# EXPERIMENTAL STUDY OF CONTROLLED FLAPS AND T-FOIL FOR COMFORT IMPROVEMENT OF A FAST FERRY

Giron-Sierra, J.M. (1), Esteban, S. (1), De Andres, B. (1), Diaz, J.M. (2), Riola, J.M. (3)

(1) Dept. Arquitectura de Computadores y Automatica, Fac. Fisicas. Universidad Complutense de Madrid
28040 Madrid, Spain.
Tf: (34) 91 394 4387; Fax: (34) 91 394 4687; e-mail: gironsi@dia.ucm.es

(2) Dept. Informatica y Automatica, Fac. Ciencias. UNED
28040 Madrid, Spain

(3) CEHIPAR, Canal de Experiencias Hidrodinamicas de El Pardo
El Pardo. Madrid, Spain

**Abstract:** Fast ships can suffer important negative effects from vertical accelerations. Concerning passengers, the sea-sickness is related, in a cumulative form, to these accelerations. Our research deals with the alleviation of vertical accelerations, using appendages that can move under control to counteract each incident wave. The appendages we are considering are a T-foil near the bow and transom flaps. After a long modelling work, involving experiments in a towing tank institution, the conditions for the study of control design have been established. First experimental confirmations of the efficacy of controlled appendages have been achieved. A well tuned P.D. has been tested, with very promising results. The paper begins with a short recapitulation of the previous research. Next, the paper focus on the experiments with a replica with appendages.

## 1. INTRODUCTION

This research started in 1997, with a main objective: to attenuate the vertical accelerations of a fast ferry. These accelerations originate sea-sickness and, if important acceleration values are attained, may have negative effects on the ship. The fast transportation of passengers is taking a great importance. It is a solution more and more used, not only for pleasure, and it is in competition with other alternatives. Therefore it is important to mind the passengers' comfort. If the navigation conditions (perhaps moderately bad) augur a negative impact on passengers' satisfaction, it may happen that a cruise is cancelled. Now, if we have the means to reduce the number of cancellations, we have the opportunity of greater benefits.

As a first alternative for the attenuation of vertical accelerations, a T-foil near the bow and transom flaps were selected. These appendages can move to counteract the effects of each incident wave. For the moment, the research is centred on heaving and pitching motions with head seas. A control system should be applied to move the appendages (we can consider the appendages, with the means to make them move, as actuators). Hence, a control design study must be achieved, to optimise the efficacy of the actuators.

The research proceeds along two main steps. The first step has a main objective: to create a simulation tool, based on models (these models obtained after an experimental study). The second step uses the simulation tool for the study, on computer, of control design alternatives; some of them (if successful results are predicted by the simulations) are to be experimentally tested. The first step has been accomplished, now the research is in the second step. In this moment the experimental set-up has been achieved and tested, and first experimental studies have been performed to confirm the efficacy of the actuators and the effects of a conventional P.D. control.

The paper introduces the main aspects of our research and continues, immediately, with a description of the experiments already done. Results are presented with some comments. These results are really promising.

## 2. SUMMARY OF THE FIRST STEP OF THE RESEARCH

To accomplish the experimental tasks, there is the collaboration of CEHIPAR (Canal de Experiencias Hidrodinamicas de El Pardo, Madrid; in English: El Pardo Model Basin) [CEHIPAR, 2000]. To establish specific targets, a fast ferry was selected, with the following characteristics: deep-V mono-hull, aluminium-made, 110m. length, 1250 passengers, able to get 40 knots or more. CEHIPAR built a scaled-down replica (1/25). The following experimental design was defined:

- Experiments with regular waves: 15 different wavelengths. For ship's speeds of 20, 30 and 40 knots.

- Experiments with irregular waves: SSN 4, 5, 6. For ship's speeds of 20, 30 and 40 knots.

