Immersed Boundary Flows on GPUs

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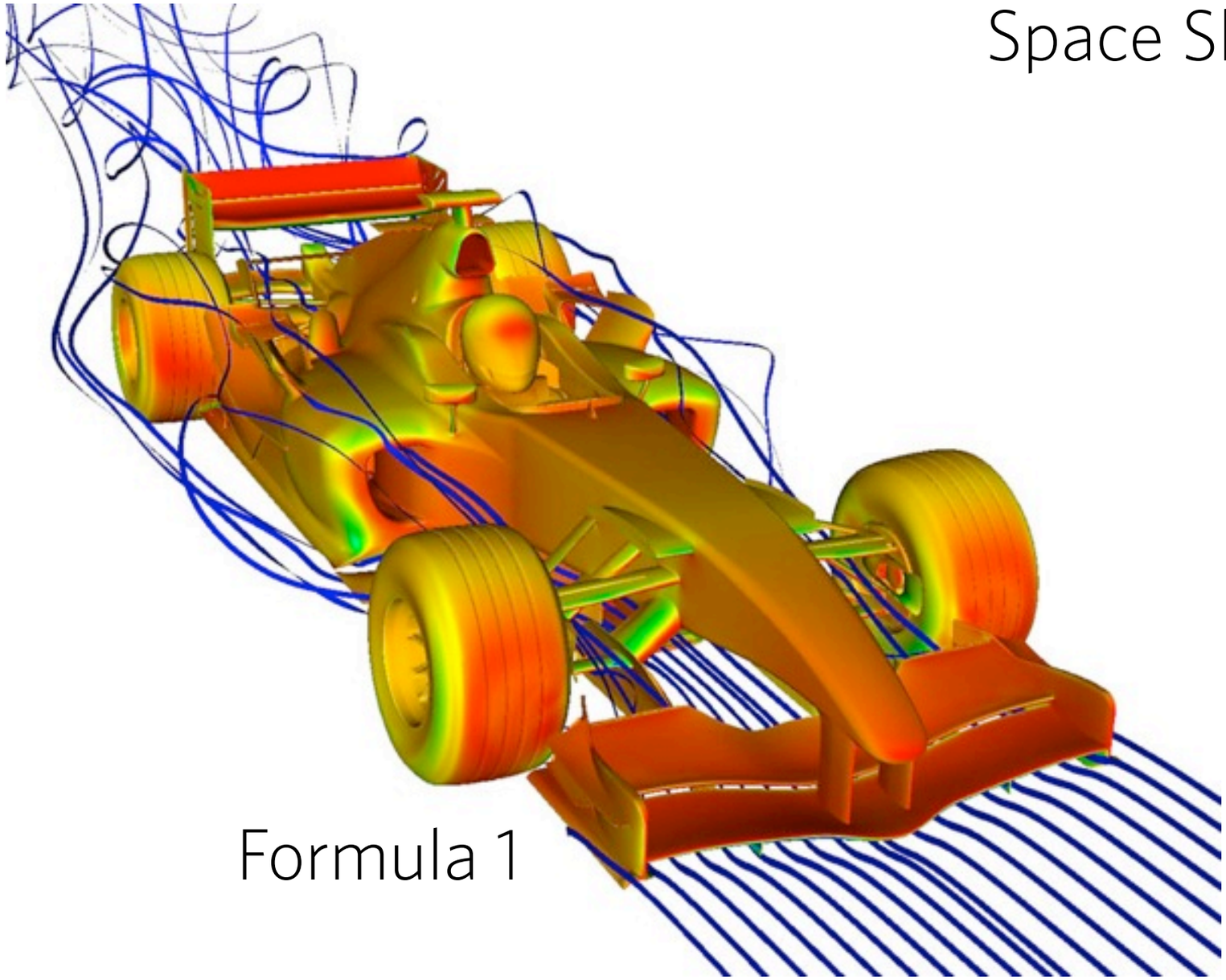
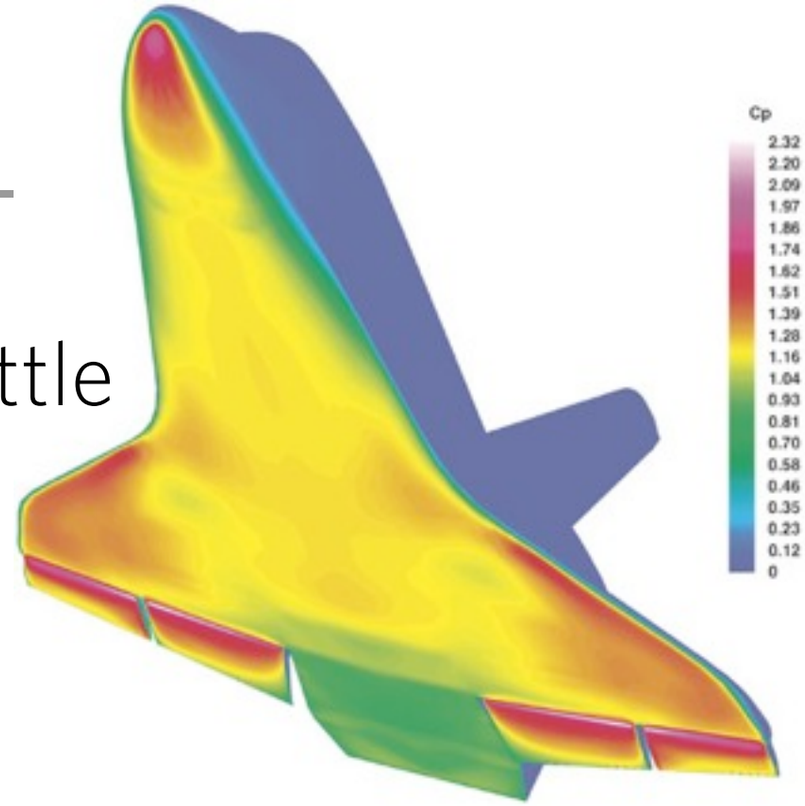
Navier-Stokes Equations

$$
\begin{aligned}
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) &= 0 \\
\rho(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}) &= -\nabla p + \mu \Delta \mathbf{u} + \mathbf{f}
\end{aligned}
$$

