A Full Potential Static Aeroelastic Solver for Preliminary Aircraft Design

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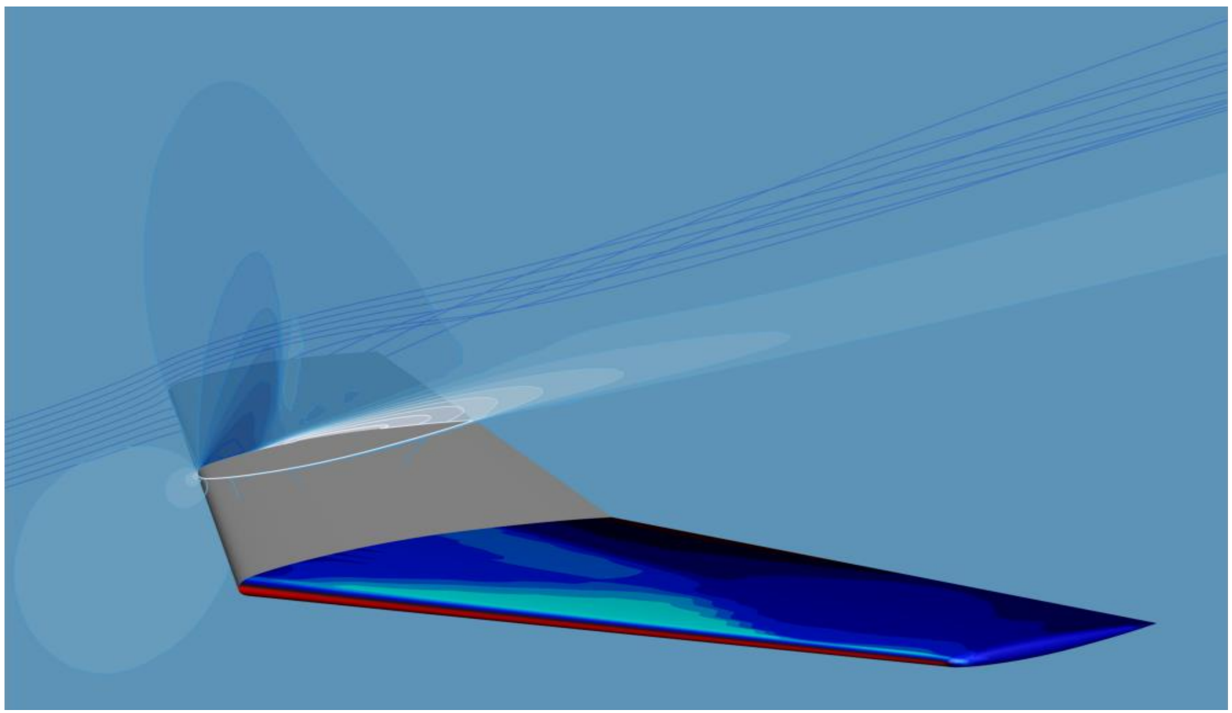


EMBRAER

Savannah, June 2019

LIÈGE université

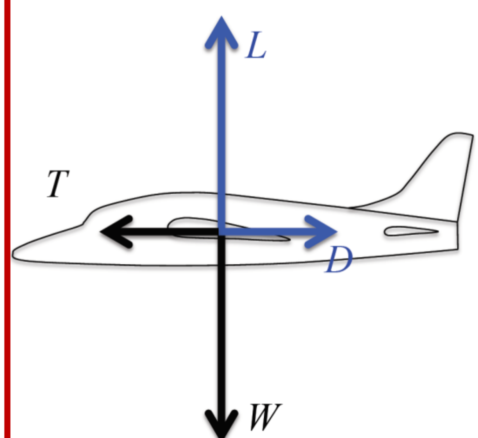
Aircraft design process

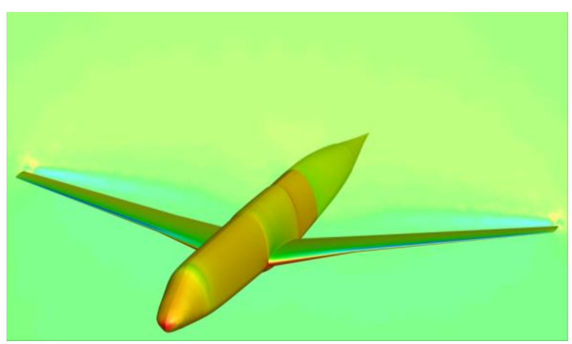
Conceptual → Preliminary → Detail

Concept (1%)
- Requirements & cost
- Aircraft configuration

Model (9%)
- Aircraft lofting
- Component optimization
- Global design

Prototype (90%)
- Manufacturing & certification
- Testing & final performance
- Flight simulators
- Local design