The experiments are performed on a basin 152m. long, 32m. wide, 5m deep, with a wave maker of 60 flaps. The replica is attached to a Computerized Planar Motion Carriage. Figure 1 shows a view of the empty basin (some people are inside, so the photograph gives an intuitive idea of dimensions). Figure 2 shows a photograph of waves generated during one of the experiments. The carriage takes data from sensors, measuring heave, pitch, height of incident wave, drag forces (port and starboard) and vertical accelerations at several places of the ship. In addition, several cameras are used for video recording of each experiment. The images have been useful to check phase relationships between waves and motions, and to see slammings (this affects to the data registered by sensors).

Figure 1: The Place of Experiments: A View of the Empty Basin.

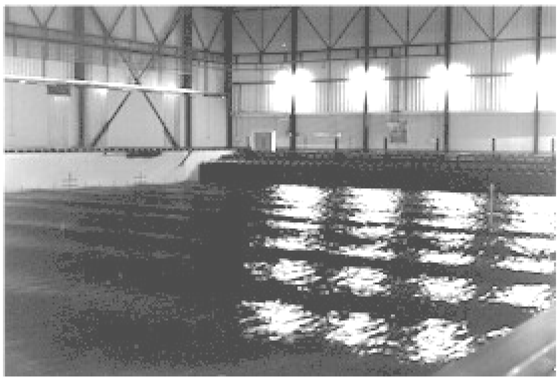

Figure 2: Generation of Waves in the Basin

Another facility of CEHIPAR is the program PRECAL. This program is based on a CAD description of the hull. It predicts the motions of the ship with regular waves. It also gives information about heaving forces and pitching moments. The program has been used to run the same experiments as in the basin. The data obtained have been useful to determine the dynamic models of the ship's vertical motions. The experimental data have been used to validate the models.

By means of several modelling techniques a set of models has been obtained, in the form of coupled transfer functions, for heaving and pitching motions at 20, 30 and 40 knots [De la Cruz, et al., 1998; De Andres Toro, et al., 2000; Esteban (a), et al., 2000].

Concerning the actuators, the approach has been first to design them, and then to get models from first principles (some are the same principles of the design) [Esteban (b), et al. 2000].

On the basis of the models, a simulation environment has been developed. The nucleus of the simulation is a structure of three SIMULINK blocks: the ship, the actuators and the controller. The simulation tool runs under MS-Windows. Thanks to the MATLAB and SIMULINK characteristics, and to the modular architecture of the simulation environment, it is easy to test several control alternatives: with P.I.D., multivariable, robust, intelligent, etc.

## 3. PREPARATION OF THE CONTROL EXPERIMENTAL STUDY

A T-foil and transom flaps have been added to the replica. Step motors (0.18º per step) were used to move these appendages. By means of encoders, with the same precision, we have information on the angle of the actuators.

Figures 3, 4 and 5 shows the replica during the assembling step, out the water. Tests of connections and basic operation of the control hardware were done then. The control hardware is based on an industrial PC with a 200 MHz. Pentium. The PC included boards for data acquisition from sensors and from encoders, and for governing the motors (generating the required pulses).

Figure 3: A View of the Replica with the T-foil and the Flaps.

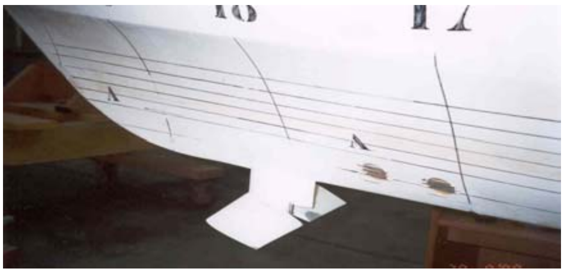

Figure 4: The T-foil near the Bow


Figure 5: The Transom Flaps

By means of EdROOM, an automatic real-time control code generation tool developed by one of our research groups, a first, simply proportional, control solution was generated for experimental testing. Out the water, the replica hangs in such a way that we can swing it. Taking advantage of this, the motion of actuators trying to counteract the ship's motions was confirmed.

Next, the replica was attached to the carriage and put on water. Connections were made between the sensors and actuators of the replica, and the industrial PC (and the carriage: it records all the information). Using the special capabilities of EdROOM, the control program was modified to admit manual modes. This was really handy for the initial tasks of checking and calibrations with the replica now on water.

