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PROJECT:

OLYMPIC CLASS KAYAK K-1 RESISTANCE TESTS

MODEL No : 202/09

CUSTOMER:

"Panhellenic Kayak and Canoe Trainers Association" (PA.SY.P.K-C)

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C O N T E N T S

ΣΕΛΙΔΑ

1. Introduction

The report presents the experimental results of a series of resistance tests on an Olympic class Kayak boat. The experiments were carried out in calm water and low regular waves. The project was assigned to the Laboratory for Ship and Marine Hydrodynamics (LSMH) of NTUA by the "Panhellenic Kayak and Canoe Trainers Association" (PA.SY.P.K-C), who also was provided the boat to NTUA-LSMH.

The tests took place during the last week of January 2009. This report is the deliverable of the project entitled:

«*OLYMPIC CLASS KAYAK K-1 RESISTANCE TESTS*»

2. Scope of the investigation

The specific scope of this experimental program was to measure the total resistance of the Kayak K-1, covering a speed range of 1 to 5m/sec. Additionally, it was asked by the customers to evaluate the performance of the Kayak in very low head waves, by measuring the added resistance and the boat's responses.

The hull was provided by PA.SY.P.K-C. It is an Olympic class racing Kayak, K-1 category, which refers to a single-seat boat, having the athlete seated while paddling. The weight category of the boat is M (medium), corresponding to an athlete's weight in the range of 70 to 80 Kgr.

3. Test Facilities and Procedures

All the experiments were performed in the towing tank of the LMSH. The dimensions of the towing tank are 91 m (effective length), 4.56 m (width), and 3.00 m (depth). The towing tank is equipped with a running carriage that can achieve a maximum speed of 5.2 m/sec. The tank is also equipped with a wave generating paddle, located at the one end of the flume. At the opposite end there is a properly shaped inclined shore, for the absorption of the generated waves. The wave making facilities can produce both harmonics and pseudorandom waves, in the frequency range from 0.3 to 1.4 Hz. The corresponding wave height can reach the level of 25 cm.

Picture 3.1. Experimental Towing Tank LSMH, NTUA

Minor alterations on the internal structure of the model were applied prior to the measurements, in order to accommodate the measuring equipments. This work was supervised by the personnel of PA.SY.P.K-C, in order to avoid any damage to the hull of the boat.

Both the tests on calm water and harmonic waves were carried out with the boat having a displacement of Δ=86.8 kg (condition A). This is the sum of the bare hull weight, the added fixtures (11.8 Kg) and the mean athlete's weight, the last taken as 75 Kg for the present study. The longitudinal position of the center of gravity (LCG) was chosen at the middle of the athlete's seat. The rod of the resistance dynamometer was mounted on the hull at this location. The mounting was done using a heave rod - pitch bearing assembly, which allows the vertical motions and trim angles (heave and pitch responses) of the boat.

The resistance measurements were performed for speeds in the range from 0.25 to 5.15 m/s, for the case of calm water and for two speeds (2.5 and 5.0 m/s) for the case of harmonic waves. All the tests were performed in fresh water.

The boat resistance, the rise of the center of gravity (CG rise), the dynamic trim and the towing speed of the model were recorder during runs on calm water. In

addition, for the case of harmonic waves, the wave elevation was measured, using wave probes.

4. Calm Water Resistance Tests

The calm water resistance tests were done for a speed range of 0.25 to 5.15 m/s. During these tests, the calm water resistance, the CG rise, the dynamic trim and the towing speed of the Kayak were recorded. The corresponding experimental results are presented in Table 4.1.

TABLE 4.1 Experimental results for the calm water resistance tests
Condition A : Δ=86.8 Kp

Speed	Resistance	Dynamic Trim	C.G. Rise (+ve rise -ve sinkage)
m/s	Kp	deg	cm
0.244	0.011	-0.029	-0.163
0.499	0.078	-0.025	-0.163
1.003	0.311	-0.007	-0.027
1.502	0.669	0.007	-0.122
2.005	1.179	0.002	-0.317
2.500	1.896	-0.043	-0.629
2.995	2.854	-0.361	-1.163
3.493	3.963	-0.628	-1.362
3.989	5.085	-0.799	-1.195
4.494	6.318	-0.866	-0.846
5.153	7.902	-0.947	-0.602

Graphs with the above results are presented in the following pages. More specifically, the resistance is plotted against the boat speed in Figure 4.1. Figures 4.2 and 4.3 present plots against boat speed of the dynamic trim and CG rise respectively.

