Potsdam Propeller CFD Benchmark

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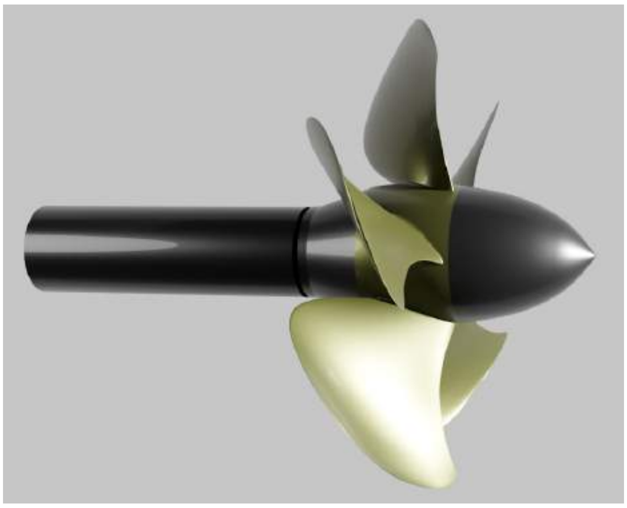
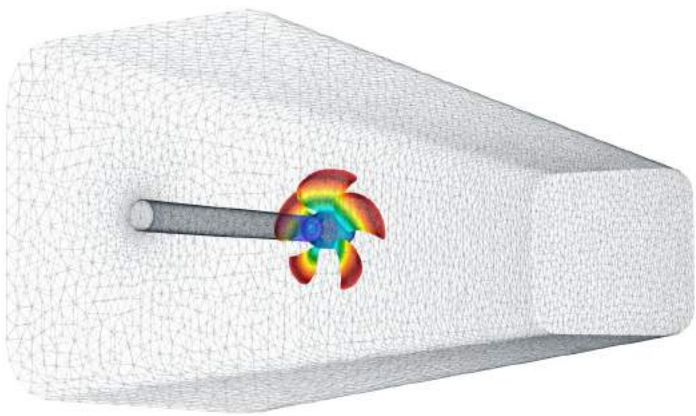
This report presents the benchmark validation of CFD simulation results of the Potsdam Propeller Test Case (PPTC), using TCFD® with POINTWISE® mesh. PPTC is a marine propulsor that was extensively measured by SVA Potsdam and related data were published [1] [2] [3]. The aim of this benchmark was to evaluate the TCFD®, computational fluid dynamics (CFD) software, on the very advanced mesh, created in POINTWISE®, mesh generation software, and to compare the results with the measurement data available. The particular goal of this benchmark is to compare the propeller ***Efficiency, Torque Coefficient, and Thrust Coefficient*** *vs.* ***Advance Coefficient*** *with the real experimental measurement of SVA Potsdam Laboratory.*

KEYWORDS: POTSDAM PROPELLER, CFD, MESH, VALIDATION, BENCHMARK, TCFD, SIMULATION, POINTWISE, ADVANCED MESH, EXTERNAL, TURBOMACHINERY, HYDRODYNAMICS, PROPELLER, SHIP, PROPULSION, INCOMPRESSIBLE, FLUID, FLOW, RANS, WATER, STEADY-STATE, WATERFLOW, AUTOMATION





Benchmark Parameters

- Mean flow speed: *4 m/s*
- Rotation speed: *900 RPM*
- Flow model: in*compressible*
- Mesh size: *4.1 M cells*
- Medium: *water*
- Speedlines: *1*
- Simulation points: *11*
- Fluid: *Water*
- Reference pressure: *1 atm*
- Reference density: *997.71 kg/m³*
- Dynamic viscosity: 9.559×10^{-4} *Pa · s*
- CPU Time: *30 core.hours/point*
- Turbulence: *RANS*
- Turbulence model: *kOmegaSST*
- Simulation type: *Propeller*
- Time management: *steady-state*
- Number of components: *2*
- Wall treatment: *Wall functions*

Potsdam Propeller CFD Benchmark Description

The high demand for improving the accuracy, quality, and credibility of the CFD simulation results, should be assessed by providing a high qualitative and intensive comparison with experimental measurement data.

