Undersea Defence Technology
13-15 May 2019
Stockholmsmässan, Sweden

CFD simulation of the swim-out launching of a torpedo

PECOT Fabian – Sirehna/Naval Group
TAILLEFET Thierry - Naval Group Ruelle

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1. Introduction and context

Various missions are able to be assigned to a submarine:

- Naval task force protection
- Commando squad transport for amphibious missions
- Mines laying
- Attacks against terrestrial, naval, and even aerial targets, by means of torpedoes and tactical missiles

Tactical weapons launching is of major importance. It can be done:

- By pulse thanks to a mechanical device with a fluid or a piston
- In swim-out → torpedoes

At each weapon is associated a safe operating envelope (immersion depth, submarine velocity, sea state).

To determine this firing domain and to guarantee the launching success → use of a numerical approach to predict the weapon hydrodynamic behavior is an interesting alternative to expensive model or full scale trials

1. Introduction and context

In that context, Naval Group chose to develop numerical methodologies to simulate weapons launchings (on the basis of the CFD code STAR-CCM+), in particular for torpedoes in swim-out.

To qualify the developed numerical tool, full-scale sea trials of the swim-out launching of a torpedo-like drone were performed.

The obtained results were compared with those of hydrodynamic calculations.

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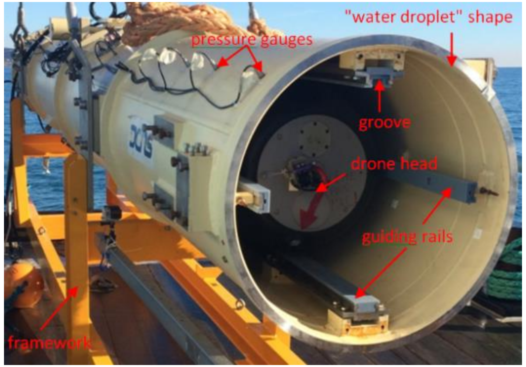
2. Full-scale sea trials

Full-scale trials of swim-out launching of a torpedo-like drone from a mono-diameter tube (closed at its bottom) in sea water at rest

Objective: provide experimental data to validate the CFD methodology

Mono-diameter tube:

- Length 6.6 m ; Ø 730 mm
- 4 rails to guide the drone + groove to avoid roll motion → 1 dof
- " Water droplet " shape at tube exit → improve water inlet
- Immersion depth: ~11 m → limit cavitation inception risk



Torpedo-like drone within Ø730 mm launching tube

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2. Full-scale sea trials

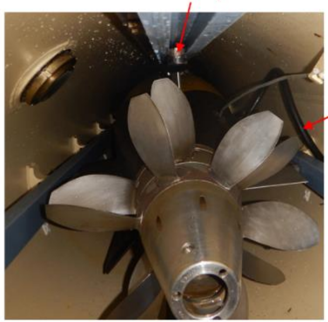
Torpedo-like drone:

- Length 5.8 m ; Max. Ø 533.4 mm
- Mass in air: 1125 kg; in water: -14 kg → no friction on rails
- Propelled by 2 counter-rotating propellers
- Upstream RPM ↔ velocity command (V_{min}=11 or V_{max}=20 kts)
- Downstream RPM → annul the total torque
- Drone aft initially located at 380 mm from tube bottom

Torpedo-like drone

Measurements:

- Rotation rates and acceleration (→ velocity and displacement) → buffer within the drone
- Pressures along the tube and at its bottom
- Films of the propellers rotation and drone motion → 2 fixed high resolution video cameras