The first studies of control have been centred on WVA attenuation (there is a place for passengers in the ship with the worst vertical acceleration: we denote this acceleration "WVA"). For such purpose, an accelerometer is placed to measure the WVA (it is a place near the bow).

## 4. INITIAL EXPERIMENTS

The experiments began with several runs without waves (calm sea). The replica is attached to the carriage with two dynamometers, so vertical motions are not allowed.

First the actuators were kept on fixed angles. Several angles were tested. Drag forces were measured. They differ little from the drag forces of the ship without appendages. Also pitching moments, caused by the actuators, are measured for several angles. Figures 6 and 7 display the results.

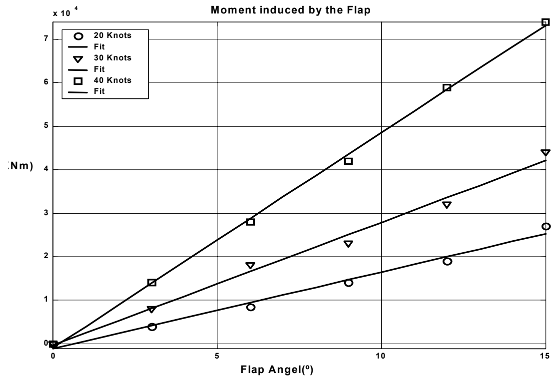


Figure 6: The Pitching Moment Generated by the Flaps

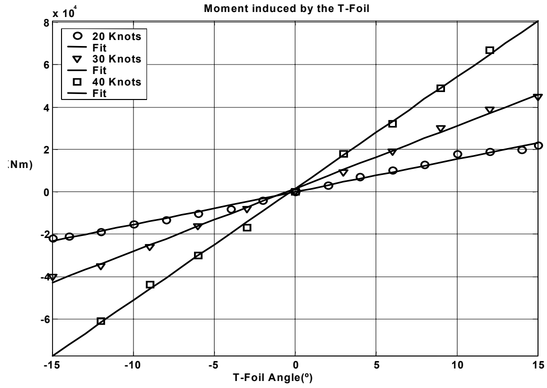


Figure 7: The Pitching Moment Generated by the T-Foil

Next, we allow for free vertical motions, and the actuators were moved periodically along runs. It was confirmed that the motors were able to move the submerged surfaces. It was also observed that the motors generate noise and hull vibrations. The signals from sensors record these bad effects of the motors. Figure 8 shows an example of the noisy signals coming from an accelerometer.

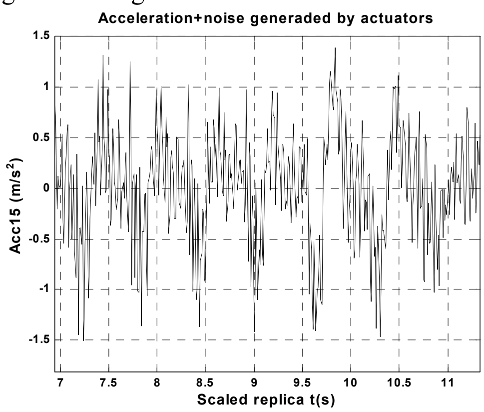


Figure 8: Noisy Signal from the WVA sensor

After that, a series of experiments with waves was performed with the actuators kept on fixed angles. It was confirmed that actuators have a remarkable efficacy to attenuate the WVA.

Finally, another series of experiments, with regular waves, was accomplished for the tuning of a P.D. The previous analysis with the simulation tool showed that integral action has no benefit in this case. Also, the analysis determined, by systematic search, an optimal tuning of the P.D. However, when coming to real experiments it was noticed that the noise from sensors made impossible to apply the predicted tuning. Therefore a study of the noise was achieved, and adequate filters were designed. The filters must eliminate as much noise as possible without modifying the phases of signals (inside the frequency band used by the control). Two alternatives were selected: one is to average each 5 samples (between control sampling periods we take five data samples); the other is a combination of a phase-advance and a low-pass filter.

