UDT
Undersea Defence Technology
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Shallow and infinite water manoeuvring: Integration of Computational Fluid Dynamics (CFD) in the design process

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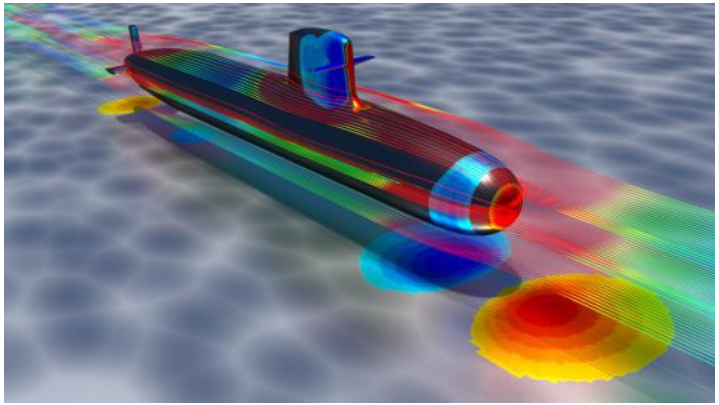

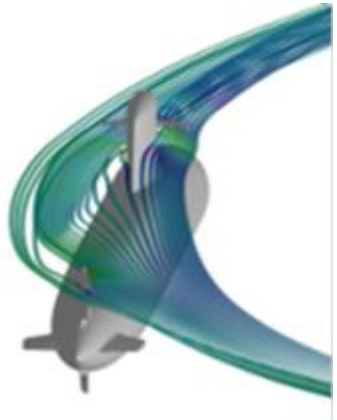

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Summary

1. **Integration of CFD within design process**
2. **CFD based methods for manoeuvring performances evaluation**
3. **Validation of CFD methods – Infinite water**
4. **Constrained and shallow water particularities**

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Integration of CFD within design process

Submarine manoeuvrability study deals with several topics :

- **Operational capability**
  - Turning capability
  - Diving capability
  - Controllability
- **Navigation safety**
  - Submarine behaviour in case of hydroplane failure or flooding
- **Control surfaces and actuator design**
  - Structural design to withstand hydrodynamic forces
  - Capacity of the actuators

Purpose of manoeuvrability studies are :

- **External shape design**
- **Performances verifications**
- **Risk management**

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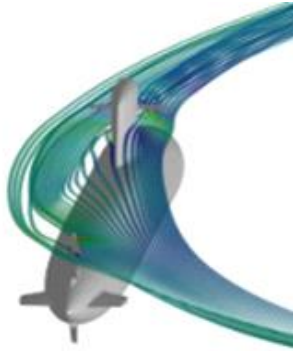
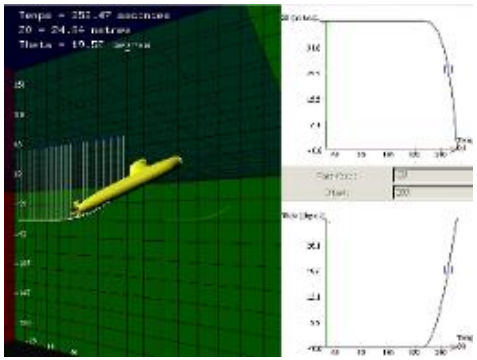
Integration of CFD within design process

Different tools can be used in hydrodynamics studies, in infinite depth or constrained water



- **Preliminary tools**
- **Computational Fluid Dynamics**
- **Free running physical model**
- **Complementary tools**