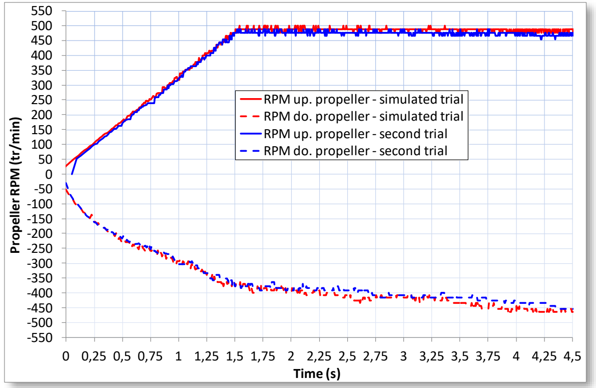


Rear part of the drone
with its 2 counter-rotating propellers

2. Full-scale sea trials

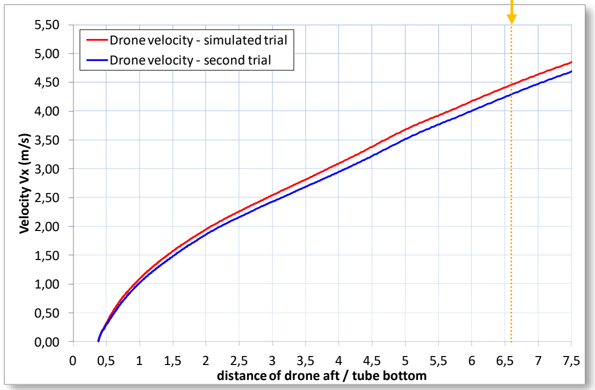
2 trials performed for each velocity command

Reproducibility → quite satisfactory



Propellers RPM - V_{max} velocity command

Drone aft at tube exit



Drone velocity - V_{max} velocity command

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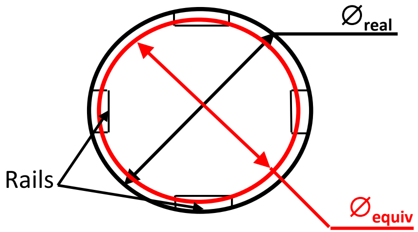
3. Numerical CFD approach

Progresses of computing and CFD → simulate the swim-out launching of torpedoes from a tube with a full CFD approach becomes possible.



Modelled tube without rails

Chosen CFD code: STAR-CCM+ (v10.06), able to :

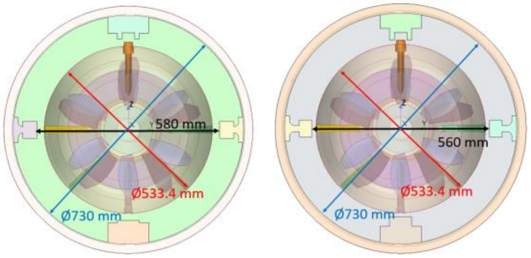
- deal with the time evolution of the calculation domain due to weapon displacement → "overset" grid method
- solve the strongly coupled URANS and 1dof weapon dynamics equations

Modelled tube with fictive guiding rails (580 and 560 mm)

2 different approaches to model the tube and its rails, by strictly keeping cross section area:

- Simple one: real tube replaced by an equivalent one without rails
- Complex one: fictive enlarged rails taken into account

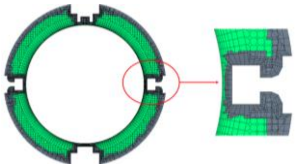
  2 considered distances between diametrically opposite modelled rails: 560 and 580 mm (instead of 537 mm in reality)



3. Numerical CFD approach

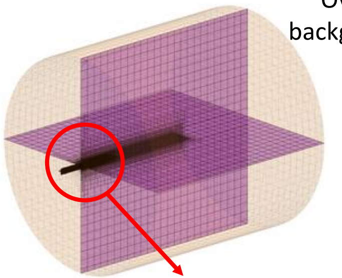
"Overset" method → superimposing of 2 non deforming meshes exchanging information data between each other:

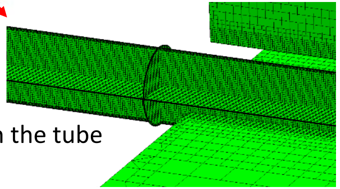
- an overset mesh around the moving drone and its propellers
- a fixed background mesh (inner tube + outer cylinder)