The purpose of this benchmark is the validation of CFD simulation software TCFD® with the mesh created in high-end meshing software POINTWISE® and to compare the results with the measurement data available. Potsdam Propeller Test Case (PPTC) is a marine propulsor that was extensively measured by SVA Potsdam and related data were published in [1], [2], and [3].

The particular goal of this benchmark is to compare the propeller Efficiency, Torque Coefficient, and Thrust Coefficient vs. Advance Coefficient with the real experimental measurement of SVA Potsdam Laboratory. The experimental investigation includes open water test and velocity field measurements at different operation conditions. A detailed description of the open water tests

conducted at the towing tank of the SVA is presented in the SVA report [1], which can be found on the SVA website (sva-potsdam.de).

At the propeller analysis, there are a few important dimensionless numbers. Those are Advance Coefficient, Thrust Coefficient, Torque Coefficient, and Efficiency. They are defined as (respectively):

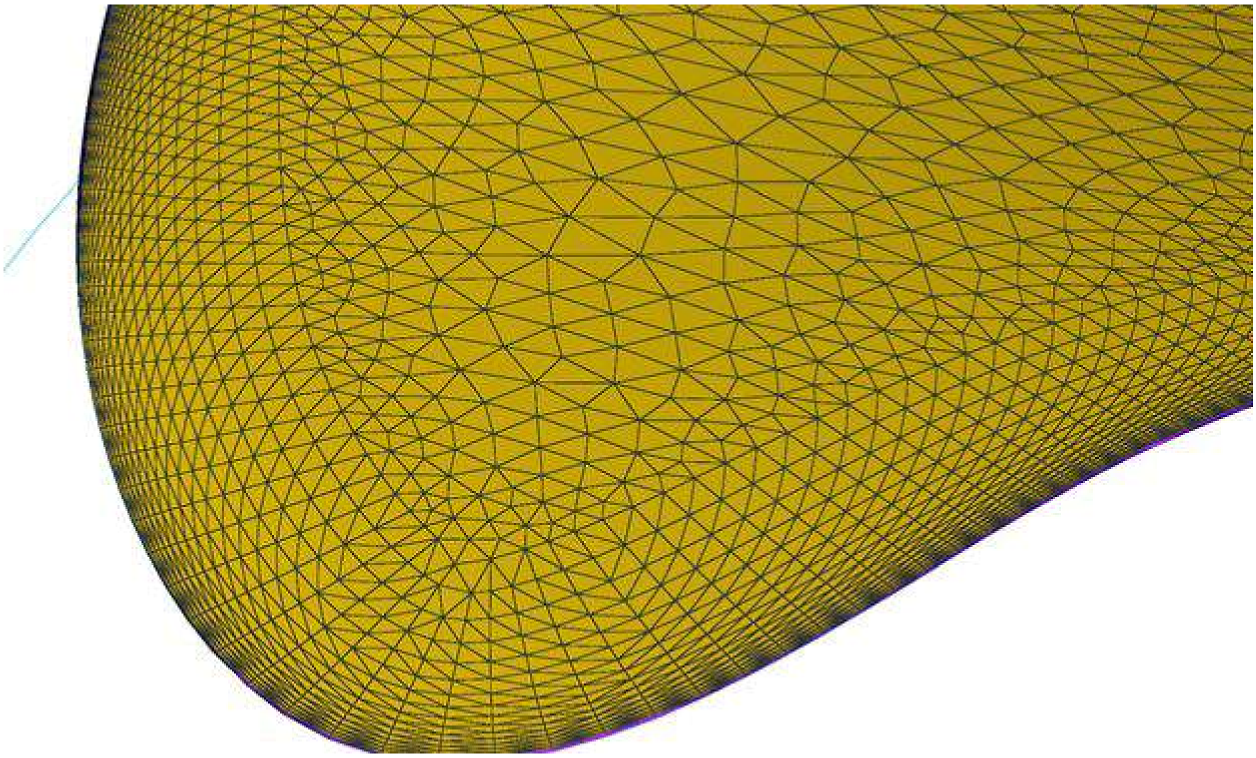
$$J = \frac{V_a}{n \cdot D} \quad , \quad K_T = \frac{T}{\rho \cdot n^2 \cdot D^4} \quad , \quad K_Q = \frac{Q}{\rho \cdot n^2 \cdot D^5} \quad , \quad \eta_0 = \frac{J\,K_T}{2\pi \cdot K_Q}$$

Where Va is the advance speed [m/s], n is the speed of rotation [1/s], D is propeller diameter [m], T is thrust [N], ϱ is water density [kg/m3], Q is torque [Nm]. The measurement results are available for Advance coefficients from J = 0.5 to 1.6 and the simulation points are chosen accordingly. Altogether, 11 Advance Coefficient modes were simulated according to the measurements.

