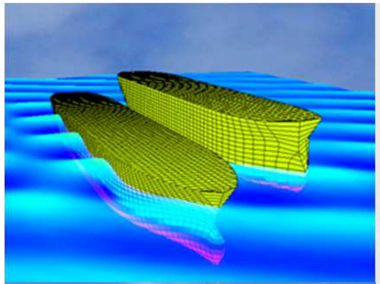
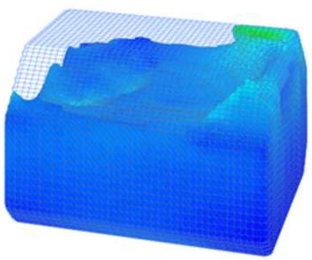
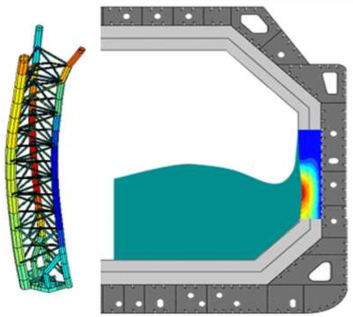






MULTIPHASE 2017

CFD Validations for Sloshing

CACHAN, October 2017

Louis DIEBOLD

BUREAU VERITAS

Move Forward with Confidence*

*Avançons en confiance

Bureau Veritas / Marine Division

CONTENTS:

BUREAU VERITAS

Move Forward with Confidence*

*Avançons en confiance

1. Validation of CFD Calculations for Liquid Global Forces

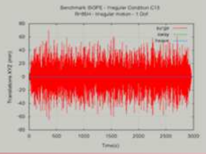
- **It is recognised that global flow is well reproduced by CFD calculations**
  - Exp./CFD agreement for liquid global forces for Anti-Roll Tank is excellent for the 1st order component and for short time durations

- **What about:**
  - longer time durations?
  - Complete global forces signal?

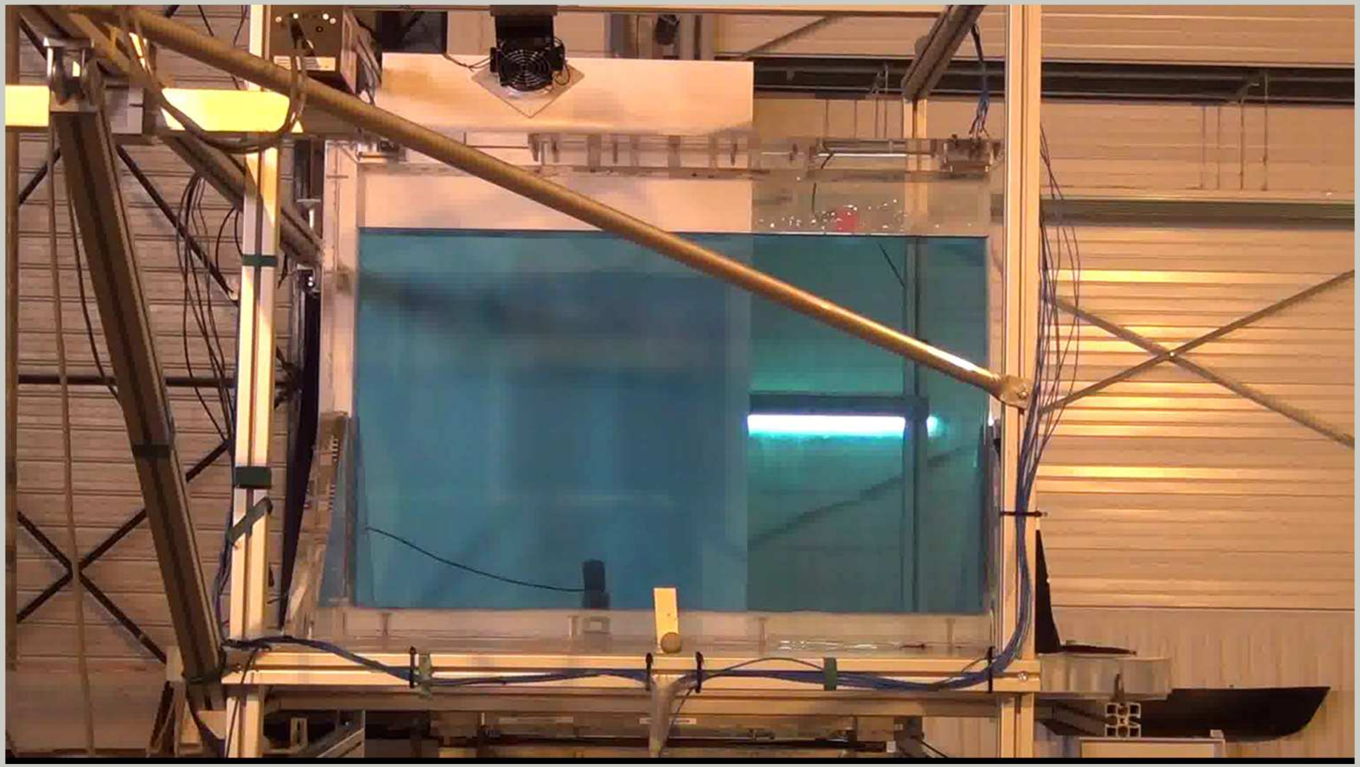
- **Sensitivity to initial conditions?**

