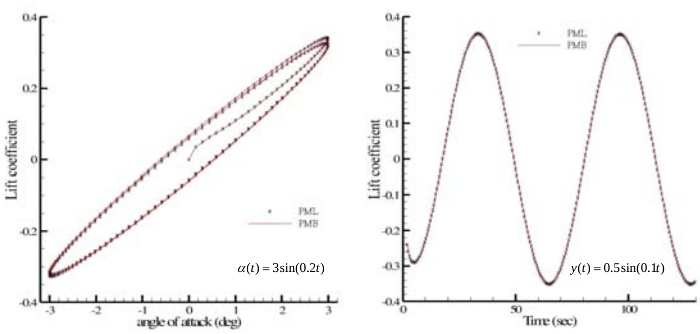
A meshless solver for the simulation of unsteady flows using CFD

Abstract:

To simulate unsteady flows associated with fixed wing aircraft using computational fluid dynamics (CFD) can be extremely difficult using conventional finite volume methods. Cases with moving geometries require mesh deformations that are limited to those where the block topology is fixed. This rules out applications when the motion is not known a-priori such as store release from a cavity. This project is based around the development of a new CFD solver called PML (Parallel MeshLess) that is designed for such cases.

Solver method:

Meshless methods provide an alternative to mesh-based flow computations as they do not require conventional grid structure such as elements and control volumes. Instead, clouds of points are used to discretise the mathematical equations that need to be solved. The use of points as opposed to cells means that the geometry changes that are encountered with cases such as store release may be dealt with.



Unsteady 2D calculations with pitching (left) and plunging (right) NACA0012 aerofoils. Lift coefficients are compared with University of Liverpool solver PMB.

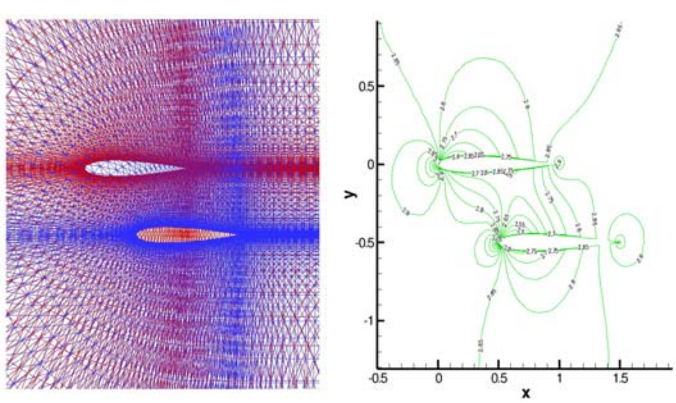
The Navier-Stokes equations, are the governing equations of fluid dynamics and can be written:

$$\frac{\partial w}{\partial t} + \frac{\partial f(w)}{\partial x} + \frac{\partial g(w)}{\partial y} = 0$$

We use the meshless method to find the flux derivatives of these equations so

$$\frac{\partial w_i}{\partial t} = -\sum_{j \in \Omega_i} b_{(i)j}.f_j - \sum_{j \in \Omega_i} c_{(i)j}.g_j$$

This system is then solved implicitly in time using a preconditioned Krylov solver with approximate Jacobians.



Two NACA0012 grids overlapping to form a biplane configuration (left). The stencil selection cuts out the points within the boundaries and the inviscid pressure results at Mach 0.5 are shown (right).

RAF Typhoon releasing a Paveway 2 (Photo: SAC Babbs Robinson)

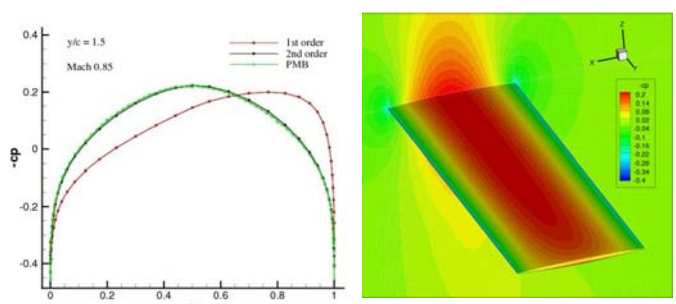
Each point *i* within a domain Ω has a stencil or cloud Ω_i consisting of neighbouring points with data values ϕ that can be used to derive an approximate linear polynomial at that point

$$\hat{\phi} = \alpha_0 + \alpha_1 x + \alpha_2 y$$

Then the derivatives of the approximating function are the coefficients, which in terms of the shape function are

$$\frac{\partial \hat{\phi}_i}{\partial x} = \sum_{j \in \Omega_i} b_{(i)j}.\phi_j \qquad \frac{\partial \hat{\phi}_i}{\partial y} = \sum_{j \in \Omega_i} c_{(i)j}.\phi_j$$

The shape functions are determined by solving the least squares problem for the stencil.



3D results for a goland wing compared with the University of Liverpool finite volume solver PMB

Stencil selection:

For problems when bodies are in relative motion, each time a boundary wall moves after a computed time step we have to recalculate the stencils for the next step. For the solver to be used effectively in practical, unsteady CFD calculations the stencil selection needs to be performed as quickly and as accurately as possible. This is achieved using a combination of tree search algorithms and a direct cutting method that constructs the stencils automatically with no user input. So that the required flow features are captured, the points for use in the solver are obtained from structured grids which are allowed to overlap and move relative to one another.

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