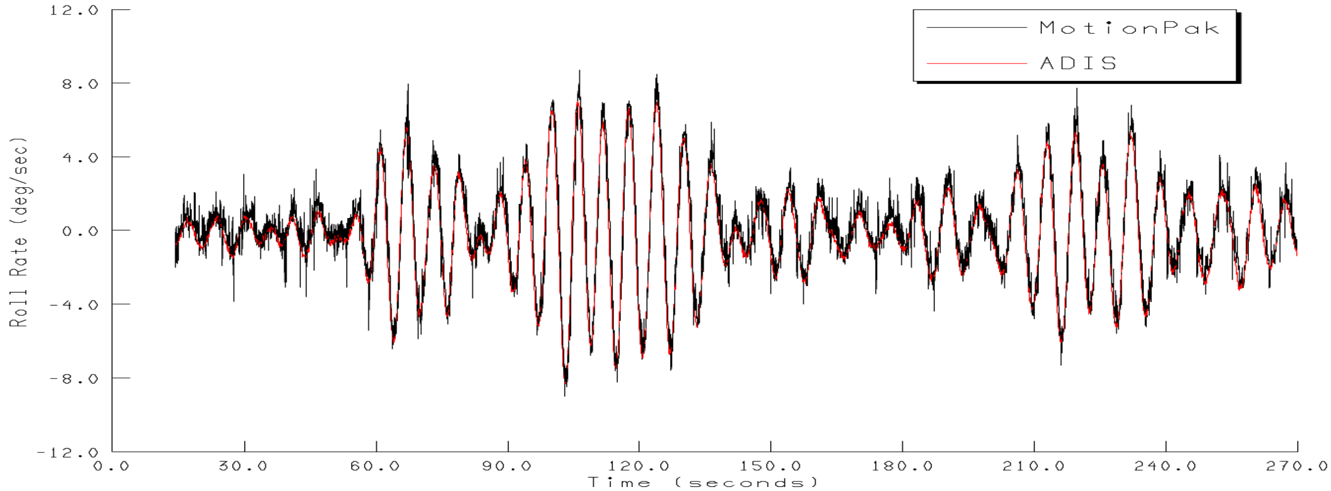

Figure A 19: Roll Rate, Irregular Wave Patterns, Following Seas, Trawling Speed

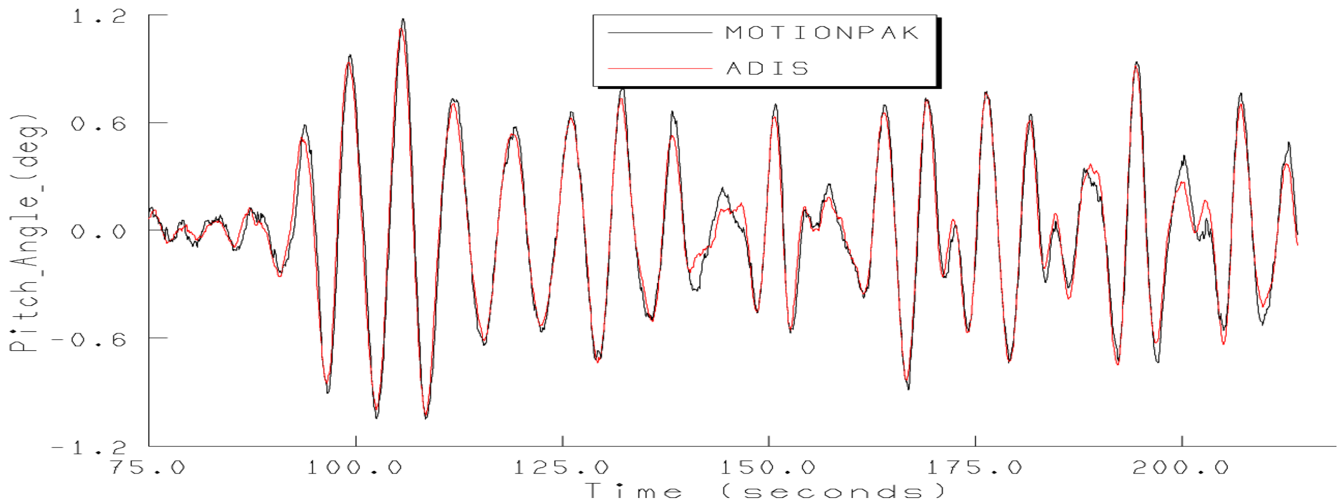

Figure A 20: Pitch Angle, Regular Wave Patterns, Beam Seas, ART Filled, Cruising Speed