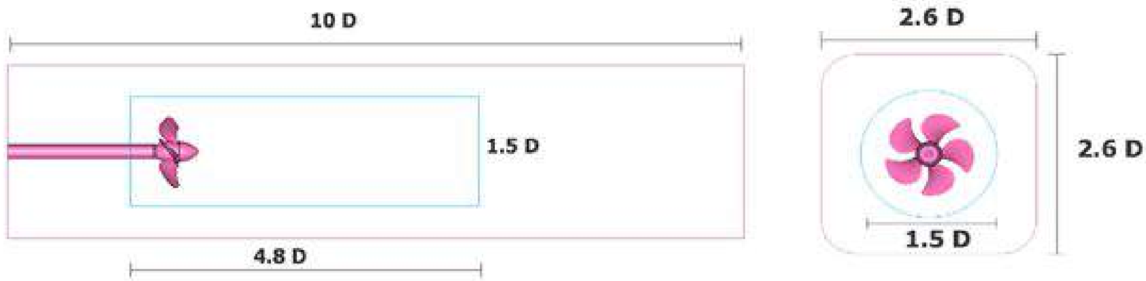
Mesh

An unstructured viscous computational mesh was constructed with Pointwise on the Potsdam propeller geometry as part of this TCFD validation benchmark. Pointwise, Inc. has previously worked with variants of the geometry for other studies. For an in-depth discussion of Pointwise technology and how it can be used for this particular geometry, please consult [4].

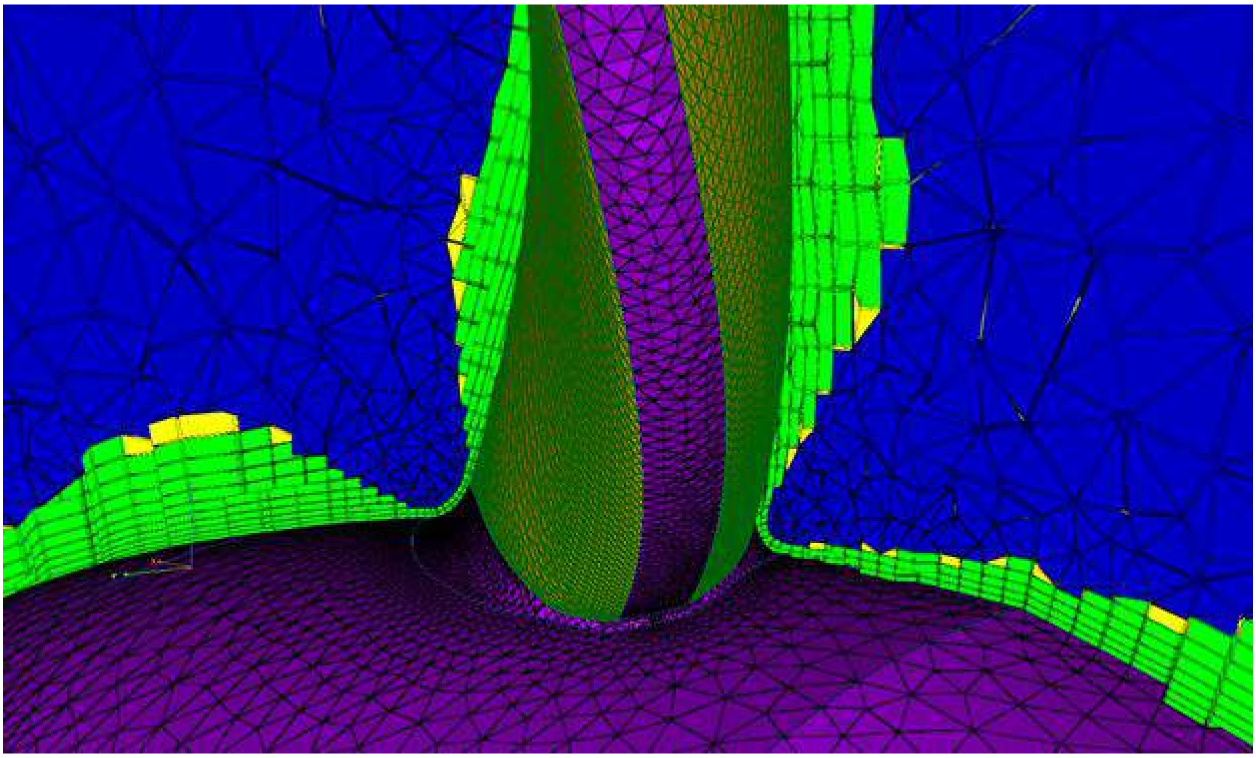
A combination of anisotropic and isotropic triangles were used in the surface mesh discretization. Areas of high curvature - such as the leading edge, trailing edge, and the tip- were resolved by utilizing Pointwise's T-Rex algorithm. This tool grows anisotropically stretched, right-angled triangles layered in the normal direction to a boundary [5], as shown below. Using this, areas of high curvature are able to be resolved without the need to isotropically refine the area. The result is an accurate adherence to the surface and a reduction in the point count. The interior of the surface mesh was resolved with isotropic triangles created using a modified Delaunay algorithm.