Finally, the relation between the volumetric total resistance coefficient (Ct_∇) and the volumetric Froude number (Fn_∇) is depicted in Figure 1.4. These parameters are defined by the following relations:

$$Ct_\nabla = \frac{R}{\left(\frac{1}{2}\rho V^2 D^{2/3}\right)}$$

$$Fn_{\nabla} = \frac{V}{\sqrt{gD^{1/3}}}$$

Where:

∇	Displaced volume
ρ	water density
v	speed
R	total resistance.

The volumetric coefficients was preferred over the normally used Ct and Fn, due to the lack of hydrostatic data (draft data, wetted surface values), or any other pertinent information (line plan, section offsets, etc), supplied by the PA.SY.P.K-C for the examined boat.

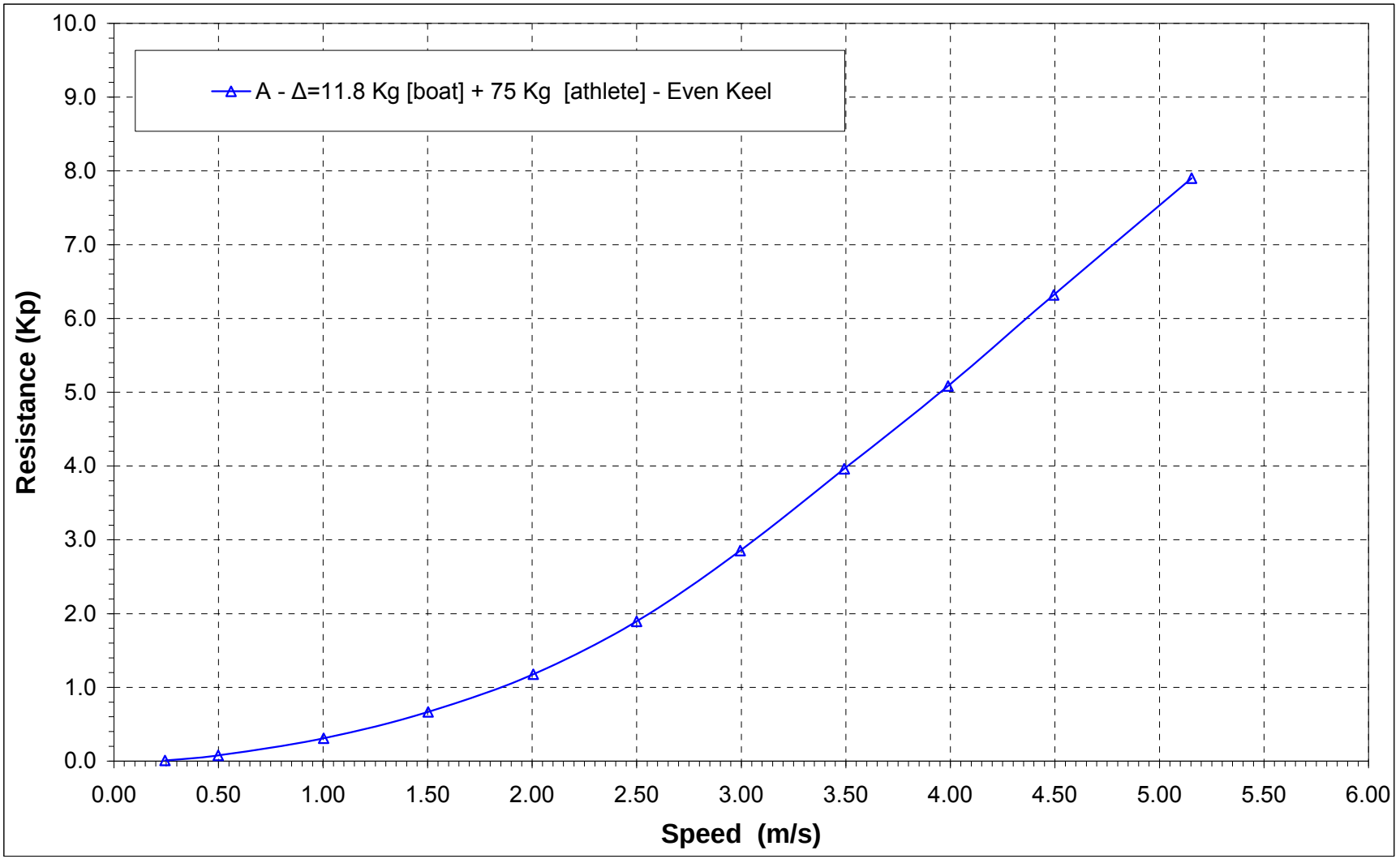

FIG. 4.1 : Resistance plotted versus speed

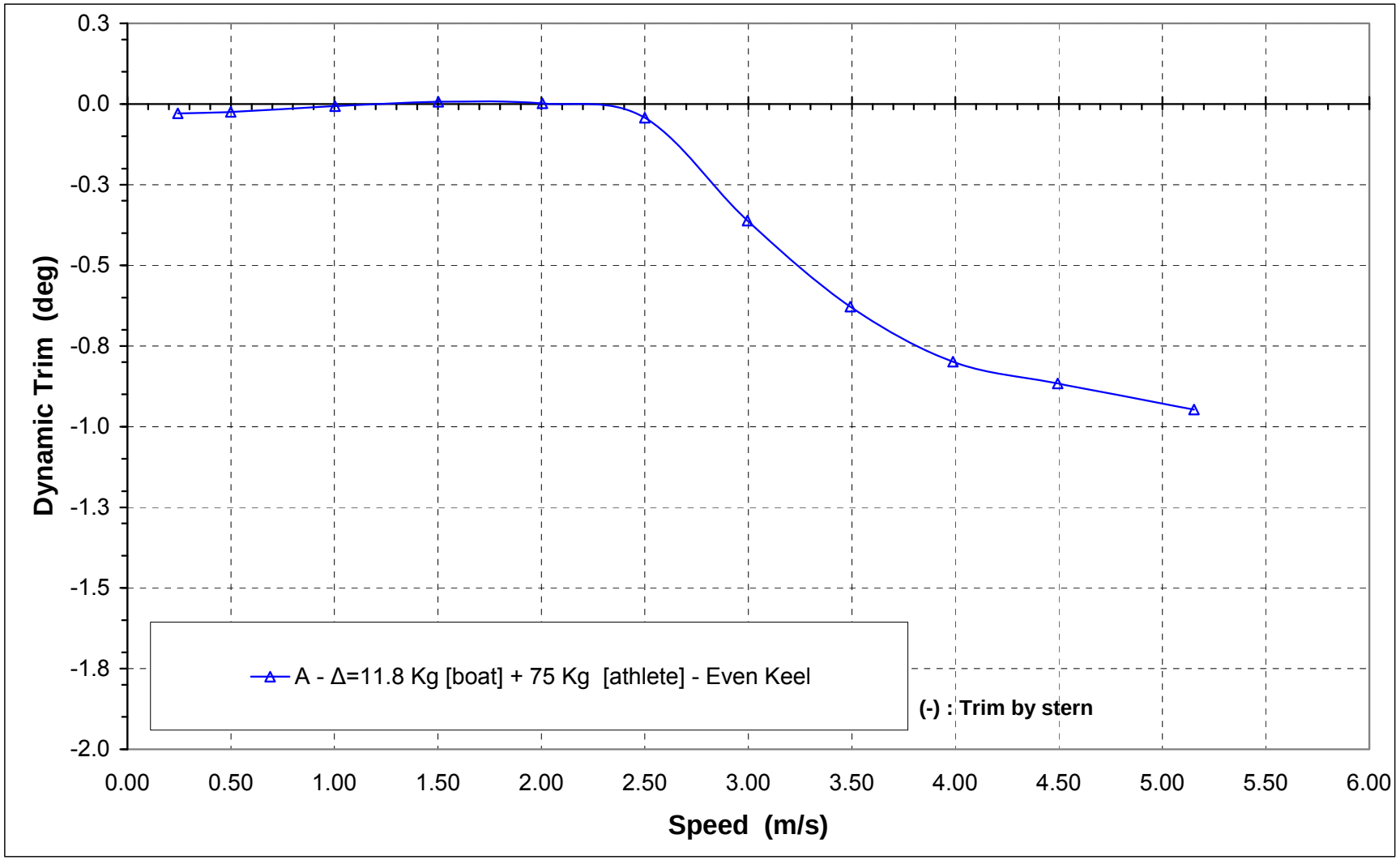
Dynamic Trim (deg)
0.3
0.0
-0.3
-0.5
-0.8
-1.0
-1.3
-1.5
-1.8
-2.0
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
Speed (m/s)
A - Δ=11.8 Kg [boat] + 75 Kg [athlete] - Even Keel
(-) : Trim by stern

