UnDiFi-2D: an Unstructured Discontinuity Fitting code

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Outline

Introduction

What is the shock-fitting?

Within a continuum framework, shock-waves and other gasdynamic discontinuities can be modelled by means of either:

Shock-capturing

All flow regions including shocks are computed by using the same discretization of the equations in integral form at all cells. This has obvious implications in terms of coding simplicity and largely contributed to the widespread popularity of S-C discretizations.

Shock-fitting

- In S-F discretizations, shocks are treated as true discontinuities.
- It consists in locating and tracking the motion of the discontinuities which are treated as boundaries between regions where a smooth solution to the governing PDEs exists.
- The Rankine-Hugoniot relations are used to calculate the space-time evolution of the discontinuity and the governing equations are discretised only within the smooth regions.

Why the shock-fitting?

Captured shocks are plagued by a number of drawbacks:

- carbuncles;
- spurious oscillations downstream of the captured discontinuities due to mesh-shock misalignment;
- accuracy degradation (to first order) in the entire shock-downstream region.

> *These limitations, related to the misrepresentation of discontinuities on a mesh with finite spacing, can only be overcome by some form of shock-fitting*[1]*.*

> *A revival of shock-fitting is one of the few remaining possibilities for revolutionary change*[2]*.*

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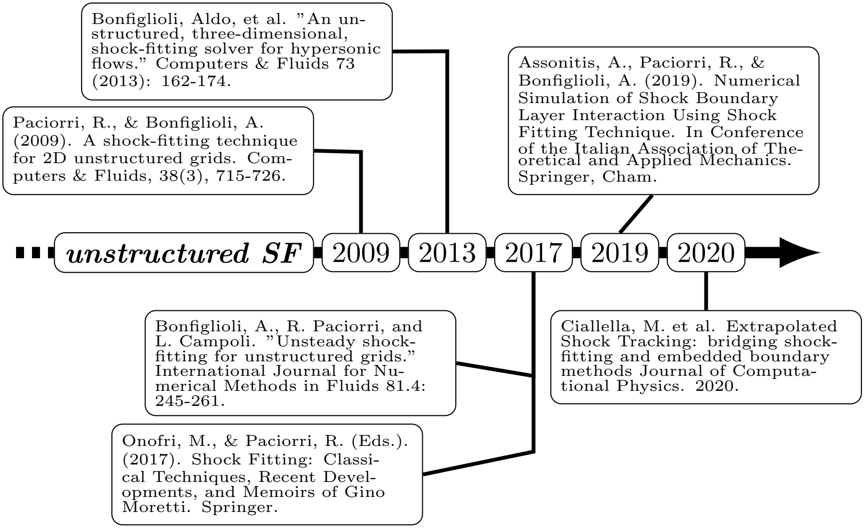
[1] Pirozzoli, S., Numerical Methods for High-Speed Flows, Annual Review of Fluid Mechanics, Vol. 43, No. 1, 2011, pp. 163–194

[2] Roe, P., Review of the book “A Shock-Fitting Primer” by Manuel D. Salas, SIAM Review, Vol. 53, SIAM, 2011, pp. 207–210

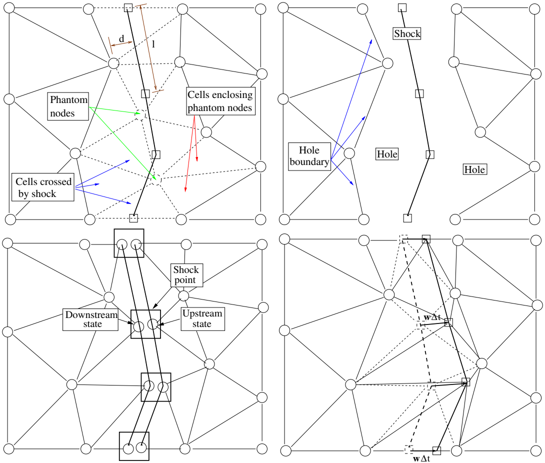
Recent developments in shock-fitting methods



Unstructured Discontinuity Fitting (UnDiFi-2D)

Unstructured shock-fitting

The basic algorithm



Cell removal and local remeshing around the shock, solution updating, shock computation and shock displacement

Unsteady unstructured shock-fitting

To make unstructured shock-fitting time-accurate, we have to:

- account for the grid velocity of the shock points by using an ALE formulation in the shock-capturing solver
- raise the time accuracy of the lagrangian motion of the shock points to second order in time

Lagrangean integration of the shock motion

The time integration of the shock position, whose accuracy is second order, uses a two-steps time integration scheme. The predictor step estimates the position of the shock at time level $n + 1/2$ using the explicit Euler scheme:

$$P_i^{n+1/2} = P_i^n + w_{sh}^n \Delta t/2.$$

and the corrector step updates at time level $n + 1$:

$$P_i^{n+1} = P_i^n + w_{sh}^{n+1/2} \Delta t.$$

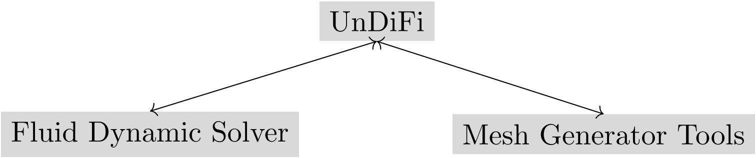
Unstructured shock-fitting

Main ingredients

- The shock front is a double-sided (upstream/downstream) internal *boundary* that is free to *float* over a background, triangular mesh, handled by **UnDiFi**.
- Local **re-meshing** is applied in the neighbourhood of the moving shock front to ensure that the shock-points and edges are part of the triangulation (constrained Delaunay).
- A shock-capturing code using **fluctuation splitting schemes** to discretise the governing PDEs in the smooth regions (but other node-centered solvers can be interfaced).

Unstructured shock-fitting

General working framework



- Examples of solvers:
  - EulFS (Unibas) [1]
  - NEO (Inria) [2, 3]
  - COOLFluiD (VKI) [4]
- **Note**: implicit and explicit solvers both for steady and unsteady simulations
- **Requirement**: vertex-based gasdynamic solvers

- Mesh Generator Tools:
  - 2D → Triangle [5], Gmsh [6]
  - 3D → TetGen [7], Yams [8], GRUMMP [9]

Unstructured shock-fitting

Features of the unstructured shock-fitting technique

- it is able to compute 2D flows with shock with small numerical errors and high accuracy also on coarse grids [10]
- it is able to compute complex flows with interacting shocks
- it is able to compute shocks in hybrid mode [11, 12]
- it is able to compute steady and unsteady flows [13]
- it is strongly modular [14]

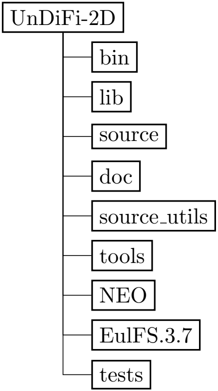
Advantages of modularity

- The high modularity allows to easily replace the *external ingredients*
- Other solvers can be added by changing the interface with UnDiFi
- Portability and maintainability of UnDiFi are simplified

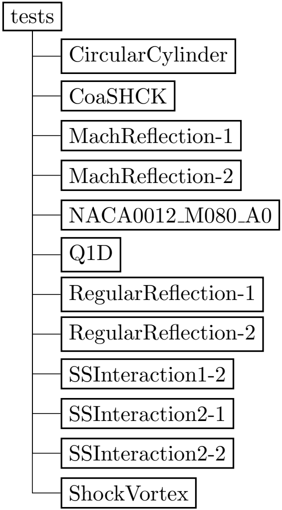
Unstructured shock-fitting

The GitHub repository

https://github.com/UnDiFi/UnDiFi-2D.git



UnDiFi-2D directory tree.



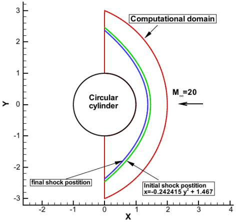
Testcases present in the `tests` directory.