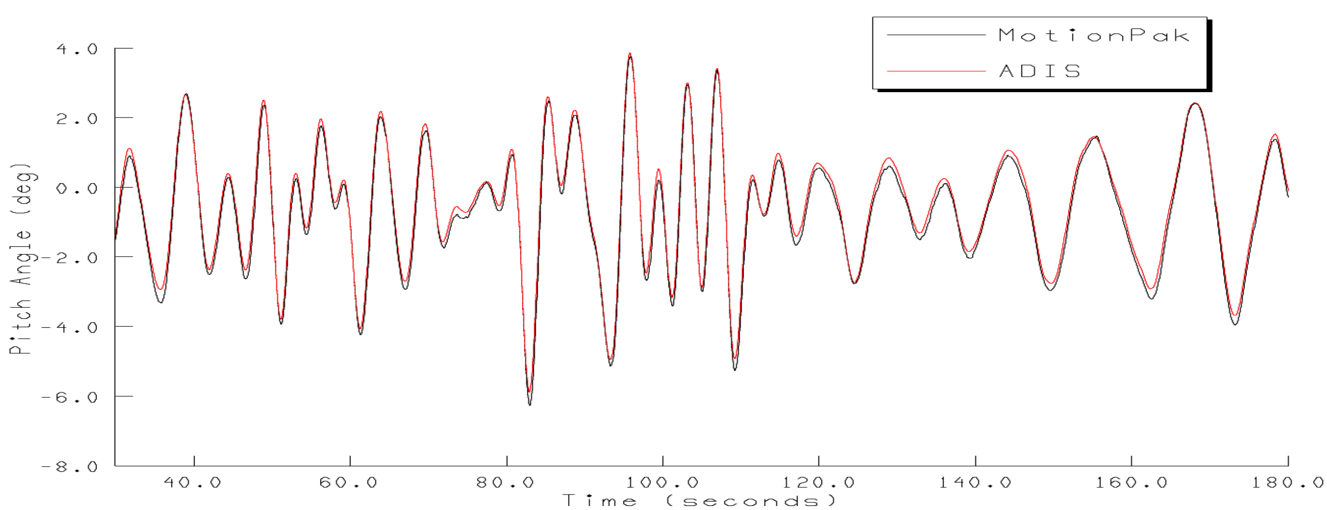

Figure A 21:Pitch Angle, Irregular Wave Patterns, Quartering Seas, Cruising Speed

