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Instrumentation Installation and Calibration

1. PURPOSE

This procedure establishes a guideline for installing and calibrating trial instrumentation for full-scale Speed/Power trials.

2. SCOPE

This procedure applies to installing and calibrating trial instrumentation for full-scale Speed/Power trials.

3. RESPONSIBILITIES

- The Trial Director is the duly authorized shipbuilder's representative responsible for the execution of all phases of the Speed/Power trials including the installation and calibration of trial instrumentation.
- The shipbuilder is responsible for the overall trial coordination between the ship's crew, trial team, and the owner's representative. A pre-trial meeting between the trial team, owner and the ship's crew will be held to discuss the various trial events and to resolve any issues regarding the installation and calibration of trial instrumentation.
- The trial team is responsible for the installation, calibration and maintenance of all required trial instrumentation and temporary cabling.


4. DEFINITIONS

None

5. PROCEDURES

5.1 Instrumentation Installation


1. The Trial Director will coordinate with the ship for the installation of the trial equipment. Specific trial instrumentation requirements will be provided by the Trial Director and Trial Engineer and are referenced in the 22nd ITTC Trials and Monitoring Specialist Committee Final Report. The Trial Director will schedule installation of instrumentation at a time of minimal conflict with ship operations. Figure 1 is an example of a typical instrumentation diagram. This figure gives the approximate locations of the equipment/sensors and data channels to be recorded.
2. The Trial Engineer is responsible for the proper handling, use, maintenance, calibration, and documentation of trial instrumentation before, during and after a ship trial. The procedure is as follows:
 - a. Begin a Trial Engineer's Notebook in which all details pertaining to the installation, calibration, and derigging of the trial instrumentation is documented.
 - b. Determine trial logistics i.e., installation location, trial site, etc.
 - c. Determine the installation requirements and prepare an instrumentation block diagram.
 - d. Determine required ship support (interfaces to ship equipment, calibration assistance, instrumentation spaces)
 - e. Determine special ship conditions, displacement, trim, clean hull and propeller

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- f. Determine scope of data collection and analysis software from the trial agenda
- g. Attend all meetings relevant to trial preparation and execution
- h. Purchase or rent required instrumentation as necessary
- i. If required, accomplish ship check as per Speed/Power Trials Ship Inspection Procedure 7.5-04-01-01.2, develop instrumentation plans, and prepare ship alterations.
- j. Direct and monitor trial instrumentation preparation by trial team
 - Determine instrumentation bias limits.
 - Coordinate calibration of instrumentation
 - Assemble all trials instrumentation in the configuration that will be used on the ship. Test the instrumentation system for malfunctioning instrumentation and/or any other complications.
- k. Coordinate development of onboard data collection and analysis
- l. Coordinate shipping arrangements and develop a shipping list of all instrumentation to be installed on the ship
- m. Brief installation team and make specific assignments
- n. Provide liaison with designated ship point of contact during installation
- o. Install instrumentation according to the installation requirements and instrument block diagram.
 - If portable radar tracking or differential GPS is utilized, a Receiver/Transmitter (R/T) unit or GPS antenna will be installed in a location along the ship's centerline as close to the ship's CG as possible. This location will ideally be located on a mast or site that is clear of obstructions, such as the ship's superstructure.
- p. Coordinate shipboard calibration checks
 - Determine bias limits on selected shipboard equipment
- q. Maintain instrumentation during the trial
- r. Document instrumentation problems during the trial.
- s. Coordinate equipment removal and shipping
- t. Coordinate return to inventory, refurbishment, repair, and post-calibration of selected equipment
 - Coordinate post-calibration of equipment
 - Identify and tag suspect or malfunctioning equipment.
 - Notify the appropriate personnel to effect repair of all malfunctioning test equipment.