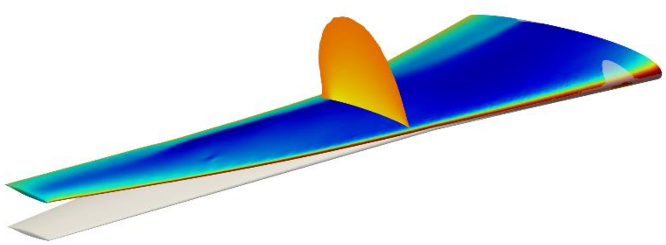


Airbus “BLADE” © T. Laurent (airliners.net)

Aeroelasticity in aircraft design

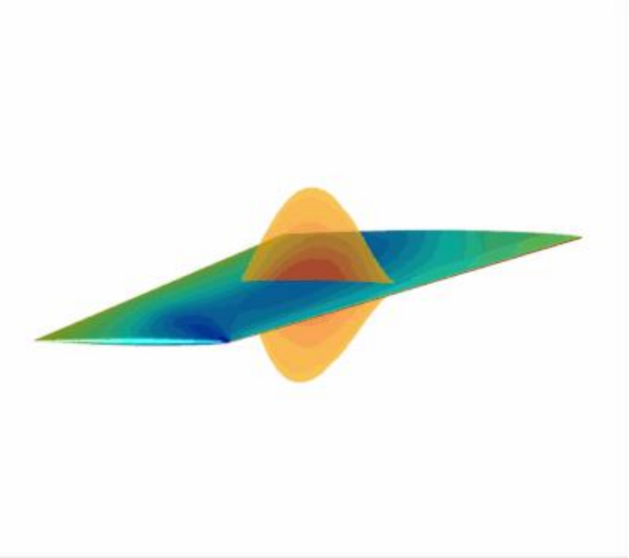
Static aeroelasticity

- Divergence speed
- Flight shape



Dynamic aeroelasiticty

- Flutter speed
- Buffeting



D. Thomas – ULiege

Enable aero-structural design and optimization

Aerodynamics for aeroelastic computations

Context

Early preliminary design

- Aerodynamic loads
- Fast linear solvers

Challenges

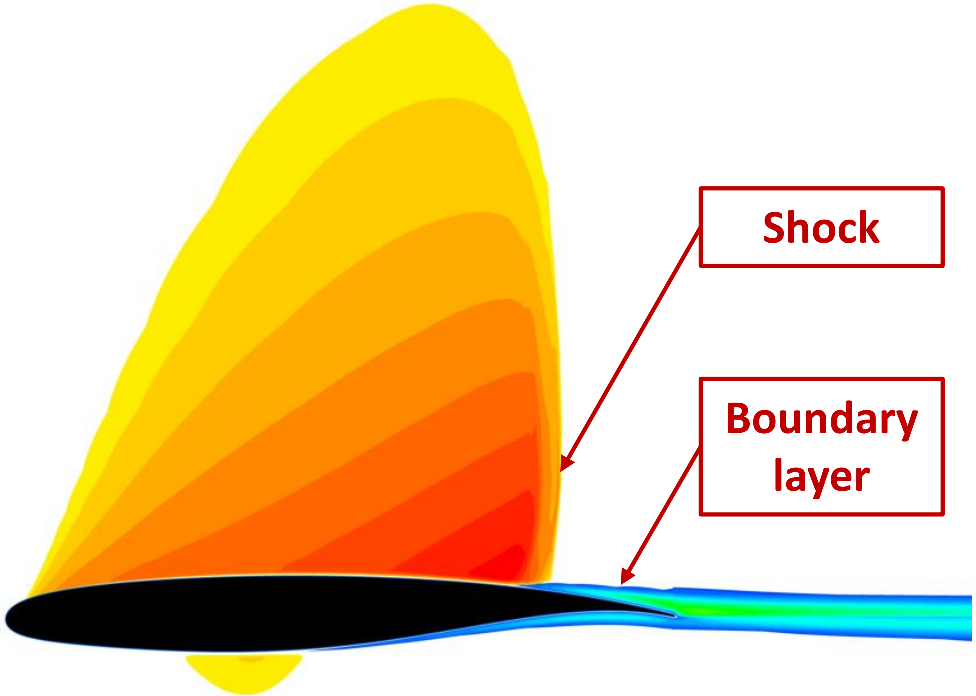
Flow nonlinearities

- Shock
- Boundary layer

Objective

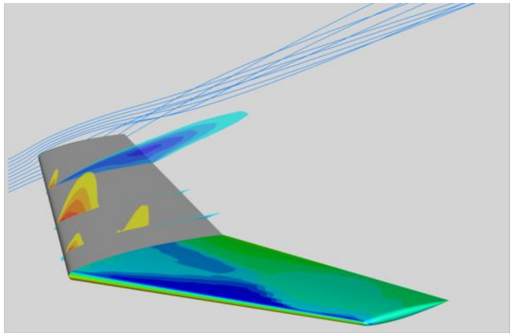
New code

- Fast
- Nonlinear
- Integrable



Research project overview

Benchmark

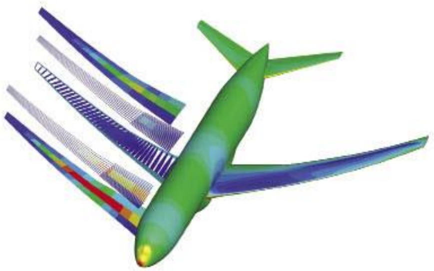


Evaluate existing models & methods that solve steady transonic flows

Development

