ESTIMATION OF THE ADDED MASS AND DRAG COEFFICIENTS RELEVANT TO THE PENDULOUS INSTALLATION METHOD (PIM) BY SEVERAL EXPERIMENTAL AND NUMERICAL METHODS

Antonio C. Fernandes, COPPE/UFRJ
Fábio P.S. Mineiro, COPPE/UFRJ
Mario Ribeiro, FMC

MAIN OBJECTIVE
ESTIMATE COEFFICIENTS THROUGH NUMERICAL AND EXPERIMENTAL METHODS

- MORISON APPROACH (Ca and Cd)

  - First INERTIA COEFFICIENTS (added mass): important in the acceleration regions (Ca)

  - Second DRAG COEFFICIENTS: terminal velocity regions (zero acceleration) (Cd)

Present work (several methods):

- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test

- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

Present work (several methods):

- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test

- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

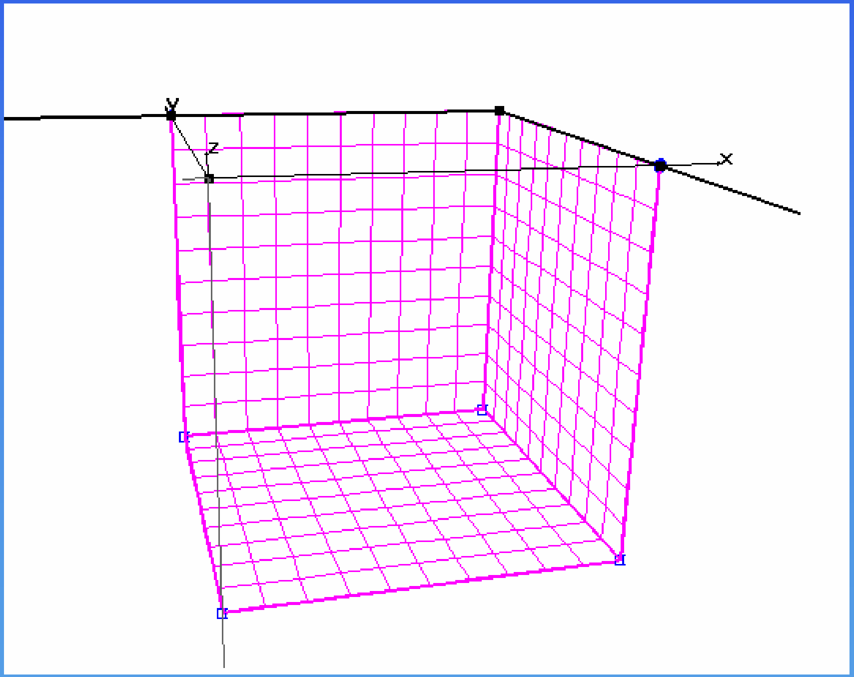
Ca via Potential Theory

- Methodology: commercial code WAMIT with high frequency and low frequency limits
- VALIDATION: Box, ratio b/a = 1; 0.5; 0.8
- FINAL VALIDATION: Ellipsoid
- APLICATION: Manifold Box Enveloped

VALIDATION: BOX   Ratio b/a = 1 (cube)

- Compare High Order X Low Order Panel option; identify adequate number of panels.

Mesh from Mesh Generator program for Low Order Panel Option:

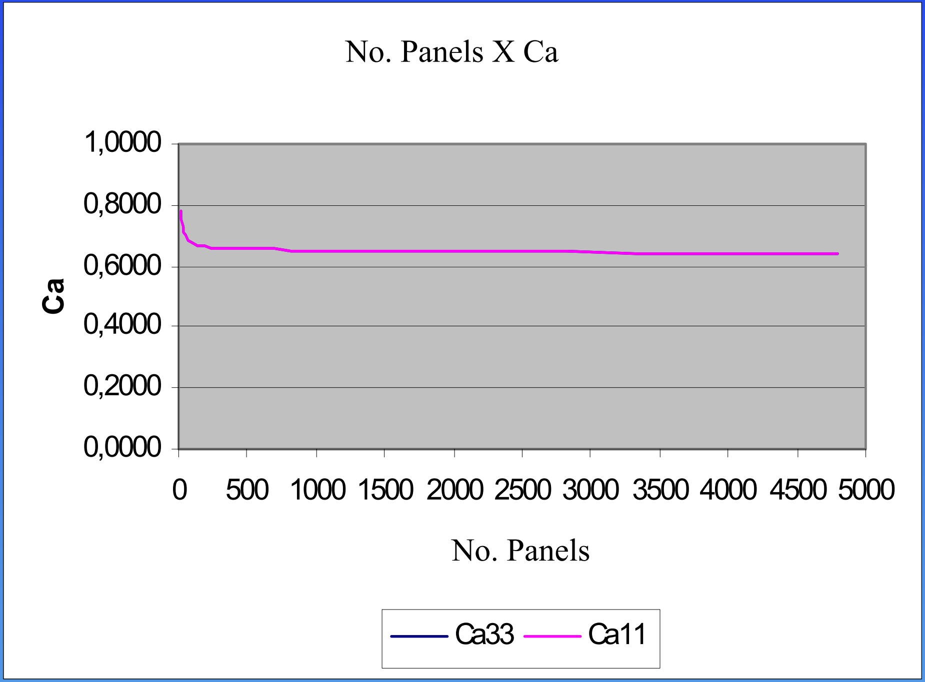


◆ LOW ORDER X HIGHER ORDER

◆ Low Order Panel:

Box

No. Panels	Ca_{33} (p=0)	Ca_{11} (p=inf)
12	0,7784356	0,7784356
32	0,7239432	0,7323756
48	0,7017358	0,7017362
108	0,6779564	0,6779562
192	0,6659260	0,6659280
300	0,6600130	0,6600128
432	0,6557704	0,6557700
1200	0,6476950	0,6476950
4800	0,6422840	0,6422824

