Acceleration of URANS for Application to Separated High-Lift Flows

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I. Introduction

DeSiReH is a European project on design, simulation and flight Reynolds number testing for advanced high lift solutions. Its objective is to improve the industrial design process for high lift devices for laminar wings in terms of product quality, efficiency and development cost reduction. DeSiReH started in 2009 and consists of 20 partners. One part of the work in the project is devoted to design of high lift concepts based on CFD calculations and optimization with experimental verification. Another part concerns the development of the numerical tools for aerodynamic optimization as well as for numerical enhancements of the CFD solvers and grid generation aspects. This paper summarise the work that has been carried out by three partners with the objective to enhance the efficiency of their in-house flow solver for unsteady CFD (URANS) calculations at and beyond maximum lift.

The objective of the different CFD enhancements was to improve the tools within the framework of a design context. The improvements achieved should be quantified to the approach available prior to DeSiReH. In addition to quantifying how much faster the unsteady calculations have become due to improvements, partners were asked to quantify how more expensive an unsteady calculation is compared to a steady state calculation.

II. Numerical approaches

The three partners CIRA; FOI and TsAGI have worked with different types of implicit solution techniques to speed up unsteady calculations.

- CIRA has introduced an implicit solution technique based on ADI and approximate factorization in their flow solver for structured grids and combining this with an improved initialization procedure for the initial flow solution at next time level.
- FOI has extended their line-implicit solver for unstructured grids to include low speed preconditioning. The approach is implemented for steady state problems and extended to unsteady problems in dual time.
- TsAGI has implemented and validated a zonal approach with multiple time steps in small cells and in combination with an implicit solution in highly stretched cells.

III. Computational Results

The numerical work has been validated on high lift test cases in 2D and on a common 3D three element landing configurations test case at a high Reynolds number case from EUROLIFT.

CIRA has shown that a more sophisticated initial prediction of the solution at next time level (linear and higher order extrapolation techniques from earlier time steps) give improved rates of convergence with a reduced number of dual time steps compared to using the solution at the previous time step as initial solution. The relative gain is higher the smaller the time step is, up to 68% gain in reduced computational effort were obtained. The gain from the improved initialization is shown in Figure 1. For unsteady calculations with multigrid acceleration in dual time, the combination of improved prediction with implicit solution techniques give results in a 90% reduction of CPU time compared to explicit subiterations and previous time step as initial solution. The unsteady calculations require a high temporal resolution with a small time step and are still an order of magnitude more expensive.

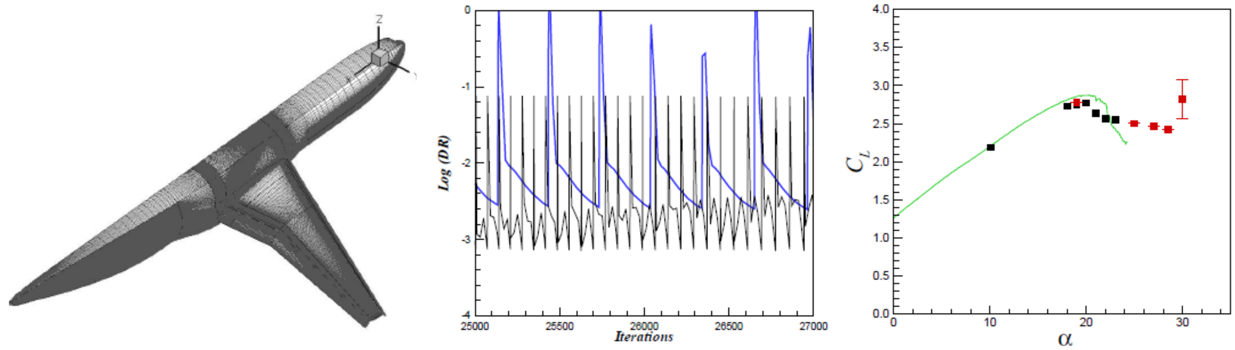

Figure 1 EUROLIFT 3-element test case *Left: Structured surface grid. Mid: Explicit inner iteration without time step prediction (blue) and with prediction (black). Right: Lift polar, unsteady calculations at the highest incidence.*

The line-implicit technique in combination with low speed preconditioning by FOI shows that a good acceleration of the computing time is obtained for low speed flows and steady state calculations. For very low speeds where preconditioning has to be used there is an acceleration of 75% or more compared to explicit integration. The gain is less for higher Mach numbers in the typical high lift regime but there is still a good speed up of about 25% or more. For time accurate calculations the combination there is a gain of about 20% or more using line-implicit integration compared to explicit iterations. The unsteady calculations are still very expensive and FOI has evaluated an alternative and affordable approach where steady state calculations are forced to an average solution which has shown to be promising. The oscillations are reduced considerably and remaining small oscillations fall within the bounds of the unsteady calculations, Figure 2.

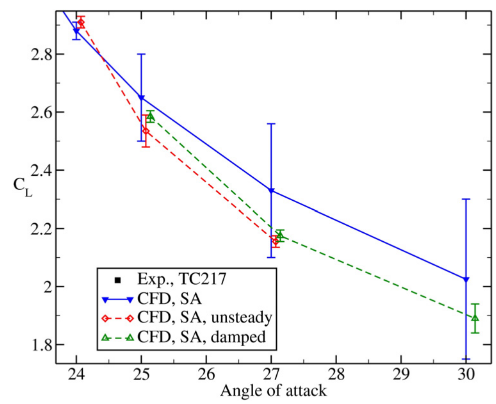

Figure 2 Lift beyond max lift, EUROLIFT 3-element case *Steady state calculations, unsteady calculations (240 Δt/T) and damped steady state calculations.*

TsAGI demonstrated that unsteady high lift calculations are very expensive compared to ordinary steady state calculations due the small time steps required to resolve temporal scales of the separated flow beyond maximum lift. The zonal approach is more efficient than the initial approach provided that the time step is small. This is illustrated in the figure below where the efficiency of the zonal approach is compared to that of the dual implicit approach. To have a sufficient resolution in time for the 3D case a time step of $\Delta t=5\times10^{-6}$ *s* is required, the zonal approach is approximately twice as efficient for this time step according to Figure 3.

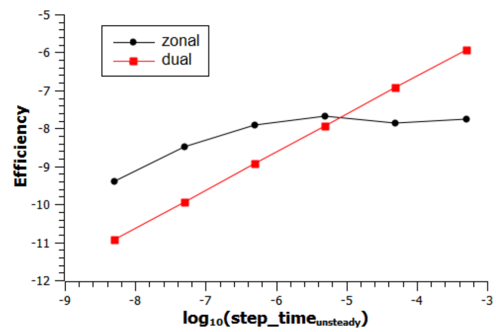

Figure 3 Efficiency for unsteady calculations, EUROLIFT 3-element case. *Comparison zonal approach and fully implicit approach in dual time.*

A common finding is that steady state calculations beyond maximum lift converge poorly and produce forces that oscillate with large unphysical amplitudes. The amplitudes are reduced when the calculations are carried out time accurately but a small time step is required to have time step independent solutions making these calculations expensive. Although an overall gain of 20% and more have been achieved in computing time, time accurate calculations are still at least one order of magnitude more expensive than steady state calculations, up to a factor of 100. In many cases a larger time step can be chosen that produces smaller amplitude oscillations that fall within the bounds of the oscillations from small time step calculations. Another alternative is offered by the approach where the steady state solution is damped towards an averaged solution.

IV. Acknowledgement

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