5.2 Instrumentation Calibration Check

1. All shipboard signals to be recorded during the trials must be calibrated after the instrumentation installation is completed and prior to the trials. Appropriate personnel from the ship's/shipbuilder's crew will be requested to assist in the calibrations of the instrumented signals. Also, ship's crew will be requested to assist in the calibration of the control surface instrumentation. The control surfaces will be cycled throughout the full operating range of the system in various operating modes. The sign convention for ship motions and control surfaces for use in calibrations is shown in Figure 2.
2. There are two stages to consider in performing instrumentation checks; the pre-

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trial check process and the post-trial check process. The procedure used by the Trial Engineer to determine whether an instrumentation check (or calibration where applicable) is successful is as follows:

- a. Pre-trial instrumentation check process
 - Conduct process in accordance with established procedures.
 - Utilize linear regression to establish calibrated gain factors.
 - Calculate coefficient of determination (R^2) values for each instrumentation check. The R^2 value must be greater than or equal to 0.975 in order for the instrumentation check to be considered valid.
 - Calculate bias limits in accordance with procedures outlined in Uncertainty Analysis of Standardization Trials on a Navy Fleet Oiler report (CRDKNSWC/HD-1428-01, Sep 93)
 - Table 1 is an example of bias limit values for a particular instrument installation set-up and can be used as an indication of problems in a particular instrument or of the instrument set-up in its entirety.
 - Data sampling during a run is typically between 0.5 and 2 samples/second and is dependent on the physical phenomenon being recorded (see Speed/Power Trial Conduct 7.5-04-01-01.6).
 - Filtering run data is recommended to avoid “spikes” in the recorded time histories. The SC suggests the use of the Chauvenet’s Criterion (Coleman and Steele, 1989) that provides a ratio of maximum acceptable deviation to precision index as a function of the number of readings, (N). Readings are automatically rejected from use in the data analysis, when they fall outside of the selected mean value bandwidth.
 - b. Post-trial instrumentation check process (where applicable)
 - Conduct instrumentation check process in accordance with procedures.
 - Utilize linear regression to establish calibrated gain factors.
 - Calculate R^2 values for each instrumentation check. The R^2 value must be greater than or equal to 0.975 in order for the instrumentation check to be considered valid.
 - Calculate bias limits in accordance with procedures outlined in Uncertainty Analysis of Standardization Trials on a Navy Fleet Oiler report (CRDKNSWC/HD-1428-01, Sep 93)
 - Table 1 is an example of bias limit values for a particular instrument installation set-up and can be used as an indication of problems in a particular instrument or of the instrument set-up in its entirety.
 - If the difference between the pre-trial instrumentation check gain factor and the post-trial instrumentation check gain factor is greater than twice the average bias limit, the Trial Engineer must inform the Trial Director. Further analysis will then be required in order to determine the validity of the data recorded.
3. As part of the pre-trial calibration, the torsionmeter zero torque readings should be

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determined since there is a residual torque in the shaft, which is resting on the line shaft bearings. This is accomplished pier-side with the use of the jacking motors. The shaft is jacked both ahead and astern and the average of the readings noted. The zeroes are set at the midpoint of the torque required to jack each shaft ahead and the torque required to jack each shaft astern. Setting the zero in this manner means that the torque measured with the ship under way includes the torque required to overcome any bearing friction. The final torque values used are derived from the drag shaft procedure conducted immediately prior to the start of the Speed/Power trials. This particular procedure is outlined in Speed/Power Trial Conduct Procedure 7.5-04-01-01.6.

4. As part of the pre-trial calibration for a ship equipped with controllable pitch propellers, determine the maximum ahead pitch, design pitch, and maximum astern pitch and then adjust the ship indicators to reflect the measurement. Determine the corrections to account for changes in pitch due to shaft compression as thrust increases and temperature effects on the propeller pitch control rod. Additionally, verify the weight of the propulsor and hub from the manufacturer's specifications for use in making thrust measurement corrections

5.3 Instrumentation Removal and Post-Trial Calibration

1. Upon completion of the trials and at pier-side, the trials team will remove the trial instrumentation. Prior to removal of test instrumentation, trials team personnel may request post-trial calibrations of the ship's

signals, if necessary. Removal of all electrical connections will be coordinated with the ship's crew and/or shipbuilder.