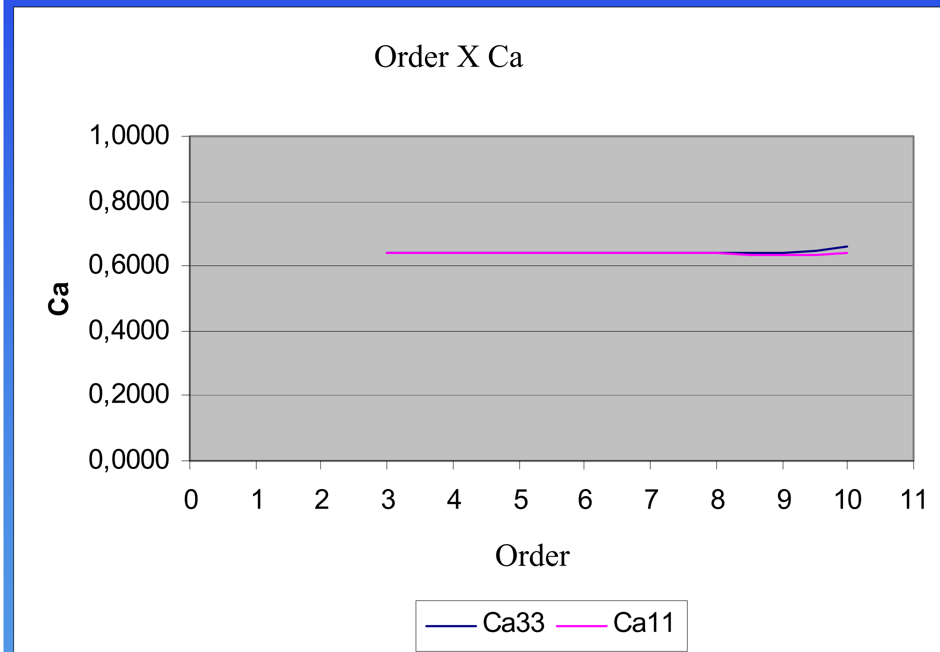


Box b/a = 1

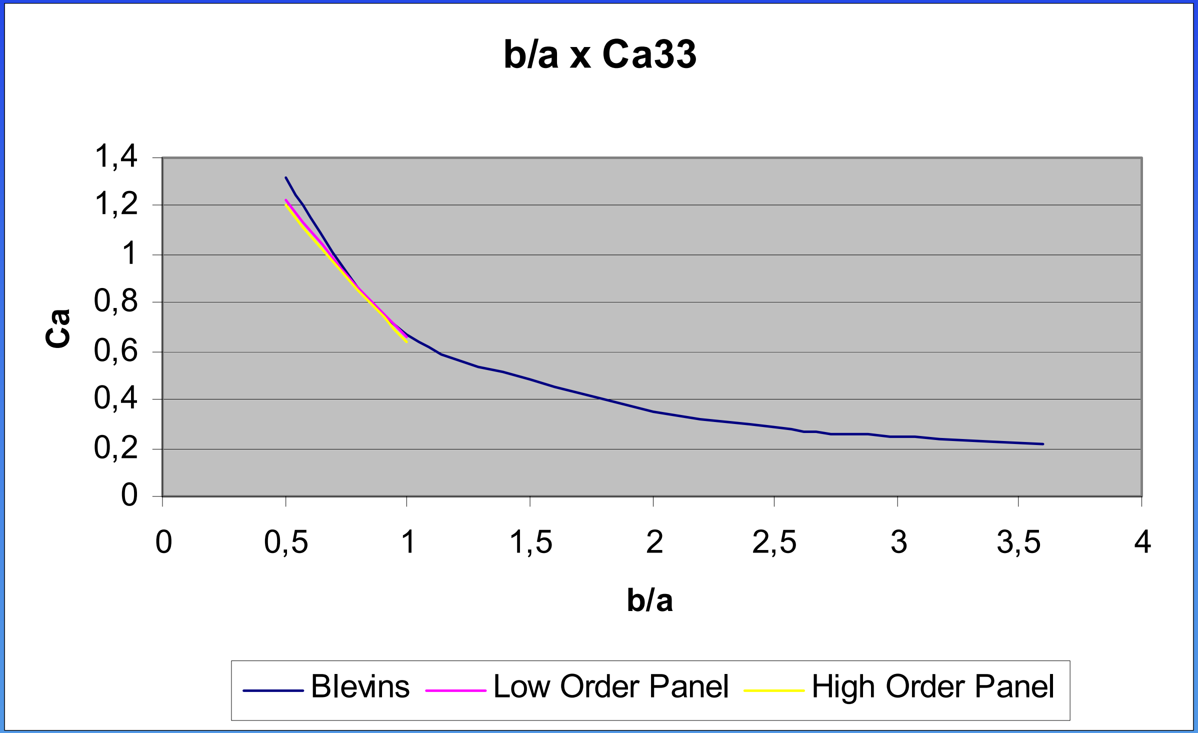
- High Order Panel:

Box

Order	No. Panels	Ca_{33} (p=0)	Ca_{11} (p=inf)
3	324	0,6618712	0,6607240
4	464	0,6601982	0,6595978
5	628	0,6594740	0,6591248
6	816	0,6591262	0,6588820
7	1028	0,6582606	0,6587506
8	1264	0,6589108	0,6587794
9	1524	0,6610808	0,6541880
10	1808	0,6669866	0,6665746



COMPARISON WITH RESULTS FROM LITERATURE (BLEVINS)

