Maneuvering model tests of the USCGC Healy (Model 546) in level ice

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/8895022
Laboratory Memorandum (National Research Council of Canada. Institute for Ocean Technology); no. LM-2006-03, 2006

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Laboratory Memorandum

LM-2006-03

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DOCUMENTATION PAGE

REPORT NUMBER	NRC REPORT NUMBER	DATE		
LM-2006-03		March 2006		
REPORT SECURITY CLASSIFICATION Unclassified		**DISTRIBUTION** Unlimited		
TITLE **MANOEUVRING MODEL TESTS OF THE USCGC HEALY (MODEL 546) IN LEVEL ICE**				
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PUBLICATION				
SPONSORING AGENCY(S) Institute for Ocean Technology, National Research Council, St. John's, NL				
IOT PROJECT NUMBER 42-2114-26 & 42-919-16		**NRC FILE NUMBER**		
KEY WORDS Manoeuvring; Model 546		**PAGES** 8, App. A	**FIGS.** 4	**TABLES** 6

SUMMARY

A complete set of resistance, propulsion, and manoeuvring model tests of the USCGC Healy (Model 546) were conducted in 2001 for correlation with the full-scale data collected during the sea trial of the same vessel conducted in the previous year (Frederking et al, 2001). Jones (2005) has reported the results of the resistance and propulsion portions of the model test series. This report, accompanying the fore-mentioned report, documents the result of the manoeuvring tests.

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ABSTRACT

A complete set of resistance, propulsion, and manoeuvring model tests of the USCGC Healy (Model 546) were conducted in 2001 for correlation with the full-scale data collected during the sea trial of the same vessel conducted in the previous year (Frederking et al, 2001). Jones (2005) has reported the results of the resistance and propulsion portions of the model test series. This report, accompanying the fore-mentioned report, documents the result of the manoeuvring tests.

ACKNOWLEDGEMENTS

Dr. Stephen J. Jones and Mr. Corwyn Moores conducted the model tests. Their contributions are gratefully acknowledged.

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MANOEUVRING MODEL TESTS OF THE USCGC HEALY (MODEL 546) IN LEVEL ICE

1.0 INTRODUCTION

A complete set of resistance, propulsion, and manoeuvring model tests of the *USCGC Healy* (Model 546) were conducted in 2001 for correlation with the full-scale data collected during the sea trials of the same vessel conducted in the previous year (Frederking et al, 2001). Jones (2005) and Jones and Lau (2006) have reported the results of the resistance and propulsion portions of the model test series. This report, accompanying the fore-mentioned report, documents the results of the manoeuvring tests.

2.0 USCGC HEALY

The *USCGC Healy* was launched on November 15, 1997, from Avondale Industries in New Orleans. She was delivered to the US Coast Guard on November 10, 1999, departed New Orleans on January 26, 2000, and proceeded north for extensive full-scale ice trials before arriving in Seattle on August 9, 2000.

The essential details of the *Healy* are shown in Table 1.

Table 1. Characteristics of *USCGC Healy*

Length, Overall	420 ft (128 m)
Beam, Maximum	82 ft (25 m)
Draft, Full Load	29 ft 3 in (8.9 m) at delivery
Displacement, Full Load	16,000 LT at delivery
Propulsion	Diesel Electric, AC/AC Cycloconverter
Generating Plant Drive Motors	4 Sultzer 12Z AU40S 2 AC Synchronous, 11.2 MW
Shaft Horsepower	30,000 Max
Propellers	2 fixed pitch, 4 bladed
Fuel Capacity	1,220,915 gal. 4,621,000 L
Speed	17 knots @ 147 RPM
Endurance	16,000 NM @ 12.5 knots
Icebreaking Capability	4.5 ft (1.4 m) @ 3 knots (continuous) 8 ft (2.44 m) Backing and Ramming
Accommodations	19 Officers, 12 CPO, 54 Enlisted, 35 Scientists, 19 Surge, 2 Visitors

The designed icebreaking capability of the *Healy* was for continuous icebreaking at 3 knots through 4.5 ft (1.37 m) of ice of 100 psi (690 kPa) strength. The full-scale trials were designed to test this capability.

2.1 Model Construction

Model 546 was constructed, in accordance with IOT's standard method, at a scale of 1:23.7. This scale was chosen so that we could use an existing set of propellers, namely our R-Class propellers 66L and 66R. The model's principal dimensions were:

Table 2. Particulars of Model 546

Overall length (LOA)	5.40 m
Length between perpendiculars (LBP)	5.10 m
Maximum beam	1.05 m
Depth at midships (D)	0.54 m
Design waterline (DWL)	0.36 m
Draft at even trim	0.37 m
Vertical C. of G. (VCG)	0.416 m
Displacement	1240 kg

A non-removable ice knife and two bossings, also non-removable, were fitted, together with the twin rudders and propellers. The model's lines plan is shown in Figure 1, the model is shown in the ice tank in Figure 2, and the stern arrangement is shown in Figure 3.

The manoeuvring tests were conducted at a friction coefficient of 0.034, corresponding to the high friction resistance tests conducted during the earlier phase (Jones, 2005). The ice density was maintained constant for two ice sheets (see Table 3, Sheets Healy17 and Healy18) at 867 ± 1 kg/m^3. For unknown reasons, one ice sheet (Healy16) had a higher density of 916 kg/m^3.

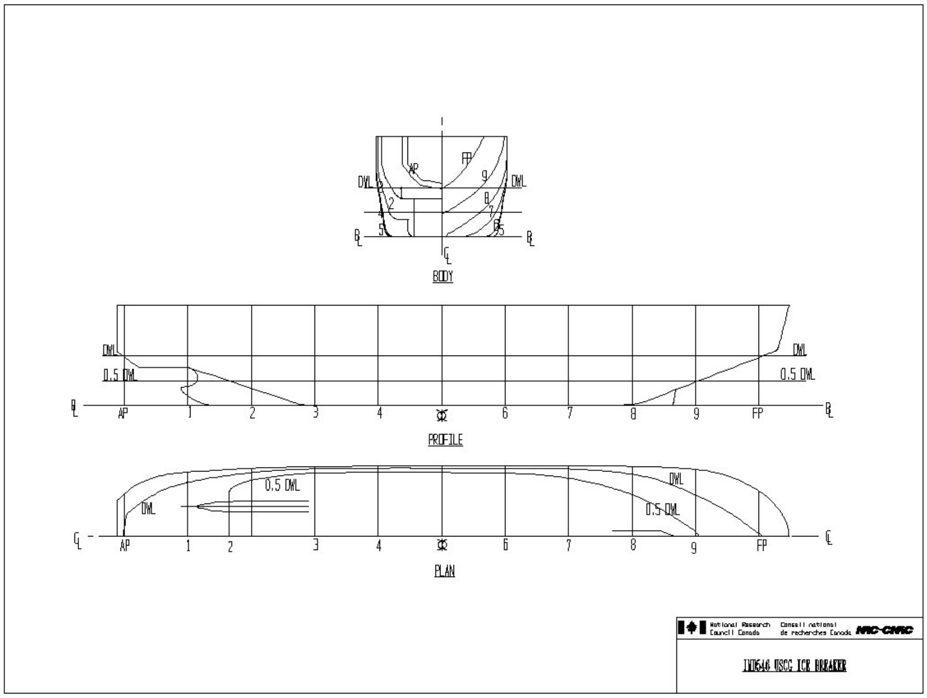

Figure 1. Lines plan of *USCGC Healy*

Figure 2. The *Healy* Model 546 shown in the ice tank

Figure 3. The stern arrangement of the *Healy* Model 546

3.0 TEST PLAN

A total of 8 self-propelled manoeuvring runs were conducted in the three ice sheets. In addition, open water bollard (overload tests carried out at zero speed) and shaft friction tests were conducted. Selected test conditions from the sea trial were duplicated for the manoeuvring tests and the turning diameters were measured. Performance predictions were then made and compared to the full-scale data previously collected. Table 3 shows details of the three ice sheets (given in full scale) that were used for the tests. Table 4 summarizes the test conditions and the results for each run. The first three runs were conducted at a target ice thickness of 75 cm and an ice strength ranging from 483 to 683 kPa. Shaft speed was varied from 9 to 10 to 12 rpm for these runs. The rest of the tests were conducted at a target ice thickness of 100 cm and an ice strength ranging from 417 to 1081 kPa. The rudder angle was kept at 30 degrees, the same as that used in the sea trial. The delivered power was kept at around 30,000 hp for most tests, which was consistent with the delivered power employed during the sea trial.

Table 3. Details of ice sheets used

Name	Date	Thickness (h)	Strength (σ_f)	Density	E/σ_f
		cm	kPa	Mg/m^3	
Healy16	23 Nov 01	74	562	0.916	1938
Healy17	27 Nov 01	100	749	0.866	2156
Healy18	29 Nov 01	97	667	0.868	1256

Table 4. Summary of test results

Run	Shaft rpm	Ice Thickness	Ice Strength	Turning Diameter	Rudder Angle	Power	HP
	rpm	cm	kPa	m	degree	kW	hp
Healy16-1	12	74.9	519	1321	29.6	22703	30433
Healy16-2	10	74.7	683	1329	29.9	14592	19560
Healy16-3	9	73.7	483	1337	30.4	9291	12455
Healy17-1	12	99.1	1081	1756	30.1	19551	26208
Healy17-3	12	100.7	417	1757	29.9	18546	24860
Healy18-1	12	96.7	621	1738	29.7	23698	31767
Healy18-2	12	97.4	751	1738	29.6	24228	32478
Healy18-3	12	97.6	628	1745	29.8	23630	31676

4.0 RESULTS

The detailed test log, the statistics, and the time histories for each test run are given in Appendix A. The ice sheet details are given in Appendix B.

4.1 Turning Circle Diameter

The channel profile was measured immediately after each test in one-meter intervals along the *x*-axis of the tank. The diameters corresponding to the inner and the outer channel edges were computed from a set of *x*-*y* coordinate pairs based on the least squared method. Details of the channel data are given in Appendix C. The turning diameter for each run is given in Table 4.

4.2 Power Level

The delivered power, $P_D = \pi \sum Q_i.rps_i$, was computed from the measured torque, Q_i , and the shaft's rps, rps_i, where the subscript *i* denotes the port or starboard propulsion, and then scaled up to full-scale. The delivered power is given in Table 4.

4.3 Full-Scale Sea Trials

The sea trial results have been reported in Frederking et al (2001). They are summarized in Table 5 for completeness.

Table 5. Summary of manoeuvring runs from the sea trials

Test	Ice Thickness	Power	Diameter	Dia./B	h/B	Dia/L
#	Cm	HP	m			
000420_1740	87	20780	1538	61.5	0.0348	12.0
000421_1348	95	28377	1538	61.5	0.0380	12.0
000421_1901	95	28830	1388	55.5	0.0380	10.8
000506_0015	140	23848	1666	66.6	0.0560	13.0
000515_1258	132.5	29254	2174	87.0	0.0530	17.0
000515_1400	132.5	29414	2128	85.1	0.0530	16.6
000515_1532	70.5	27222	470	18.8	0.0282	3.7
000515_1532	70.5	23234	528	21.1	0.0282	4.1
000515_1532	70.5	23440	1142	45.7	0.0282	8.9
000515_1615	70.5	29299	1274	51.0	0.0282	10.0
Average	96.4	26370	1385	55.4	0.0386	10.8

4.4 Comparison With Full-Scale Data

Figure 4 gives the non-dimensional turning diameter as a function of the non-dimensional ice thickness for the model and full-scale data. Despite the discrepancy in ice strength and power level tested between the model tests and sea trials, the model test data agree well with the sea trial data except for the three data points identified in the figure. These 3 outliers should be further investigated; they are possibly due to large-scale cracks in the ice sheet.

A multi-variance regression of the turning diameter conducted for the eight test runs as a function of ice thickness, ice strength, and the power level gives the following equation:

$$D = -2.502 + 21.67 h_i - 0.226 \sigma_f - 0.0095 P_D \qquad (1)$$

where D is the turning diameter (m), h_i is the ice thickness (cm), σ_f is the flexural strength of ice (kPa), and P_D is the power level (kW). The influences of ice thickness and delivered power on the turning circle are expected; however, it is not clear why increasing ice strength would result in decreasing turning diameter. In any case, the model test data show only a slight influence of ice strength on the turning diameter.

Full-scale turning circle diameters obtained from similar ice thicknesses, i.e., Runs 00515_1532, 00515_1615, 00421_1348, and 00421_1901, were selected for direct comparison with the model test data. Table 6 gives the turning diameters computed from Equation 1 and their corresponding full-scale measurement for the selected runs. Despite a small sample size, the comparison shows consistency.

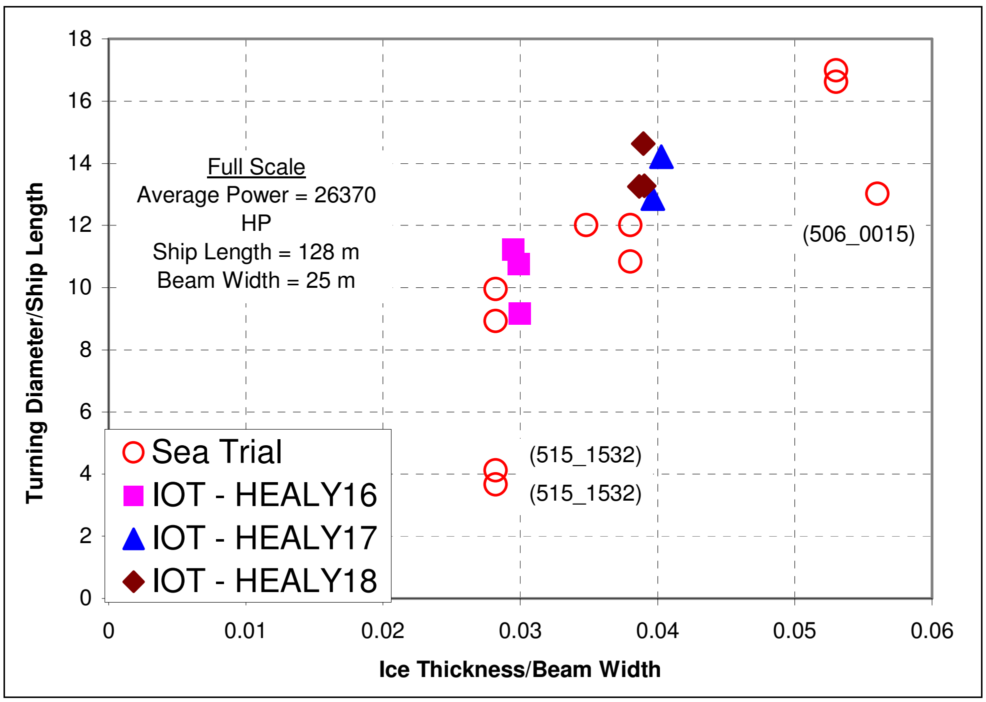

Figure 4. The non-dimensional turning diameter as a function of non-dimensional ice thickness for the sea trial and model test data

Table 6. Predictions from model test data (Equation 1) in comparison with selected full-scale data measurements

Test	Prediction from Model Scale Data (Equation 1)							Measured Average Dia./L
	Ice Thickness	Ice Strength	Average Power	Average Diameter, Dia.	Dia./B	h/B	Dia./L	
#	Cm	kPa	HP	m				
00515_1532 & 00515_1615	70.5	300	26370	1208	48.3	0.0282	9.4	9.4
00421_1348 & 00421_1901	95	262	28600	1726	69.0	0.038	13.5	11.4

5.0 DISCUSSIONS AND CONCLUSION

An analysis of the *USCGC Healy* manoeuvring tests data showed a good correlation between the model tests and the sea trial results. Multi-variance regression was performed with the model test data and the result compared with selected full-scale measurements. The turning diameter obtained during the model tests was the same in one case and slightly larger than its counterpart measured at sea trial in another case. The three outliers associated with the sea trial results (identified in Figure 4) warrant closer re-examination of these data points. The hull friction (0.034) used in the model tests was slightly lower than the target of 0.05. The effect of this discrepancy was not incorporated in the analysis.

6.0 REFERENCES

Frederking, R., Kubat, I., and G. Timco (eds.), 2001. *Proceedings of POAC '01*, National Research Council of Canada, Ottawa, Vol. 2, p.891-973.

Jones, S.J., 2005. "Resistance and propulsion model tests of the USCGC Healy (model 546) in ice," Institute for Ocean Technology Report LM-2005-02, National Research Council of Canada, St. John's.

Jones, S.J., and Lau, M., 2006. "Propulsion and Manoeuvring Model Tests of the *USCGC Healy* in ice and correlation with full-scale," *International Conference and Exhibition on Performance of Ships and Structures in Ice*, July 16-19, 2006, Banff, Alberta.

Appendix A
Test log, data statistics and time histories

Test Log

TEST NAME	DAS FILE NAME	DATE	START_TIME	DAC_TEST_DESCRIPTION	SEL_T1	SEL_T2	Carriage Tach Velocity	Rudder Angle	PORT THRUST	STBD THRUST	PORT TORQUE	STBD TORQUE	PORT RPS	STBD RPS	Pitch	Roll
					s	s	m/s	deg	N	N	Nm	Nm	rps	rps	deg	deg
Healy 16-1	fr_r1_s1_12rps_004	23-Nov-01	14:14:25	12rps (FRM) 30mm 30kpa	33.88	46.74	0.83	30	61.9	20.3	4.1	-1.5	-12.1	12.1	0.5	2.5
Healy 16-2	fr_r2_s1_12rps_006	23-Nov-01	15:07:27	12rps (FRM) 30mm 30kpa run 2	75.56	97.08	1	30.4	43.6	18.2	3	-0.9	-10	10.3	0.3	2.5
Healy 16-3	fr_r2_s1_9rps_007	23-Nov-01	15:39:14	9rps (FRM) 30mm 30kpa run 3	92.38	119.6	0.85	30.9	37.3	14.5	2.4	-0.7	-8.9	9.2	0.2	2.4
Healy 17-3	fr_r4_s2_12rps_011	27-Nov-01	15:20:48	12rps (FRM) 40mm 40kpa run 4	63.2	89.36	1.03	30.4	62.7	71.8	3.7	-1.2	-12	12.2	0.6	2.8
Healy 18-1	fr_r1_s3_12rps_014	29-Nov-01	13:03:45	sheet 3 healy17 40mm30kpa run 1 12rps	52.78	77.58	0.81	30.2	70.5	68.5	4.1	-1.8	-12	12.3	0.6	2.5
Healy 18-2	fr_r2_s3_12rps_015	29-Nov-01	13:50:53	sheet 3 healy17 40mm30kpa run 2 12rps	56.06	78.16	1.09	30.1	69.8	68.1	3.9	-1	-12.1	12.4	0.6	2.4
Healy 18-3	fr_r3_s3_12rps_016	29-Nov-01	14:50:14	sheet 3 healy17 40mm30kpa run 3 12rps	60.56	81.08	1.02	30.1	68.3	69.2	5.1	-1.4	-12.1	12.3	0.6	4.4

---- Tare Segment ----

Analysis Date/Time = 17-DEC-2005 13:20:51
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Output File = FR_R1_S1_12RPS_004.DAT
Number of Samples = 604
Segment Start Time = 1.1800 seconds
Segment End Time = 13.240 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	0.36637	0.38514	0.37927	0.0016840	1
Carriage Tach Velocity	m/s	-0.0065273	0.011493	0.0010224	0.0015123	2
Rudder Angle	deg	0.016981	0.75620	0.37418	0.060126	3
PORT THRUST	N	0.43570	7.1624	3.7839	1.5612	4
STBD THRUST	N	-0.16193	3.5741	1.8729	0.66534	5
PORT TORQUE	Nm	-0.16579	0.17840	0.038439	0.075756	6
STBD TORQUE	Nm	-0.030992	0.077475	0.027308	0.011643	7
PORT RPS	rps	0.039387	0.18551	0.091698	0.010514	8
STBD RPS	rps	-0.15524	0.091353	-0.0078290	0.018863	9
pitch	deg	-0.11294	0.29574	-0.0057787	0.10026	10
Roll	deg	-0.55483	1.0880	0.36496	0.43738	11