6. REFERENCES


1. 22nd ITTC Trials and Monitoring Specialist Committee Final Report
2. Uncertainty Analysis of Standardization Trials on a Navy Fleet Oiler report (CRDKNSWC/HD-1428-01, Sep 93)
3. Speed/Power Trials Ship Inspection Procedure 7.5-04-01-01.2
4. Ships and marine technology – Guidelines for the assessment of speed and power performance analysis of speed trial data, Final Draft International Standard ISO/FDIS 15016:(E), ISO/TC 8/SC 9/WG 2 of 2001
5. Speed/Power Trial Conduct Procedure 7.5-04-01-01.6
6. Coleman, H.W. and Steele, W. G., 1989 "Experimentation and Uncertainty Analysis for Engineers", John Wiley & Sons, Inc., 1989.

7. RECORDS

1. Trial Engineer's Notebook
2. Trial equipment shipping list
3. Instrumentation block diagram
4. Trial agenda

8. ATTACHMENTS

1. Table 1. An Example of Bias Limit Values of Various Trials Data Channels for Verification of Acceptable Instrumentation Installation
2. Figure 1. Typical instrumentation diagram

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3. Figure 2. Sign convention used for ship motions.

The 22nd ITTC SC Final Report indicates the importance of obtaining a continuous data recording of a measurement by means of a computer and the conducting of an uncertainty analysis on that data. Consequently, the predecessors of the current SC listed the following measurements in order of their importance:

1. Primary – These quantities represent the critical trial data that must be acquired in order for the trial to be considered valid:

- a. ship speed over the ground
- b. shaft torque
- c. shaft revolutions

2. Secondary - These quantities are important in order to correct trial data, if required, and to provide a more precise evaluation of the behavior of the ship during the speed runs. These measurements are used to determine the validity of the trial results:

- a. relative wind speed and direction

- b. water depth
- c. wave and swell height, length, period, and relative direction
- d. rudder angle
- e. ship heading and ship track

3. Tertiary - The following is a suggested list of data to be acquired in the course of conducting speed runs to increase the level of confidence in the trial results and/or to add scientific knowledge in the development of procedures to correct for environmental actions:

- a. ship pitch angle
- b. ship roll angle
- c. propeller pitch
- d. propeller shaft thrust

It should be noted that it may not be possible to obtain a continuous recording for some of the “measurements” such as swell length, period or direction. Measurements such as these are listed accordingly to indicate it’s usage in the trial data analysis, specifically the correction of trial data to account for environmental and/or ship conditions.


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Table 1. An Example of Bias Limit Values of Various Trials Data Channels for Verification of Acceptable Instrumentation Installation

Channel Name	Units	Bias Error	Typical Full Scale Value	Percent Error Relative To Typical Full Scale Value
Control Surface	deg	± 0.500	25.0	2.0
EM Log	kn	± 0.500	40.0	1.25
Heading	deg	± 1.000	360.0	0.3
Roll	deg	± 0.500	60.0	1.0
Pitch	deg	± 0.500	30.0	1.7
Depth	m	± 5.000	120	1.3
Throttle Ahead	turns	± 0.200	15	1.3
Throttle Astern	turns	± 0.200	14	1.3
1st Stage Shell	kPa	± 10.000	5170	1.3
Load Cell	Nm	± 1,800	81,350	3.0
Thrust				
Shaft Speed	r/min	± 0.500	100.0	0.5
Roll Rate	deg/s	± 0.200	18.0	1.1
Pitch Rate	deg/s	± 0.200	18.0	1.1
Yaw Rate	deg/s	± 0.200	18.0	1.1
Astern Bowl	kPa	± 10.000	5170	1.3
Oil Pressure	kPa	± 30.000	20,680	1.0
Vacuum	kPa	± 0.200	101	1.4
Shaft Torque	Nm	± 5,000	677,900	1.0
X Acceleration	m/s ²	± 0.010	9.8	1.0
Y Acceleration	m/s ²	± 0.010	9.8	1.0
Z Acceleration	m/s ²	± 0.010	9.8	1.0
Ship Speed	kn	± 0.100	20.0	0.5
Wind Speed	kn	± 0.500	40.0	1.3
Wind Direction	deg	± 5.000	360	1.4
Propeller Pitch	%	± 2.000	120.0	1.7

