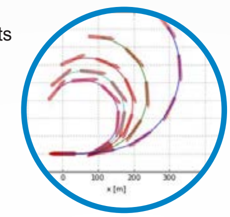
Your Maritime Solution Partner

1 Concept evaluation

- Hull main parameters
- Location and size of the sail and control surfaces
- Choice of propulsion arrangement

3 Power Requirement

- Resistance and self-propulsion tests in the towing tank
- Wake flow distribution
- Rudder forces and moments



Simulation of turning circle manoeuvre in Submo. The interface to Submo can be entirely web server-based either in-house or in the cloud.

5 Manoeuvring performance

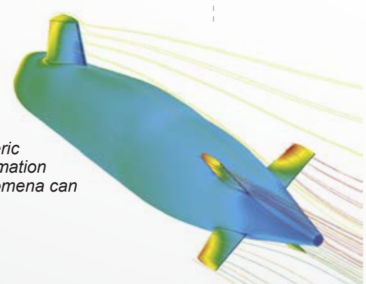
- Captive tests in wave basin, hydrodynamic coefficients for simulation model
- Simulations of standard manoeuvres and depth change
- Autopilot and depth controller design
- Stability in the horizontal and vertical planes

Designing the submarine

Verifying the design – model tests and simulations

2 Basic hydrodynamic design

- Hull
- Sail
- Control surfaces



CFD calculation of a generic submarine. Detailed information about different flow phenomena can be obtained.

4 Propeller design

- Cavitation tunnel tests
- High efficiency
- Good cavitation properties
- Low radiated noise

Model of the IZAR P650 tested at SSPA. The same model was used in all SSPA facilities.

TOWING TANK

CAVITATION TUNNEL

MARITIME DYNAMICS LABORATORY

Hydrodynamics for submarines

Developing the hydrodynamics for submarines at SSPA involves a combination of simulation and model testing in order to evaluate the performance of the submarine, such as speed-power requirements, manoeuvring characteristics, cavitation properties and radiated noise from the propellers in deeply submerged, periscope and surface conditions. Evaluating emergency recovery manoeuvres and autopilot designs are also important tasks. Recently, SSPA has been developing the hydrodynamics and propeller design for the new Swedish A26 submarine, which will be built in Sweden by Saab Kockums. SSPA has been involved in hydrodynamic development work for submarines since 1940 and has significant experience in submarine hydrodynamic design.

Designing the submarine

The concept and design phases involve the use of empirical evidence from SSPA's rich submarine database, simulation tools and CFD. Typically, the design is verified through model testing at all three of SSPA's major facilities, namely at its towing tank, cavitation tunnel and large wave basin MDL (Maritime Dynamic Laboratory) and through simulations.

From the outset of the concept stage, it is important to make an early assessment of the impact of the main parameters of the hull, sail, control surfaces and propulsion arrangement on the manoeuvring characteristics and full-scale speed-power performance. Typically, investigating the effect of changing the size of control surfaces and sail, to get the most favorable effect on stability and manoeuvring performance for the submarine. The effect of lengthening the submarine by inserting a new section also holds great interest during the early stages of the project, since it will have an impact on the manoeuvring characteristics, the resistance and the speed-power performance of the submarine.

Usually, standard manoeuvres are simulated (i.e. zig-zag tests, turning circles and depth changes) to explore what happens if the area of the control surfaces is increased, the sail is moved in the longitudinal direction, the forward planes are inclined, etc.

A submarine in a simulator environment. The crew can practise repeat manoeuvres and practise operations which are not easy to perform on a real submarine.

In operation

6 Simulator

- Crew training
- Development of hardware for a submarine's bridge

In operation

- Depth keeping in periscope conditions under a seaway
- Simulation of emergency recovery manoeuvres
- Compensation and trimming
- Safe operation envelopes

Early predictions of depth control in periscope conditions under a seaway can also be performed. When a submarine is operated at periscope depth under a seaway, the disturbances due to waves are large. The performance is usually quantified by calculating the number of snort head submergences for different sea states, speeds and wave directions.