- **Do exotic flows (more difficult to simulate) exist?**

Irregular Condition ⇨ C13



- **Irregular condition C13**
- **Distribution of liquid global forces**

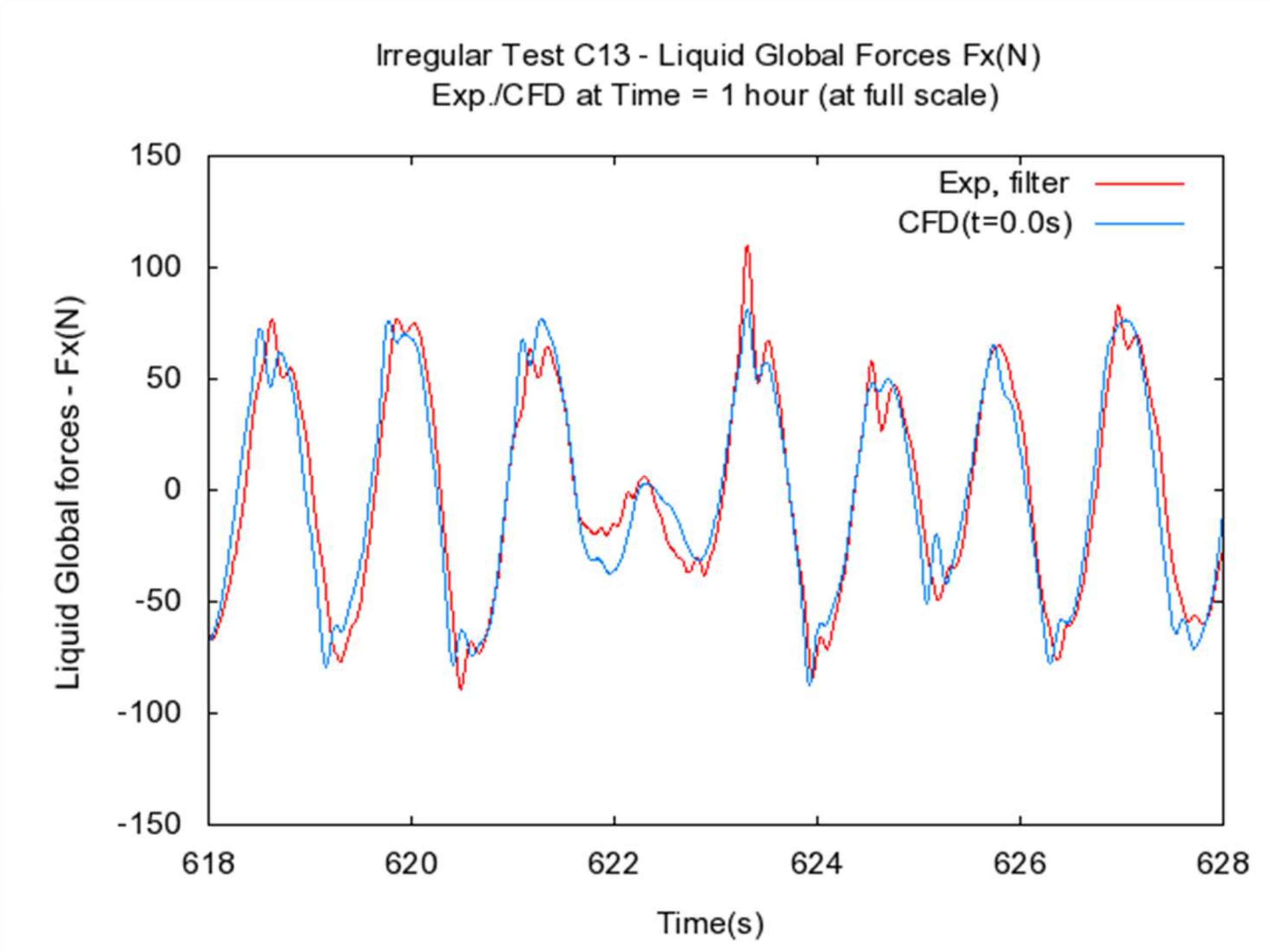


Liquid Global Forces

&

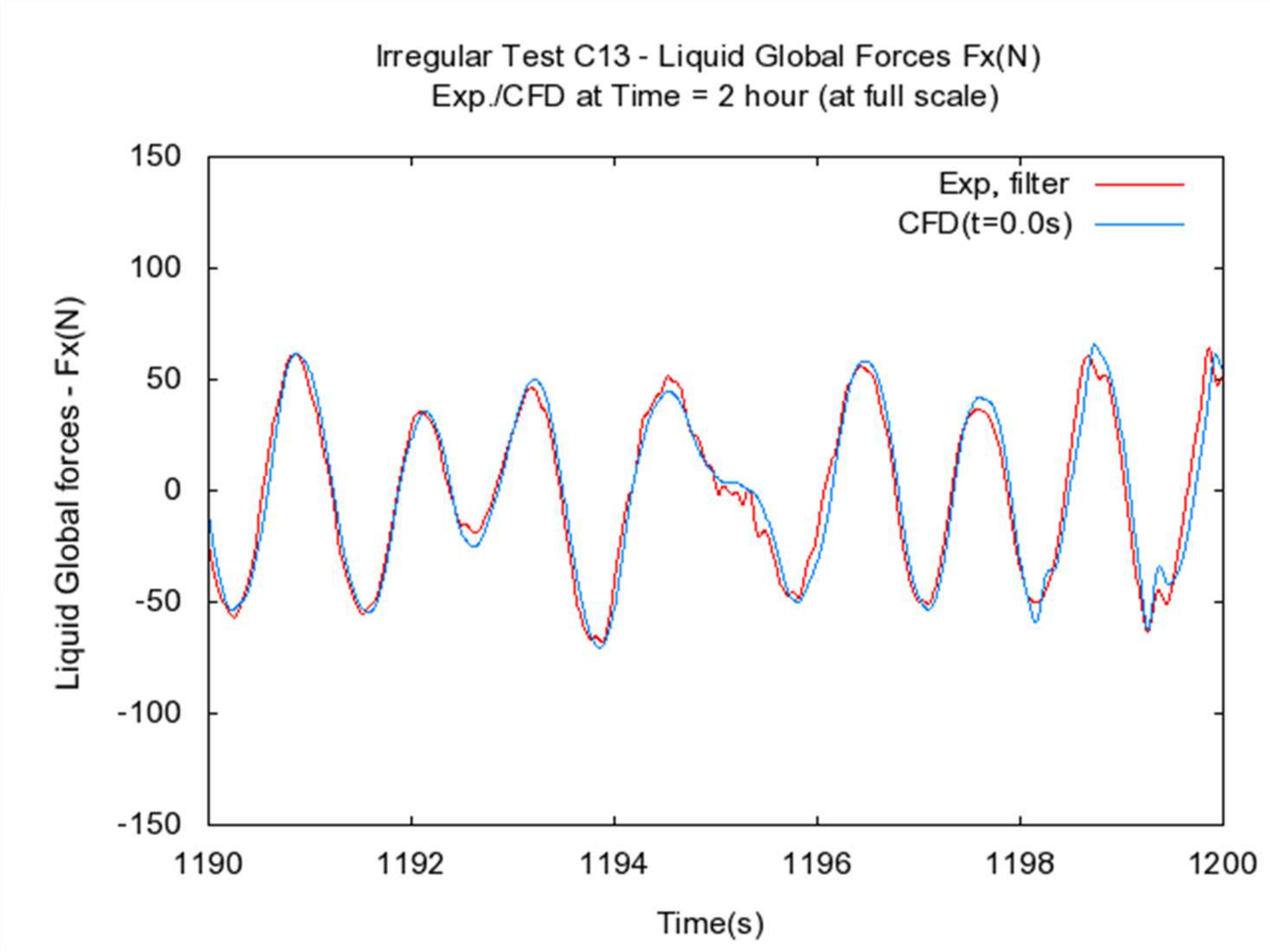
EPF of Liquid Global Forces Maxima

Irregular test – Video test C13
Liquid global forces



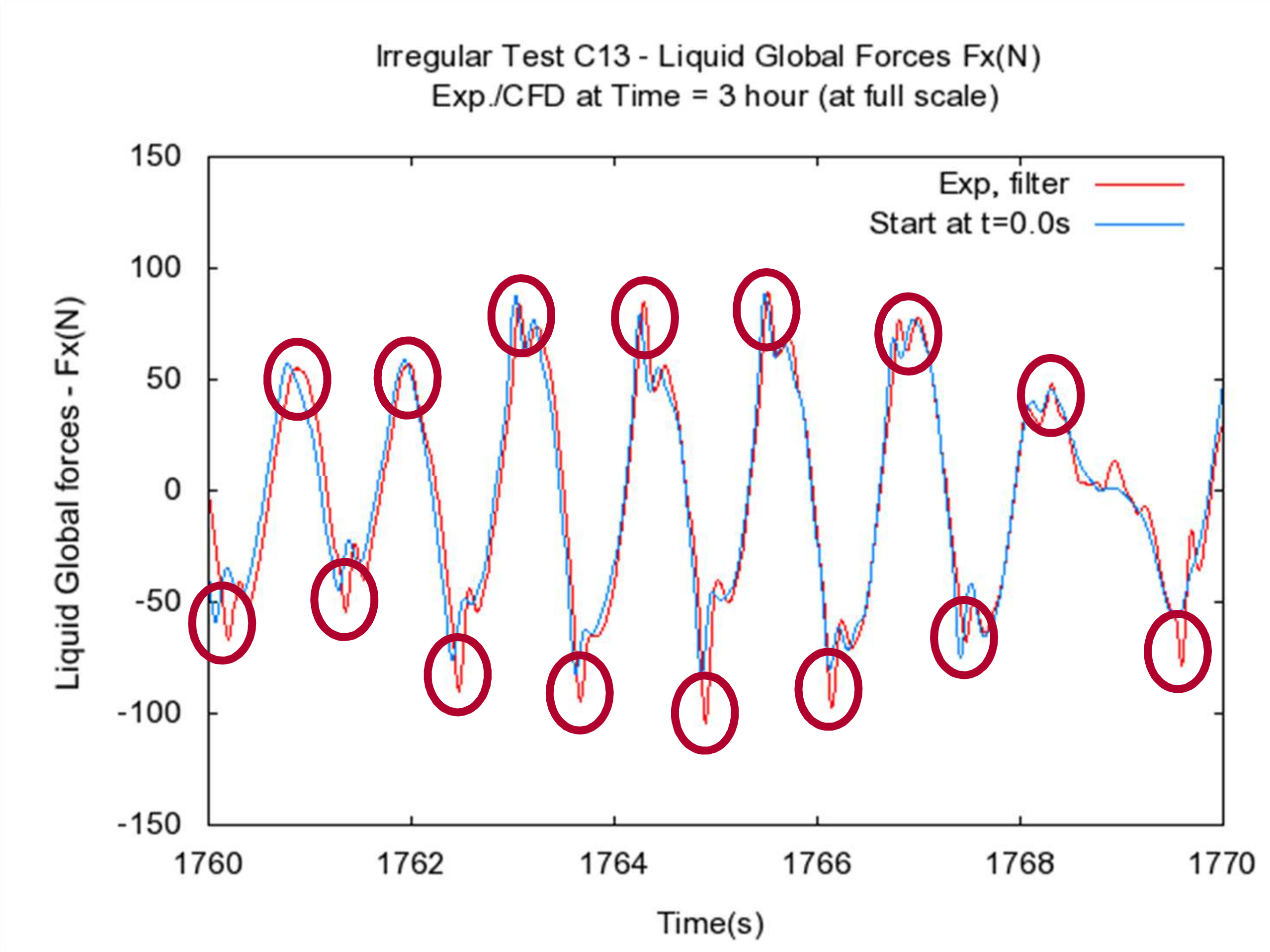
1 HOUR SIMULATION at full scale

Irregular test – Video test C13
Liquid global forces



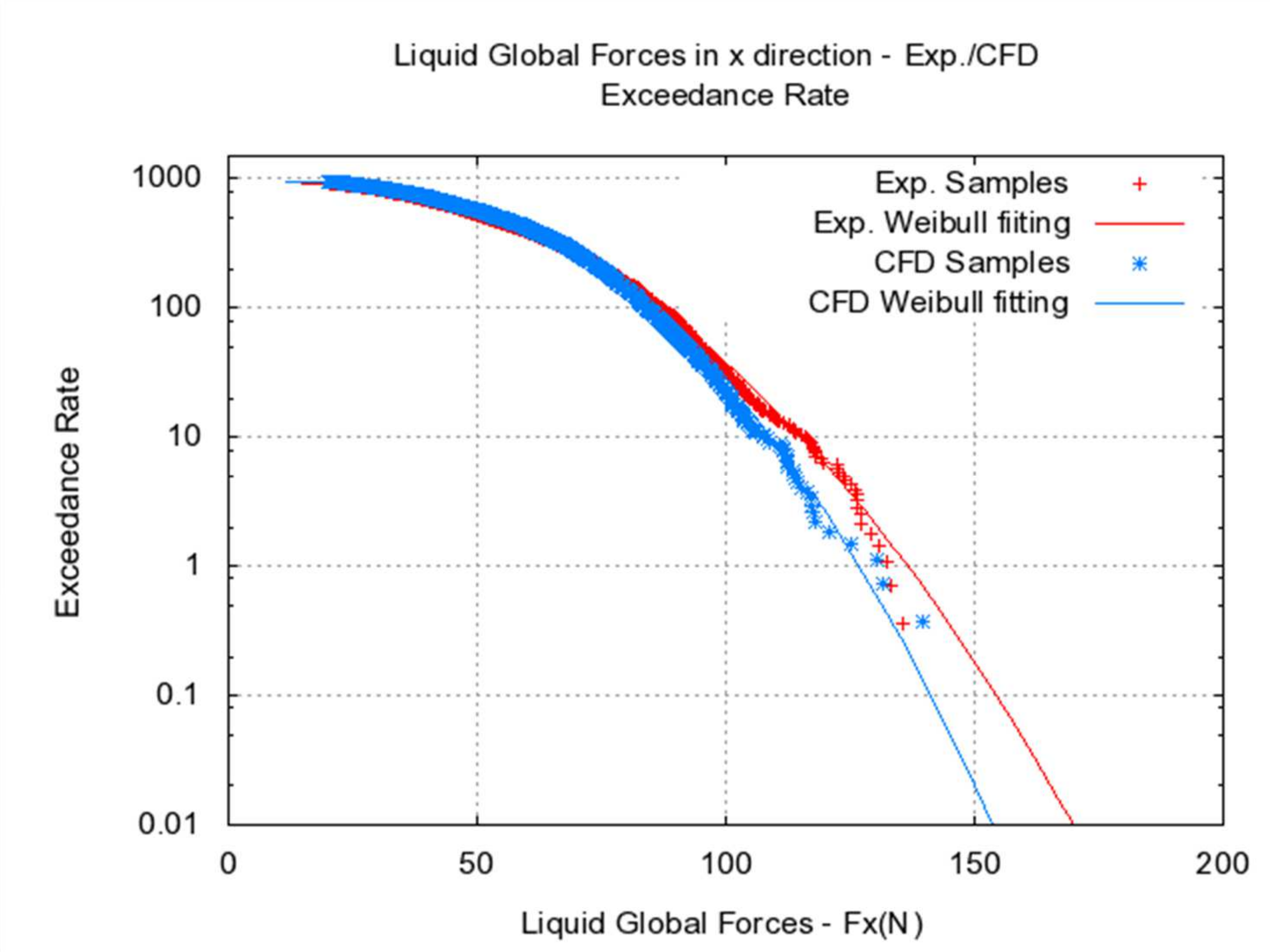
2 HOUR SIMULATION at full scale

Irregular test – Video test C13
Liquid global forces



3 HOUR SIMULATION at full scale

Irregular test – Video test C13
Exceeding Probabilty Function of Liquid Global Forces Maxima



Good agreement between Exp. & CFD

Irregular test – C13
Repetitiveness of Global Flow?

► **For C13 test, global flow comparison between**

- Flow started from rest at t=0s
- Flow started from rest at t=1hour – 25s

} Comparison at t=1hour

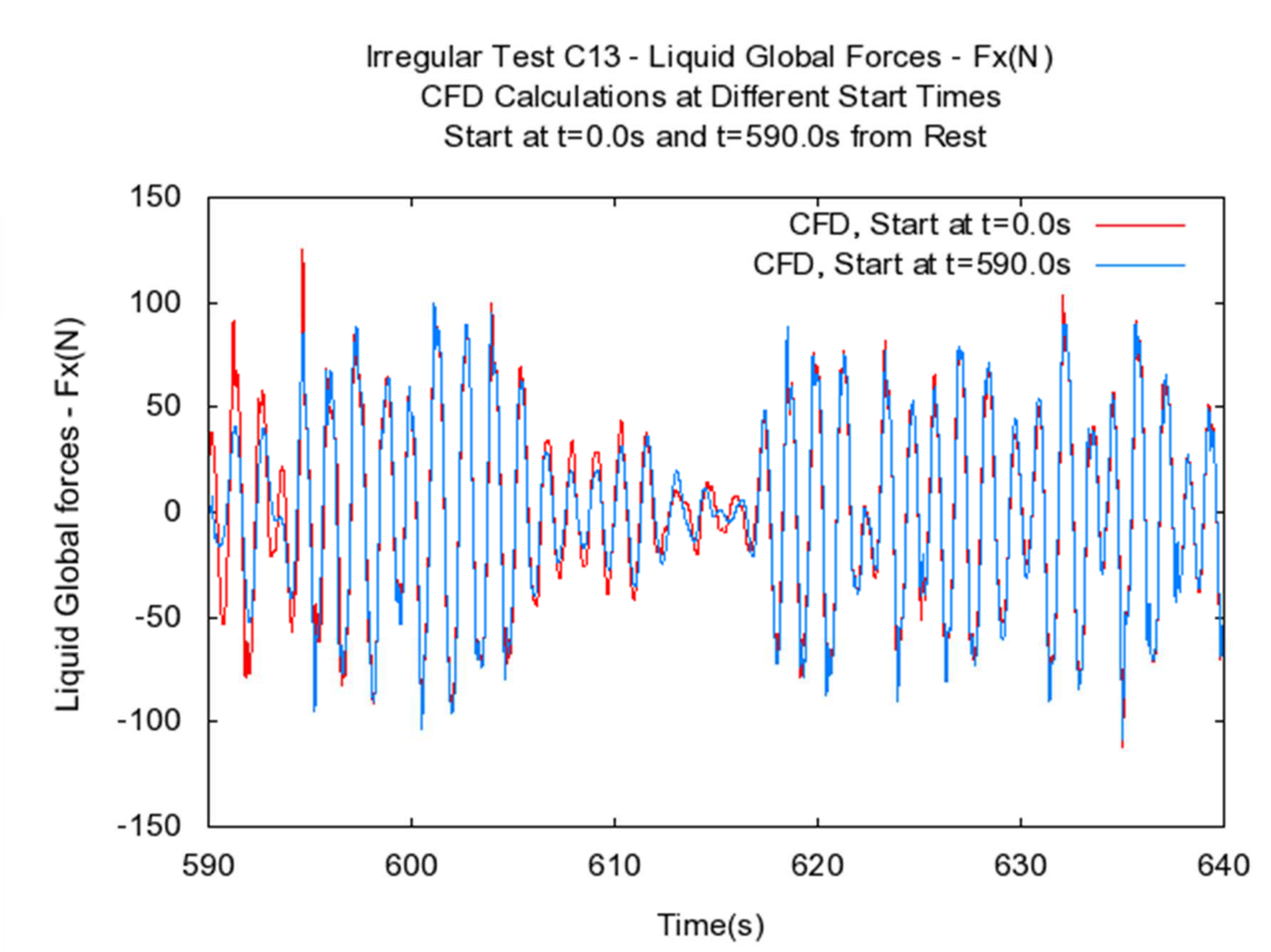
- Flow started from rest at t=0s
- Flow started from rest at t=2hour – 25s

} Comparison at t=2hour

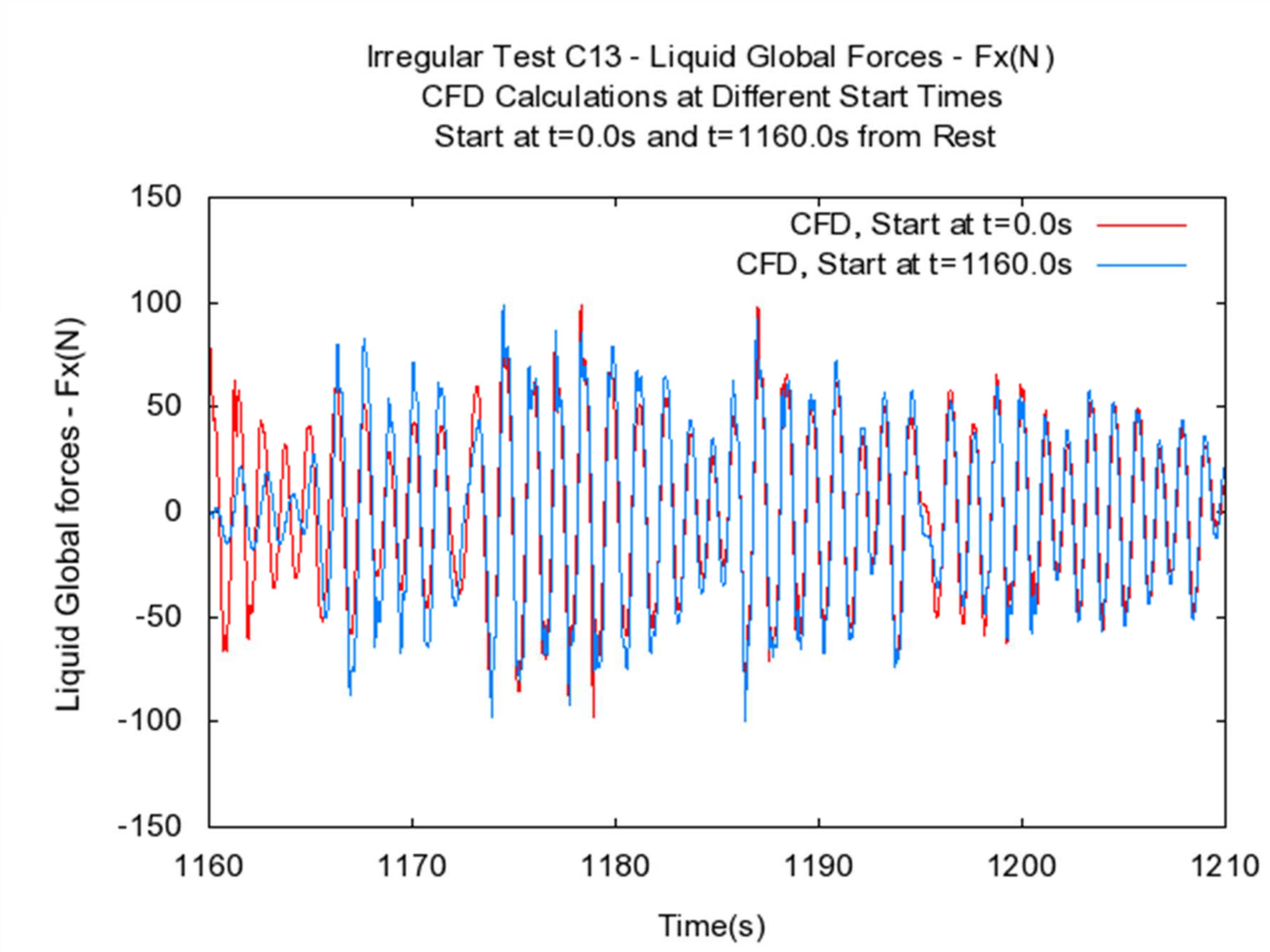
- Flow started from rest at t=0s
- Flow started from rest at t=3hour – 25s

