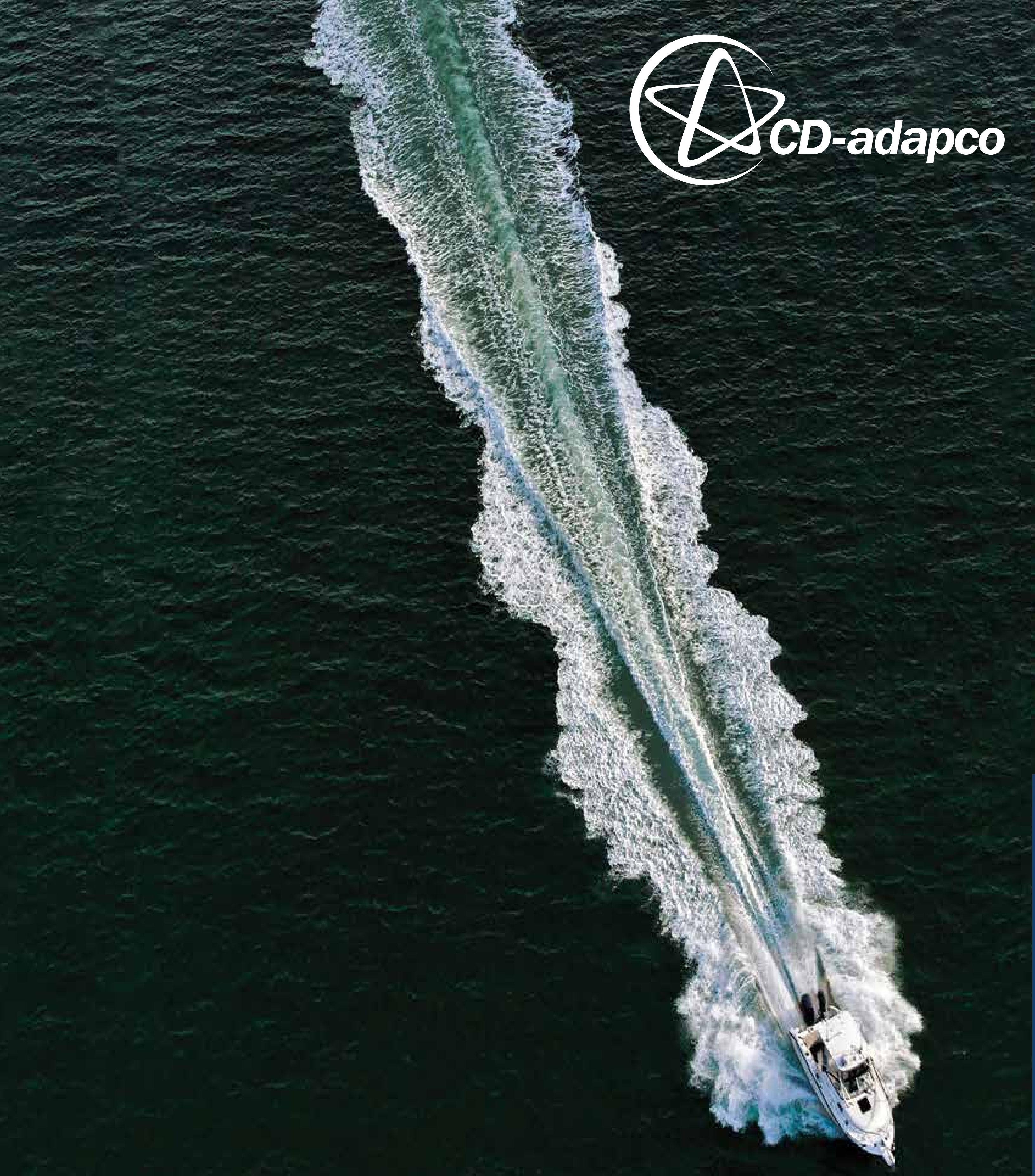


CD-adapco

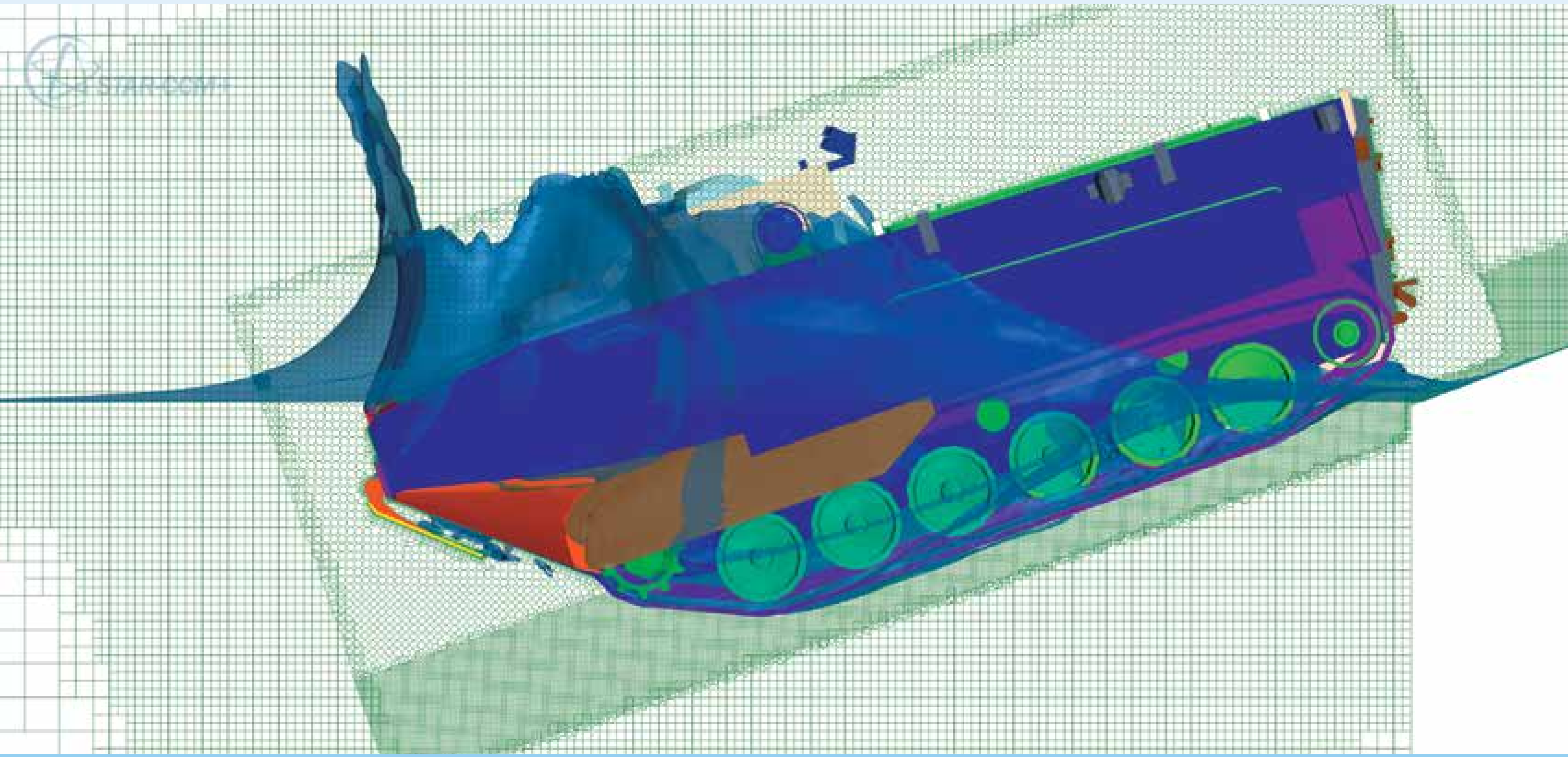
STAR-CCM+ Capabilities for Marine Applications

A **CD-adapco** Technical Review

STAR-CCM+ Features

Introduction

CD-adapco offers specific simulation tools and procedures in STAR-CCM+ to fit the needs and requirements of the marine industry. This brochure reviews a number of these capabilities, most of which have been developed in close collaboration with classification societies (Lloyd's Register, Germanischer Lloyd, Det Norske Veritas, American Bureau of Shipping, etc.), industrial partners (Daewoo, Hyundai, Keppel, Samsung, Technip, etc.) and towing tank facilities (FORCE Technology, CTO, Brodarski Institut, etc.) to ensure their relevance to our customers.



Above: *Overset mesh around an Assault Amphibious Vehicle (AAV7) for water entry.*

Handling of Complex Geometries

Thanks to its unrivaled meshing technology, STAR-CCM+ enables users to quickly, easily and efficiently prepare and generate meshes for the most complex geometries and large assemblies. With both manual and automatic surface preparation tools as well as state-of-the-art polyhedral and trimmed cell meshing, STAR-CCM+ cuts geometry preparation and meshing time down from weeks (or even months) to hours. For multi-domain studies such as conjugate heat transfer and fluid-structure interaction, fully conformal meshes can be created automatically. A number of specialized meshers are also available, including generation of prismatic elements for thin objects, generalized cylindrical geometries and boundary extrusion. These capabilities allow engineers to simulate the performance of a complete system in a single integrated environment without having to break it down into smaller or de-featured units. For example, a ship could be represented with both its superstructure and appendages, while simulating both the water and air flows inside and outside the vessel and simultaneously performing heat transfer and stress analyses.

Grid Adaptation to Moving Bodies

One of the greatest challenges for marine applications is to adapt the grid to the moving body, be it rigid or deformable. STAR-CCM+ offers several options to the user:

- **Rigid motion of the whole mesh:** this option is suitable for a single body moving in an infinite environment and a flat free surface.
- **Mesh morphing (of either the whole mesh or a number of regions):** the mesh morpher keeps the grid topology and moves the internal vertices according to the boundary motion.
- **Embedded (sliding interfaces):** following the body movement, the whole mesh is translated while the region around the body is rotated using a sliding grid approach.
- **Overset mesh: a new, revolutionary feature to simulate the relative motion of bodies. One background grid is fixed to the environment and one overlapping grid is attached to each moving body.**

When preparing surfaces for volume meshing, an extensive set of tools is available, including error diagnostics, fine grained manipulation of surface primitives, topological identification, as well as defeaturing, boolean and imprinting operations on CAD or triangulated surfaces.