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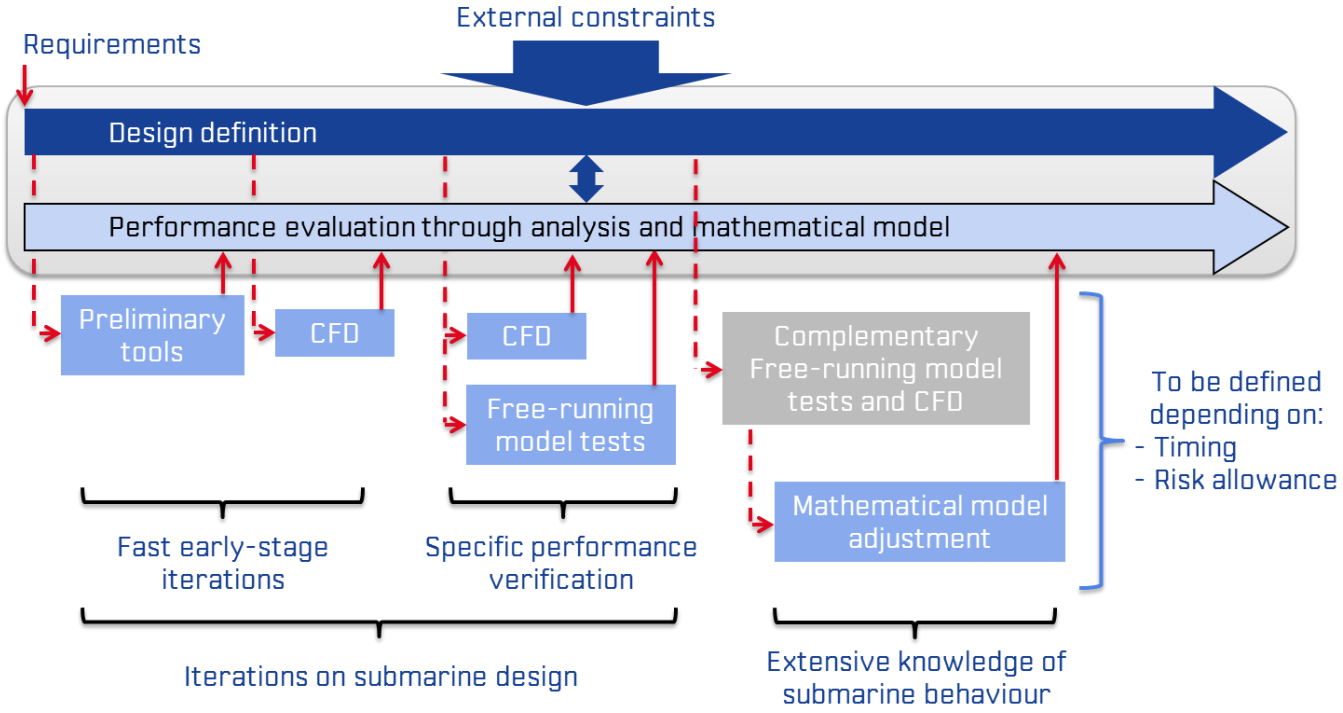
Integration of CFD within design process

Design for manoeuvring capabilities : standard design phase



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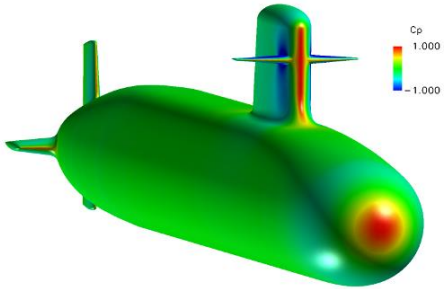
CFD methods for submarine manoeuvrability

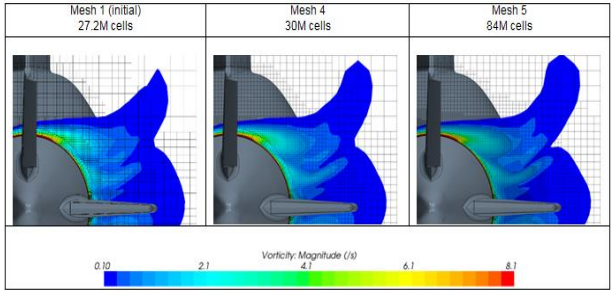
The calculation method was defined to be :

- Fully qualified against reference data
- Reliable
- Efficiently applicable to the design needs



The construction of the method was performed in 3 steps :

1. Definition of a calculation setup
2. Verification of setup convenience to the whole range of studied cases
3. Embedment of method into an automated process



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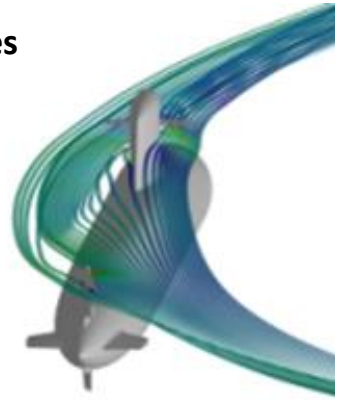
CFD methods for submarine manoeuvrability

Captive simulation modelling :

- **Similar approach to captive model tests**
- **Steady state flow on submarine, in a set of various configuration**
  - Straight course, drift, incidence, vertical and horizontal turns, rudders and hydroplanes angles
- **Evaluation of the efforts on submarine and stock torque on hydroplanes**



Free running simulation modelling :

- **Simultaneous solving of hydrodynamic flow and submarine movement**
- **Reproduction of steady state trajectories of reference manoeuvres :**
  - Turning with rudder angle
  - Vertical and horizontal dynamic stability (turning with 0° hydroplane angle)
  - Trim change