} Comparison at t=3hour

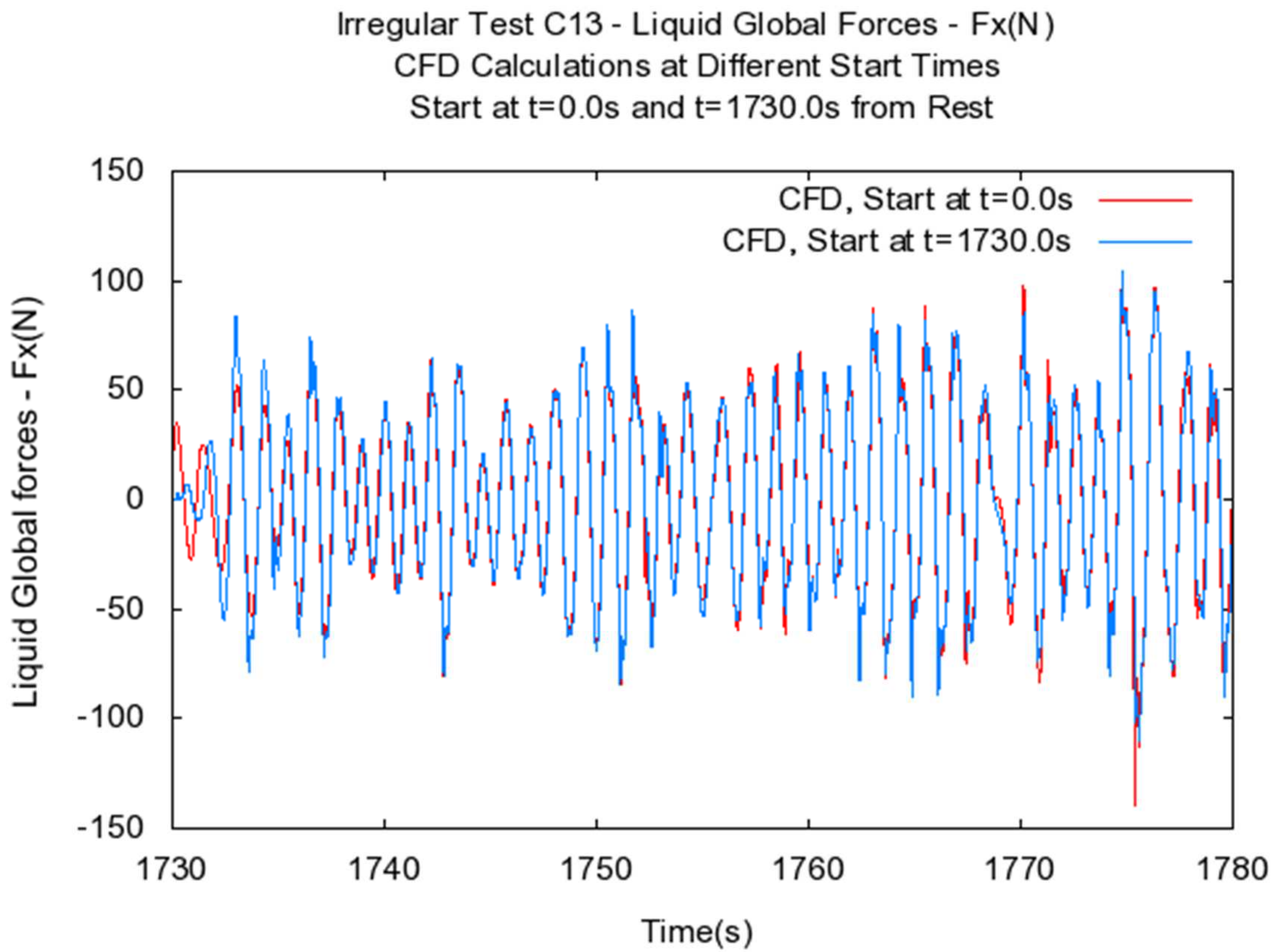
Irregular test – C13
Repetitiveness of Global Flow at t=1hour



Irregular test – C13
Repetitiveness of Global Flow at t=2hour



Irregular test – C13
Repetitiveness of Global Flow at t=3hour



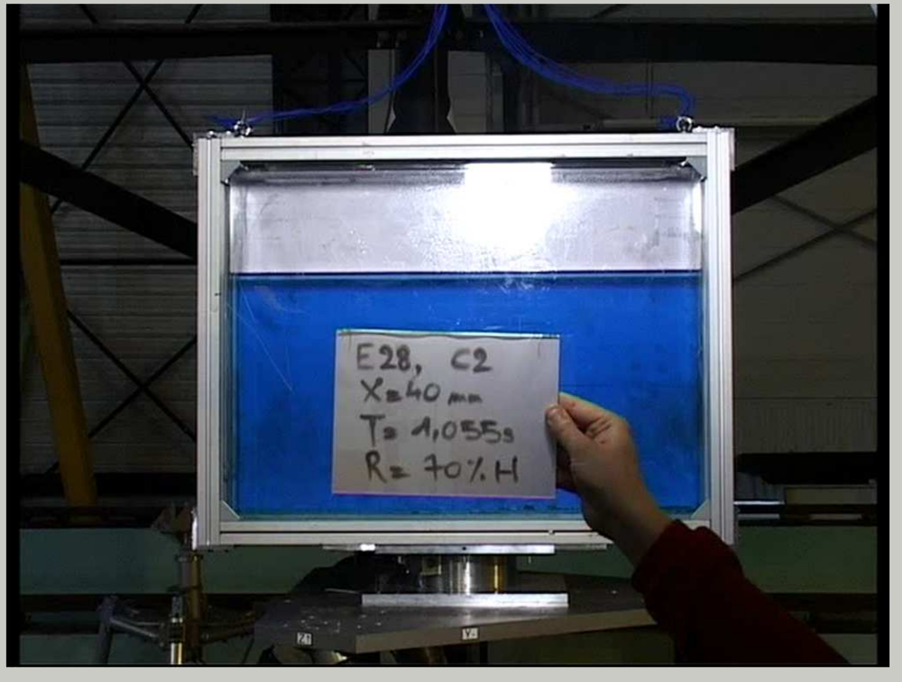
Repetitiveness of Global Flow

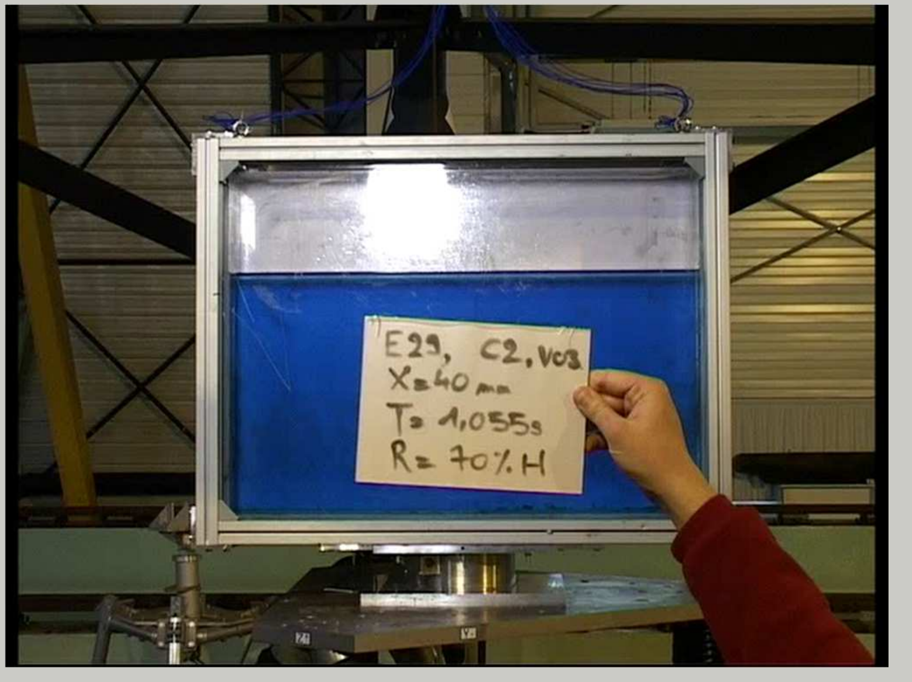
- **If one wants to perform statistics on one given impact at one given instant T**
  - Using repetitiveness
  - Not necessary to repeat the test since beginning
  - Just repeat the test from rest at T-20s

- **In ISOPE 2011, repetitiveness was also demonstrated for 3D tank for irregular excitation**

- **Repetitiveness ⇨ always true?**

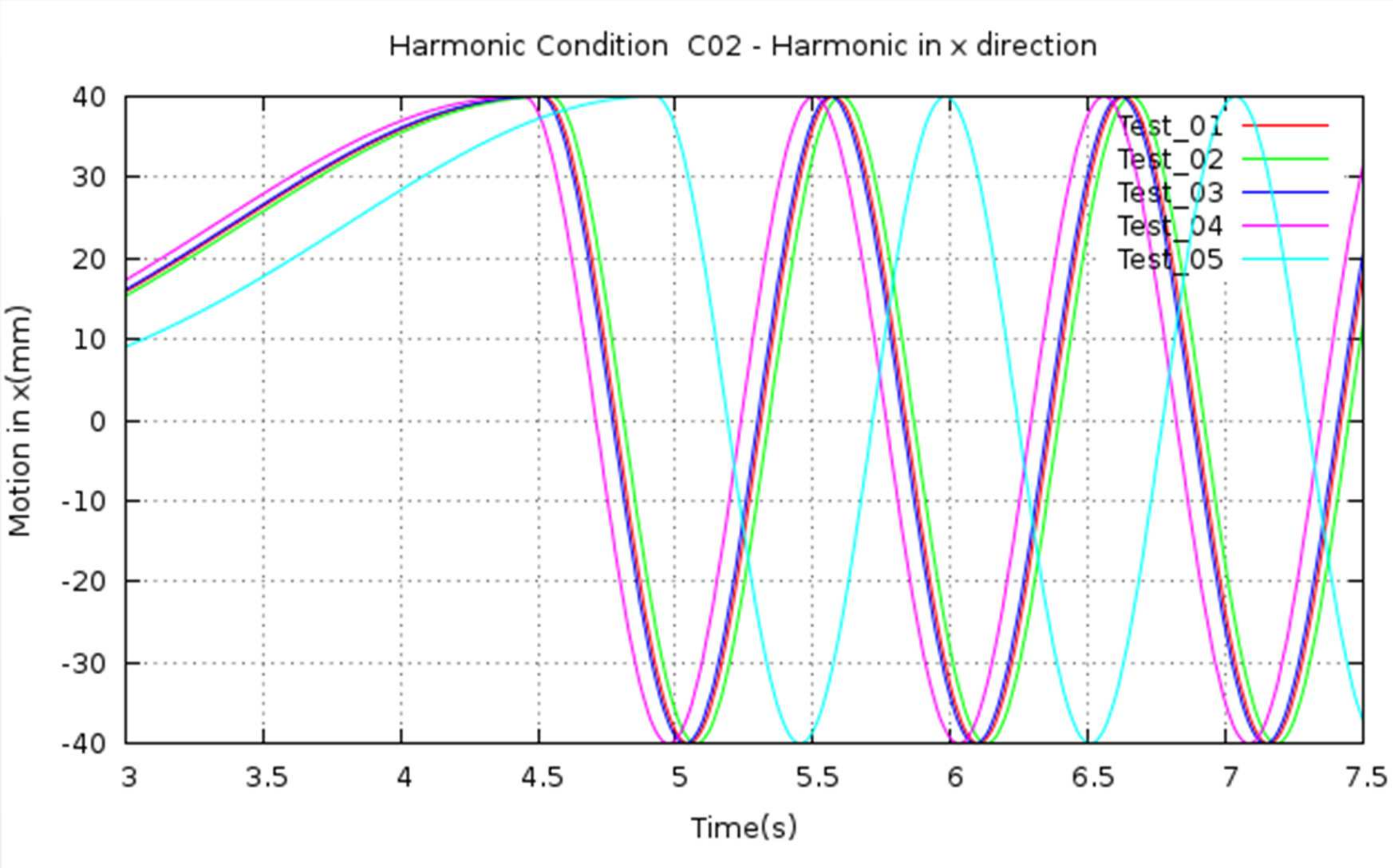
- See other irregular test for 3D tank, repetitiveness is also demonstrated (see SOPE 2011)
- Is the global flow always repetitive?
- No, see the C02 harmonic tested during the 1st benchmark (ISOPE 2012)



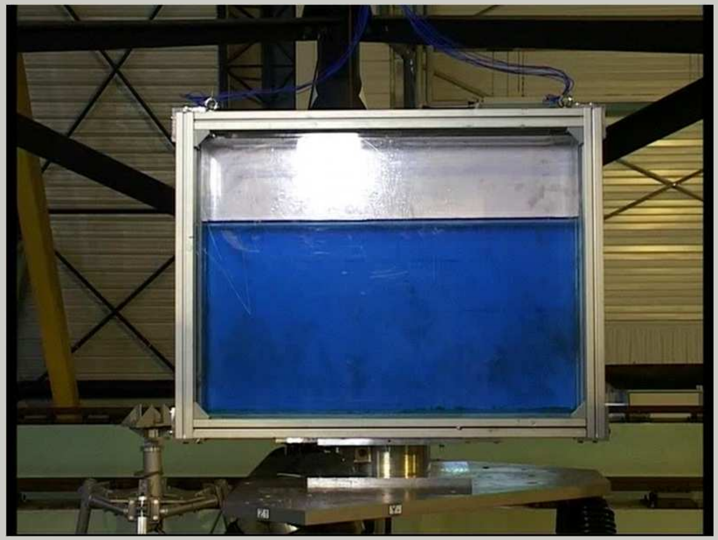


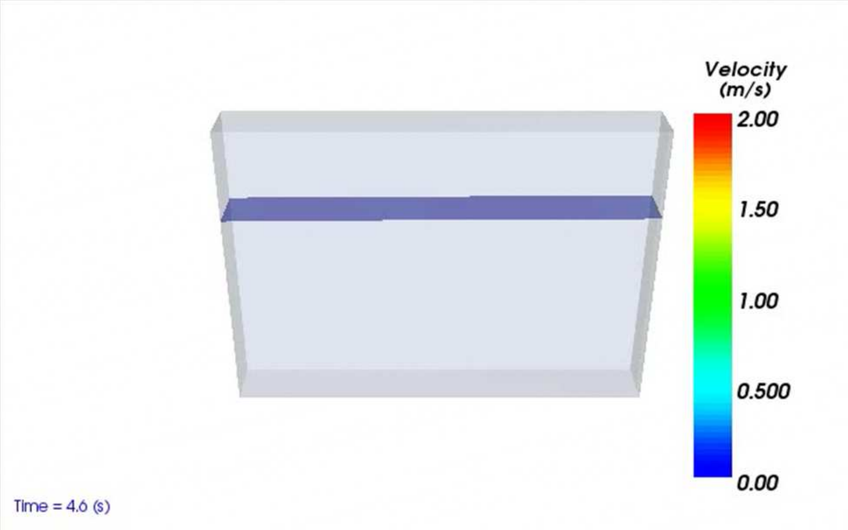
► Can this non symmetric flow be repeated by CFD?

