Mitteilung

Projektgruppe / Fachkreis: Numerische Aerodynamik

Application of time step adaptation on the simulation of a gust encounter

Christian, Lenz
Deutsches Zentrum für Luft- und Raumfahrt e. V.
Institut für Aerodynamik und Strömungstechnik,
Lilienthalplatz 7, 38108 Braunschweig
Christian.Lenz@dlr.de

Introduction

With today's computational power, unsteady simulations of flow problems are of increasing interest. Up to now, many CFD codes require the definition of a constant time step size which is then used throughout the whole computation. For simple applications such as a pitching airfoil a suitable choice can be estimated. In complex flow configurations however it is in general non-trivial to choose a suitable time step size which is appropriate for the whole simulation such that the solution resolves all physical phenomena like oscillations or vortices. Furthermore, it might be advantageous to adapt the time step size during the simulation to reduce the computational cost. For instance when simulating a gust encounter, one could choose a small time step size during the time the gust hits the aircraft and a rather large one before and after the gust encounter.

Aim

The goal of this work is to implement an adaptive time step size control algorithm using embedded Runge-Kutta methods in the DLR flow solver TAU. To show the applicability of the method we simulate a gust encounter of a generic fighter configuration.

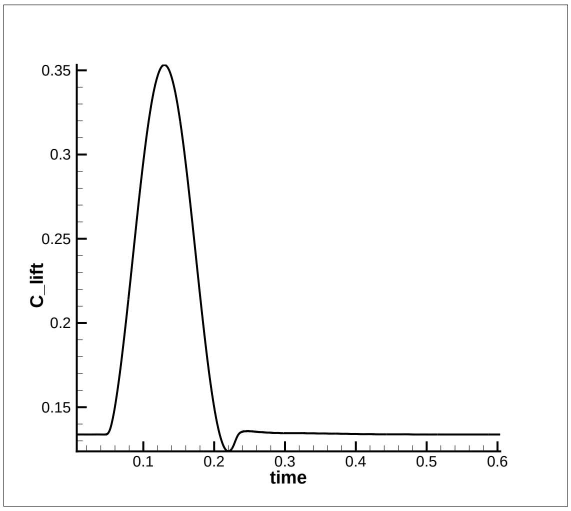
Procedure

Embedded Runge-Kutta methods determine with negligible numerical overhead two solutions of different order in each time step. These are exploited to get a local error estimate of the solution to adapt the time step size during the flow simulation by use of a suitable control algorithm. In order to choose rather large time steps without getting stability issues we use implicit Runge-Kutta methods. In detail, we focus on using an Explicit first stage Singly Diagonally Implicit Runge-Kutta (ESDIRK) method due to Kværno [1]. The method has order 3 and is L-stable with an A-stable method of order 2 embedded for error estimation. To control the time step size we use the digital filter H211b with $b = 4$ due to Söderlind [2].

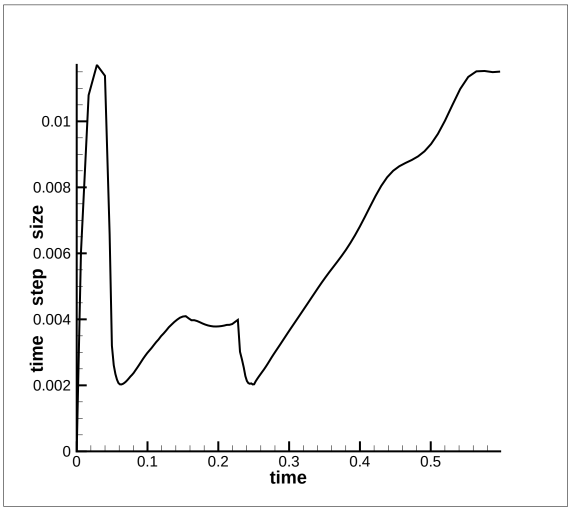
Results

We investigate a gust encounter of the SDM generic fighter configuration with a vertical $1-\cos$ gust. The inviscid computation is done on a grid with 59542 points. The simulation is at Mach 0.5 with the gust starting $8\mathrm{m}$ in front of the plane, such that it will hit the plane at about $t = 0.05\mathrm{s}$. The gust has a length of $30\mathrm{m}$ and a maximum amplitude of $10\frac{\mathrm{m}}{\mathrm{s}}$, which is in the typical range of values used for aircraft certification.

As can be seen on the right figure, the implemented time step adaptation algorithm chooses a rather large step size at the beginning of the simulation followed by a significant drop in the step size when the plane reaches the gust. After the plane passed the gust, the time step size is increased again since the plane is approaching a steady state. A comparison to computations without time step adaptation shows a



C-lift evolution for the gust encounter



Choice of time step size for the gust encounter

reduction of computational cost without loss of accuracy for this test case (cf. Table 1). The gain in computational time varies depending on the chosen physical simulation time. Simulations having large time intervals with few physical changes and small time periods where the physics require small time steps are expected to show the largest reduction in computational time when using an adaptive step size selection.

time step size	normalized CPU time
adaptive	1.0
constant	1.32

Table 1: CPU times with adaptive or constant time step for similar accuracies

References

[1] A. Kværnø. Singly diagonally implicit Runge-Kutta methods with an explicit first stage. *BIT Numerical Mathematics*, 44(3):489–502, 2004.

[2] G. Söderlind. Digital filters in adaptive time-stepping. *ACM Transactions on Mathematical Software*, 29(1):1–26, 2003.