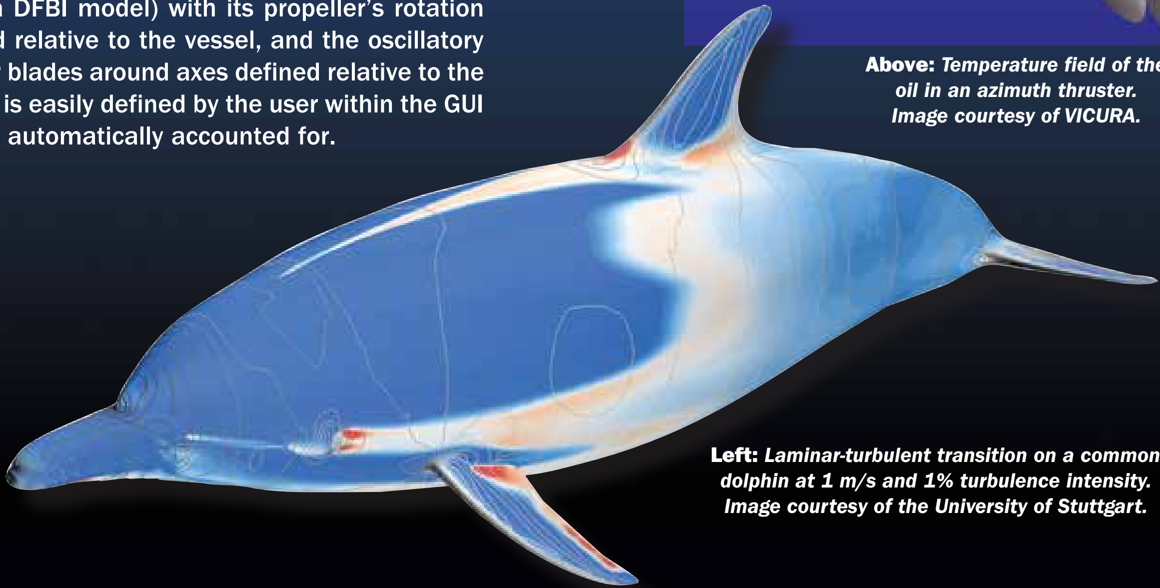
STAR-CCM+ Features

Motion Models

Most marine and offshore analyses are transient by nature and require that mesh vertices be displaced in real time. STAR-CCM+ offers the following motion models, specifically suited for such applications:

- **Prescribed rigid-body motion:** including rigid translation and/or rotation (e.g. propeller rotation, prescribed motion of control surfaces, etc.)
- **Dynamic Fluid-Body Interaction (DFBI):**
  - Coupled computation of flow and motion of floating or flying bodies in 6 DoF, including fluid, propulsion and external forces and moments (such as springs, catenaries and other body couplings);
  - Combination of prescribed motions and additional degrees of freedom (e.g. planar motion mechanism).
- **Superposition of multiple motions:** allows users to simulate more complex body part motions and combine various grid adaptation options (e.g. rigid body motion, mesh morphing and overlapping grids). For example, superposing the motion of a vessel (controlled by a DFBI model) with its propeller's rotation around an axis defined relative to the vessel, and the oscillatory motion of the propeller blades around axes defined relative to the propeller: each motion is easily defined by the user within the GUI and their interaction is automatically accounted for.

Above: *Temperature field of the oil in an azimuth thruster. Image courtesy of VICURA.*

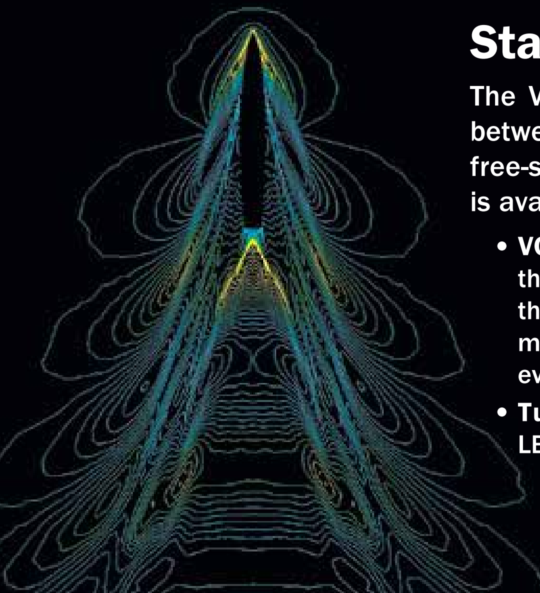


Left: *Laminar-turbulent transition on a common dolphin at 1 m/s and 1% turbulence intensity. Image courtesy of the University of Stuttgart.*