Develop a fast aerodynamic solver for transonic loads computation based on the most efficient flow model

Integration



Implement an interface to integrate the newly developed methodology into a design framework

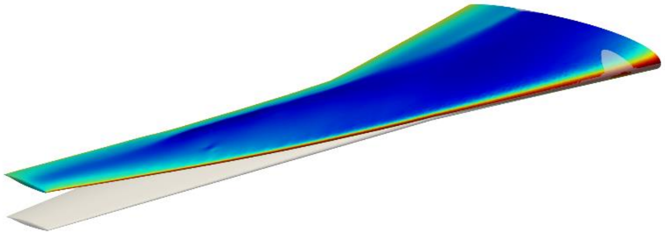
Presentation overview

Methodology

- Framework
- Flow
- CUPyDO

Results

- Solvers and benchmark
- Aerodynamic computations
- Aeroelastic computations



Framework – python wrappers

Python

```python
import flow
import gmsh

# Build mesh
msh = gmsh.meshLoader(rae.geo)

# Define problem
pbl = flow.Problem(msh)
pbl.add(flow.Neumann(…))
pbl.add(flow.Kutta(…))

# Run solver
solver = flow.Solver(pbl)
solver.run()

# …
```

SWIG

C++

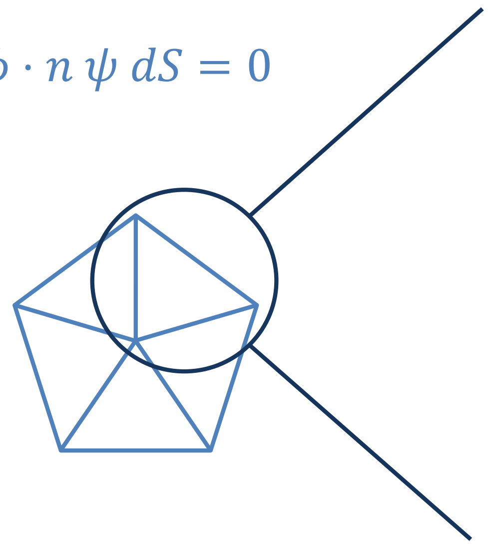
```cpp
class FLOW_API Solver : public wObject
{
public:
Solver(std::shared_ptr<Problem> _pbl);
void run();
};
```