If one of the prescribed channels does not conform to the standards presented above, it is the responsibility of the Trial Engineer, in conjunction with the Trial Director and appropriate personnel to ascertain the problem with the instrumentation and resolve the problem in an expeditious manner. Trial team personnel

should use engineering judgment to remedy problems as applicable.

The calculated bias error must result in a value less than or equal to the percent error relative to the typical full-scale value, shown in the table above.



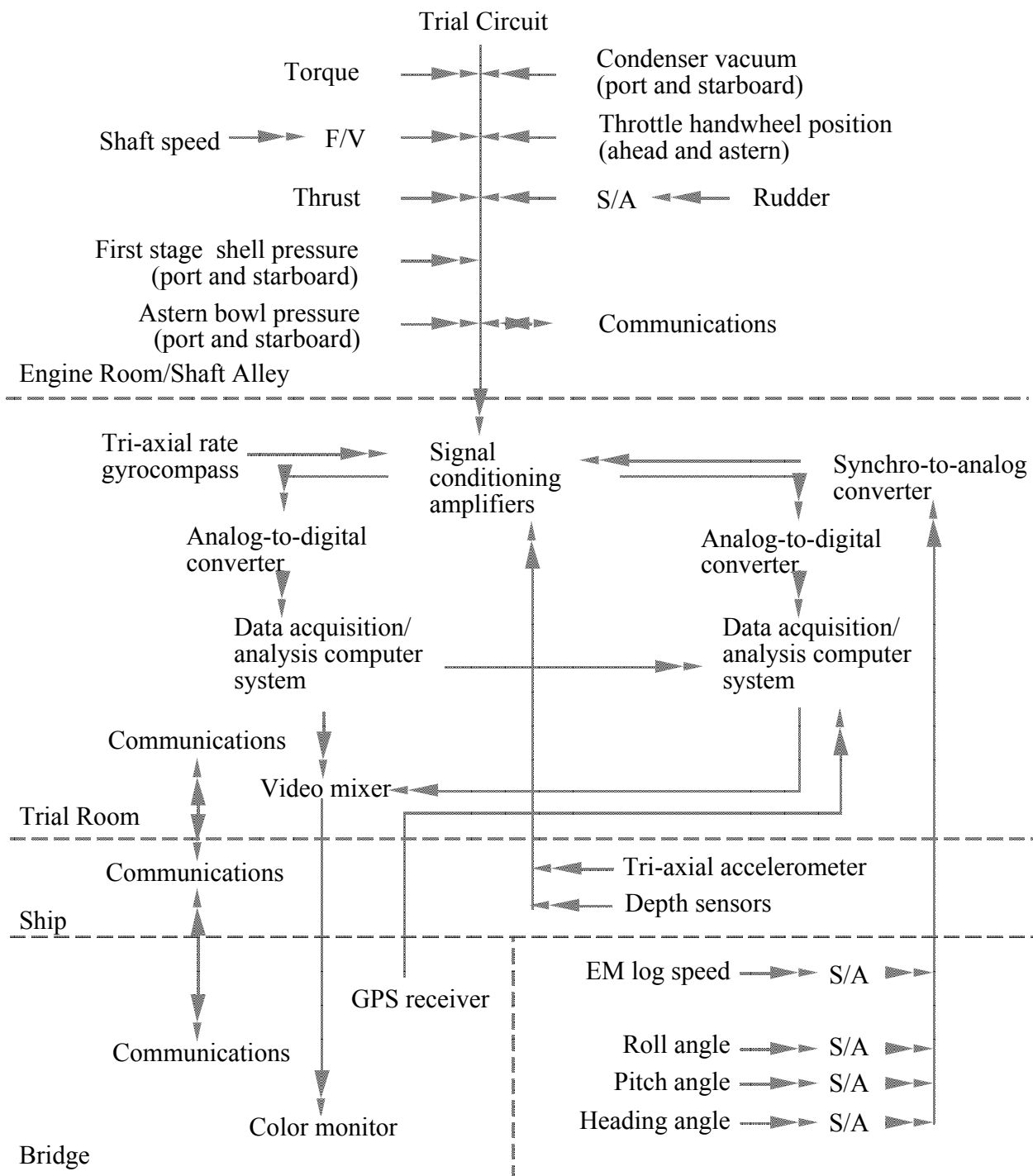
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Notes: S/A = synchro-to-analog
F/V = frequency-to-voltage


