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Measurements during SWATH Ship Sea Trials

A new ship must undergo a rigorous set of sea trials to receive final certification [1]. The sea trials program measures the vessel's performance against its design specifications and code requirements. The performance evaluation includes the ship's powering requirements (ability to achieve and maintain its design speed in a variety of conditions), fuel economy, maneuvering capabilities (safe and efficient handling), and seakeeping ability (stability and comfort in a seaway).

One of my tasks over the past few years has been to measure a ship's performance during sea trials. These tests require temporary measurement equipment not usually contained in the ship's built-in instrumentation suite. This article describes that temporary measurement equipment and its operation.

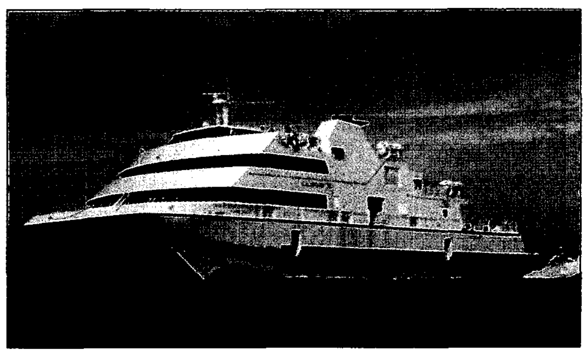

Fig. 1. Super 4000 Class passenger ferry, Cloud X during sea trials (courtesy of Swath International Limited).

Cloud X Sea Trials

Swath International, Ltd. is currently conducting trials on its new Super 4000 passenger ferry, Cloud X (see Fig. 1). This builder's trials phase of testing will be followed by acceptance trials required for U.S. Coast Guard certification. The trials are being conducted in the Pacific Northwest, where the vessel was built. Upon certification, the Cloud X will relocate to Florida, where it will operate daily round trips between Miami and Key West.

A portable, PC-based measurement system monitors, records, and analyzes signals from over 50 measurements, incorporating signals from onboard systems as well as from sensors added for these trials. The system already provides valuable data for design verification, system debugging, and an early assessment of the Cloud X's speed, power requirements, fuel economy, and maneuvering ability.

About the Cloud X

The Cloud X is a small-waterplane area, twin-hull (SWATH) ship. Fig. 2 shows the basic geometry of a SWATH ship. The waterplane area is defined as the cross-sectional area of a ship's hull, in the horizontal plane, at the waterline. By reducing this area and separating it between the two hulls, a SWATH ship has a far superior ride in rough seas, when compared to more conventional ships. While the Cloud X resembles a catamaran above the water, the photo in Fig. 3 shows how narrow the struts are near the waterline, allowing this ship to run more comfortably in high seas. A properly designed SWATH ship will often have the motion characteristics of a ship ten times its displacement.

The Cloud X is the first in the Super 4000 class design and is the product of many years of research by Swath International.

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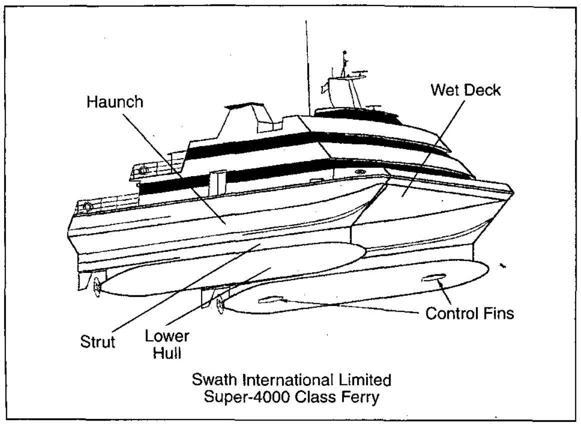

Fig. 2. Typical design geometry for SWATH (courtesy of Swath International Limited).

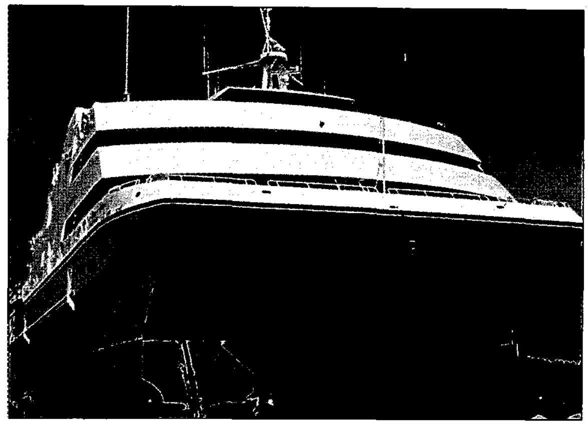

Fig. 3. Super 4000 Class passenger ferry, Cloud X on land (courtesy of Swath International Limited).