After meshing the geometry, the outer boundary of the moving reference frame (MRF) as well as the outer boundary of the computational domain were meshed utilizing isotropic triangles and the Delaunay algorithm. The MRF is cylindrical domain approximately 4.8 D long (4.8x the propeller diameter) and 1.5 D in diameter. It starts just upstream of the propeller and extends downstream into the wake. A farfield block was generated outside of the MRF corresponding to 10 D and 2.6 D; these were the limits taken from the file provided.



The volume mesh is a combination of a prismatic core surrounded by isotropic tetrahedral cells. The prismatic portions of the grid were initialized using T-Rex. Starting from the surface mesh, anisotropic tetrahedral cells were grown until reaching a desired stop criteria, colliding with another front, or violating quality criteria. If an element stops advancing this did not prevent adjacent elements from continuing. After the tetrahedral layers are grown, the cells are combined to form prisms (or hexagons if the surface mesh is made up of quadrilateral cells). This reduces the total cell count of the mesh without sacrificing quality. Once the near-wall viscous mesh was generated, the remainder of the volume was populated with isotropic tetrahedral cells. The total cell count was just below 4.1 million cells. The average maximum included angle was 101, and the maximum was 170. The average volume ratio was 1.8 with a maximum of 28.



The data for the mesh is included in the table.

Mesh Elements	points	faces	internal faces	faces per cell	hexahedra
#	*1018546*	*8753113*	*8434441*	*4.203379*	*2052*
Mesh Elements	prisms	pyramids	tet wedges	polyhedra	**cells**
#	*788137*	*39373*	*0*	*0*	***4,088,985***