Tube with rails modelling
Overset interfaces

Overall view of the background region mesh

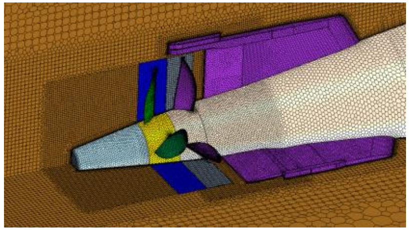




Zoom on the tube

Meshes built according to previous experience in simulations of weapons ejection:

- Background region → trimmed hexahedral cells
- Overset cylindrical regions → polyhedral cells
- Global mesh ≈ 10 millions cells



Overset regions - Zoom on the drone rear part + 2 propellers

3. Numerical CFD approach

Propellers rotations management → 2 methods used:

- "MRF" (Moving Reference Frame) method: in each propellers region, Navier-Stokes equations are solved in rotating frame
- "Sliding grid" method: simulation of physical rotations (in opposite directions)

Rotation rates imposed in simulations from experiments

1 dof drone motion along tube axis, without any solid friction on rails

Flow assumptions :

- Unsteady, non compressible, turbulent and monophasic flow (cavitation model disabled)
- RANS k-ω SST turbulent model
- Schnerr & Sauer cavitation model → dynamic equation for vapour volume fraction

Boundary and initial conditions:

- No slip conditions on walls;
- Null relative pressure outlet far from the tube
- Water initially at rest

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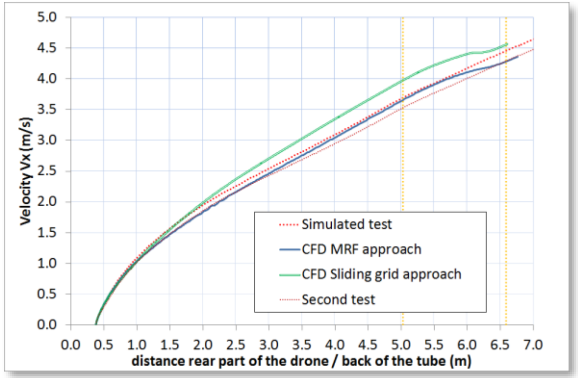
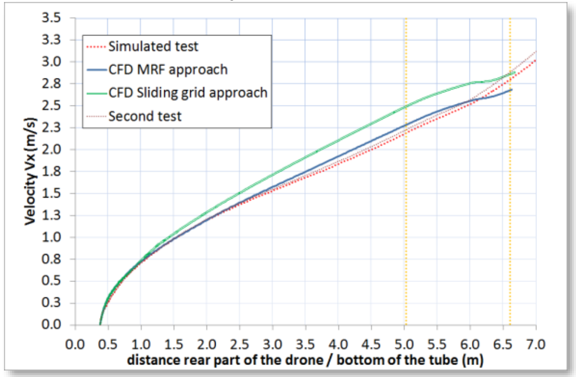
4. Comparison trials/simulations results without rails modelling

Velocity:

- The drone accelerates inside and outside the tube
- Satisfactory correlations between experimental and numerical results
- "MRF" results closer to experimental ones, even if, up to an aft position of 2.5 m, "sliding grid" → better correlation
- Maximum velocity deviation between numerical and trials results at tube exit < 0,2 m/s (≈ magnitude of the velocities discrepancy between both similar tests)
- "MRF" computations less time-consuming than "sliding grid" ones: 15 to 20 hours vs 6-8 days, on 80 cores