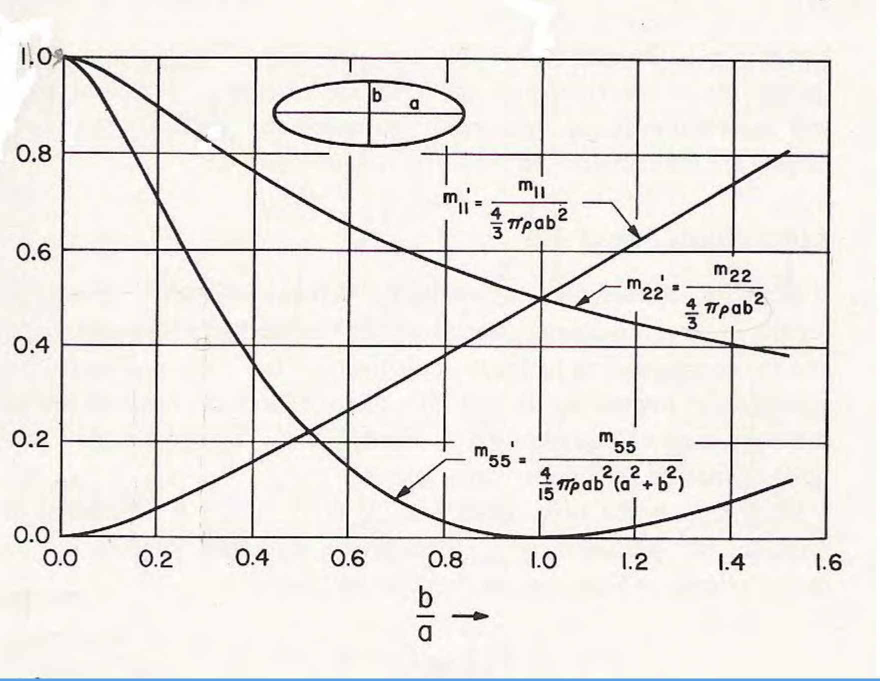


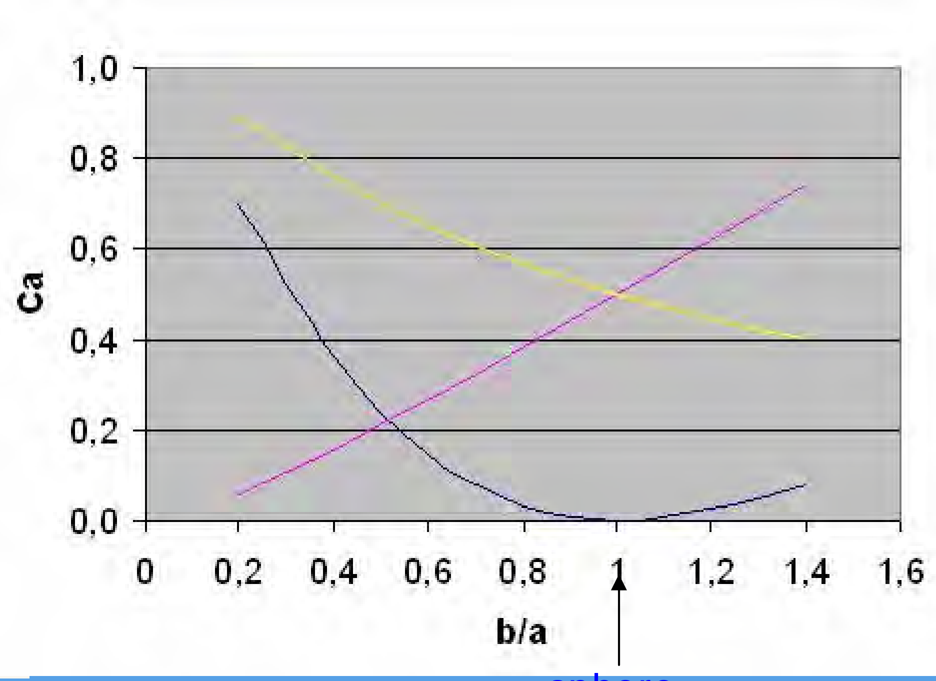
FINAL VALIDATION: Ellipsoid

Equal to well known results from Newman!

Newman (used very much since it is the unique published results for rotation properties)

NEWMAN'S | **Present Method**





APPLICATION: Box with Manifold Envelope

- Manifold dimensions: 16,635 x 8,5 x 5,149
  - Using High Order Panel de 4th order.

Ca11	Ca22	Ca33	Ca44	Ca55	Ca66
1,2377	1,6441	2,1500	0,3100	0,3195	0,4248

This is an unusual result:
added rotation properties for this rectangular box

Present work (several methods):

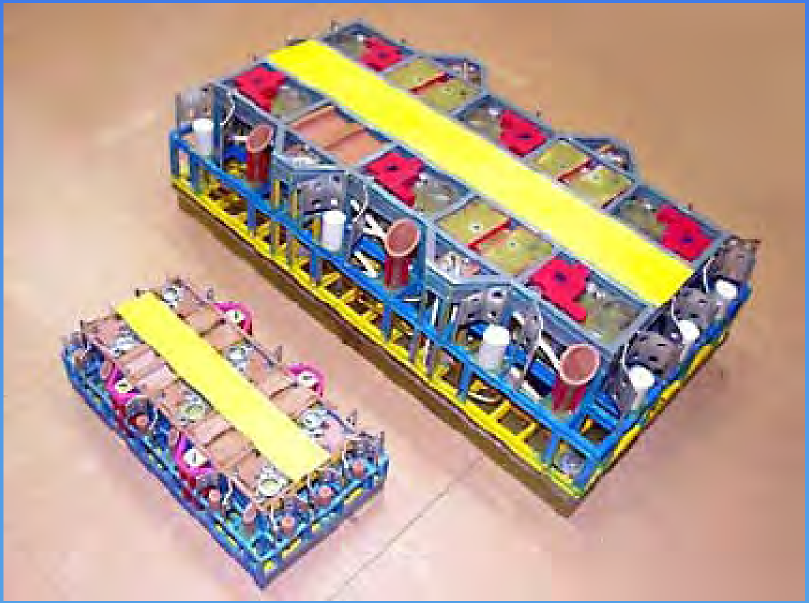
- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test

- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

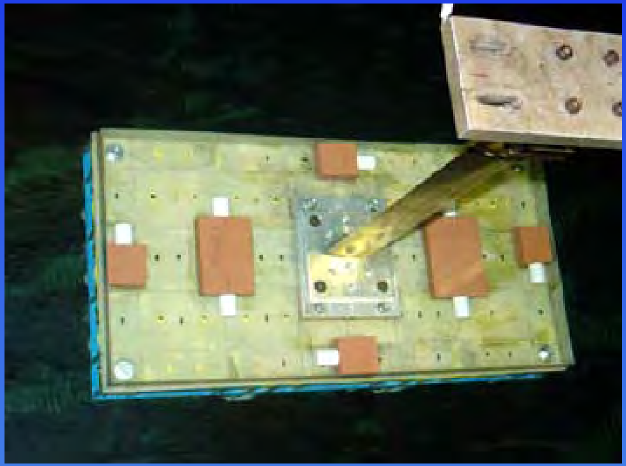
Experimental Method: Models

Two scales for further comparison

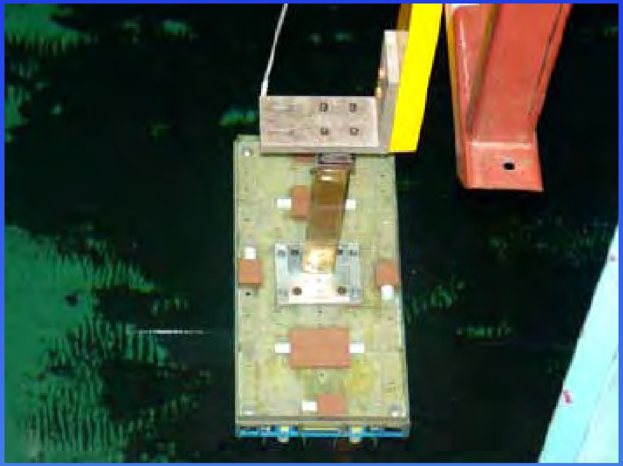
1:35 and 1:70



- The model testing uses the constant towing velocity (Cd) and constant towing acceleration (Ca) in towing tank.
- Directions X, Y and Z.