State-of-the-art Volume of Fluid & Turbulence Models

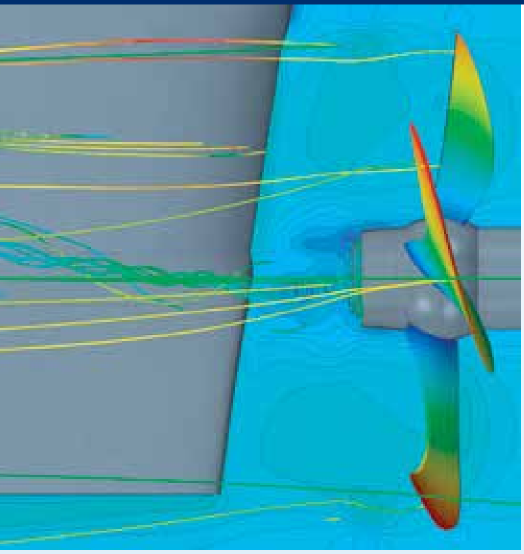
The Volume of Fluid (VOF) multiphase model allows the movement of the interface between the fluid phases to be accurately captured, as is typically required for marine, free-surface flows applications. In addition, a range of high-end turbulence models is available.

- **VOF Model:** STAR-CCM+ uses an original High-Resolution Interface-Capturing (HRIC) scheme that provides a resolution of the free surface by a single computational cell. It is part of the multi-component, multiphase framework in STAR-CCM+ that allows users to consider multiple fluids (such as water, oil and air) and account for phase changes (e.g. cavitation and evaporation at the free surface). Both liquid and gaseous phases can be compressible.
- **Turbulence Models:** All state-of-the-art approaches are available, including RANS, LES and DES.
  - For RANS, all major models are included (Spalart-Allmaras; linear and non-linear k-ε and k-ω families of models; transition model; Reynolds-stress transport model).
  - For wall treatment, low-Re, wall functions and all-y+ variants are available, for both smooth and rough walls.
  - For DES-approach, IDDES based on various near-wall RANS treatment is available.
  - LES-approach offers static and dynamic Smagorinsky and WALE models.



Above: *Simulation of the flow around the DTMB 5415 US Navy Combatant at high Froude Number.*

STAR-CCM+ Applications



Above: *Propeller hub vortex. image courtesy of MAN Diesel & Turbo.*

Prediction of Propulsion

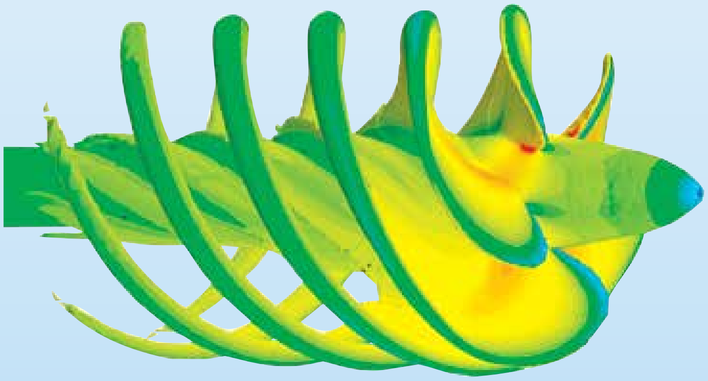
Simulations of propulsion flows is an important category of marine applications in STAR-CCM+. Typical applications include:

- Steady-state simulation for a single propeller blade using periodic conditions (i.e. first step propeller optimization): this can be used in lieu of open-water propeller tests;
- Prediction of propeller-ship-rudder interactions, using a rotating region attached to the propeller and either sliding or overset grids: this can be used in lieu of self-propulsion tests;
- Prediction of propeller ventilation and cavitation effects on performance;
- Prediction of water-jet flows and performance of propulsion-enhancing devices, etc.;
- Simulation of propeller dynamic pitch.

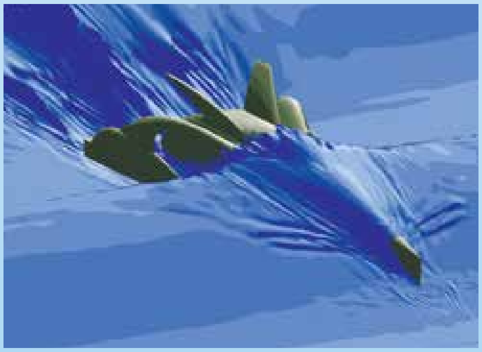
Furthermore, CD-adapco has developed specific models for propulsion simulations, such as the Body Force Propeller Method (a virtual disc model) and the possibility of coupling a STAR-CCM+ simulation to external codes providing propulsion body forces.

Prediction of Cavitation

In marine applications, simulation is used to optimize the design not only for better performance at the nominal operating conditions but also to delay the onset of cavitation on the propeller or to minimize its extent and effects further downstream (e.g. on the rudder behind a propeller). Predicted rates of collapse of cavitation bubbles near walls can be used to estimate the danger of cavitation erosion. With DES-simulations, it is also possible to predict cavitation-induced noise and pressure fluctuations on the hull. Such simulations can be used in lieu of cavitation tank tests.