Velocity - V_{max} velocity command



Velocity - V_{min} velocity command

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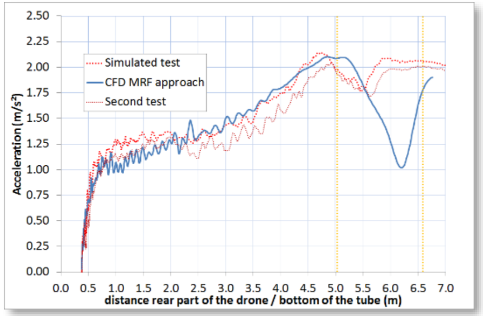
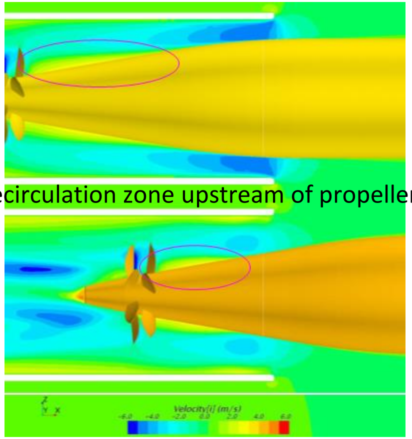
4. Comparison trials/simulations results without rails modelling

Acceleration:

- Very good correlation, until the drone conical part leaves the tube
- Instead of tests, significant acceleration drop in simulation, while the conical part exits
- In simulation, this drop is concomitant with the rise of the incoming flow mean velocity on propellers (at blades feet)
- It is due to a progressive disappearance of a recirculation zone located upstream of the propellers
- Complementary computation without rudders modelling → no influence of these rudders on drone dynamics

Acceleration - V_{max} velocity command





Recirculation zone upstream of propellers

<u>Hypothesis</u>: removal of the guiding rails, altering the 3D local flow, is responsible for drone dynamics discrepancies between simulations and trials, while conical part exits

→ Assumption to be confirmed by simulations with rails modelling

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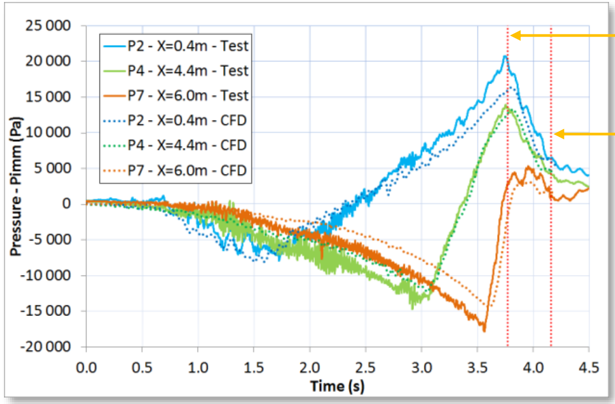
4. Comparison trials/simulations results without rails modelling

Pressures:

- Satisfactory correlations simulations/experiments at each point
- Small offsets whose levels depend on pressure sensors locations
- 3 stages for pressure evolutions inside the tube:
  - The pressure decreases due to water inlet, until the junction overtakes the considered point
  - It rises until the junction leaves (pressure > immersion one) ← flow compression between tube and drone conical part
  - It decreases and reaches the immersion one



Junction at tube exit

Drone aft at tube exit

Relative pressures inside tube
V_{max} velocity command

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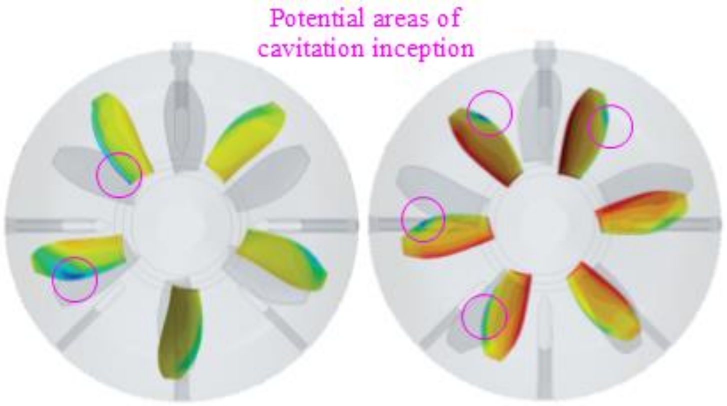
4. Comparison trials/simulations results without rails modelling

Cavitation inception risk:

- Even though cavitation was not simulated, risk of cavitation inception was assessed by comparing absolute pressure P and saturated vapor one P_v → If P < P_v, the phenomenon should occur
- "MRF" simulations → no risk of cavitation inception
- "Sliding grid" simulations → many small potential areas of cavitation inception

⇒ additional "sliding grid" simulation with cavitation model enabled

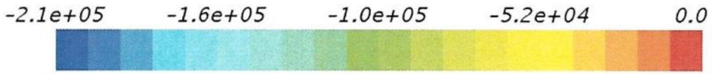


Upstream propeller extrados   Downstream propeller extrados

Cavitation risk - "sliding grid"
V_{max} velocity command

Cavitation limit = -2,1.10^5 Pa

Pressure - $P_{immersion}$ (Pa)



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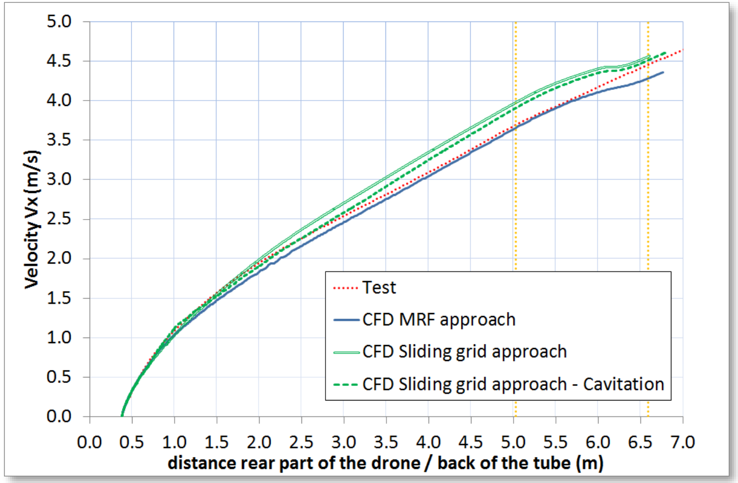
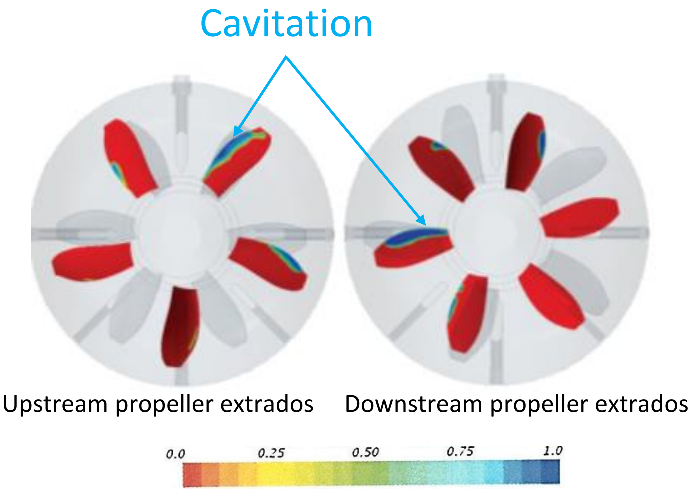
4. Comparison trials/simulations results without rails modelling

Cavitation model impact:

- Cavitation inception on leading edges of the propellers blades extrados (pockets and/or bubbles clouds)
- Practically no influence on drone dynamics
- Simulation with cavitation model enabled is a bit time-consuming: 20 days on 80 cores



Velocity (with and without cavitation modelling)
V_{max} velocity command



Vapour volume fraction - "sliding grid "
V_{max} velocity command

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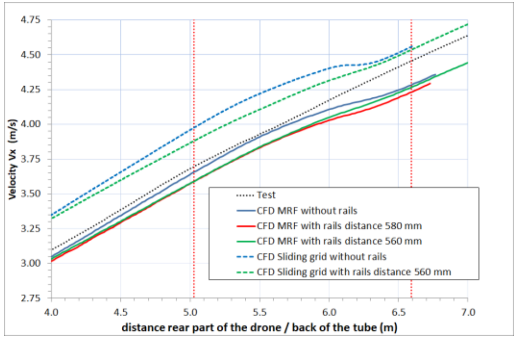
5. Comparison trials/simulations results with rails modelling

