

LINEARISED FREQUENCY DOMAIN SIMULATIONS OF FOLDING WINGTIPS WITH OVERSET MESHING

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ABSTRACT

Recent developments in wing design focus on increased wingspans enabled through folding wingtips. On the one hand, an increased wingspan offers superior aerodynamic efficiency through better lift-to-induced-drag ratios. On the other hand, higher aspect ratio wings require better gust load alleviation measures during flight, and current airport infrastructure (gate limits) govern the permissible maximum wingspan during ground operations. Folding wingtips are considered a solution for both challenges [Pattinson et al, 2015, Healy et al, 2022]. Simulating the steady and unsteady aerodynamic loads using computational fluid dynamics in the transonic regime will be necessary in future for such more fuel-efficient wing designs. A compounding complexity is that the computational mesh must be readily deformed to different significant fold angles. Directly generating a mesh for each fold angle would be prohibitive and mesh deformation techniques quickly reach their limits for larger deformations. In particular, the grid can become significantly distorted around the hinge line with traditional methods, with stretched cells below the hinge and compressed cells above. An example is shown in Figure 1, in which a 60-degree fold is enacted at the wingtip of an AGARD LANN wing [Zwaan, 1985] by performing a localised rotation of the volume at 90% span (to a grid described by, for example, [Edwards et al, 2025]). The shape of the wingtip is retained after the fold, but the mesh distortion around the hinge is evident.

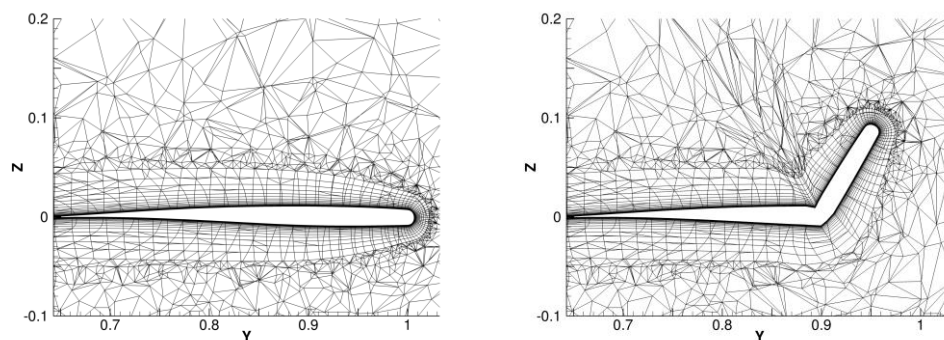


Figure 1 Traditional mesh deformation approaches result in significant mesh distortions. Left: AGARD LANN wing [Zwaan, 1985] slice along $x=0.55$ m. Right: 60-degree fold generated at 90% span with a localised volumetric shape-preserving rotation around the wingtip hinge line.

Unsteady aerodynamic loads are needed for aircraft design and certification in relation to aircraft aeroelastic flutter. Fast computational fluid dynamics methods, such as the well-

known linearised frequency domain (LFD) method [Thormann & Widhalm, 2013], are now well integrated into industrial processes and widely used for transonic flow. While the LFD method relies on the small-amplitude assumptions for the dynamic content of a signal, the reference state for linearisation can include large non-linear static aeroelastic wing deformations, and those due to a folding wingtip, and moderately strong aerodynamic non-linearities, that is shocks and mild separation in the transonic regime. The harmonic Fourier content of the aerodynamic response to periodic structural deformation (or gust forcing) around this non-linear state is directly computed, rather than, as with a time-stepping method, inferred over multiple oscillation cycles after initial transients have decayed. For each structural deformation (or gust forcing) mode and each frequency, just one linear system needs to be computed.

The computational fluid dynamics tool chosen in this work is the new-generation code CODA (CFD Software by ONERA, DLR and Airbus, CODA) [Stefanin Volpiani et al, 2024]. CODA operates in parallel on heterogeneous high-performance computers using distributed and shared memory with hybrid message passing interface and open multi-processing. The solver is highly adaptable incorporating: various flow/turbulence models; finite-volume or discontinuous Galerkin methods for unstructured meshes; multiple options for inviscid and viscous fluxes and gradient reconstruction; and various time integration schemes. Importantly CODA can enact automatic differentiation, so that the Jacobian matrix need not be stored explicitly for the computation of matrix-vector products. For the solution of linear systems, CODA primarily uses the linear algebra library Spliss, which flexibly nests iterative Krylov methods, stationary iterative methods and matrix inversion routines for multiple levels of preconditioning. In the context of LFD computations, for which each structural deformation mode results in linear systems which only differ in their right-hand sides, advanced vector extensions can be employed [Edwards et al, 2025].