The design is quite complex, and the vessel contains many industry firsts. For example, Cloud X is the first SWATH passenger ferry in the world to combine a gas turbine-propulsion system and the SWATH hullform. It also is the first in the United States to be designed and built under the new international set of regulations for high-speed craft [2].

The Cloud X is a lightweight aluminum ferry, 37.5 m long, 18 m wide, and designed to carry up to 367 passengers at a design speed of 27 knots. Two 4000-hp gas turbines, each in a lower hull, power the ship through reduction gearboxes that turn four-blade, controllable-pitch propellers. The ship has rudders behind each propeller for turning at speed and uses differential propulsion for maneuvering at low speed. A novel ride-control system enhances the already excellent seakeeping characteristics of the SWATH hullform. Four horizontal stabilizing or control fins maintain the running trim, heel, and average deck height above the water. The fins also actively control the ship's motions in rough seas [3].

Try explaining to the Captain and crew of a $20M ferry, operating in a crowded shipping lane, that they need to "wait a minute," while your computer finishes printing out data, so you can record their next maneuver.

Ride-Control System

The ship's ride-control system uses information from motion sensors to control the angular position of the two pairs of fins mounted on the inboard sides of the lower hulls (see Figs. 2 and 3). The system supplies control forces and moments that are proportional and in opposite sense to the wave-induced motions. A control computer monitors the ride-control sensors, computes the ship's motions, and generates the appropriate command signals to the individual electromechanical actuators for the fins.

Two automatic control modes operate differently depending on the wave height (Fig. 4). When the waves are moderate to high, the controller keeps the ship straight and level, or platform, to minimize the ship motions. In extreme waves, the controller causes the ship to follow, or "contour," the waves rather than try to drive through them. A proprietary "antislam" algorithm gives the ship the minimum vertical motion to avoid slams and maximize passenger comfort.

The system uses four vertical and three horizontal accelerometers to resolve motions. Instrumentation on the fin shafts measures fin angle, as well as fin lift and drag forces. Pressure gauges, mounted fore and aft through the bottom of each lower hull, sense the depth of the hulls below the water's surface. A temporary ultrasonic sensor mounted out over the bow measures the relative bow height of the main deck to the sea surface; it has also been used to calibrate the draft sensors at various speeds.

Sea Trials Instrumentation and Measurements

The data-acquisition hardware chosen for the sea trials had to be easily transportable and expandable to add new channels and have supporting software that would not take too long to program. The hardware had to support multiple signal types (analog current/voltage, counter-timer, digital, and RS232) from both the existing onboard sensors and the sensors added just for the sea trials. The system software had to monitor, log, and replay data and calculate basic statistics.

Data-Acquisition Hardware

I chose an IOtech DaqBook 120 as the main data-collection unit, since it could easily be transported between the office and the ship during the early stages of the project. It is housed externally and connects to either a laptop or a desktop computer through a standard or enhanced parallel port. The unit has provisions for analog and digital I/O, counter timer inputs, and D/A output, providing up to 100k readings/s throughput. With three (DBK-15) multiplexer cards, the DaqBook is currently configured for up to 61 analog input channels, with expansion capability to 256. These universal input multiplexer cards with their built-in PGIAs (amplifiers), various jumper settings, and scaling resistor sockets, can be easily configured to accommodate a wide range of analog voltage/current input levels.

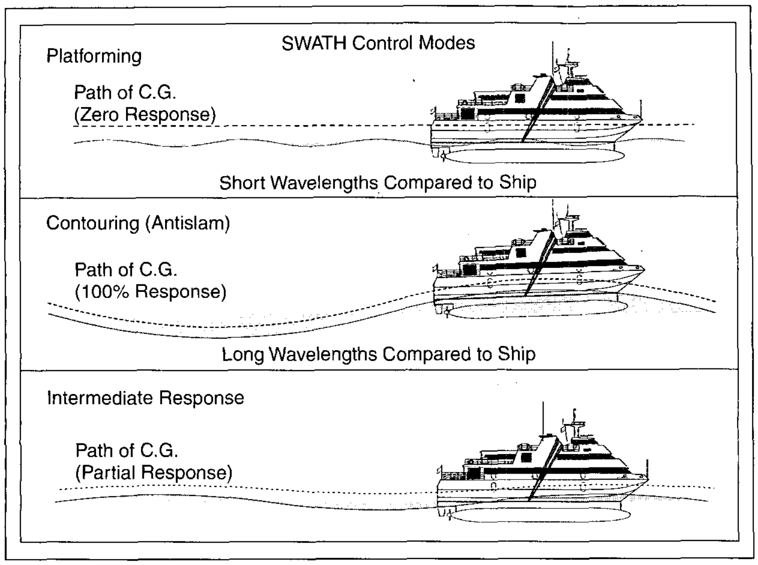

Fig. 4. Modes of automatic ride control (courtesy of Swath International Limited).