Above: *Iso-surface of vorticity from a marine propeller.*



Above: *DFBI simulation of the Earthrace wave piercing boat.*

Prediction of Wave Impact

Predicting the effects of wave impact on vessels and offshore structures is one of the greatest challenges in marine engineering. It requires efficiently generating a desired sea state and a time-accurate simulation of wave propagation, as well as the ability to handle breaking waves and induced motion or deformation of the structure (when coupled to an FEA code).

Applications include:

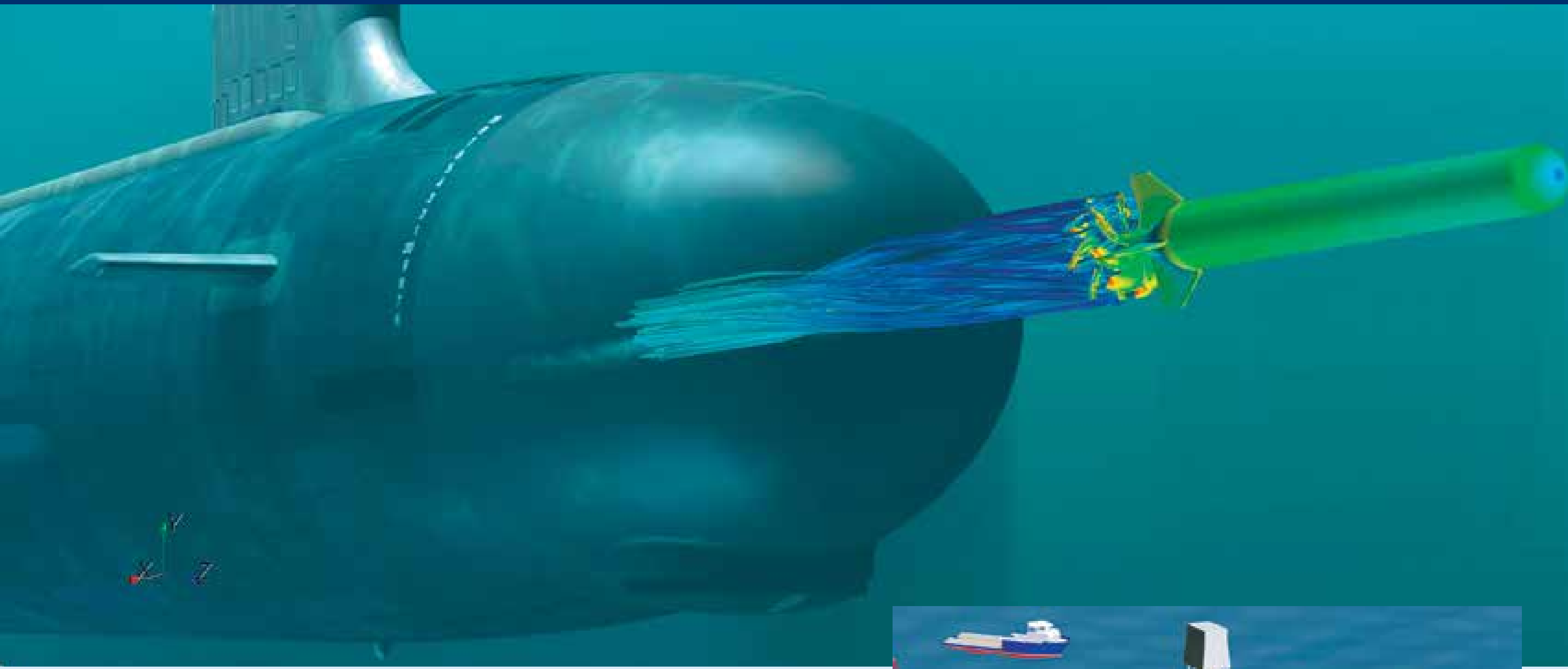
- Lifeboats (or other structures) drop;
- Wave impact on offshore structures.

Sloshing, Slamming, Whipping and Springing

Sloshing in ship tanks is important from several points of view: the resulting loading on the structure and how it affects the ship stability are of major concern. Similarly, when designing a new or optimizing an existing ship, slamming, whipping and springing are issues that need to be addressed. In order to compute such flows, the solution method must allow breaking waves, buoyancy effects on trapped gas, and an accurate prediction of ship motions in waves. STAR-CCM+ offers all of those capabilities and has been extensively used to predict such phenomena.

Above: *Winston Churchill Destroyer in waves.*

STAR-CCM+ Applications



Above: *Torpedo hydrodynamics analysis.*

Design Optimization & Innovation

STAR-CCM+ can be used to gain insight into a phenomenon, optimize a design, and solve/analyze a flow problem. Examples of innovations through simulation include:

- Modified lifeboat shape for reduced aft acceleration;
- Spoiler on ship hull for reduced resistance;
- Slot in a guard plate for Voith-Schneider Propeller (VSP) leading to major performance improvements;
- Inclination of the Voith Radial Propeller (VRP) axis for reduced losses;
- Design of the wave-piercing trimaran Earthrace.