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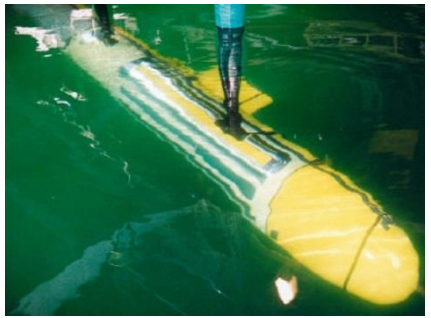
Validation of CFD methods : infinite water

Validation strategy : 2 types

- **Sea trials records**
- **Model tests measurements**



The origin of the reference validation result depends on the considered characteristics:

- **For manoeuvring performances, the values determined from the submarines sea trials are considered**
- **For the evaluation of forces on rudders and linear manoeuvring coefficients, model scale captive model tests results are considered**

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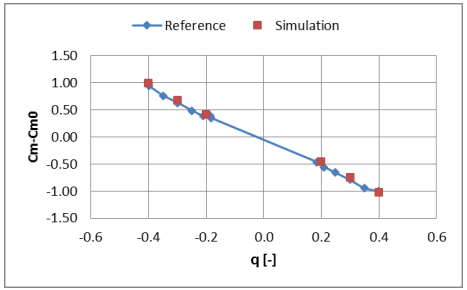
Validation of CFD methods : infinite water

Validation synthesis of captive simulation

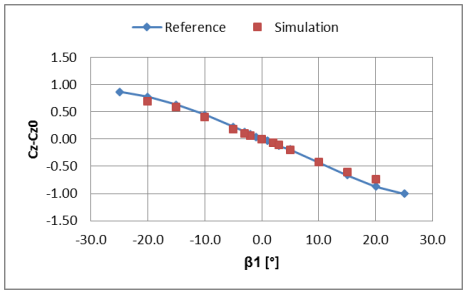
- Validation process includes 6 main submarines
- Comparison made between CFD results and validation cases shows a good agreement

Examples of comparisons :



Hydroplane efficiency

Z force

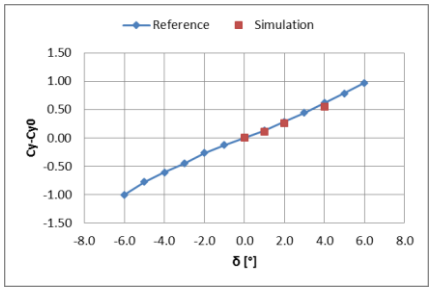


Drift coefficient

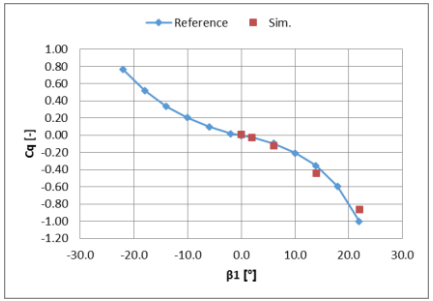
Y force

Pure vertical rotation

Y moment



Stock torque



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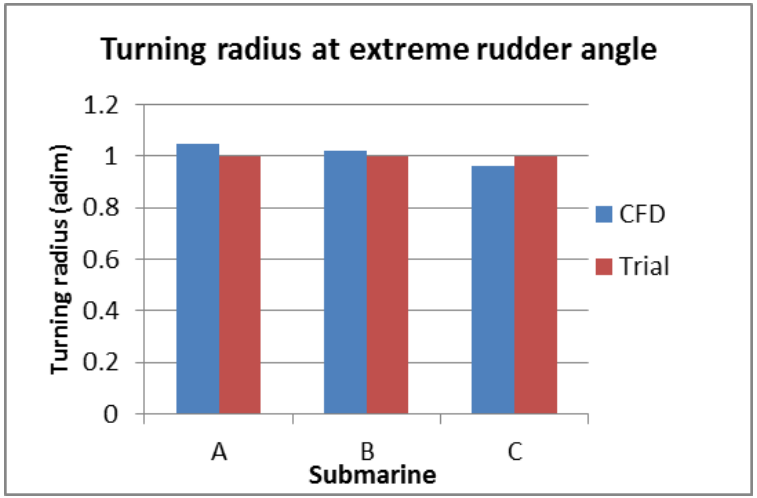
Validation of CFD methods : infinite water