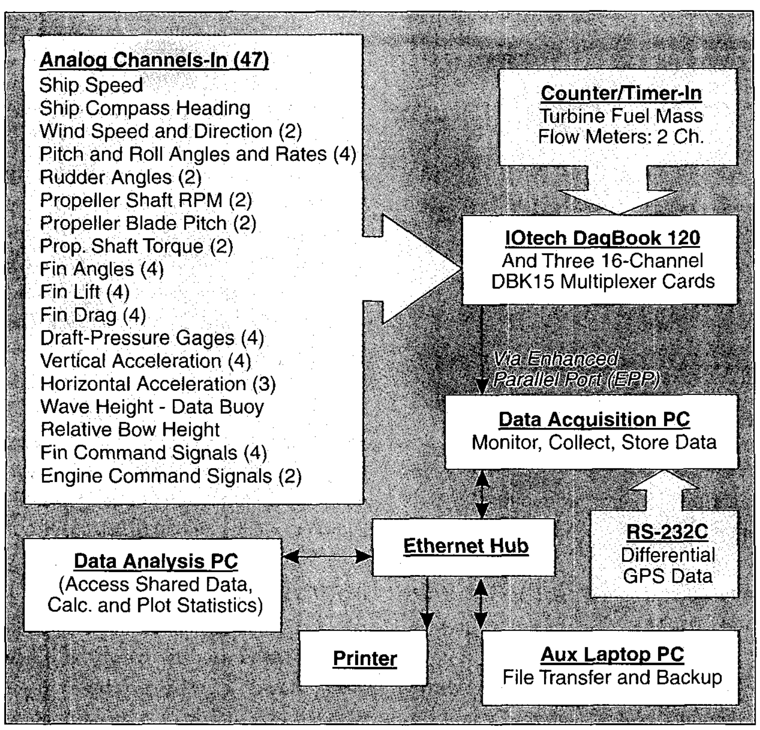

Fig. 5. Block diagram of the measurement path (courtesy of Swath International Limited).

Fig. 5 shows the separate data collection and analysis computers on a Windows peer-to-peer Ethernet network. The data-collection computer always stays in "collect mode" and can start recording to disk with a single keystroke. The analysis computer can simultaneously access shared data files, run analysis, and print results. Also, new or updated software developed offship can easily be transferred from a laptop using the network. Early attempts to log data with just the laptop and print the results during testing ended in some frustration. Try explaining to the captain and crew of a $20M ferry, operating in a crowded shipping lane, that they need to "wait a minute," while your computer finishes printing out data, so you can record their next maneuver (ouch)!

The analysis computer's additional serial ports are connected to sensors that provide setup and calibration options via RS232. For example, the calibration procedure for the KVH fluxgate compass is initiated in software and involves rotating the ship slowly through 360°, after which, the program gives a score indicating the accuracy of the calibration. The ship's ultrasonic over-the-bow sensor can also be accessed and set up via RS-232, providing additional information, including outside air temperature, while supplying the "relative bow motion" measurement as an analog signal to the Daqbook.

Software

DATA ACQUISITION

A commercial Windows software package, SnapMaster, from Hem Data, provides the data collection and analysis. The software allows easy access to the various functions of the DaqBook without requiring programming. Features include the ability to set up and change channel lists, data sample rates, and recording times as needed. A sensor database tracks the calibration history of each sensor and applies its scale factors to the measured data. Data from various input types (analog-in, counter timer, and RS232) can be monitored and logged to disk using a graphical interface. Fig. 6 shows a typical display page with the icon style "instruments" for data acquisition and analysis shown above the data plots. Measurements can be displayed in several graphic formats on up to eight different screens.

Although the software can collect data on RS-232, getting the GPS data stream from RS232 into the SnapMaster program was not so easy. Ultimately, a small Visual Basic program was written to parse the

GPS "messages" into individual channels that could be read using a dynamic data exchange (DDE) input function.

ANALYSIS

Typically, the recorded time histories are replayed on the screen and a time slice is identified that best represents the condition of interest. The basic statistics (minimum, maximum, mean, and standard deviation) are then computed over the selected range for each channel, and exported to a summary spreadsheet (using DDE). Additional capabilities of frequency and histogram analysis and digital filtering are used in some cases. Measured data channels can also be combined to create new "calculated" channels that can be analyzed in the same way as the measured signals. For example, this feature is used to create a "shaft-horsepower" channel from the torque and RPM channels.