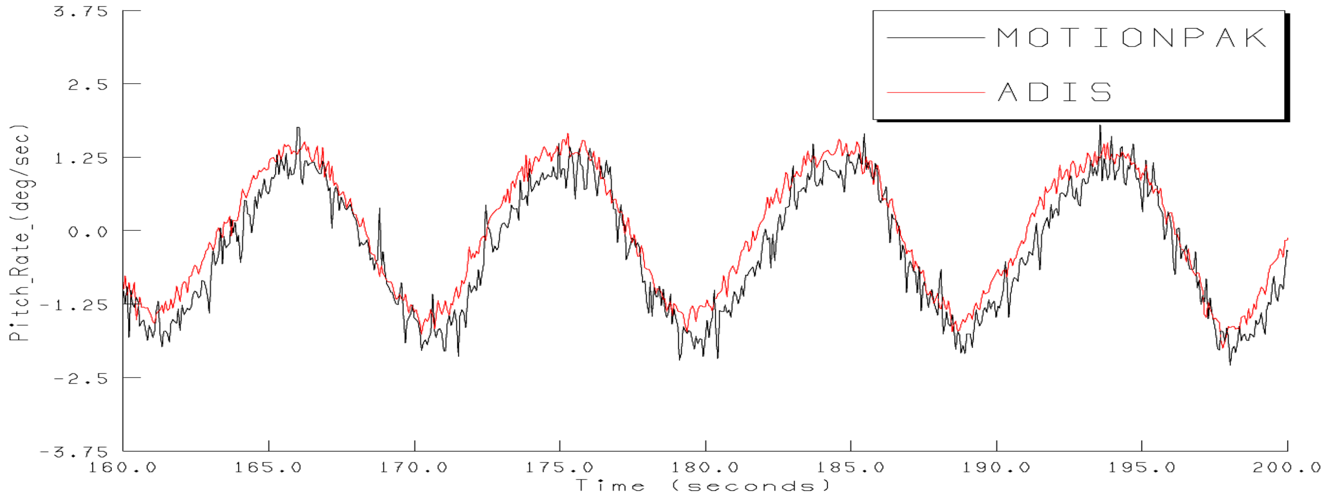

Figure A 22: Pitch Rate, Regular Wave Patterns, Quartering Seas, ART Empty, Cruising Speed

