Abstract: In this paper a new experimental system for studies about the integrated course and active appendages control is introduced. The research focuses on fast ships. The appendages considered are moving flaps, fins, and a T-foil. They are used for motion smoothing. The fast ships use powerful waterjets that can be oriented for course control, instead of using rudders. When an actuator moves, course control is disturbed. An integrated actuators and course control system is needed. This is a main target of our research. A departing point for the research is to provide an experimental system for control studies. This system consists of an autonomous scaled physical model and an external support system (ESS). The on-board control system is based on a CAN bus, using several smart nodes. The paper describes the distributed control system of the physical model, and the ESS. The distributed architecture of the model on-board system can be easily ported to real ships, since the CAN bus can be extended to relatively long distances.

Key-Words: ship control, ride control, seakeeping, CAN bus system, experimental ship control systems, scaled ship physical model.

1 Introduction
Some modern fast ships use active appendages, such moving flaps, fins, etc., for motion smoothing. Also, they use waterjets that can be oriented for course control, instead of using rudders. When a fin moves, it has a good influence to counteract rolling motion, but it can also disturb the ship heading. Likewise, any other action of the appendages and the waterjets cause good effects but collateral problems. An integrated control system is needed. This is a main target of our research. A departing point for the research is to provide an experimental system for control studies. This system consists of an autonomous physical model and an external support system (ESS). After considering a centralised computer-based system to handle the sensors and actuators in the model, this concept was abandoned and a more capable and flexible solution was devised. The new solution is based on a CAN bus, using several smart nodes. The distributed architecture of the model on-board system can be easily ported to real ships, since the CAN bus can be extended to relatively long distances.

Along this paper we will present first the research framework, which is related with fast ferries. Then, we will focus on the requirements to be observed for the scaled experimental system, which convey several difficulties. The main parts of the paper follow, describing the new distributed control solution for the model on-board system. Practical details are given, with several photographs. Finally, the paper describes the ESS system, showing some screens of the computer that, from the border of a basin or any other place in open-air experiments, is capable to monitor the data captured by sensors on the ship during the control experiments.

Relevant bibliographic references about seakeeping and ride control are [1][2].

2 Research Context
Our research deals with control design for pitch, heave and roll motion smoothing, while keeping a constant ship course, using actuators such flaps, fins and T-foil. A particular fast ferry has been selected for case study.

Figure 1 shows a view of the fast ferry. She has the following characteristics: 110 m. long, 1,250 passengers, aluminium-made deep-V monohull, reaching 40 knots or more. She uses powerful waterjets for propulsion and heading, having no
rudder. This ferry is actually operating, between Denmark and Norway. The internal distribution of the ship, with a large market in the center, makes the passengers to be seated both sides of the ship or near the bow. These places experiment the highest vertical accelerations. Vertical oscillatory accelerations with frequencies around 1 rad/sec. cause seasickness [3]. An important objective of the research is to increase passenger’s comfort, avoiding seasickness.

Fig. 1. Photograph of the fast ferry

The research started with the simple case of the fast ferry with head seas. Only pitch and heave motions are considered. These two motions are smoothed by means of transom flaps and a T-foil. A physical model of the ship, at 1/25 scale, has been built. It has been used for experiments in “El Canal de Experiencias Hidrodinamicas de El Pardo” (CEHIPAR), Madrid. The towing tank facility has a long channel for quiet water experiments, and a 150m x 30m basin with wavemaker. The physical model has been towed along the channel to measure the drag and lift of actuators. It has been also towed in the basin with several sea conditions for two purposes. First to get data for pitch and heave motion modelling. Second for testing of motion alleviation control designs. This step of the research has been reported along several publications, such [4][5].

Now the more general case of the fast ferry with any heading is considered. Pitch, roll and heave cause vertical accelerations. In addition to the flaps and the T-foil, lateral fins are included for roll smoothing. The actuators may also induce effects on yaw, sway and surge motions. A 6DOF study is required. Figure 2 shows the location of the actuators: two transom flaps, two lateral fins and a T-foil near the bow.