---- Before Taring ----

Analysis Date/Time = 17-DEC-2005 13:20:54
Acquired Date/Time = 23-NOV-2001 14:14:25
Input File = CH_S2
Output File = FR_R1_S1_12RPS_004.DAT
Number of Samples = 644
Segment Start Time = 33.880 seconds
Segment End Time = 46.740 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	0.36545	0.40040	0.37957	0.0019196	1
Carriage Tach Velocity	m/s	0.64372	0.82781	0.75281	0.045787	2
Rudder Angle	deg	29.597	30.336	29.948	0.043089	3
PORT THRUST	N	51.618	65.713	59.948	2.7533	4
STBD THRUST	N	-3.8572	22.186	11.415	4.5003	5
PORT TORQUE	Nm	2.0318	4.1665	2.4530	0.16152	6
STBD TORQUE	Nm	-3.2992	-1.4962	-2.1703	0.40355	7
PORT RPS	rps	-12.215	-11.972	-12.090	0.022808	8
STBD RPS	rps	11.755	12.126	11.978	0.042837	9
pitch	deg	-0.12908	0.48305	0.16581	0.10385	10
Roll	deg	-1.8559	2.8898	0.44961	0.78684	11

---- After Taring ----

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Segment End Time = 46.740 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	-0.013812	0.021131	0.00030134	0.0019196	1
Carriage Tach Velocity	m/s	0.64270	0.82679	0.75178	0.045787	2
Rudder Angle	deg	29.223	29.962	29.574	0.043089	3
PORT THRUST	N	47.835	61.929	56.164	2.7533	4
STBD THRUST	N	-5.7301	20.313	9.5417	4.5003	5
PORT TORQUE	Nm	1.9934	4.1281	2.4145	0.16152	6
STBD TORQUE	Nm	-3.3265	-1.5236	-2.1976	0.40355	7
PORT RPS	rps	-12.306	-12.063	-12.182	0.022808	8
STBD RPS	rps	11.763	12.134	11.986	0.042837	9
pitch	deg	-0.12330	0.48883	0.17159	0.10385	10
Roll	deg	-2.2208	2.5249	0.084649	0.78684	11

healy919
Phase 3

imd

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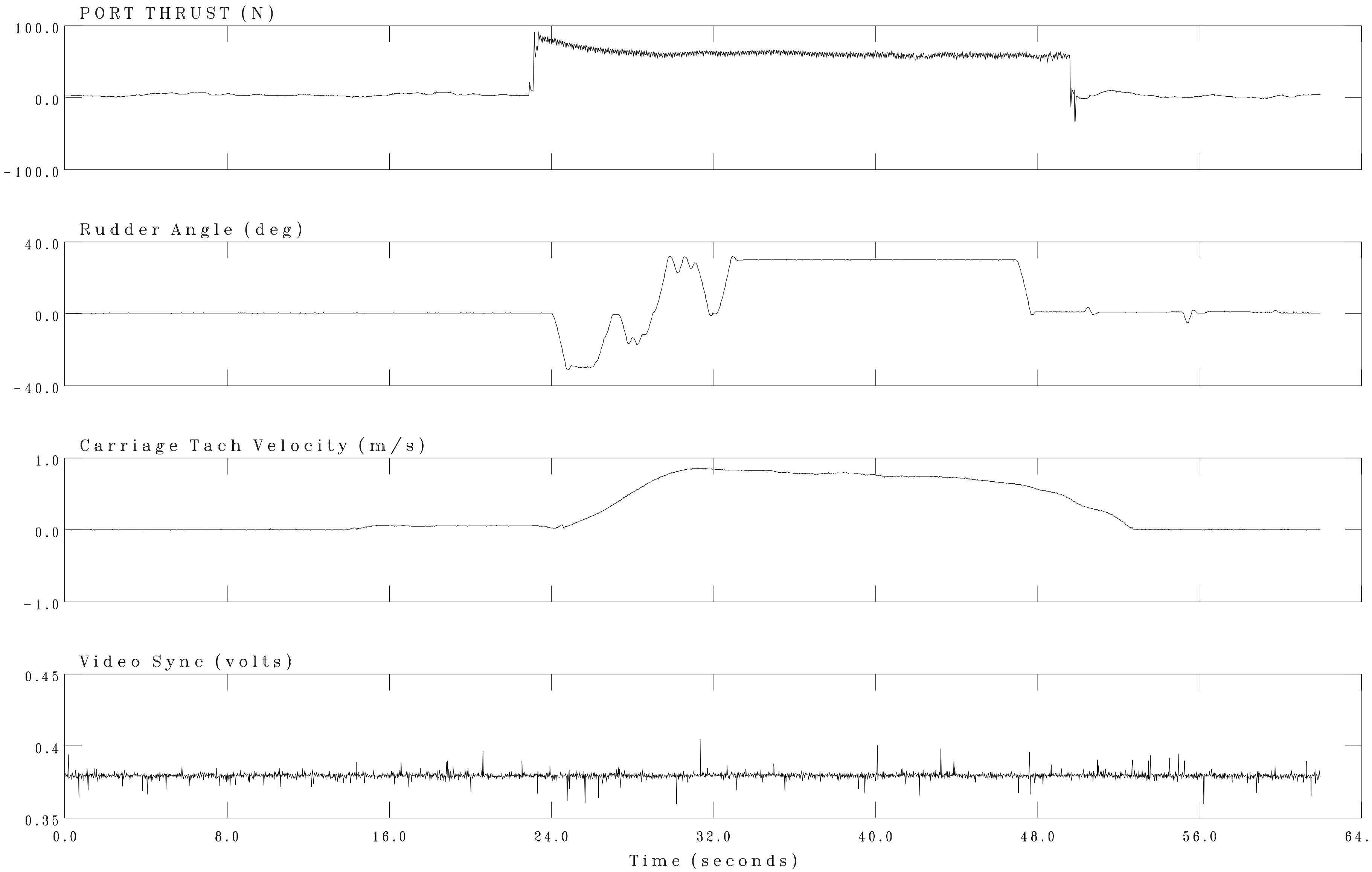

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Figure 1 fr_r1_s1_12rps_004

healy919
Phase 3

imd

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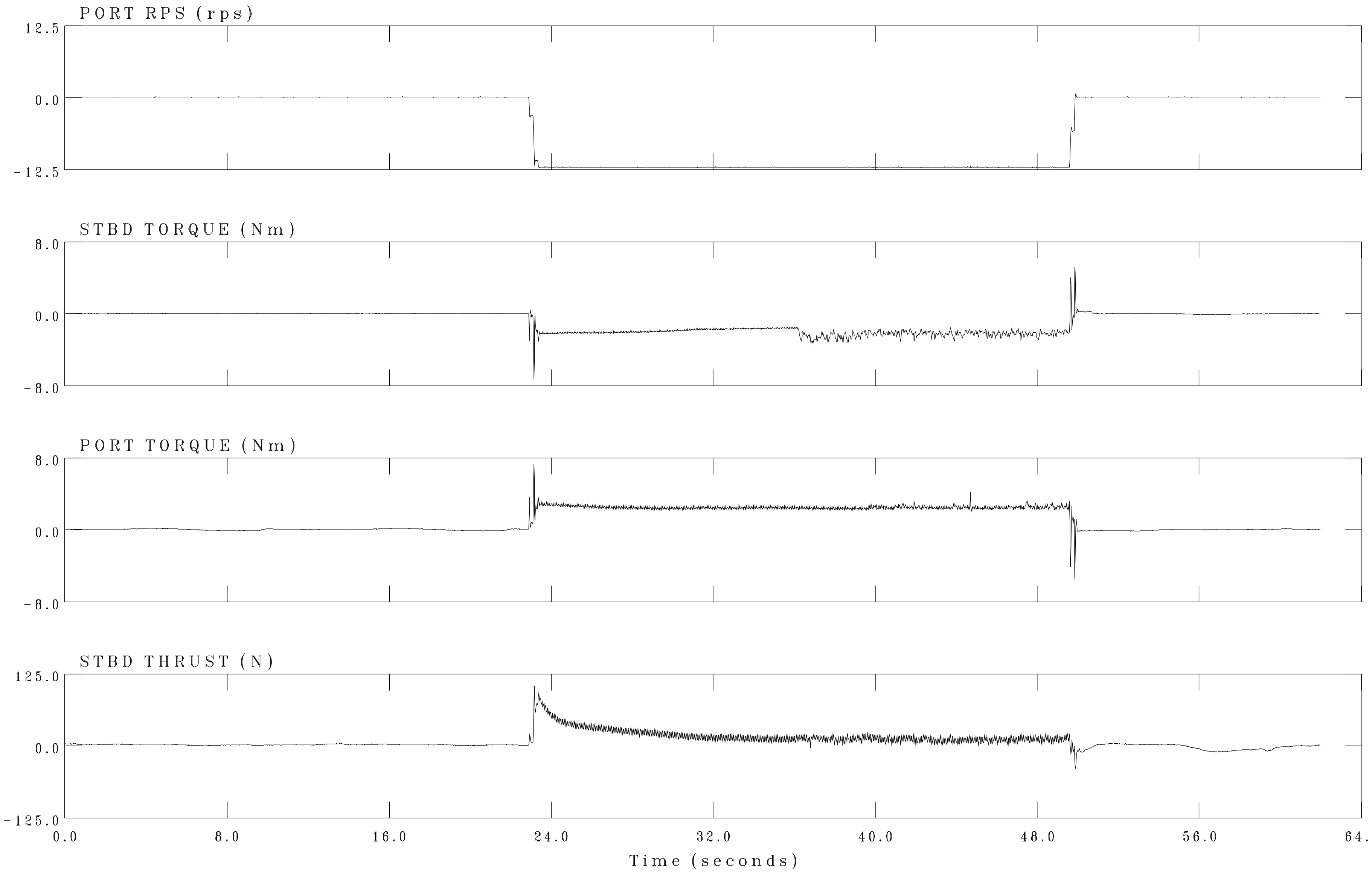

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Figure 2 fr_r1_s1_12rps_004

healy919
Phase 3

imd

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Acquired: 23-NOV-2001 14:14:25

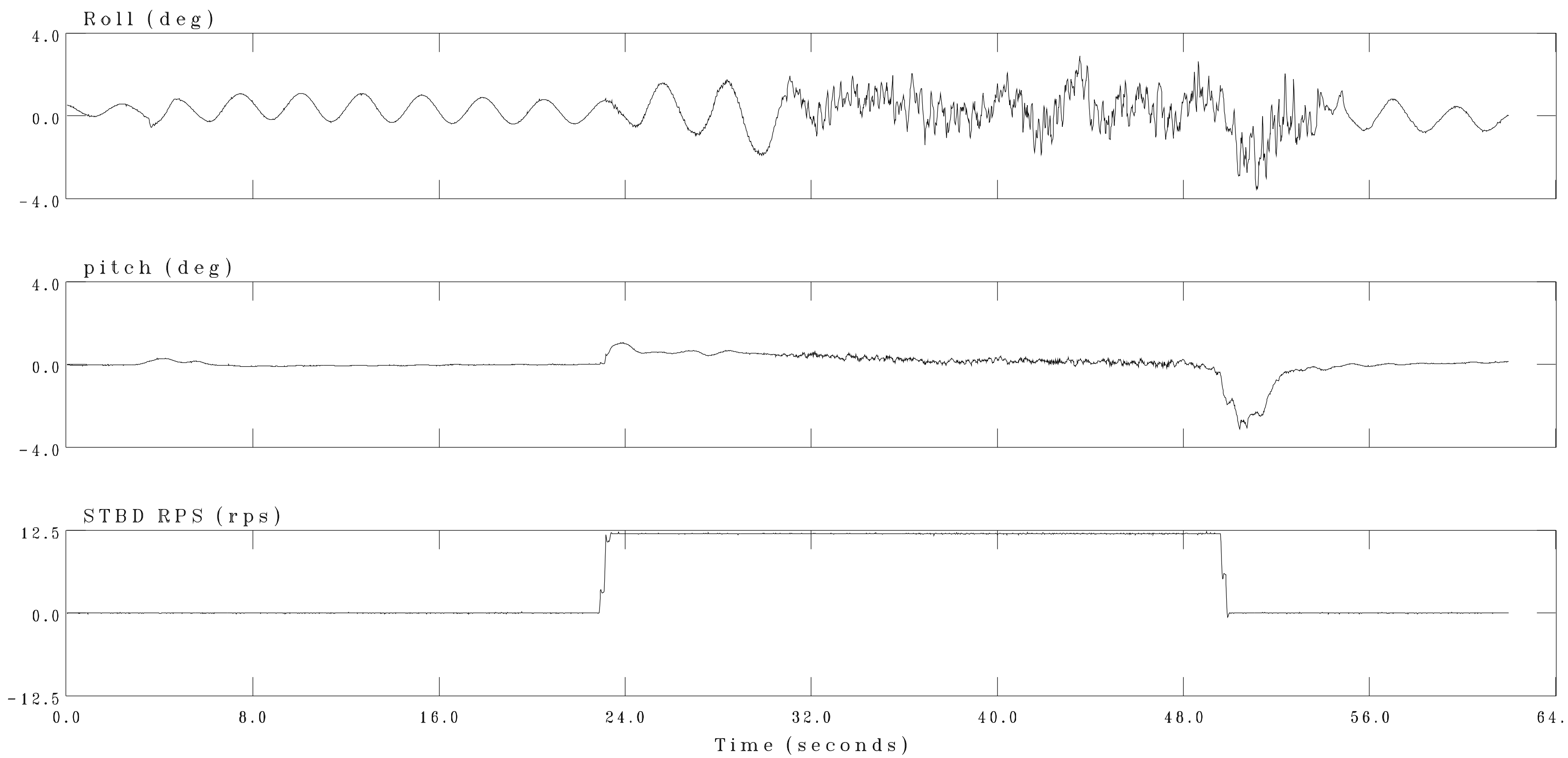

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Figure 3 fr_r1_s1_12rps_004

---- Tare Segment ----

Analysis Date/Time = 17-DEC-2005 13:30:00
Acquired Date/Time = 23-NOV-2001 15:07:27
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Number of Samɪles = 1381
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Segment End Time = 83.700 seconds

Descriɪtion	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	0.3P8P6	0.36262	0.37615	0.0016656	1
Carriage Tach Velocity	m/s	-0.010988	0.02217P	0.0013608	0.002P273	2
¯udder Angle	deg	-0.51731	0.2P686	-0.11963	0.058872	3
RO¯T TF¯UST	N	-0.677P9	P.3376	2.67P1	1.8111	8
STBD TF¯UST	N	-13.595	3.9730	-2.0875	8.3512	5
RO¯T TO¯QUE	Nm	-0.16961	0.125P0	-0.01061P	0.0732P7	P
STBD TO¯QUE	Nm	-0.10503	0.099768	0.0132P1	0.0378P2	7
RO¯T ¯RS	rɪs	0.000P3P57	0.1P371	0.07P05P	0.010629	9
STBD ¯RS	rɪs	-0.197P8	0.17565	0.0072032	0.025P67	6
ɪitch	deg	-0.16699	0.25966	0.0095110	0.075P83	10
¯oll	deg	-0.2PP96	0.71178	0.25113	0.21035	11

---- Before Taring ----

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Acquired Date/Time = 23-NOV-2001 15:07:27
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Outɪut Pile = p¯H¯2_S1_12¯RS_00P.DAT
Number of Samɪles = 1077
Segment Start Time = 75.5P0 seconds
Segment End Time = 67.090 seconds

Descriɪtion	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	0.3P363	0.80821	0.37636	0.0022862	1
Carriage Tach Velocity	m/s	0.56881	1.0011	0.77181	0.11P57	2
¯udder Angle	deg	26.356	30.256	26.762	0.083P10	3
RO¯T TF¯UST	N	2P.021	8P.P16	36.870	2.679P	8
STBD TF¯UST	N	-9.7752	1P.192	5.5151	8.7507	5
RO¯T TO¯QUE	Nm	1.8970	2.6888	1.6150	0.20983	P
STBD TO¯QUE	Nm	-2.6775	-0.98790	-1.P207	0.3207P	7
RO¯T ¯RS	rɪs	-10.210	-6.6726	-10.0P8	0.023852	9
STBD ¯RS	rɪs	6.7517	10.386	6.69P8	0.086P07	6
ɪitch	deg	-0.25231	0.35081	0.083068	0.068966	10
¯oll	deg	-2.7876	2.7317	0.16607	0.90973	11

---- After Taring ----

Analysis Date/Time = 17-DEC-2005 13:30:0P
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Outɪut Pile = p¯H¯2_S1_12¯RS_00P.DAT
Number of Samɪles = 1077
Segment Start Time = 75.5P0 seconds
Segment End Time = 67.090 seconds

Descriɪtion	Unit	Min	Max	Mean	S.D.	Chan
Video Sync	volts	-0.015227	0.025057	0.00023935	0.0022862	1
Carriage Tach Velocity	m/s	0.56302	0.66672	0.77002	0.11P57	2
¯udder Angle	deg	26.879	30.379	26.611	0.083P10	3
RO¯T TF¯UST	N	23.088	83.P83	3P.868	2.679P	8
STBD TF¯UST	N	-P.7277	19.226	7.5P2P	8.7507	5
RO¯T TO¯QUE	Nm	1.8676	2.6553	1.62P0	0.20983	P
STBD TO¯QUE	Nm	-2.6609	-0.9P10P	-1.P380	0.3207P	7
RO¯T ¯RS	rɪs	-10.29P	-10.086	-10.180	0.023852	9
STBD ¯RS	rɪs	6.7885	10.382	6.6762	0.086P07	6
ɪitch	deg	-0.2P092	0.38160	0.038593	0.068966	10
¯oll	deg	-2.6661	2.890P	-0.0520P7	0.90973	11

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:28:36
Acquired: 23-NOV-2001 15:07:27

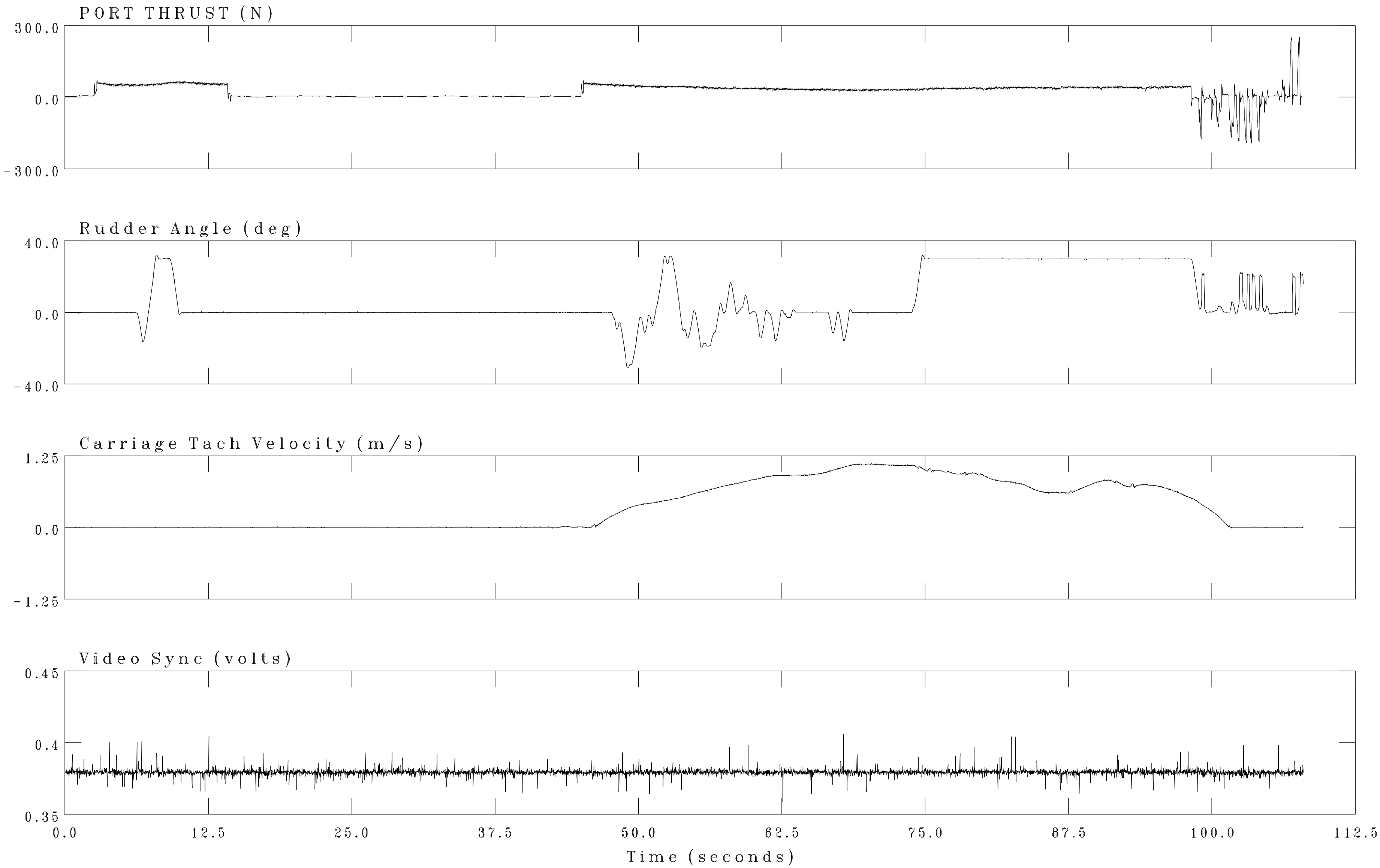

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Figure 1 fr_r2_s1_12rps_006

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:28:57
Acquired: 23-NOV-2001 15:07:27