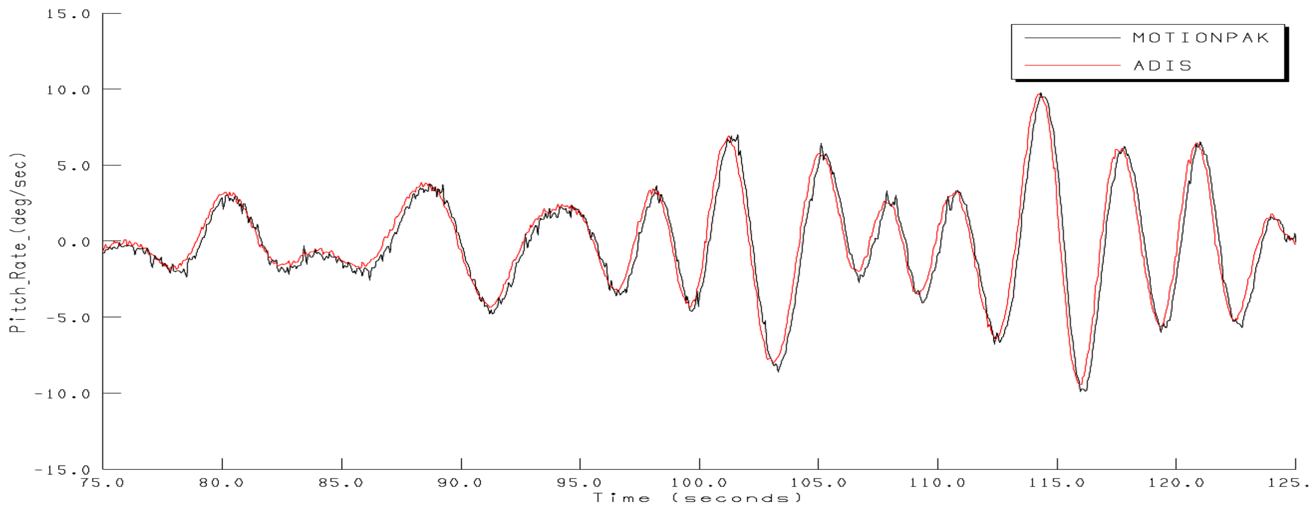

Figure A 23: Pitch Rate, Irregular Wave Patterns, Head Seas, Cruising Speed

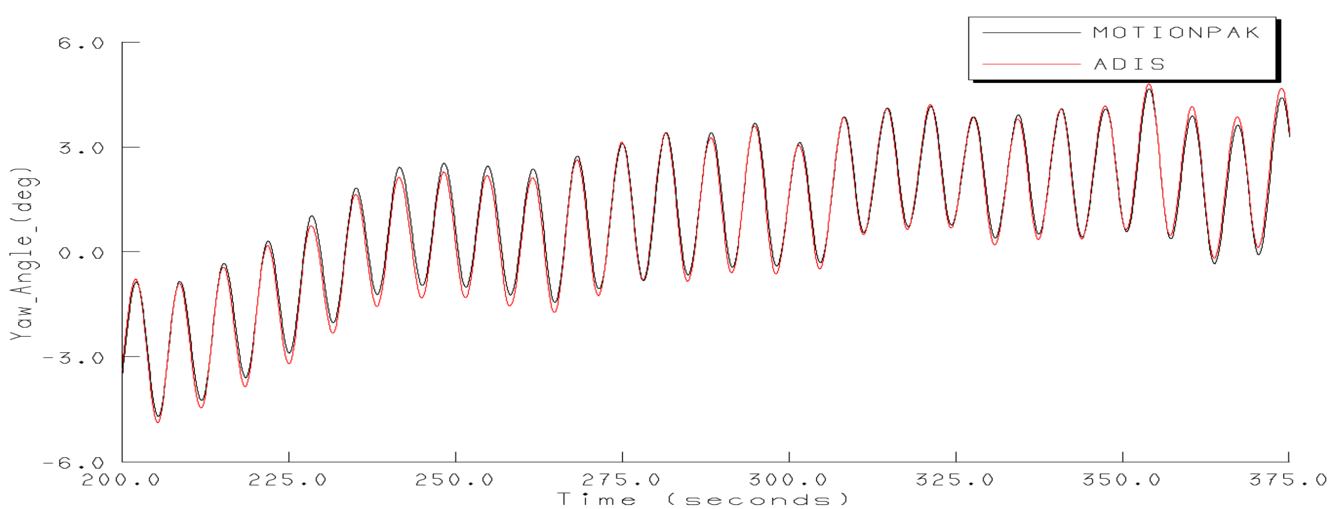

Figure A 24: Yaw Angle, Regular Wave Patterns, Quartering Seas, ART Filled, Trawling Speed

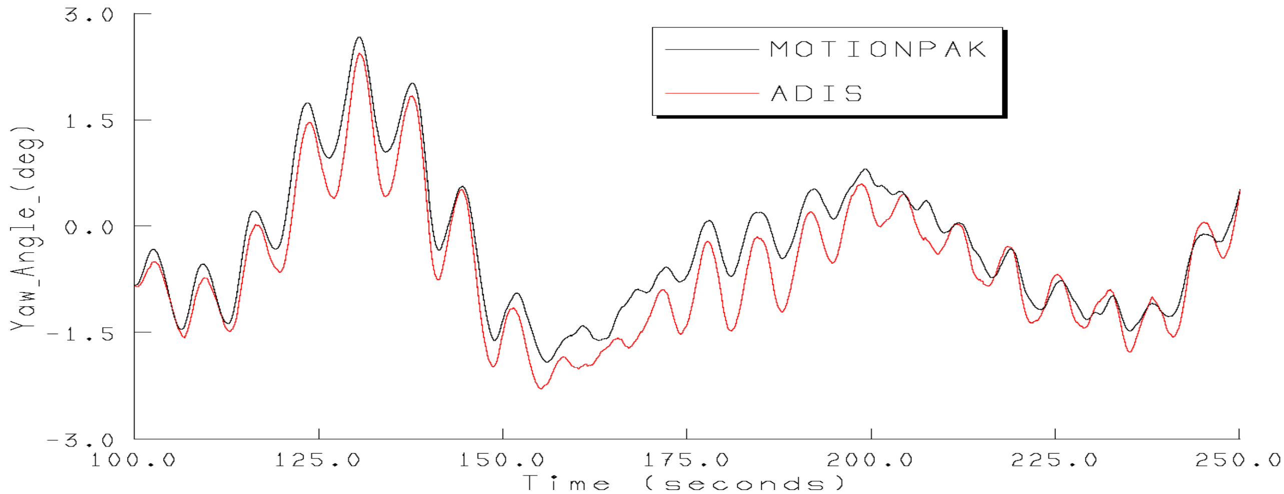

Figure A 25: Yaw Angle, Regular Wave Patterns, Beam Seas, ART Empty, Trawling Speed