Fig. 2. Location of the actuators

It is no longer advisable to use a towed physical model for the new experiments with any ship’s heading. Consequently, a new, smaller physical model has been developed for autonomous motion. Stringent requirements of weight, robustness and power consumption have been considered. New technologies have been included. A distributed monitoring and control system has been developed. This system uses digital radio for distant monitoring and supervision of experiments by an off-shore unit (the ESS). The off-shore unit displays the dynamic behaviour of the ship with animated 3D graphics. Both the on-board system and the off-shore unit can be used with real ships.

The control of the actuators is multiobjective. Small waves do not deserve actuator action, wasting energy and system lifetime. Also, high angles of attack of the actuators induce cavitation, which destroys the actuators. Consequently, the control must try to minimize seasickness, while selecting when to react against waves and keeping cavitation as low as possible.

The experimental study for the optimal control design begins with a series of experiments to determine a 6DOF model of the ship with actuators. On the basis of the model, a simulation environment will be developed, and control design studies will be done. The second part of the experimental study will be devoted to control design validation.

3 Requirements for the Experimental System

The experiments are made in the CEHIPAR basin with wavemaker, using the new physical model. A set of sea states, SSN4, 5 and 6, with JONSWAP spectra is selected for the experiments. Two speeds, 30 and 40 knots, are studied. Twelve ship’s headings, regularly spaced along the 180º are considered. That means 72 cases.

The physical model is not towed. Instead, it uses waterjets for autonomous motion. There will be no
cables connecting the replica to external instrumentation or control system. It is interesting to note that from the beginning we need a first version of control, to get constant ship courses along the experiments.

The data to be obtained are records of the six motions and accelerations, and the control signals. A selection of the data will be transmitted via radio to the off-shore unit, for real-time supervision and monitoring. During an experiment, all data are saved by the on-board computer. At the end of the experiment, all on-board saved data are transmitted to the off-shore unit to be saved on hard disk.

Apart from the CEHIPAR basin, other experimental scenarios are considered, such ponds or quiet sea coast.

The scale chosen for the new physical model was 1/40, the smallest size having results confidence. Since the real scale ship is aluminium made, the weight of the replica must be less than 29 kg. This is an implementation challenge. There are important limitations to the weight and energy consumption of the on board system. All the energy must be obtained from on board batteries (an important contribution to total weight).

Scaled down waterjets and actuators must be included in the physical model. Adequate sensors must be selected. The complete electronic system must be low consumption. In particular on-board computer, radio transmitters and microcontrollers must require low currents.

The on-board software has the following responsibilities:

- Implement autonomous course and ride control of the scaled ship.
- Acquire and process data captured by on-board sensors.
- Keep in conversation with the ESS using a radio link

To take into account situations where the on-board system loses control, a manual control intervention from the ESS is allowed. For this safety function, a conventional R/C control system is provided.

4 Implementation of the Model

The 1/40 scaled hull has been built with light fibers, using balsa rigs and solid foam for mechanical reinforcement. It weighs 12 kg. A metallic structure has been built to suspend the ship from elastic bands. This is made for laboratory studies, out of the water, to check course and ride control functions by moving manually the ship, looking at the actuator motions and recording data from sensors. Figure 3 shows a view of the laboratory system with the ship.

Scaled down flaps, fins and T-foil has been added to the model. The fins and the T-foil are made in aluminum, with a curved profile. The flaps are more simple, in plastic and flat profile. High-torque high-speed servos, to be driven by PWM signals, are in charge of moving the active surfaces. Figure 4 shows a photograph of one of the lateral fins., and figure 5 shows a photograph of the T-foil.

