

DEVELOPMENT OF THE FIRST-PRINCIPLES ADAPTIVE EULER METHODOLOGY TO FSI AND BUFFETING

Johan Jansson, Kristoffer Wingstedt, Susanne Claus, Anders Karlsson, Pär Gustafsson, Erik Sätterskog, Olivier Amoignon, and Christian Helanow*

*Corresponding author: jjan@kth.se
KTH Royal Institute of Technology, Sweden
100 44, Stockholm
Sweden

ABSTRACT

We describe the Adaptive Euler methodology [1, 2, 3], and the development of a generalization to fluid-structure interaction (FSI), together with supporting validation of flow separation and buffeting from the Aeroelastic, Drag and High Lift Prediction Workshops and industrial test cases. Our proposed FSI methodology includes both a general Immersed Unified Continuum variant, as well as a simpler partitioned variant iterating between fluid and structure.

Adaptive Euler is a first-principles, direct FEM simulation of the unsteady Euler equations with adjoint-based adaptive error control, realized with automated discretization from mathematical notation in our FEniCS [8] framework. We describe good validation and high efficiency of benchmarks in the High Lift Prediction Workshop[1] where the main challenge is predicting separation of a full aircraft, described by NASA Vision 2030 as one of the Grand Challenges in the field. We also present preliminary validation results for transonic buffeting on a full aircraft, with high efficiency, using benchmarks from the Aeroelastic and Drag Prediction Workshops, as well as wing-tail buffet industrial test cases.

We show that Adaptive Euler by the scientific method in our reproducible Digital Math framework predicts drag, lift, pitch moment and pressure distribution for a full aircraft in close correspondence with experiments in the 4th and 5th High Lift Prediction Workshops, with very high efficiency, estimated to be 100x faster and cheaper than RANS, the industry standard for efficient aerodynamics, corresponding to appx. 100 core hours on a commodity computational resource. We show similar preliminary results for transonic flow in the Aeroelastic and Drag Prediction Workshops.

To account for elastic structures, we develop an FSI generalization, Adaptive Euler FSI, enabling, for example, flutter prediction and improved buffeting prediction. We have previously developed a Unified Continuum FSI (UC) methodology [10] for lower Reynolds number settings such as biomechanics, with applications of vocal folds, human heart, etc. In UC the fluid and structure are formulated and solved as one continuum, with a marker function selecting the constitutive law. This gives generality and automatability of e.g. stability, error control, optimization and control, implementation, etc.

We describe two FSI variants:

1. **Top-down:** Adaptive Euler Immersed Unified Continuum FSI where we aim for full generality and automation. In addition to the generality offered by the above described UC methodology, we also have an “immersed” representation of the structure geometry, meaning the structure geometry is represented and treated as an unknown

just as velocity, pressure, etc. This provides full generality for arbitrary motions and supports automation of e.g. adjoint-based error control. In the immersed representation we may additionally use a CutFEM approach [9] to improve accuracy.

2. **Bottom-up:** Adaptive Euler Partitioned FSI where we aim to be able to re-use and “plug into” existing industrial and scientific workflows as easily as possible. Here we simply iterate between solving the fluid and structure separately, and deform the geometry/mesh. This allows to e.g. re-use an existing well-validated structure workflow, and easily couple to Adaptive Euler, but there may be limitations in generality due to mesh algorithms, and we cannot automatically take into account e.g. errors from the coupling.

We describe preliminary results from Adaptive Euler FSI, as well as perspectives to relevant industrial applications and the Aeroelastic, Drag and High Lift Prediction Workshops.

The guiding incentive for this work is to develop an efficient and versatile tool for aeroelasticity modeling with the Adaptive Euler methodology. Such a product is highly sought after and is motivated in part by the CFD Vision 2030 set by NASA and the Certification by Analysis 2040 Vision set by Boeing. The consequences of this would include—but are not limited to—the eventual development of a full fluid-structure interaction (FSI) framework that may be used for applications in aerospace engineering.

References

- [1] Jansson, J., Johnson, C., & Scott, R. (2022). Predictive Euler CFD-Resolution of NASA Vision 2030. In AIAA AVIATION 2022 Forum (p. 3589).
- [2] Johan Jansson (jjan@kth.se), Claes Johnson, L. Ridgway Scott, Rebecca Durst, Predictive Aerodynamics: Adaptive Euler Real Flight Simulation <http://digitalmath.tech/hiliftpw4-aiaa>
- [3] <http://digimat.tech/paper-euler-short/>
- [4] Certification by Analysis Vision 2040 <https://ntrs.nasa.gov/citations/20210015404>
- [5] Daumas, L., Chalot, F., Forestier, N., & Johan, Z. (2009). Industrial use of linearized CFD tools for aeroelastic problems. IFASD, 54, 21-25.
“The Galerkin/least-squares (GLS) formulation introduced by Hughes and Johnson, is a full space-time finite element technique ...”
- [6] Current (2024) Aeroelasticity Prediction Workshop: <https://aiaa-dpw.larc.nasa.gov/>
- [7] Hulshoff, S. J. (2013). Aeroelasticity. Lecture notes Aerodynamics Master Track, TU Delft.
- [8] Logg, A., Mardal, K. A., & Wells, G. (Eds.). (2012). Automated solution of differential equations by the finite element method: The FEniCS book (Vol. 84). Springer Science & Business Media.
- [9] Burman, E., Claus, S., Hansbo, P., Larson, M. G., & Massing, A. (2015). CutFEM: discretizing geometry and partial differential equations. International Journal for Numerical Methods in Engineering, 104(7), 472-501.
- [10] Hoffman, J., Jansson, J., & Stöckli, M. (2011). Unified continuum modeling of fluid-structure interaction. Mathematical Models and Methods in Applied Sciences, 21(03), 491-513.