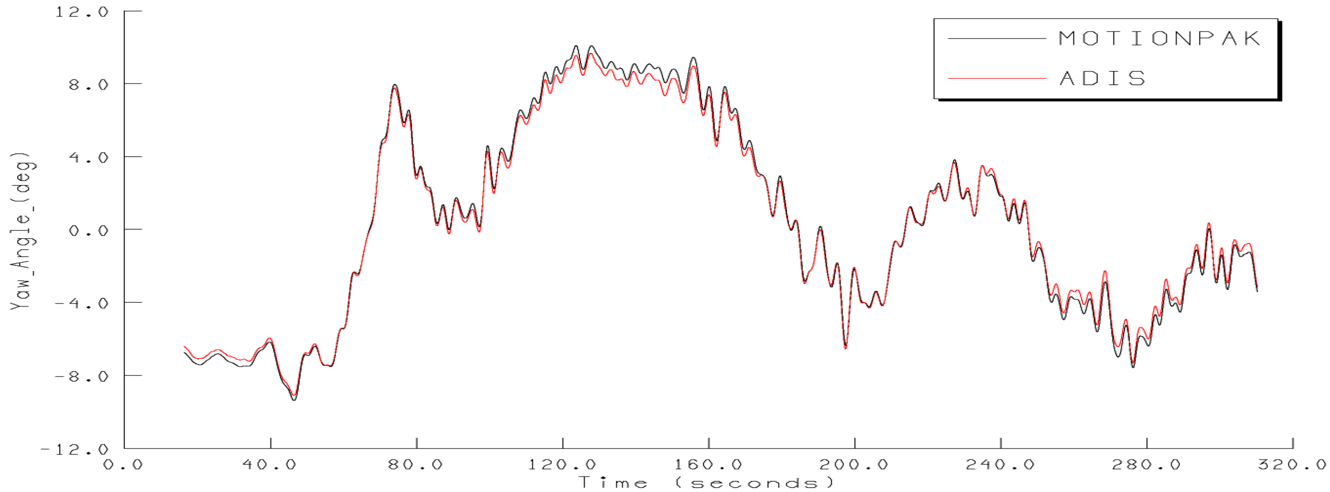

Figure A 26: Yaw Angle, Irregular Wave Patterns, Beam Seas, Trawling Speed

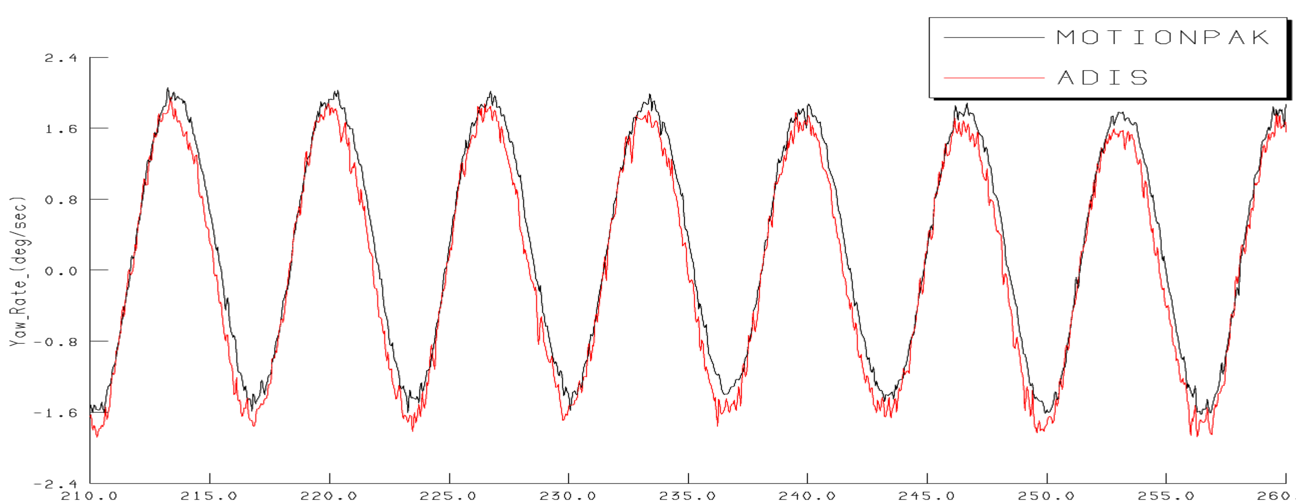

Figure A 27: Yaw Rate, Regular Wave Patterns, Quartering Seas, ART Filled, Trawling Speed