FIG. 4.2 : Dynamic trim plotted versus speed

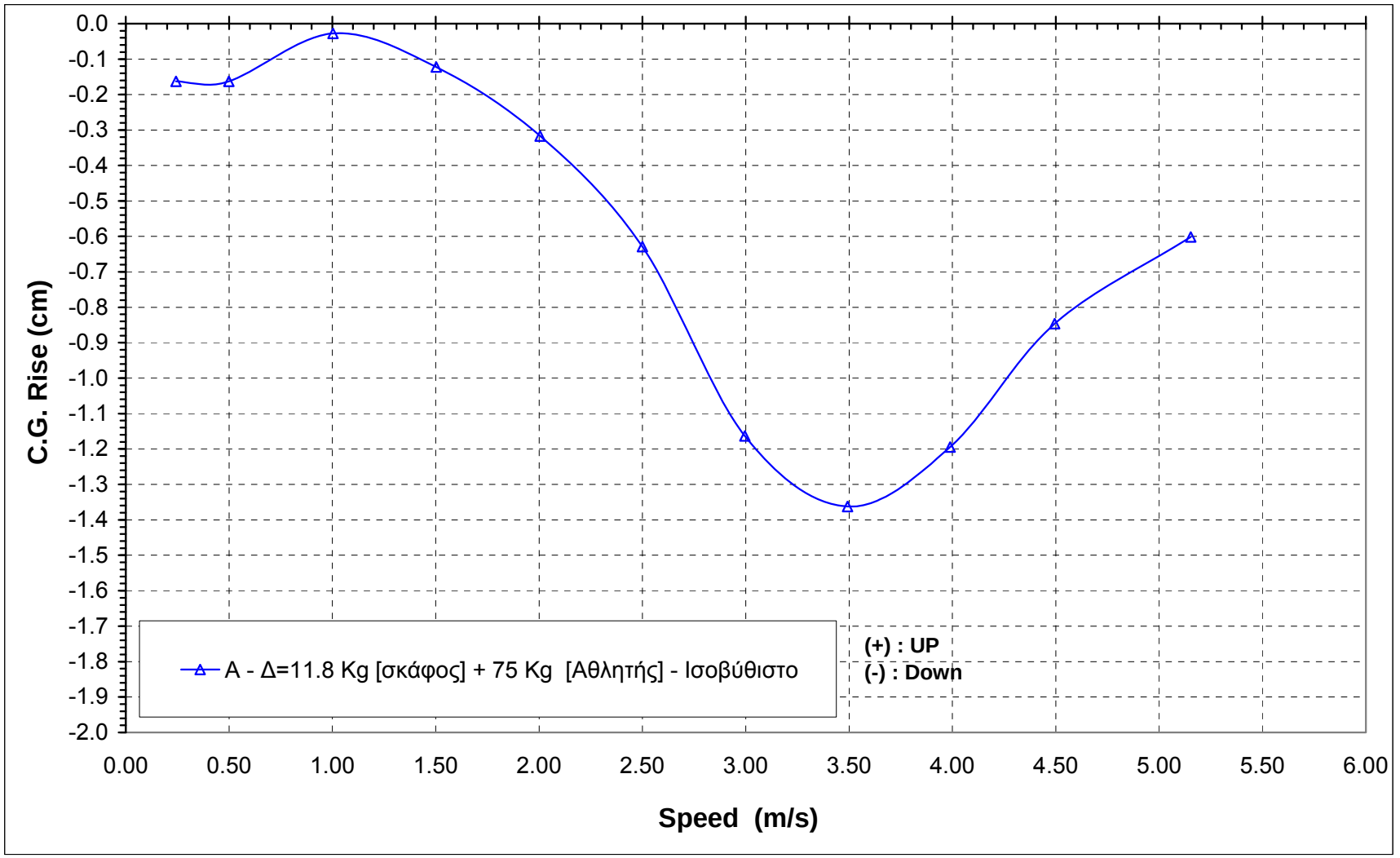

FIG. 4.3 : Dynamic C.G. rise plotted versus speed

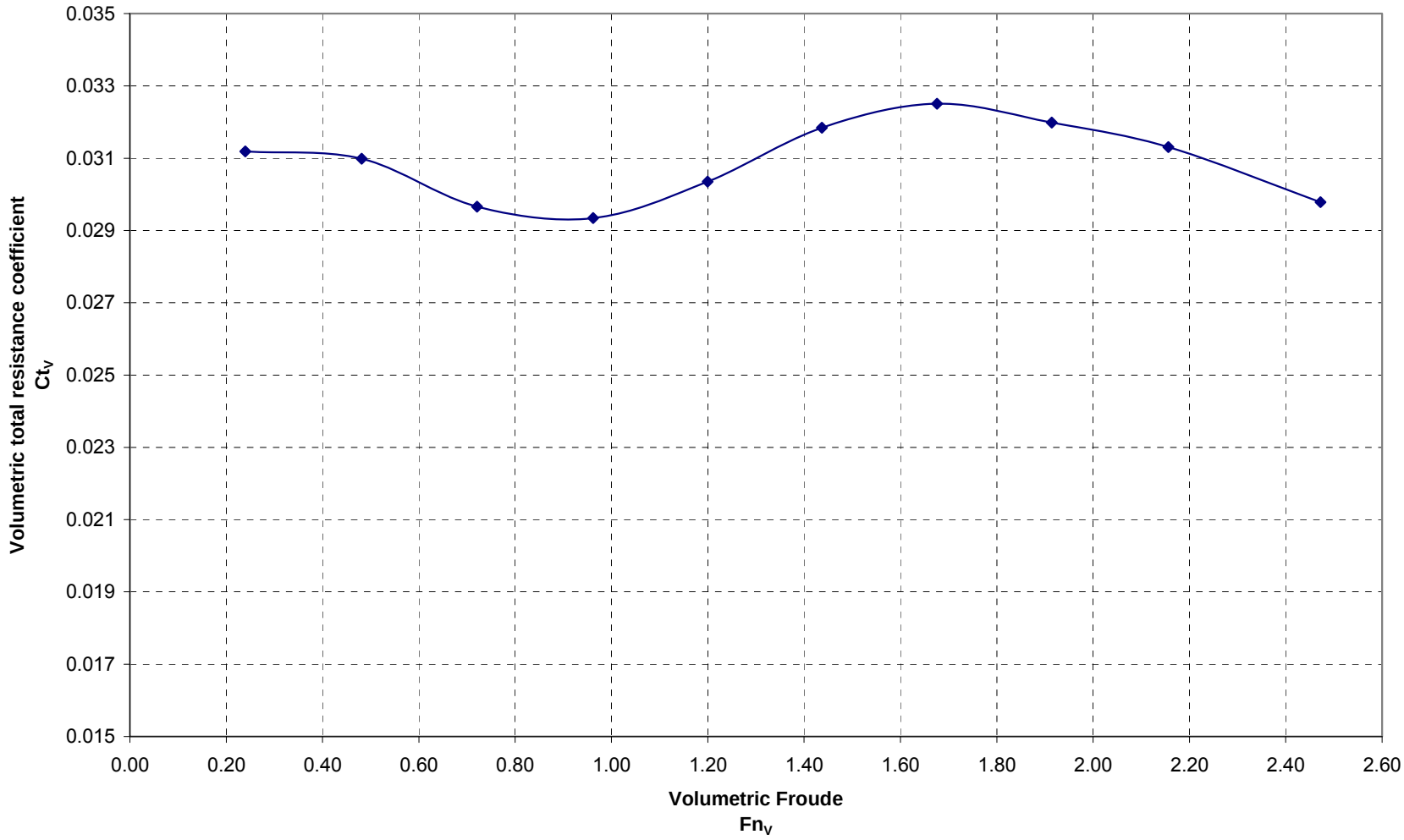
Volumetric total resistance coefficient
Ct_V
0.035
0.033
0.031
0.029
0.027
0.025
0.023
0.021
0.019
0.017
0.015
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
Volumetric Froude
Fn_V

FIG. 4.4 : Volumetric total resistance coefficient

5. Tests in regular waves

The tests in regular waves were done at the speed of 2.5 m/s for wave frequencies 0.3 Hz, 0.5 Hz, 0.7 Hz and 0.9 Hz and at the speed of 5.0 m/s for wave frequencies 0.3 Hz and 0.5 Hz.

During the tests, the following responses were measured:

- C.G. rise
- Pitch
- Added resistance
- Wave Height

The experimental results for these tests are presented in Table 5.1. Based on the recorder time histories of the boat responses the Response Amplitude Operators (RAOs) in heave (at the CG position) and in pitch motion were calculated and presented in Table 5.1, together with the measured values of wave amplitude and mean added resistance.

The non dimensional RAO values were calculated using the following formulae:

$$RAO_{HEAVE} = \xi_o / \zeta_o$$

$$RAO_{PITCH} = \theta / (k\, \xi_o)$$

Where : ξ_o : heave response amplitude

ζ_o : wave amplitude

θ : pitch amplitude [rad]

λ : wave length

k : wave number ($k=2\pi/\lambda$)

TABLE 5.1 Experimental results for the tests in regular waves

CONDITION A : Δ=86.8 kp

Model speed	Wave frequency	Wave Amplitude	RAO Heave	RAO Pitch	Added Resistance	Resistance increase
m/s	Hz	cm			Kp	%
2.5	0.3	5.9	0.936	1.111	0.016	0.8
2.5	0.5	5.3	0.565	0.598	0.157	8.3
2.5	0.7	5.3	0.139	0.053	0.132	7.0
2.5	0.9	4.8	0.042	0.018	0.221	11.7
5.0	0.3	5.8	1.045	1.164	0.139	1.9
5.0	0.5	5.2	1.000	0.780	0.873	11.6