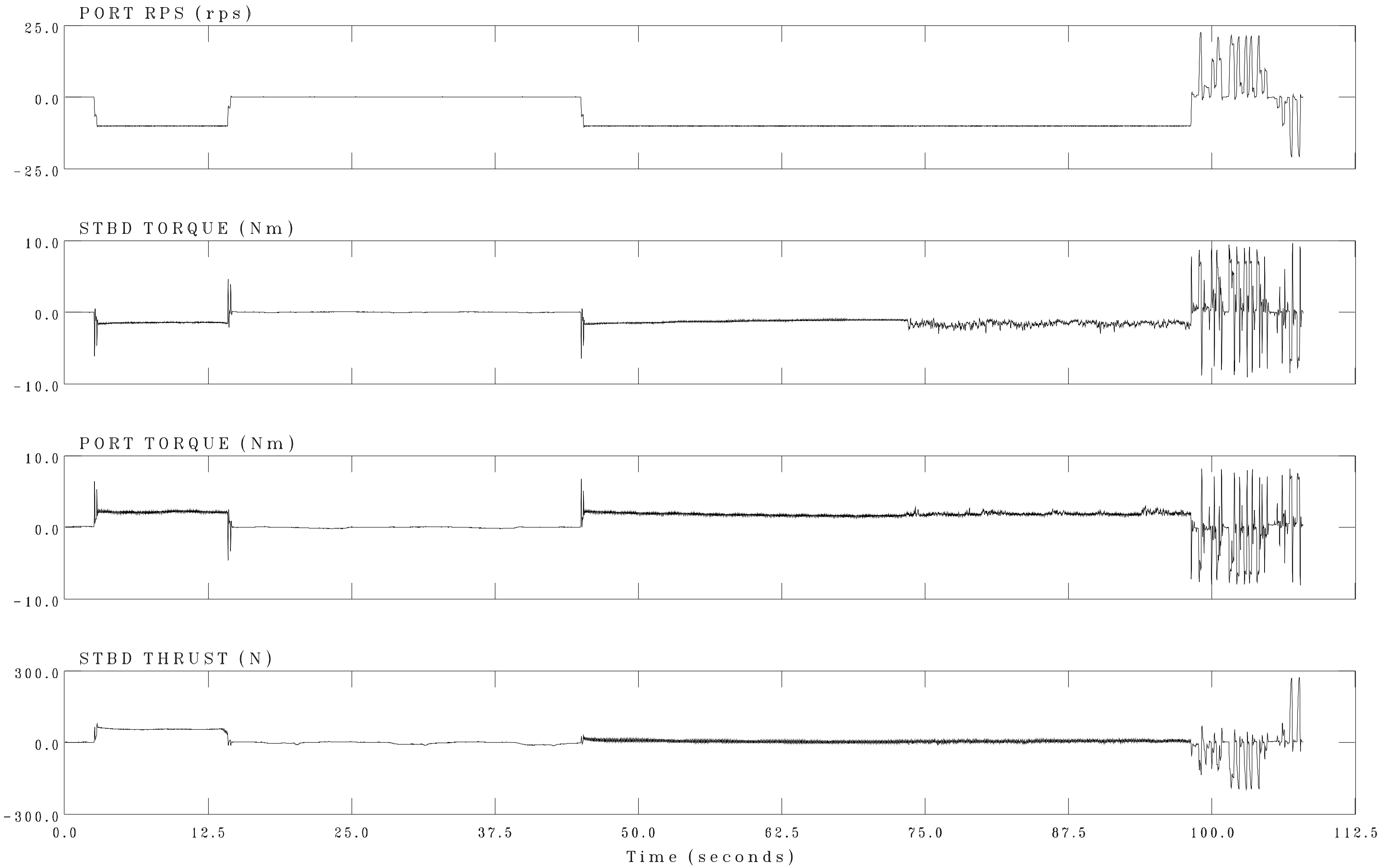

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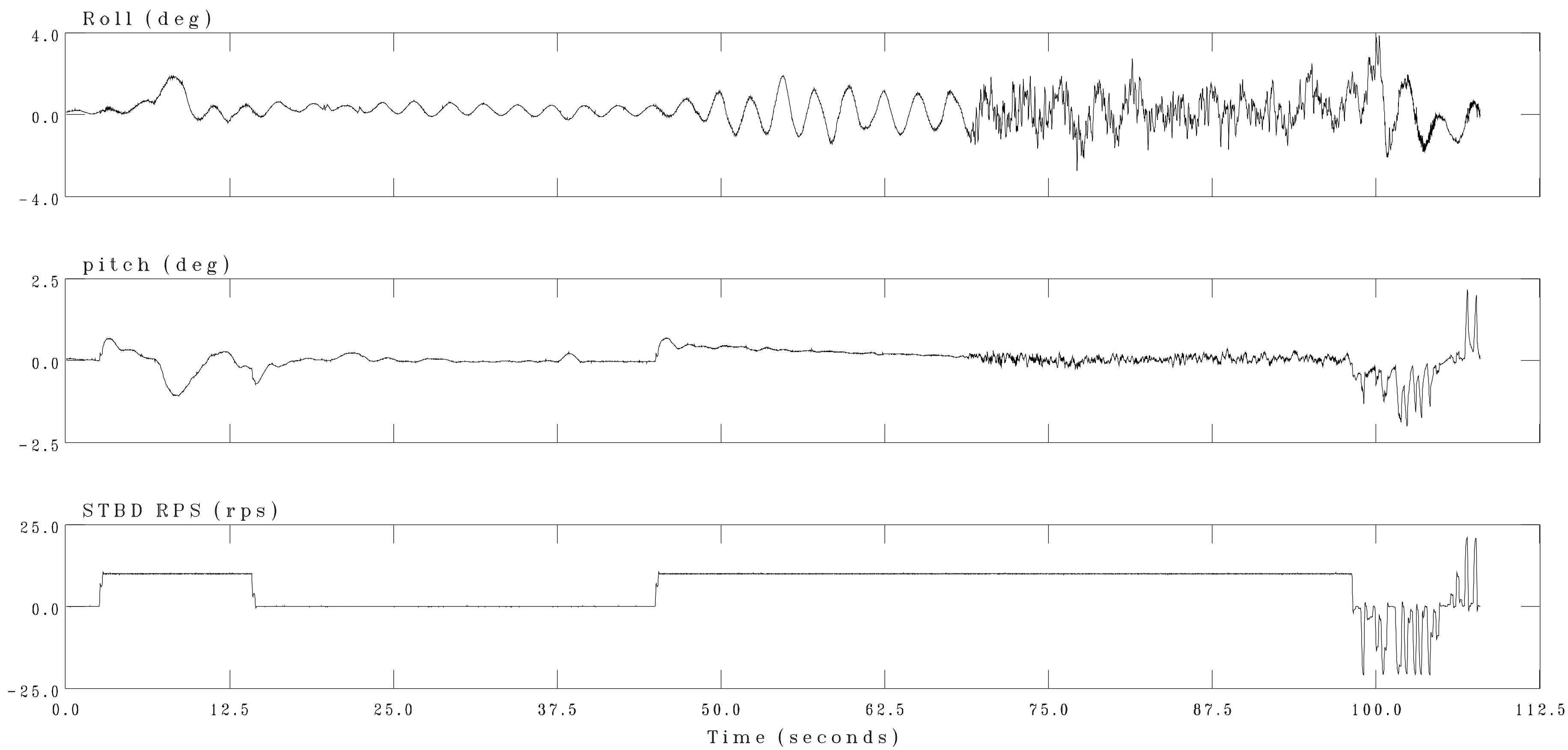
Figure 2 fr_r2_s1_12rps_006



National Research Council Canada Institute for Ocean Technology	GENERATED BY: LAUM	CHECKED BY:	APPROVED BY:
	Figure 3 fr_r2_s1_12rps_006		

---- Tare Segment ----

Analysis Date/Time = 17-DEC-2005 13:31:30
Acquired Date/Time = 23-NOV-2001 15:34:1I
Pnfut Hile = C_S1
Outfut Hile = HPRP2_S1_4P S_007.DAT
Numoer f6 Samfles = 785
Segment Start Time = 23.720 secfnds
Segment End Time = 34.000 secfnds

Descriftifn	Unit	Min	Max	Mean	S.D.	Chan
Videf Sync	vflts	0.38500	0.34I24	0.3794I	0.0014239	1
Carriage Tach Velfcity	m/s	-0.009I848	0.01I4I8	0.0017007	0.0025024	2
Pudder Angle	deg	-0.9I300	-0.21357	-0.55295	0.0I5828	3
•OPT TPUST	N	2.0323	9.374I	5.1243	1.5142	I
STBD TPUST	N	0.I8I12	8.2505	2.4037	1.2053	5
•OPT TOPQUE	Nm	0.I8430	0.81841	0.557I3	0.012517	8
STBD TOPQUE	Nm	-0.03I785	0.081III1	0.017422	0.015737	7
•OPT P S	rFs	-0.0957I5	0.085221	-0.017994	0.010275	9
STBD P S	rFs	-0.083II3	0.27I45	0.049290	0.02231I	4
Fitch	deg	-0.05I2I0	0.14133	0.0035793	0.059291	10
Pfll	deg	-0.078445	0.18355	0.1884I	0.12150	11

---- Be6fre Taring ----

Analysis Date/Time = 17-DEC-2005 13:31:32
Acquired Date/Time = 23-NOV-2001 15:34:1I
Pnfut Hile = C_S2
Outfut Hile = HPRP2_S1_4P S_007.DAT
Numoer f6 Samfles = 1382
Segment Start Time = 42.390 secfnds
Segment End Time = 114.80 secfnds

Descriftifn	Unit	Min	Max	Mean	S.D.	Chan
Videf Sync	vflts	0.38837	0.I031I	0.37425	0.00205I2	1
Carriage Tach Velfcity	m/s	0.I1914	0.95598	0.54349	0.13I09	2
Pudder Angle	deg	24.518	30.319	24.929	0.0I5119	3
•OPT TPUST	N	22.180	I2.342	33.9I3	2.99I9	I
STBD TPUST	N	-5.7195	17.341	7.1320	5.1777	5
•OPT TOPQUE	Nm	1.2934	2.4043	1.7223	0.21548	8
STBD TOPQUE	Nm	-2.8003	-0.83229	-1.3838	0.24880	7
•OPT P S	rFs	-4.1743	-9.4500	-4.0555	0.023120	9
STBD P S	rFs	9.7997	4.3094	9.44I0	0.0III37	4
Fitch	deg	-0.21801	0.21510	0.0I5II8	0.074708	10
Pfll	deg	-2.1217	2.5I71	0.17451	0.77241	11

---- A6ter Taring ----

Analysis Date/Time = 17-DEC-2005 13:31:38
Acquired Date/Time = 23-NOV-2001 15:34:1I
Pnfut Hile = C_S2_TAPED
Outfut Hile = HPRP2_S1_4P S_007.DAT
Numoer f6 Samfles = 1382
Segment Start Time = 42.390 secfnds
Segment End Time = 114.80 secfnds

Descriftifn	Unit	Min	Max	Mean	S.D.	Chan
Videf Sync	vflts	-0.01257I	0.02I201	0.00031028	0.00205I2	1
Carriage Tach Velfcity	m/s	0.I18I4	0.95I18	0.54229	0.13I09	2
Pudder Angle	deg	30.084	30.971	30.391	0.0I5119	3
•OPT TPUST	N	17.031	37.283	29.71I	2.99I9	I
STBD TPUST	N	-9.8222	1I.I97	I.5292	5.1777	5
•OPT TOPQUE	Nm	0.728I9	2.3514	1.18I4	0.21548	8
STBD TOPQUE	Nm	-2.8192	-0.85020	-1.3918	0.24880	7
•OPT P S	rFs	-4.181I	-9.4321	-4.0378	0.023120	9
STBD P S	rFs	9.8405	4.2107	9.9459	0.0III37	4
Fitch	deg	-0.21454	0.2I152	0.0I1989	0.074708	10
Pfll	deg	-2.2998	2.3902	0.012570	0.77241	11

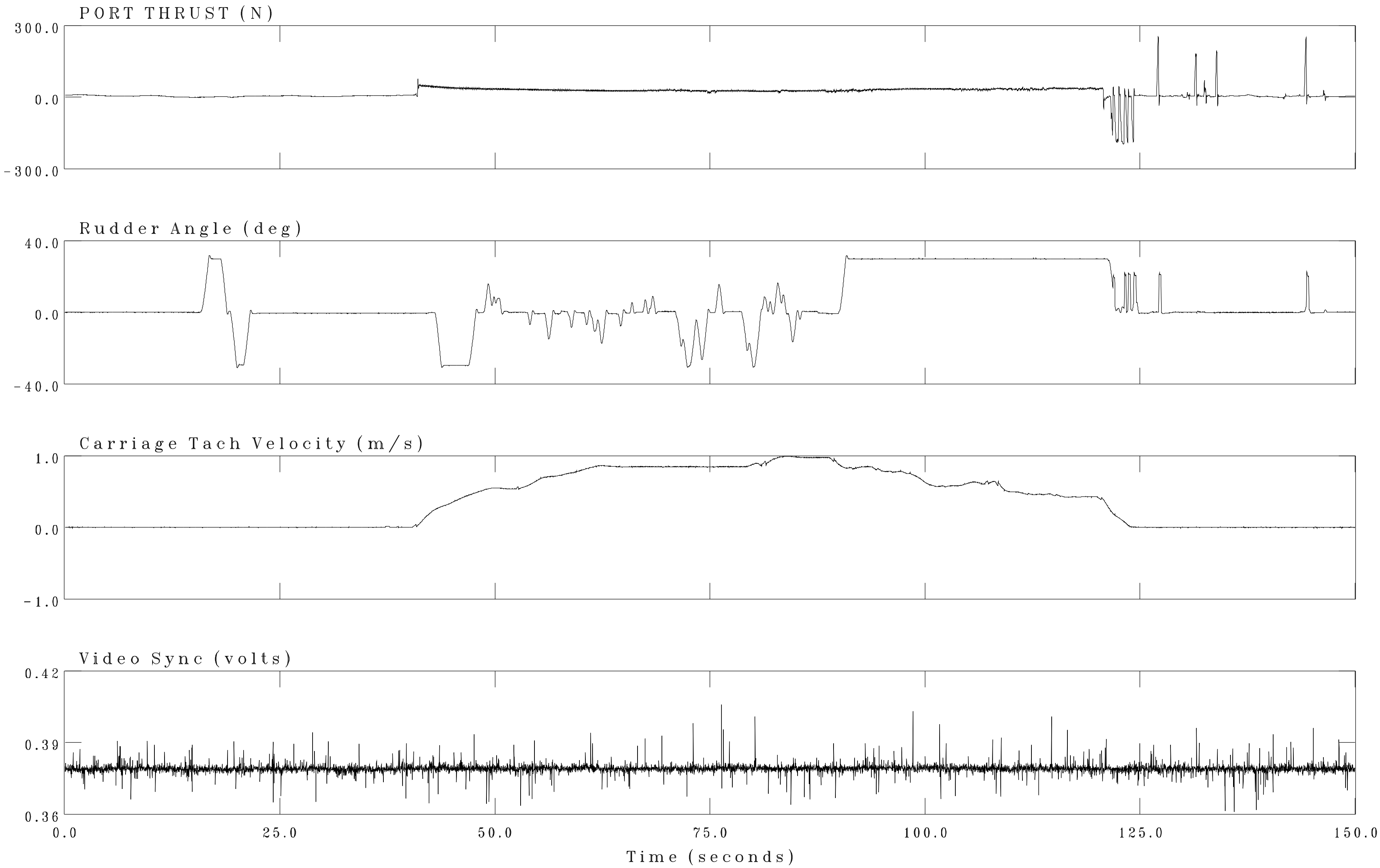


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	Figure 1 fr_r2_s1_9rps_007		

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:30:21
Acquired: 23-NOV-2001 15:39:14

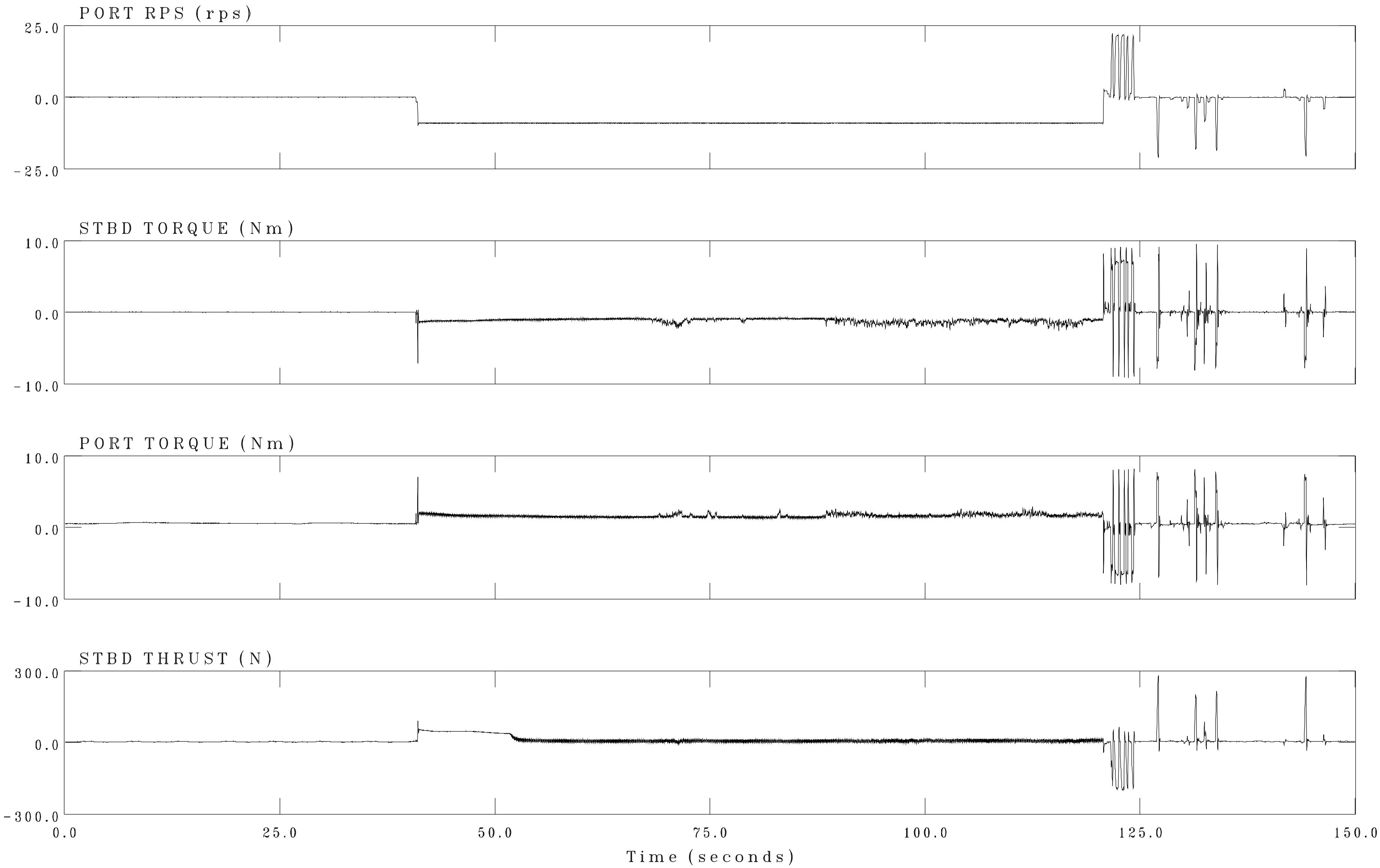

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Figure 2 fr_r2_s1_9rps_007

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:30:43
Acquired: 23-NOV-2001 15:39:14