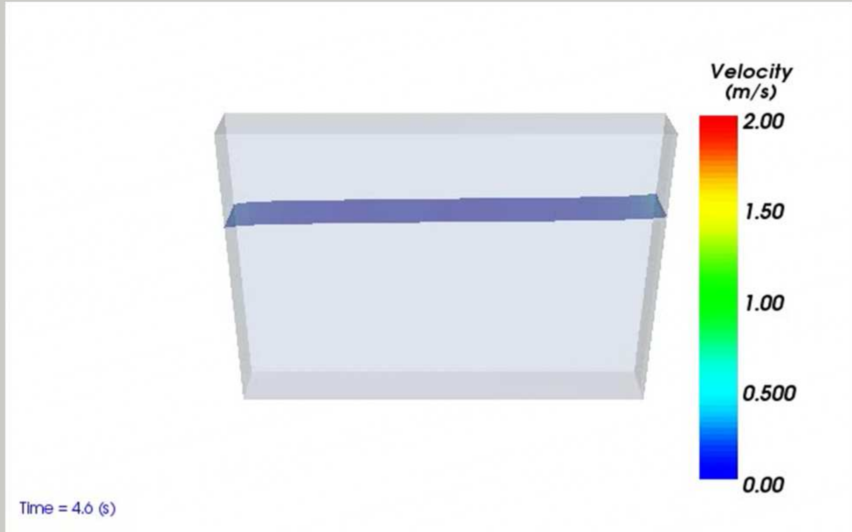
- Using actual signal sent to the test rig (hexapod)?



Exp./CFD




Velocity (m/s)
2.00
1.50
1.00
0.500
0.00
Time = 4.6 (s)


Velocity (m/s)
2.00
1.50
1.00
0.500
0.00
Time = 4.6 (s)

Harmonic Condition C02
Other explanation for non symmetric flow

► **Motion reproduction problem**

This condition enhances a really sensitive and unstable mode. For instance, during one repetition at Marintek, a one-off small variation of the motion has been observed and switched the impacted panel from r1 to r2 as shown in Figure 9.

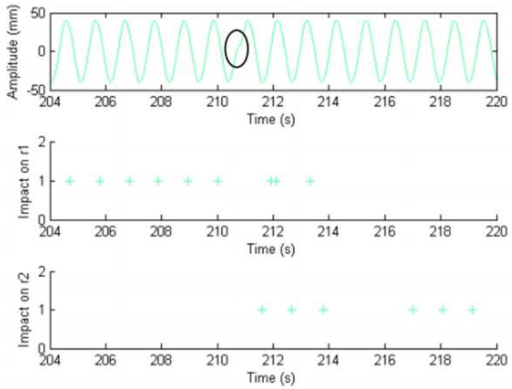
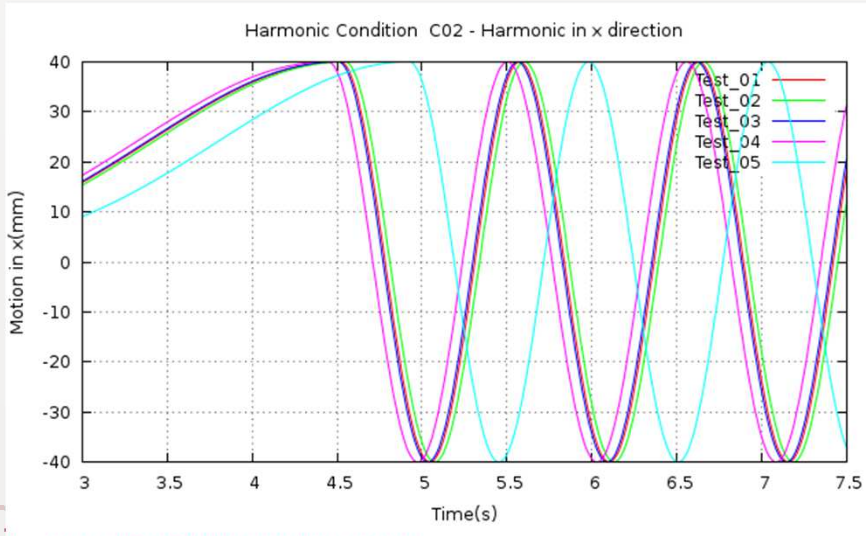


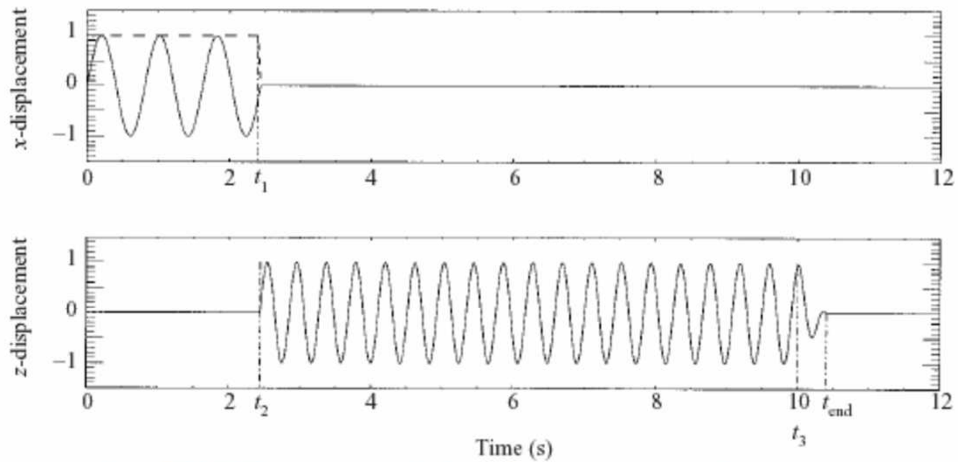
Figure 9. Marintek's recorded motion on C02 (repetition 3) with impacts on r1 and r2

In this non-symmetric condition, exceedance probabilities are still plotted on the sensor having the maximum ER. Results are shown in Figure 10.

► **Different ramp motions**



- **Horizontal & Vertical motions**
  - => Faraday instabilities
  - See the free surface elevation



- **Is CFD capable to reproduce such steep water waves in the tanks?**
  - Viscosities influence

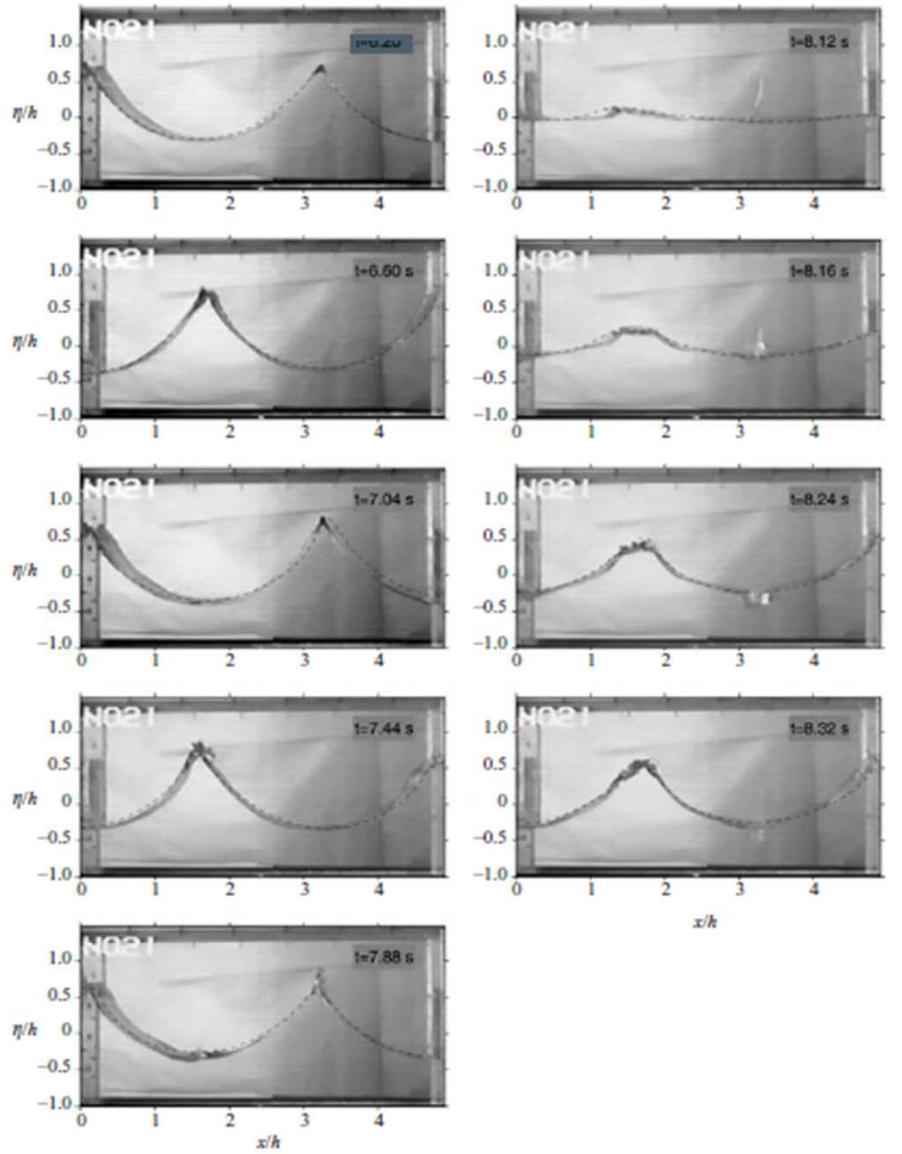
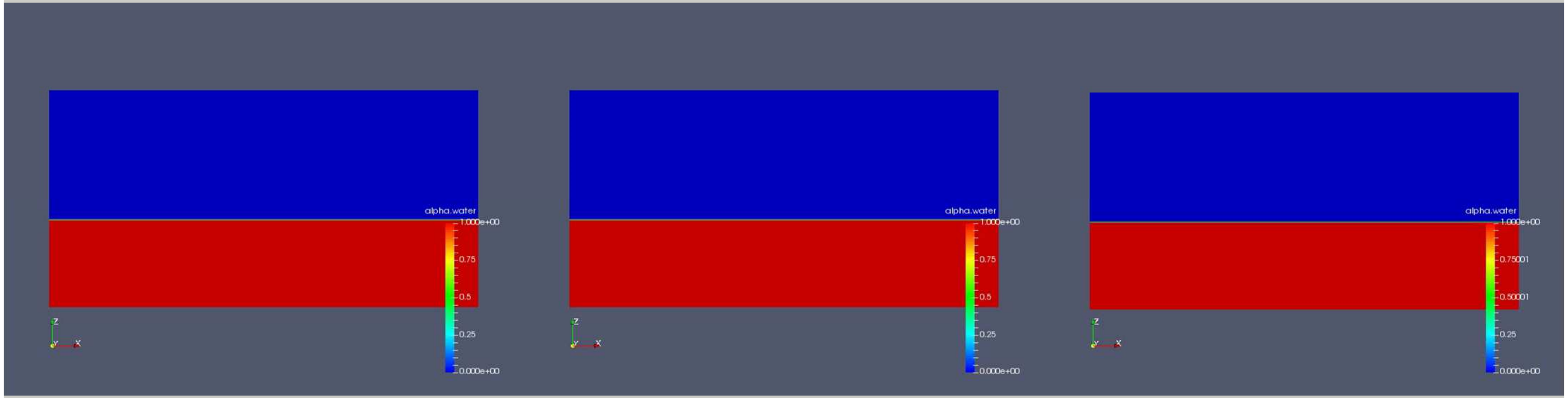


FIGURE 16. Comparison of experimental results and numerical results of an irrotational flow solver, experiment V21. The numerical free-surface elevation is plotted as a dashed line. Time values are given in the upper right corner of each image.