Model testing for direction X.



Model testing for direction Y.

Model testing for direction Z.

◆ Test Matrix

Direction	Terminal Velocity (m/s)	Acceleration (g)
X	0,5	0,01
X	0,5	0,02
X	0,5	0,03
X	0,5	0,04
Y	1,0	0,02
Y	1,0	0,04
Y + pl	1,0	0,02
Y + pl	1,0	0,04
Z	1,0	0,02
Z	1,0	0,04

- For Ca estimation:
  - new methodology: impose constant **acceleration**
    measure the forces on the support pile (H)
    the pile has its own effect (should be taken into account)

$$M_{aM} = X_A / a - X_{AH} / a_H - M_M$$

$$X_A = (M_M + M_{aM} + M_H + M_{aH}) \times a$$

$$X_{AH} = (M_H + M_{aH}) \times a_H$$

- During the tests four typical regions were identified:
- ✓ Region 1 initial acceleration
- ✓ Region 2 constant velocity platform
- ✓ Region 3 exit from the constant velocity platform
- ✓ Region 4 stop (memory effects)

Results from the Acceleration Test: Added Mass Coefficients

	Region 2	Region 4		Panels Method
C_{aX}	1,24	1,23		1,24
C_{aY}	1,71	1,20		1,64
C_{aY+Pl}	1,51	2,02		1,64
C_{aZ}	2,27	2,26		2,15

- ✓ The added mass coefficients for X direction for regions 2 and 4 are extremely close of the result of Panels Method!
- ✓ For Z direction the results are still close to Panels Method although it does not have symmetry.
- ✓ For Y direction the effect of the added plate was to decrease the added mass in region 2 and to increase in region 4, as expected

Present work (several methods):

- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test

- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

Drag Coefficients – Steady Flow

The drag coefficients were calculated for directions X, Y and Z, in 1:35 scale, using equation:

$$C_d = \frac{F_d}{\frac{1}{2}\rho A V_m^2}$$

Where:

F_d drag force

ρ water density

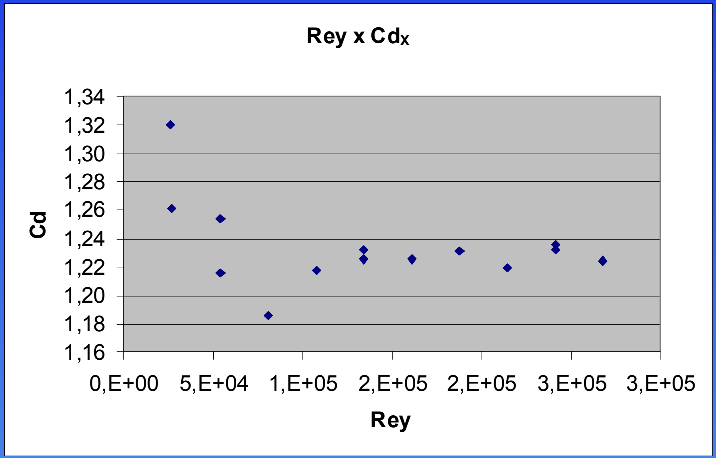
A frontal area

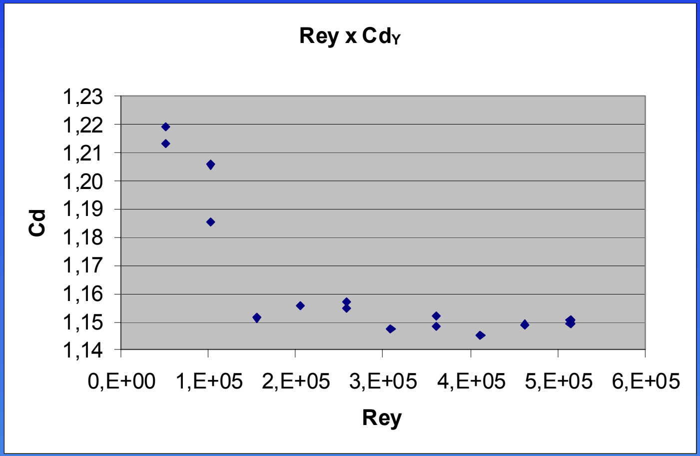
V_m manifold velocity

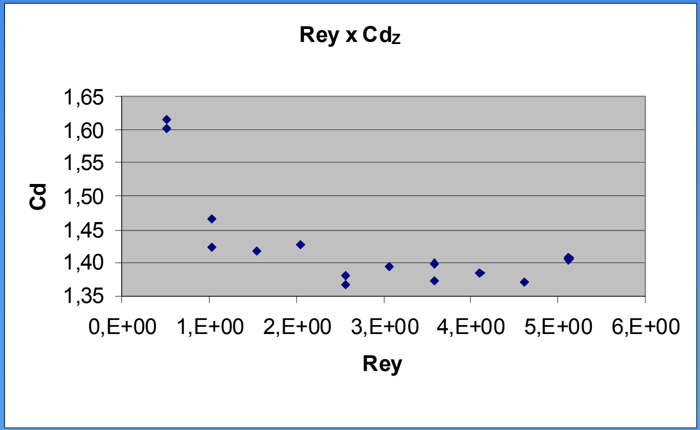
The Reynolds number

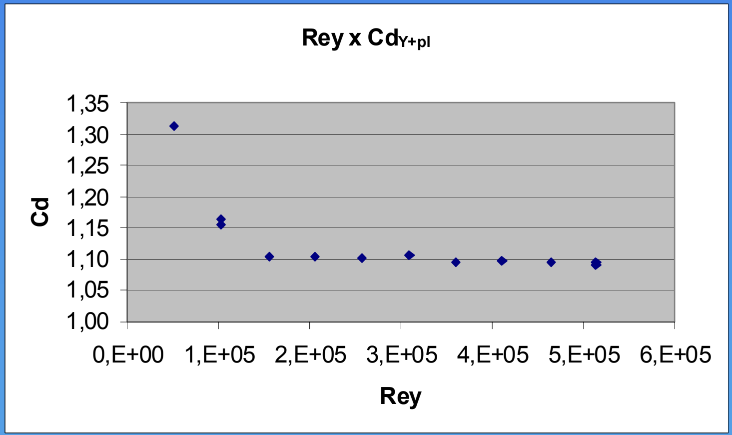
$$Rey_m = \frac{V_m L}{\upsilon}$$

Drag Coefficients X Reynolds









◆ Drag Coefficients - Steady Flow

- ✓ The final drag coefficients obtained after the transition (Reynolds number higher than 2×10^5):

Cd_X	Cd_Y	Cd_{Y+PL}	Cd_Z
1,23	1,16	1,10	1,40

- ✓ The plate decrease a little bit the drag coefficient for Y direction.

