TCAE

TCAA - BANCIIIc3 - NACA 0012- Benchmark

Computational Aero-Acoustics Methodology for Airfoils

Project Summary

January 31, 2024

CFDsupport

KEYWORDS:

Computational Aero-Acoustics, CAA, BANCIIIc3, Benchmark, NACA 0012, Airfoil, 3D, 10% span, Acoustic Analogy, Ffowcs Williams-Hawkings, Farassat1A, Finite Volume, transient 1s, CFD, Cell-centered, SnappyHexMesh, 8 inflation layers, TCAE environment, OpenFOAM, compressible, *k-ω-SST DES,* U=53 m/s, Re=70000, AOA 6 degrees, SPL, Polar plots, Sound reconstruction

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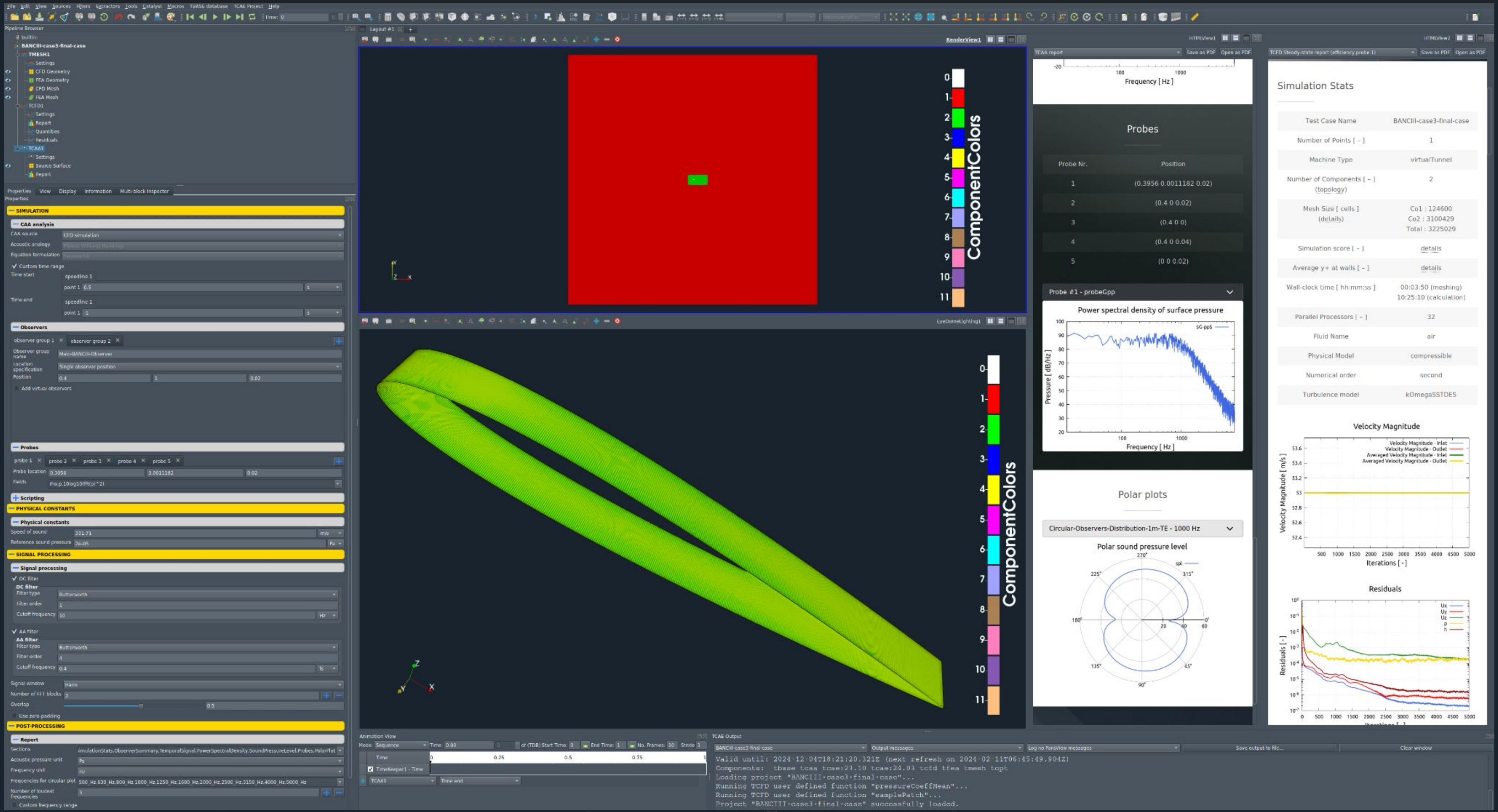
TCAE interface



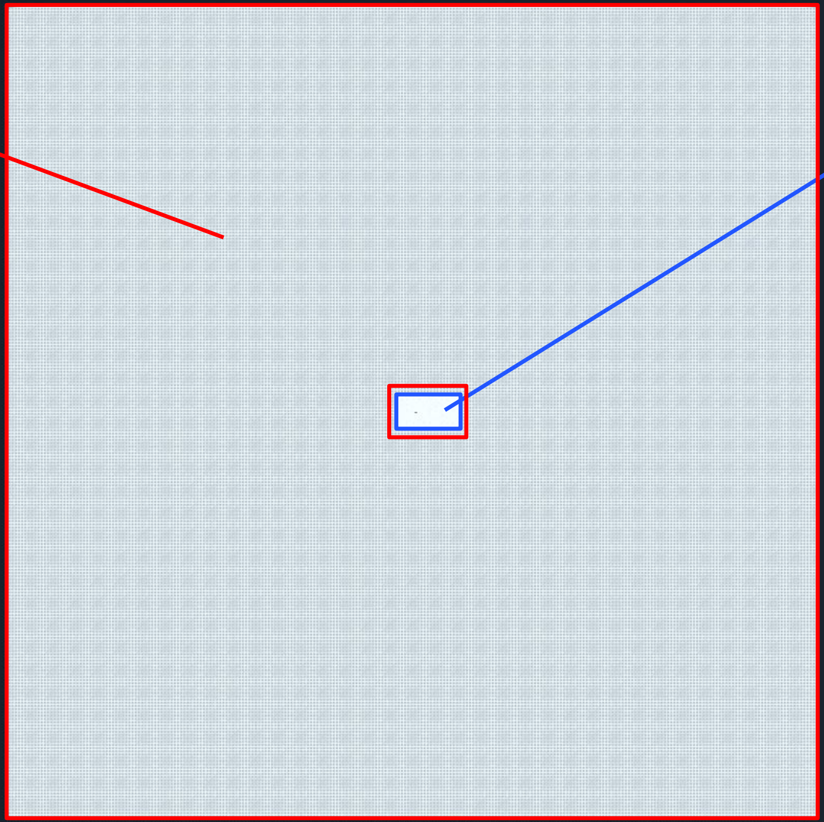
Mesh Topology

- blockMesh

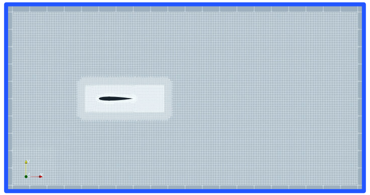
```
XOmax  25.0;
XOmin -25.0;

YOmax  25.0;
YOmin -25.0;

ZOmax  0.04;
ZOmin  0.00;

XImax  3.0;
XImin -1.0;

YImax  1.0;
YImin -1.0;

xSize 0.2;
ySize 0.2;
zSize 0.02;
```

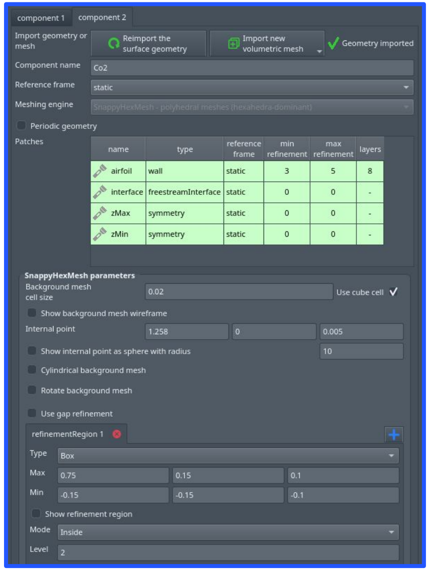
Span (z-thickness) = 0.04cm
(10% of chord length)

/mnt/users share/Projects/Vestas/TCAE-NACA0012-Chord0,4-3DSnappy-Span0,04-AirfoilRefLev55-15nCBL-lesDelta1e-4-Euler-zubr1234