The main sensor is an inertial unit located at the c.o.g. This unit weighs 2 Kg. and requires 24 v., 1 amp. Since it is advisable to add some redundant sensors, three 2-axis accelerometers and a digital compass were also put in the physical model. The three accelerometers were located to measure heave
and pitch acceleration, vertical acceleration due to roll, sway and surge acceleration, and yaw acceleration. The compensated digital compass is devoted to course control. It was isolated by anti-magnetic film from the rest of the system, to avoid the influence of motors (which create magnetic fields).

The physical model has two scaled down waterjets, with an additional appendage to change the jet orientation. There is no rudder. The waterjets are driven by powerful DC motors, with a maximum consumption each of 30 amps (at 6 V).

Figure 6 shows a photograph of the stern with the waterjet outlets and the two flaps.

**Fig. 6. A view of the model stern.**

Laboratory studies have been done to determine which batteries to use. Several modern battery technologies have been evaluated through a laboratory device designed for this purpose. The best, and only, alternative for the high peak currents required by the waterjets is NiCad. For the electronic system, including sensors, computer and microcontrollers, there are other alternatives, such new alkaline batteries, offering high Amp-hour capacities for almost constant currents around 1 Amp. Servos do require, when they move, more than 1 Amp each, so it is good to use here NiH (high capacity, able to sustain moderate current peaks). The weight of NiCad is around 1.3 Kg. for every 30 watt-hour. Each waterjet sinks around 100 watts in experiments corresponding to 40 knots (fortunately, it is not necessary to put the waterjets at maximum current). In consequence, for 1 hour experimental autonomy, batteries contribute with around 11 kg to the model weight.

During experiments, die weight must be allocated for scaled replication of the real ship inertias. Some lead kgs. must be allowed for this purpose.

## 5 CAN Bus Based On-Board Control System

An on-board distributed monitoring and control system was developed and put in the physical model. The missions of the on-board system are the following:

- To acquire, condition and record all signals from on board sensors along experiments.
- To control the actuators of the ship.
- To transmit real-time data to the ESS.
- To transmit the complete record of data, at the end of experiments, to the ESS.
- To obey to orders given by the ESS.

Figure 7 depicts a diagram of main functions of the on board system. One of the blocks in the figure includes sensors for data acquisition and control. Another block is devoted to actuators handling. A third block is in charge of wireless communications. And finally there is a central block, with a low power embedded computer, for govern, coordination and data processing. Notice that there is a block to admit high priority remote control orders. The purpose of this last block is to be able to stop and recover the physical model when there are problems.

![Block diagram of the on-board system.](image)

Initially, the point-to-point solution was tried, putting the embedded PC as the center to which every sensor and actuator was connected. This was physically possible, since the embedded PC we selected has many I/O ports, so if we have 11 servos to control, 8 sensors and the inertial unit to monitor, and one radio-link, it is possible to connect them to 21 ports. However, it is really difficult to develop the software to handle all these components properly. After some trials with the centralized architecture, it was clear that other approach should be devised.

A distributed control architecture was decided. Figure 8 shows a diagram of the system architecture. It consists of seven nodes connected via CAN bus and a central embedded PC. The
reasons for using a CAN bus are related to the complexity of the system, and the long distances that can be expected for real applications on ships. This bus is well proven, and there are easy to get off-the-shelf components for CAN bus based systems.

The following table shows data about the CAN bus bit rate, in function of cable length.

<table>
<thead>
<tr>
<th>Bit rate</th>
<th>Cable length</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Kb/s</td>
<td>6.7 Km</td>
</tr>
<tr>
<td>50 Kb/s</td>
<td>1.3 Km</td>
</tr>
<tr>
<td>125 Kb/s</td>
<td>530 m</td>
</tr>
<tr>
<td>250 Kb/s</td>
<td>270 m</td>
</tr>
<tr>
<td>500 Kb/s</td>
<td>130 m</td>
</tr>
<tr>
<td>1 Mb/s</td>
<td>40 m</td>
</tr>
</tbody>
</table>

The embedded PC has been selected according with the following criteria: small size, light weight, small energy consumption, enough computing power. After considering several alternatives, the Tern 586 Engine was chosen.