Present work (several methods):

- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test

- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

EXPERIMENTAL METHOD: VERTICAL RELEASE IN A DEEPWATER WAVE BASIN

- The vertical release tests were made in a deepwater wave basin, 15m, at LabOceano(COPPE).
- The trajectory (s) was registered by a camera for a video tracking treatment later on. The velocity (V) was evaluated derivating the trajectory through the time steps using the Extrapolation Mathematical Model (EMM)
- The Extrapolation Mathematical Model (EMM) is applied with the data from the tests in the Ocean Basin. When the two curves superpose each other the added mass and drag coefficients are achieved.
- All the added mass and drag coefficients entered in the EMM for the three directions are the same values obtained from the steady flow, confirming these results.

VERTICAL RELEASE IN A DEEPWATER WAVE BASIN

EMM: Expedite Mathematical Model

$$(m+m_a)\frac{dV}{dt}=\alpha-\beta V^2$$

$$(m+m_a)\frac{dV}{\alpha-\beta V^2}=dt$$

where

$$A\equiv\sqrt{\frac{\alpha}{\beta}}$$

$$B\equiv arctgh(\frac{V_0}{A})$$

$$C\equiv\frac{\sqrt{\alpha\beta}}{(m+m_a)}$$

$$\alpha\equiv(m-\rho\nabla)g$$

$$\beta\equiv\frac{1}{2}\rho A_F C_D$$

$$V=A\,tgh(B+Ct)$$

Hypothesis C_D m_a constants

EMM: Expedite Mathematical Model

$$s = \frac{A}{C} \ln \cosh(B + Ct)$$

$$a = \frac{AC}{\cosh^2(B + Ct)}$$

$$V_T = \sqrt{\frac{(m - \rho\nabla)g}{\frac{1}{2}\rho C_D A_F}}$$

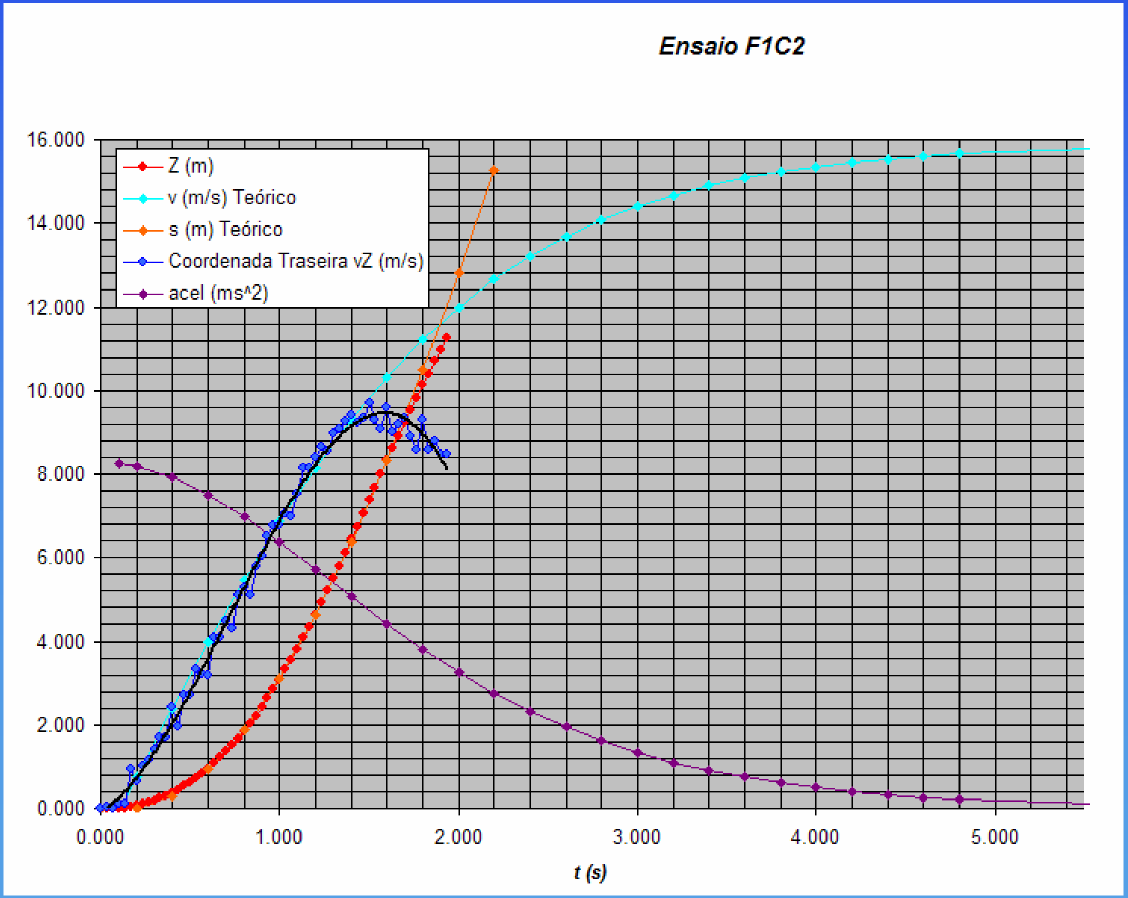
$$T_{0,99} = \frac{arctgh\left(\frac{0.99 \cdot v_T}{B}\right)}{C} - B$$