Both noise and filters were integrated into the simulation environment, for a more realistic design. By means of EdROOM it was easy to incorporate the filters into the real-time control code. New experiments were run, and a good tuning of the P.D. was accomplished, based on the predicted tuning. For each speed, 20, 30 or 40 knots, there is a different, optimal tuning. However, the study on the simulation environment says that there is a single sub-optimal tuning that can be used for any speed, always with little difference respect to optimal effects.

## 5. EXPERIMENTS FOR CONFIRMATION AND EVALUATION

Usually the ship will face, when carrying passengers, small or moderate waves. In consequence it is interesting to focus the research on a subset of the complete range of wavelengths CEHIPAR can generate (regular waves). Hence, the experiments with regular waves were achieved according to the following specifications of waves:

| Num | wo(rad/s) | $\lambda$/Lpp | H(m) | Slope |
|---|---|---|---|---|
| 18 | 0.8947 | 0.695 | 1.911 | 1/40 |
| 19 | 0.8369 | 0.798 | 2.195 | 1/40 |
| 21 | 0.7375 | 1.025 | 2.819 | 1/40 |
| 23 | 0.6617 | 1.281 | 3.523 | 1/40 |
| 25 | 0.5708 | 1.717 | 4.722 | 1/40 |

To complete the experiments, also irregular waves were used, with the following specifications:

| SSN | Height Range | Frequency Range |
|---|---|---|
| 4 | 1.25-2.5 | 1.04-0.78 |
| 5 | 2.5-4.0 | 0.78-0.63 |
| 6 | 4.0-6.0 | 0.63-0.48 |

Notice that sea states over SSN 4 may motivate cruise cancellations.

The experiments have been accomplished for the three speeds: 20, 30 and 40 knots. It was confirmed that the higher the speed, the more effective the actuators. Several of the more relevant results are presented in the following. In particular, the results for 40 knots are selected, since this is the most competitive speed.

The next figures show a comparison of the WVA measured during three different conditions: without actuators, with fixed actuators, with controlled moving actuators using a combination filter. Figure 9 shows these results for 40 knots and SSN 4. Figure 10 does the same for 40 knots and SSN 5.

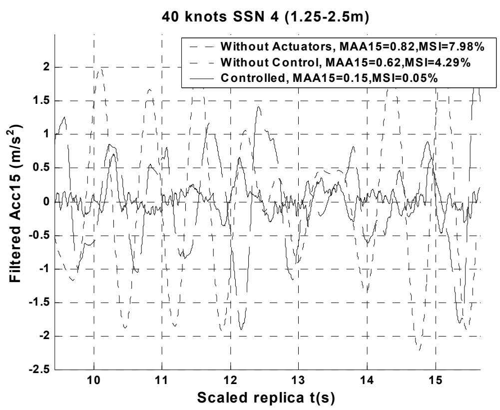


Figure 9: The WVA at 40 knots with SSN 4.

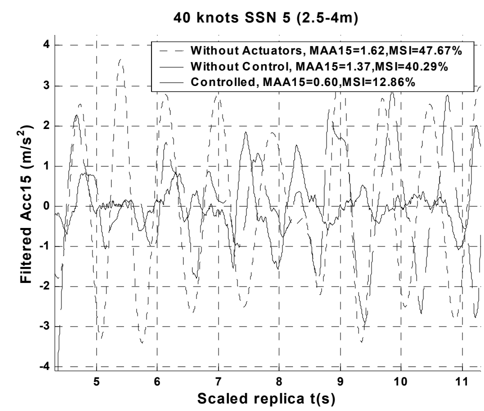


Figure 10: The WVA at 40 knots with SSN 5.

The next figure shows the reductions of WVA for regular waves 19:

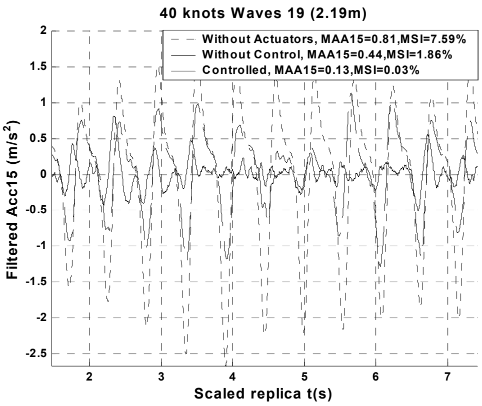


Figure 11: The WVA at 40 knots and Regular Waves 19.

