

ASSESSMENT OF LINEARISED FREQUENCY DOMAIN CAPABILITY WITH OVERSET MESHING

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ABSTRACT

The increasing geometric complexity of aircraft designs, such as future wings incorporating folding wing tips [1], creates new challenges for computational modelling techniques. There is a need for accurate, and cost effective, predictions of unsteady aerodynamics, including those required for aeroelastic flutter and gust load analyses; hence changing geometries need to be accounted for [2]. For instance, with a folding wing tip, there are multiple design choices for the flare angle, which is the angle of the wing tip hinge with respect to the line of flight. The coast angle is the fold angle at steady cruise where the aerodynamic and gravitational forces about the hinge are balanced, creating a balanced system, which depends on various factors including flow conditions and hinge stiffness. Using mesh deformation will become unfeasible for large deformation angles, due to the potential creation of highly skewed or negative volume cells, necessitating remeshing. Instead, overset (also known as Chimera) meshing can be used to model the moveable geometry. Here, multiple meshes are generated which when used together will produce the whole computational domain. Continuing with the folding wing tip example, there would be two meshes. The main one would contain the majority of the computational domain and the wing. The second mesh would contain just the wing tip. A hole would be cut in the main mesh (often automatically) for the second mesh, allowing for a small overlap region between the two where variables are interpolated. This allows the wing tip to be moved, or changed entirely, without affecting the rest of the mesh.

Linear frequency domain (LFD) methods [3] have become well established for computing aerodynamic responses to structural forcing, while considering the inherent limitations due to the assumption of small perturbations around a non-linear reference equilibrium state. This type of analysis allows the aerodynamic response due to structural forcing to be computed directly in the frequency domain, lowering the computational cost compared to time-accurate simulations. The equation governing the LFD problem,

$$(\mathbf{J} - i\omega\mathbf{I})\mathbf{Y} = \mathbf{B} \quad (1)$$

is derived in, for example, [4]. Concisely, the left-hand side contains the Jacobian matrix, \mathbf{J} , describing the linearisation about the base state, whereas the right-hand side, \mathbf{B} , is derived from the structural motion. The system is frequency dependent with a chosen frequency ω . The unsteady aerodynamic loads, or generalised aerodynamic forces (GAFs), can be computed from the solution, \mathbf{Y} .

While both overset meshing and LFD have been in use for a number of years, to the best of our knowledge, LFD with overset capability has not been demonstrated. This work will provide a comprehensive assessment of such capability using the new generation CFD software by ONERA, DLR and Airbus (CODA) [5] for test cases of increasing complexity from a low Reynolds number cylinder with vortex shedding to transonic three-dimensional wings. A key feature of CODA for simulations with linearised methods is the inclusion of automatic

differentiation [6], meaning many combinations of flow equations, including turbulence models, and spatial discretisations can be used without relying on hand differentiation. It also means that the Jacobian matrix does not need to be stored explicitly. This also enables, in principle, seamless differentiation across overset interpolation regions.

The first part of this work explores fluid instabilities that do not require mesh motion to scrutinise the Jacobian operator itself. We use CODA’s built-in Krylov-Schur eigenvalue solver for this kind of global stability analysis [7]. This will verify that the Jacobian matrix is properly differentiated across the interpolated region by CODA’s automatic differentiation capability and that there are no discrepancies in the resulting eigensolution. Then, mesh motion will be introduced with the LFD solver to check the unsteady aerodynamic responses, starting with simple two-dimensional test cases and rigid-body motion. For this, the surface can be split between two overset meshes. This will confirm that the mesh motion has been properly applied to each mesh, there are no discontinuities in the surface response and the GAFs are correct. As the functionality and accuracy of each test case is confirmed, the complexity of the problem will be increased. Some preliminary results are described in the following.

The first test case, to check the Jacobian operator, is a two-dimensional low Reynolds number cylinder solved using the Navier-Stokes equations. Figure 1 presents a zoomed-in section of the computational domain and the global stability results. The mesh consists of a quasi-structured inner mesh extending to $2D$ in each direction, with D being cylinder diameter, and an unstructured outer mesh extending to a circular farfield at $50D$ in each direction. It can be seen that the overset region, shown by the black lines in the eigensolution, has no effect on the vortex shedding, confirming the accuracy of the Jacobian operator.