OpenFOAM v4.0 => 3 different viscosities were tested

► **Horizontal motion + vertical motion**



kin. visc. = 1.0^{E}-08

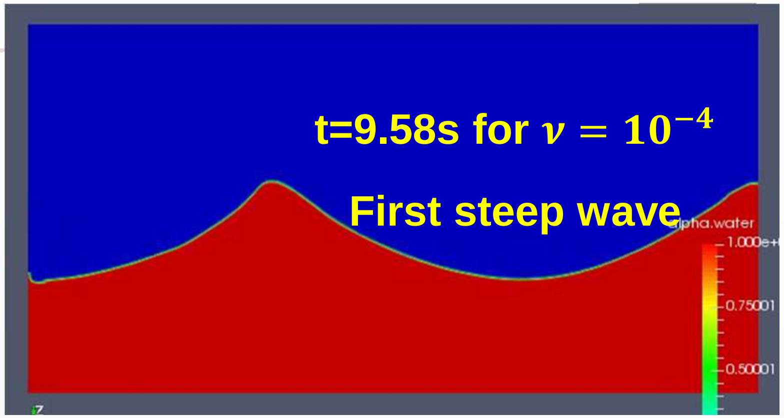
kin. visc. = 1.0^{E}-06

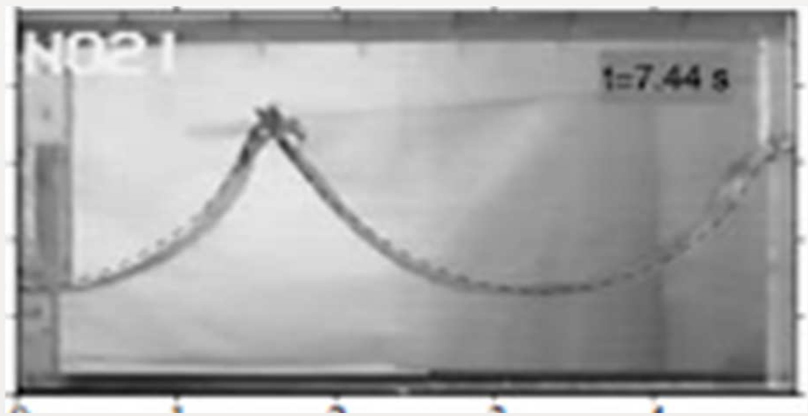
=> water

kin. visc. = 1.0^{E}-04

Sloshing Experimental Benchmark (Initiated by GTT)

- ► **First steep waves (in time) depend on viscosity**
  - t=9.58s for $\nu = 10^{-4}$
  - T=12.46s for $\nu = 10^{-6}$ & 10^{-8}
- ► **First steep waves appear first with highest viscoity**
- ► **CFD/Exp. agreement; for steep waves**
- ► **CFD steep waves appear later than in experiments**
- ► **Can we get better results with CFD or FSID (Scolan)?**





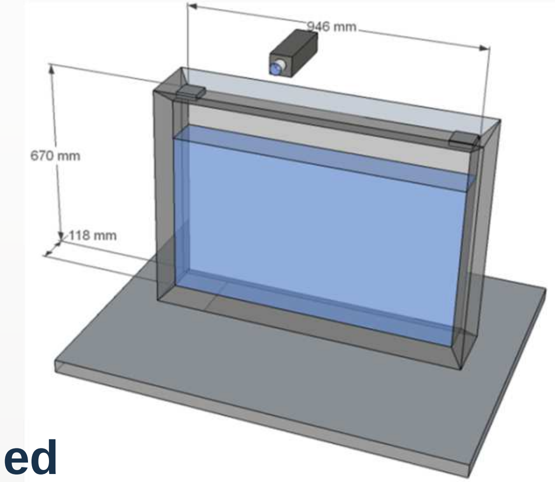
CFD Validations for Global Flows

- **It is recognised that global flow is well reproduced by CFD calculations**
  - Exp./CFD agreement for liquid global forces for Anti-Roll Tank is excellent for the 1st order component and for short time durations
- **What about:**
  - longer time durations?
  - Complete global forces signal?
  - CFD is capable to reproduce long duration simulations with a very good accuracy for liquid global forces
- **Sensitivity to initial conditions?**
  - CFD is capable to « catch » sensitive initial conditions
- **Do exotic flows (more difficult to simulate) exist?**
  - Exotic flow such as faraday instabilites are more difficult to reproduce using CFD
  - CFD can predict steep waves which depend on viscosities
  - CFD steep waves appear later than in experiments
  - See with Bredmose for experiments

2. Experimental Sloshing Benchmark

Sloshing Experimental Benchmark (Initiated by GTT)

- **Simple test conditions**
  - 2D tank (1/40th longitudinal LNG tank slice)
  - Water and air
  - One filling height (85%H)
  - 3 types of motions ⇨ SIW, Harmonic & Irregular



- **3 selected input parameters to be tightly controlled**
  - Tank positionning
  - Filling level
  - Actual motion of the rig
- **Simple measurements**
  - High speed camera
  - Min 1000 fps
  - Pressure sensor maps
  - From 16 up to 72 sensors

Objectives

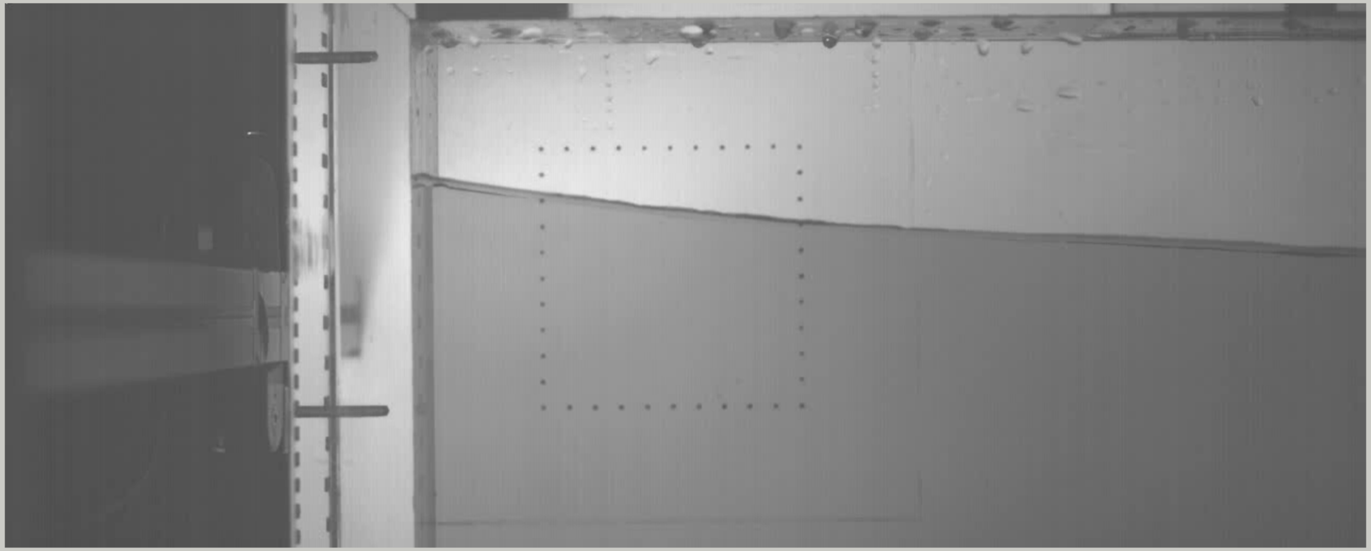
- **Sloshing community aims to settle the tests best practices**
  - 1st benchmark in 2011-2012 and 2nd benchmark in 2012-2013
- **Why BV participated? ⇨ Following BV sloshing assessment (BV NI 554)**
  - Sloshing model tests ⇨ mandatory
  - BV CFD calculations for independent review

  } Exp./CFD Comparison
- **To enrich as much as possible the ISOPE sloshing benchmark database**
  - Liquid global forces ⇨ To improve understanding of the experiments
  - To better understand the experiments ⇨ Exp./CFD comparisons

Flow		Global		Local	
		Free surface	Global Forces	Free surface	Pressure
Exp.	SIW	X	X	X	X
	Irregular	X	X		
CFD	SIW	X	X	X	X
	Irregular	X	X		

Single Wave Impacts ⇨ SIW C18
High Speed Camera ⇨ Wagner Type

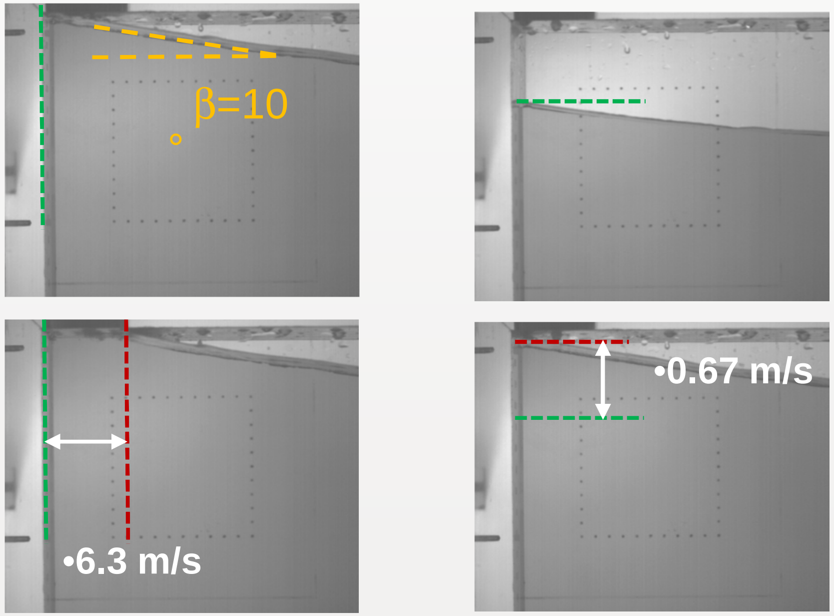
- Single Wave Impact C18
- Wagner Type
- Repetitive in terms of pressure… hmmm…
- Travelling character of pressure captured



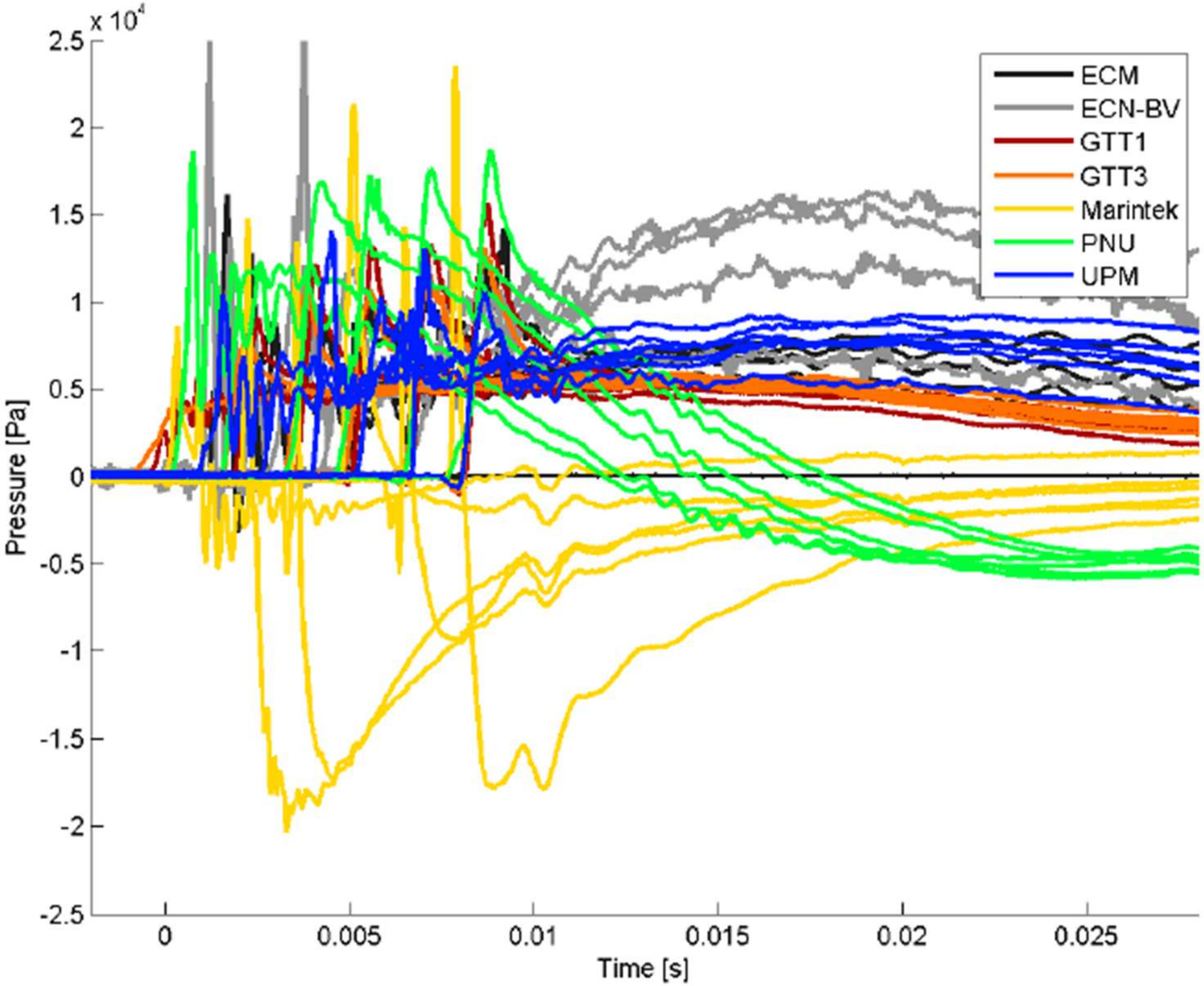
Some comparisons CFD vs experiments
Wagner

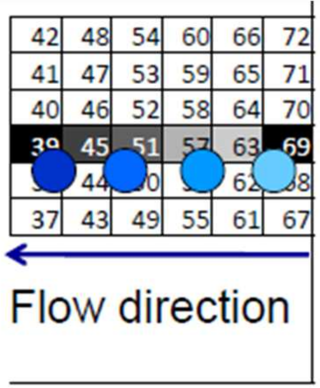
► C18 experiments vs Wagner model

- High speed video for
  - » Free surface angle : 10°
  - » Relative fluid velocity : 0.67m/s