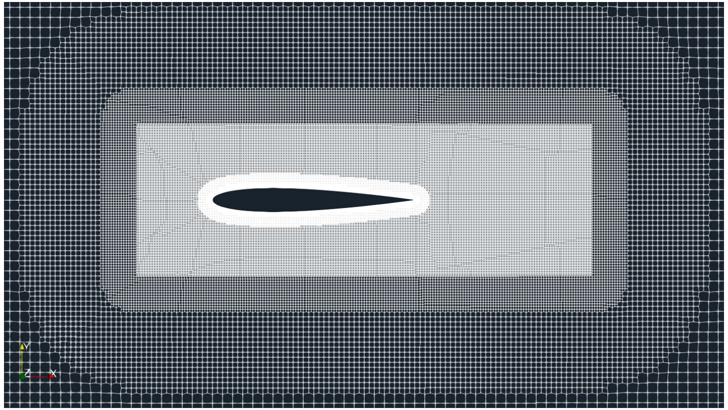
- snappyHexMesh

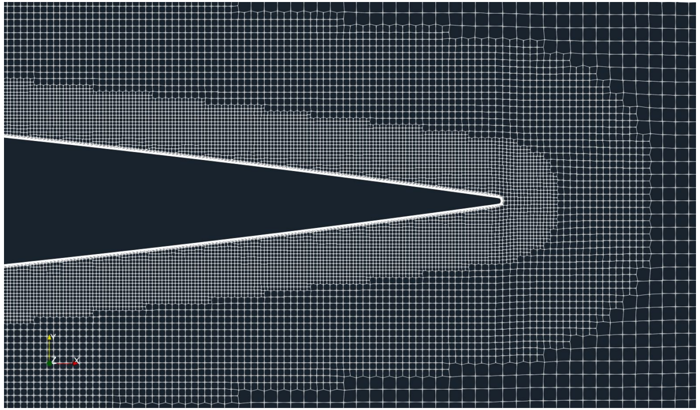


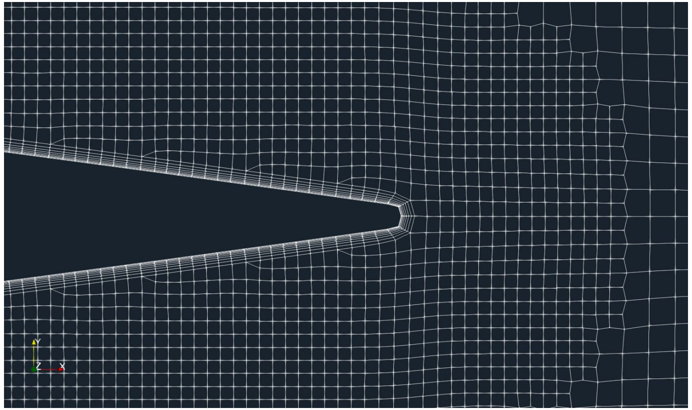


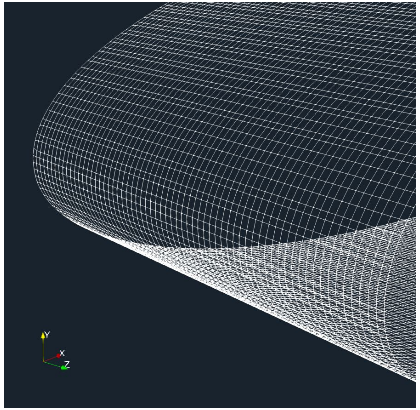
Mesh Statistics

- Hexahedra-dominant mesh
  - Cell size in the refined block: 2.5 mm
  - Cell size near the airfoil: 0.625mm
  - First inflation layer thickness: 0.032mm
  - Inflation layers: 15
  - 64 cells in spanwise direction (span = 40mm ~ 10% chord)
  - Overall cell count: 3 800 000 cells



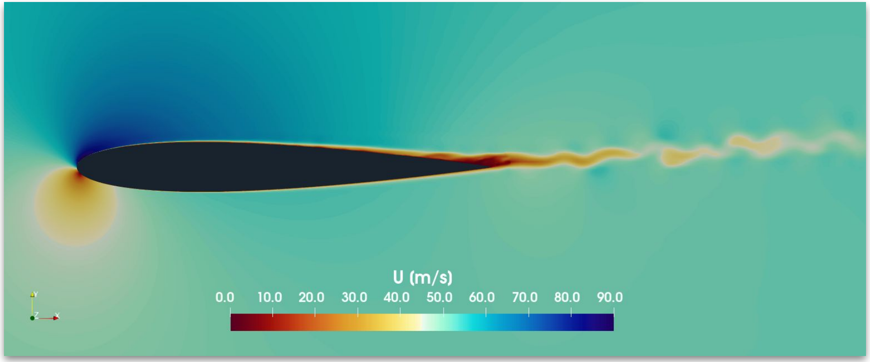


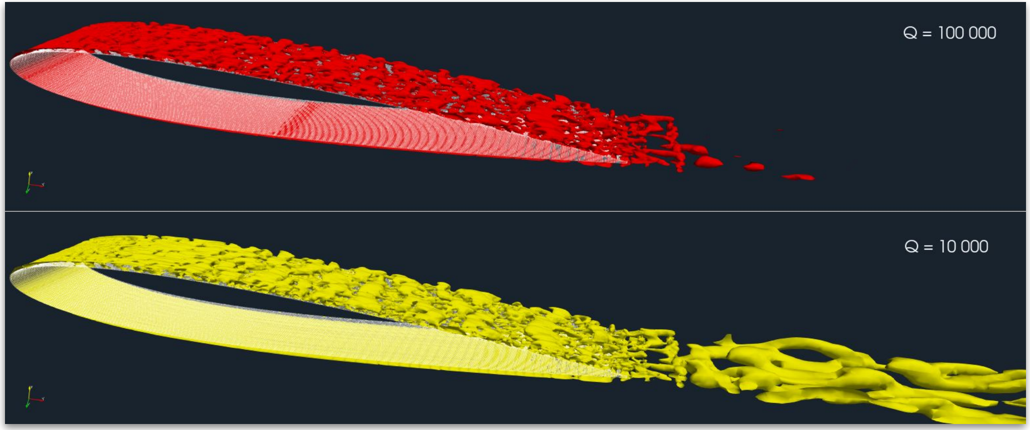




CFD Simulation Setup

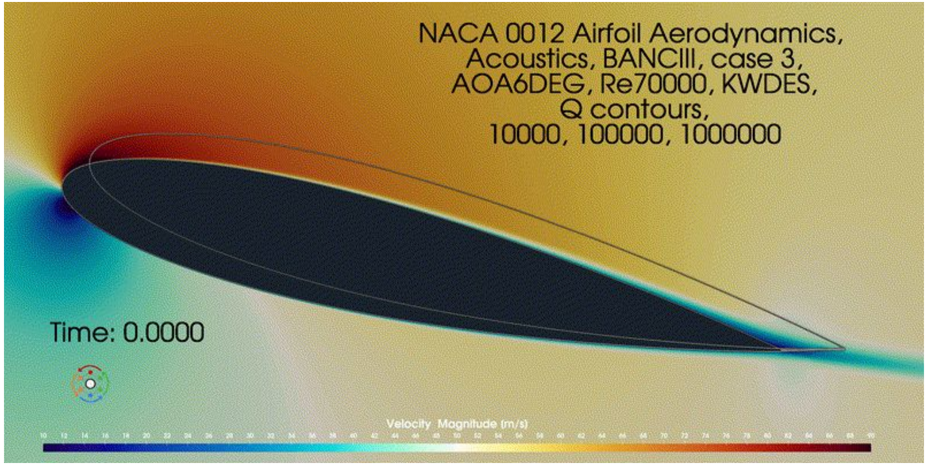
- *Transient, compressible* solver
  - Physical run-time: T=1s
  - Time step: 5e-5s
  - Acoustic data sampling: T=0.5-1s
  - Sampling the airfoil surface pressure
  - *steady-state (k-ω)* solution initialization





- *BANC III, case 3*
- U=53 m/s
- AOA 6 degrees
- Turbulence: *k-ω-SST DES*
- CPU time: ~ 600 core hours (one day with good PC)
- TCAA module (based on libAcoustics)