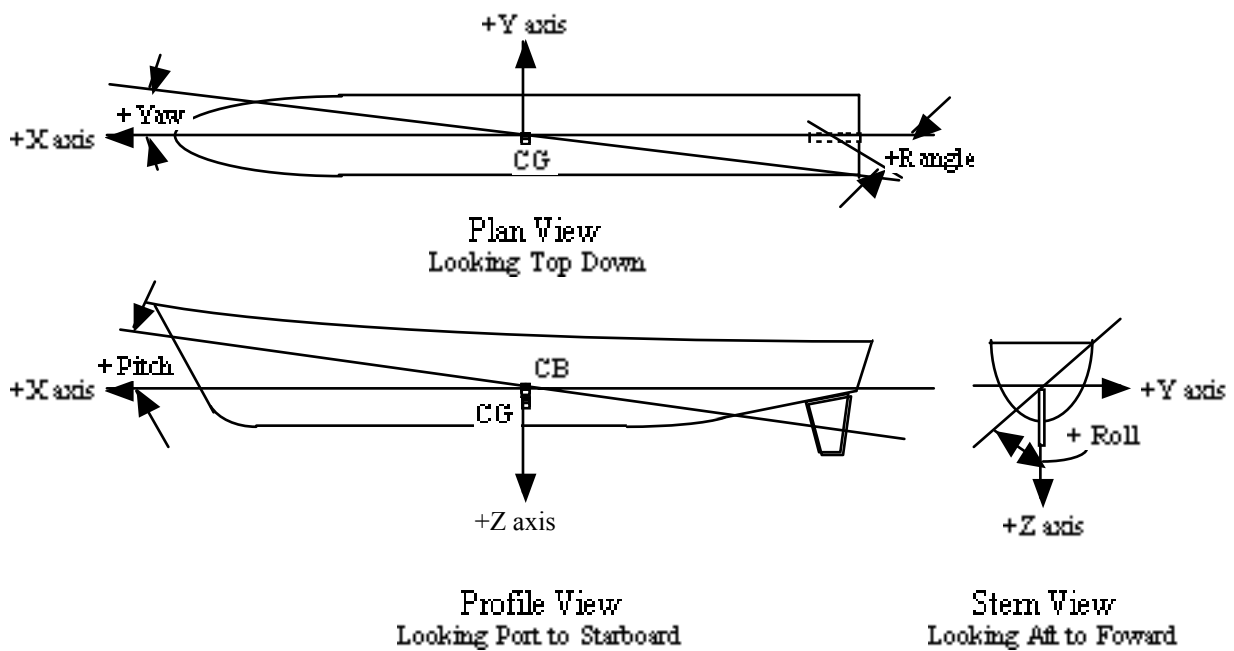
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Figure 1. Typical instrumentation diagram.



All clockwise ship motions and control surfaces are considered positive when the ship is viewed from port to starboard, top down, and aft to forward as indicated above.

Note: R = rudder
 CB = center of buoyancy
 CG = center of gravity

Figure 2. Sign convention used for ship motions