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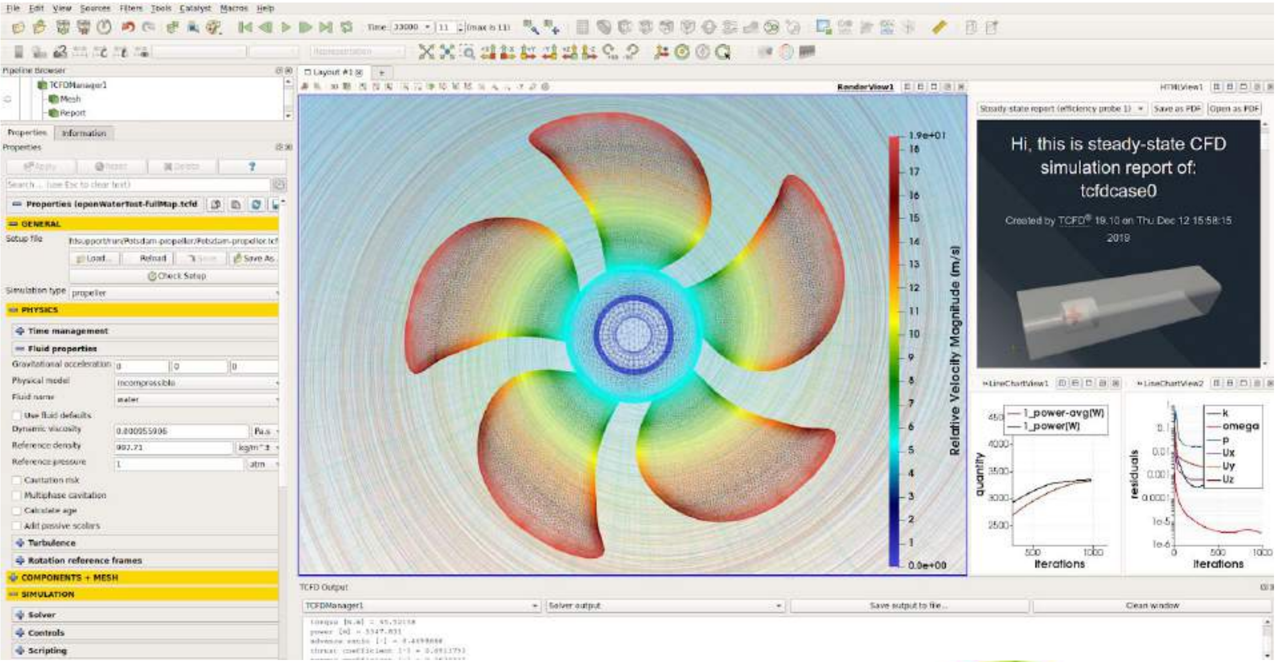
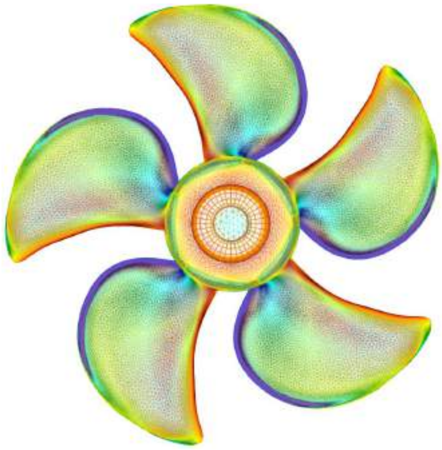
CFD support

TCFD® Simulation Setup

The simulation run in TCFD is quite straightforward. The external mesh, created in POINTWISE, is simply loaded and the simulation parameters are set. The simulation type is the *propeller*. Time management is *steady-state*. The fluid flow model is *incompressible*. The mesh has *two*

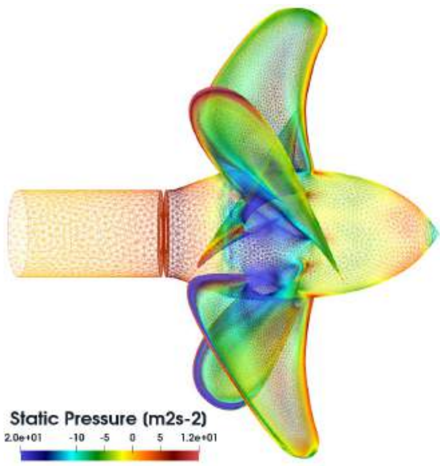


components (the water tunnel and the cylinder with propeller inside) of total *4.1M* cells. The inlet flow velocity defines the advance coefficient and the velocity varies from *1.7* to *5.9* m/s in *11* points. The outlet boundary condition is static pressure. For turbulence modeling, the RANS modeling approach has been used with the *k-omega SST* turbulence model with the wall functions. The fluid properties of water are selected. The density of 997.71 kg/m3. Dynamic viscosity of 9.559e-4 Pa.s.