CFD Simulation Setup

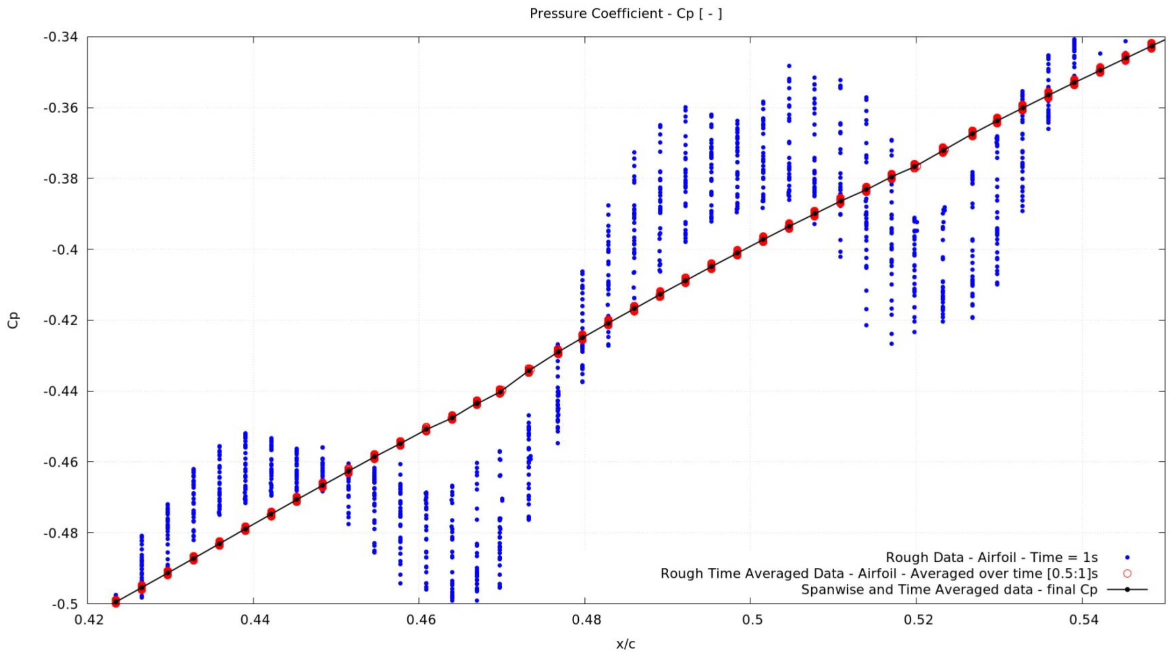


- https://www.cfdsupport.com/download/NACA0012-BANCIII-CASE3-Q-contours-zoom1-30.gif
- https://www.cfdsupport.com/download/NACA0012-BANCIII-CASE3-Q-contours-zoom2-20.gif
- https://youtu.be/6mKSCT1-wK4

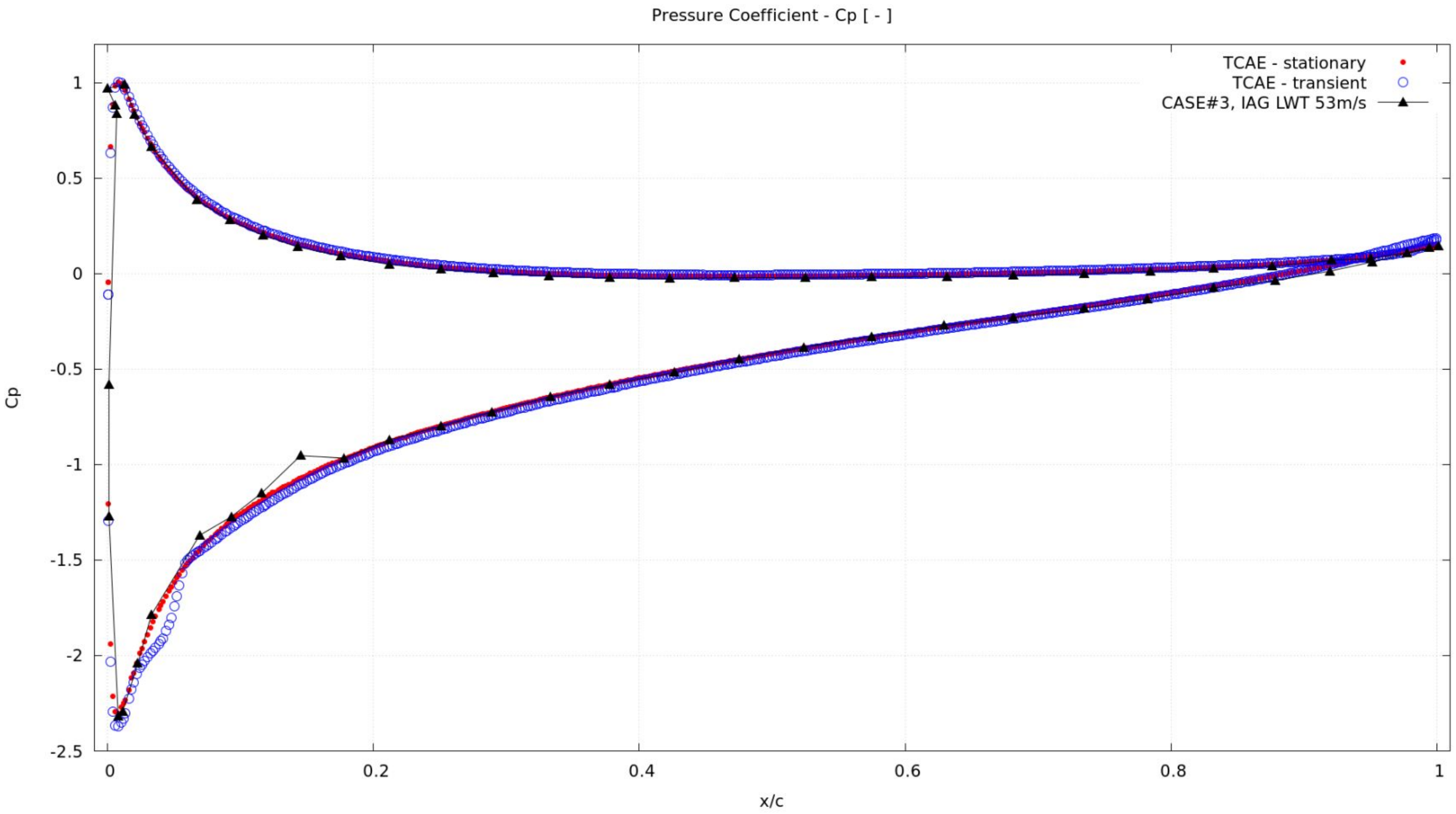
CFD Evaluation

Cp Evaluation

- *Cp* coefficient is evaluated from *transient* results as a *time* and *spanwise average*
  - Automated processing implemented