Overall satisfactory agreement between trials and "MRF" simulations results, with or without rails modelling

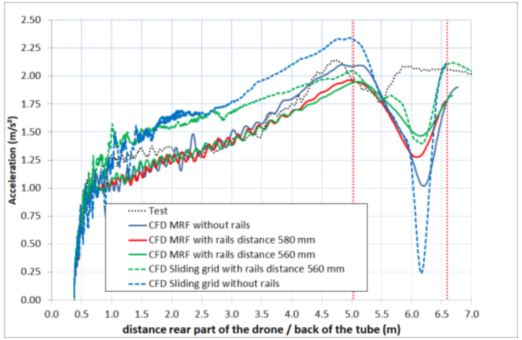
"Sliding grid" simulations systematically overestimate drone velocity

Guiding rails modelling reduces the acceleration drop (while the rear conical part exits), all the more the distance between opposite rails decreases

- If this distance was enough reduced to be close to its real value → simulated acceleration profile should logically fit the trial one.



Velocity – V_{max} velocity command



Acceleration – V_{max} velocity command

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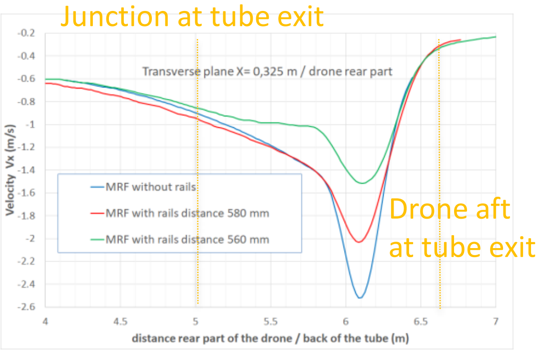
5. Comparison trials/simulations results with rails modelling

Acceleration drop is related to a thrust drop.

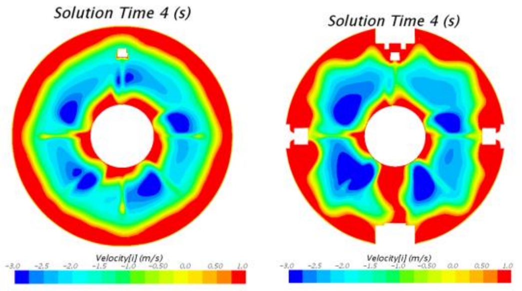
It is due to an increase of the incoming flow mean axial velocity on the propellers following the disappearance of a recirculation zone upstream of the propellers.

This mean velocity rise is lower, when rails are modelled and the distance between diametrically opposite ones is smaller.

Radial distribution of the axial flow velocity upstream of the propellers is drastically altered by the presence of rails.



Mean axial velocity upstream of the propellers
V_{max} velocity command



Axial flow velocity upstream of the propellers with and without rails modelling

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6. Conclusions

Overall correlations trials/simulations are satisfactory

- drone displacement, velocity, acceleration + pressures within the tube

CFD methodology can now be used to predict the performances of torpedoes swim-out launchings from Naval Group submarines.

The replacement of the real tube by an equivalent one without guiding rails in the model does not allow to perfectly capture the drone dynamics, when its rear conical part is leaving the tube.

- An acceleration drop that either does not exist in reality or is overestimated is predicted.

Guiding rails modelling improves correlations during the cone exit phase.

- The local flow just upstream of the propellers is more accurately described.

6. Conclusions

Nevertheless, guiding rails modelling has drawbacks:

- more complex modelling (← more complex CAD, finer meshes close to the rails)
- increase of the calculations times (← finer meshes)
- less robust "overset" method (← more complex interfaces)

"MRF" approach with neither rails modelling nor cavitation model activation is the best compromise between computation time and results accuracy.

If pressure < satured vapour one on large areas on propellers blades extrados, a new simulation with cavitation model enabled should be performed.