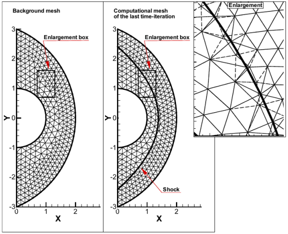
Numerical results

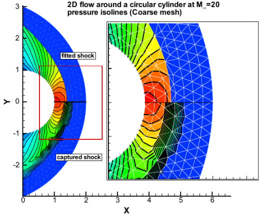
CircularCylinder-1

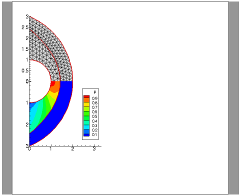
Steady flow post a circular cylinder at M=20

`UnDiFi-2D/tests/CircularCylinder-1`





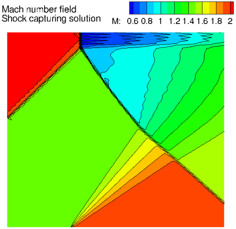




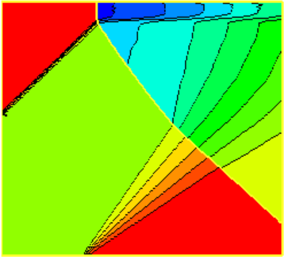
```
./run.sh -s Solver -m Mode -f Flow
Solver:  EulFS
Mode:  capturing/fitting
Flow:  steady
```

Mach reflections: hybrid mode

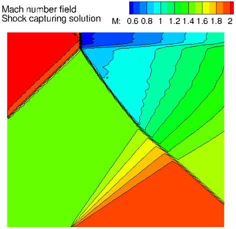
UnDiFi-2D/tests/MachReflection-2



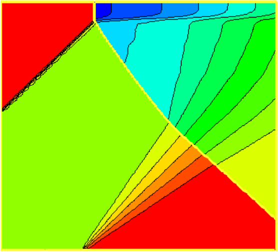
./run.sh -s EulFS -m capturing -f steady



./run.sh -s EulFS -m fitting -f steady



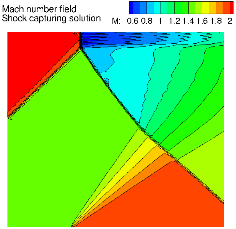
./run.sh -s NEO -m capturing -f steady



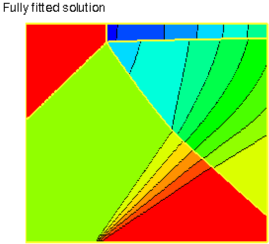
./run.sh -s NEO -m fitting -f steady

Mach reflections: capturing/fitting mode

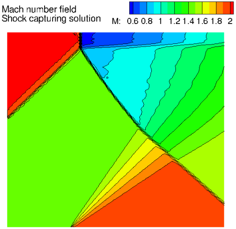
UnDiFi-2D/tests/MachReflection-1



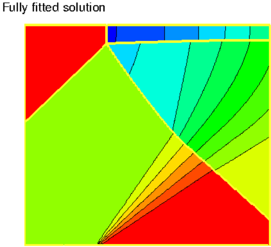
./run.sh -s EulFS -m capturing -f steady



./run.sh -s EulFS -m fitting -f steady



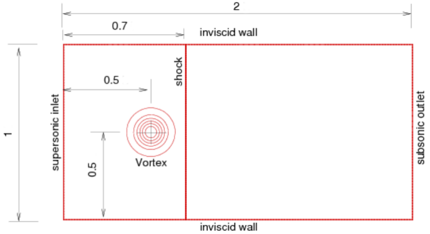
./run.sh -s NEO -m capturing -f steady

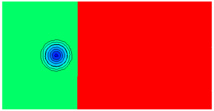


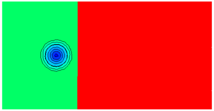
./run.sh -s NEO -m fitting -f steady

Shock-vortex weak interaction (WR)

UnDiFi-2D/tests/ShockVortex







./run.sh -s Solver -m Mode -f Flow

Solver: NEO

Mode: capturing/fitting

Flow: unsteady

Conclusions

A discontinuity-fitting technique for 2D unsteady flows on unstructured grids has been presented and is available at:
`https://github.com/lkampoli/UnDiFi-2D.git`

- Its main features are:
  - unstructured-grid framework
  - modularity
  - vertex-based formulation
  - time-accurate in 2D
  - implicit/explicit solvers
- The repository contains several ready-to-go testcases, user-friendly scripts and consistent documentation

On-going activities include:

- shock wave-boundary layer interaction (SWBLI) [15]
- topological changes and shock detection by CNN [16, 17]
- extrapolated shock-tracking [18]

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