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Measurements and Sensors

50 CHANNELS

The initial sea trials plan called for 16 channels to assess the Cloud X's powering, fuel economy, maneuvering, and seakeeping performance. The channel list grew to over 50 sensors after the system was installed—a typical problem with engineers. Table 1 provides a list of the measurements with the general types of signals and transducers used. The channel types are mostly analog except for GPS data and fuel-flow measurements. Of the 47 analog channels, six come from the propulsion system control panels and 28 come from the ride-control system. The remaining measurements are from sensors placed onboard only for the trials. In some cases, the ship has a permanent transducer that is either inaccessible or unavailable, such as the ship's permanent rudder angle sensors. For the rudders, a temporary

Table 1. List of Measurements and Sensors.

Measurement	*Signal*	*Transducer*
Ship speed	0-5 V	Paddle-wheel type
Ship compass heading	±2.5 V	Electronic fluxgate compass
Wind speed and direction	4-20 mA	Anemometer on ship's mast
Pitch and roll angles and rates	±5 V	Stabilized vertical reference
Rudder angles (2)	0.5-1.5 mA	Rudder angle—rotary ±45°
Propeller shaft RPM (2)	0-5 V	From propulsion control panel
Propeller blade pitch (2)	±10 V	From propulsion control panel
Prop. Shaft torque (2)	±2 V	Torque/strain gage transmitter
Fin angles (4)	0-10 V	Rotary angle transmitter
Fin lift (on fin shafts) (4)	0-10 V	Strain gauge bridge on fin shaft
Fin drag (on fin shafts) (4)	0-10 V	Strain gauge bridge on fin shaft
Draft-pressure gauges (4)	0-10 V	Thin-film-type pressure gage
Vertical acceleration (4)	0-10 V	Inertial grade, linear servo-type
Horizontal acceleration (3)	0-10 V	Inertial grade, linear servo-type
Wave height data buoy	±5 V	50-cm diameter buoy with telemetry
Relative bow motion	4-20 mA	Ultrasonic distance sensor
Fin command signals (4)	0-10 V	D/A from ride control system
Turbine command signals (2)	0-10 V	From propulsion control panel
Fuel flow rate (2)	0-2000 hz	Turbine-type mass flow meter
GPS—latitude, longitude, course (over ground), speed (over ground), timecode	Via RS232	Differential GPS (DGPS)

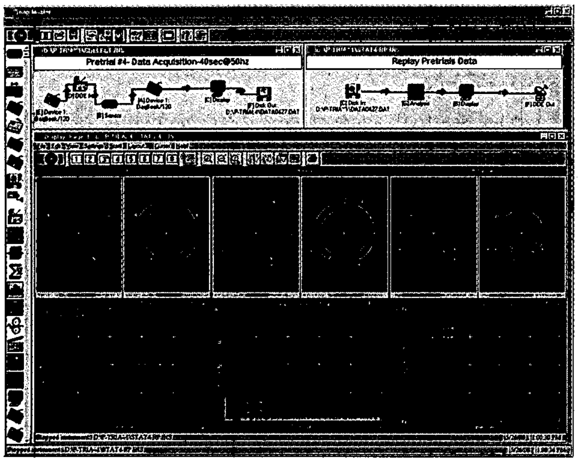

Fig. 6. Data-collection screen (courtesy of Swath International Limited).

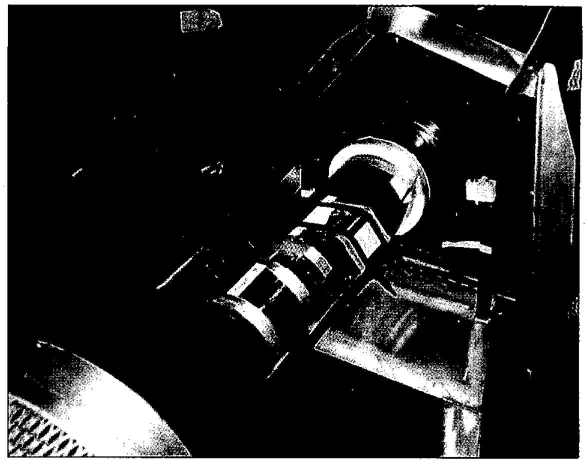

Fig. 7. Torque sensor setup on propeller shaft: gauges, batteries, transmitter, and antenna (courtesy of Swath International Limited).

sensor placed in parallel provides the measurement during trials. Signal cables running from all sensors or cabinets to the DaqBook mount to the ship's overhead (or ceiling) and can be easily removed. We installed some equipment, such as the anemometer and the differential GPS (DGPS) beacon receiver just for the sea trials, but they have now become part of the ship's permanent equipment. While the sensors are too numerous to discuss in detail, a few examples are discussed below.

