Axial Fan Optimization Workflow

Turbomachinery design optimization using TCFD® and CAESES®

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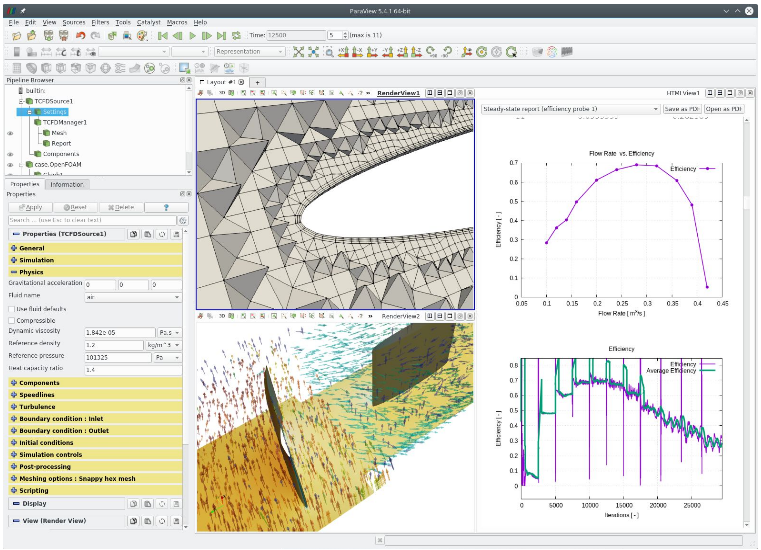
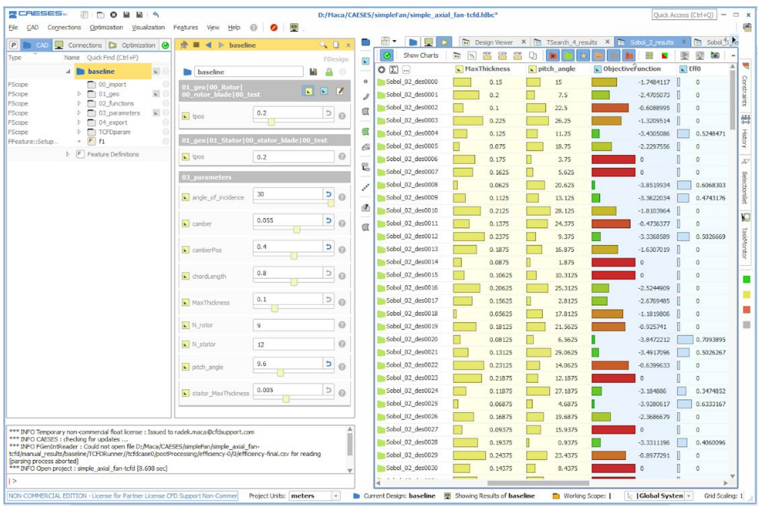
TCFD®

CFD Support introduces the new generation of CFD simulations. **TCFD®** brings extreme increase of productivity to CFD simulations. **TCFD®** is unlimited in terms of users, jobs, or cores. **TCFD®** is fully automated and its beauty is that it is the user who decides how deep to dive into CFD or not at all. And all the options remain open at the same time. **TCFD®** scales CFD simulations to available hardware power.



CAESES®



CAESES® is a software product that combines unique CAD capabilities for simulation engineers with tool automation and optimization.

The focus of **CAESES®** is simulation-ready geometries and the robust variation of these geometry models for faster and more comprehensive design studies and shape optimizations.

Smart and Efficient Workflow

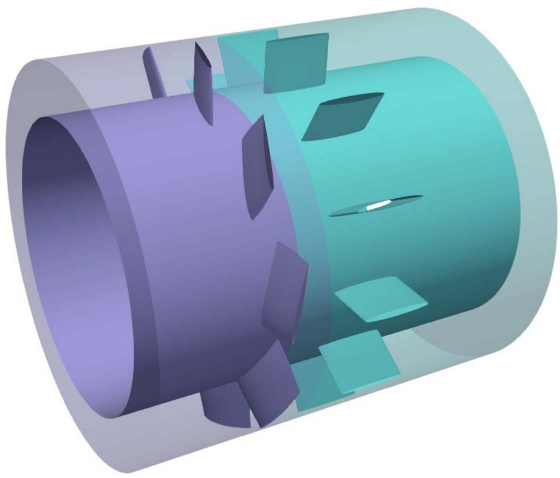
A modern CAE workflow consists of complex and automated processes connecting particular tasks together. Each part of the workflow has to be mastered without any mistake to get remarkable results. Therefore, the future of CAE lies in connecting the best software packages made by professionals into one complex workflow.

We are proud to introduce a smart and efficient turbomachinery design optimization workflow connecting two software packages **TCFD**® and **CAESES**®.

Study Example - Axial Fan

A typical goal of fan manufacturers is to develop a new very efficient fan or to improve parameters of an existing one, which is typically well known and tested. As an example of the workflow we have chosen an existing axial fan geometry with the following parameters:

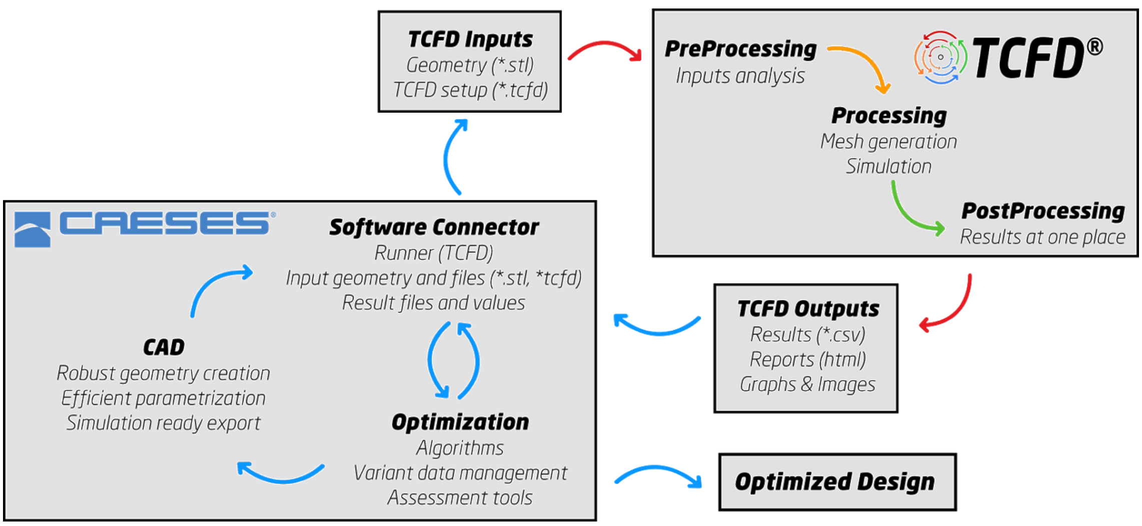
Diameter	280 mm
RPM	3000
Max power	100 W
Max pressure	410 Pa
Max air capacity	1100 m^3/h
Peak efficiency	69%



There are two goals of this study. The first one **maximizing the fan efficiency** in the range of flow rates from **576 m^3/h** to **1296 m^3/h**. The second goal is **increasing the air flow capacity**.

Workflow Outline

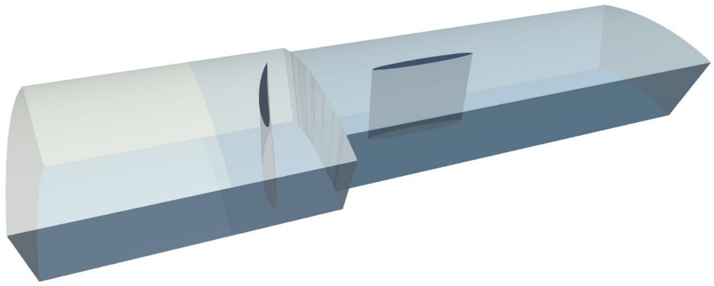
First of all, the fan geometry has to be created. **CAESES**® provides a CAD environment including robust and easy geometry variation, efficient parametrization and simulation-ready export. Afterward, a CFD simulation setup template for exported geometry is created in **TCFD**® and returned back into **CAESES**® software connector. Finally, an optimization process in **CAESES**® is preset and each geometry variation is automatically processed and simulated with **TCFD**®.



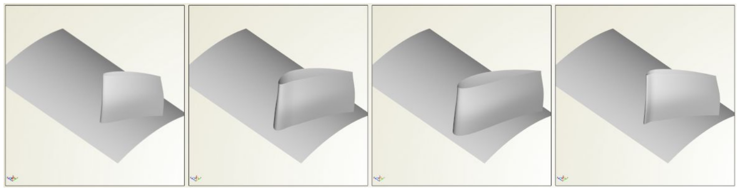
Axial Fan Parametrization - **CAESES®**

The axial fan flow domain was created to fit CFD requirements. The whole geometry was split into rotor and stator domain. For saving computational resources and simulation speed-up the flow domain contains one periodical blade segment only. The geometry parameterization is briefly summarized below:

- Number of stator blades: **12**
- Stator blade geometry: **fixed**
- Number of rotor blades: **9**
- Rotor blade geometry:



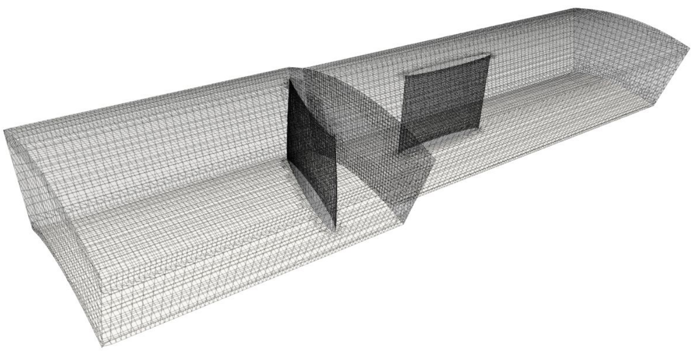
		Range	
Parameter	Orig	Min	Max
Angle of Incidence	14	10	30
Camber	0.03	0	0.1
Camber Position	0.4	0.1	0.7
Chord Length	0.8	0.6	1.0
Maximum Thickness	0.09	0.05	0.25
Pitch Angle	2	0	30

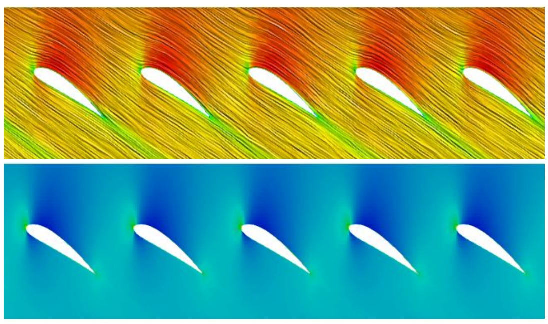


CFD Setup - **TCFD®**

For a successful simulation, the input geometry and proper CFD setup have to be provided. In a smart GUI of **TCFD®** a templated configuration file (*.tcfd) can be set and saved. The setup contains both definitions of a computational mesh created from multibody STL exported from **CAESES®** (stator.stl, rotor.stl), CFD parameters and a results customization:

- Solver settings:
  - Steady-state
  - Incompressible
  - Turbulent (kOmegaSST)
  - Rotation with MRF
  - 600 iterations per point
- Simulation settings:
  - 3000 RPM
  - 6 points
  - Inlet volumetric flow rate:
    - 1296 - 576 m^3/h
  - Outlet static pressure
  - Mixing plane (Stage) approach
- Computational mesh:
  - Rotor: ~ 45 000 cells
  - Stator: ~ 50 000 cells
  - Y+: ~ 30
  - BG cell size: 3 mm
- Post-processing:
  - Efficiency probes
  - Variables dimensions
  - Blade-to-blade views
  - Meridional averages





Optimization - **CAESES**®

CAESES® contains state-of-the-art optimization algorithms ranging from single-objective strategies for fast studies to more complex multi-objective techniques.

An optimization process is a complex set of tasks which has to be taken into account for a good optimization process. First of all, one should answer these questions before designing an optimization process:

- How many CPU resources I have?
- How much time does one simulation take?
- What time do I have to finish my optimization project?
- How many simulations can I make during the project time?
- How many design variables can I play with for the given number of simulations?
- Which optimization method gives me relevant results concerning all the question above?

Let's answer these question for this case study. We have one Intel® Xeon® E5645 CPU with 12 cores. One **TCFD**® simulation takes about 15 minutes. We have 3 days to finish the optimization, i.e., we can simulate roughly up to 300 designs. We have 6 design variables. First, we will perform a global sensitivity analysis (Sobol). A reasonable number of points for sufficient coverage of a design space is 2^{N+1}, where N is a number of design variables. The rest of available simulations we want to spend for a local analysis (TSearch) in the neighborhood of the best design obtained from the global analysis. Taking these assumptions into account, we can spend 250 simulations for the Sobol and 50 simulations for the TSearch.

Finally, an objective function has to be defined. Following our task, i.e., optimize fan efficiency in a range of given flow rates, the objective function is defined as a sum of efficiencies for all 6 simulated points imported from **TCFD**®. The efficiency of those simulated points which are out of a working range (e.g., those points which have negative pressure drop) are set to zero.

Before the optimization process is run, we simulated the original design:

	angle_of_incidence	camber	camberPos	chordLength	MaxThickness	pitch_angle	ObjectiveFunction
OrigGeometry	14	0.03	0.4	0.8	0.09	2	-2.4524156

After 250 simulations we get the best design listed in Table below.

	angle_of_incidence	camber	camberPos	chordLength	MaxThickness	pitch_angle	ObjectiveFunction
Sobol_02_des012	15.234375	0.008203125	0.12109375	0.8765625	0.19296875	5.0390625	-1.8769609
Sobol_02_des013	5.234375	0.058203125	0.42109375	0.6765625	0.09296875	20.039062	-0.9818503
Sobol_02_des0131	7.734375	0.020703125	0.34609375	0.9265625	0.16796875	16.289062	-0.4599403
Sobol_02_des01	17.734375	0.070703125	0.64609375	0.7265625	0.06796875	1.2890625	-3.9384293
Sobol_02_des013	12.734375	0.045703125	0.49609375	0.8265625	0.11796875	23.789062	-3.0227703

Then, the TSearch local optimization method starting from the best Sobol design was run resulting in finding a design with improved objective function:

	angle_of_inciden	camber	camberPos	chordLengt	MaxThickness	pitch_angl	ObjectiveFunction
TSearch_04_des002	17.734375	0.05	0.61859375	0.7365625	0.06178125	2.5953125	-3.9887901
TSearch_04_des002	17.734375	0.05	0.61859375	0.7365625	0.06178125	1.8828125	-3.9946402
TSearch_04_des0	17.734375	0.05	0.60828125	0.7365625	0.06	1.3929688	-4.0007976
TSearch_04_des002	17.734375	0.05	0.59410156	0.7365625	0.06	1	-3.9918146
TSearch_04_des002	17.773047	0.05	0.60828125	0.7365625	0.06	1.3929688	-3.999858

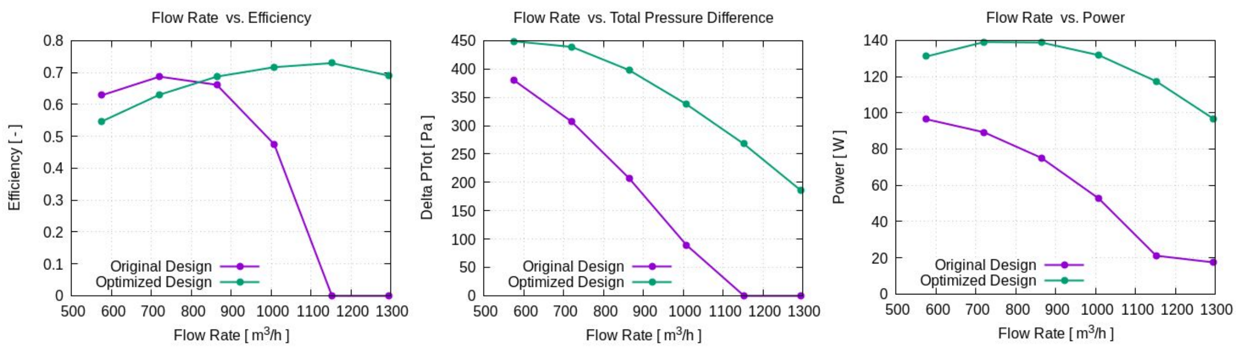
It is clearly seen that the optimization process improved the objective function value about 1.5 which can be read as improving fan efficiency about 25% for each simulated point.

Optimized Design Analysis - **TCFD®**

Based on the results in previous Section, improving efficiency for each simulated point by 25% seems to be unbelievable. Let’s do a short analysis of the original and the optimized fan geometry to make it clear.

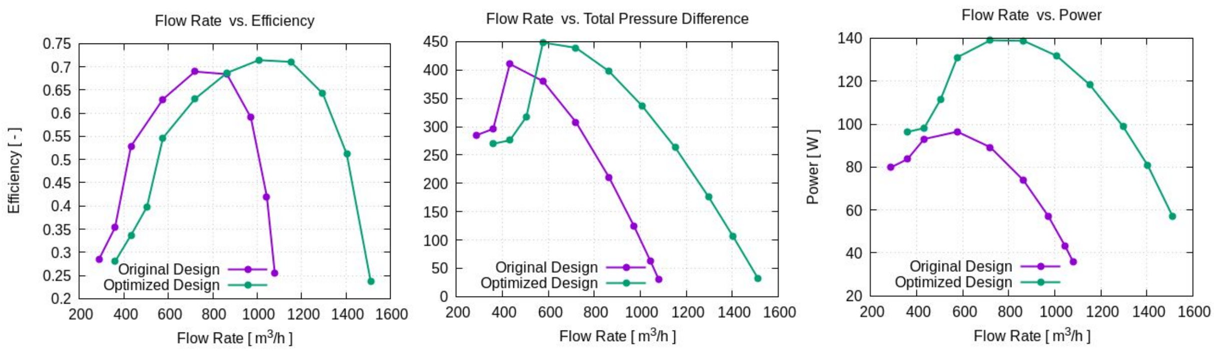
We do not need any additional work in sense of generating results, making visualization, etc. **TCFD®** makes these steps automatically. Each individual CFD simulation run has its own results report in web responsive (.html) format, or PDF format. Additionally, each simulation has its own csv files with all important variables (efficiency, flow rates, torque, power, pressure drops, etc.). Therefore, a connection with **CAESES®** is so smart and straightforward.

We will focus on the main axial fan parameters: efficiency, total pressure, and power.



From the efficiency graph above, we can clearly see that the original design cannot operate in the new range of flow rates. This is the reason why there is a big difference in the objective function values. Additionally, the optimized design generates a higher pressure drop. In another words, the optimized design induces higher flow rate at the similar condition compared to the original design. The higher flow rate performance results in a higher power supply.

To fully examine and compare the fan designs, we should simulate the whole operating range. It can be done by few clicks. In GUI we can load the setup file for the particular design, update the inlet condition to cover the whole operating range and run the simulation which brings us to the new set of results:

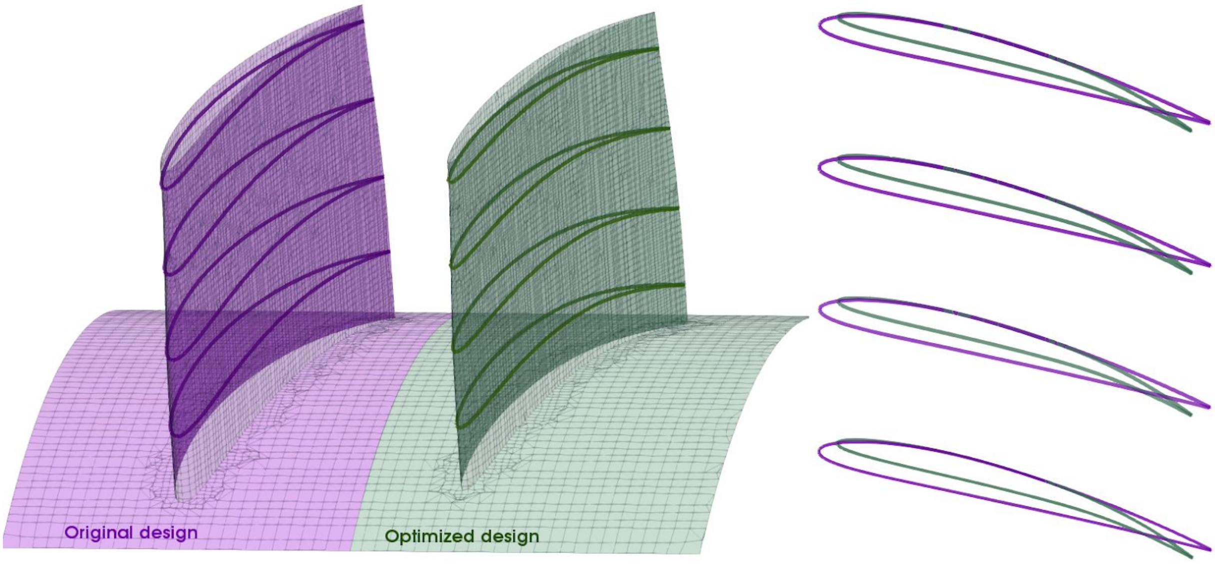


The complete maps tell us that the optimized design has a maximum air capacity over 1500m^3/h, a peak efficiency is increased to 72%, a maximum pressure drop rises to 450 Pa and a working range is wider. The price of these significant improvements is 40W in a power supply.

	Max power [W]	Max ΔPTot [Pa]	Max air cap. [m3/h]	Peak Eff. [%]
Original Design	100	410	1150	69
Optimized Design	140	450	1550	72
Improvement	40	40	400	3

Conclusion

In a short period of time, the axial fan geometry was optimized by increasing its efficiency and the air flow capacity. Alltogether, 300 simulations were performed to obtain the optimized design. The total CPU time spent is about 900 core-hours. By making such an extensive study, we obtained the optimized fan with all the important new design parameters.



This study clearly shows a synergy between **TCFD®** and **CAESES®**. This combination brings the engineers a smooth and modern CAE tool to make their engineering more efficient. **CAESES®** gives you an unlimited access to the geometry modeling and optimization. **TCFD®** brings an unlimited CFD power of no additional costs in terms of number of users, jobs or cores. The available hardware resources can be used at 100%, without any restrictions. This process is automated and can be tailored for any other turbomachinery case. Therefore, it is suitable not only for highly-skilled engineers but for all the engineers from diverse industries.

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