Above: *CFD is routinely used to predict, quantify and mitigate some of the risks associated with floating and fixed offshore structures. Analyses include ventilation assessment, gas leak dispersion, helideck environment modeling, as well as smoke and fire modeling. Image courtesy of Atkins Ltd.*

Estimating Hull Performance (EHP) in Calm Water: a NEW Tool for Naval Architects

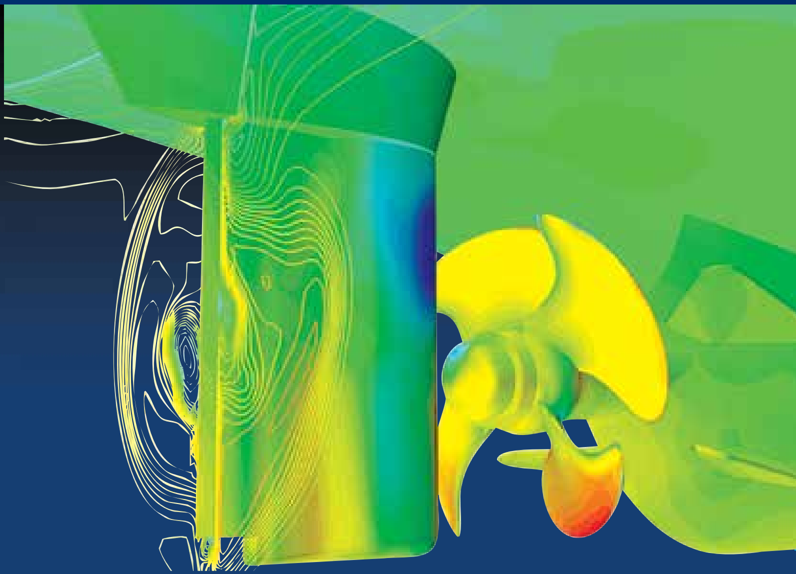
EHP (Estimating Hull Performance) is a brand new CD-adapco Virtual Product Development add-on to STAR-CCM+, and provides naval architects with a streamlined GUI-driven process to simulate powered hull motion in calm water. EHP has been tailored for analyses of unappended displacement hulls. With its automatic set-up and intuitive, user-friendly GUI, EHP can be used by all naval architects, including those with very little CAD or CFD experience. EHP guides users from CAD import, through solution of single or multiple speeds in a single session, to automatic PowerPoint generation with images and reports of the results. You can even use your own company PowerPoint template. After model setup, EHP gives optional direct access to the simulation (.sim) file, which can easily be adapted to more complex geometries and/or specific conditions, thereby allowing more experienced users to harness the full power of STAR-CCM+ to deliver high-quality predictions for various scenarios.

STAR-CCM+ Features

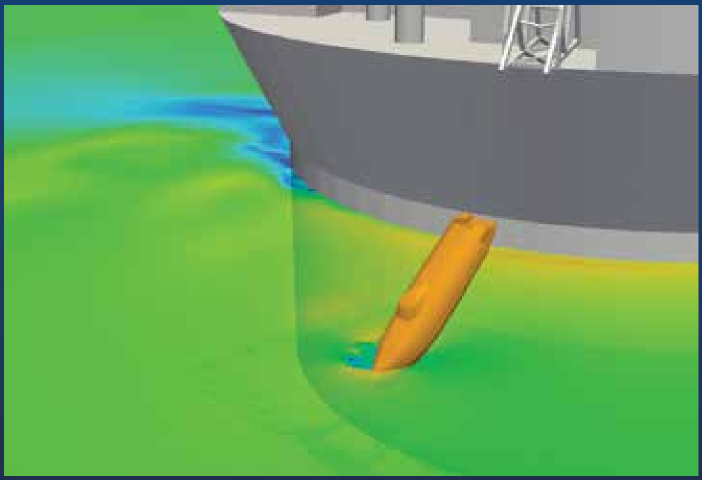
Waves

STAR-CCM+ offers dedicated wave generation methods for marine applications.

- **Wave Models:** Several wave models were introduced on request of classification societies and other clients:
  - Linear 1st-order wave theory;
  - Non-linear Stokes 5th-order wave theory (after Fenton, 1985);
  - Pierson-Moskowitz and JONSWAP spectra (long-crested irregular waves);
  - Superposition of linear waves with arbitrary direction of propagation, amplitude and period (manual set-up for short-crested wave spectra);
  - Internal wave generation.
- **Wave Damping:** Wave damping is used to ensure that no unwanted wave reflection occurs at the boundaries of the solution domain. This is achieved by introducing resistance to the vertical motion in the vicinity of the selected boundaries. Expanding (extruding) the grid in these regions supports the wave damping by increasing numerical dissipation.