In general terms it can be said that the fixed actuators eliminate about a 50 % of the WVA. Moving the actuators with a control system made this reduction reach around 75%.

The experiments with regular waves 21 made notice some slamming (the ship without appendages). The action of the controlled moving actuators eliminate slamming. It can be said that the operational range of the ship, to carry passengers, has been widened.

By some batch processing of the temporal signals, some qualification indexes can be extracted for a fast evaluation. This can be used for a general estimation of the good effects of appendages and control. Figure 12 displays the reduction of MAA (Mean Absolute WVA), at 40 knots for several Hm of waves. Figure 13 displays the reduction of MSI (Motion Sickness Incidence) [O'Hanlon, MacCawley, 1974] for the same specifications.

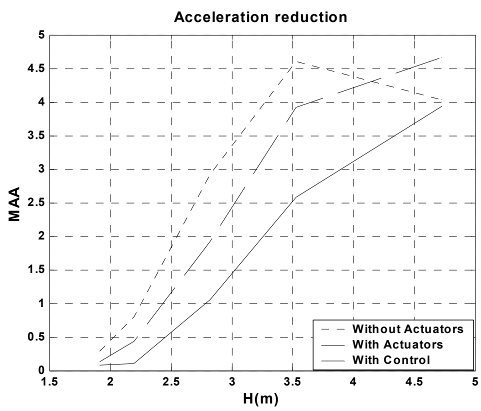


Figure 12: Reduction of MAA at 40 knots

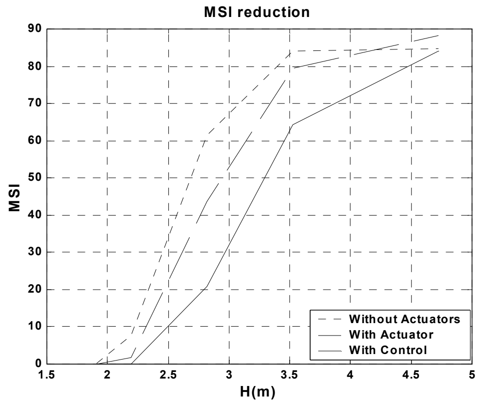


Figure 13: Reduction of MSI at 40 knots.

## 6. CONCLUSIONS

Our research deals with the attenuation of vertical motions, heave and pitch, of a fast ferry with head seas. For such purpose a T-foil near the bow and transom flaps were applied. These appendages can be moved under control, to counteract the effects of each incident wave. We have to obtain the most efficient control design.

Along the research, a first step has been covered, dedicated to modelling. This step has been based on CAD-based simulations and experiments with a scaled-down replica. All that has been achieved using CEHIPAR facilities. The main result of the first step is the development of a simulation tool, where control alternatives can be studied before real application. The research is now dealing with experimental tests of appendages and control, using the same replica and the CEHIPAR facilities.

In this paper a description of the experimental tasks has been summarized, and the most relevant results of the first experimental series with the replica with appendages have been presented. An industrial PC has been used for real-time control, and a digital P.D. controller has been tested.

The results attained are satisfactory indeed. There is a considerable reduction of the MSI at the normal operational conditions of the ship (small or moderate waves). In addition, the operational range of the ship, to carry passengers, is enlarged. The efficacy of actuators and control has been experimentally confirmed.

We think the results obtained are promising for the fast ferries in general. The methodology used in our research paves the way for the modelling and optimal control of other ships.

Now, the research is coming to consider other motions of the ship and a more general navigation context, not only head seas. There are also other aspects for further research, concerning improvements of the appendages.

**Acknowledgements**

The authors want to thank the support of the CICYT Spanish Committee (project TAP97-0607-C03-01), and the collaboration of the CEHIPAR staff.

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