WIKKI

Technology

for reliable CFD simulations

Reliable CFD results are ensured by some of our advanced unique technology and capabilities within the Naval Hydro Pack. All top level solvers are efficiently parallelise, with practically no limit on number of cores and number of simultaneous jobs.

Numerics

Our top–level solvers are built on top of `foam-extend`'s **Finite Volume framework**, where we offer a number of transient solvers and a specialised steady–state solver for steady resistance in calm water. All of our solvers resolve the pressure–velocity coupling using the dynamic pressure p_d as the working variable and appropriate buoyancy–invariant boundary conditions. A number of standard Reynolds Averaged Stress (RAS) models and Large Eddy Simulation (LES) models are available.

These unique features of our transient solvers enable us to run simulations significantly faster and more robust compared to other CFD software:

- Special single–fluid formulation where the jump conditions at the free surface are enforced with the **Ghost Fluid Method (GFM) in order to remove parasitic velocities near the free surface**,
- Time–accurate **PIMPLE time–advancement algorithm** with under–relaxation, **which is robust on very high flow and free surface Courant numbers (large time–steps)**,
- **SWENSE** (Spectral Wave Explicit Navier Stokes Equations) for efficient wave propagation where the incident field is explicit in the CFD simulation, solving only for the perturbation around the incident field.
- **Implicit relaxation zones** are used to prevent wave reflection and introduce waves into the CFD domain. The unique formulation in the Naval Hydro Pack does not require the user to specify wave damping coefficient.

Rigid body motion (6DOF) equations are strongly coupled to the fluid flow within the PIMPLE loop, with two unique procedures for improved convergence of pressure and 6DOF equations:

- **Enhanced coupling** where the 6DOF equations are integrated after each pressure correction step,
- **Monolithic coupling** where the 6DOF equations are solved as a constraint in the pressure equation.

Rigid Body Motion

Rigid body motion (6DOF) equations are solved with a **fourth order accurate geometric integrator** which does not need a parametrisation of rotation matrix with Euler angles or quaternions, avoiding gimbal lock. **The integrator has a generic interface to constraints (*e.g.* prescribed trajectory) and restraints (*e.g.* mooring systems)**.

Interface Capturing

Three different interface capturing schemes are available in the Naval Hydro Pack:

1. **Algebraic Volume–of–Fluid method**. Standard discretisation schemes are available (CISCAM, HRIC) along with more advanced interface compression treatment with discretisation practice that does not depend on the flow Courant number. The method is suitable for steady resistance, seakeeping and manoeuvring simulations.
2. **Level Set method**. Our Level Set method implicitly transports the signed distance field allowing large time–step simulations. The method redistances the signed distance field during the transport, rendering additional explicit redistancing steps unnecessary. The method is suitable for steady resistance, seakeeping and manoeuvring simulations at high Froude numbers, where the VOF method might suffer from ventilation issues.
3. **Geometric Volume–of–Fluid method: isoAdvector**. The isoAdvector method is the most accurate interface capturing method as it relies on geometric reconstruction and advection of the interface. The cost of accuracy is the method's Courant number limit of 1, requiring smaller time–steps. The method is suitable for problems with violent free surface behaviour such as green sea simulations.

Dynamic Mesh Handling

Following dynamic mesh strategies can be used for CFD simulations:

- **Algebraic mesh deformation**. Mesh is deformed according to body motion in way that the points move rigidly near the body, and smoothly damped towards outer boundaries. Such procedure is extremely time efficient and suitable for sinkage and trim, seakeeping and most of the manoeuvring simulations.

- **Generalized Grid Interface** (GGI). A mass conservative sliding interface between two non–conforming mesh regions, suitable for propellers and rudders which move relative to a freely floating object.
- **Immersed Boundary**. Moving bodies are represented with the STL surface, avoiding creation of the body–fitted mesh. The method is suitable for complex body motions, where pressure effects are dominant and resolving the near wall flow features is less important.
- **Overset Mesh**. Overset Mesh requires multiple body–fitted meshes and enables simulations with complex body motions, while having the ability to resolve near wall flow features.

Wave Modelling

We provide a complete set of regular and irregular potential flow theories, ranging from simple linear monochromatic wave (Stokes first or Airy wave theory) to the most advanced **Higher Order Spectrum** method. All wave theories are readily coupled to our top–level solvers via implicit relaxation zones and optionally SWENSE solution decomposition.

Numerous monochromatic wave theories are available:

- First, second and fifth order Stokes wave theory,
- First and third order cnoidal wave theory,
- Solitary Stokes wave,
- **Fully nonlinear stream function wave theory**.

Unidirectional or multidirectional irregular sea states can be prescribed by:

- A list of arbitrary monochromatic waves,
- One of the pre-built sea spectra: Bretschneider, Pierson Moskowitz and JONSWAP,
- **Higher Order Spectrum method** which takes into account nonlinear wave–wave interaction and nonlinear wave modulation.

Any wave theory can be combined with one of our models for current:

- Constant current along the depth,

- Parabolic current and
- Power law current.

For our simulations, we prefer to use **stream function wave theory for monochromatic waves** and **Higher Order Spectrum method for irregular sea states** because the overhead of calculating potential flow solution is negligible compared to CFD solution, while they provide the most accurate representation of the wave field that includes nonlinear effects.

Actuator Disc Model

The **time–efficient actuator disc model is based on thrust and torque open water curves:** $K_T(J), K_Q(J)$, making it easy to use for naval architects. Compared to discretised, rotating propellers using either Generalized Grid Interface or Overset Mesh, it provides significant reduction of CPU time for self–propulsion and manoeuvring simulations, while maintaining the necessary accuracy for integral quantities (*e.g.* thrust).

The actuator disc model is often used with different controllers depending on the type of self–propulsion simulations:

- Target propeller rotation rate,
- Target shaft power,
- Target forward speed.

Post Processing Utilities

The Naval Hydro Pack makes it easy to keep track of:

- Forces and torques on a specified body or wall,
- Wetted surface of a body or wall,
- Wave gauges (for Volume–of–Fluid and Level Set simulations),
- **General ship hydrodynamics output**, including: viscous and pressure coefficients, motions, ITTC viscous resistance estimate, *etc.*.
- **Smart pressure probes**, screening for extreme pressure spikes on a specified body or wall, reconstructing the time of impact and reporting: time, location and pressure at the location.
- **Maximum pressure indicator**, reporting maximum pressures on a given body at

the end of simulation, reporting: time at which the maximum has been achieved, location and maximum pressure.

Validation Suite and Tutorials

Along with numerous tutorials demonstrating various capability, we have the **validation suite where our best practices are collected and constantly updated**. The validation suite contains cases relevant for marine, coastal and offshore engineering:

- Simple free surface flow over a ramp,
- **Progressive wave** simulation,
- **Higher order wave loads on a surface–piercing cylinder**,
- **Calm water resistance with and without sinkage and trim**,
- **Seakeeping of a ship** in
  - **Head waves**,
  - **Oblique waves (bow quartering waves)**.

Under Development

We constantly develop our code to improve performance and versatility. Currently, we are focusing our developments on:

- **Single–phase weakly nonlinear free surface solver** for extremely efficient seakeeping and manoeuvring simulations,
- **Extension of the Ghost Fluid Method for compressible air flow**, which will enable accurate simulations where compressible effects might be important, such as: sloshing, slamming and green water,
- **Robustness improvements in automatic fringe assembly in Overset Mesh**, which will lower user effort,
- **Performing extensive verification and validation for manoeuvring simulations**.