After completion of the initial design phase, CFD calculations can be carried out to analyse the flow field for the submarine hull form and any appendages, as well as to conduct transition location studies and analyses of the propeller-hull interaction and scaling effects. Flow separation should be avoided as the turbulence generated could degrade the noise signature. When designing the shape of the fore body, separation should be prevented to optimise sonar effectiveness.

Verifying the design through model testing and simulations

Model testing is conducted on a scale model that has been manufactured and equipped with a propeller, active aft control surfaces and forward hydroplanes. With the autopilot engaged, the submarine model can be free-sailing.

The normal procedure is to carry out resistance and self-propulsion tests using a stock propeller at different depths. 3D wake measurements are performed to obtain the flow field entering the propeller disc. This is used as an input for the initial propeller design. There are also different techniques to determine the streamlines of the flow of the submarine, e.g. paint tests. It is also possible to measure the forces and moments of the control surfaces. This is needed to determine the size of the hydraulic pumps required to operate the control surfaces and to check whether the control surfaces are well balanced or not.

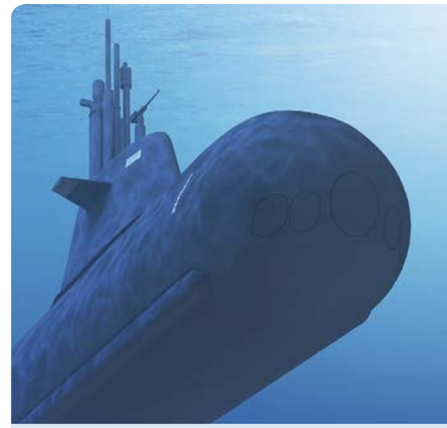
The demands on the submarine propeller are high: a compromise between strength, radiated noise, cavitation and efficiency is sought. The propeller design is verified through cavitation tunnel testing. Determining the incipient cavitation as well as the noise and pressure pulse measurements are typical of the tasks performed.

The deep water and periscope manoeuvring performance is predicted by simulations. A "six degrees of freedom" mathematical model is developed (essentially rigid body dynamics) to describe the steering dynamics of the submarine. The mathematical model includes three forces and three moment equations (surge, sway, heave, roll, pitch and yaw). Each of the equations contains derivative and hydrodynamic coefficients that are determined in captive tests during which forces and moments are measured as simplified motions, e.g. straight line tests with different rudder or drift angles as well as circle and oscillation tests. During these tests, the model is equipped with a six-component balance attached to the multi-motion carriage in MDL.

The autopilot and depth control designs are normally developed using the mathematical model. The mathematical model is eventually validated against the sea trial. If there are differences in the submarine dynamics between the simulated results and the results obtained when tested in full scale, the hydrodynamic coefficients are updated in the mathematical model. Thereafter, the control system will require a redesign.

In operation

The mathematical model can be plugged into a simulator environment for developing hardware on a submarine's bridge and for simulator training. Safe operating envelopes (SOE) can be obtained through simulations since they depict the combinations of speed and depth at which the submarine will be able to recover safely in the event of a flooding or hydroplane jam accident. Recovery trajectories can then be calculated.



SSPA has been performing hydrodynamic development work for submarines since 1940 and has been involved in the development and testing of all classes of Swedish submarines. This work has included scale models and full-scale tests, all of which account for a total of well over 600 studies. Recently, SSPA has been developing the hydrodynamics and propeller design for the new Swedish A26 submarine, which will be built in Sweden by Saab Kockums. SSPA has also performed submarine testing for several other European countries as well as for the Australian Collins-class submarines. For the last 15 years, SSPA has tested and participated in the development programmes for eight different "non-Swedish" submarine projects, including the IZAR P650 project for NAVANTIA in Spain and two projects on behalf of HDW (Howaldtswerke-Deutsche Werft AG).

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Jonny received his M.Sc. degree in Naval Architecture from the Chalmers University of Technology in 1989 and his Ph.D. in Thermo-Fluid Dynamics from Chalmers in 1994. He has worked for SSPA since 2009, except for one year spent on research and consultancy projects related to manoeuvring and seakeeping. He specialises in submarine hydrodynamics, model testing and the simulation of manoeuvring performance. Jonny co-ordinates the manoeuvring and seakeeping team.

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