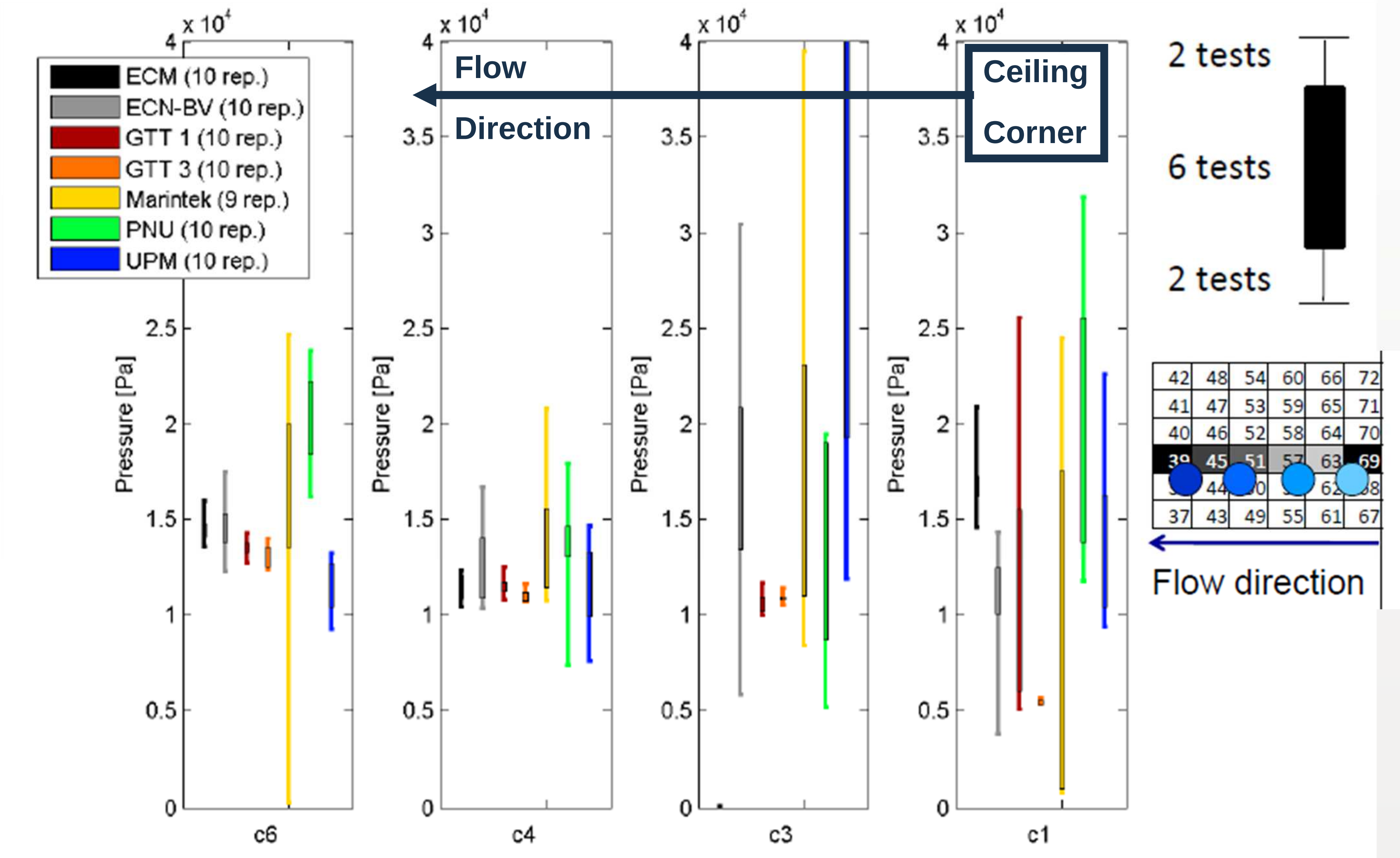
Single Wave Impacts ⇨ SIW C18
Pressure Time Histories for All Participants





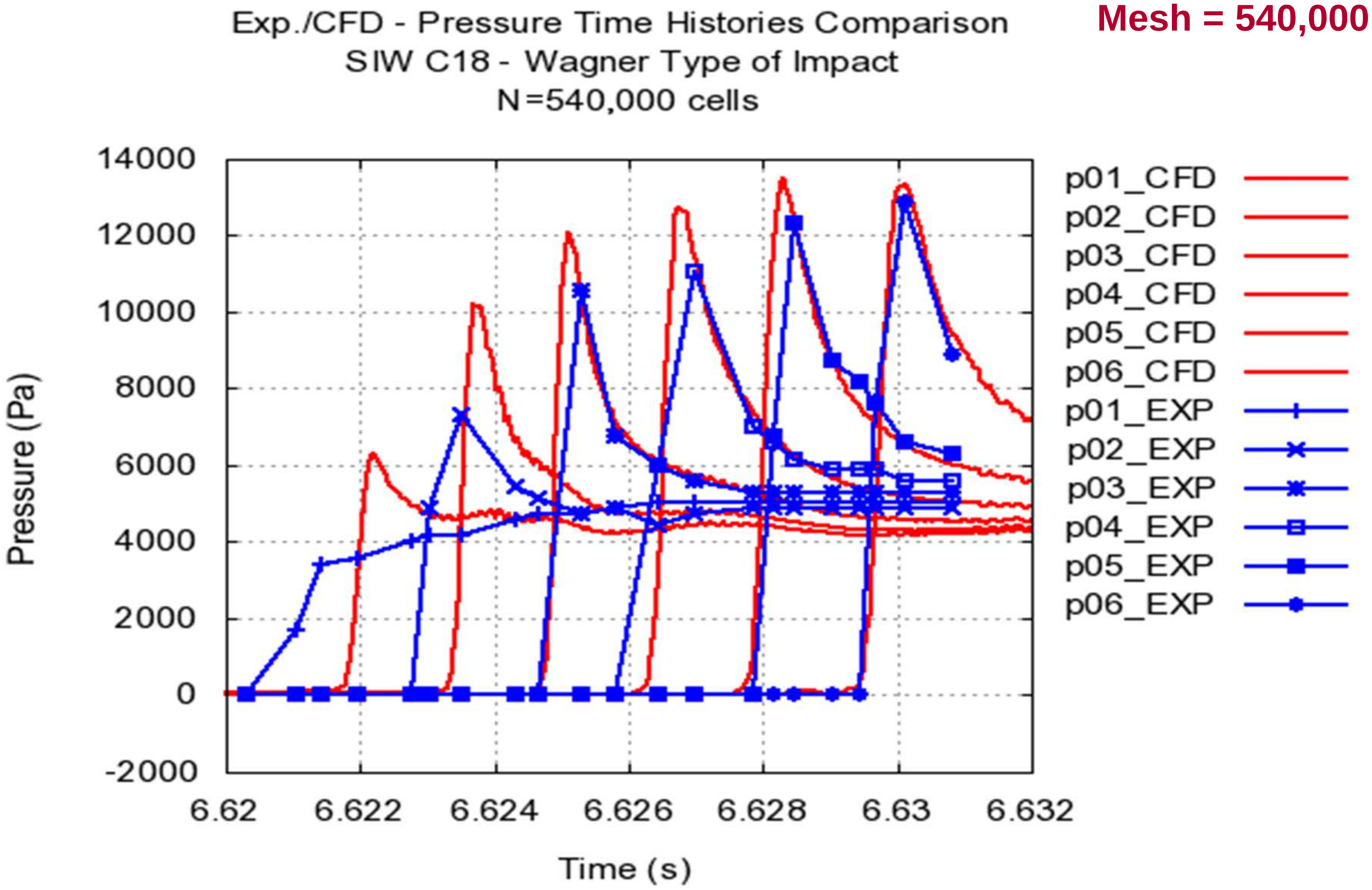
- Comparable wave front speeds between participant
- Difference between maximum pressure values at a given column of sensors
- Exhibit strange sensor behaviours
- Should be compared to Wagner's model

Single Wave Impacts ⇨ SIW C18
Pressure Repeatability for All Participants



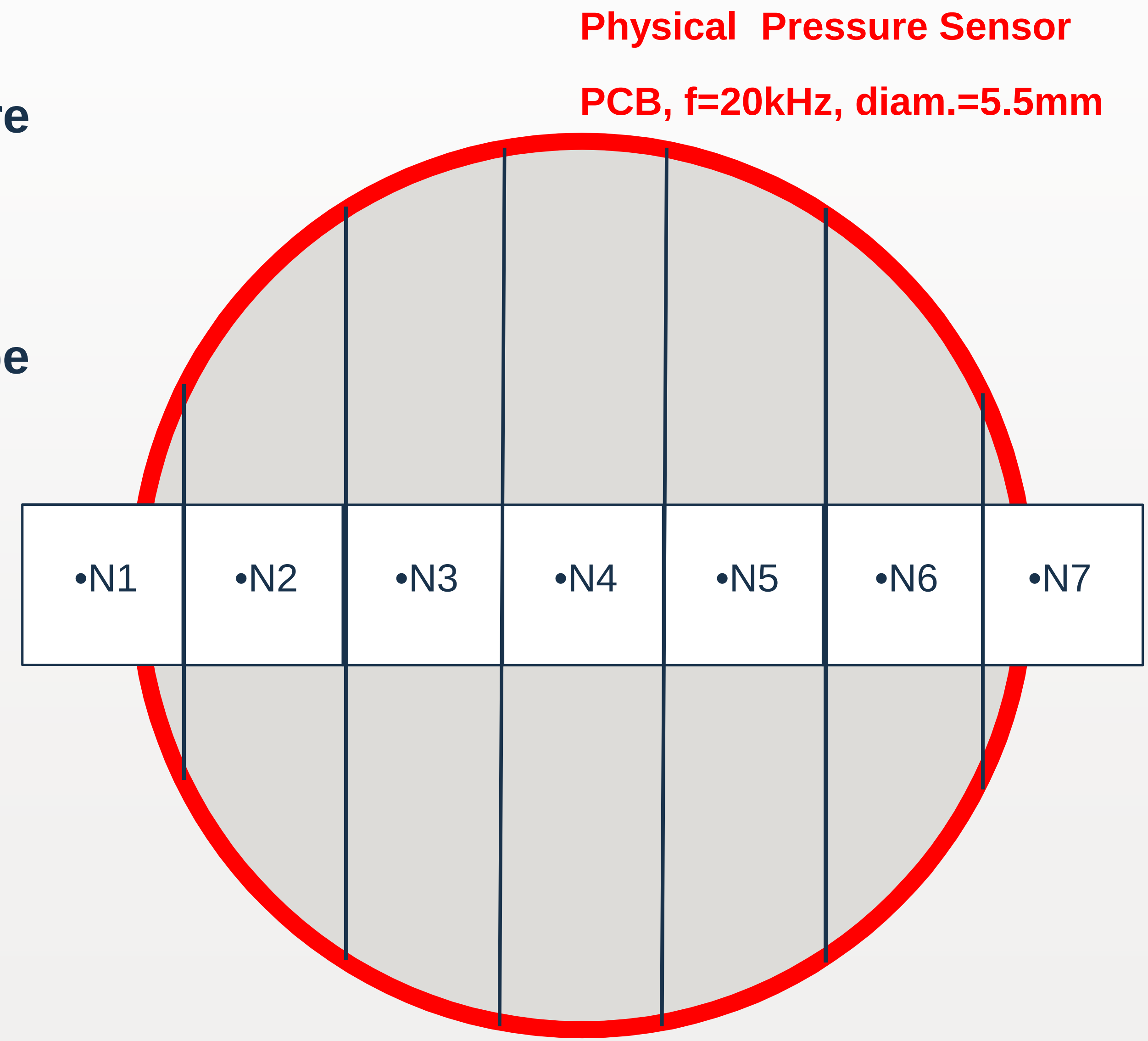
► **Exp. (GTT3 the most repeatable) /CFD comparison**

Mesh = 540,000 cells



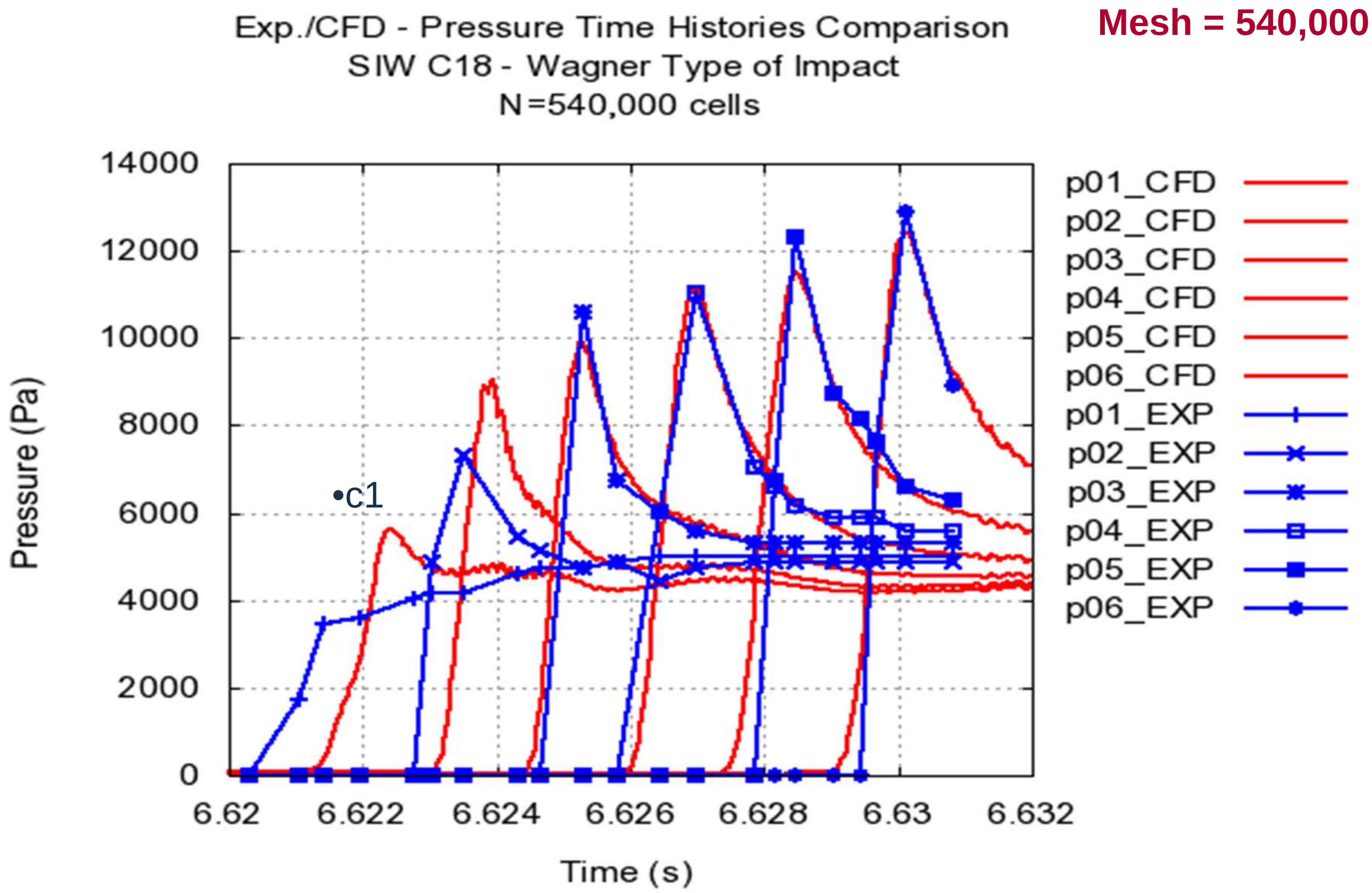
Numerical Post-Processing for Pressure Sensors