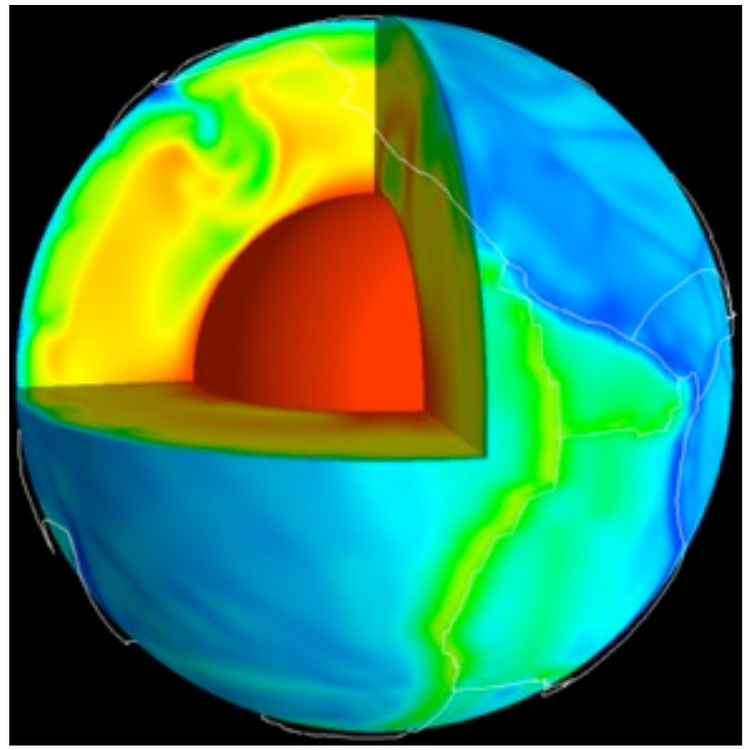
Computational Fluid Dynamics



Formula 1



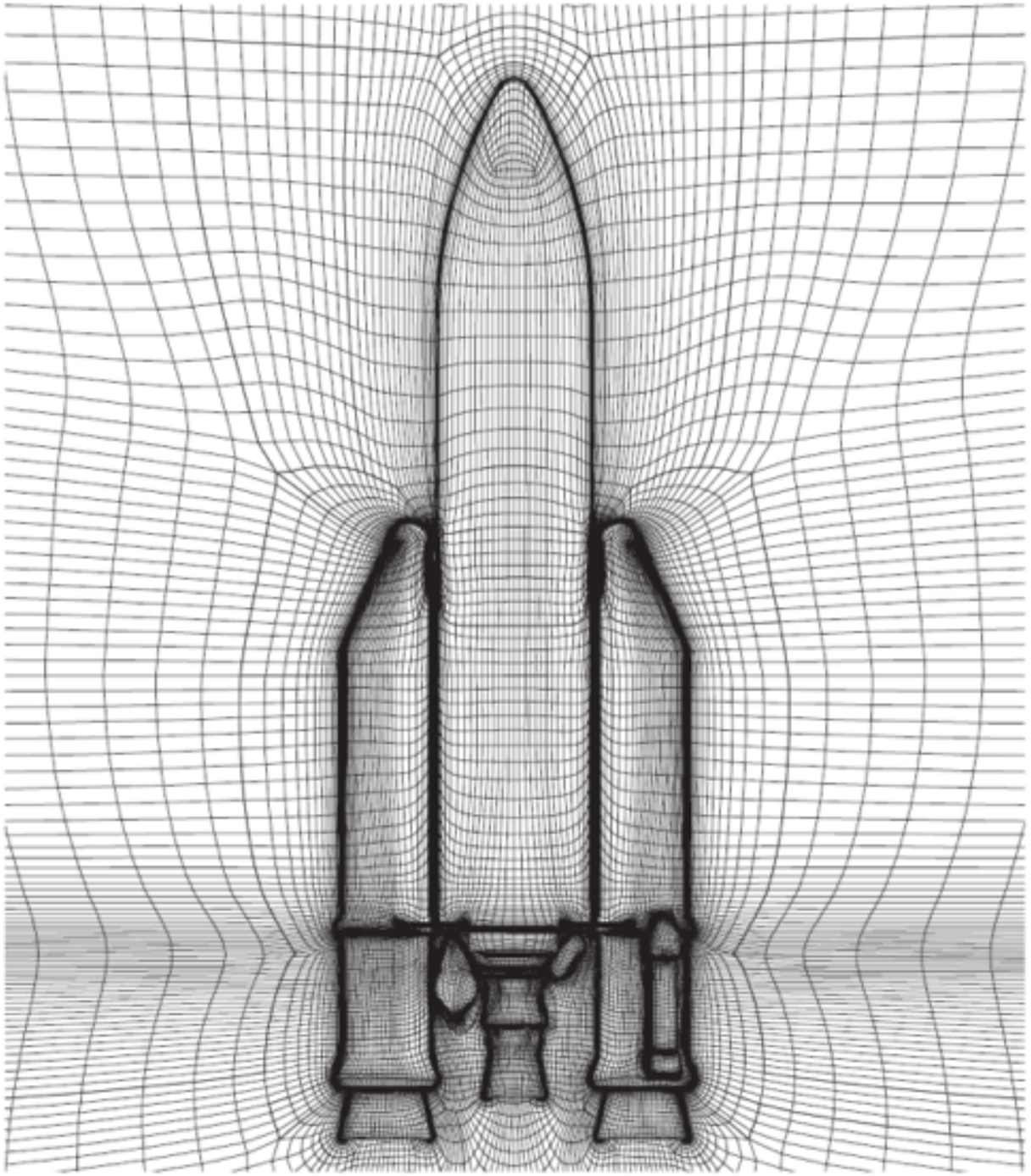
Space Shuttle



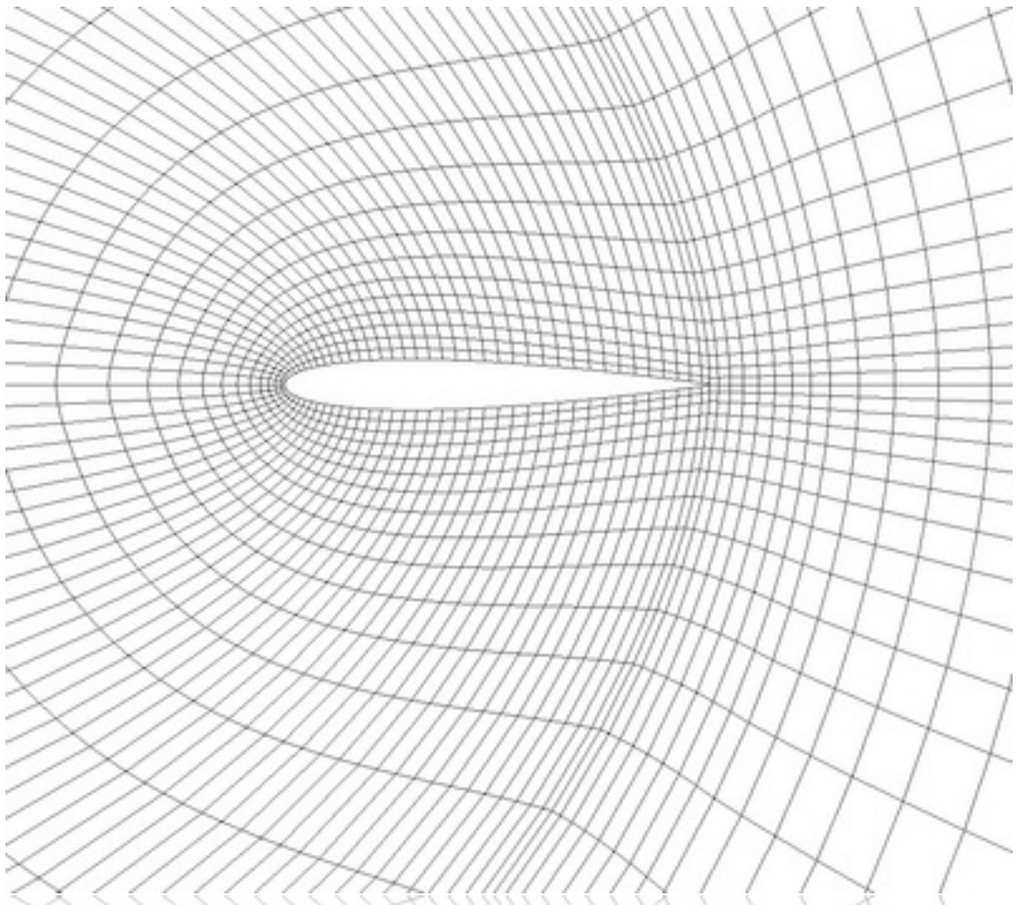
Geodynamics

Computational Grid

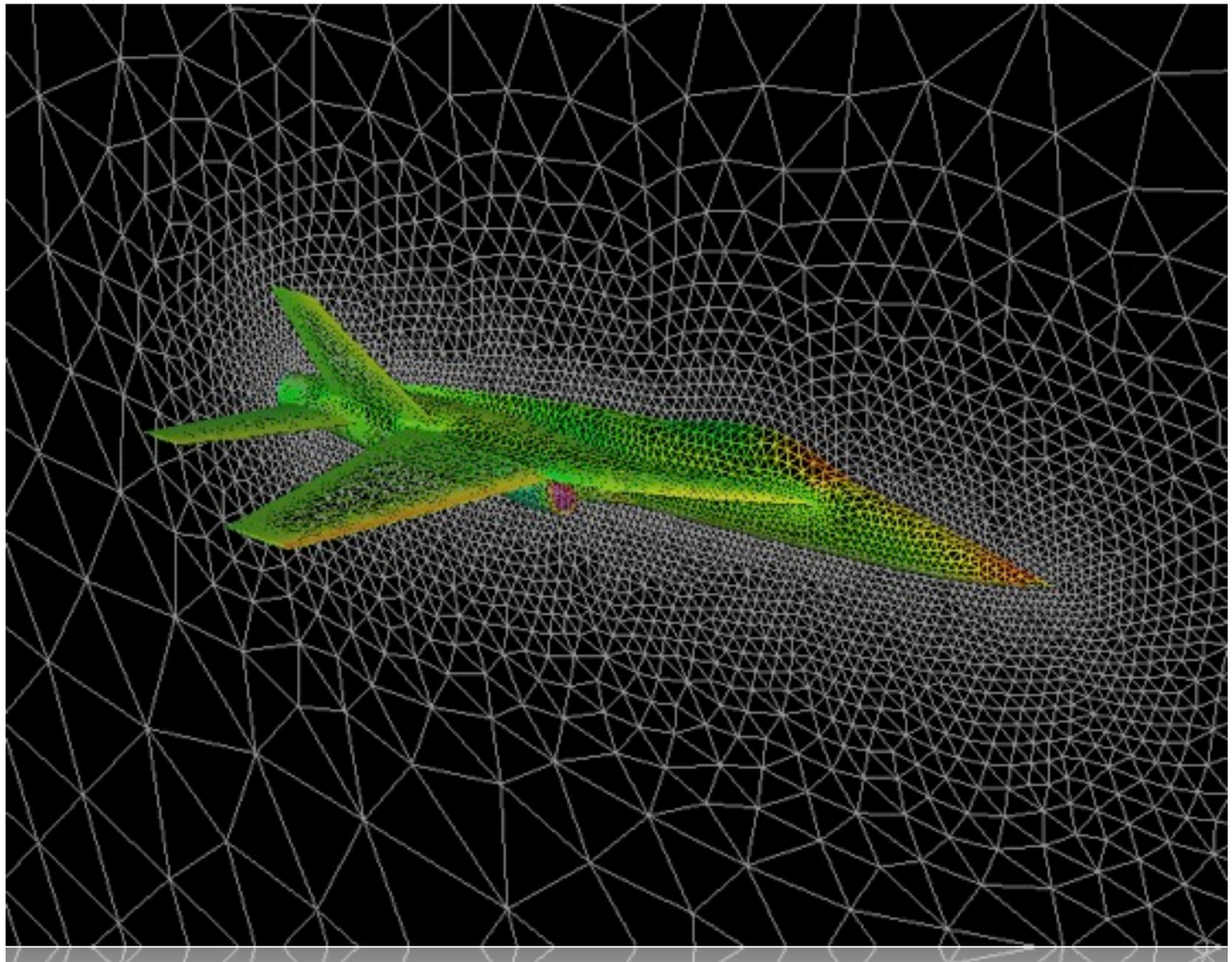
Computational Grid



Meshes



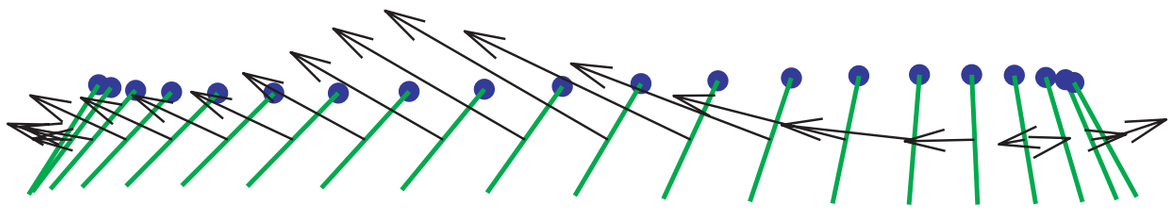
Structured



Unstructured

Moving Bodies

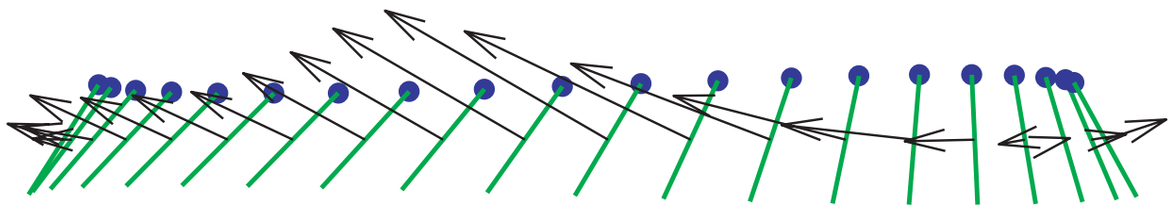
Image: Jane Wang et al , 2004



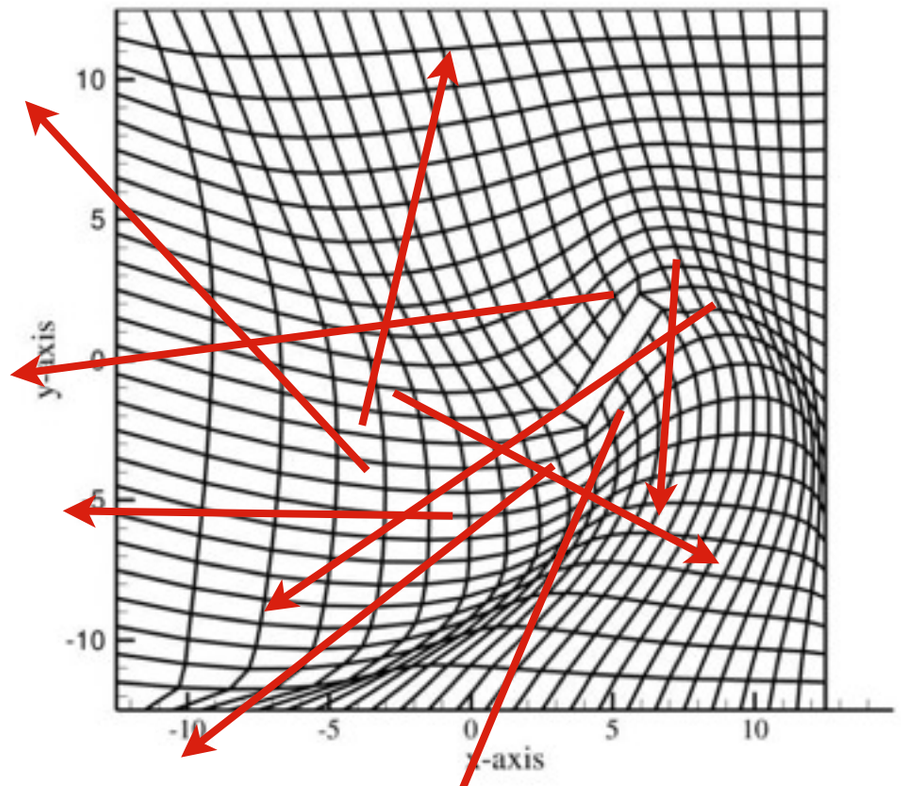
Flapping Airfoil

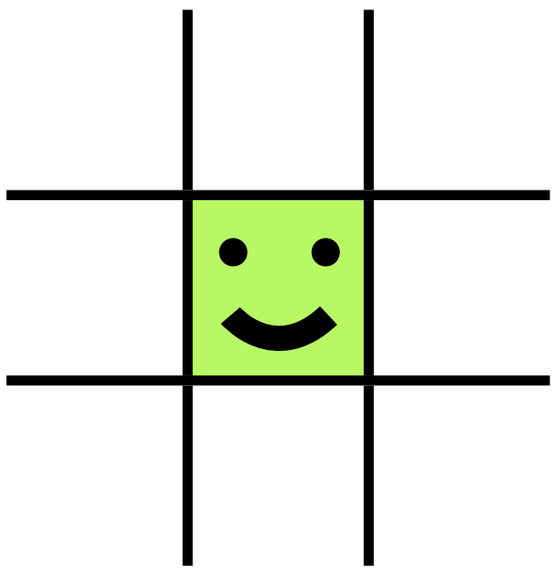
Moving Bodies

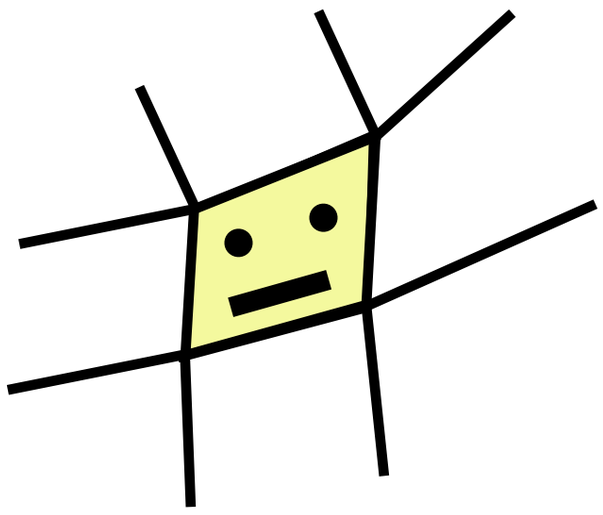
Image: Jane Wang et al , 2004

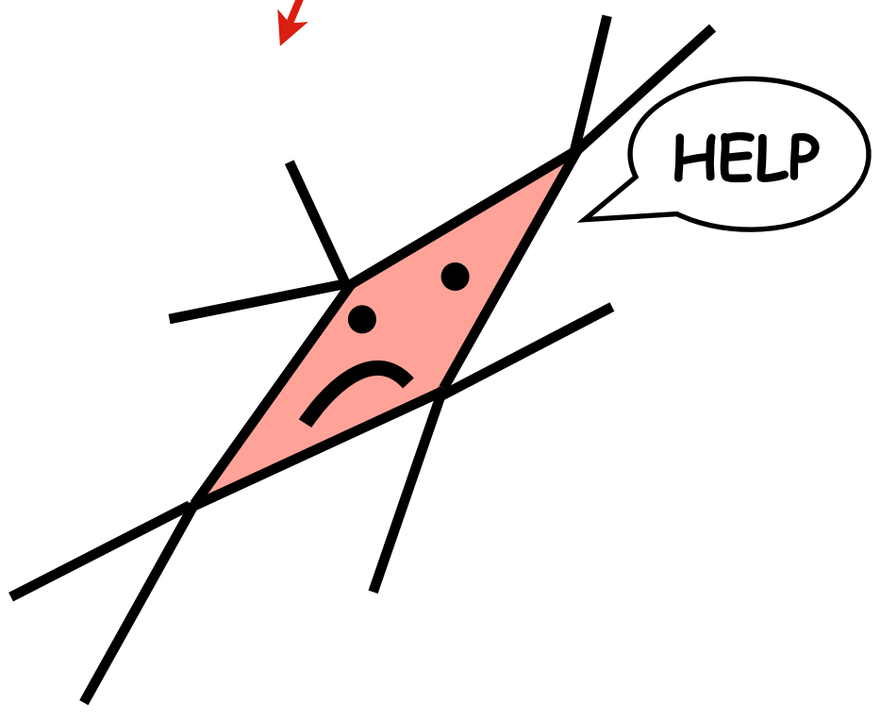


Flapping Airfoil

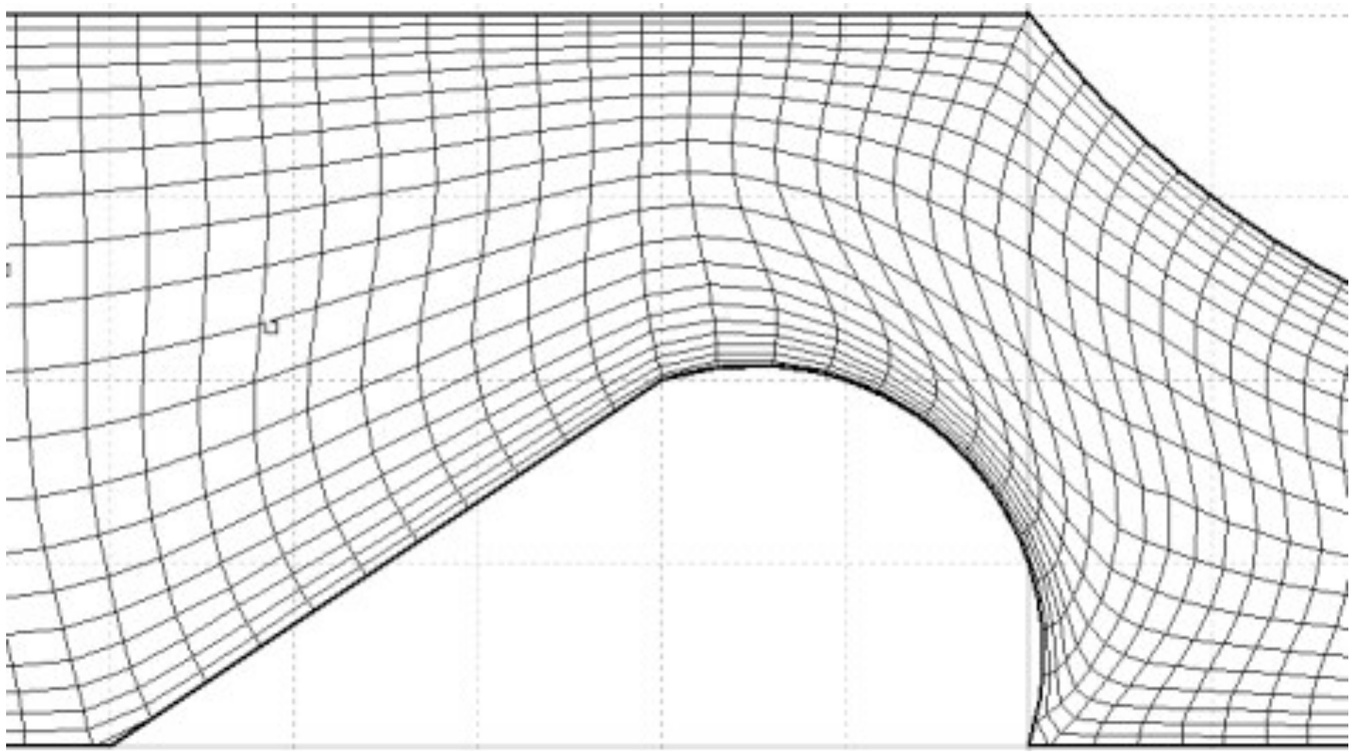








Non-conforming Grids



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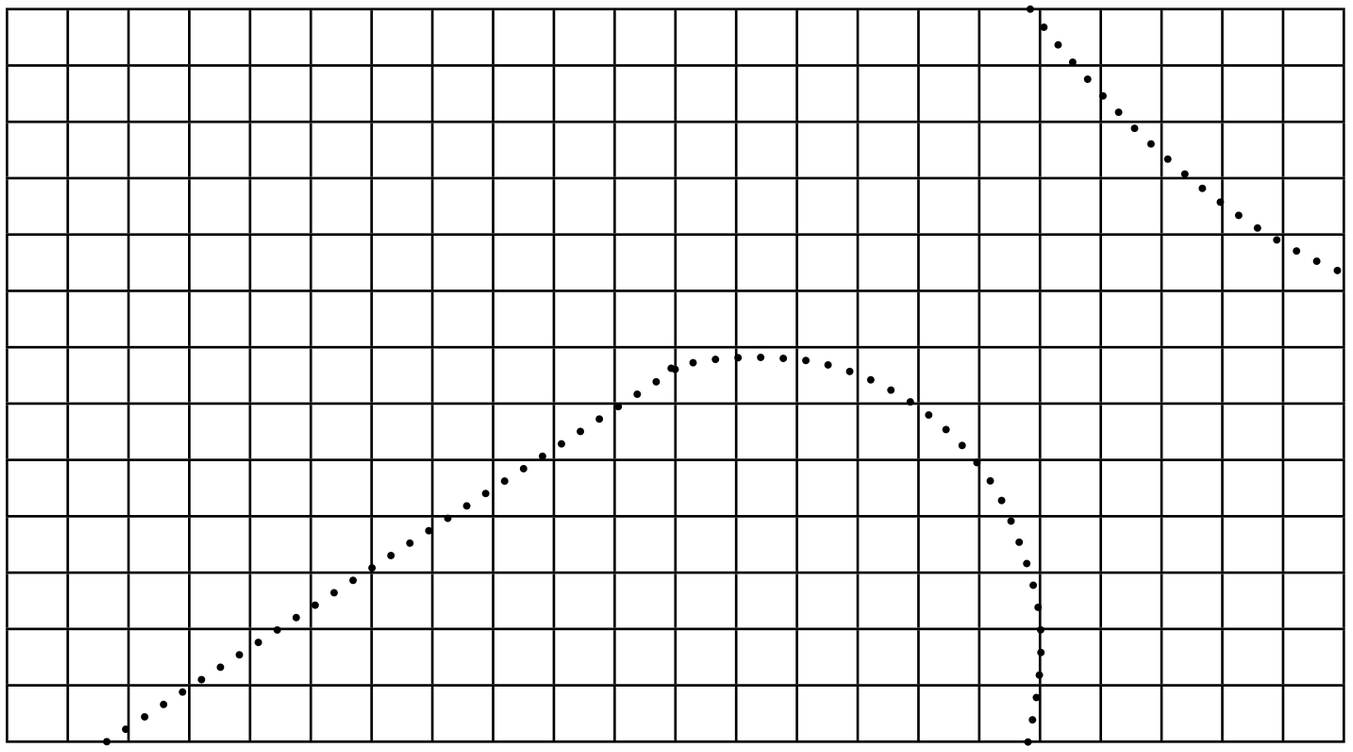
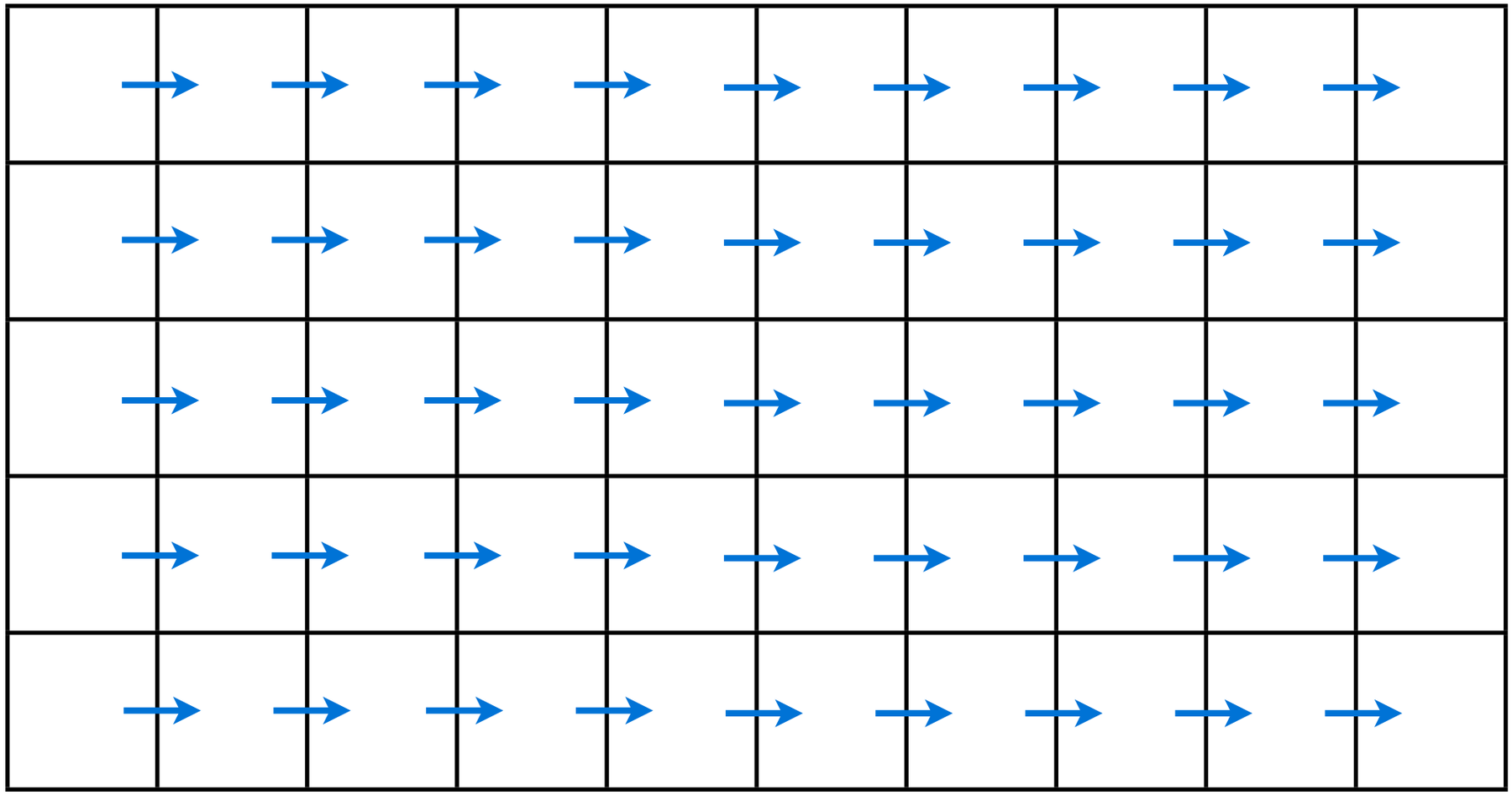
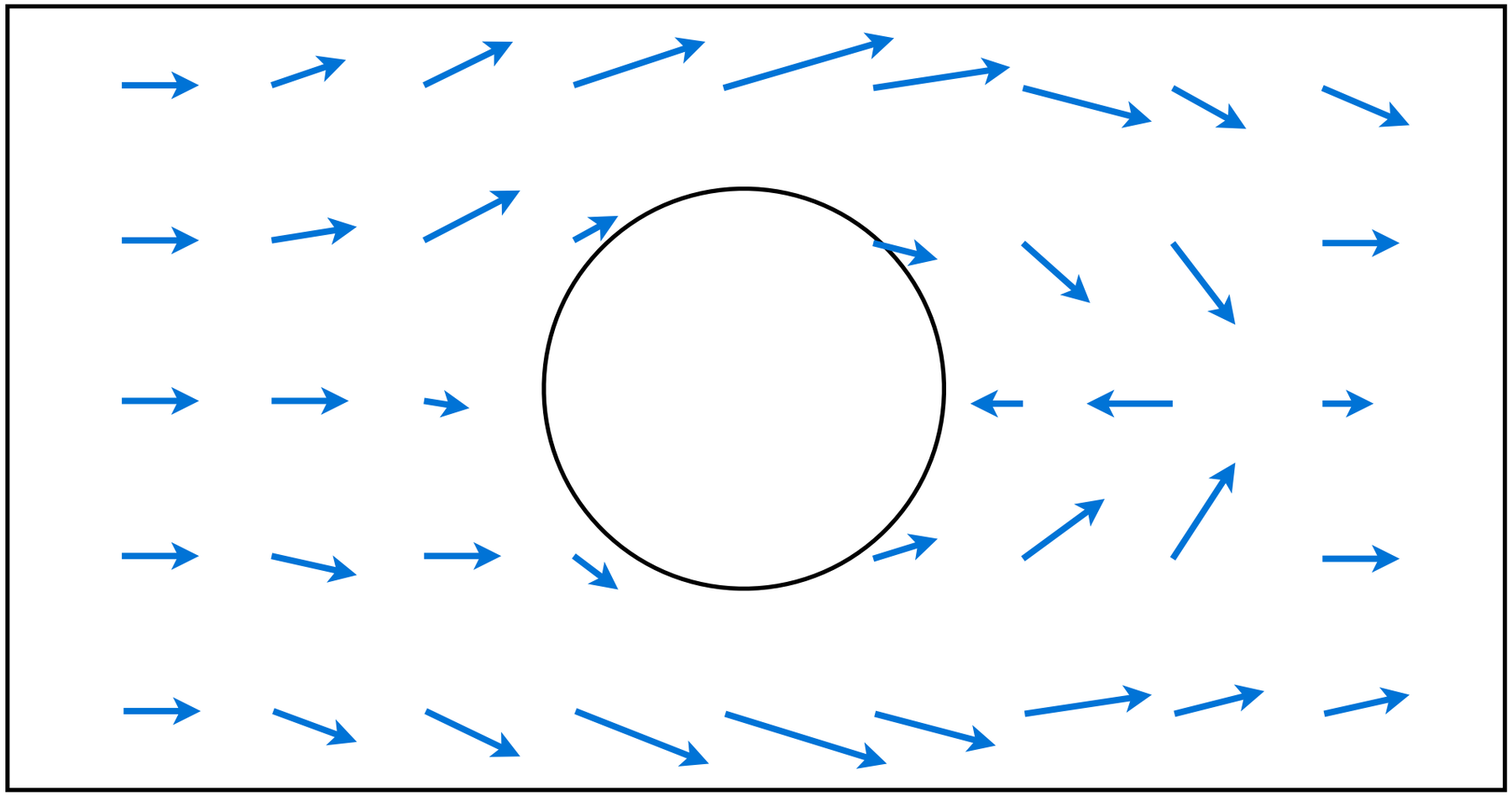


Immersed Boundary Method!

Immersed Boundary Method

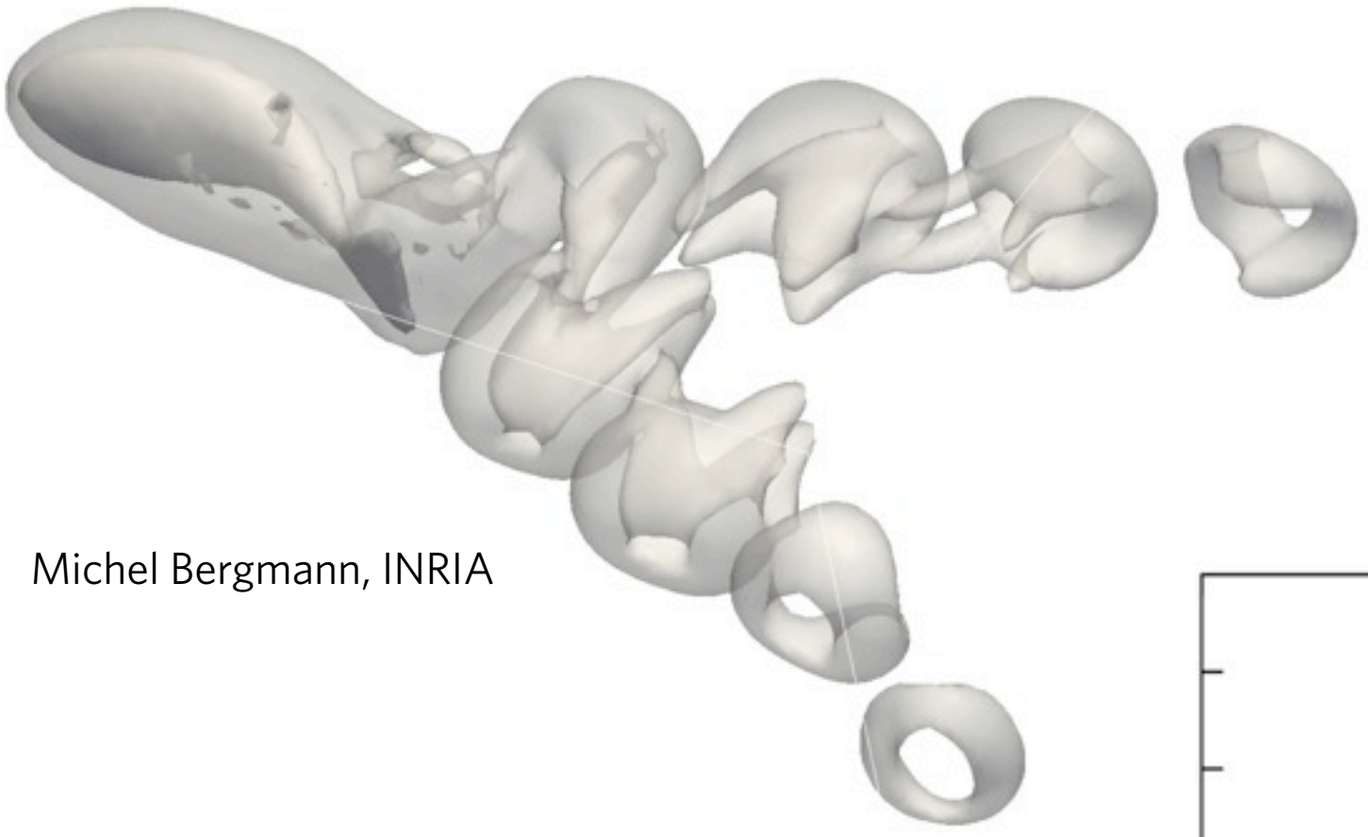


Immersed Boundary Method



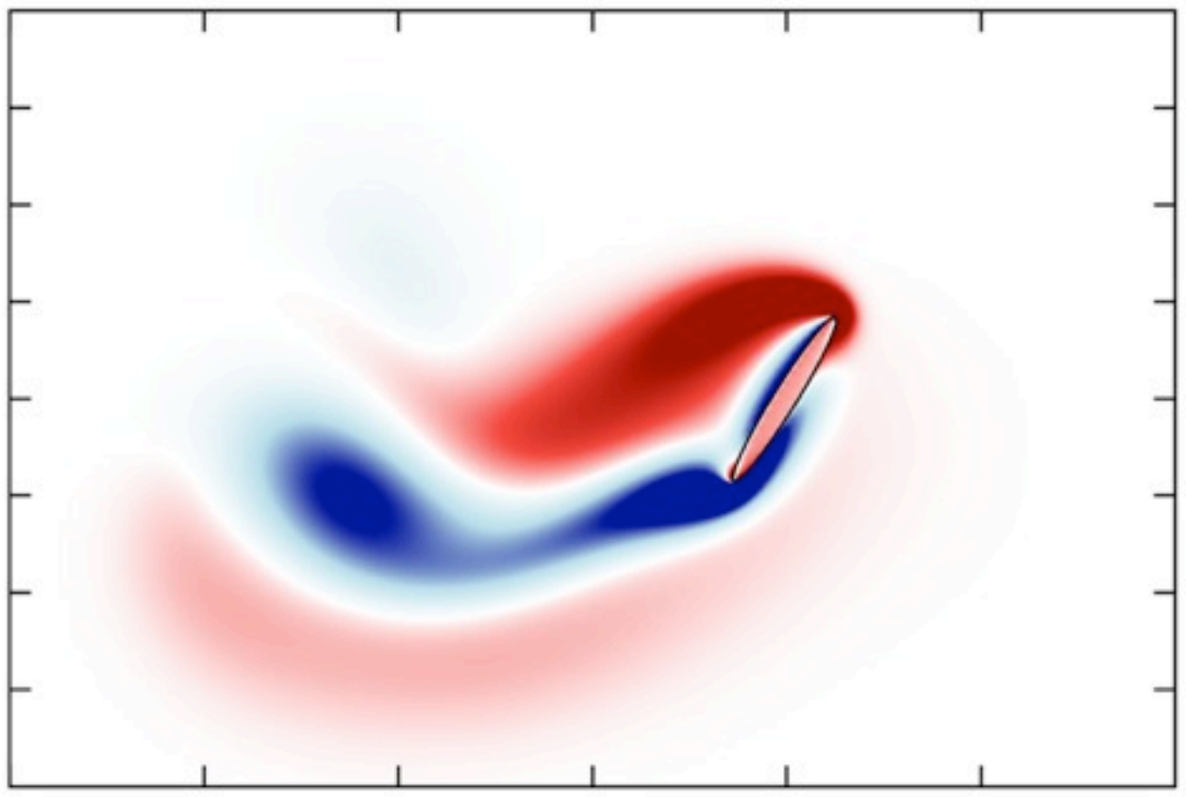
Taira & Colonius, 2007

Immersed Boundary Method



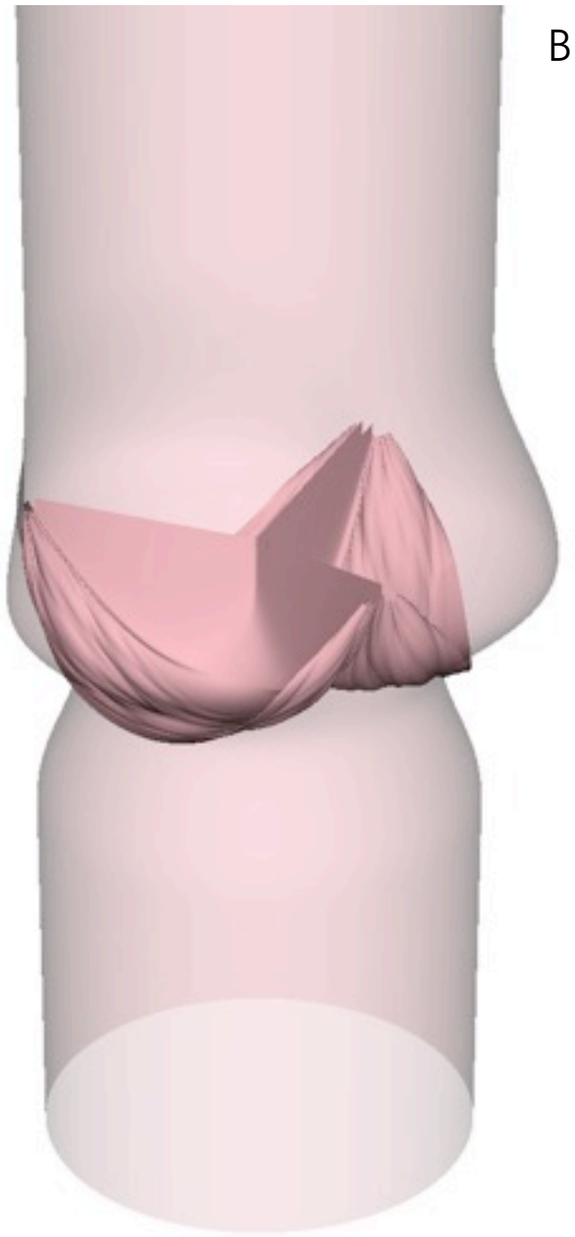
Michel Bergmann, INRIA

Swimmers



Flapping insect wing

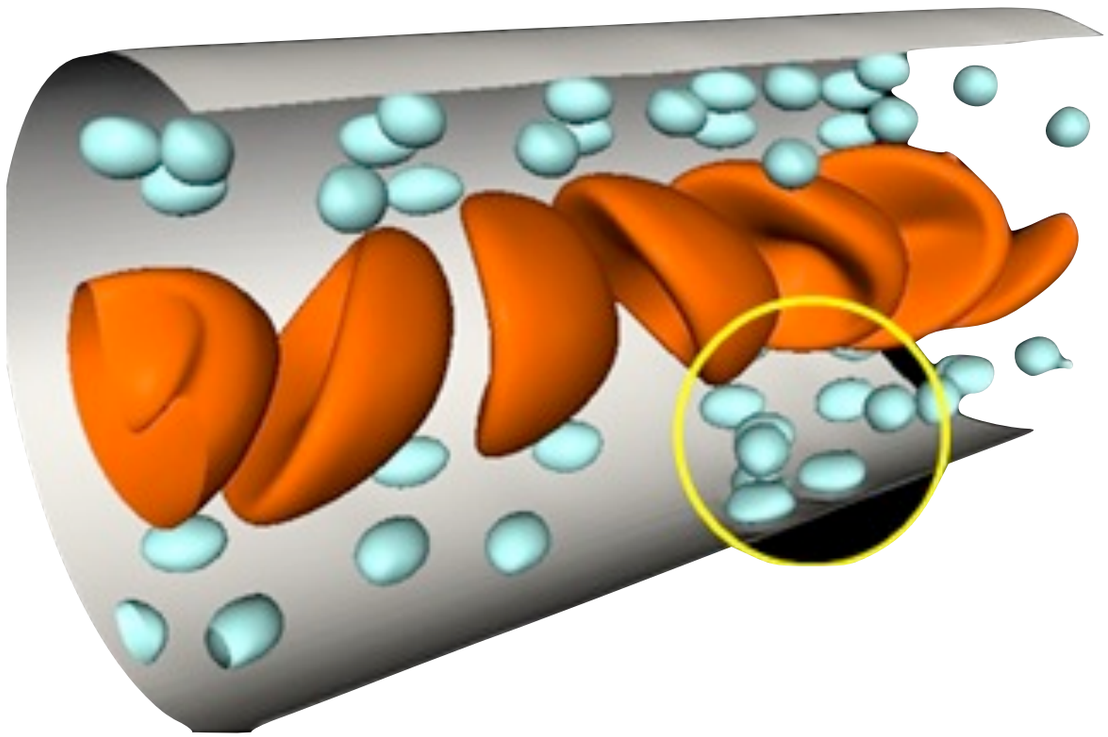
Immersed Boundary Method



B E Griffith, NYU

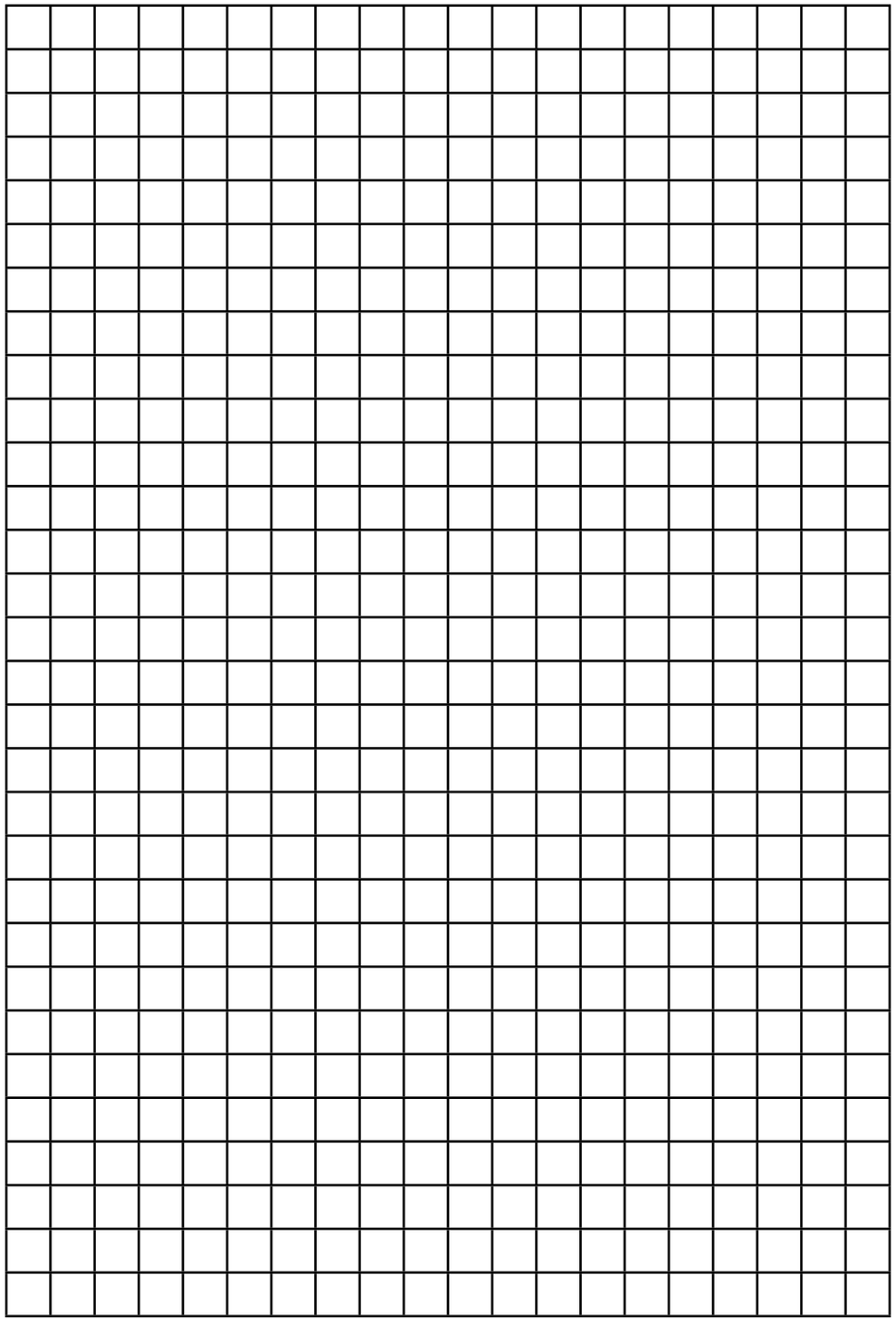
Blood flow through
the aortic valve

Shu Takagi, RIKEN