For the nodes, the PIC 18F485 microcontroller was selected. This chip includes in firmware the CAN bus protocol. The embedded PC access the bus via one of these microcontrollers. The A/D channels of the embedded PC are used for a direct, fast interaction with the inertial unit.

Along experiments, the system measures all six motions and accelerations. Some measurements are redundant due to a variety of reasons (safety, bias compensation, time constants, etc.). The on-line information on motions and accelerations are used for ride control. There are other sensors that inform about the ship heading. This information is the basis for course control.

At the stern of the ship there are two waterjets, two servos for orientation of the waterjets, and two servos for reversing the water flow (for the ship to go back), and two servos to move the flaps. By means of PWM control, the speed of the motors driving the waterjets can be controlled. All these motors are controlled by two CAN bus nodes. Another CAN bus node, near the bow is in charge of the T-foil. One of the CAN bus nodes, located near the c.o.g. is in charge of the fins.

An important advantage of the distributed architecture is the easy implementation of some local functions. For instance, the microcontrollers in charge of moving the actuators include routines to simulate the dynamic characteristics of the hydraulic cylinders, which move the actuators in real ships. Also, the microcontrollers perform signal conditioning functions with respect to sensors.

The wireless communication system is based on a digital radio unit, called MaxStream. It serves as a digital wireless transceiver. It is a low-power small metallic module.

The use of a CAN bus implies the design of a messaging protocol, assigning i.d. numbers to each kind of message. In this case, a simple method was devised, with the embedded PC marking sampling periods, asking to sensors, and giving orders to actuators. A procedure to separate messages, to avoid time congestion, was devised. A code module for the CAN bus interaction was developed to be handled by control and monitoring programs. These control and monitoring programs are developed on conventional PC computers. Once an application program is successfully developed, the user compiles it and gets an executable code. This code is further downloaded to the embedded PC.

The general activity of the ship during experiments (initialise, do some pre-defined manoeuvres, transfer recorded data, etc.) has been described as a finite automaton, which is implemented in software and executed by the embedded PC.

An advantage of the use of a fieldbus is that the several parts of the system (radio communication, servomotors, compass, etc.) can be easily distributed in different places, perhaps at relatively long distances. For instance, the compass should be placed far from magnetic fields; and radio communications should no interfere with data acquisition.
6 The External Monitoring and Control System

The ESS is simply made with a conventional (portable) computer and a box containing another MaxStream and a microcontroller. Box and computer communicate via serial RS232 port.

The ship and the ESS communicate through radio, using digital packets. A protocol has been defined for the purposes of the experiments. The ESS can be located at the border of the basin, or perhaps in a boat (in open air experiments). It was noticed that research with autonomous naval physical models could add interesting features to the CEHIPAR experimental facility. Therefore, the architecture of the on board system must be modular and flexible. The idea is to provide a sort of “universal” monitoring and control system, able to be applied quickly and easily to any other marine vehicle.

The wireless communication paves the way for the use of internet. This is a powerful idea: experiments from distance.

The ESS shows a 3D animated visualization of the ship behaviour, together with a view of recorded signals. The software has been developed using the powerful tools of Builder C++. A Windows visualization environment has been obtained for monitoring of signals coming from the physical model to the ESS. Figure 9 shows a screen of the monitoring application.

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7 Conclusion

This paper presents a new distributed monitoring and control system, based on CAN bus, for integrated course and ride control of a ship. The research refers to a practical case, concerning a fast ferry and the use of several moving actuators.

The purpose of the paper is to devise an experimental environment with an autonomous scaled model, having an on board computerized system and a wireless connection to an external computer. Relatively strict requirements of weight, size and power, made difficult to develop the on board system. However, the results obtained are encouraging. The distributed architecture, based on the CAN bus, is flexible enough to be applied to other naval physical models or real ships.

References: