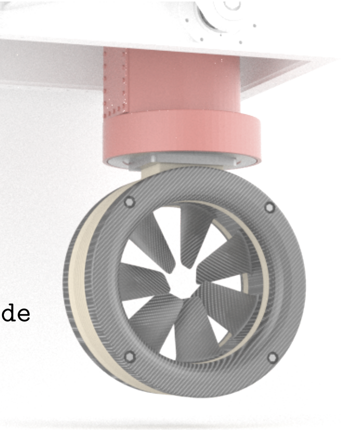
silentdynamics

Automated Simulation of Propellers and Turbomachinery using OpenFOAM and InsightCAE



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Contents

Personal background:

- Propeller designer until 2014 (at Voith Turbo company)

Rim-driven thrusters

- as ducted propeller, tunnel thruster, pump, ...
- special topics:
  - no tip gap
  - large friction losses

Carbon fiber propellers

- flexible blades
- fluid structure interaction

Experiences:

- CFD required for design tasks
- team members with different habits and experience with CFD

Requirements for CFD analyses:

- quick
- standardized

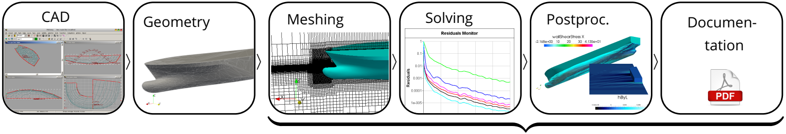
Solution

- Automate tasks (scripts)
- Add GUI (later)

How to do?

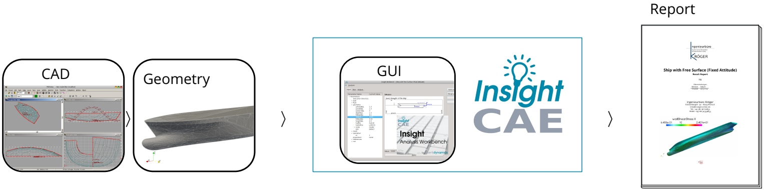
1. Shell scripts
   - Pro: simple, next logical step after command line
   - Con: limited, even floating point arithmetics is a mess
2. Python scripts (my first attempt)
   - Pro: scalable, much freedom
   - Con: if project grows large: very difficult to debug and maintain
3. C++ project (later $\Rightarrow$ InsightCAE)
   - Pro: mature, all possibilities, best maintainability
   - Con: programming skills, more boilerplate in project setup

Common practice: *manual* analysis workflow:



- labour consuming
- complicated, error prone

InsightCAE: *automated* workflow:

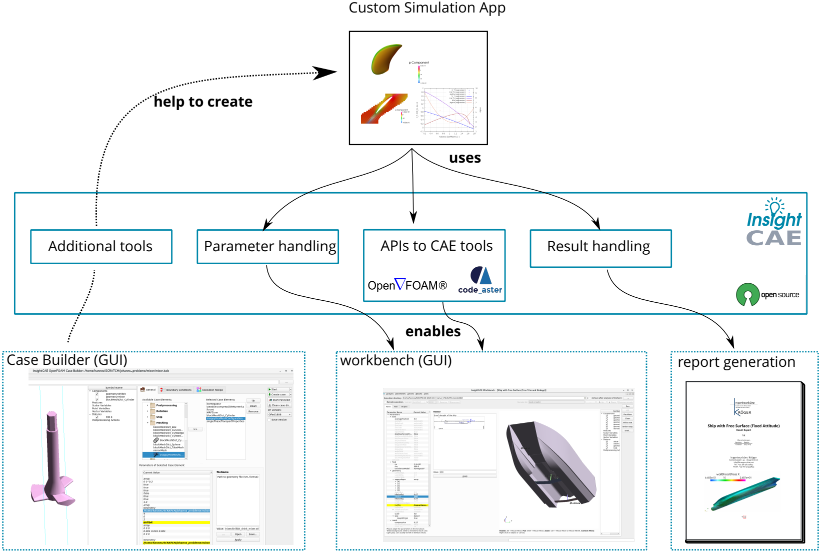


InsightCAE:
is a **framework** to create simulation ”apps”

provides:

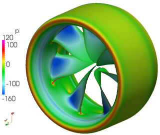
- parameter handling
- user interface
- provides API to CAE tools (mainly OpenFOAM)
  - written in C++
  - with Python integration (through SWIG)
- bundles further tools, add-ons

InsightCAE is an open source project
`https://github.com/hkroeger/insightcae`

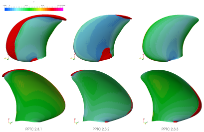

Custom Simulation App
help to create
uses
Additional tools
Parameter handling
APIs to CAE tools
Result handling
OpenFOAM®
code_aster
Insight CAE
open source
enables
Case Builder (GUI)
workbench (GUI)
report generation
Ship with Free Surface (Fixed Attitude)

Propeller Design

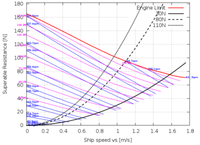
scope:



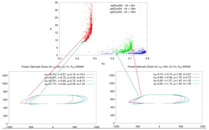
CFD (OWC)



with cavitation



propulsion



optimisation

- CFD analysis
  of single operating point or batch
- extensive postprocessing

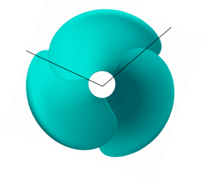
structured or unstructured?

- automated creation of structured meshes is possible, but
  - requires many parameters
  - and/or tight integration with CAD modeller

$\Rightarrow$ unstructured meshing

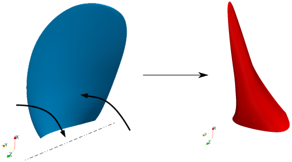
domain shape

- wedge-shaped domain only for low EAR common: pitch-following domain geometry required
- include curved lateral boundary geometry
  - ok for tetrahedral meshes
  - waste of effort for trimmed meshers

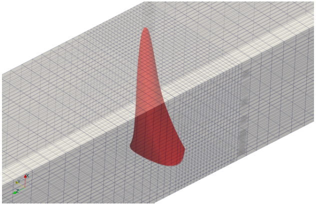


Example A: transforming geometry, mesh in rectangular domain

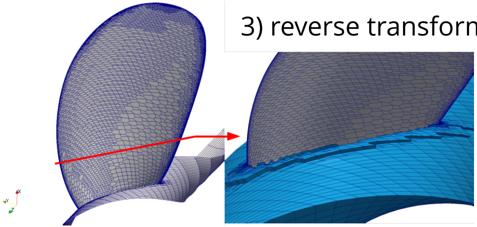
1) transform geometry



2) run snappyHexMesh (rect. template)