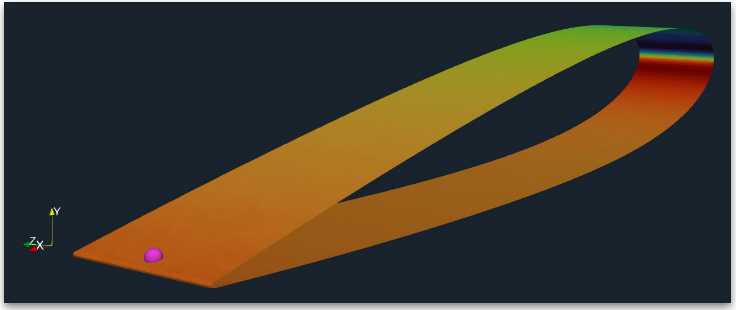


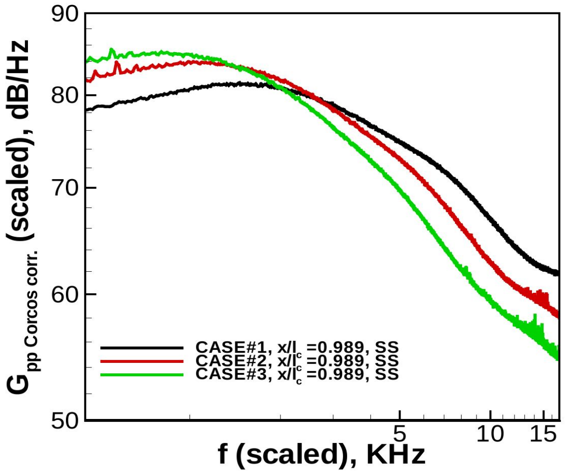
Cp Evaluation

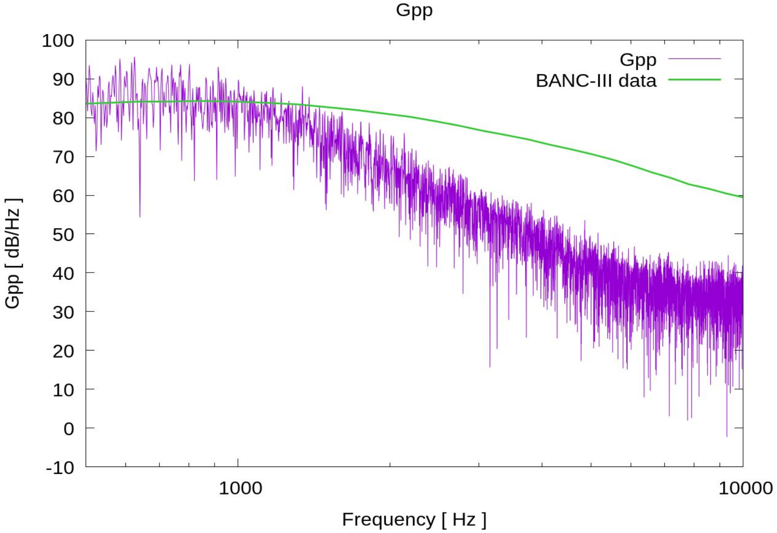


Pressure Evaluation

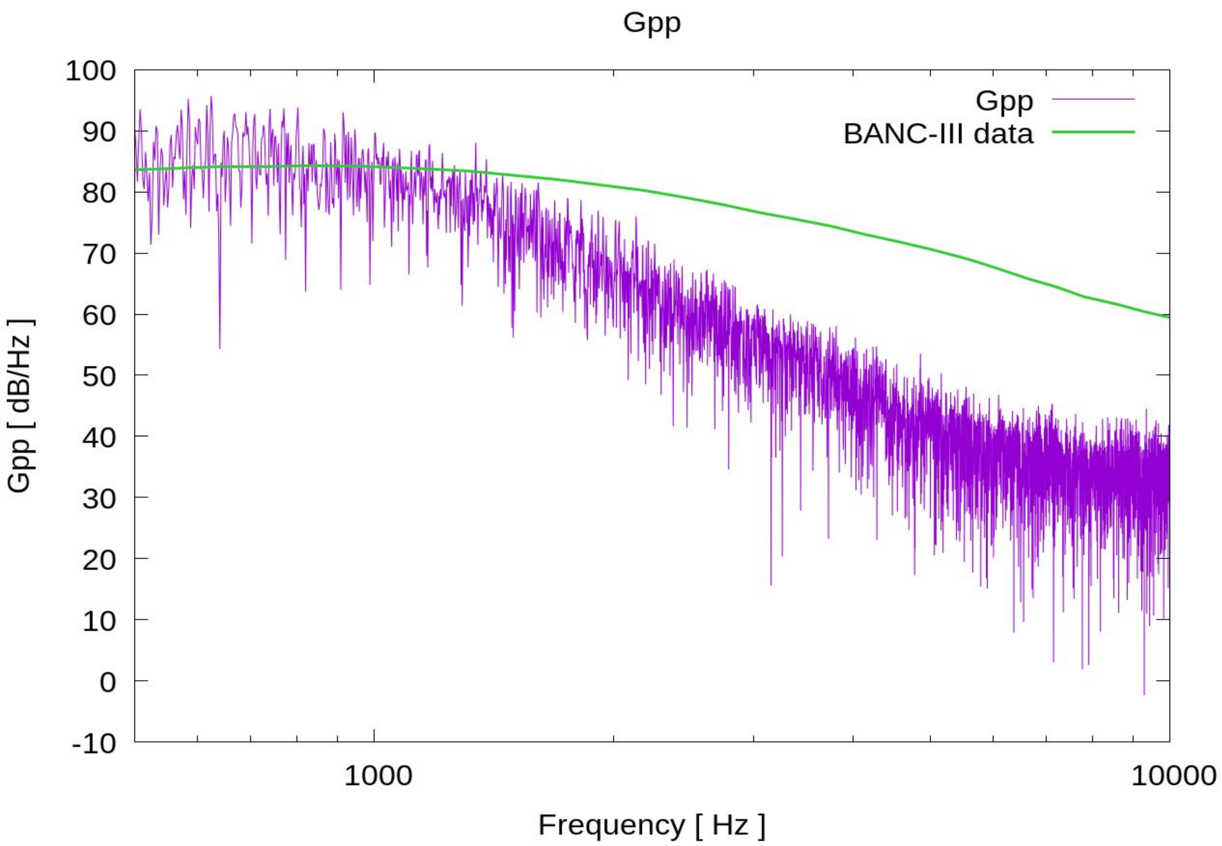
- Power spectral density: BANC-III Report, fig. 10
  - Suction side point [*0.3956, 0.0011182, 0.02*]
  - Single point close to the trailing edge
  - Surface *pressure* evaluation