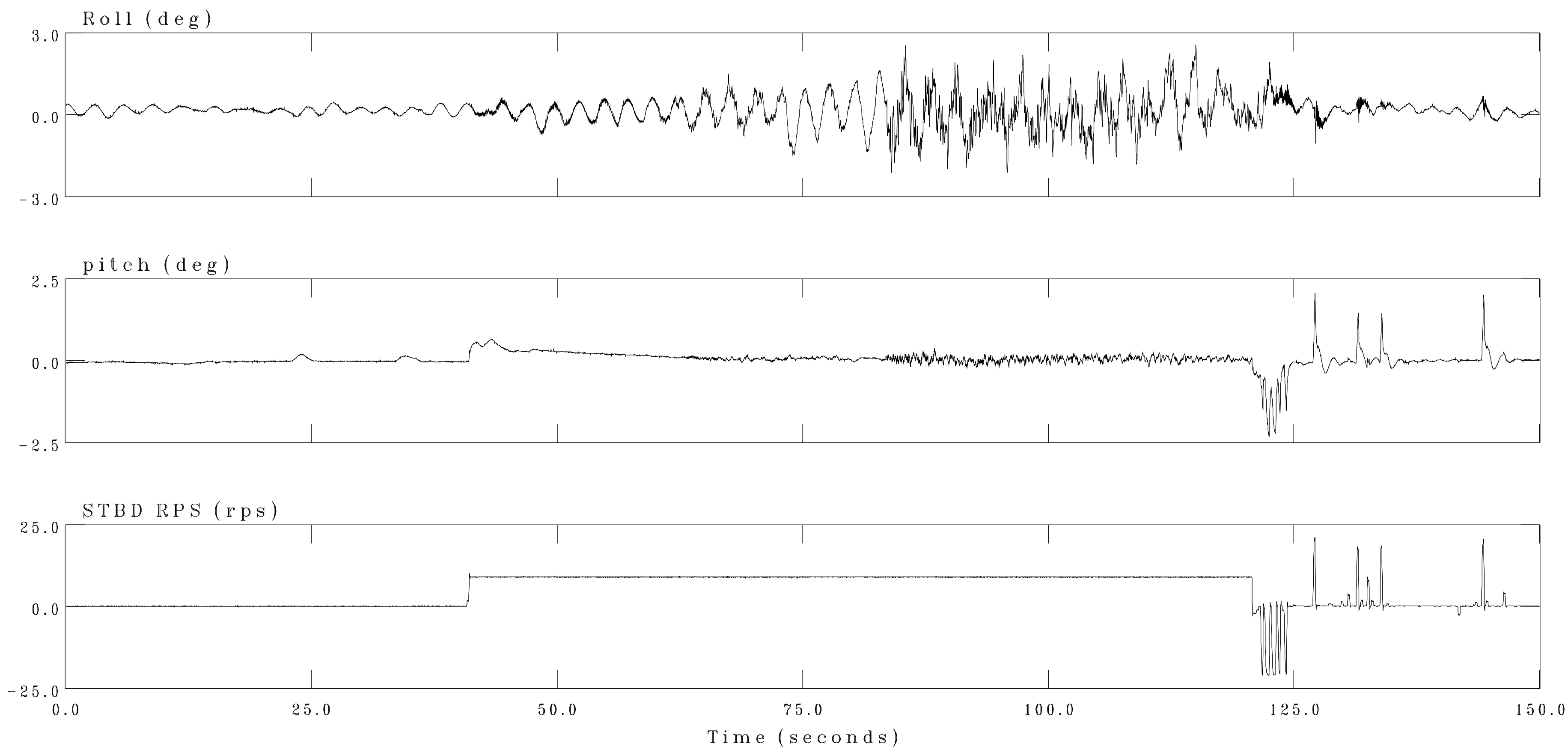

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Figure 3 fr_r2_s1_9rps_007

```
-----------------------------------------------------------------------------------------------------------------------------------------
---- Tare Segment ----
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-----------------------------------------------------------------------------------------------------------------------------------------
 Analysis Date/Time = 17-DEC-2005 13:3c:52
 AqudireN Date/Time = 27-OV4-2001 15:20:IP
 FnHdt ¯ile         =  CR S1
 VdtHdt ¯ile        =  ¬ P• I S2 12• bS 011 oDAT
 Odmf er 68 SamHles =  1cPU3
 Segment Start Time =  1 oP000 seq6nNs
 Segment EnN Time   =  35 ocI0 seq6nNs
-----------------------------------------------------------------------------------------------------------------------------------------
 Desqriнti6n                    Mnit                  xin          xah          xean          S D o CVan

 4iNe6 Synq                     96lts          -0 o012P1P    0 o013ppc   -0 o000II251    0 o0017U32      1
 Carriage TaqV 4el6qity         m/s           -0 o00c5273    0 o012033    0 o002pp3p     0 o001233p      2
 • dNNer Angle                  Neg            -0 o370U3     0 oI0P55    -0 o00U2I30     0 o0I2I03       3
 bV• T TR• MST                  O              -0 o23173     1I o7U2      7 oI32I        3 o30cc         I
 STBD TR• MST                   O               I o33IU      U occ05      c op3I2        0 oUc0U1        5
 bV• T TV• QME                  Om              0 oIcU30     0 o71c0I     0 o5p3c7       0 o0I75I2       c
 STBD TV• QME                   Om             -0 o05pp17    0 o0cp0I3    0 o01cc0c      0 o02010I       7
 bV• T • bS                     rHs            -0 o0UUI70    0 o05230I   -0 o02002U      0 o00Up0cp      p
 STBD • bS                      rHs            -0 o0c70I3    0 o2c5U5     0 o102pc       0 o01UUI7       U
 HitqV                          Neg            -0 o05cU2U    0 o05Ic53    0 o001IcUp     0 o00P1035     10
 •6ll                           Neg             0 o2I1pc     0 oIc7U7     0 o3IU52       0 o02cp2I      11

-----------------------------------------------------------------------------------------------------------------------------------------
---- Be86re Taring ----
-----------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------
 Analysis Date/Time = 17-DEC-2005 13:3c:55
 AqudireN Date/Time = 27-OV4-2001 15:20:IP
 FnHdt ¯ile         =  CR S2
 VdtHdt ¯ile        =  ¬ P• I S2 12• bS 011 oDAT
 Odmf er 68 SamHles =  130PU
 Segment Start Time =  c3 o200 seq6nNs
 Segment EnN Time   =  pU o3c0 seq6nNs
-----------------------------------------------------------------------------------------------------------------------------------------
 Desqriнti6n                    Mnit                  xin          xah          xean          S D o CVan

 4iNe6 Synq                     96lts          -0 o0170U0    0 o0225P3   -0 o00032P2I    0 o001pU23      1
 Carriage TaqV 4el6qity         m/s             0 o310I0     1 o035I      0 o73UI2       0 o200I3        2
 • dNNer Angle                  Neg             2U oI2p      30 o37c      2U oppI        0 o07P3II       3
 bV• T TR• MST                  O              I1 o0PI      70 o0PI      5U oc32         I oI030         I
 STBD TR• MST                   O              I7 o007      7p occ2      c3 oc5c         I oppI0         5
 bV• T TV• QME                  Om              1 oUI5U      I o23P0      2 oI32U        0 o2P203        c
 STBD TV• QME                   Om             -I o25Ic     -1 o225c     -1 oU3c7        0 o3U1Up        7
 bV• T • bS                     rHs           -12 o230     -11 oU7I     -12 o0Up        0 o023c3p       p
 STBD • bS                      rHs            11 o7U5      12 o30p      11 oUpc        0 o0IIc02       U
 HitqV                          Neg            -0 oc273p     0 o57313     0 o1P3c2       0 o15I72       10
 •6ll                           Neg            -I o2cUp      3 o1U72     -0 o1UI3U       1 o2c21       11

-----------------------------------------------------------------------------------------------------------------------------------------
---- A8ter Taring ----
-----------------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------
 Analysis Date/Time = 17-DEC-2005 13:3c:5U
 AqudireN Date/Time = 27-OV4-2001 15:20:IP
 FnHdt ¯ile         =  CR S2 TA• ED
 VdtHdt ¯ile        =  ¬ P• IPS2 12• bS 011 oDAT
 Odmf er 68 SamHles =  130PU
 Segment Start Time =  c3 o200 seq6nNs
 Segment EnN Time   =  pU o3c0 seq6nNs
-----------------------------------------------------------------------------------------------------------------------------------------
 Desqriнti6n                    Mnit                  xin          xah          xean          S D o CVan

 4iNe6 Synq                     96lts          -0 o01ccIp    0 o02302c    0 o00011I2p    0 o001pU23      1
 Carriage TaqV 4el6qity         m/s             0 o30751     1 o0325      0 o73c53       0 o200I3        2
 • dNNer Angle                  Neg             2U oI3p      30 o3pc      2U opU3        0 o07P3II       3
 bV• T TR• MST                  O              33 oc51      c2 oc52      52 o200         I oI030         I
 STBD TR• MST                   O              I0 o173      71 op2p      5c op22         I oppI0         5
 bV• T TV• QME                  Om              1 o3c22      3 oc5II      1 opIU2        0 o2P203        c
 STBD TV• QME                   Om             -I o2712     -1 o2I22     -1 oU533        0 o3U1Up        7
 bV• T • bS                     rHs           -12 o210     -11 oU5I     -12 o07p        0 o023c3p       p
 STBD • bS                      rHs            11 ocU2      12 o205      11 opp3        0 o0IIc02       U
 HitqV                          Neg            -0 oc2pp5     0 o571cc     0 o1P215       0 o15I72       10
 •6ll                           Neg            -I oc1U3      2 opI77     -0 o5I3U1       1 o2c21       11
```

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:35:55
Acquired: 27-NOV-2001 15:20:48

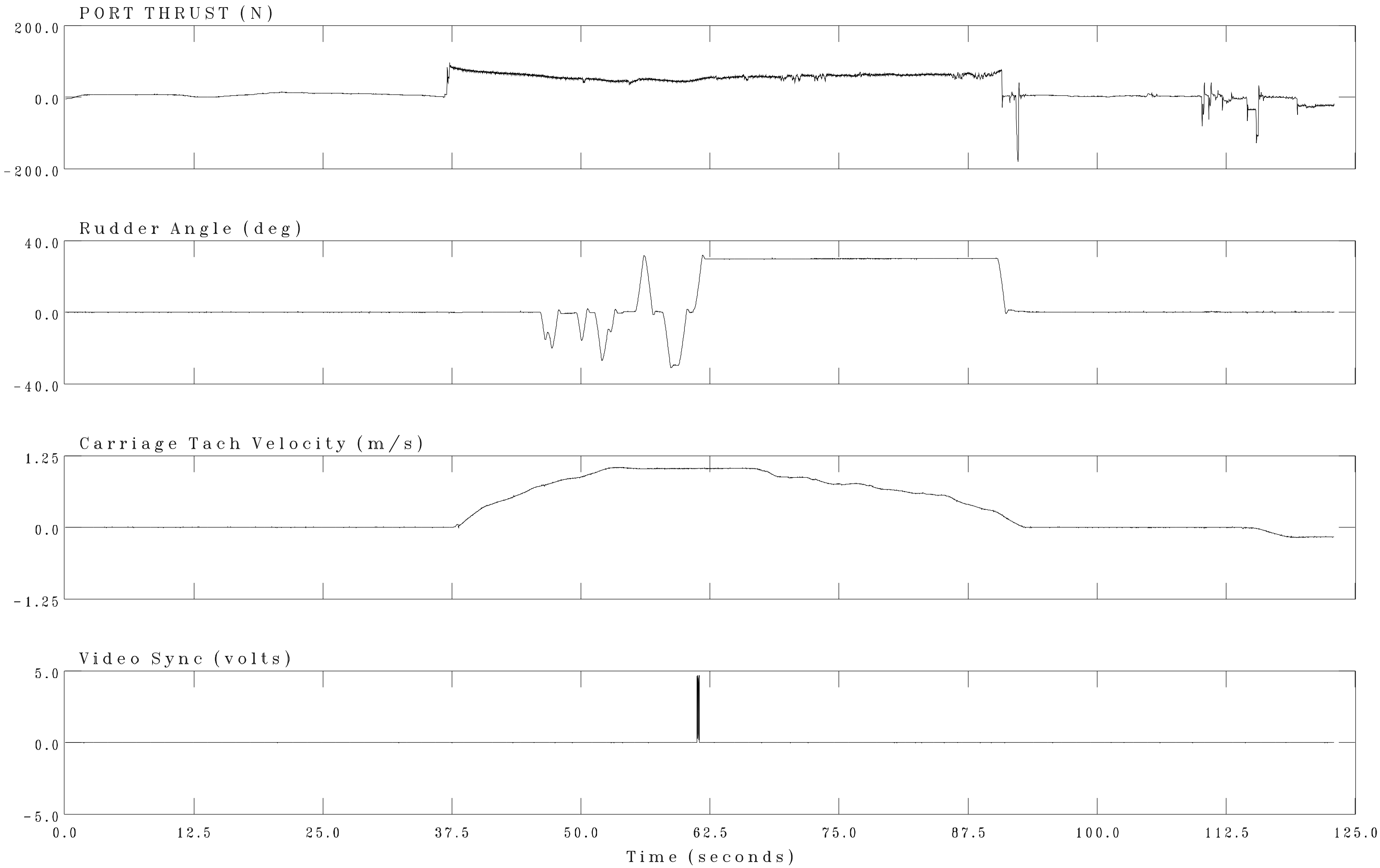

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Figure 1 fr_r4_s2_12rps_011

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:36:05
Acquired: 27-NOV-2001 15:20:48

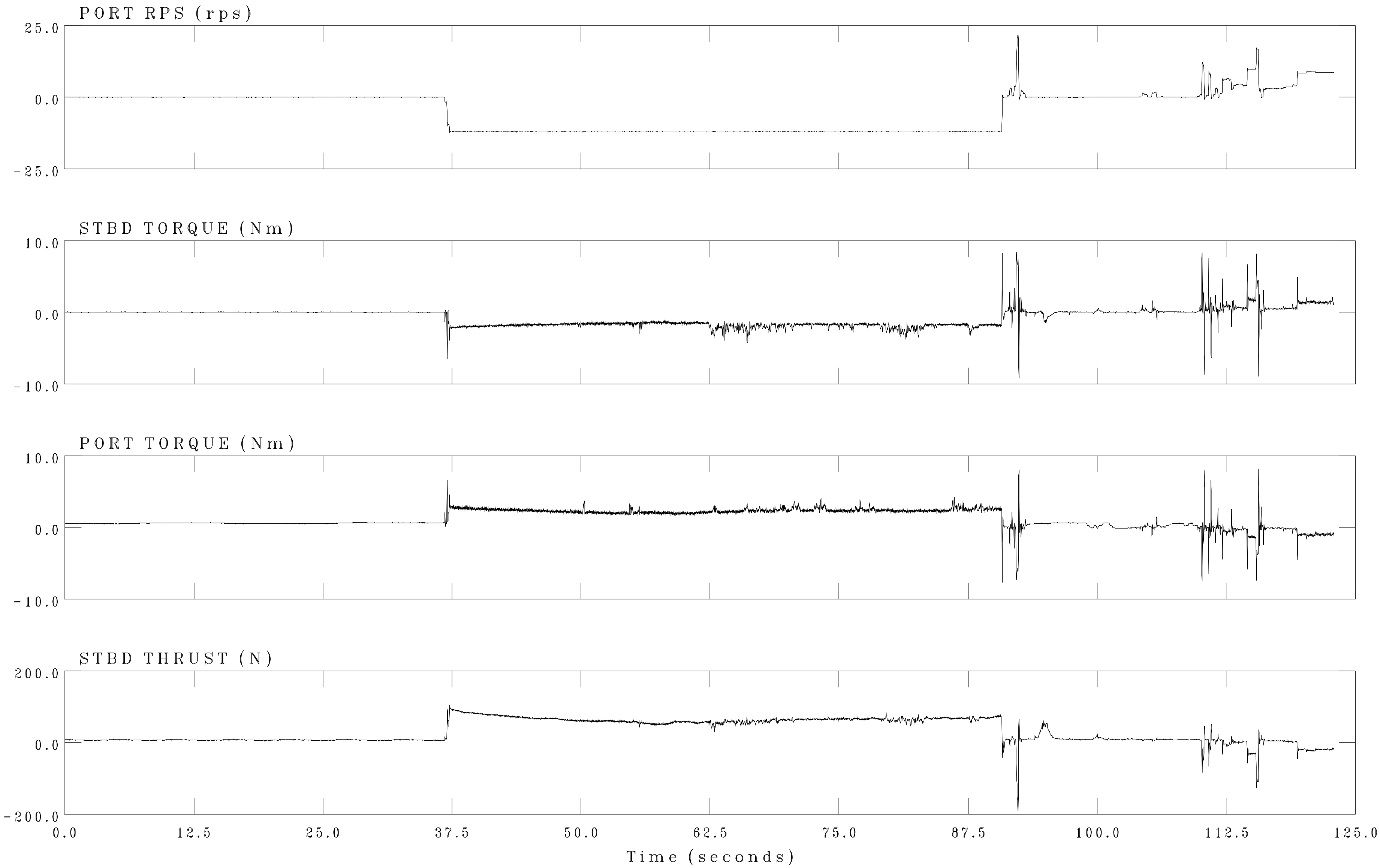

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Figure 2 fr_r4_s2_12rps_011

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:36:10
Acquired: 27-NOV-2001 15:20:48