- ✓ **CPU/memory efficient**
- ✓ **User friendly**
- ✓ **Flexible**

Flow – formulation

$$\nabla \cdot (\rho \nabla \phi) = 0$$

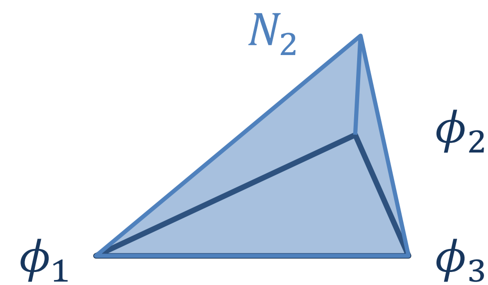
$$\iiint_\Omega \rho \nabla \phi \cdot \nabla \psi \, dV - \iint_\Gamma \rho \nabla \phi \cdot n \, \psi \, dS = 0$$

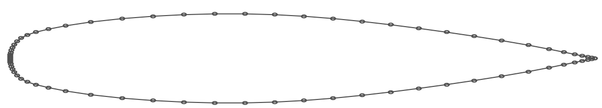


$$x = N_i\big(x(\xi,\eta), y(\xi,\eta)\big) x_i$$

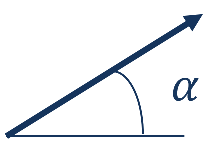
$$y = N_i\big(x(\xi,\eta), y(\xi,\eta)\big) y_i$$

$$\phi = N_i\big(x(\xi,\eta), y(\xi,\eta)\big) \phi_i$$





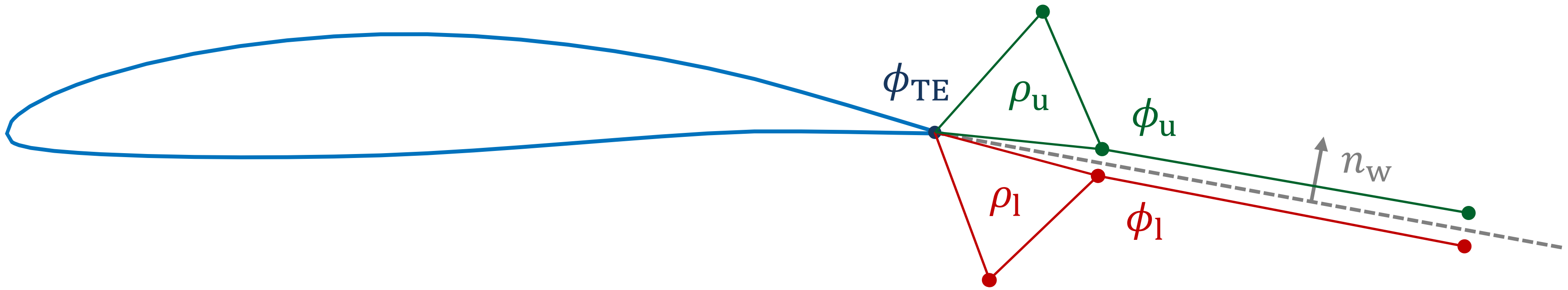
$$\nabla \phi \cdot n = 0$$



$$\nabla \phi_\infty = \{\cos\alpha, \sin\alpha\}$$

$$\nabla \phi \cdot n = \nabla \phi_\infty \cdot n$$

Flow – Kutta condition



Formulation

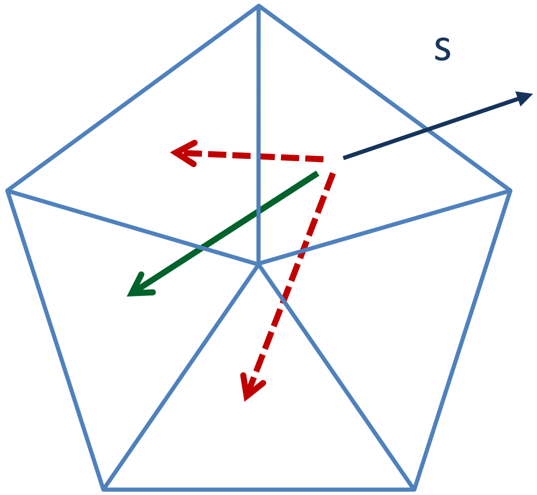
$$\rho_{\mathrm{u}} \nabla_{\mathrm{n}} \phi_{\mathrm{u}} = \rho_{\mathrm{l}} \nabla_{\mathrm{n}} \phi_{\mathrm{l}} \quad \rightarrow \iint \psi \, [[\rho \nabla \phi \cdot n]] \, dS = 0$$

$$p_{\mathrm{u}} = p_{\mathrm{l}} \quad \rightarrow \iint \left(\psi + \frac{h}{2} U_{\infty} \cdot \nabla \psi \right) [[|\nabla \phi|^2]] \, dS = 0$$