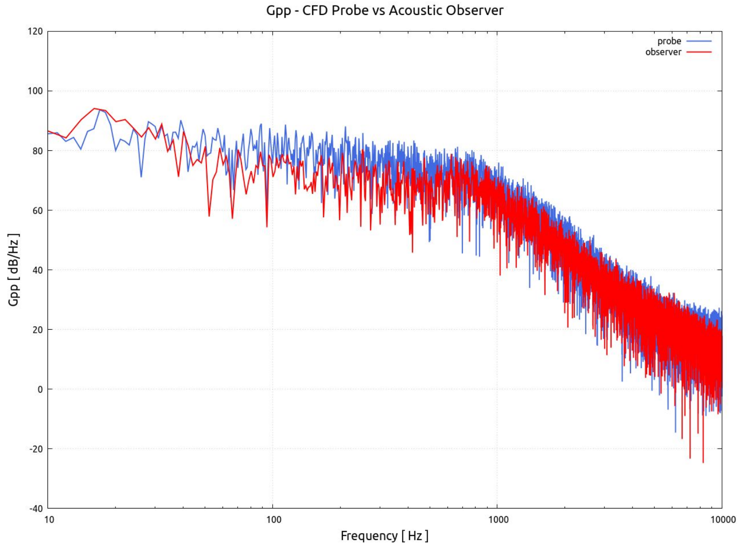


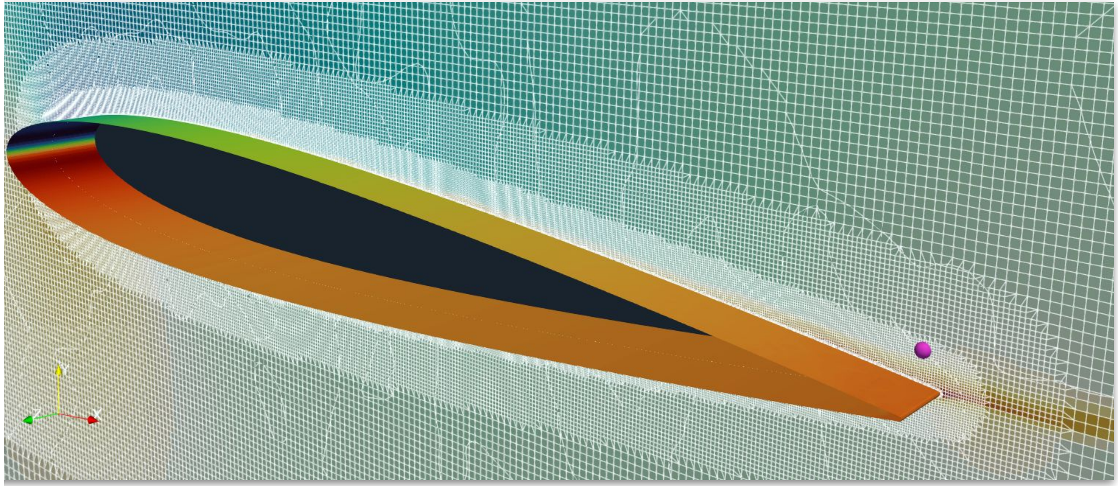
Pressure Evaluation



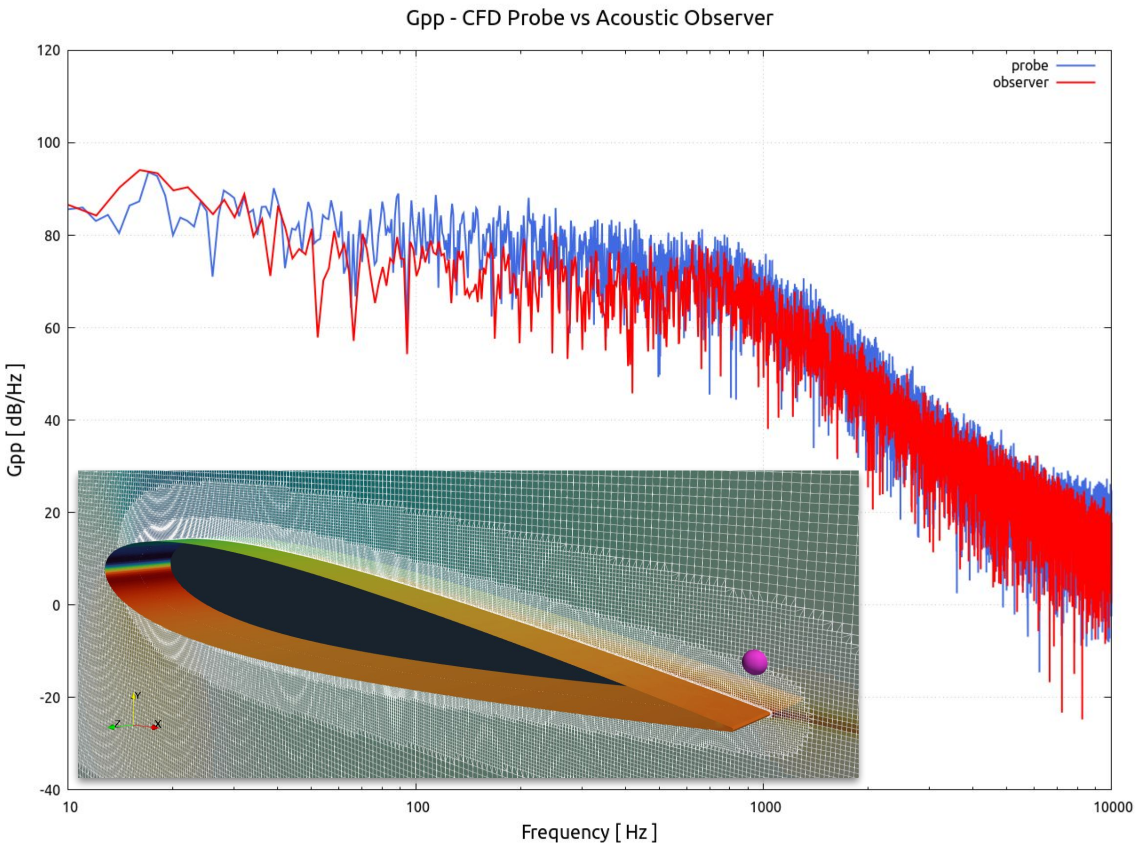
CFD Probe vs Acoustic Observer

- Comparison of power spectral density evaluated from
  - CFD results pressure fluctuations - **Probe**
  - Acoustics pressure fluctuation (Acoustic analogy - FWH) - **Observer**

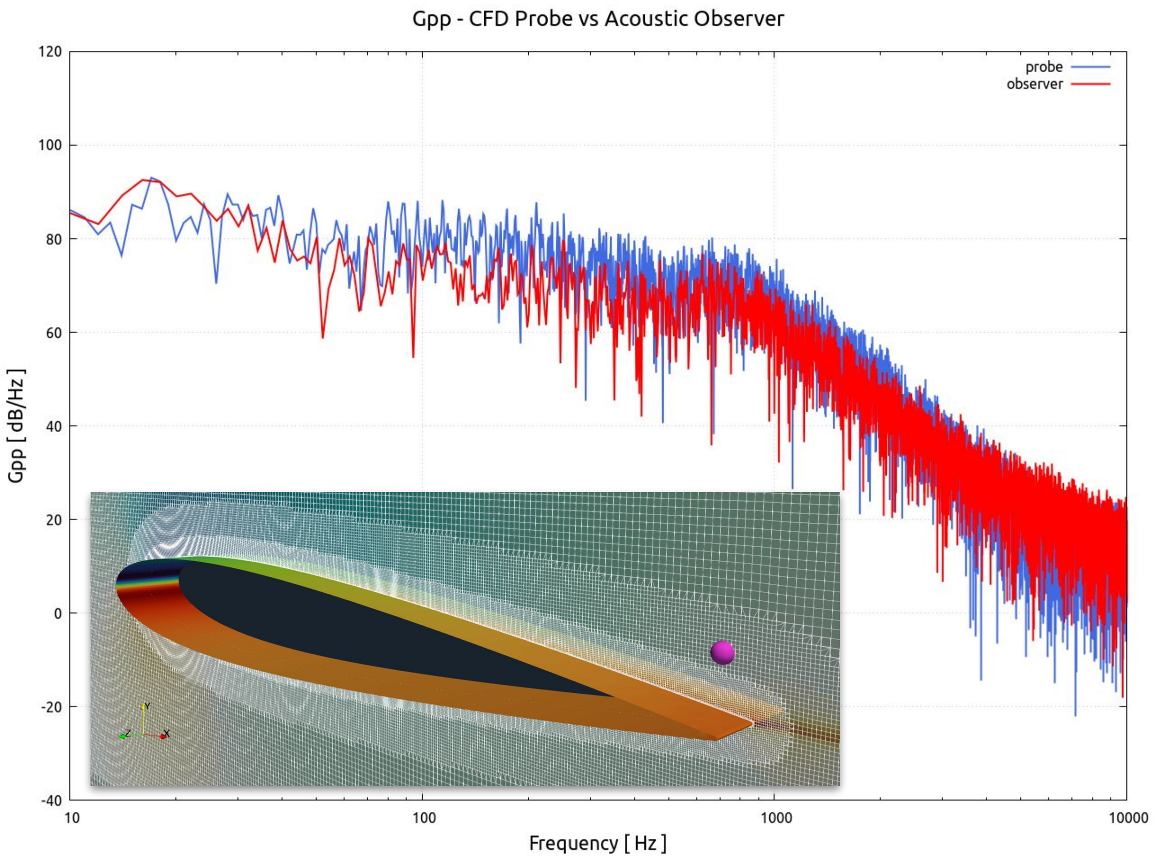




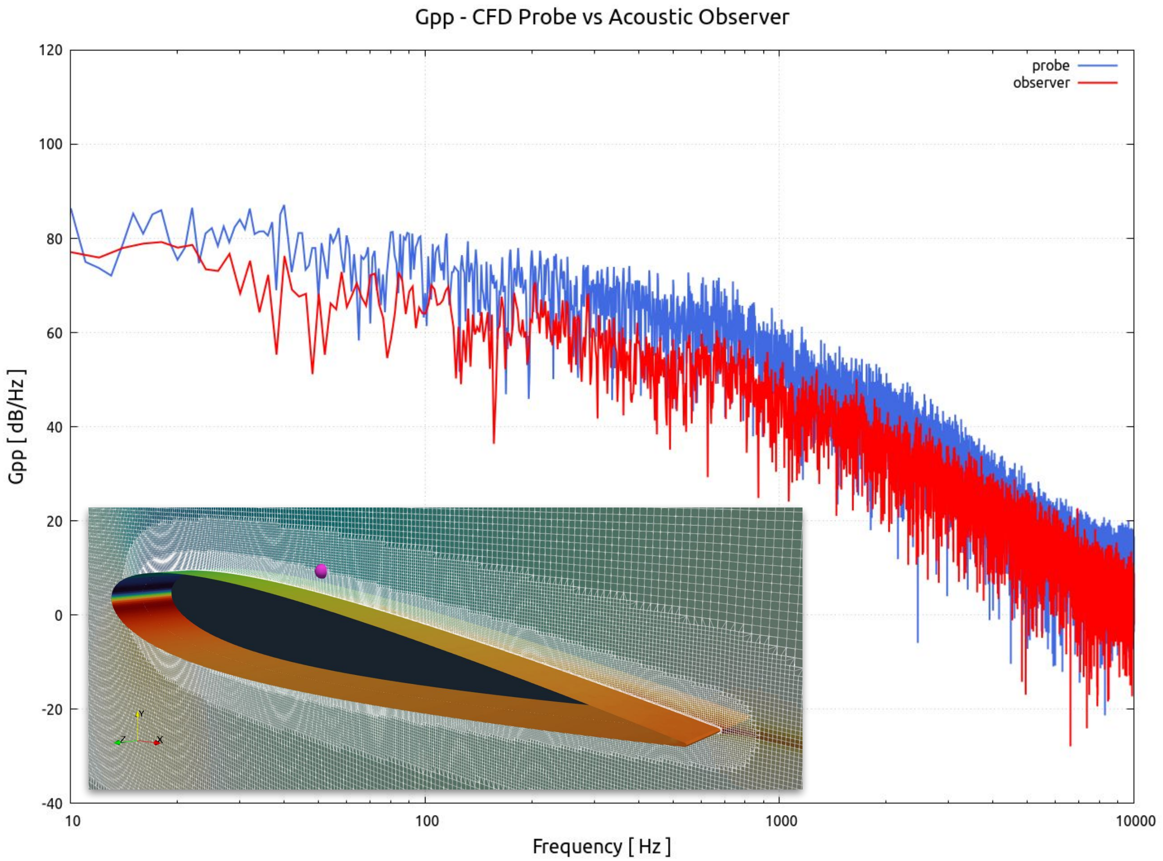
CFD Probe vs Acoustic Observer



CFD Probe vs Acoustic Observer



CFD Probe vs Acoustic Observer



Signal Processing

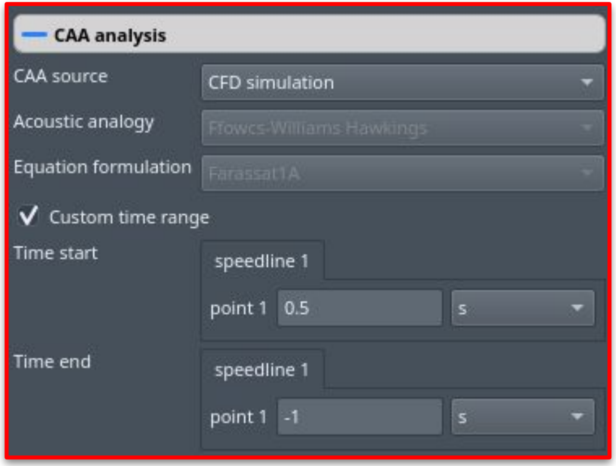
Signal Processing Setup

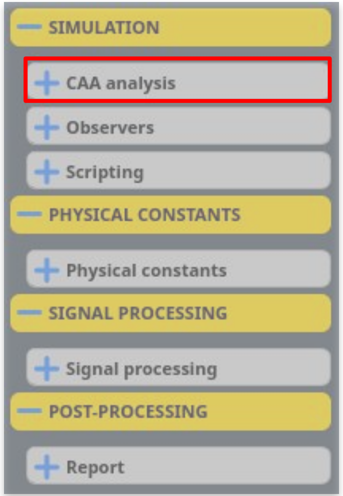
- TCAA module
- Raw signal is centered to origin and Butterworth filters are applied
- Welch method is used to transfer the signal to frequency spectrum
  - Signal is divided into three overlapping segments
  - On each segment Hann window is applied and Fourier transform is executed
  - Transformed segments are reassembled
- PSD and SPL are evaluated from the final signal in frequency domain