6. Conclusions

In the previous chapters the results of the resistance tests performed in the Laboratory for Ship and Marine Hydrodynamics of NTUA, on a "Kayak K-1" boat were presented. The towing resistance of the boat was measured for a wide range of the speed parameter, starting from low values and covering the range of interest for this boat (Figure 4.1). In addition, the dynamic rise of the center of gravity and the corresponding pitch were recorder for the aforementioned speed range and presented in (Figures 4.2 and 4.3). The resistance results were also presented through the use of the non dimensional volumetric coefficients Ct_{∇} and Fn_{∇} (Figure 4.4). A minimum of the total resistance coefficient is observed in the area of Fn_{∇} ~0.9 and a maximum for Fn_{∇}~1.7. These values correspond to the interactions of the generated wave pattern on the resistance of the boat.

Finally, the performance of the boat subjected to low amplitude heading harmonic waves was investigated. The pertinent results for the heave and pitch motions and for the mean added resistance are presented in Table 5.1. Based on the presented values it can be concluded that the added resistance is negligible for wave lengths much larger than the boat length (low frequency range, examined frequency 0,3 Hz) and can reach values from 7 to 12%, for faster waves (examined frequencies 0,5, 0,7 and 0,9 Hz) and for wave heights of 10 cm.

The data acquired during this experimental work can form a basis for further investigation and deeper understanding of the athlete-boat interaction, especially for high performance and high competitive boats, like the case at hand.

7. Photographs

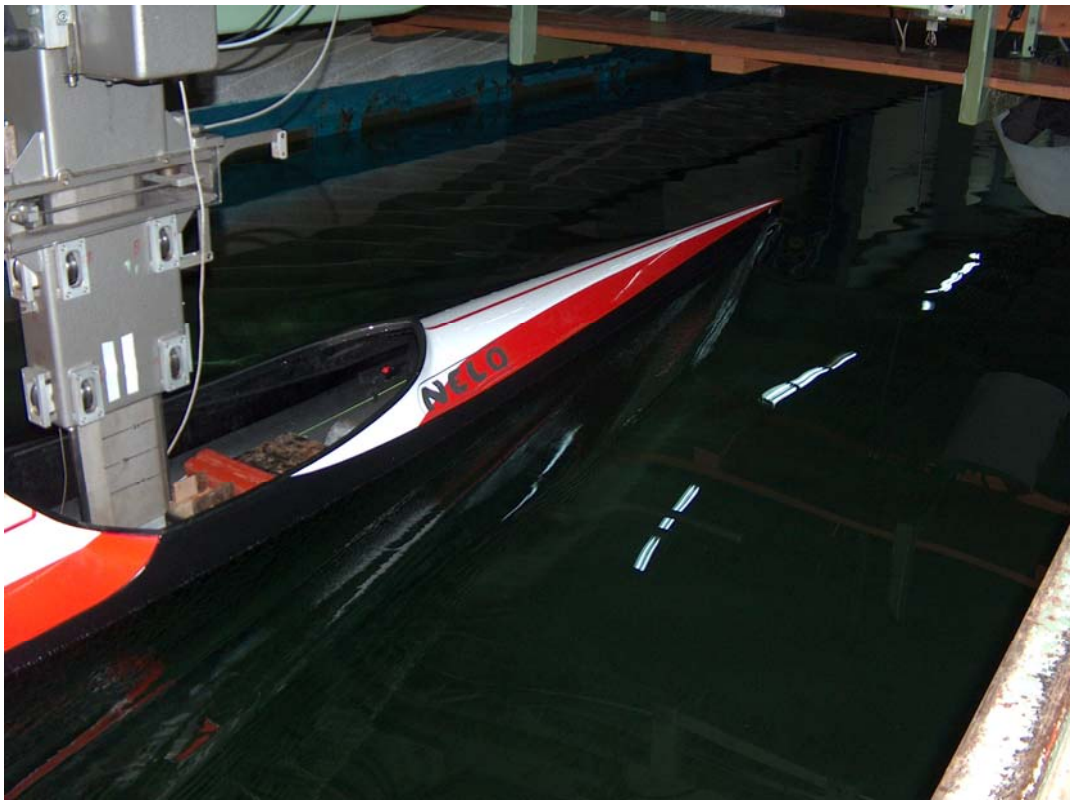

Photo 7.1 : "Kayak K-1". Calm water resistance test. Speed 2.5 m/s.