Flow – shock treatment

Density upwinding

$$\tilde{\rho} \sim \rho - \mu \frac{\partial \rho}{\partial s} \Delta s$$



Newton-Raphson procedure

$$F(\phi) = 0 \Rightarrow \frac{\partial F}{\partial \phi} \Delta \phi + F \approx 0$$

- ✓ Analytical tangent matrix
- ✓ Quadratic (3 points) line search
- ✓ Adaptive viscosity ramping

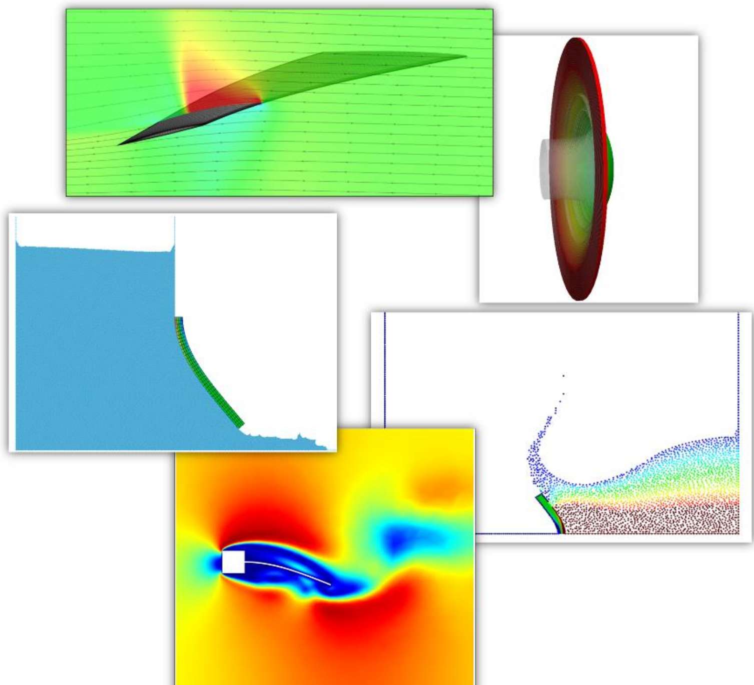
$$\mu = \boldsymbol{\mu}_{\mathbf{c}_{\downarrow}} \left(1 - \frac{\boldsymbol{M}_{\mathbf{c}_{\uparrow}}^{\mathbf{2}}}{M^2} \right)$$