TCAA

- The whole workflow is implemented in TCAA module

- Current implementation uses *Farassat1A* equation formulation of *Ffowcs-Williams Hawkings* acoustic analogy

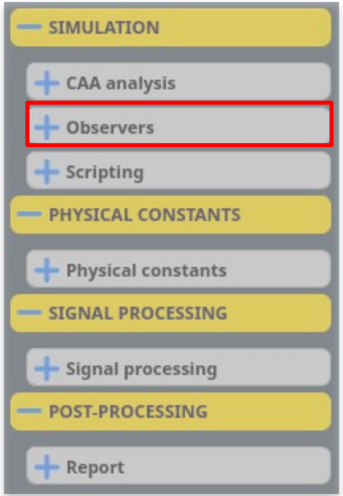


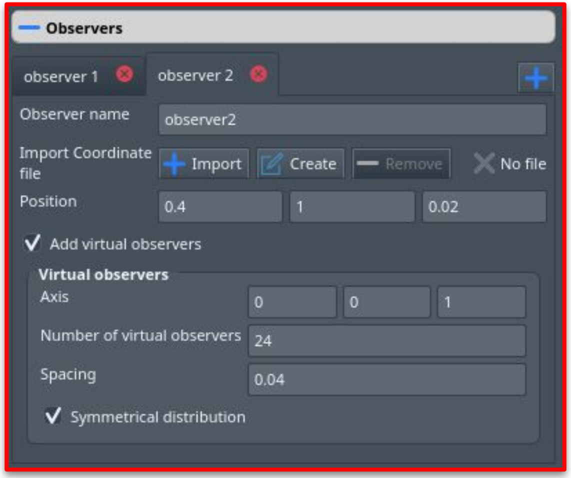


- The source data are taken directly from CFD simulation
- User can defined a custom time range for processing the source data

TCAA

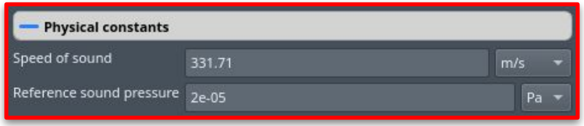
- Observer is a point in the far field where the acoustic pressure is evaluated by acoustic analogy
- Add virtual observers allows to scale the source (CFD) span to a general scale, typically 1m
- Observers location can be also imported from file to define more general distribution

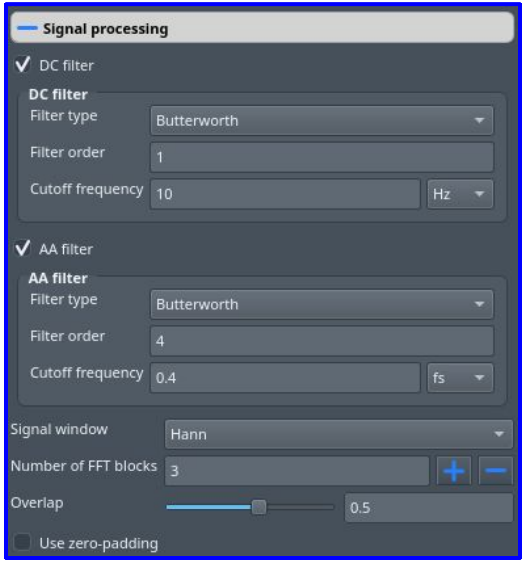


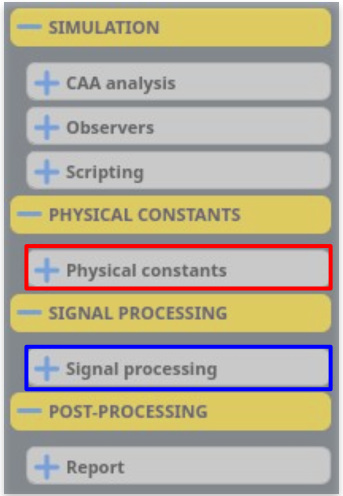


TCAA

- Physical constants define reference speed of sound and pressure level for 0 dB



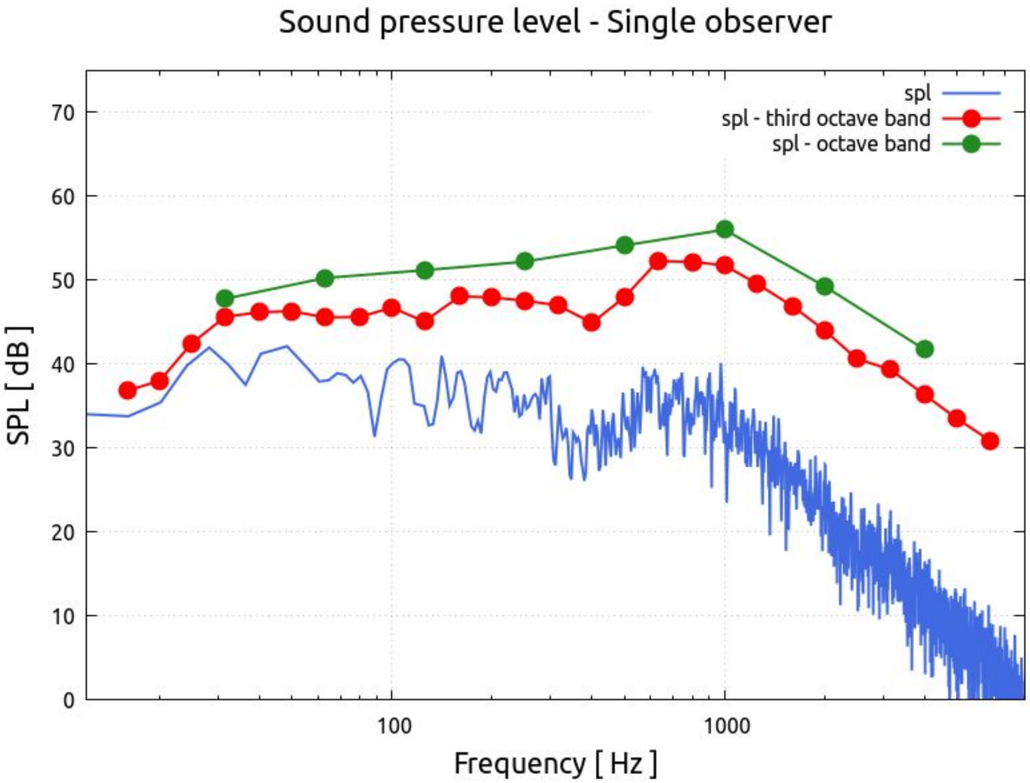




- Signal processing can be applied to clear the input data from unwanted noise, oscillation or data extremes