Validation synthesis of free running simulation

- **Turning rate submerged with extreme rudder angle were computed for 3 submarines**
- **The comparison between CFD results and sea trials data gives an assessment of main manoeuvring characteristic (diameter of trajectory)**
- **Less than 5% difference is found**



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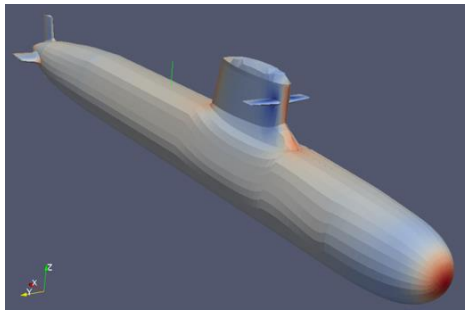
Constrained and shallow water particularities

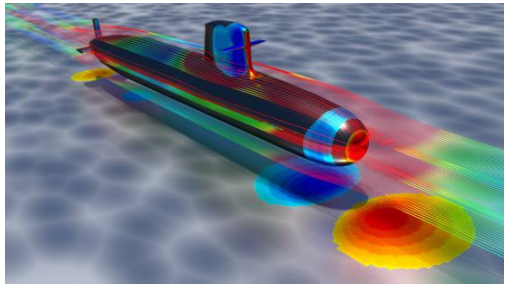
When navigating in constrained and shallow water, supplementary hydrodynamic efforts are to be taken into account. This may affect :

- **Autopilot optimisation**
- **Safe operating envelope definition**



To take into account shallow water specificities in submarine design :

- **Model tests close to bottom can be made, but are difficult to realise and insufficient**
- **For submarine design, Naval Group developed a complementary set of computation methods:**
  - Simplified method based on Boundary Element model, for parametric studies and optimisation on a wide range of situation
  - CFD calculation, for specific operational cases validation



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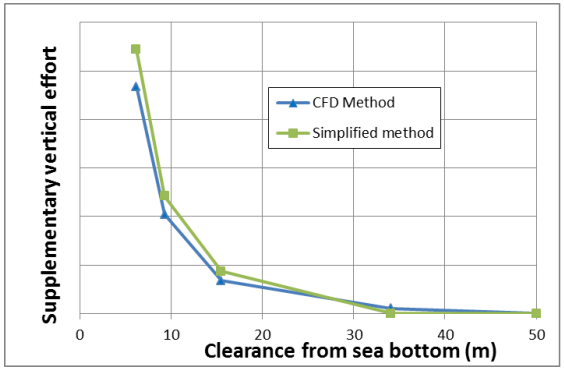
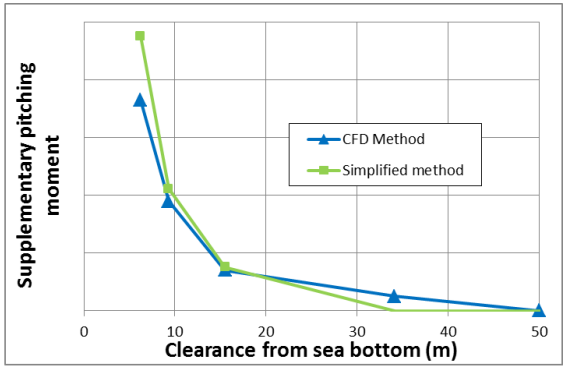
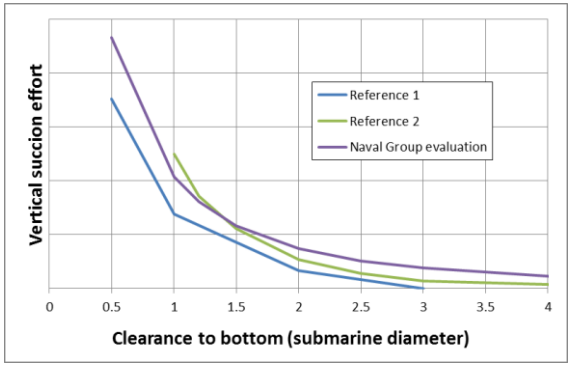
Constrained and shallow water particularities

Flat sea bottom example : validation of simplified method VS CFD calculations





Comparison of Naval Group CFD with existing literature on submarines :



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Conclusion

- **The current process for submarine manoeuvrability assessment fully integrates CFD methods**

- **These CFD methods were developed and applied by Naval Group for the past decades, and validated by comparison with sea trials and model tests on several seagoing submarines**

- **Constrained and shallow water manoeuvrability can be handled more accurately through these methods**
  - **Allows reduction of navigation margins and optimisation of autopilot**

THANK YOU FOR YOUR ATTENTION