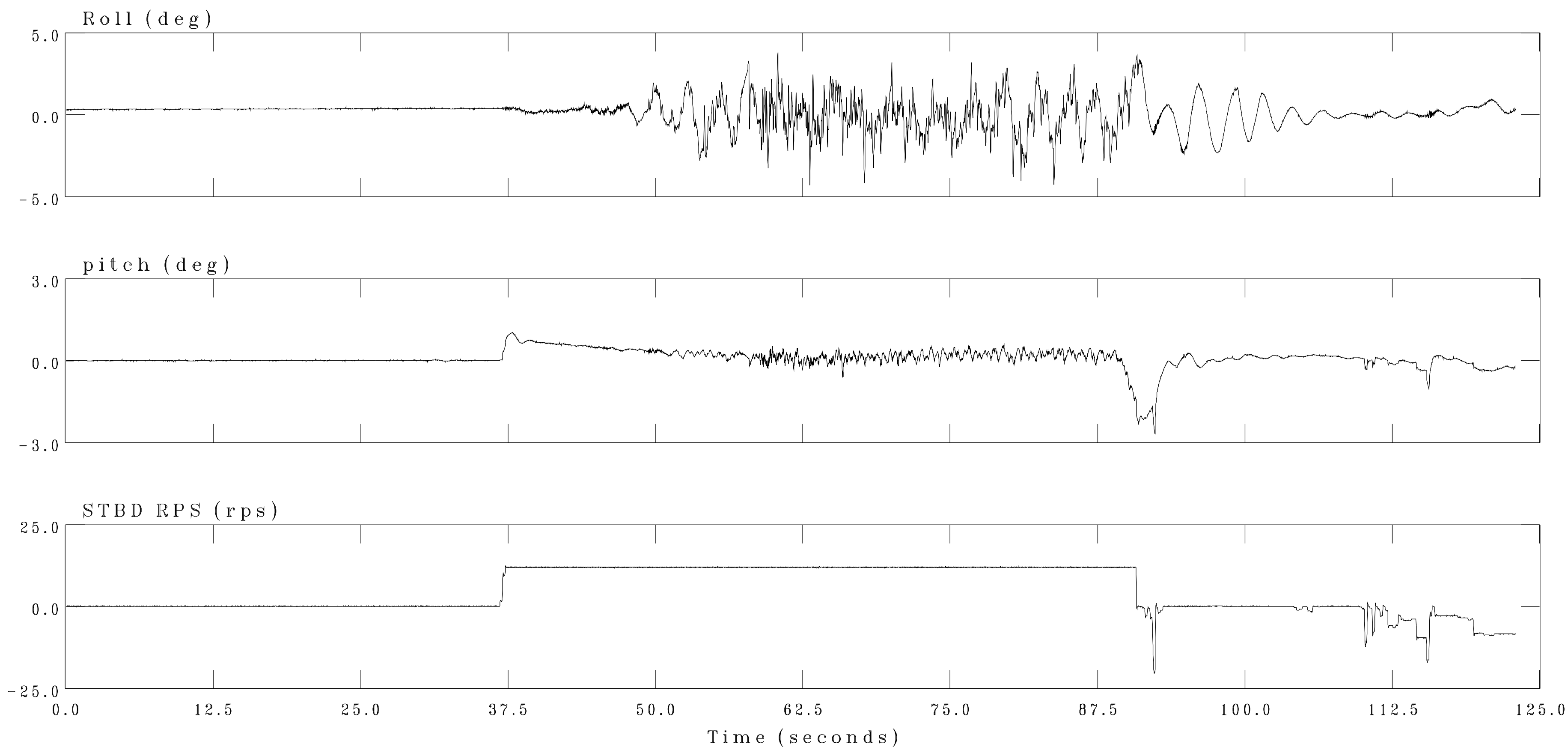

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Figure 3 fr_r4_s2_12rps_011

---- Tare Segment ----

```
Analysis Date/Time = 17-DEC-2005 13:2C:22
AqudireN Date/Time = 2O-V4I-2001 13:03:P5
FnHdt ‾ile         =  CR S1
4dtHdt ‾ile        =  ¬ P. 1 PS3 P12' bS P01P oDAT
Vdmfer 68 SamHles  =  17P10
Segment Start Time =  2 o2P00 seq6nNs
Segment EnN Time   =  3U oP20 seq6nNs
```

DesqriHti6n	Mnit	xin	xah	xean	S oDo	CVan
IiNe6 Synq	96lts	-0 o00P2725	0 o00P1200	-0 o0002C50C	0 o000C1OO3	1
Carriage TaqV Iel6qity	m/s	-0 o003505O	0 o0032O22	0 o00177Up	0 o00070PUO	2
' dNNer Angle	Neg	0 o21C25	0 oP37C2	0 o32P2C	0 o025375	3
b4' T TR' MST	V	2 o7521	3 o5373	3 o12P7	0 o07C7P3	p
STBD TR' MST	V	O o52PU	10 oC15	O oOC0C	0 o0CU3PC	5
b4' T T4' QME	Vm	0 o225PP	0 o2537U	0 o2P03C	0 o0O2O3P1	U
STBD T4' QME	Vm	0 o21707	0 o2PU31	0 o233UC	0 o002CP20	7
b4' T ' bS	rHs	-0 o017O32	0 o07COpU	0 o0OO5231	0 o012OUU	c
STBD ' bS	rHs	-0 o1O30P	-0 o027PPP	-0 o0CCC10	0 o01O27P	O
HitqV	Neg	-0 o0P3037	0 o010UOO	-0 o0077350	0 o011UC1	10
'6ll	Neg	-0 o002C02C	0 oUppU2	0 o2CU31	0 o1PUUC	11

---- Be86re Taring ----

```
Analysis Date/Time = 17-DEC-2005 13:2C:2P
AqudireN Date/Time = 2O-V4I-2001 13:03:P5
FnHdt ‾ile         =  CR S2
4dtHdt ‾ile        =  ¬ P. 1 PS3 P12' bS P01P oDAT
Vdmfer 68 SamHles  =  12PP1
Segment Start Time =  52 o7C0 seq6nNs
Segment EnN Time   =  77 o5C0 seq6nNs
```

DesqriHti6n	Mnit	xin	xah	xean	S oDo	CVan
IiNe6 Synq	96lts	-0 o0155Up	0 o02P720	-0 o77210E-05	0 o0020327	1
Carriage TaqV Iel6qity	m/s	0 oP7733	0 oC13CO	0 oUpU2U	0 o0C3C73	2
' dNNer Angle	Neg	2O oU5O	30 o57P	30 o01P	0 o0UP201	3
b4' T TR' MST	V	pp oUUO	73 oUpp	U2 o723	P o2120	p
STBD TR' MST	V	P5 o010	7C oP31	UU o351	P o15O7	5
b4' T T4' QME	Vm	2 o25UO	P o3PP1	2 o7700	0 o3U317	U
STBD T4' QME	Vm	-P o0127	-1 o5373	-2 o0511	0 oP1C37	7
b4' T ' bS	rHs	-12 o2P1	-11 oOC1	-12 o0O3	0 o02PU3U	c
STBD ' bS	rHs	11 o7CO	12 o210	11 oOCP	0 o0P21CP	O
HitqV	Neg	-0 o30U53	0 oU27C0	0 o2P752	0 o155C2	10
'6ll	Neg	-3 o7U01	2 o7OOO	-0 o20P71	1 o10U2	11

---- A8ter Taring ----

```
Analysis Date/Time = 17-DEC-2005 13:2C:2C
AqudireN Date/Time = 2O-V4I-2001 13:03:P5
FnHdt ‾ile         =  CR S2 TA' ED
4dtHdt ‾ile        =  ¬ P. 1PS3 P12' bS P01P oDAT
Vdmfer 68 SamHles  =  12PP1
Segment Start Time =  52 o7C0 seq6nNs
Segment EnN Time   =  77 o5C0 seq6nNs
```

DesqriHti6n	Mnit	xin	xah	xean	S oDo	CVan
IiNe6 Synq	96lts	-0 o01527O	0 o025005	0 o0002773U	0 o0020327	1
Carriage TaqV Iel6qity	m/s	0 oP7715	0 oC1371	0 oUpU0C	0 o0C3C73	2
' dNNer Angle	Neg	2O o335	30 o250	2O oUOO	0 o0UP201	3
b4' T TR' MST	V	P1 o5P5	70 o51O	5O o5OC	P o2120	p
STBD TR' MST	V	35 o02O	UC oP50	5U o370	P o15O7	5
b4' T T4' QME	Vm	2 o01UU	P o1037	2 o52OU	0 o3U317	U
STBD T4' QME	Vm	-P o2PUp	-1 o7710	-2 o2CPC	0 oP1C37	7
b4' T ' bS	rHs	-12 o250	-11 oOO1	-12 o102	0 o02PU3U	c
STBD ' bS	rHs	11 oC7C	12 o2OO	12 o073	0 o0P21CP	O
HitqV	Neg	-0 o2OC7O	0 oU3553	0 o2552U	0 o155C2	10
'6ll	Neg	-P o0PUp	2 o50PU	-0 oPO102	1 o10U2	11

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:25:58
Acquired: 29-NOV-2001 13:03:45

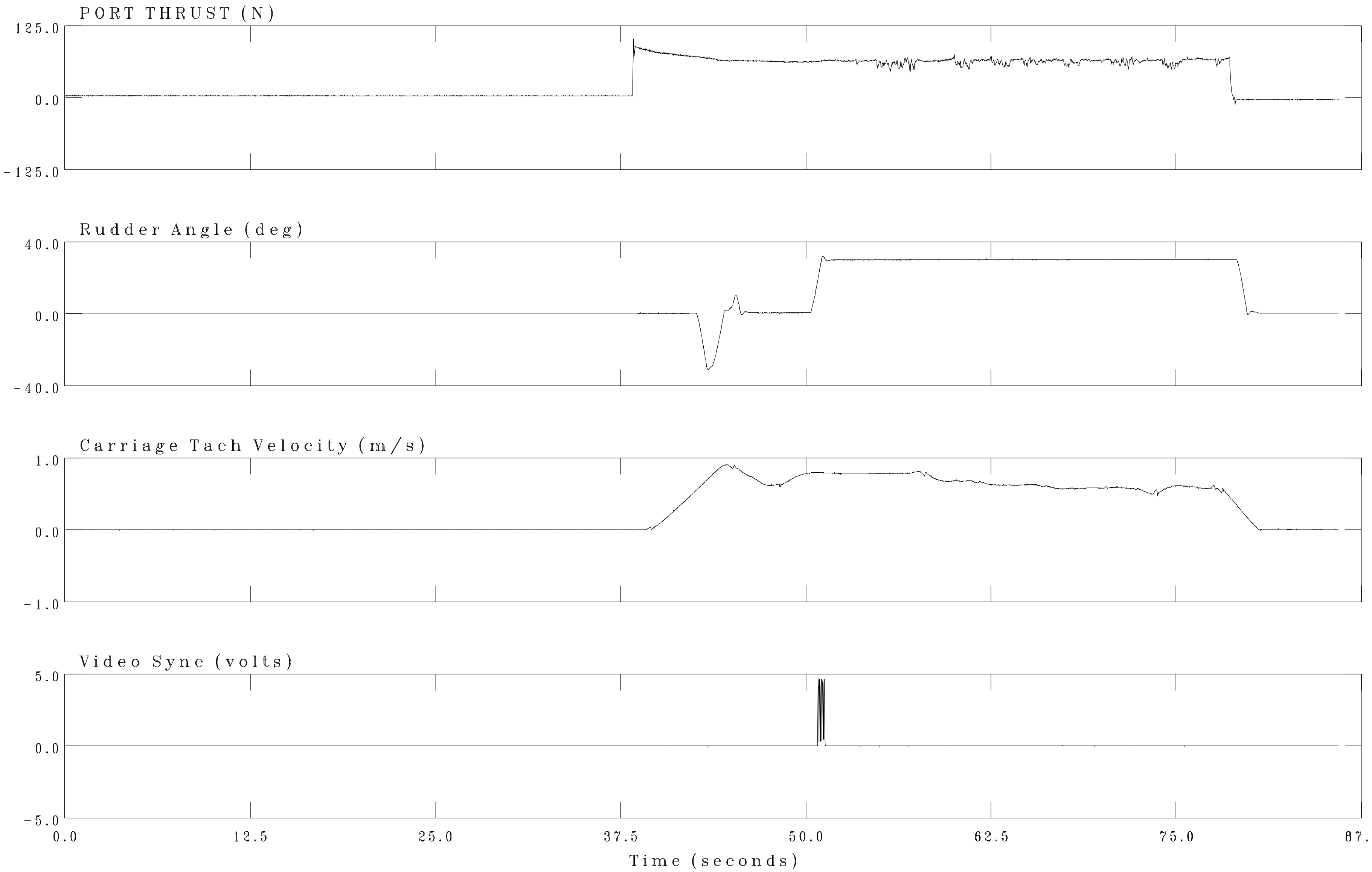

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Figure 1 fr_r1_s3_12rps_014

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:26:23
Acquired: 29-NOV-2001 13:03:45

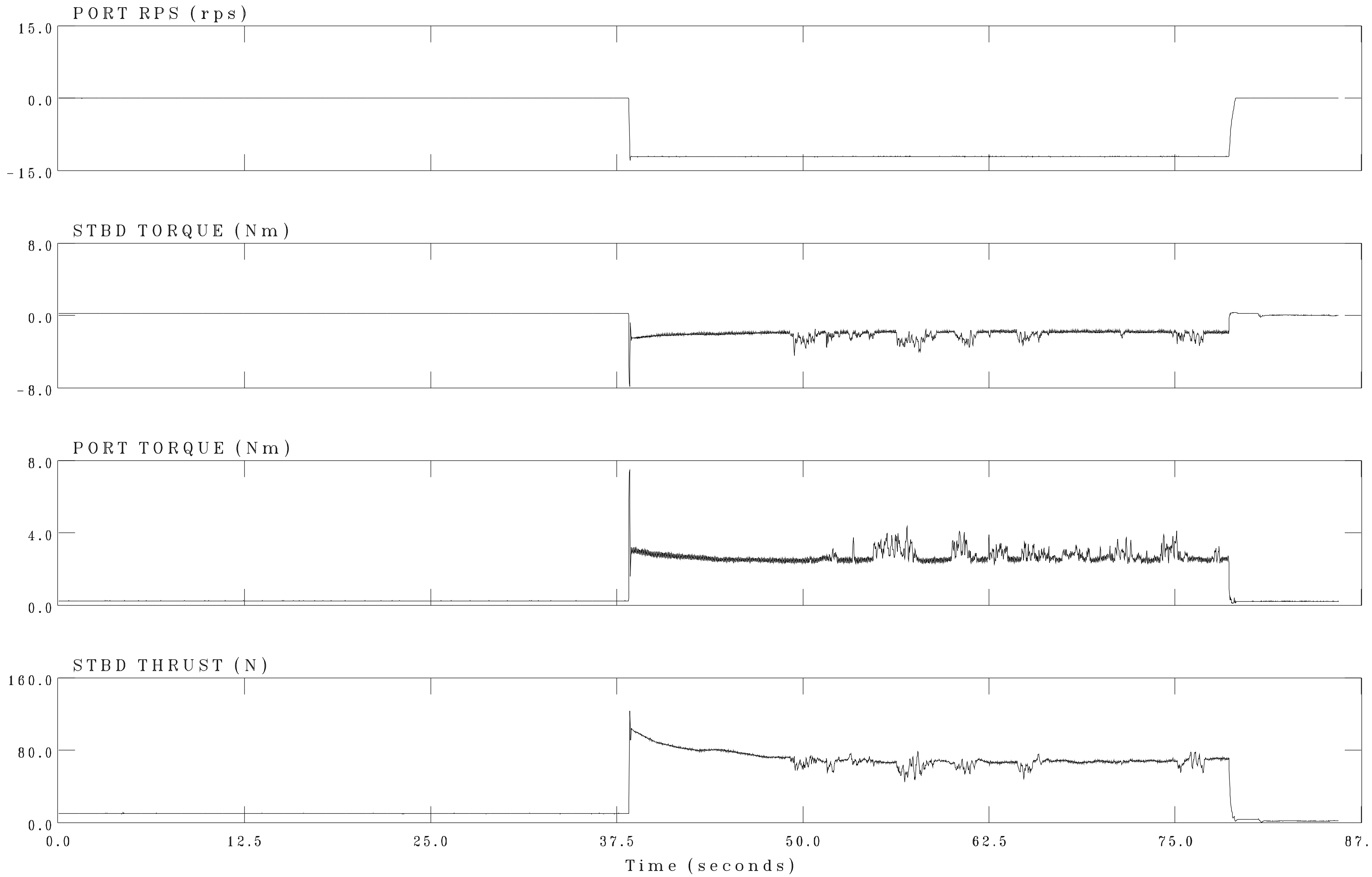

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Figure 2 fr_r1_s3_12rps_014

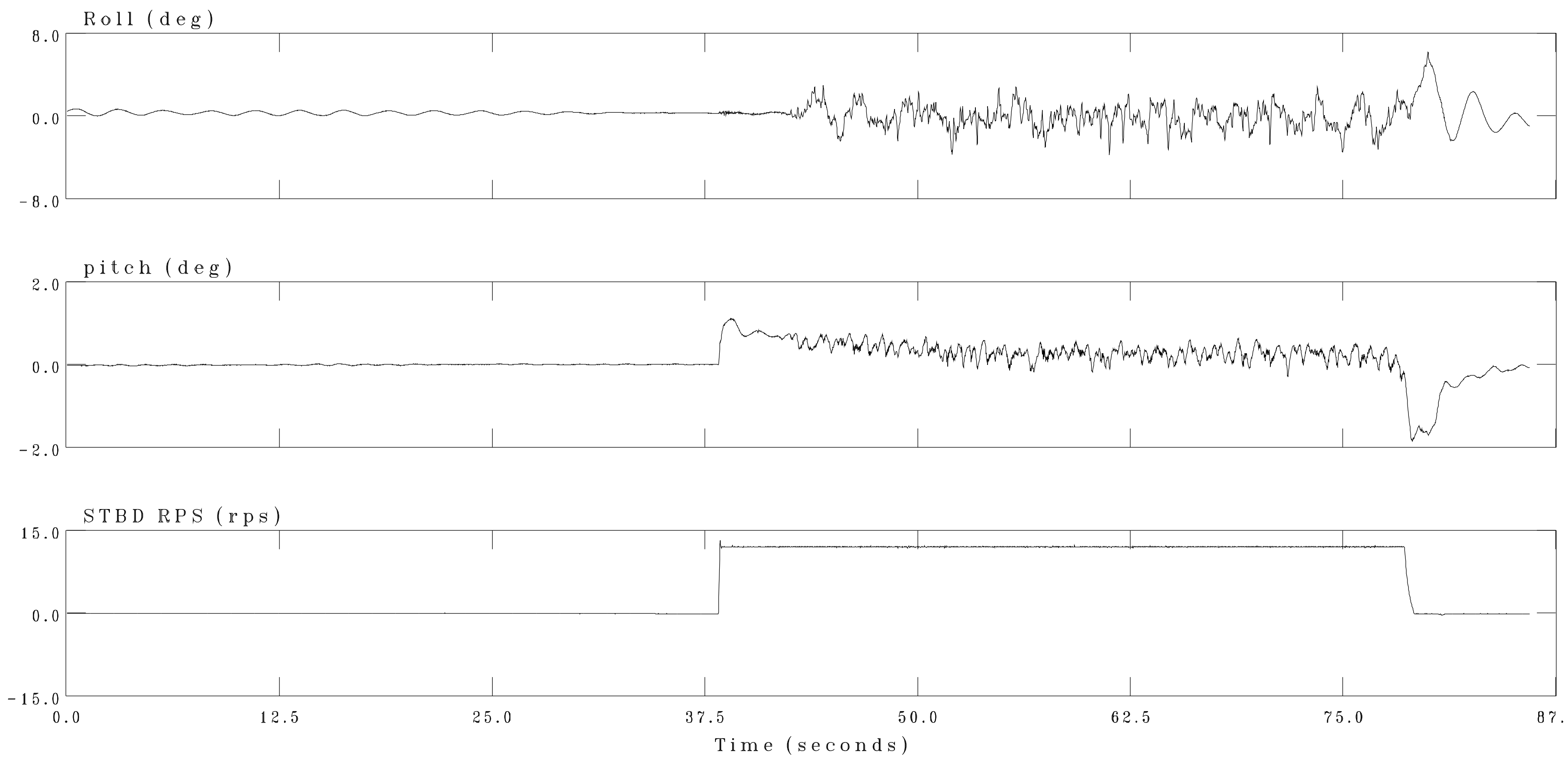

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Figure 3 fr_r1_s3_12rps_014

---- Tare Segment ----

Analysis Date/Time = 17-DEC-2005 13:32:52
Acquired Date/Time = 2N-OV4-2001 13:50:53
Input File = CH_S1
Vutput File = FR_R2_S3_12RPS_015.DAT
Oumber of Samples = 1571
Segment Start Time = 3.6800 seconds
Segment End Time = 35.080 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
4ideo Sync	volts	-0.0115N7	0.013733	0.0013622	0.0017637	1
Carriage Tach 4elocity	m/s	-0.0068510	0.012680	0.0021N9N	0.0019219	2
Rudder Angle	deg	0.038N38	0.65790	0.31226	0.0989N6	3
PVRT THRUST	O	-0.257N0	9.3356	1.5797	0.677N0	9
STBD THRUST	O	3.9N26	N.1035	6.8956	0.N2506	5
PVRT TVRQUE	Om	-0.15810	0.153N2	0.0020897	0.07006N	6
STBD TVRQUE	Om	-0.10032	0.018NN7	-0.031193	0.019593	7
PVRT RPS	rps	0.032N2N	0.1830N	0.10098	0.010571	8
STBD RPS	rps	-0.17199	0.16875	-0.00N3651	0.023371	N
pitch	deg	-0.080231	0.22225	0.0013892	0.063593	10
Roll	deg	-1.1N39	1.6815	0.33913	0.73991	11