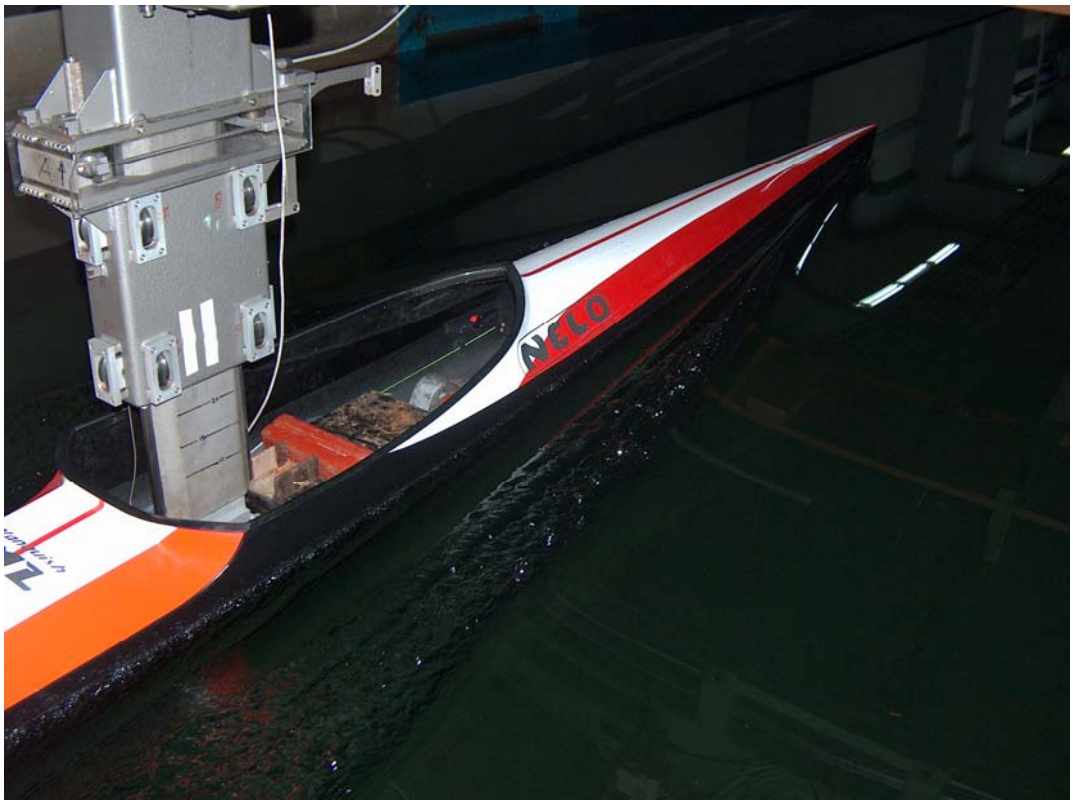

Photo 7.2 : "Kayak K-1". Calm water resistance test. Speed 5.0 m/s.

Photo 7.3 : "Kayak K-1" Tests in regular waves. Wave frequency 0.3 Hz. Speed 2.5 m/s.