CUPyDO – contributions

Romain Boman

David Thomas

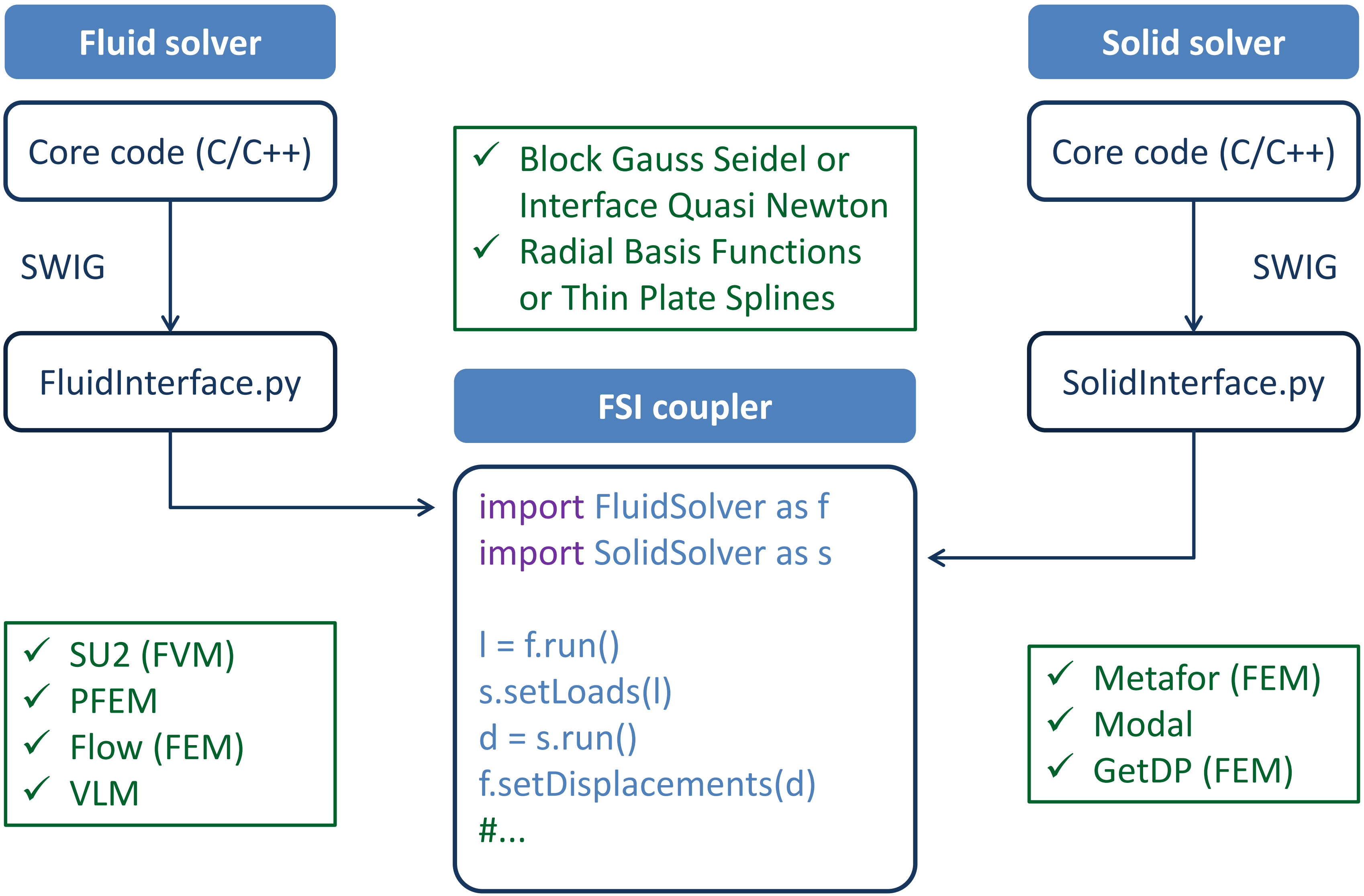
Marco L. Cerquaglia



Adrien Crovato

Mariano Sanchez M.

CUPyDO – architecture



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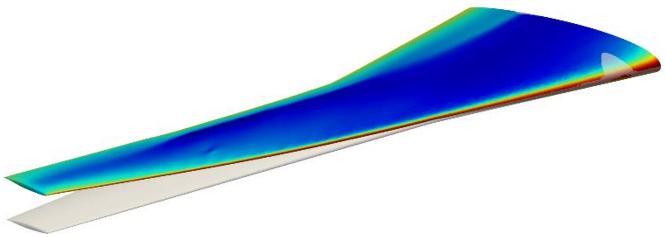
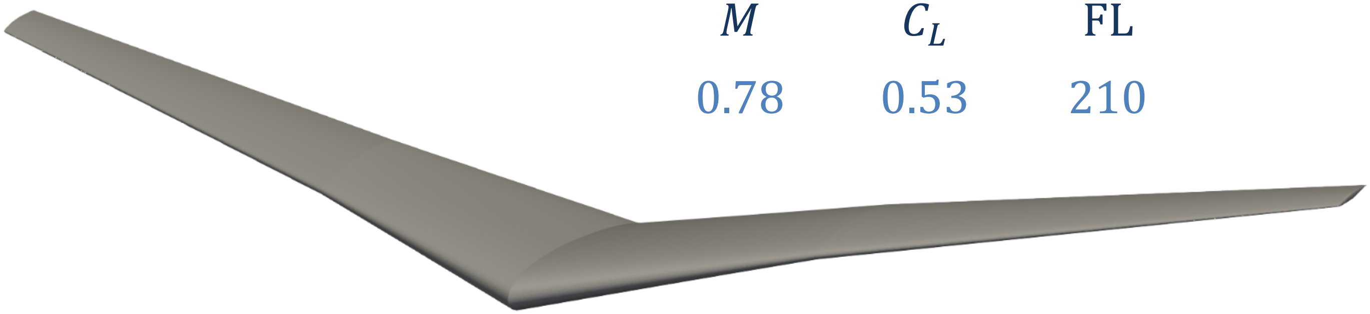