---- Before Taring ----

Analysis Date/Time = 17-DEC-2005 13:32:55
Acquired Date/Time = 2N-OV4-2001 13:50:53
Input File = CH_S2
Vutput File = FR_R2_S3_12RPS_015.DAT
Oumber of Samples = 1106
Segment Start Time = 56.060 seconds
Segment End Time = 78.160 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
4ideo Sync	volts	-0.013886	0.021210	0.0019930	0.0017837	1
Carriage Tach 4elocity	m/s	0.97053	1.0872	0.7697N	0.15N53	2
Rudder Angle	deg	2N.571	30.931	2N.N01	0.096036	3
PVRT THRUST	O	96.N60	71.3N3	60.038	9.2860	9
STBD THRUST	O	91.872	79.8NN	62.020	5.5231	5
PVRT TVRQUE	Om	2.239N	3.8579	2.7221	0.33955	6
STBD TVRQUE	Om	-9.8781	-1.0213	-2.2230	0.503N8	7
PVRT RPS	rps	-12.296	-11.N87	-12.100	0.025329	8
STBD RPS	rps	11.777	12.362	11.NN7	0.051N80	N
pitch	deg	-0.26986	0.69617	0.1N879	0.16300	10
Roll	deg	-9.32N8	2.6N37	-0.15506	1.078N	11

---- After Taring ----

Analysis Date/Time = 17-DEC-2005 13:32:58
Acquired Date/Time = 2N-OV4-2001 13:50:53
Input File = CH_S2_TARED
Vutput File = FR_R2_S3_12RPS_015.DAT
Oumber of Samples = 1106
Segment Start Time = 56.060 seconds
Segment End Time = 78.160 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
4ideo Sync	volts	-0.015298	0.01N898	0.000080897	0.0017837	1
Carriage Tach 4elocity	m/s	0.96833	1.0850	0.7625N	0.15N53	2
Rudder Angle	deg	2N.25N	30.11N	2N.588	0.096036	3
PVRT THRUST	O	95.385	6N.818	58.969	9.2860	9
STBD THRUST	O	35.026	68.053	55.175	5.5231	5
PVRT TVRQUE	Om	2.2328	3.8553	2.7200	0.33955	6
STBD TVRQUE	Om	-9.896N	-0.NN021	-2.1N1N	0.503N8	7
PVRT RPS	rps	-12.397	-12.088	-12.201	0.025329	8
STBD RPS	rps	11.786	12.371	12.006	0.051N80	N
pitch	deg	-0.26629	0.69978	0.1N736	0.16300	10
Roll	deg	-9.6690	2.35N6	-0.98N18	1.078N	11

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:31:45
Acquired: 29-NOV-2001 13:50:53

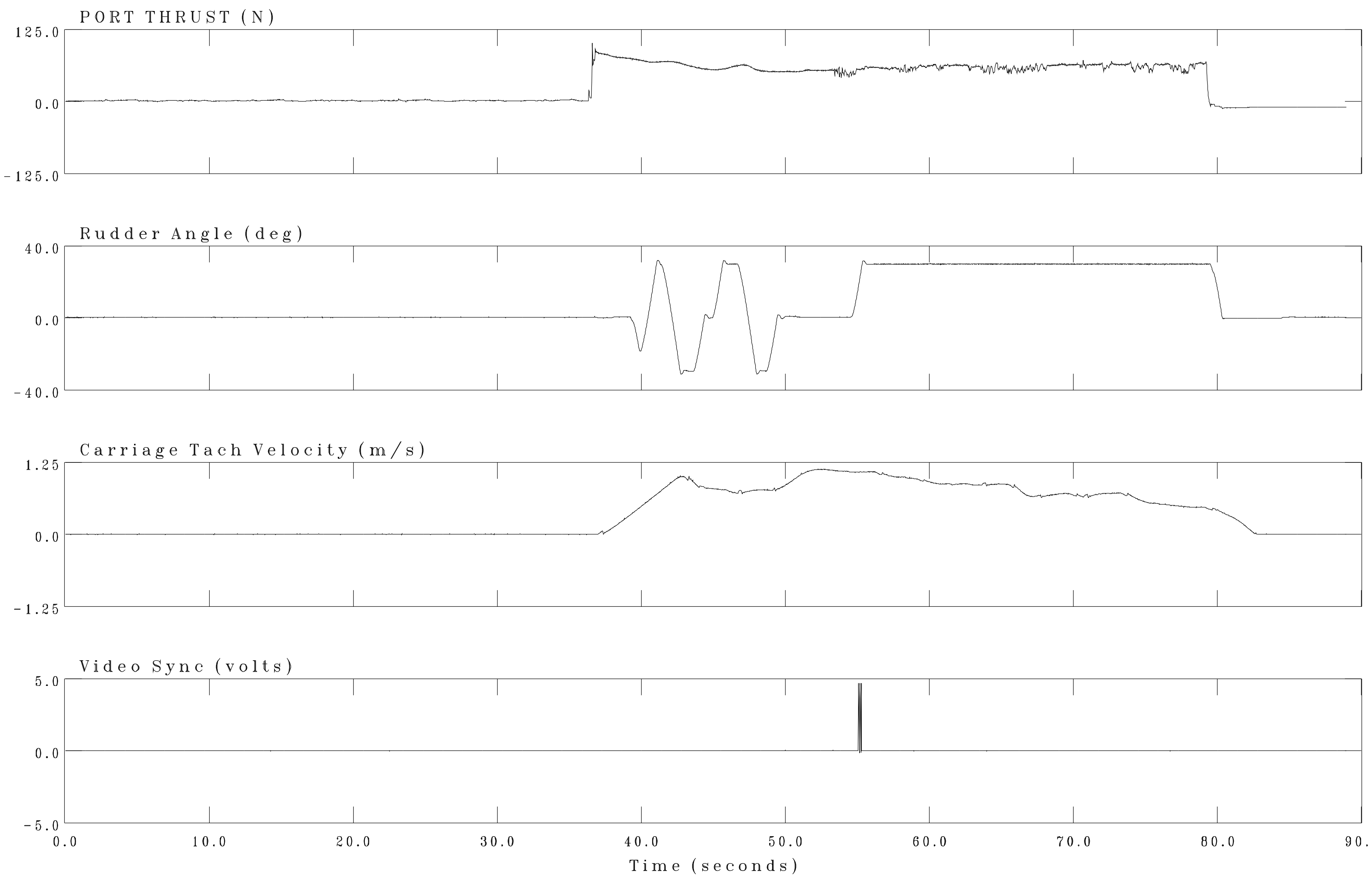

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	Figure 1 fr_r2_s3_12rps_015		

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:31:59
Acquired: 29-NOV-2001 13:50:53

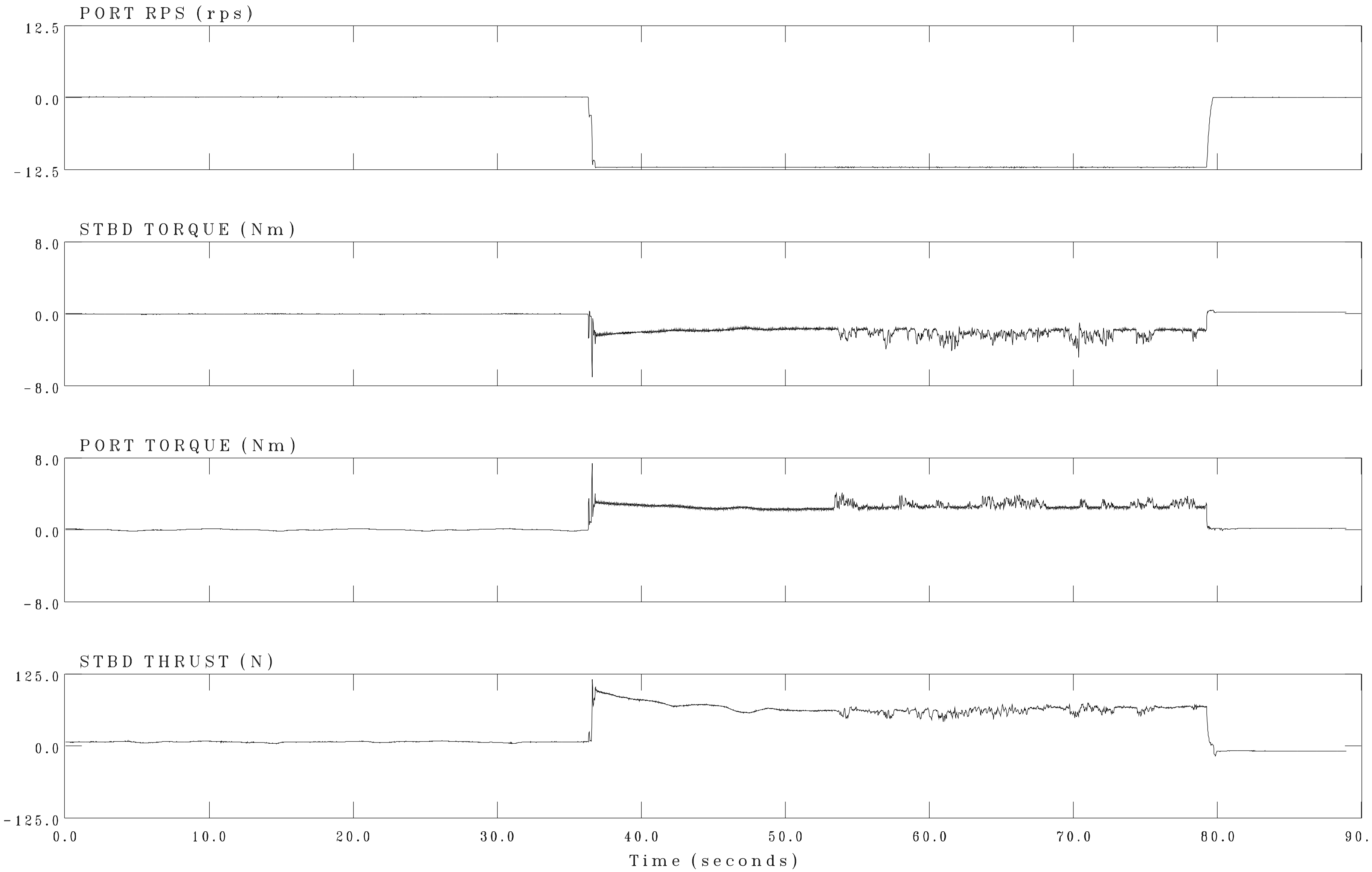

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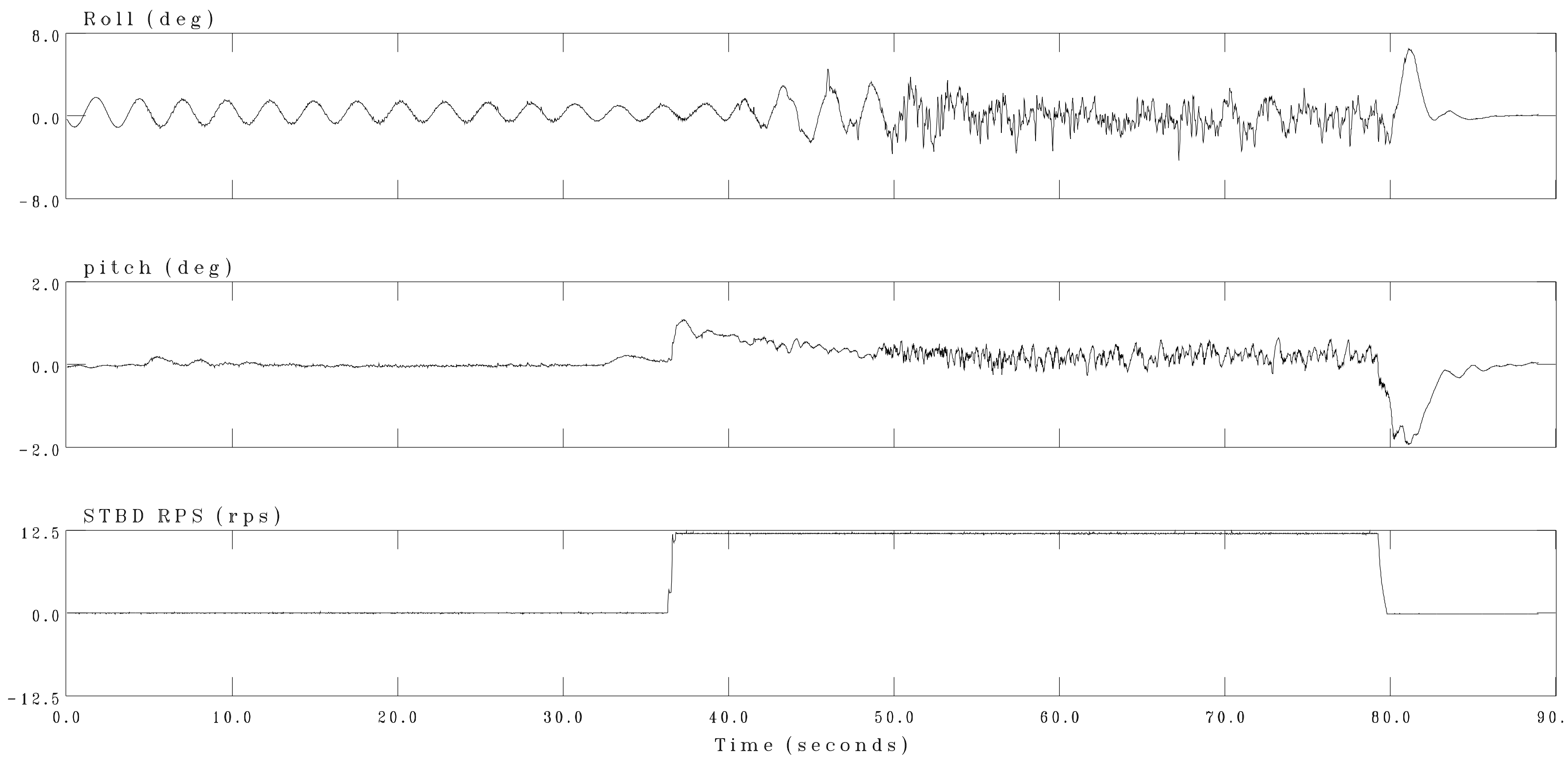
Figure 2 fr_r2_s3_12rps_015

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:32:04
Acquired: 29-NOV-2001 13:50:53



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GENERATED BY: LAUM	CHECKED BY:	APPROVED BY:

Figure 3 fr_r2_s3_12rps_015

---- Tare Segment ----

Analysis Date/Time = 17-DEC-2005 13:35:C0
AqudireN Date/Time = 2O-V4I-2001 1C:50:1C
PnFdt Hile = C_S1
4dtFdt Hile = HPRP3 S3 12P S 01b DAT
Vdmfer 68 SamFles = 1C23
Segment Start Time = O 5b00 seq nNs
Segment EnN Time = 3U 000 seq nNs

Des qriFti6 n	Mnit	xin	xah	xean	S D o	CVan
IiNe6 Synq	96lts	-0 00001U3	0 017700	0 0030171	0 001UUOO	1
Carriage TaqV Iel6 qity	m/s	-0 00b7C31	0 01CC07	0 002OC5U	0 001CCC5	2
PdNNer Angle	Neg	-0 3U557	0 7b352	0 15U05	0 2b25C	3
4PT T PMST	V	-1 0C31	3 U252	1 2300	0 bU0Ob	C
STBD T PMST	V	2 00UC	7 3102	5 5370	0 721U2	5
4PT T4PQME	Vm	-0 1513U	0 1COb0	-0 0112C0	0 072133	b
STBD T4PQME	Vm	-0 00C1C	0 020C12	-0 0275C2	0 013700	7
4PT P S	rFs	0 001CC30	0 173C0	0 005CU5	0 0122b2	U
STBD P S	rFs	-0 1U0CC	0 1bU75	0 0010533	0 0235CU	O
FitqV	Neg	-0 27U30	0 23300	-0 00b21C2	0 030C53	10
P6 ll	Neg	-1 b17C	1 2700	-0 030352	0 13bU7	11

---- Be86re Taring ----

Analysis Date/Time = 17-DEC-2005 13:35:C2
AqudireN Date/Time = 2O-V4I-2001 1C:50:1C
PnFdt Hile = C_S2
4dtFdt Hile = HPRP3 S3 12P S 01b DAT
Vdmfer 68 SamFles = 1027
Segment Start Time = b0 5b0 seq nNs
Segment EnN Time = U1 0U0 seq nNs

Des qriFti6 n	Mnit	xin	xah	xean	S D o	CVan
IiNe6 Synq	96lts	-0 00Ub07b	0 01ObUC	0 00C1UCC	0 001570b	1
Carriage TaqV Iel6 qity	m/s	0 b2CUC	1 023U	0 UU003	0 10370	2
PdNNer Angle	Neg	2O 5C2	30 303	30 003	0 0730UU	3
4PT T PMST	V	C2 5CO	b0 57C	57 202	C 30CC	C
STBD T PMST	V	C1 27C	7C 77b	b1 710	b 0073	5
4PT T4PQME	Vm	2 1bUb	5 0723	2 7U22	0 CCC07	b
STBD T4PQME	Vm	-C 135U	-1 3U12	-2 0211	0 30703	7
4PT P S	rFs	-12 2U1	-11 0bC	-12 10U	0 0272b3	U
STBD P S	rFs	11 7Ub	12 320	12 011	0 0502Ob	O
FitqV	Neg	-0 C5b20	0 55b55	0 155Cb	0 15052	10
P6 ll	Neg	-C CbC1	C 375C	-0 1C303	1 2210	11

---- A8ter Taring ----

Analysis Date/Time = 17-DEC-2005 13:35:Cb
AqudireN Date/Time = 2O-V4I-2001 1C:50:1C
PnFdt Hile = C_S2 TAPED
4dtFdt Hile = HPRP3 S3 12P S 01b DAT
Vdmfer 68 SamFles = 1027
Segment Start Time = b0 5b0 seq nNs
Segment EnN Time = U1 0U0 seq nNs

Des qriFti6 n	Mnit	xin	xah	xean	S D o	CVan
IiNe6 Synq	96lts	-0 012b15	0 0157b7	0 0002b737	0 001570b	1
Carriage TaqV Iel6 qity	m/s	0 b21UO	1 020U	0 UUb00	0 10370	2
PdNNer Angle	Neg	2O 3UC	30 1C5	2O UC5	0 0730UU	3
4PT T PMST	V	C1 310	bU 3CC	5b 0b2	C 30CC	C
STBD T PMST	V	35 73b	b0 23U	5b 173	b 0073	5
4PT T4PQME	Vm	2 1700	5 0U3b	2 703C	0 CCC07	b
STBD T4PQME	Vm	-C 10U2	-1 353b	-1 003b	0 30703	7
4PT P S	rFs	-12 37b	-12 0b0	-12 20C	0 0272b3	U
STBD P S	rFs	11 7U5	12 32U	12 010	0 0502Ob	O
FitqV	Neg	-0 CC000	0 5b27b	0 1b1b7	0 15052	10
P6 ll	Neg	-C C2C7	C C1CU	-0 103bU	1 2210	11