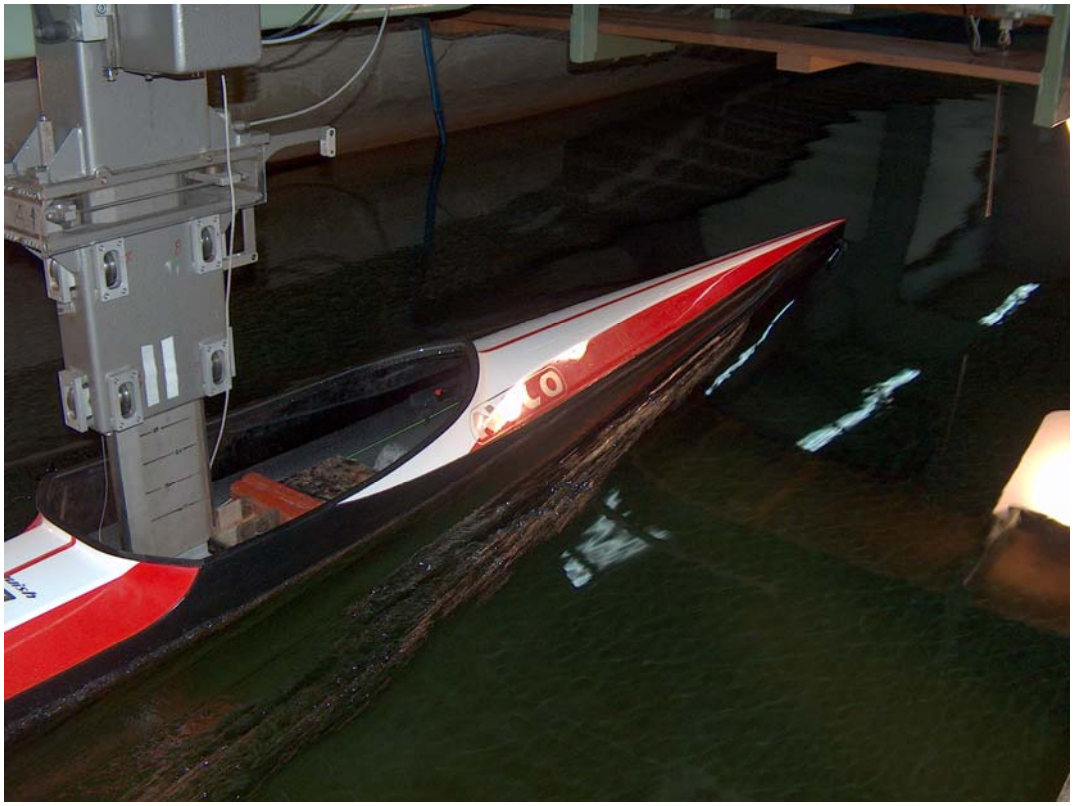

Photo 7.4 : "Kayak K-1" Tests in regular waves. Wave frequency 0.3 Hz Speed 5.0 m/s.

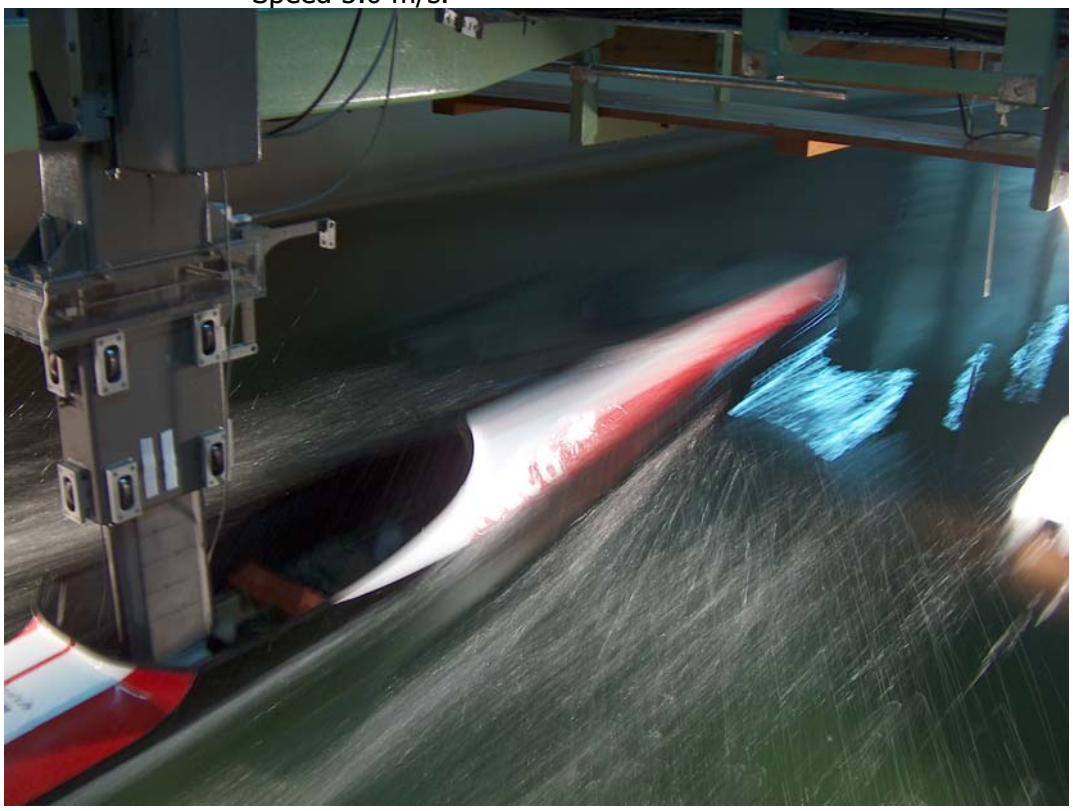

Photo 7.5 : "Kayak K-1" Tests in regular waves. Wave frequency 0.5 Hz, speed of 5.0 m/s.