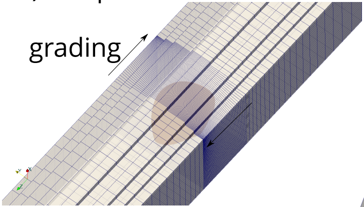


3) reverse transformation on mesh

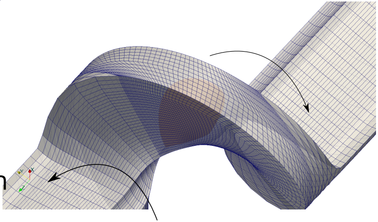


Example B: transforming template mesh, mesh in real space

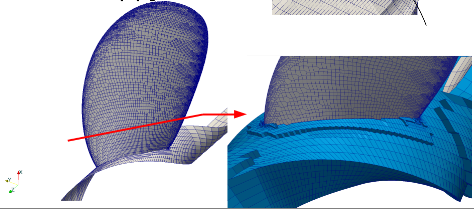
1.) template mesh



2.) transform template

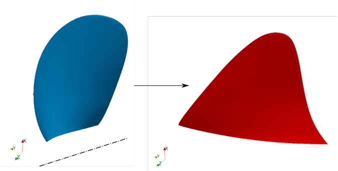


3.) run snappyHexMesh

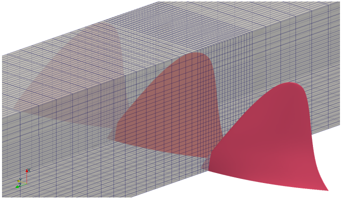


Example C: repeat geometry, intersect with cyclic boundary

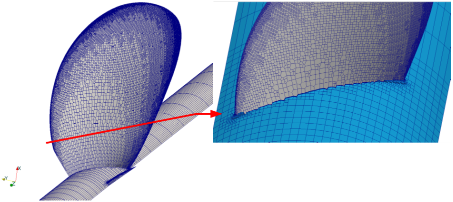
1.) transform geometry



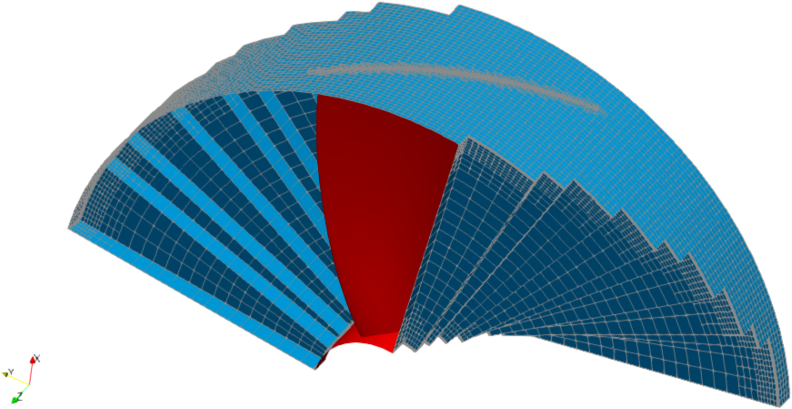
2.) mesh transformed geometry



3.) reverse transform mesh

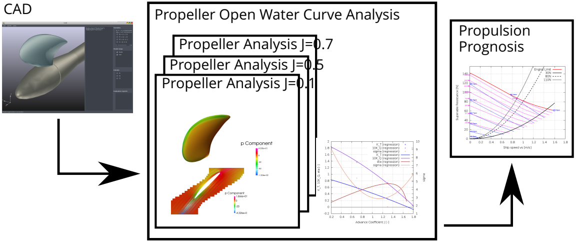


- staircase-like cyclic boundaries

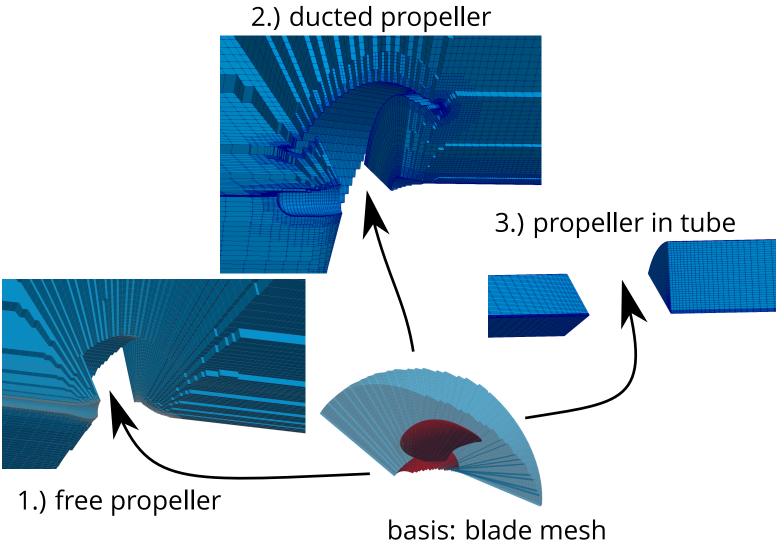


Open water curves

- basis is simulation app for single operating point
- InsightCAE provides support to create batch analyses
  - supporting multithreaded execution, queue systems, etc.
  - with extended postprocessing
- operating points are computed parallel, not sequential
  - easier to continue in case of non-convergence
  - faster, if sufficient hardware is available