TORQUE-HORSEPOWER MEASUREMENT

A small system measures propeller torque with a strain gauge bridge bonded to the ship's propeller shaft. A battery-powered transmitter provides excitation to the strain gauges and transmits the strain data on a 49-MHz FM signal to a receiver/demodulator, where it converts to an analog signal that is proportional to the torque. The transmitter and batteries are actually taped to the propeller shaft (Fig. 7).

While providing excellent results, the initial use of this torsion measurement was not without some start-up problems. On one of the first trips out to sea, the torque transmitter batteries died and Cloud X had to shut down one shaft at a time, in a busy ship channel, so that a fresh set of batteries could be strapped onto the propeller shaft. After that embarrassment, I replaced them with higher amp-hour rechargeable batteries that could run several days on a single charge. Unfortunately, the crew came in early one morning and fired up the turbines before I had a chance to warn them about the battery chargers and the extension cords that were still attached to batteries on the propeller shafting. The 150-ft extension cord traveled across the deck rather quickly and disappeared down a hatch in the main deck as it wrapped itself around the propeller shaft at 300 rpm. On yet another trip to sea, having mastered communication with the crew about the chargers, I forgot to switch the transmitters on prior to leaving port. So, the request had to go out to the captain once more to please shut the turbines down (again, in a busy ship channel) so that each transmitter could be switched on. This may be why they are called "Trials."

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FIN CALIBRATION

Calibration of the fin shaft lift and drag at the shipyard is not elegant, but quite effective. The task involves rotating the fin shafts through various angles with heavy preweighed concrete blocks attached (Fig. 8).

DAQ FLEXIBILITY

On recent sea trials, the flexibility of the measurement system was demonstrated when a problem developed with the propeller pitch indicator circuit. We quickly mounted two linear string potentiometers to the propeller's hardware to replace the problematic signal, and with a couple hundred feet of cable, a signal conditioner, and a quick calibration, voila!

Test Results

Powering

Powering data is probably the most important information to the ship's owner, since it defines the operating speed and fuel economy that can be expected when the ship goes into service. We must identify the optimum running conditions during the sea trials because the torsion meter will only be onboard during the sea trials. We evaluate Cloud X's propulsion system by measuring the propeller shaft rpm and shaft torque and calculating the ship's shaft power versus its speed for a number of running conditions. Tests will determine the most economical running trim angle using fins and movable water ballast.

The Cloud X has achieved its design speed during the sea trials. Speed trials are traditionally conducted on a marked "measured mile" course, but with DGPS on board, the ship's speed can be determined accurately at any time.

Maneuvering

Measurements of the ship's speed and trajectory, using DGPS, during various maneuvers help quantify the ship's maneuvering performance. Rudder angles, speed, power, trim, and heel angles are all monitored together with the ship's trajectory in a turn. Turns are conducted at various speeds, and the effects of wind and current can be deduced from the data to compare the performance between various runs.

Seakeeping and Ride-Control Evaluation

Using the measurements of pitch and roll angles and rates, vertical accelerations, and relative bow motion, along with seaway data from a wave buoy, the Cloud X's motion data can be compared with the detailed design predictions that were based on model test data and seakeeping prediction programs. Ride-quality analysis will be conducted on the acceleration measurements (typical one-third octave vertical accelerations) and compared to published habitability standards and motion-sickness data [4]. The motions will be measured with the ride-control system on and off, so that its effectiveness can be evaluated and adjustments made if necessary.

Summary

The hydrodynamics of a SWATH ferry such as the Cloud X are extremely complex and subject to many variables. The sea trials measurement system onboard has already provided valuable insight into the variables affecting the performance of the Cloud X.

The measurement system is simple, easy to reconfigure, and allows for expansion as needed. New channels of nearly any type can be easily integrated into the measurement system on the spot.

Trials are to resume in November, and already several ideas are in the works for new measurements to be added. Check our website at http://www.swath.com for progress updates.

Fig. 8. Using a 3-ton concrete block to calibrate lift and drag on a fin shaft (courtesy of Swath International Limited).

References

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[2] *International Code of Safety for High Speed Craft*, International Maritime Organization, 1995.

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[4] G.R. Lamb, "Ferry routes, ship motions and passenger comfort—analyzing the relationship," presented at the Cruise + Ferry '91 Conference, London, England, 1991.

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