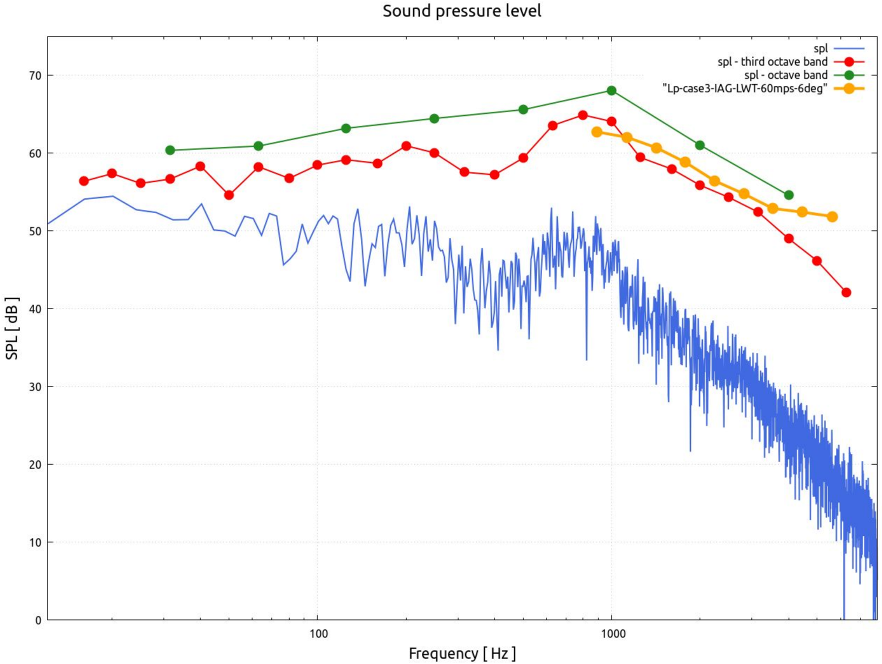
SPL Evaluation

Fundamental Results - SPL - span 0.04m - single observer

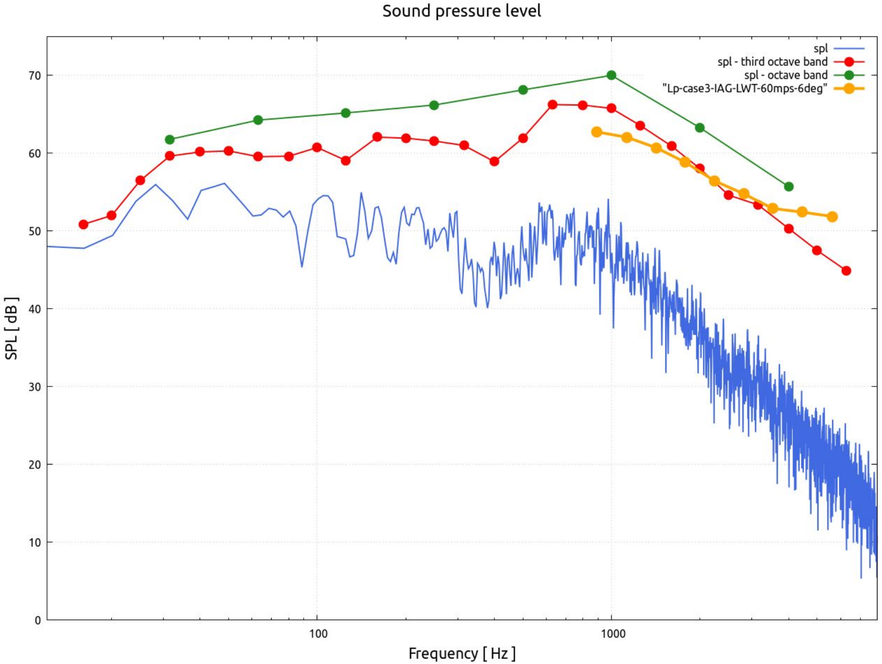


Mesh Convergence Test

Original Mesh, 8IL, 3.2 MCells

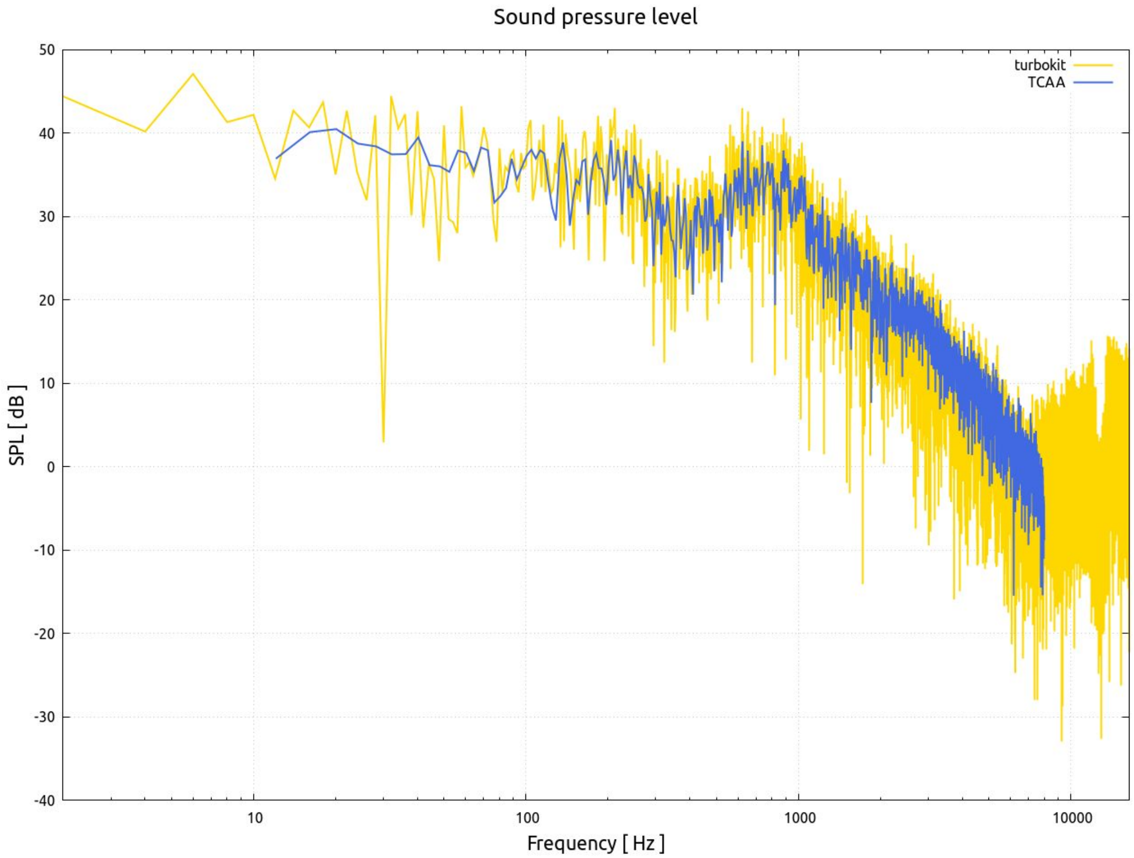


Original Mesh, 15IL, 3.8 MCells

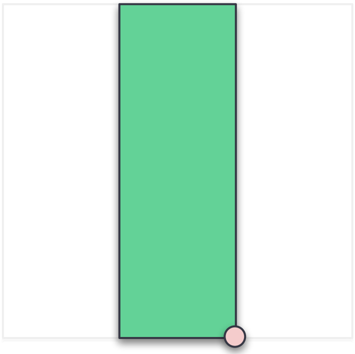


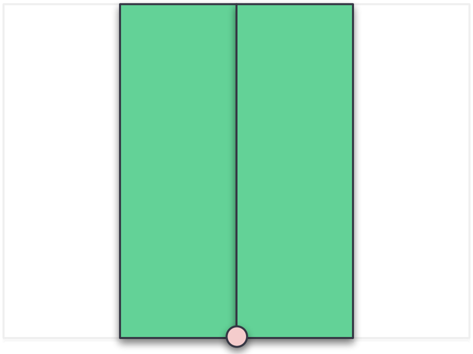
Signal Processing - TCAA vs. Turbokit

- Comparison to other CAA code - Turbokit
- To check possible implementation mistake
- Turbokit is a CAA (FWH-based) code developed by Prof. Sofiane KHELLADI, Ecole Nationale Supérieure d'Arts et Métiers, Paris