- Several numerical pressure sensors for one physical pressure sensor
- Diameter = 5.5mm
- Not only N4 should be considered but {N1,…,N7}
- Numerical post-processing for numerical pressure sensors

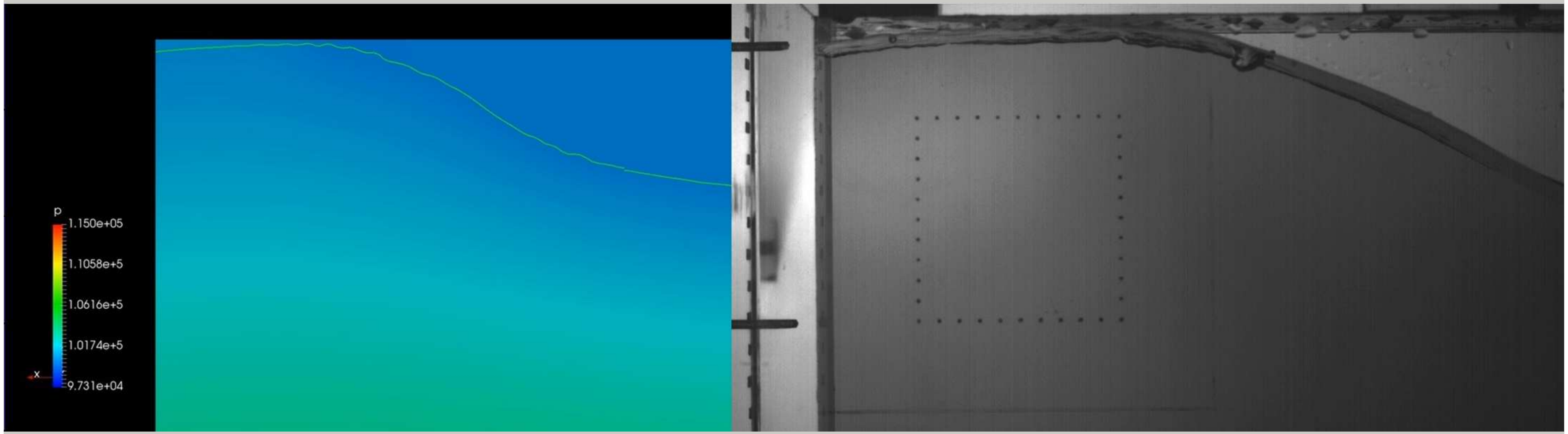


► Exp. (GTT3 the most repeatable) /CFD comparison

Mesh = 540,000 cells

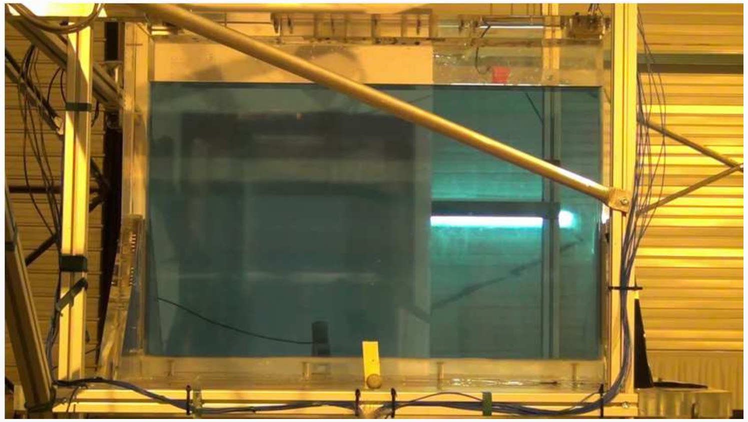


Single Wave Impacts ⇨ SIW C18
Exp./High Speed Camera ⇨ Air Pocket Impact



- ► Single Impact Wave C16
- ► Air pocket impact
- ► Repetitive in terms of pressure

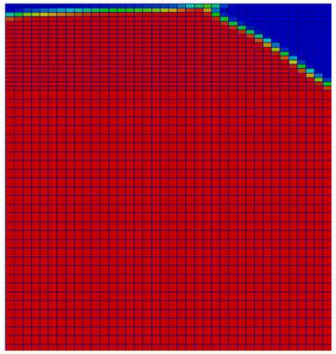
Pressure Time Histories ⇨ Compressible Model to be Included



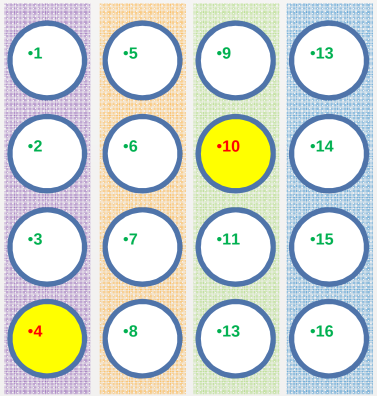
Air Pocket

Pressure sensors within air pocket

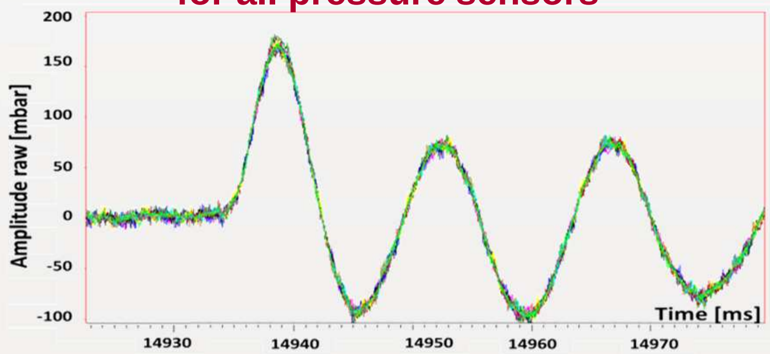
Zoom CFD



Cluster of Pressure Sensors



Pressure Time Histories for all pressure sensors



⇨ Need for compressible model

Single Wave Impacts ⇨ SIW C16
Pressure Time Histories ⇨ Exp./CFD Comparison

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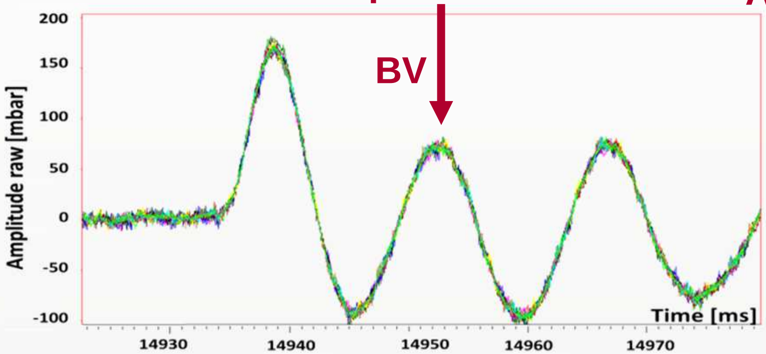
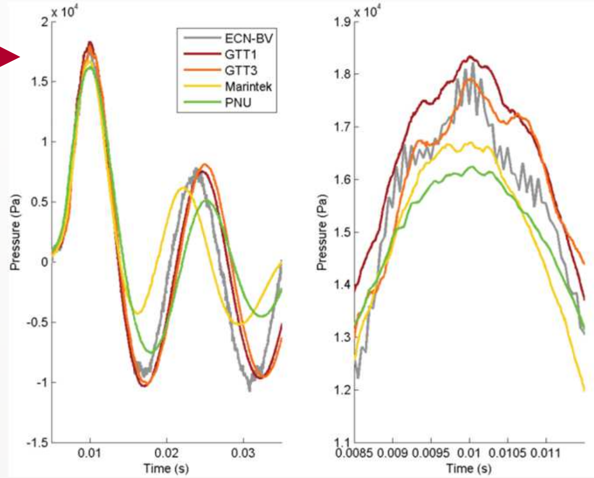
- ► **Exp.**

Pressure Time Histories for all pressure sensors

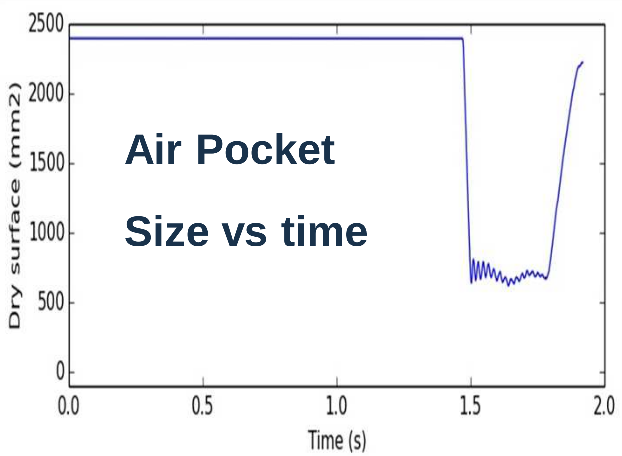


All



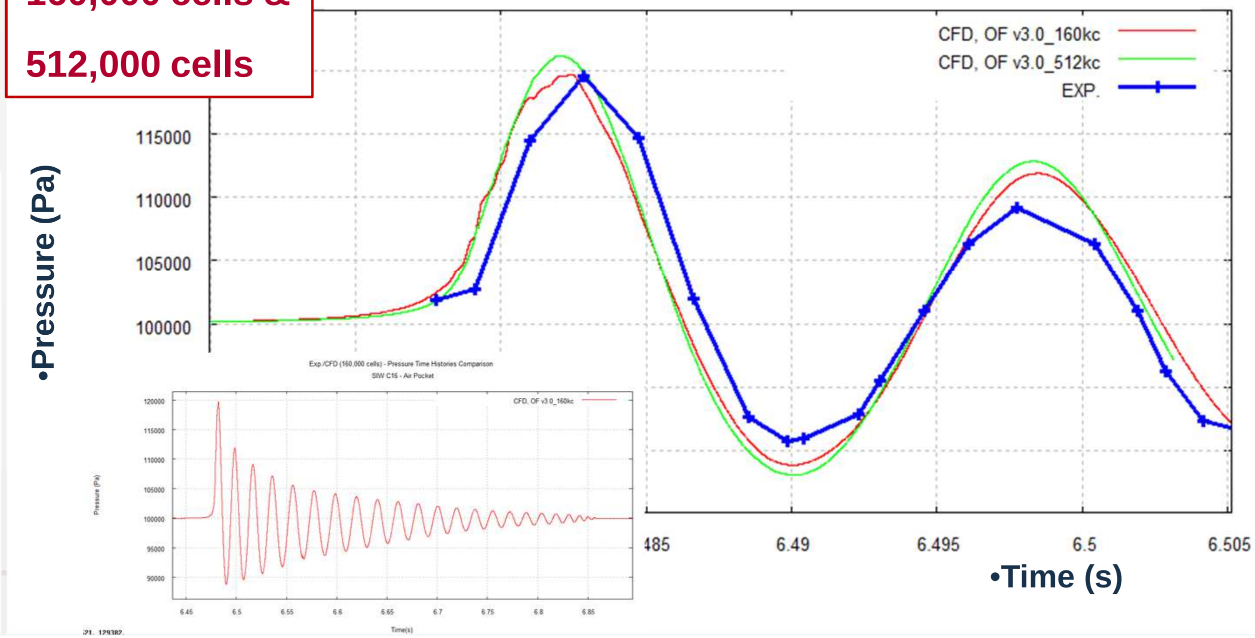
- ► **Exp./CFD comparison**

Mesh = 160,000 cells & 512,000 cells



Exp./CFD (160,000 & 512,000) – Pressure Comparisons

SIW C16 – Air Pocket



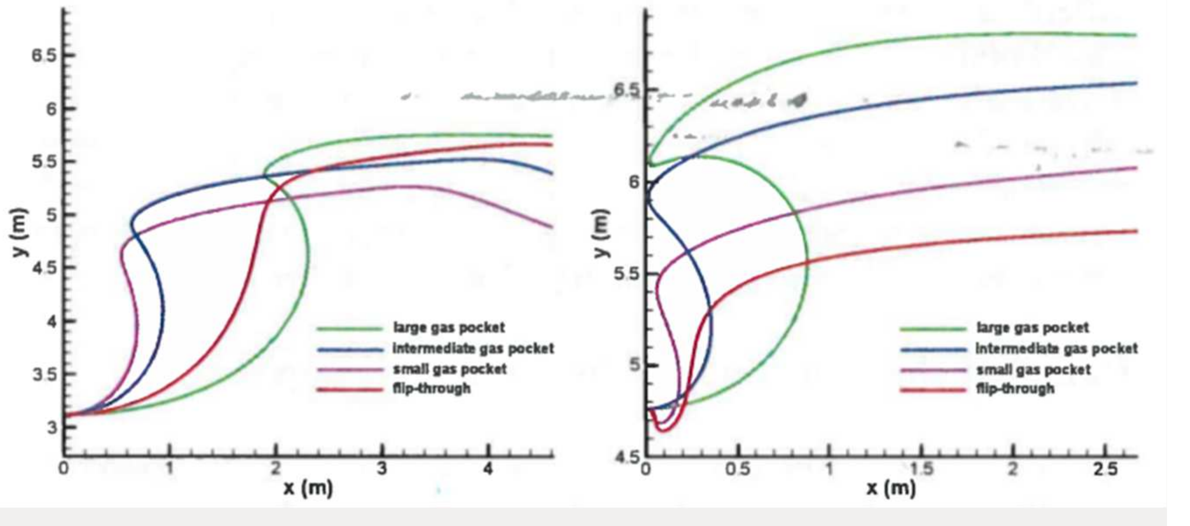
Experimental Sloshing Benchmark

- **For Wagner type of impact**
  - Discrepancies between the particpants
    - » Why?
  - GTT measurements less variations between different runs
  - CFD agrees well with GTT experimental results except for pressure sensors close to the ceiling's corner
- **Impact with air pocket**
  - Good agreement between the particapnts for the measurements
  - Need for compressible model
  - Air pocket is captured by CFD
  - Differences for the period oscillation
  - Need to improve the compressible model