Results

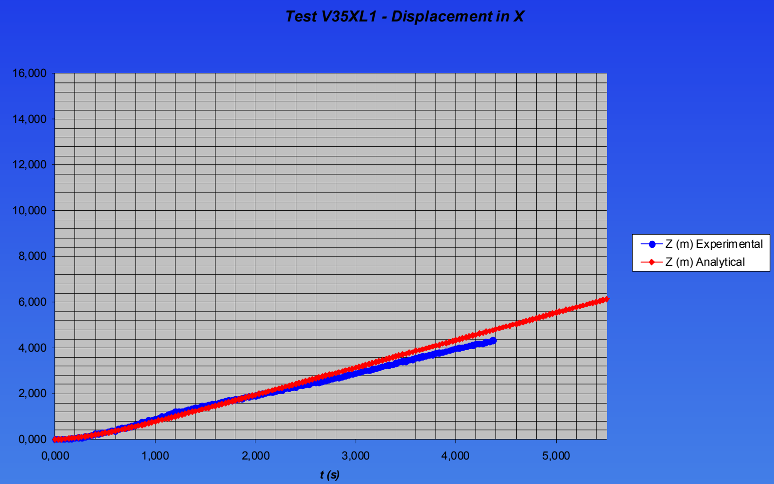
•*Data for adjustment*

PARAMETRICO	
m	0.0296
ro.V	0.0040
g	9.8000
C_D	0.5000
Área frontal	0.0040
ma/(ro.V)	0.2000
M+ma	0.0304
V_0	-0.9000
ρ	1.0000
m-(ro.V)	0.0256
Alfa	0.2513
Beta	0.0010
A	15.9053
B	-0.0566
C	0.5195
T. Acel.	5.20
V (0.99)	15.75
V (0.99)	60.98

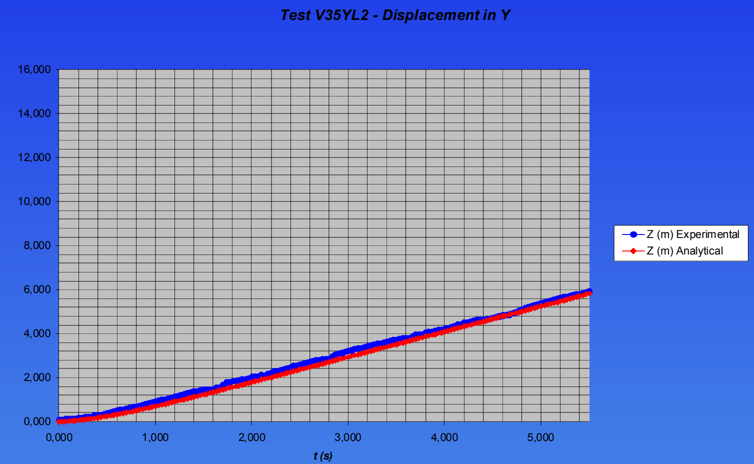
•*Results*



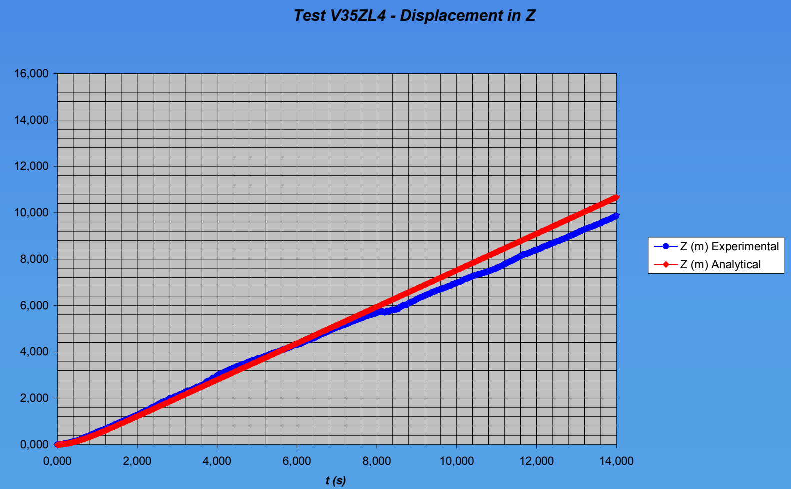
Displacement in X axis



Displacement in Y axis



Displacement in Z direction



Present work (several methods):

- **Ca via two methods**
  - Potential Theory
  - Possibly new experimental method in towing tank (Constant Acceleration Test)
  - Forced oscillation test
- **Cd via three methods**
  - Experimental Translation in a Towing Tank (Resistance Test)
  - Possibly new experimental method in a ocean basin (Vertical Launching Test)
  - Forced oscillation test

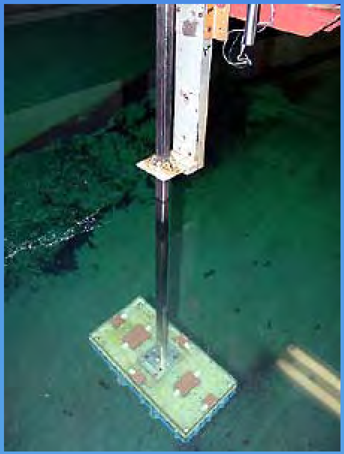
EXPERIMENTAL METHOD: FORCED OSCILLATION

- Forced oscillation tests obtain both the added mass and drag coefficients.
- The Reynolds number (Rey) and the Keulegan-Carpenter number (KC) must be evaluated.