Solvers and benchmark case

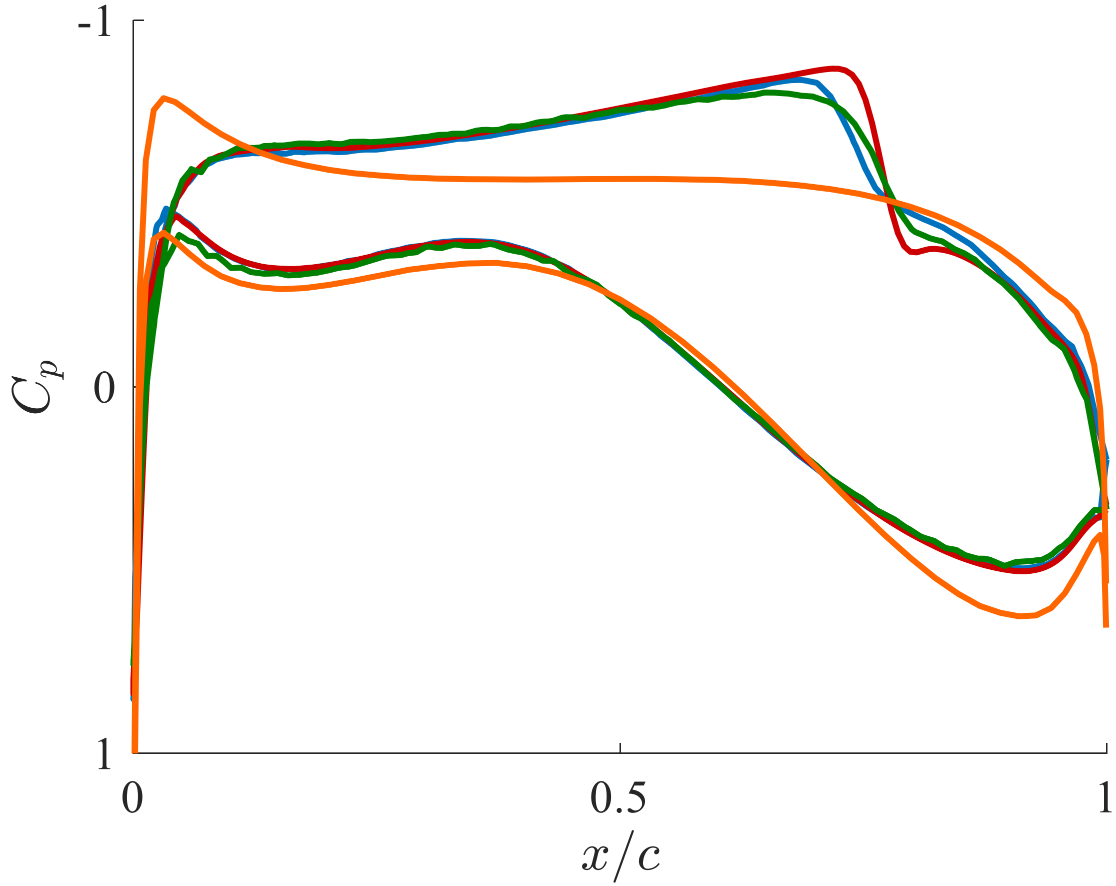
SU2	Euler	Finite Volume
Tranair	Full Potential	Finite Element
Flow	Full Potential	Finite Element
Panair/NASTRAN	Linear Potential	Boundary Element