3. *Wave Impacts*

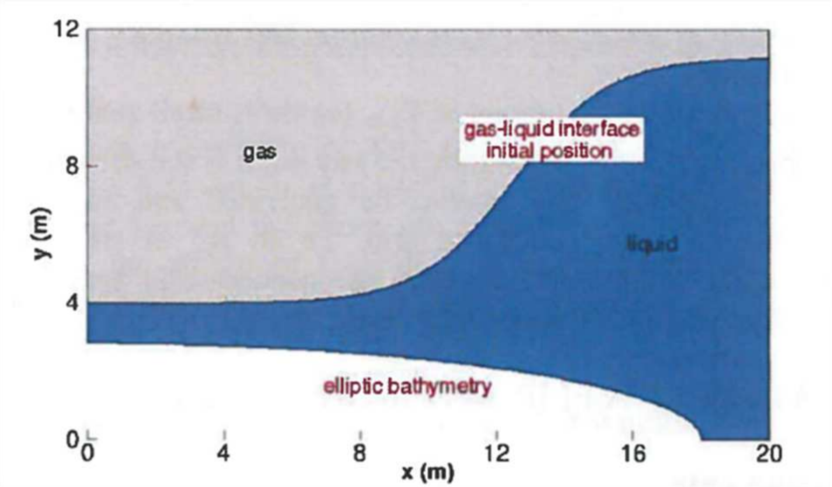
Wave Impacts - Context

- **Direct application of the results from the numerical benchmark on the compressible solver from OpenFoam**
- **4 cases of impacts considered :**
  - Flip Through Impact FTI
  - Small Gas Pocket Impact
  - Intermediate Gas Pocket Impact
  - Large Gas Pocket Impact



Wave Impacts - Context

- ► **Simulation from scratch with CFD takes too much CPU → potential code FSID developed by Yves-Marie Scolan**
- ► **FSID : potential bi-fluid code, initilization of the problem with a free surface according to the formula** $\boldsymbol{y} = \boldsymbol{h} + \boldsymbol{a}.\tan\left[r\left(x - x_p x_l\right)\right]$

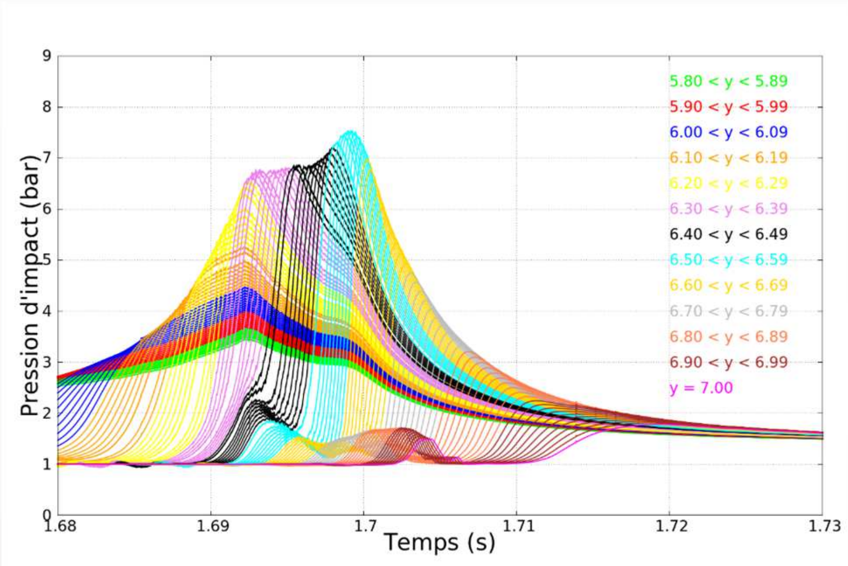


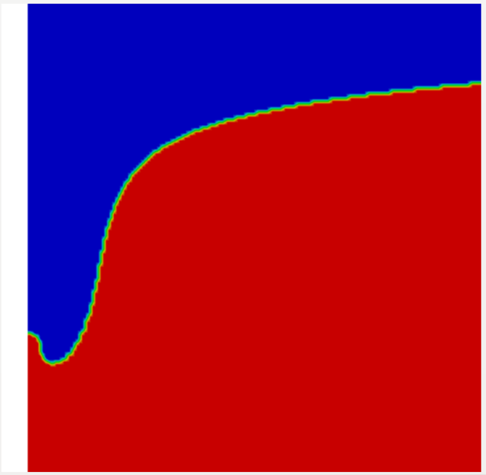
	h (m)	a (m)	xp (m)	xl (m)	r	t0 (s)
FTI	7.6	3.6	3.1	20	0.44	1.675
SGPI	7.6	3.6	2.5	20	0.44	1.550
IGPI	7.6	3.6	2.3	20	0.44	1.675
LGPI	7.6	3.6	2.5	20	0.36	2.070

- ► **Coupling between FSID and OpenFoam to simulate the impact :**
  - we simulate the problem with OpenFoam from a time t0 as late as possible
  - we choose the size of the window and the number of cells

Wave Impacts – Flip Through Impacts Results

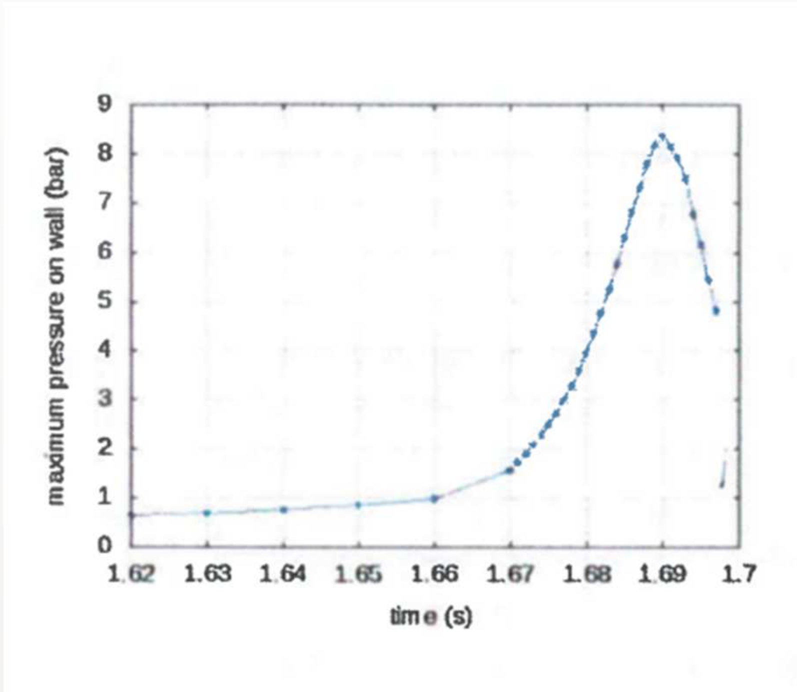
OF results



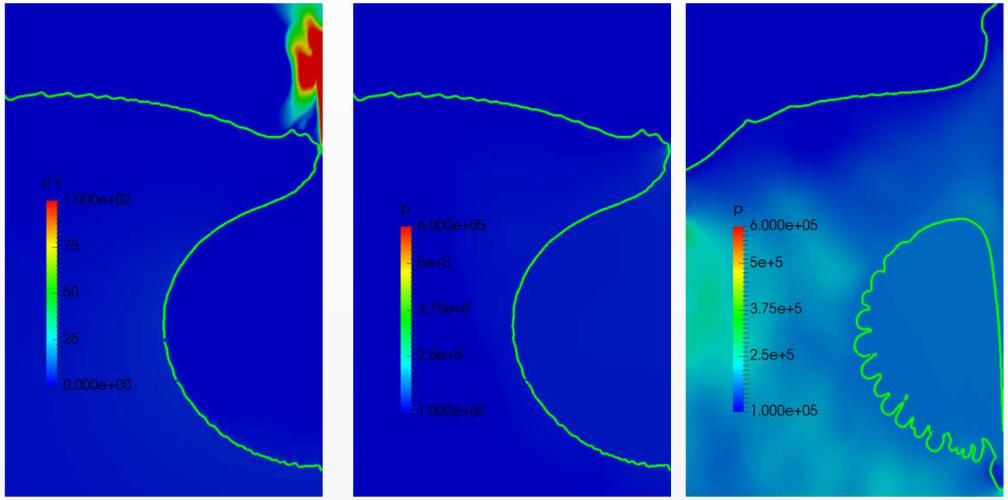


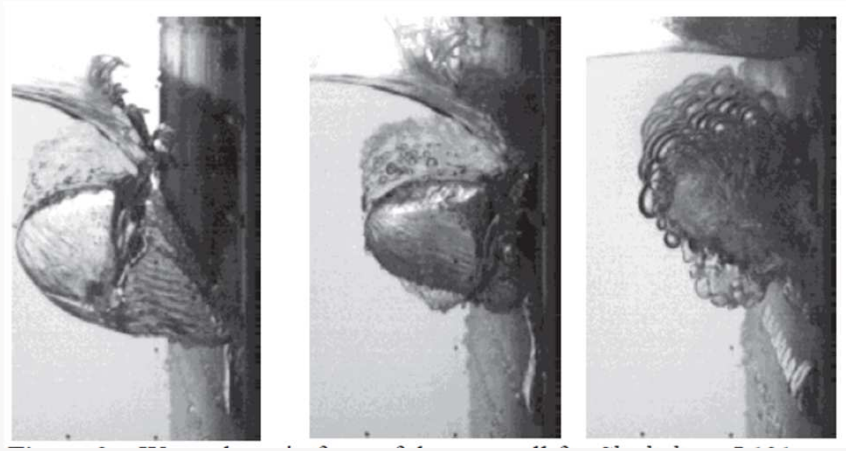
Free surface initialization in OpenFoam t0=1,675 s

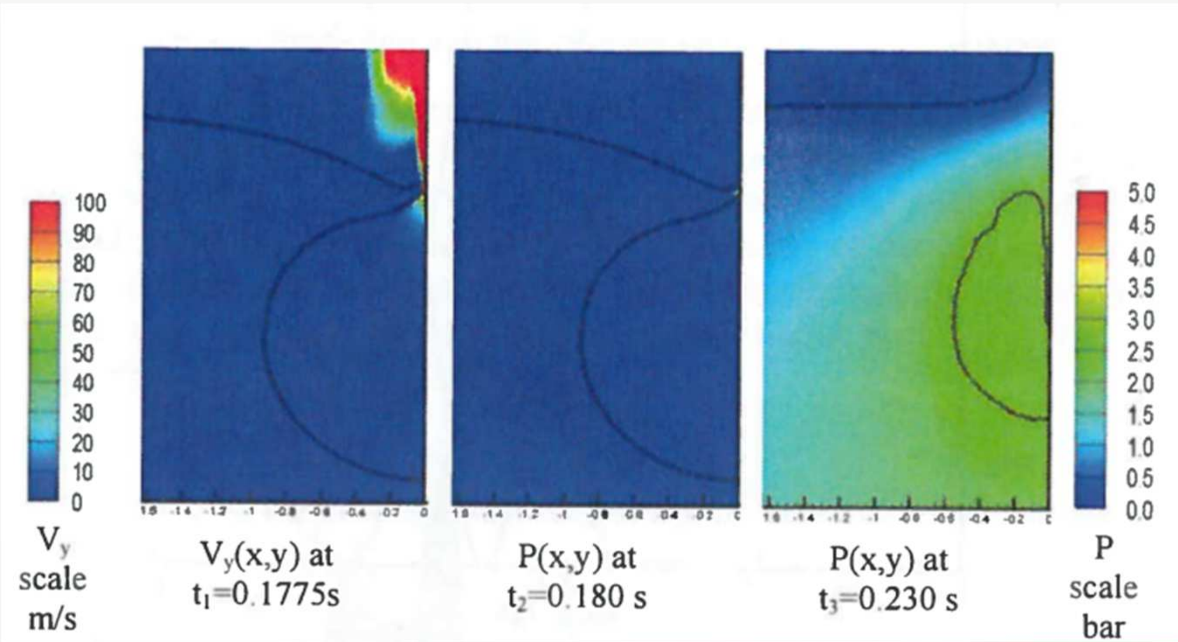
CADYF results (Hay et al.)



Wave Impacts – LGPI results
Velocity, Pressures & FS Instabilities (Rayleigh-Taylor)







Wave Impacts – Discussion

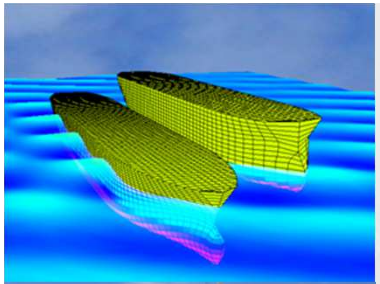
► **Preliminary calculations, a lot of work still to be done :**

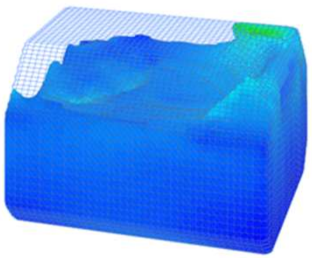
- Large Pocket will allow the study of Small Gas Pocket and IGPI
- Influence of the window size?
- Influence of the condition on the right wall ?
- Influence of the time at which we start the simulation on OpenFoam
- Coupling between FSID and OpenFoam?

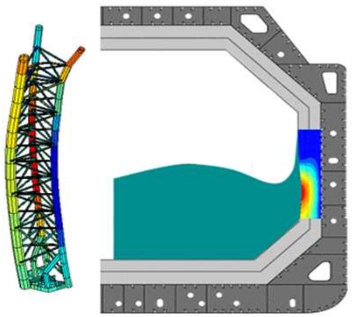
3. Discussion & Conclusion

Discussion

- ► **For global flows, still exotic flow (Bredmose) are challeging**
- ► **For SIW impacts**
  - To be careful before any comparison with experiments
  - Pressure sensor size is to be taken into account
- ► **SIW with air procket**
  - Pressure peak is captured by CFD
  - Differences for period oscillation
  - Need to improve the compressible model
- ► **Wave Impacts**
  - FSID & CFD or pure CFD
  - Improvements for Flip Trough & Large pocket







MULTIPHASE 2017

CFD Validations for Sloshing

CACHAN, October 2017

Louis DIEBOLD

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