$$KC = 2\pi \frac{A}{L}$$

$$C_a = \frac{M_a}{\rho \forall}$$

$$C_d = \frac{F_d}{\frac{1}{2}\rho A V_m^2}$$

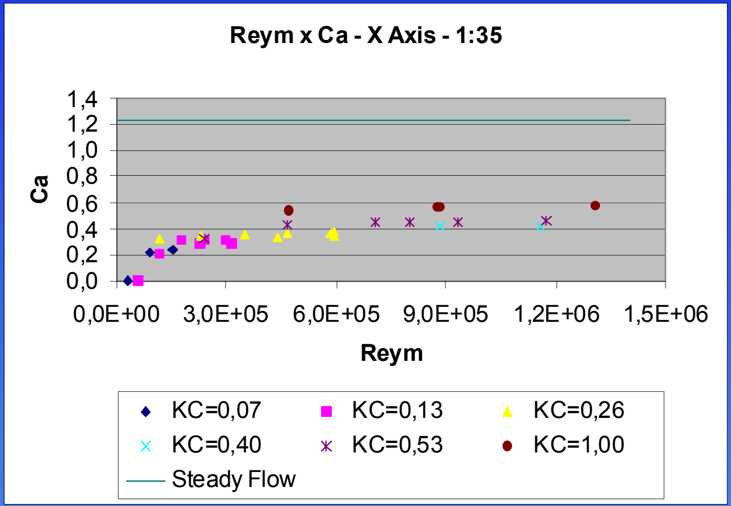


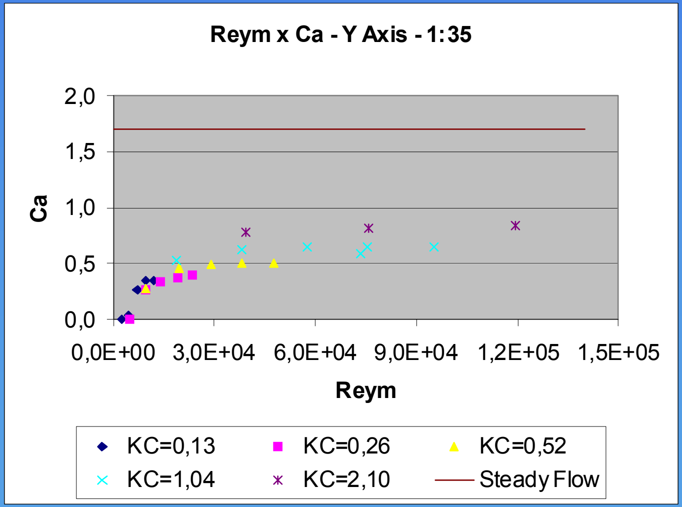
orced oscillation X direction

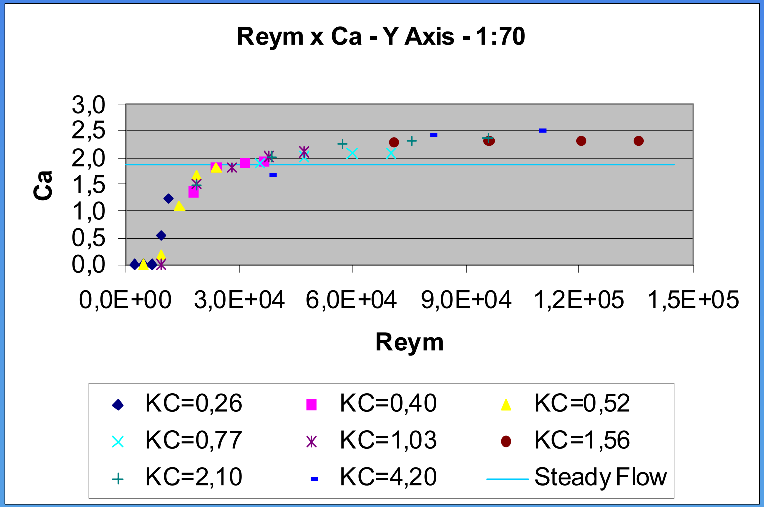
Y direction

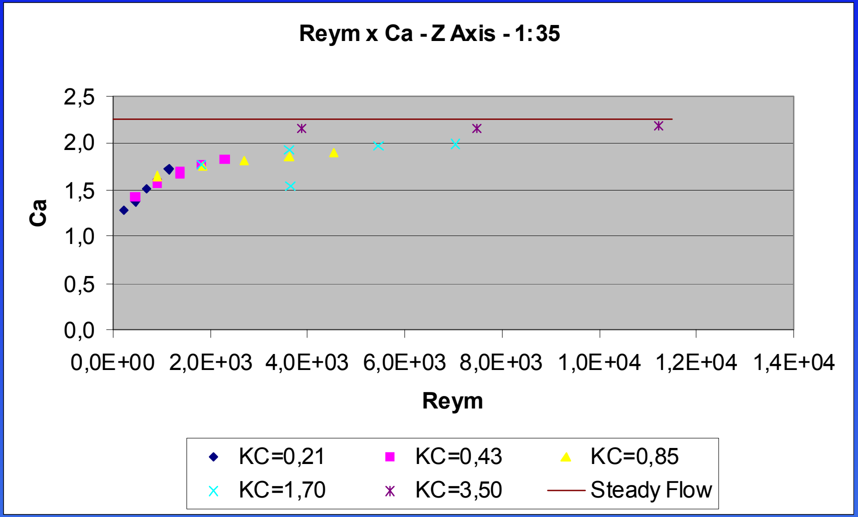
Z direction

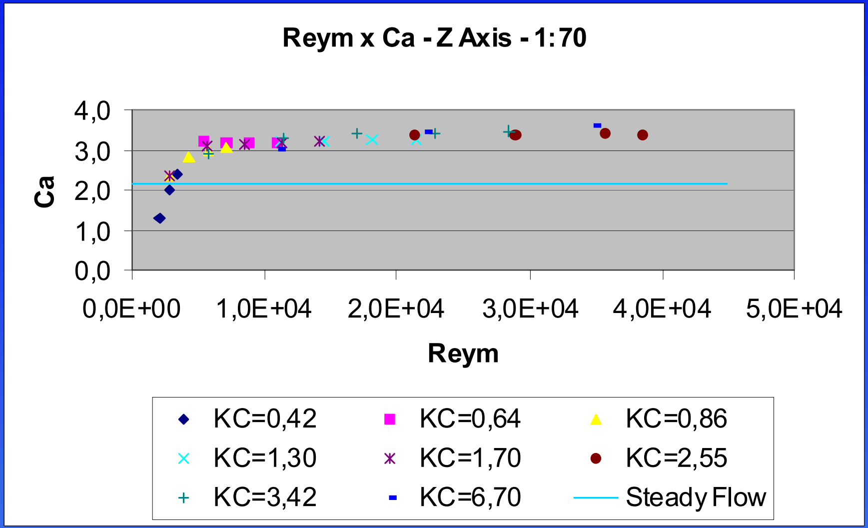
◆ Added Mass Coefficients – Forced Oscillation