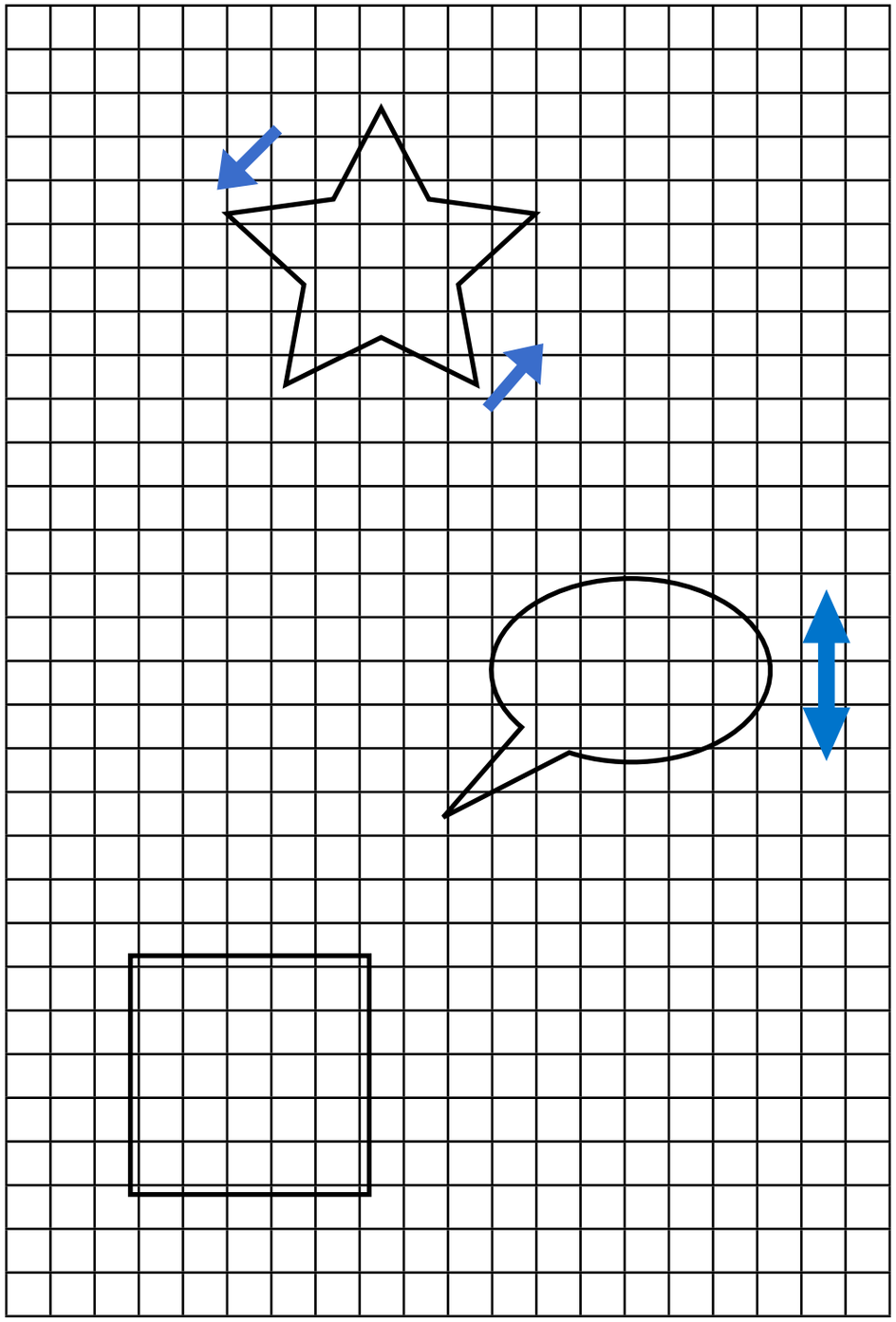


Red blood cells in capillaries

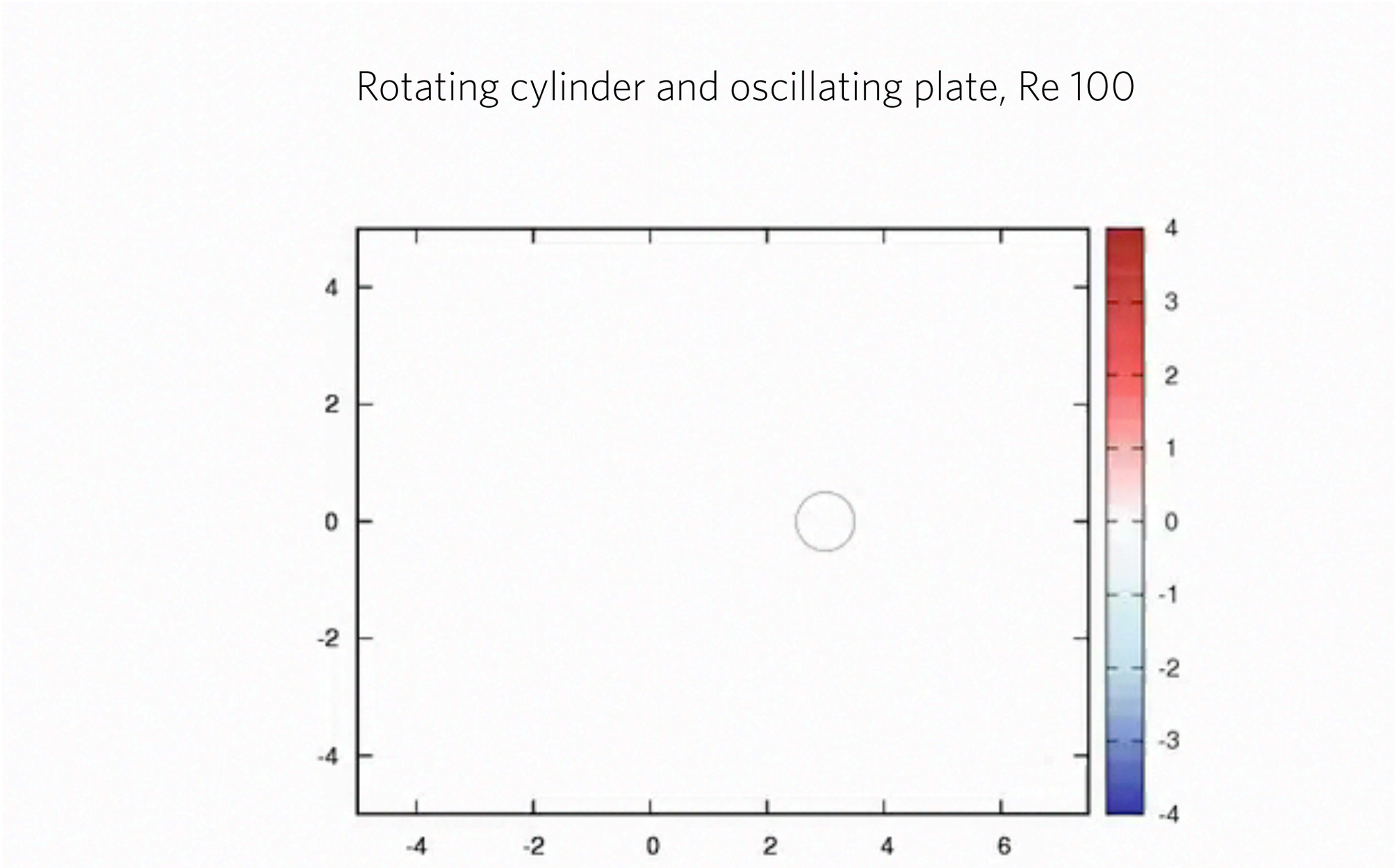
Immersed Boundary Method



Immersed Boundary Method



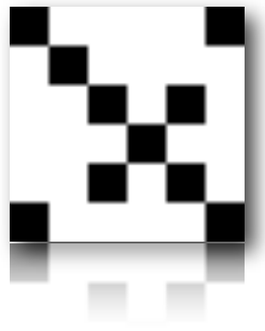
Immersed Boundary Method



GPU Acceleration

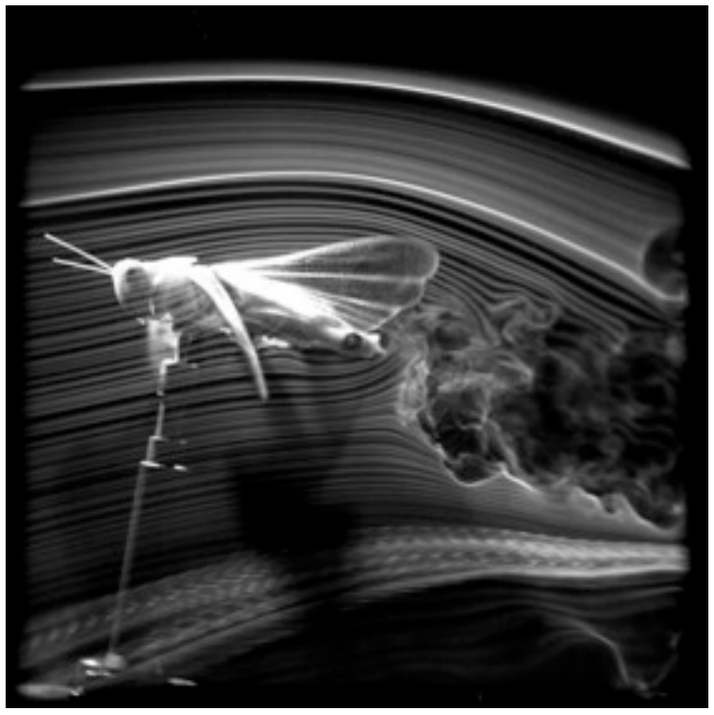
- Pressure & force calculation - **90%**
  - Sparse Linear system

- CUSP
  - NVIDIA Research

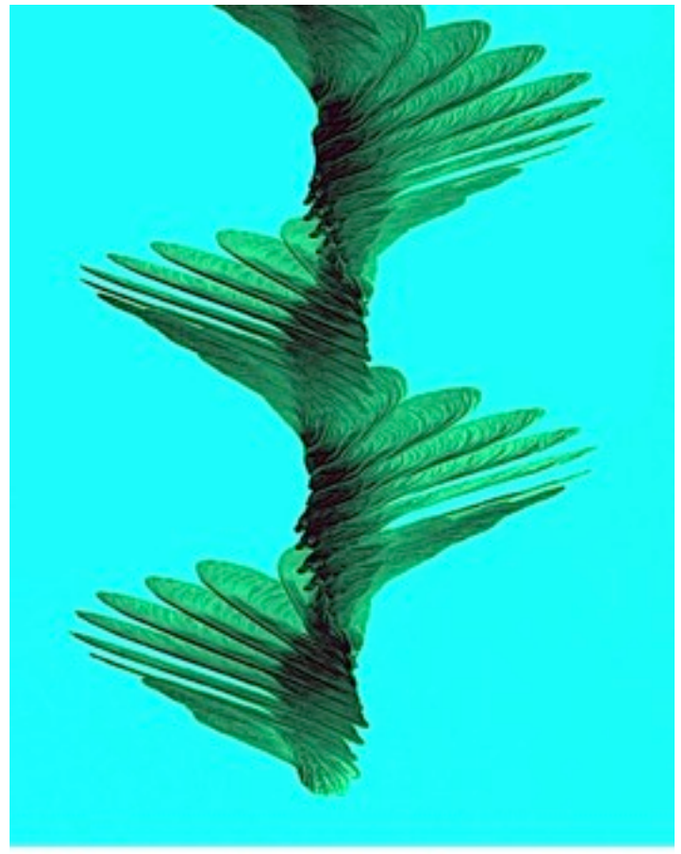


- Pressure solve (2-D)
  - **9x** faster (1 GPU vs 1 CPU core)