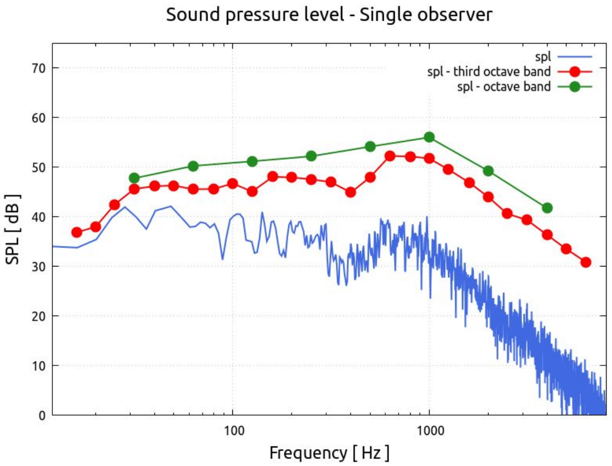
$10\log_{10}$ transformation

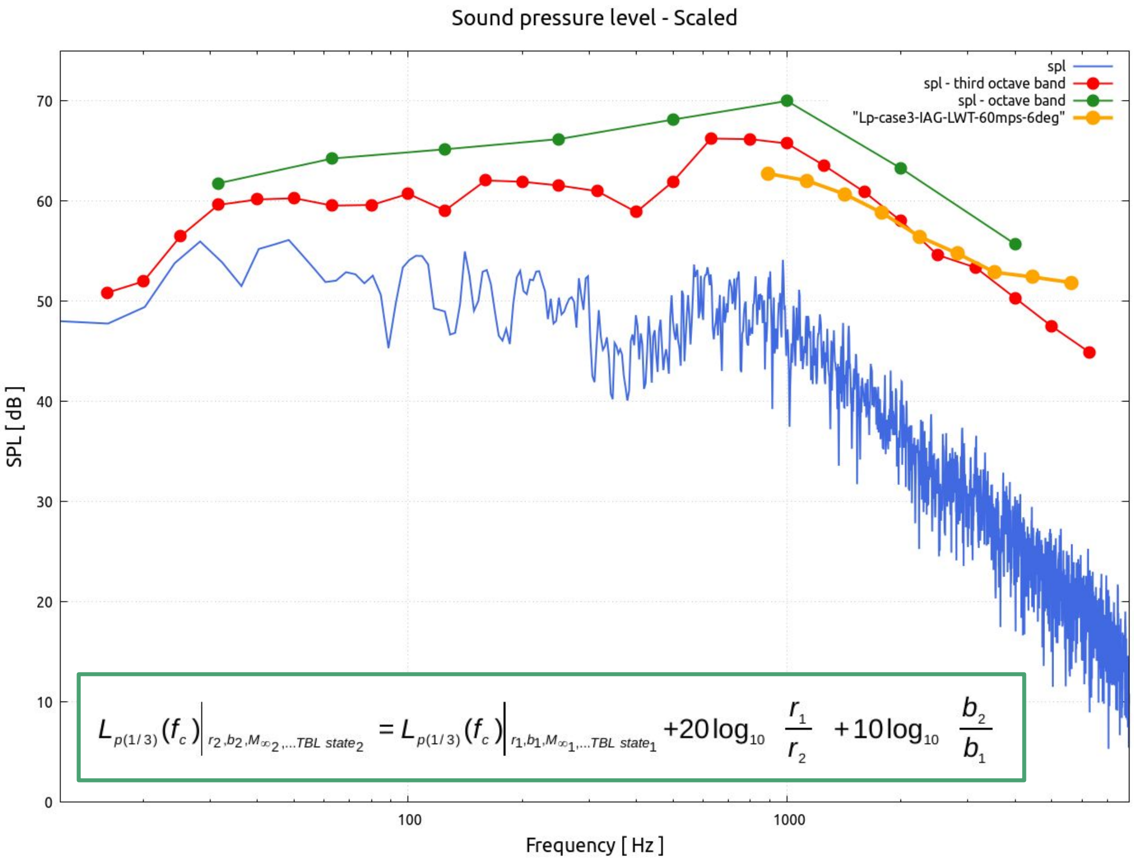




$$L_{p(1/3)}(f_c)\Big|_{r_2,b_2,M_{\infty 2},\dots TBL\ state_2} = L_{p(1/3)}(f_c)\Big|_{r_1,b_1,M_{\infty 1},\dots TBL\ state_1} + 20\log_{10}\frac{r_1}{r_2} + 10\log_{10}\frac{b_2}{b_1}$$

Scaling to 1m span by the orig. article - SPL - span 1.00m

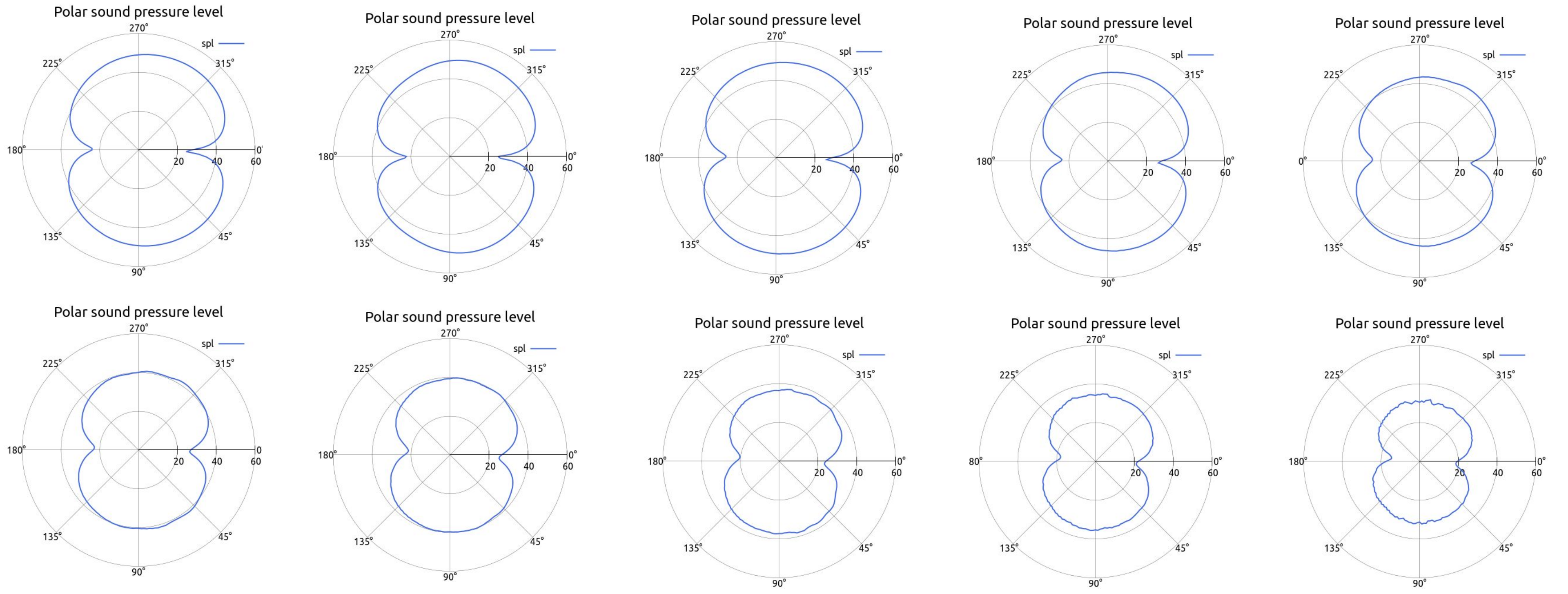




$$L_{p(1/3)}(f_c)\Big|_{r_2,b_2,M_{\infty 2},\ldots TBL\ state_2} = L_{p(1/3)}(f_c)\Big|_{r_1,b_1,M_{\infty 1},\ldots TBL\ state_1} + 20\log_{10}\frac{r_1}{r_2} + 10\log_{10}\frac{b_2}{b_1}$$

Polar Plots of SPL

500Hz, 800Hz, 1000Hz, 1250Hz, 1600Hz, 2000Hz, 2500Hz, 3150Hz, 4000Hz, 5000Hz



Conclusions

Conclusion

- The workflow is created and ready to use, The results pass the benchmark, Simulations are repeatable, All the data are available for further processing.
- The lesson has been taken, Project Work Hours: >400 [hours] (Research, Implementation, Setup & Simulation Runs, Evaluation).
- Total CPU time: >60 000 [core*hours].
- It has been shown how to make a comprehensive Computational Aeroacoustics analysis on an airfoil in a single automated workflow.
- The TCAE results were successfully compared to the measurement data and with other CFD simulation results.
- There was no special tuning used in the CFD simulation at all. There remains a lot of space for tuning CFD methodology, especially for mesh resolution, turbulence modeling, and numerical schemes.
- TCAE has shown to be a very effective tool for Computational Aero-Acoustics simulations.
- This benchmark was intentionally written so short not to overwhelm its reader with too many details. The original intention was to show the modern simulation workflow and its accuracy.
- The benchmark details are listed in the references below.
- All the technical details regarding CFD & FEA simulation are listed in the TCAE Manual.
- The benchmark geometry and data are freely available for download on the CFDSUPPORT website https://www.cfdsupport.com.
- More information about TCAE can be found on CFD SUPPORT website: https://www.cfdsupport.com/tcae.html
- Questions will be happily answered via email info@cfdsupport.com.

References

[1] Herr, Michaela & Ewert, Roland & Rautmann, Christof & Kamruzzaman, M. & Bekiropoulos, Dimitrios & Iob, Andrea & Arina, Renzo & Batten, Paul & Chakravarthy, Sukumar & Bertagnolio, Franck. (2015). Broadband Trailing-Edge Noise Predictions-Overview of BANC-III Results. 10.2514/6.2015-2847.

[2] TCAA simulation REPORT: https://www.cfdsupport.com/download/report/naca0012-acoustics/TCAAReport.html

[3] Case study: https://www.cfdsupport.com/naca-0012-acoustic-benchmark.html

[4] https://en.wikipedia.org/wiki/Sound_pressure

[5] http://www.sengpielaudio.com/calculator-leveladding.htm

[6] https://www.linkwitzlab.com/faq.htm#Q21

[7] http://physics.bu.edu/py231/db3.pdf

[8] TCAE Training

[9] TCAE Manual

[10] TCAE Webinars

The END.