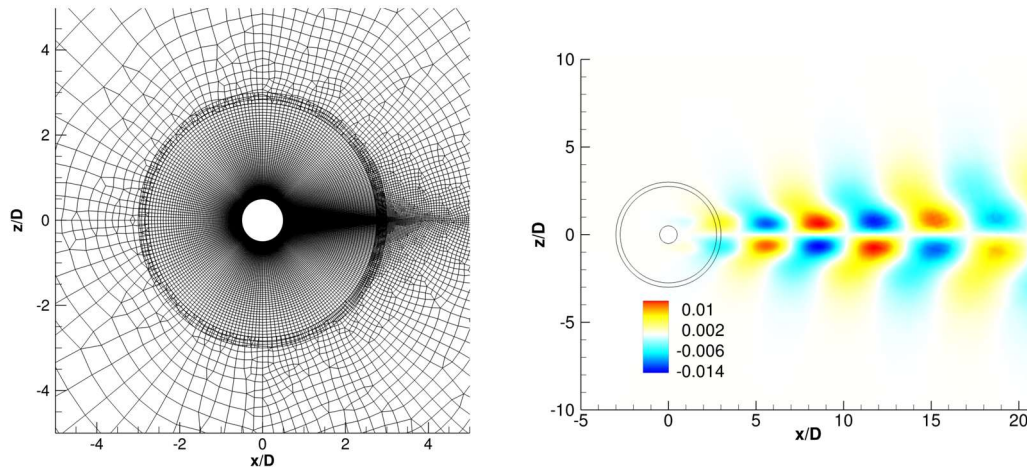


Figure 1: Left: Zoomed in overset mesh for cylinder test case, showing quasi-structured inner mesh and unstructured outer mesh. Right: Krylov-Schur eigenvector for the real part of x-momentum at Reynolds number 50 showing von-Karman vortex shedding.

Next, to test the unsteady aerodynamic responses, a subsonic Euler NACA 0012 case was produced. This consisted of a single mesh which was split into two parts at around 50% chord to produce two overset meshes with an overlap of approximately 10% chord, as shown in figure 2a. The LFD results are presented in figure 2b, showing the real part of C_p for a pitching mode with non-dimensional reduced frequency $\omega^* = 0.1$. It can be seen that the overset and single meshes give identical results, confirming correct functionality of both the overset interpolation and LFD solver.

Since shock waves have a sensitivity to (lack of) conservatism and the transonic regime is of great interest to commercial flight, the final paper will include transonic cases. Finally, we

intend to push this work further onto more realistic use-cases, potentially aerofoils with a moveable flap and three-dimensional wings.

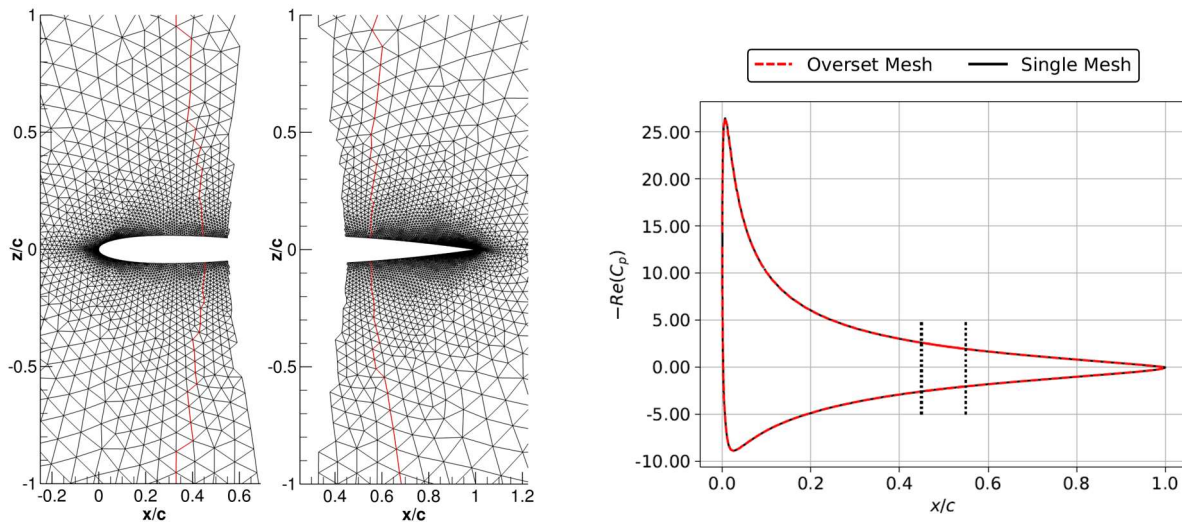


Figure 2: Left: Overset mesh used for NACA 0012 test case. Red lines indicate overlap region for overset. Right: Initial NACA 0012 LFD results. Dotted lines indicate overlap region for overset.

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