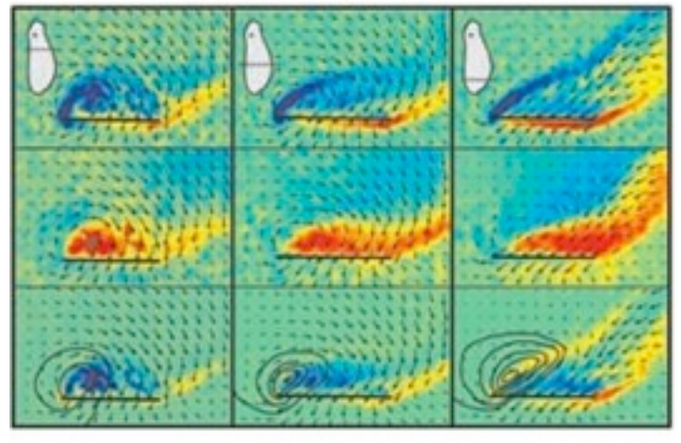
Bio-Aerial Locomotion



Insect Flight



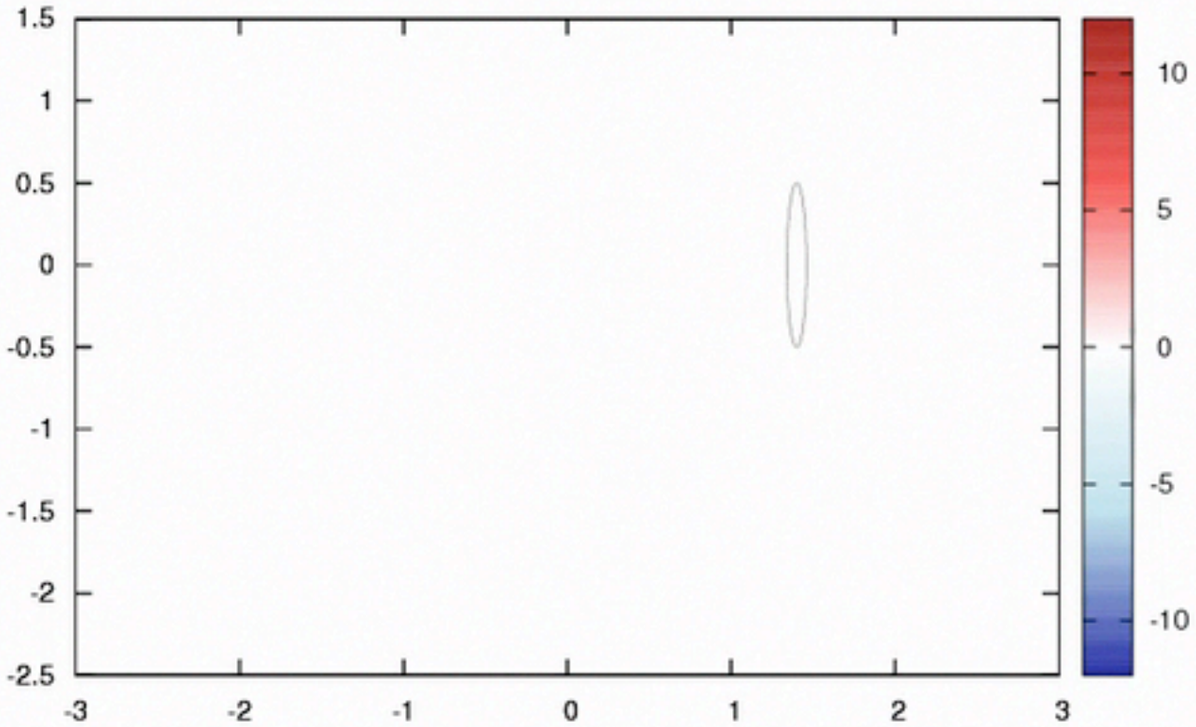
Lentik at al, 2009, Science

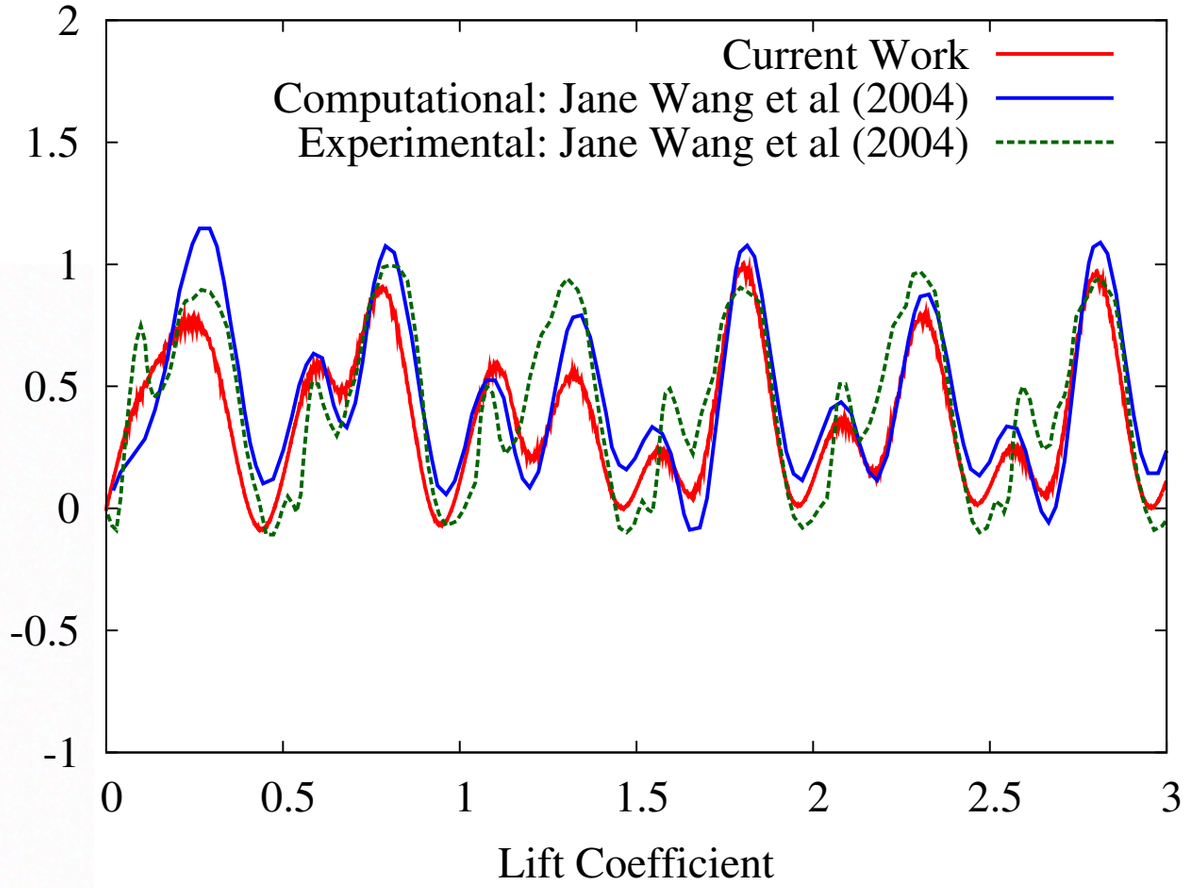


Falling Maple Leaf

Birds

Flapping Airfoil



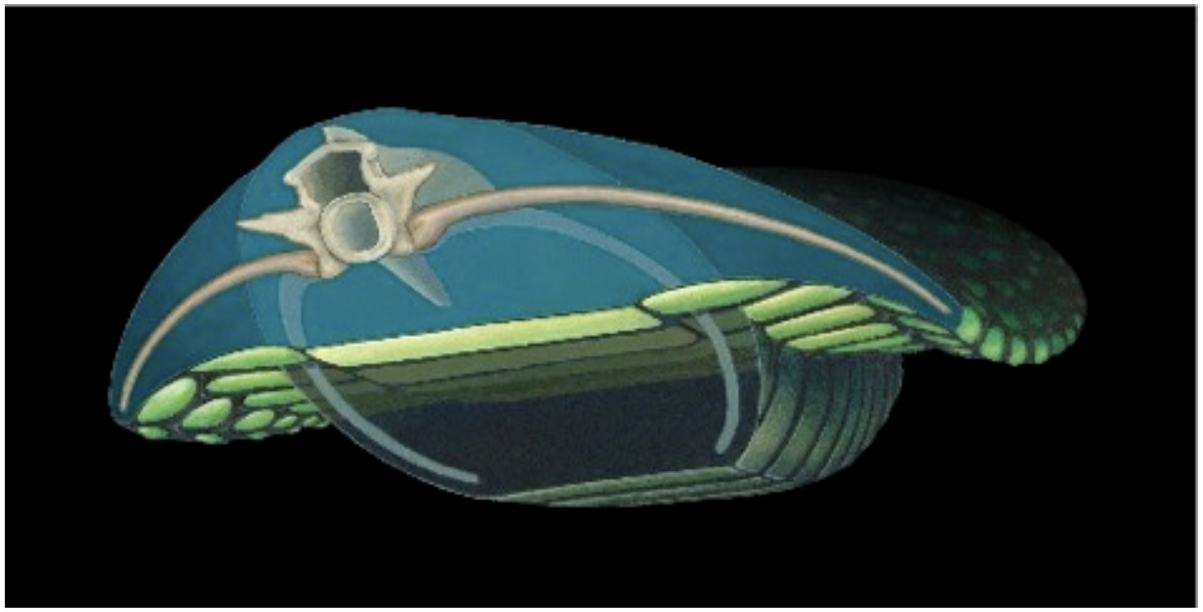


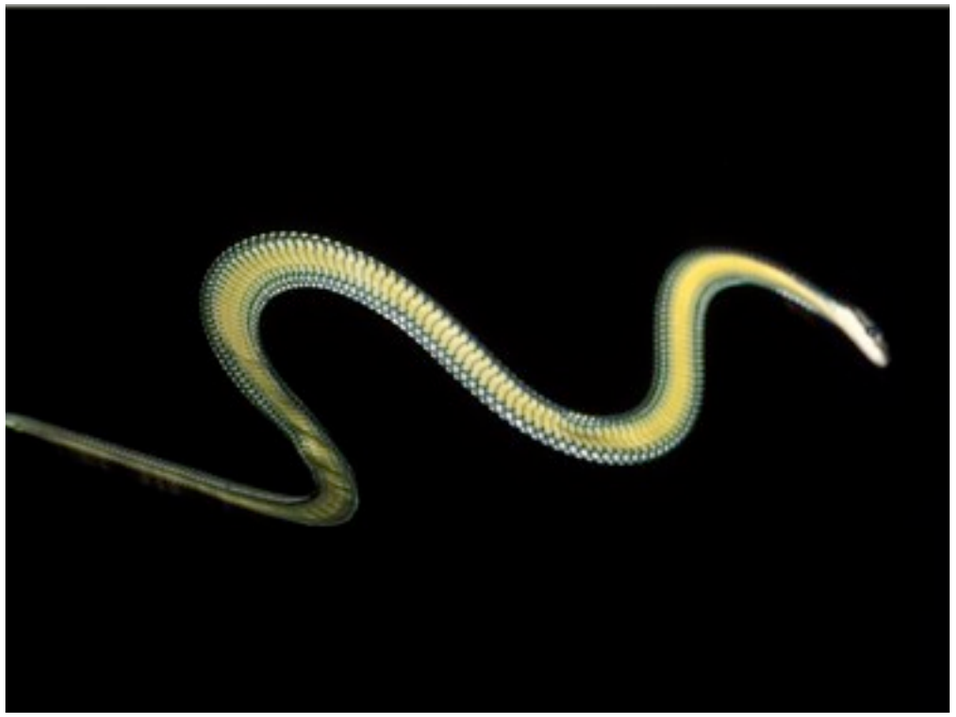
Re 75, Amplitude 1.4, Pitch Amplitude 45°, Frequency 0.25