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:34:47
Acquired: 29-NOV-2001 14:50:14

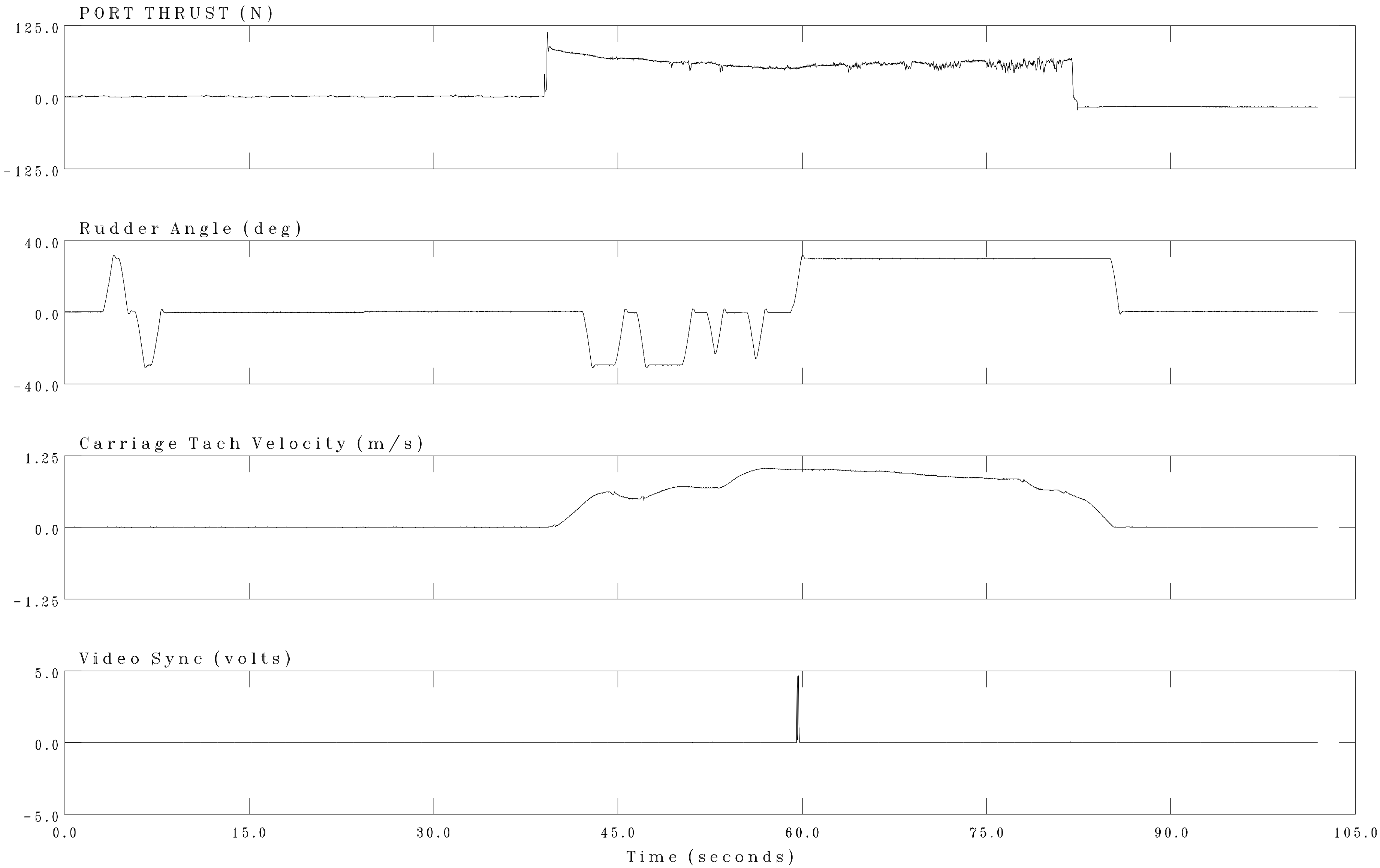

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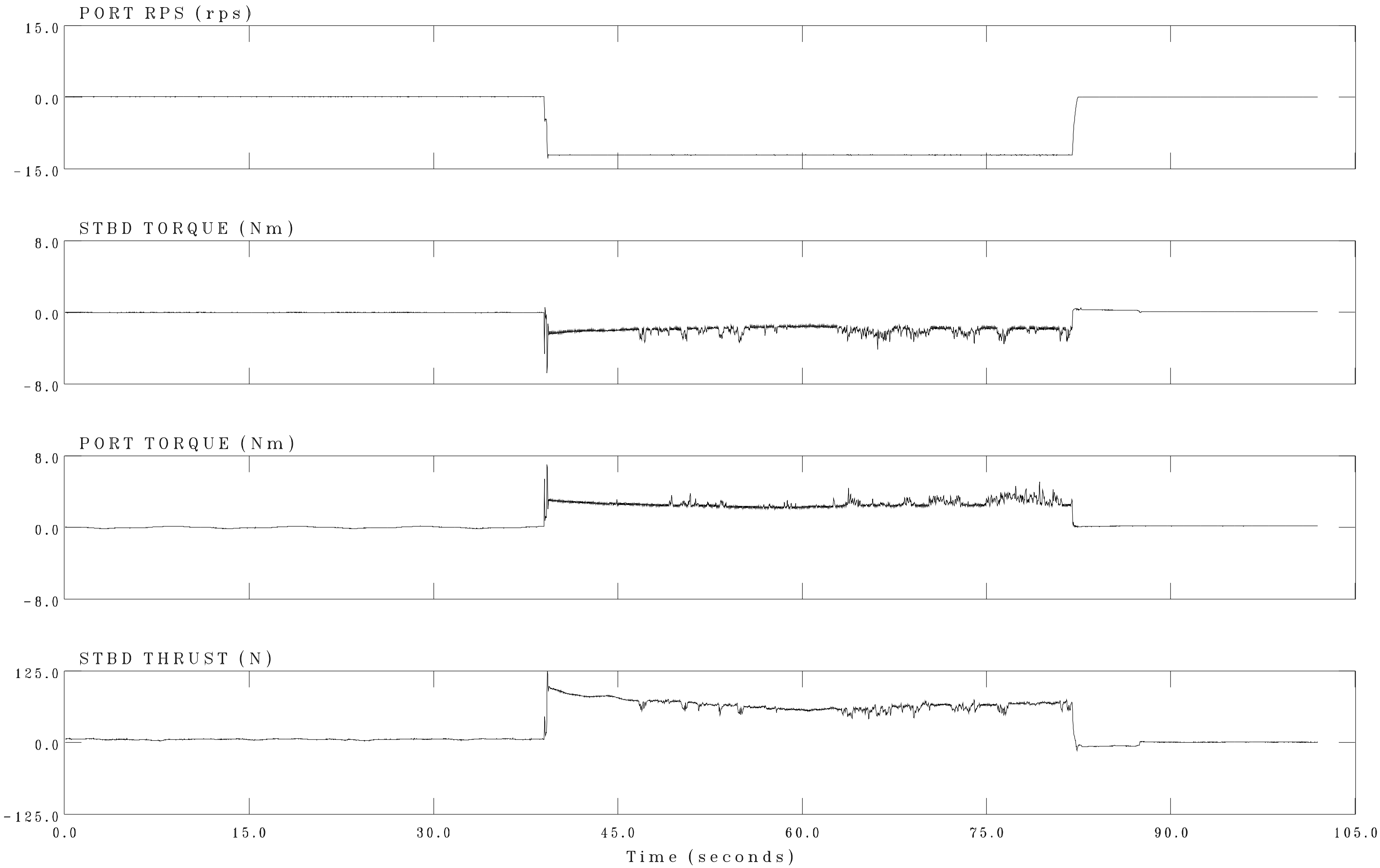
	Figure 1 fr_r3_s3_12rps_016		

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:34:58
Acquired: 29-NOV-2001 14:50:14



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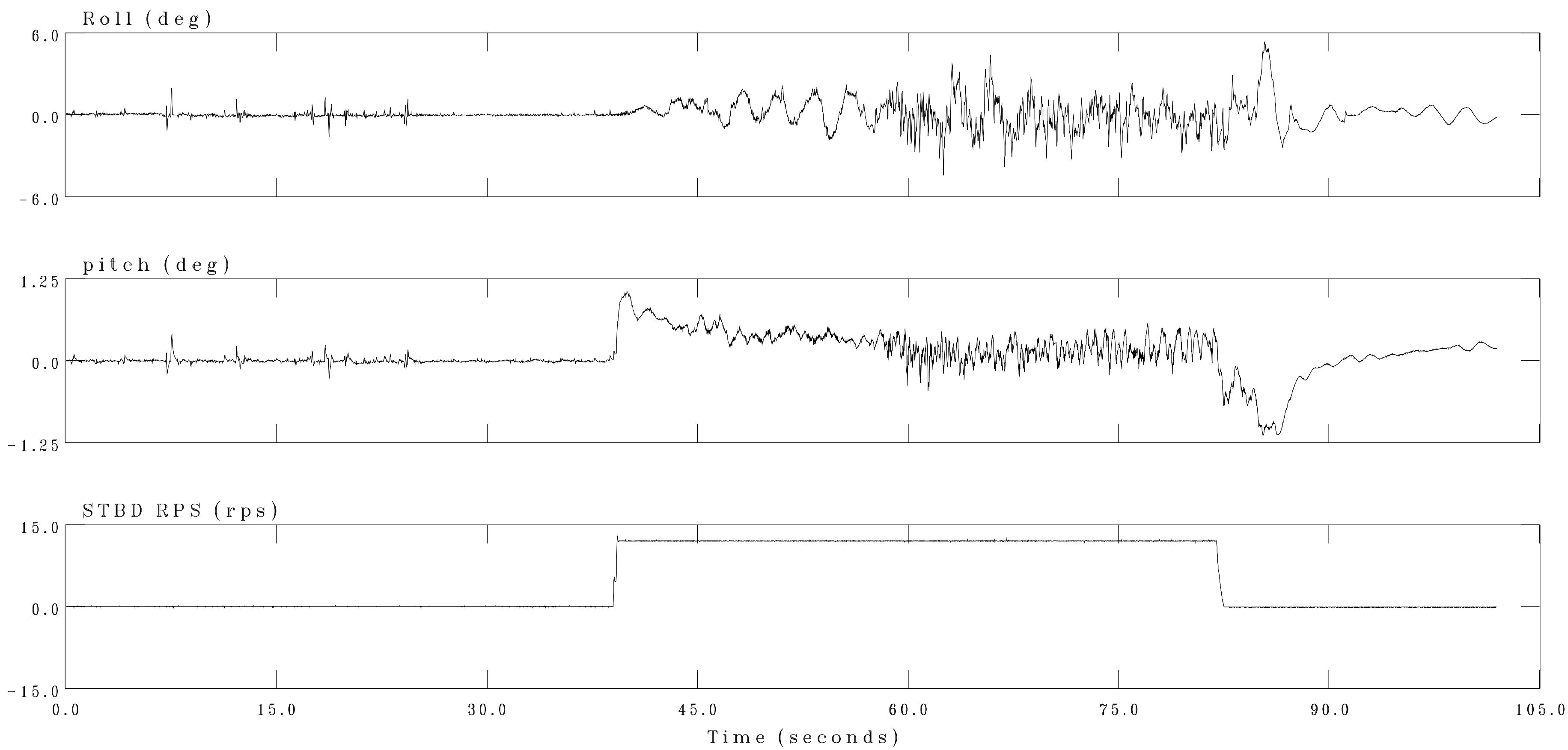
GENERATED BY: LAUM	CHECKED BY:	APPROVED BY:

Figure 2 fr_r3_s3_12rps_016

healy919
Phase 3

imd

Analyzed: 17-DEC-2005 13:35:03
Acquired: 29-NOV-2001 14:50:14



National Research Council Canada Institute for Ocean Technology	GENERATED BY: LAUM	CHECKED BY:	APPROVED BY:
	Figure 3 fr_r3_s3_12rps_016		

Appendix B
Ice sheet summary

NRC - INSTITUTE FOR MARINE DYNAMICS

ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: HEALY16 Project Number: 919

Warm up commenced: 03:25 23-NOV-2001

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0850	5.41	N	30.8 ± 1.6 n= 3									
		S	29.4 ± 0.4 n= 3									
0900	5.58	40N	30.0	94. ± 2.9								
			30.4	34.(u/d 36%)								
			30.5									
0902	5.61	40S	30.5	85. ± 5.0								
			30.7	43.(u/d 49%)								
1158	8.55	39N	31.1	49. ± 3.5								
			31.3	22.(u/d 45%)								
1201	8.60	39S	31.6	55. ± 4.3								
			31.9	22.(u/d 40%)								
1340	10.25	40	31.1		31.	32.5	1938	10.0				
1350	10.41	41S	31.0	16. ± 1.3								
			30.6	17.(u/d107%)								
1352	10.45	41N	30.8	33. ± 3.0								
			30.9	15.(u/d 44%)								
1432	11.11	N	31.9 ± 1.1 n= 9									
		S	31.4 ± 1.0 n= 9									
1523	11.96	N	31.6 ± 1.0 n=13									
		S	31.4 ± 0.6 n=13									
1552	12.45	N	31.1 ± 0.6 n=12									
		S	31.1 ± 0.8 n=12									
1612	12.78	43N	30.3	24. ± 2.0								
1616	12.85	43S	30.2	16. ± 2.2								
1618	12.88	43N	30.0									.923
1623	12.96	43S	30.1									.912

Run #	Date	Time	Hours from Warm-up	Flexural Strength north	south	mean
TURN CIRC 1	11/23/2001	1414	10.81	33.1	22.9	28.0
TURN CIRC 2	11/23/2001	1507	11.70	28.0	18.2	23.1
TURN CIRC 3	11/23/2001	1539	12.23	25.3	15.9	20.6

NRC - INSTITUTE FOR MARINE DYNAMICS

ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: HEALY17 Project Number: 919

Warm up commenced: 00:03 27-NOV-2001

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0819	8.27	N	42.2 ± 1.1 n= 3									
		S	41.3 ± 1.3 n= 3									
0841	8.63	40S	41.7		52.	104.7	2156	12.4				
0855	8.87	39N	41.9	49. ± 2.3								
			42.2	31.(u/d 63%)								
0857	8.90	39S	42.6	47. ± 2.6								
			42.4	34.(u/d 72%)								
1009	10.10	38N	42.5	47. ± 0.5								
			42.5	25.(u/d 52%)								
1011	10.13	38S	42.8	45. ± 1.7								
			42.7	33.(u/d 72%)								
1015	10.20	38S	42.7									.851
1050	10.78	N	41.8 ± 0.8 n=12									
		S	41.8 ± 0.8 n=12									
1055	10.87	40N	42.9	41. ± 5.8								
			42.4	14.(u/d 33%)								
1059	10.93	40S	42.9	21. ± 3.3								
			43.3	17.(u/d 80%)								
1200	11.95	N	42.0 ± 1.2 n= 9									
		S	42.0 ± 1.2 n= 9									
1213	12.17	36S	41.7									.880
1338	13.58	41N	42.0	29. ± 3.0								
			42.3	16.(u/d 54%)								
1340	13.62	41S	43.1	29. ± 1.0								
			42.3	16.(u/d 53%)								
1455	14.87	45N	42.8	23. ± 3.3								
			42.0	16.(u/d 69%)								

1457	14.90	45S	43.3	23. ± 4.4	
			43.2	19.(u/d 81%)	
1541	15.63	N	42.3 ± 0.5 n=13		
		S	42.6 ± 0.3 n=13		
1558	15.92	62S	41.8		.868

Run #	Date	Time	Hours from Warm-up	Flexural Strength north	south	mean
TURN CIRC 1	11/27/2001	0935	9.53	47.9	39.0	43.5
TURN CIRC 2	11/27/2001	1145	11.70	36.1	31.2	33.7
TURN CIRC 3	11/27/2001	1520	15.28	22.6	21.7	22.1

NRC - INSTITUTE FOR MARINE DYNAMICS

ARCTIC VESSEL RESEARCH SECTION

ICE MECHANICAL PROPERTIES SUMMARY

Test Name: HEALY18 Project Number: 919

Warm up commenced: 21:46 28-NOV-2001

Time	Warm-up hrs	Loc	hi mm	Sf kPa	Lc cm	E MPa	E/Sf	Lc/hi	K1c N/m	Sf/K1c m-.5	Sc/s kPa	Rhoi Mg/m3
0835	10.81	N	41.9 ± 1.2 n= 3									
		S	40.1 ± 0.1 n= 3									
0843	10.95	40S	41.8		46.	65.6	1256	11.1				
0858	11.20	40N	41.7	51. ± 2.2								
			41.3	30.(u/d 60%)								
0904	11.30	40S	40.4	50. ± 2.6								
			40.2	34.(u/d 67%)								
1030	12.73	39N	41.6	46. ± 3.4								
			41.6	24.(u/d 53%)								
1033	12.78	39S	41.0	53. ± 1.4								
			40.7	17.(u/d 32%)								
1114	13.46	38N	41.7	42. ± 1.8								
			42.0	29.(u/d 69%)								
1118	13.53	38S	41.1	49. ± 4.0								
			40.9	17.(u/d 34%)								
1225	14.65	37N	41.2	33. ± 2.7								
			41.3	21.(u/d 64%)								
1230	14.73	37S	40.7	34. ± 2.3								
			41.0	22.(u/d 64%)								
1314	15.46	N	40.7 ± 0.9 n=12									
		S	40.8 ± 0.9 n=12									
1331	15.75	24N	39.5									.861
1406	16.33	N	41.4 ± 0.8 n=12									
		S	41.3 ± 0.6 n=12									
1421	16.58	48N	41.2									.875
1434	16.80	36N	40.9	28. ± 1.2								

1439	16.88	36S	40.6	27. ± 1.3	
			40.5	16.(u/d 61%)	
1520	17.56	N	41.1 ± 0.6 n=11		
		S	41.3 ± 1.0 n=11		
1535	17.81	60S	41.1		.868

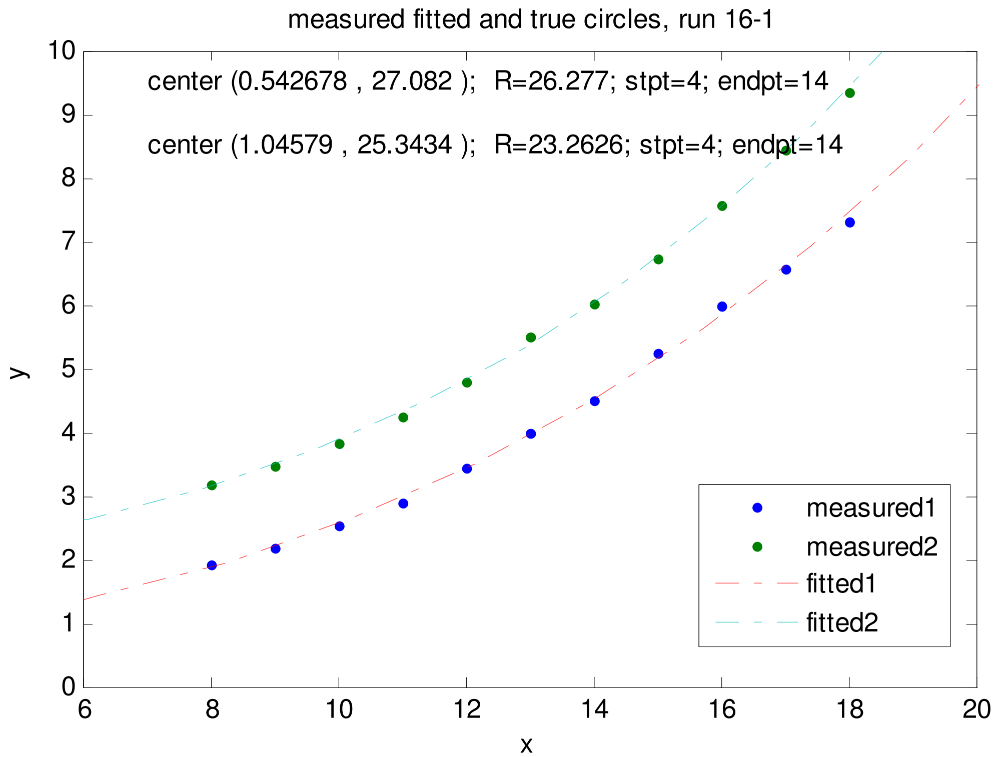
Appendix C
Turning circle diameter analysis