In this work, aerodynamic loads (specifically generalised aerodynamic forces) are computed for a three-dimensional wing with a folded wingtip. A swept wing with a constant taper ratio is used, incorporating a NACA0012 aerofoil and zero twist along the span. A hinge fairing, positioned at two-thirds of the wingspan, is created by locally thickening the aerofoil section and revolving it through 360° to form a symmetric fairing, as shown in Figure 2. The fairing is aligned with the desired hinge flare angle.

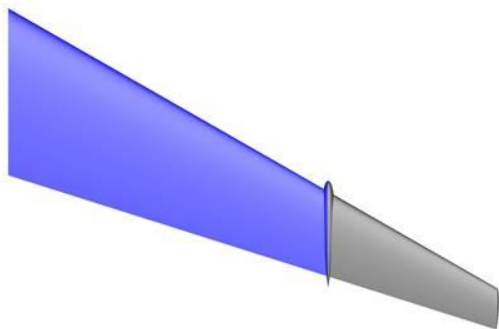


Figure 2 Wing with folding wingtip and fairing



Figure 3 Automatic background mesh hole cutting

A chimera (overset) meshing strategy is employed allowing for large motions of the folding wingtip, as described by, for example, [Stickan et al, 2019] for generic flight control surfaces. A background mesh contains most of the wingspan up to and including the fairing. An overset

mesh is created for the wingtip with a small overlap region on the fairing. As the wingtip rotates, the overset mesh moves with the wingtip and automatic hole cutting is used to remove cells on the background mesh, as shown in Figure 3. The grid quality around the wingtip is directly retained, rather than distorted as in traditional methods.

We show for the first time (to the best of our knowledge) how such LFD capability works in conjunction with the overset meshing philosophy. With this methodology established, unsteady oscillatory aerodynamic loads are readily computed at any given fold angle. Results from the LFD calculations are scrutinised with respect to corresponding time-stepping oscillatory solutions. The success of each approach is compared at large fold angles. Comparisons are also made between the overset method and a traditional volumetric mesh deformation method (see for example Figure 1), in which the grid is distorted to produce a fold, to highlight the benefits of the overset approach. The fold angles achieved with a mesh deformation method are limited by the distortion of the mesh. The overall ambition of the contribution is the demonstration of LFD simulation capability with overset meshes on a large three-dimensional aircraft test case, ultimately contributing to future industrial needs in wing design, analysis and certification.

REFERENCES

- Pattinson, J., Wilson, T., and Herring, M., “High fidelity simulation of the folding wing tip for loads alleviation,” Proceedings of the International Forum on Aeroelasticity and Structural Dynamics IFASD, 2015.
- Healy, F., Gu, H., Rezgui, D., and Cooper, J., “Observations on the Effect of Geometric Nonlinearities on a Representative Civil Aircraft Incorporating Flared Folding Wingtips,” Proceedings of the International Forum on Aeroelasticity and Structural Dynamics IFASD, 2022.
- Zwaan, R. J., “LANN wing: pitching oscillation,” Compendium of Unsteady Aerodynamic Measurements, Addendum No. 1, AGARD R-702, 1985.
- Edwards, S., Timme, S., Vevek, U.S., Pattinson, J. and Krzikalla, O., 2025. Accelerating Linearised Frequency-Domain Simulations for Unsteady Aerodynamics using Vectorisation. In *AIAA AVIATION FORUM AND ASCEND 2025* (p. 3862). <https://doi.org/10.2514/6.2025-3862>.
- Thormann, R., and Widhalm, M., “Linear-frequency-domain predictions of dynamic-response data for viscous transonic flows,” *AIAA Journal*, Vol. 51, No. 11, 2013, pp. 2540–2557. <https://doi.org/10.2514/1.J051896>.
- Stefanin Volpiani, P., Chapelier, J.-B., Schwöppe, A., Jägersküpper, J., and Champagneux, S., “Aircraft Simulations Using the New CFD Software from ONERA, DLR, and Airbus,” *Journal of Aircraft*, Vol. 61, No. 3, 2024, pp. 857–869. <https://doi.org/10.2514/1.C037506>, publisher: American Institute of Aeronautics and Astronautics.
- Stickan, B., Thormann, R., and Bleecke, H., “Control surface modelling of unsteady large amplitude motion via chimera CFD technique,” International Forum on Aeroelasticity and Structural Dynamics IFASD, 2019.