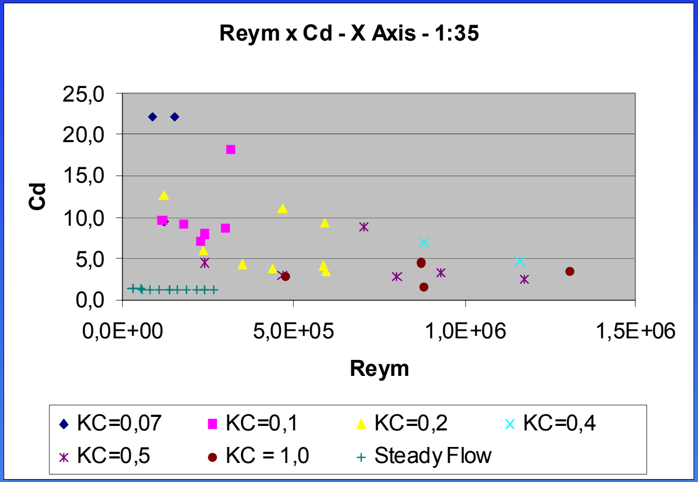


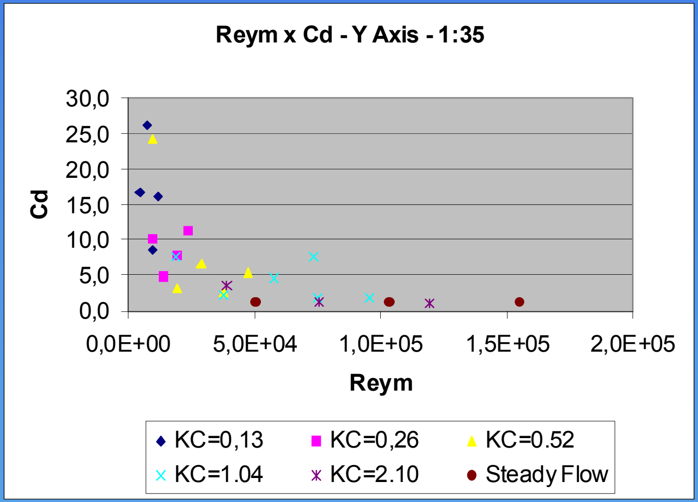


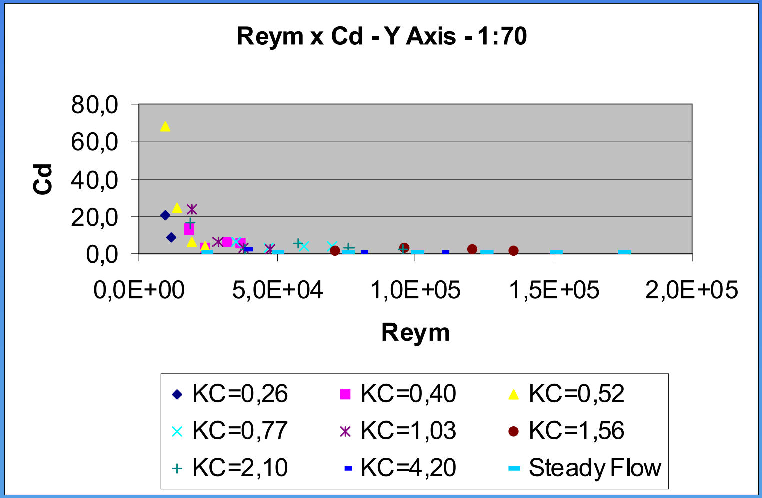


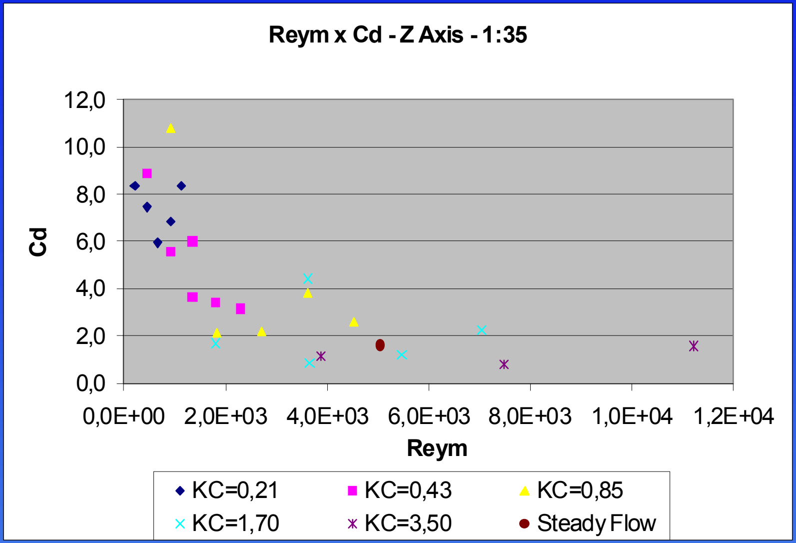
- The experience indicated that the values from the 1:70 scale are suffering from scale effects and should be discarded.

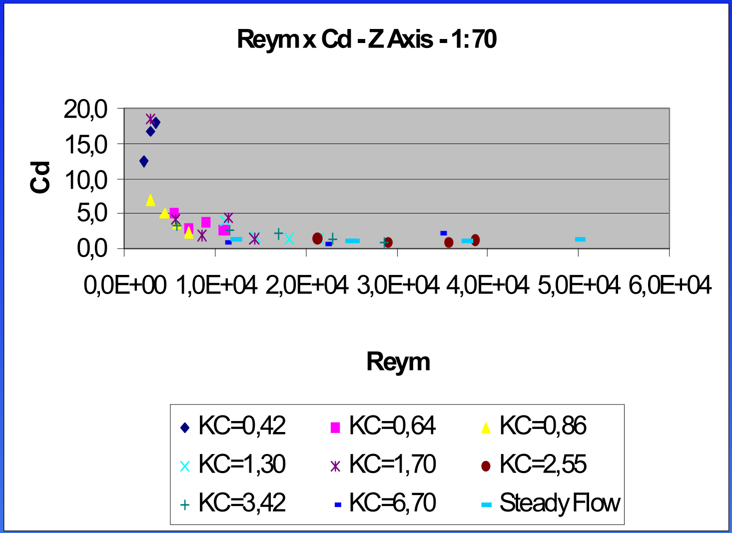
◆ Drag Coefficients – Forced Oscillation











- Again, the experience indicated that the values from the 1:70 scale are suffering from scale effects and should be discarded.

SUMMARY OF THE RESULTS FOR ADDED MASS (Ca)

	Ca_{11}	Ca_{22}	Ca_{33}	Ca_{44}	Ca_{55}	Ca_{66}
Panel's Method	1,24	1,64	2,15	0,31	0,32	0,42
Steady Flow 1:35	1,24	1,71	2,26	-	-	-
Vertical Release	0,60	0,84	2,15	-	-	-
Forced Osc. 1:35	0,57	0,84	2,19	-	-	-

- SUMMARY OF THE RESULTS FOR DRAG COEFFICIENT (Cd)

	Cd_{11}	Cd_{22}	Cd_{33}
Steady Flow 1:35	1,23	1,16	1,43
Vertical Release	1,23	1,16	1,43
Forced Osc. 1:35	1,57	1,13	1,55

THANK YOU!

Antonio C. Fernandes, COPPE/UFRJ
Fábio P.S. Mineiro, COPPE/UFRJ
Mario Ribeiro, FMC