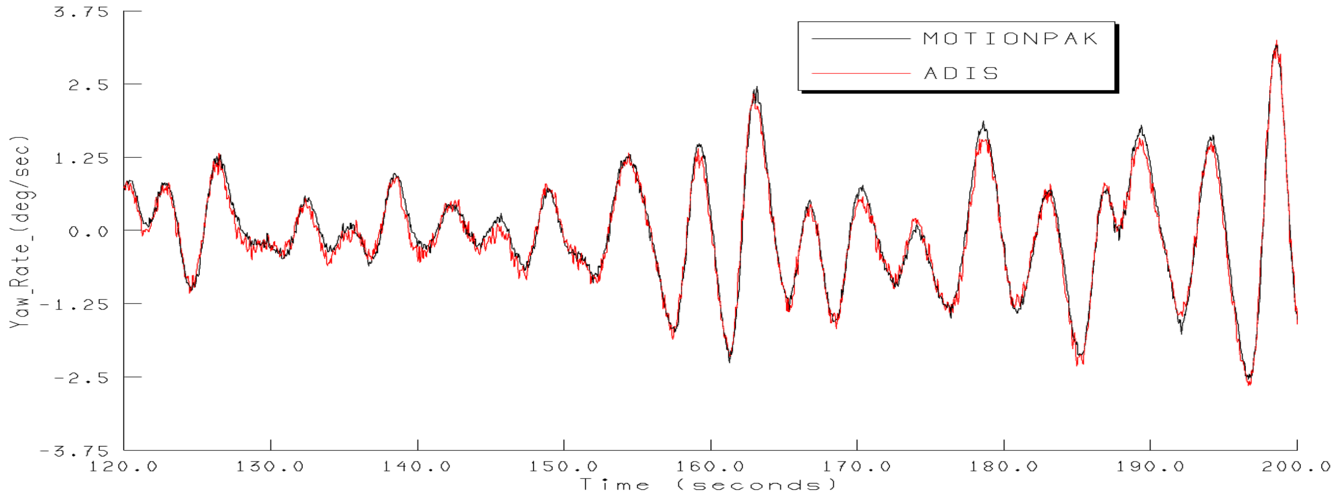

Figure A 28: Yaw Rate, Irregular Wave Patterns, Beam Seas, Trawling Speed

APPENDIX B

Digital Copy of All Figures with Legend

HOW TO NAVIGATE FIGURES ON DISK

- ALL ROLL ANGLE PLOTS WERE TARRED TO A MEAN VALUE OF ZERO FOR BETTER COMPARISON.
- GRAPHS ARE IN .EPS FORMAT. USE GSVIEW OR ADOBE ILLUSTRATOR TO VIEW

REGULAR WAVE PATTERNS:

Eg. (2) (4)

CASE4_3_SEQ2_PITCH_ANGLE

(1) (3) (5)

1: Case Number:

CASE	WAVE HEADING	ANTI-ROLL TANK	SPEED
1	Beam	Empty	Trawling (4 knots)
2	Beam	Filled	Trawling (4 knots)
3	Beam	Empty	Cruising (8 knots)
4	Beam	Filled	Cruising (8 knots)
5	Quartering	Empty	Trawling (4 knots)
6	Quartering	Filled	Trawling (4 knots)
7	Quartering	Empty	Cruising (8 knots)
8	Quartering	Filled	Cruising (8 knots)

2: Sub Case Number: Indicates which run (of 7) was compared.

3: Sequence: Indicates which sequence was used for comparison. Several sequences merged together make one full length run comparable to seakeeping trials.

4:Direction: Direction of motion (Surge, Sway, Heave, Roll, Pitch, or Yaw).

5:Motion Characteristic:

Displacement	_D
Acceleration	_ACCEL
Angle	_ANGLE
Angular Rate	_RATE

IRREGULAR WAVE PATTERNS:

Eg.

(2) (4)

ART_TBEAM_SEQ1_HEAVE_D

(1) (3) (5)

1: Anti Roll Tank : ART indicates anti-roll tank is filled. If not included, anti-roll tank is empty.

2: Speed and Wave Heading: First letter indicates speed: Drift, Trawling (4 Knots), or Cruising (8 Knots). The second word represents wave heading (Beam, Bow Following, Head, and Quartering).

3: Sequence: Indicates which sequence was used for comparison. Several sequences merged together make one full length run comparable to seakeeping trials.

4:Direction: Direction of motion (Surge, Sway, Heave, Roll, Pitch, or Yaw).

5:Motion Characteristic:

Displacement	_D
Acceleration	_ACCEL
Angle	_ANGLE
Angular Rate	_RATE