Above: *Instantaneous pressure field on the stern region of the hull and on the propeller. Image courtesy of FORCE Technology.*



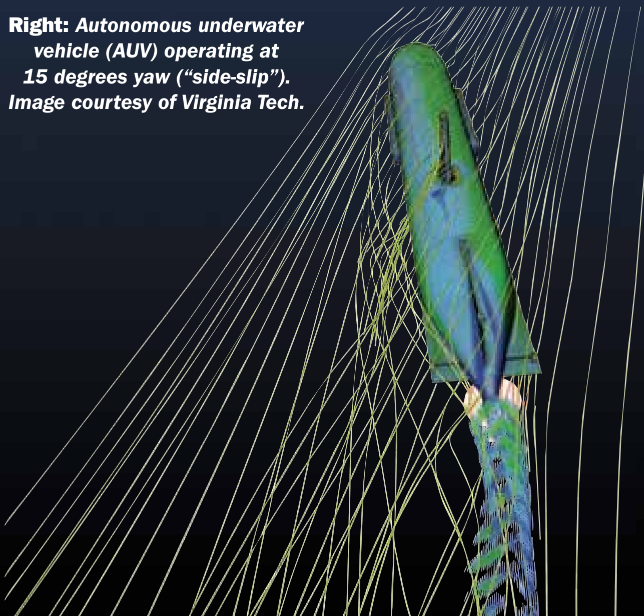
Above: *STAR-CCM+ analysis of dynamic effects during the launch of the Norsafe GES52 free-fall lifeboat from an offshore installation. Image courtesy of CFD Marine AS.*

Fluid-Structure Interaction

Increasingly important multiphysics simulation tools are allowing engineers to replicate and predict the realistic physical behavior of complex systems where the interactions of fluid and structural responses are significant. The following options are available:

- Implicit coupling to the external Finite Element Analysis (FEA) code ABAQUS;
- Implicit coupling to the Finite-Volume solid stress model within STAR-CCM+;
- Explicit coupling to other external FEA codes;
- A co-simulation API offering libraries that can be called by external FEA codes to achieve implicit coupling with STAR-CCM+.

Right: *Autonomous underwater vehicle (AUV) operating at 15 degrees yaw ("side-slip"). Image courtesy of Virginia Tech.*



Phase Change

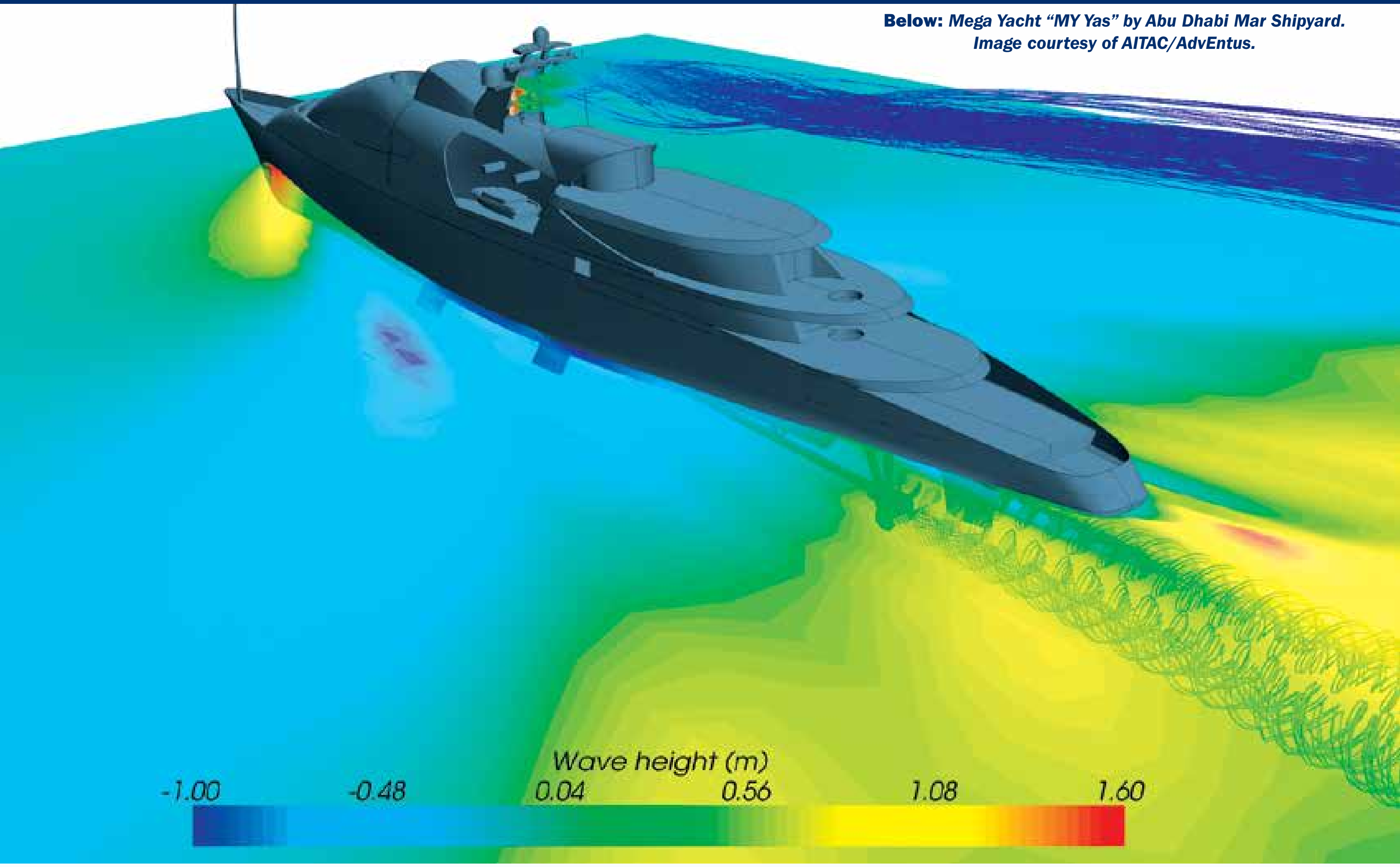
STAR-CCM+ offers several options for modeling phase change:

- Nucleate, transitional and film boiling;
- Enthalpy-controlled melting and solidification;
- Bubble-dynamics cavitation model based on Rayleigh-Plesset equation.

An arbitrary number of phases can be used. Various phase-interaction models are available, including surface-tension and gravitational effects. In addition, the Discrete Element Method (DEM) can be used to study the motion of ice pieces around the hull and propeller zone, and assess the effectiveness of propeller protection devices (e.g. fins). By coupling the flow and DEM solvers with a structural solver, the potential damages caused by the impact of ice pieces onto the hull or the rudder may also be investigated.

STAR-CCM+ Applications

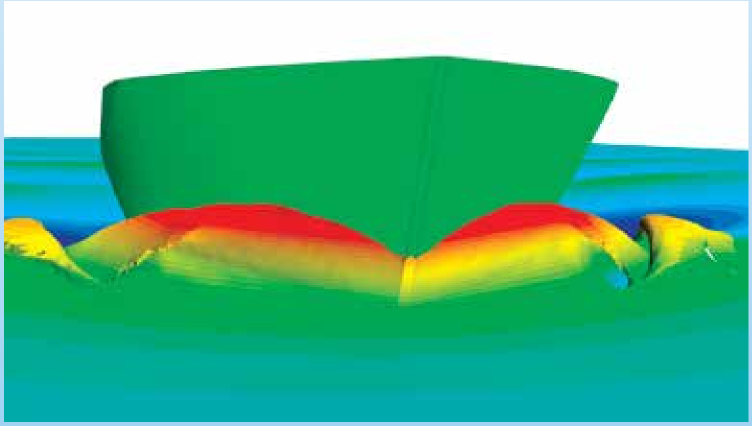
Below: *Mega Yacht "MY Yas" by Abu Dhabi Mar Shipyard.*
Image courtesy of AITAC/AdvEntus.



Introduction

Using cutting-edge solver technology, CD-adapco's customers have been able to tackle some of the most demanding problems facing the marine industry, allowing engineers to predict how designs will react in operation before budget is committed to the construction of expensive prototypes. Application areas include:

- Prediction of ship resistance in calm water and in waves;
- Prediction of sea-keeping and maneuvering, slamming and sloshing loads;
- Prediction of wave and wind loading on offshore and underwater structures;
- Analyses of oil and pollutant dispersions;
- Cavitation control and propulsion system optimization.



Above: *RANS simulation of a breaking bow wave.*
Image courtesy of FORCE Technology.

Motion of Floating Bodies

STAR-CCM+ can perform coupled simulations of flow and flow-induced motions of floating or flying bodies (ships, lifeboats, offshore structures, weapons etc.). Applications include virtual towing tank experiments in model scale as well as full-scale simulations of realistic scenarios:

- Prediction of ship resistance, trim and sinkage;
- Analysis of various sea-keeping and maneuvering problems;
- Study of ship motion in calm water & in waves (self-propulsion tests).

> ***"At Cape Horn Engineering we have been using CD-adapco´s CFD code STAR-CCM+ for many years. With three consecutive Volvo Ocean Race wins and an ongoing participation in the pinnacle of yachting sport, the America´s Cup, we consider STAR-CCM+ a leading edge tool for the design of winning yachts. As far as we are concerned, model tank testing is a thing of the past."***
>
> **Rodrigo Azcueta, Cape Horn Engineering S.L.**

> ***"Azimut|Benetti has been pushing the CFD design of its yachts since 2005 and we trust that we could not reach our actual standards and confidence in CFD results with any other commercial CFD software or company. With CD-adapco, we managed to tailor the power of CFD to our particular naval & nautical challenges (volume of fluid, free surface, DFBI in naval applications) thanks to a close collaboration and mutual know-how integration. During these years, we have experienced the competence and support of the CD-adapco technical staff, who help us every day to perform our work."***
>
> **Francesco Serra, Azimut|Benetti Group**

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