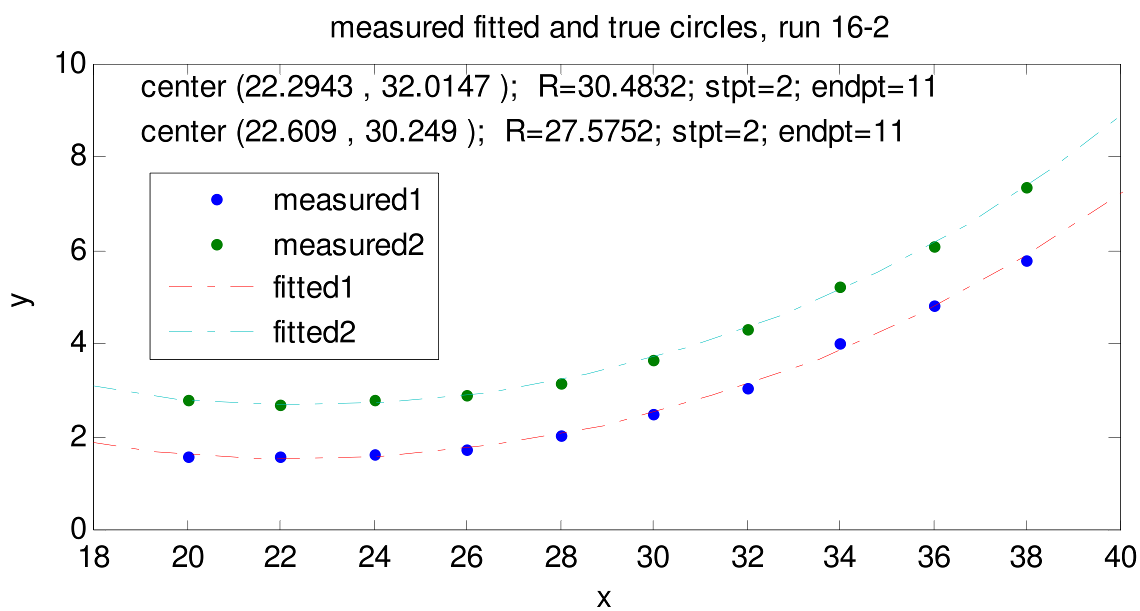
The turning diameter was estimated from the measured channel profile, i.e., a set of *x*, *y* pairs that are supposed to reside on a circular arc, but with some noise. For a set of measured *x* and *y* coordinate pairs, the equation for the circle to these points is:

$$(x-x_c)^2+(y-y_c)^2=R^2 \qquad \text{C1}$$

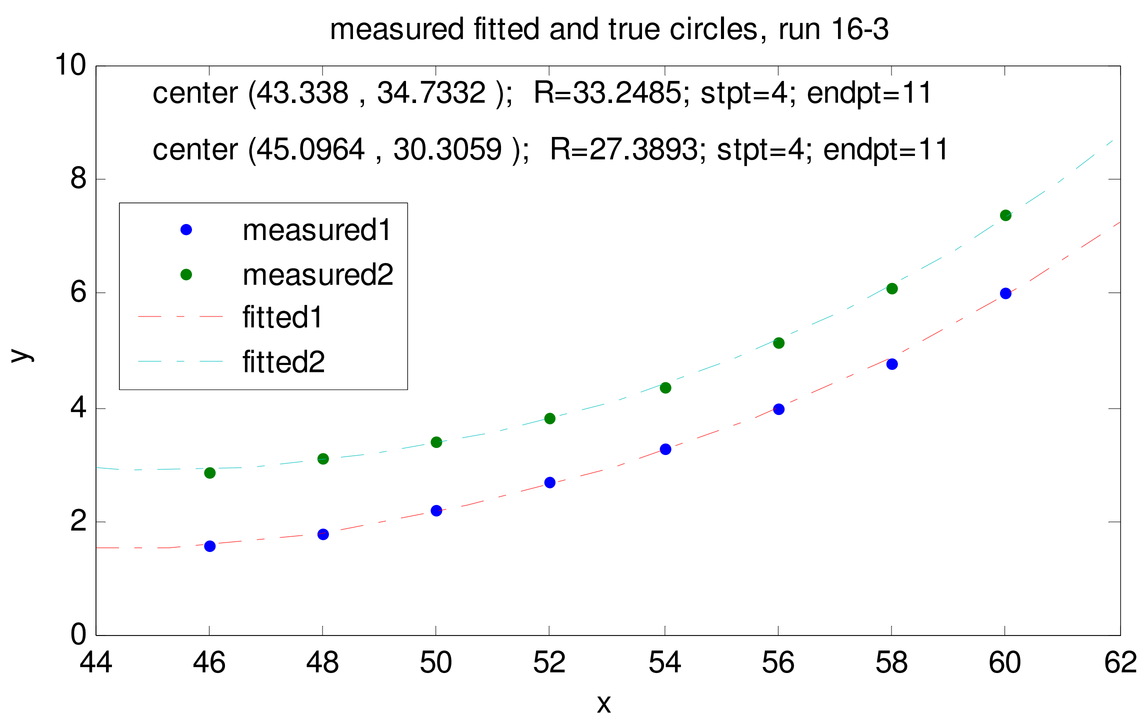
where x_c, y_c and R are the *x* and *y* coordinates and the radius of the circle, respectively.

Figures C1 to C8 show the channel profile for each test runs respectively.

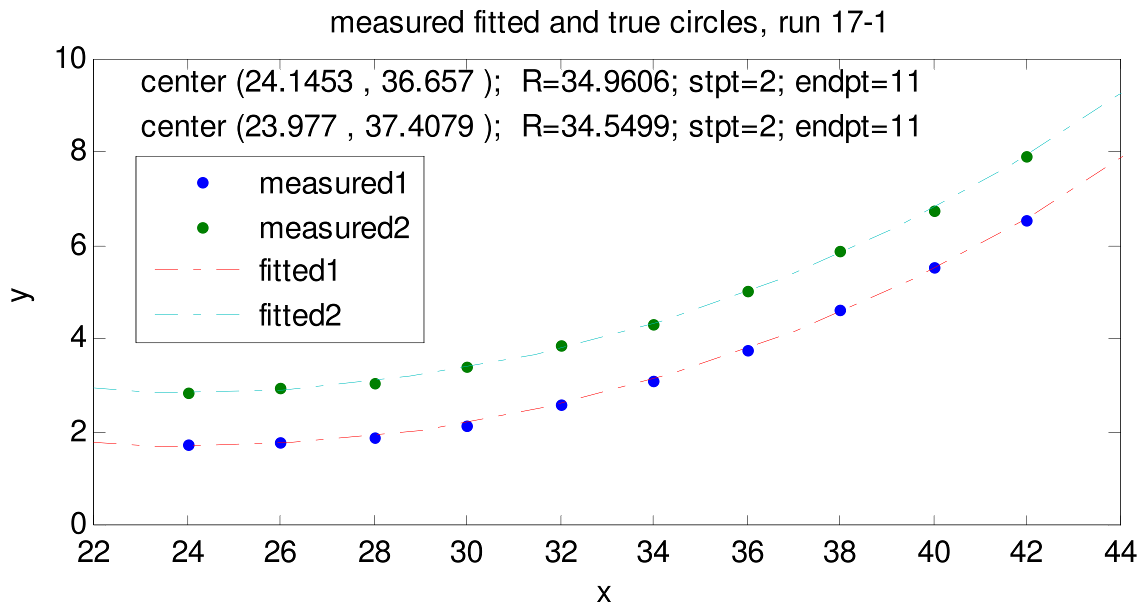


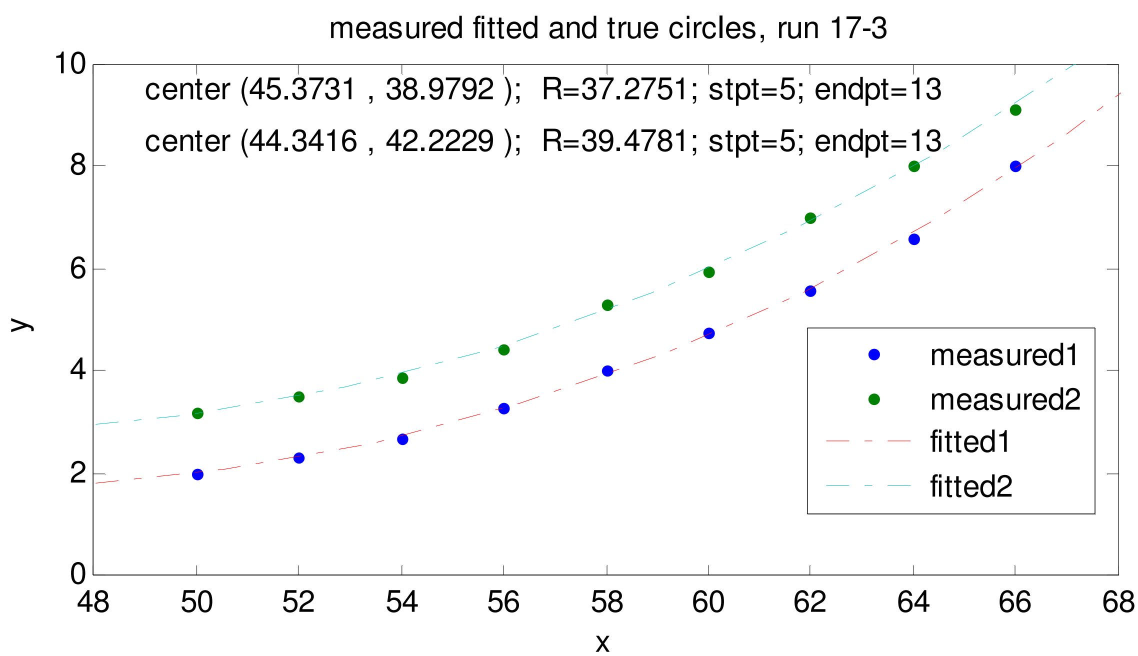


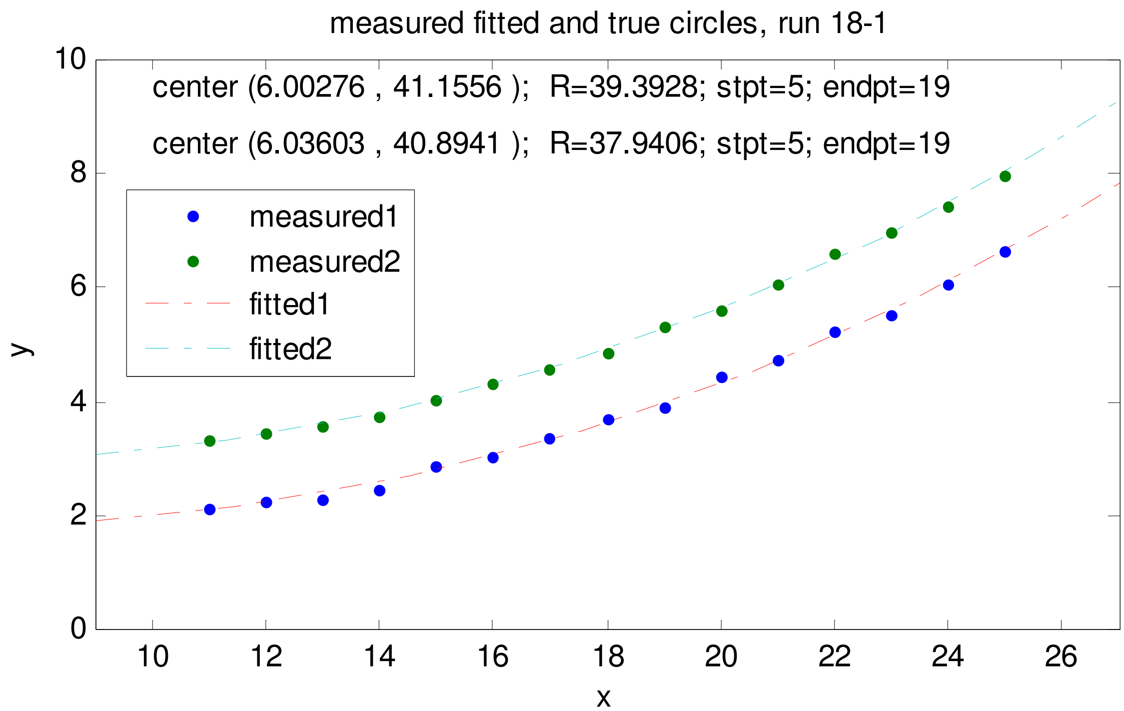
measured fitted and true circles, run 16-2
center (22.2943 , 32.0147); R=30.4832; stpt=2; endpt=11
center (22.609 , 30.249); R=27.5752; stpt=2; endpt=11
measured1
measured2
fitted1
fitted2
y
x

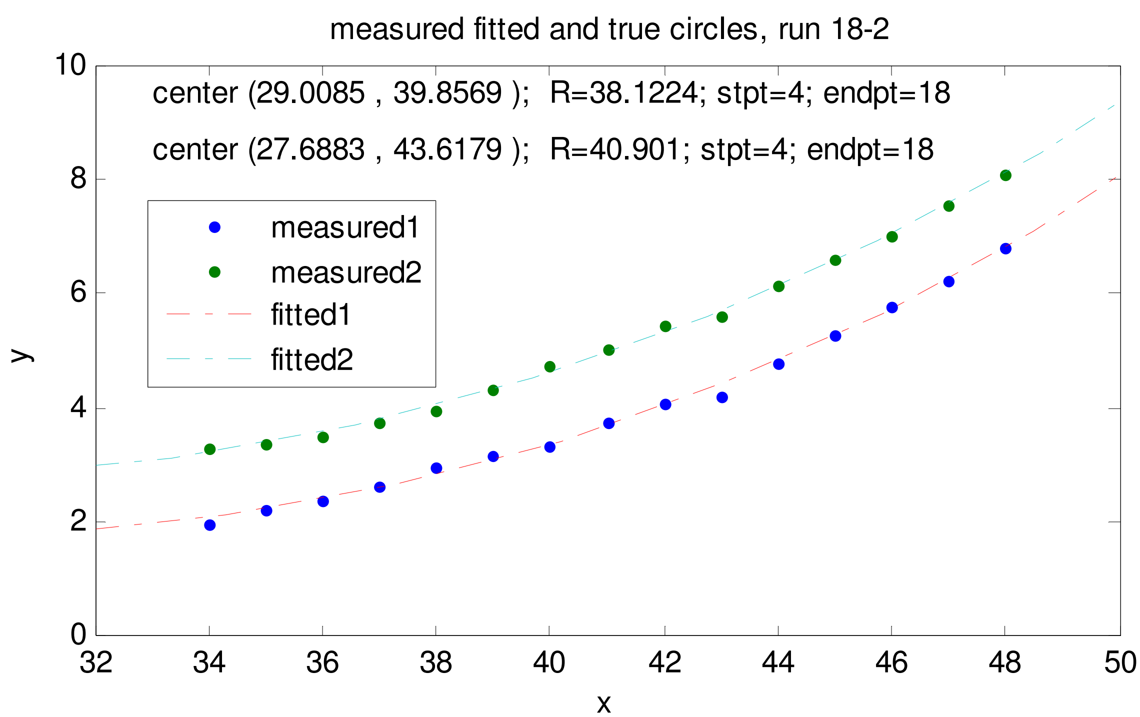


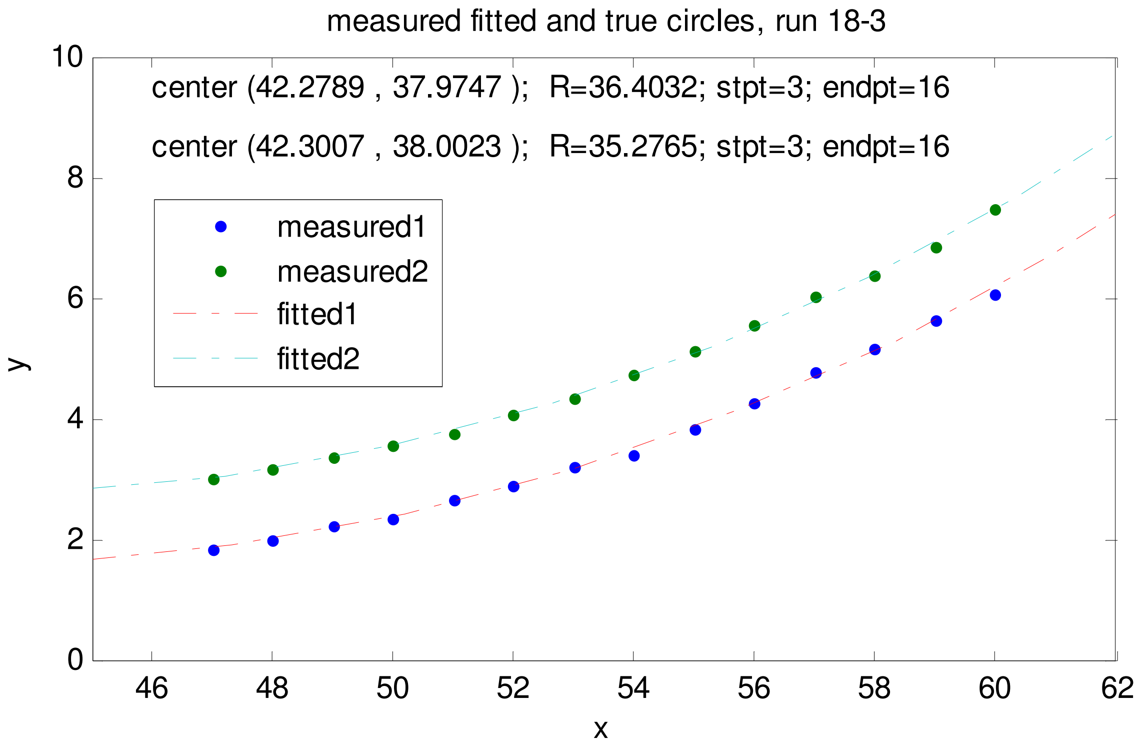
measured fitted and true circles, run 16-3
center (43.338 , 34.7332); R=33.2485; stpt=4; endpt=11
center (45.0964 , 30.3059); R=27.3893; stpt=4; endpt=11
measured1
measured2
fitted1
fitted2
y
x


measured fitted and true circles, run 17-1
center (24.1453 , 36.657); R=34.9606; stpt=2; endpt=11
center (23.977 , 37.4079); R=34.5499; stpt=2; endpt=11
measured1
measured2
fitted1
fitted2
y
x


measured fitted and true circles, run 17-3
center (45.3731 , 38.9792); R=37.2751; stpt=5; endpt=13
center (44.3416 , 42.2229); R=39.4781; stpt=5; endpt=13
measured1
measured2
fitted1
fitted2
y
x


measured fitted and true circles, run 18-1
center (6.00276 , 41.1556); R=39.3928; stpt=5; endpt=19
center (6.03603 , 40.8941); R=37.9406; stpt=5; endpt=19
measured1
measured2
fitted1
fitted2
y
x


measured fitted and true circles, run 18-2
center (29.0085 , 39.8569); R=38.1224; stpt=4; endpt=18
center (27.6883 , 43.6179); R=40.901; stpt=4; endpt=18
measured1
measured2
fitted1
fitted2
y
x


measured fitted and true circles, run 18-3
center (42.2789 , 37.9747); R=36.4032; stpt=3; endpt=16
center (42.3007 , 38.0023); R=35.2765; stpt=3; endpt=16
measured1
measured2
fitted1
fitted2
y
x
10
8
6
4
2
0
46
48
50
52
54
56
58
60
62