Flying Snakes

Flying Snakes

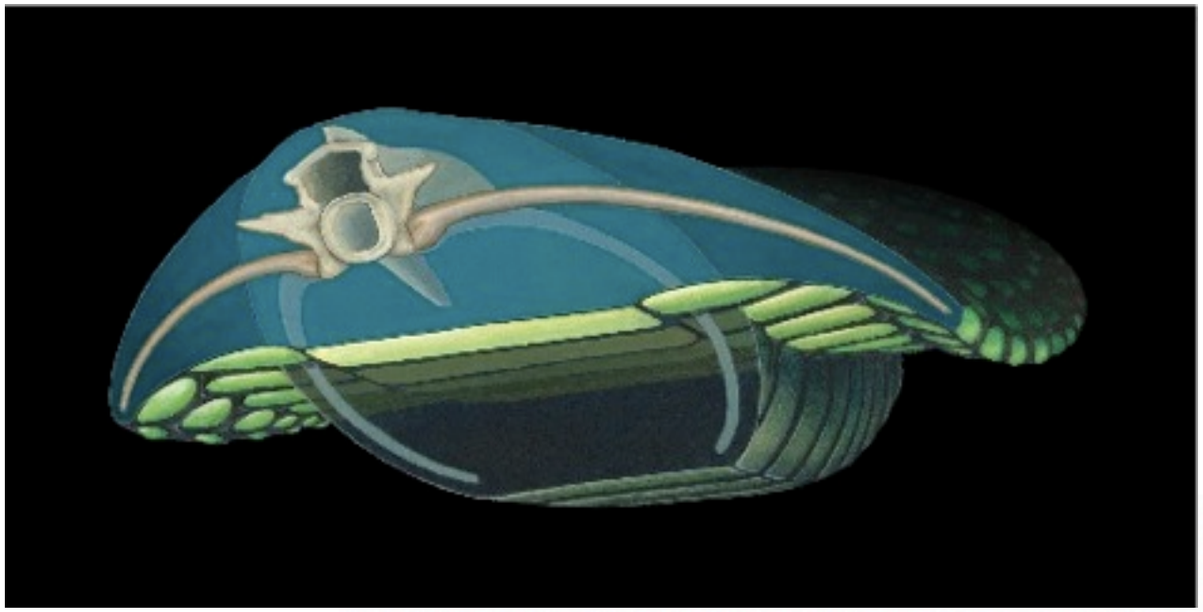
Chrysopelea

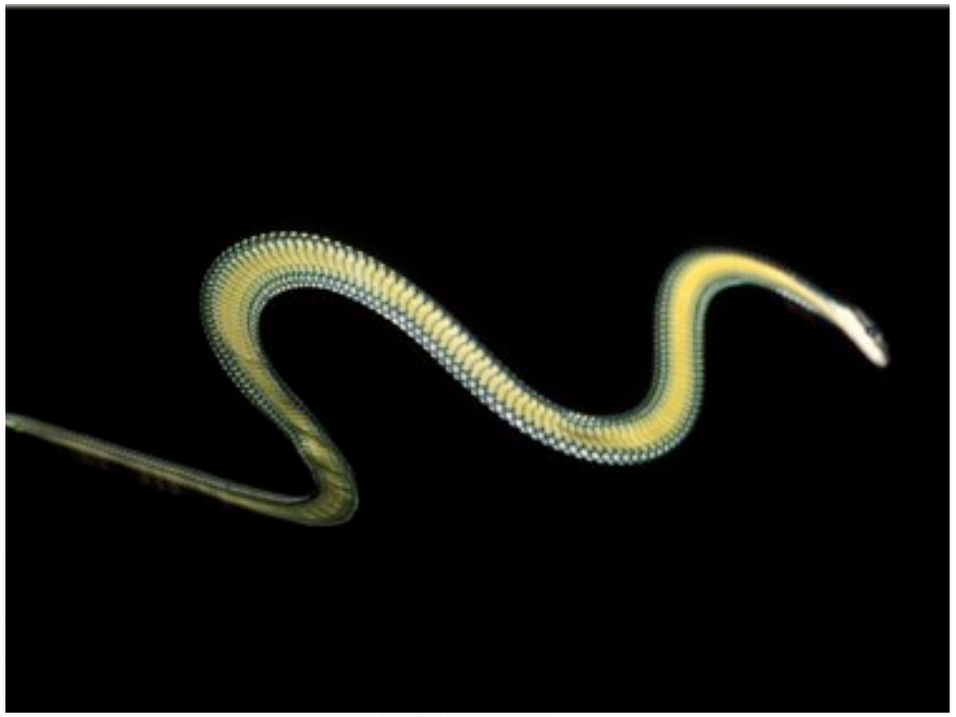




(c) Jake Socha

Chrysopelea





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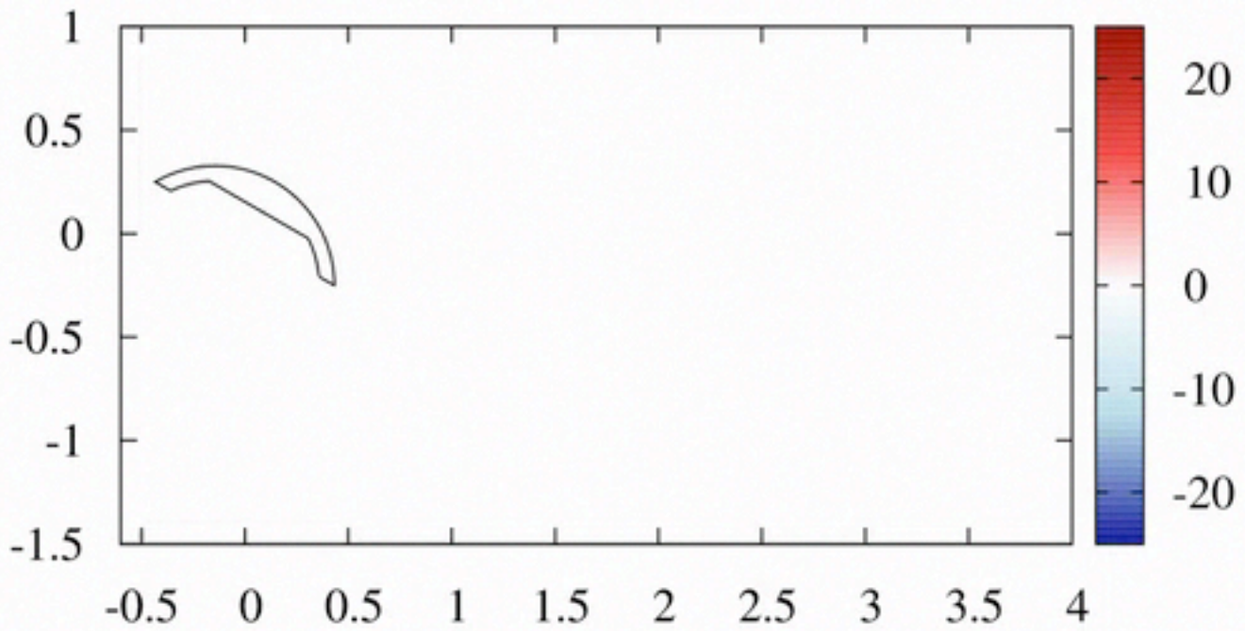
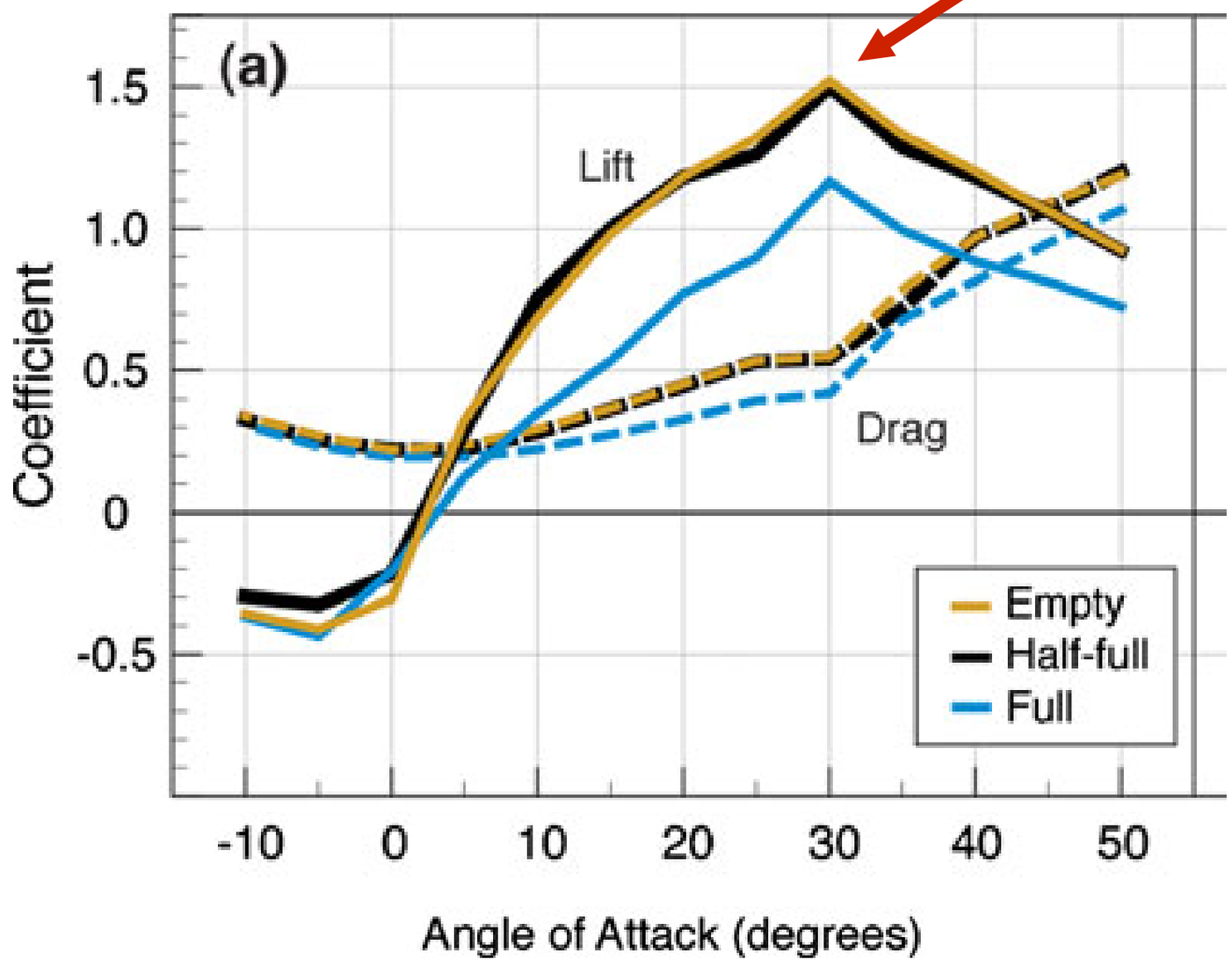


Lift vs Angle of Attack

Reynolds Number **15,000**

Snake operates here!



Why the peak?

Miklasz et al, 2010, Experimental Mechanics

Research Areas

Fluid Structure Interaction

Energy

Conclusions

- Immersed boundary method
  - Looks promising
  - Simple implementation
  - New applications
- Improvements
  - 3D solver
  - New parallel-friendly numerical algorithms