$\Rightarrow$ sample report Wageningen Ka 4-70


2.) ducted propeller
3.) propeller in tube
1.) free propeller
basis: blade mesh

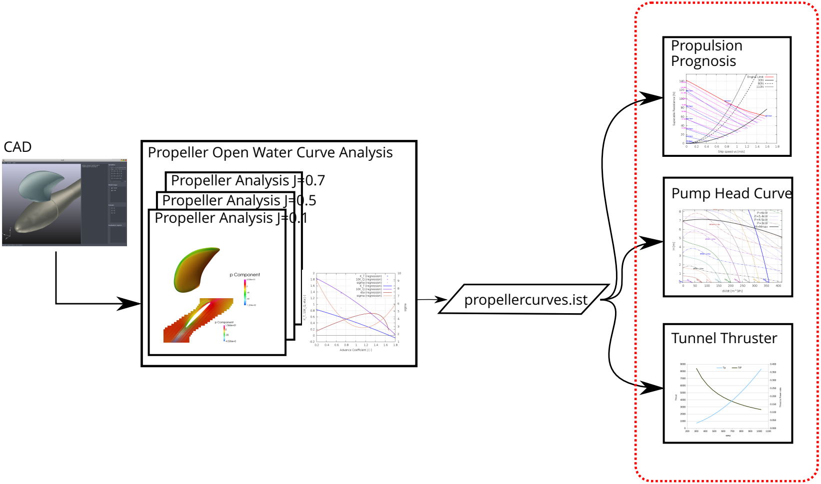
Ducted Propeller, Rim Thrusters

- shroud may be rotating (rim thruster) or at rest (conventional duct);
  without or with gap
- rim thruster: no attempt to resolve motor air gap flow
  leakage flux and friction losses are treated in consecutive post processing apps

Pumps, Tunnel Thrusters

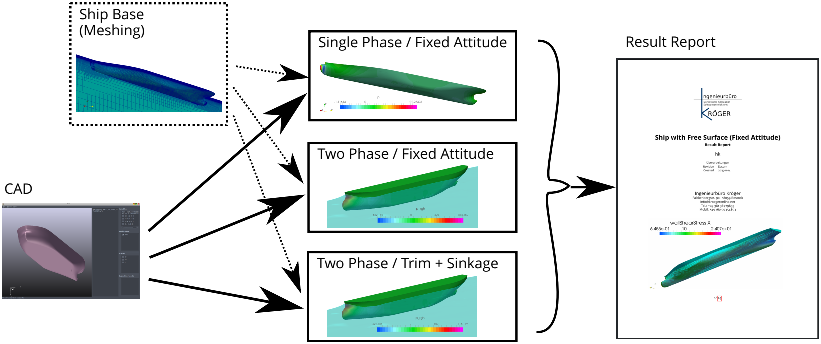
- "propeller in tube"-CFD provides characteristic curves
- thrust prediction and/or head curves are computed in consecutive post processing apps

⇒ characteristic curve analyses yield regression coefficients



Further Tools in Ship Add-On:

- automated resistance simulation
- for displacement vessels up to hydrofoil crafts



Propeller **actuator disc** model

- Features:
  - radial thrust distribution

$$\frac{f_x(\hat{r})}{F} = \hat{r}^m \left(\frac{a-\hat{r}}{a}\right)^n ,$$

$$\hat{r} = (r - r_H)/(R - r_H)$$

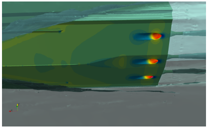
  - tangential component (jet swirl)

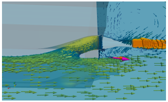
$$f_\theta / f_x = P/(2\pi r)$$

- coupled to motion solver

water jet model

- replacement of waterjet pump by coupling BC between two patches
- thrust synchronized with resistance, coupled to motion solver





Further turbomachinery activity

- compressible radial turbines
- high pressure ratio $p_{in}/p_{out} \approx 50$, $Ma \gg 1$
- real gas effects

Solution involves:

- foam-extend-3.2, mixing plane interface required
- sonicMRFFoam solver
- careful initialization
- custom tools to solve issues with mapping...

WiP

- parallel runs with mixing plane: very poor scalability and bad reliability (serial ok)
- integration of CoolProp library with sufficient performance

InsightCAE: current developments

- release cycle defined
  - new release once a year (May, 1st)
  - two packages from `master` and `next-release` branch
- extend Case Builder[1] features
  - support CHT setup
- extend remote execution capabilities
  - integration into workbench GUI
  - command line tool "analyze" ⇒ web server mode (incl. REST API)
- extend the documentation
  formerly in Github wiki
  `https://github.com/hkroeger/insightcae/wiki`,
  now moved into separate LaTeX document, stored at
  `https://github.com/hkroeger/insightcae-documentation`

[1] freely available OpenFOAM GUI

Open for questions

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Tel.: +49 381 36 77 98 53

https://github.com/hkroeger/insightcae
https://silentdynamics.de/en/insightcae-documentation/

```
$ sudo add-apt-repository http://downloads.silentdynamics.de/ubuntu
$ sudo apt-key adv --recv-key --keyserver keys.gnupg.net 79F5CBA4
$ sudo apt-get update
$ sudo apt-get install insightcae-base
```