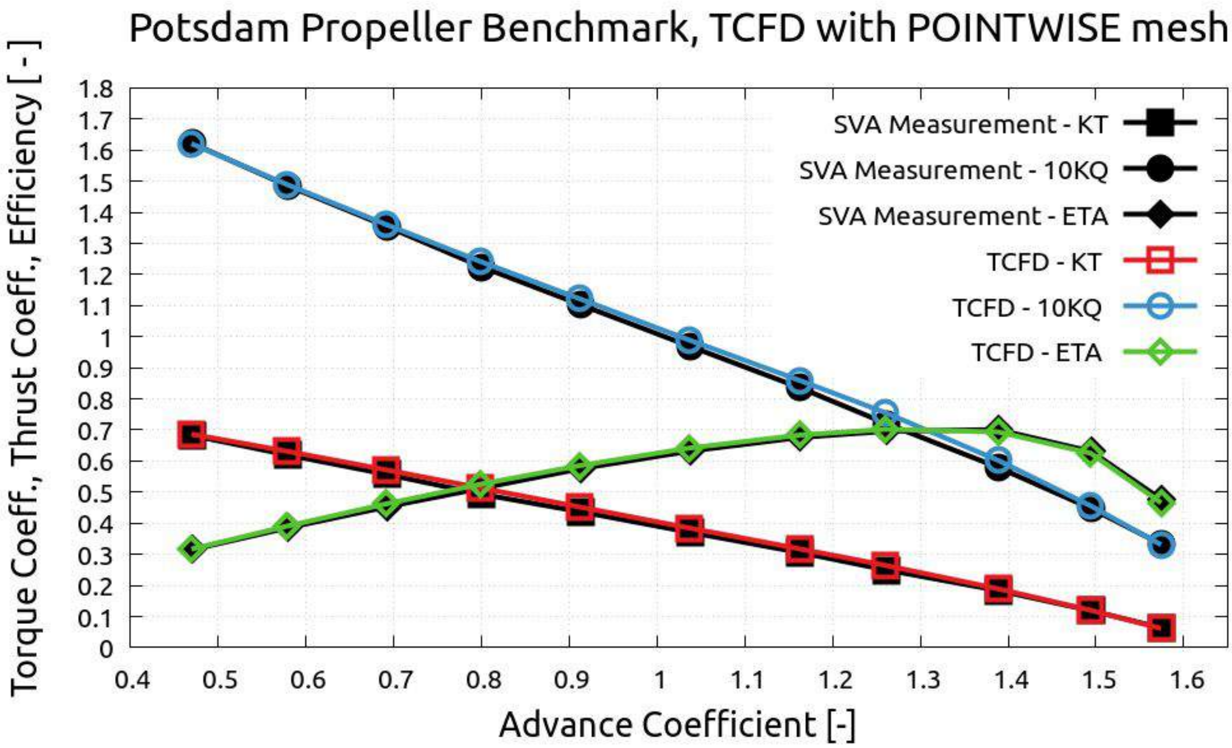
TCFD® Simulation Post-processing

TCFD® includes a built-in post-processing module that automatically evaluates the required total quantities, such as propeller efficiency, thrust coefficient, torque coefficient, forces, force coefficients, flow rates, and much more. All these quantities are evaluated throughout the simulation run, and all the important data is summarized in tabled .csv files as well as in the HTML report, which can be updated anytime during the simulation for every run. Furthermore, visual postprocessing of the volume fields can be done with ParaView.



Efficiency, Thrust & Torque Coefficient vs. Advance Coefficient

A propeller is the most common propulsor on ships, imparting momentum to a fluid which causes a force to act on the ship. The most comprehensive propeller performance information is provided by displaying all the key characteristics into one graph.



Conclusion

The CFD analysis of the PPTC was performed successfully. It has been shown that the TCFD® in connection with POINTWISE® provides very accurate results that are in perfect agreement with the measurement data.

All the simulation and measurement data are freely available. Potential questions about TCFD® are to be sent to *info@cfdsupport.com*. Questions about POINTWISE® are to be sent to pointwise@pointwise.com.

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[4] Carrigan, T., Bagheri, B., "A Study of the Influence of Meshing Strategies on CFD Simulation Efficiency," NAFEMS World Congress 2017, NWC17-466, 2017.
[5] Steinbrenner, J. P. and Abelanet, J.P., "Anisotropic Tetrahedral Meshing Based on Surface Deformation Techniques," AIAA-20060554, AIAA 45th Aerospace Sciences Meeting, Reno, NV.