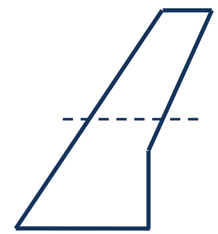
Embraer Benchmark Wing

M	C_L	FL
0.78	0.53	210



Pressure distributions





$$\frac{y}{b} = 0.406\ (\bar{\bar{c}})$$

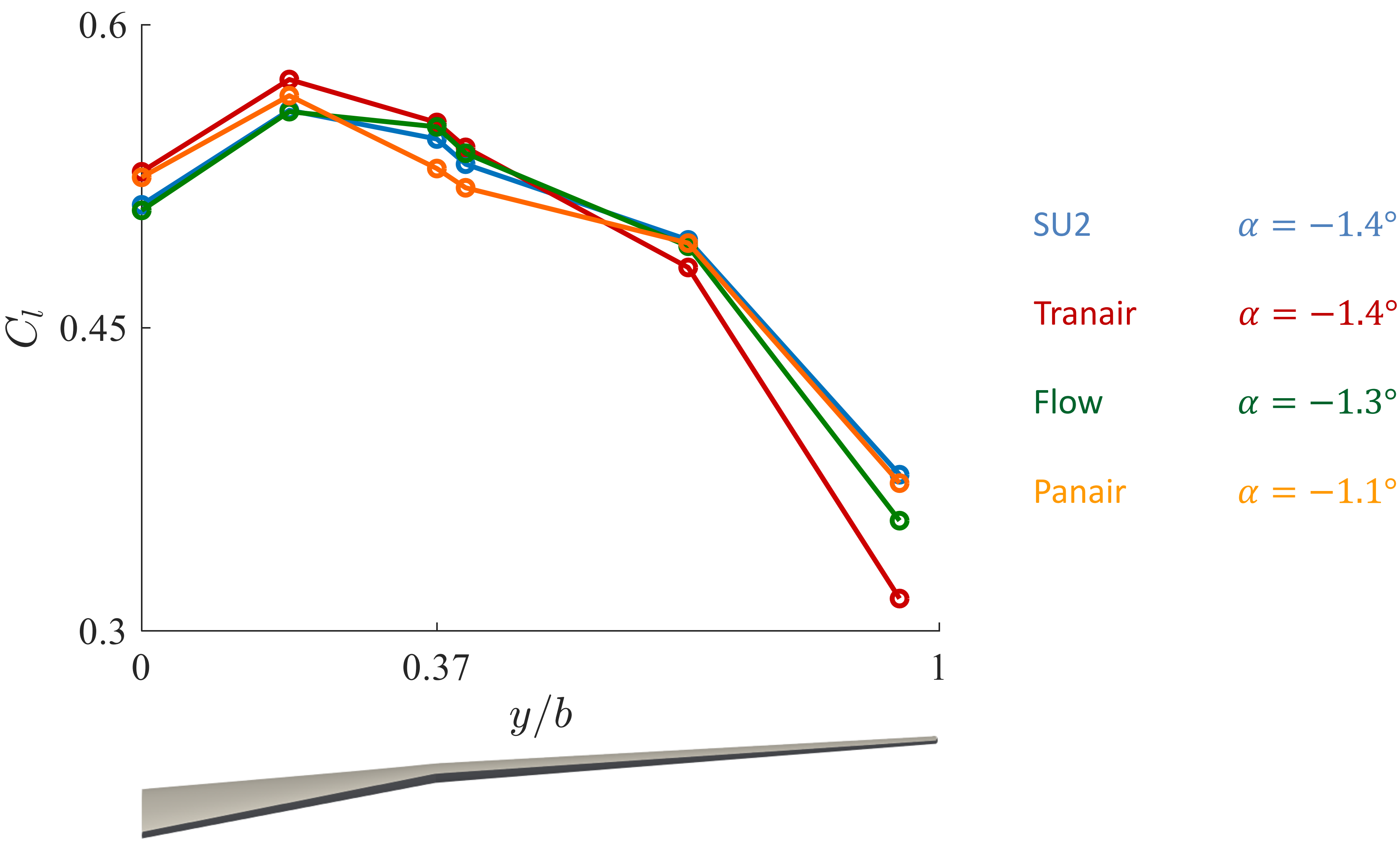
SU2 6×9000 [s]

Tranair 1×500 [s]

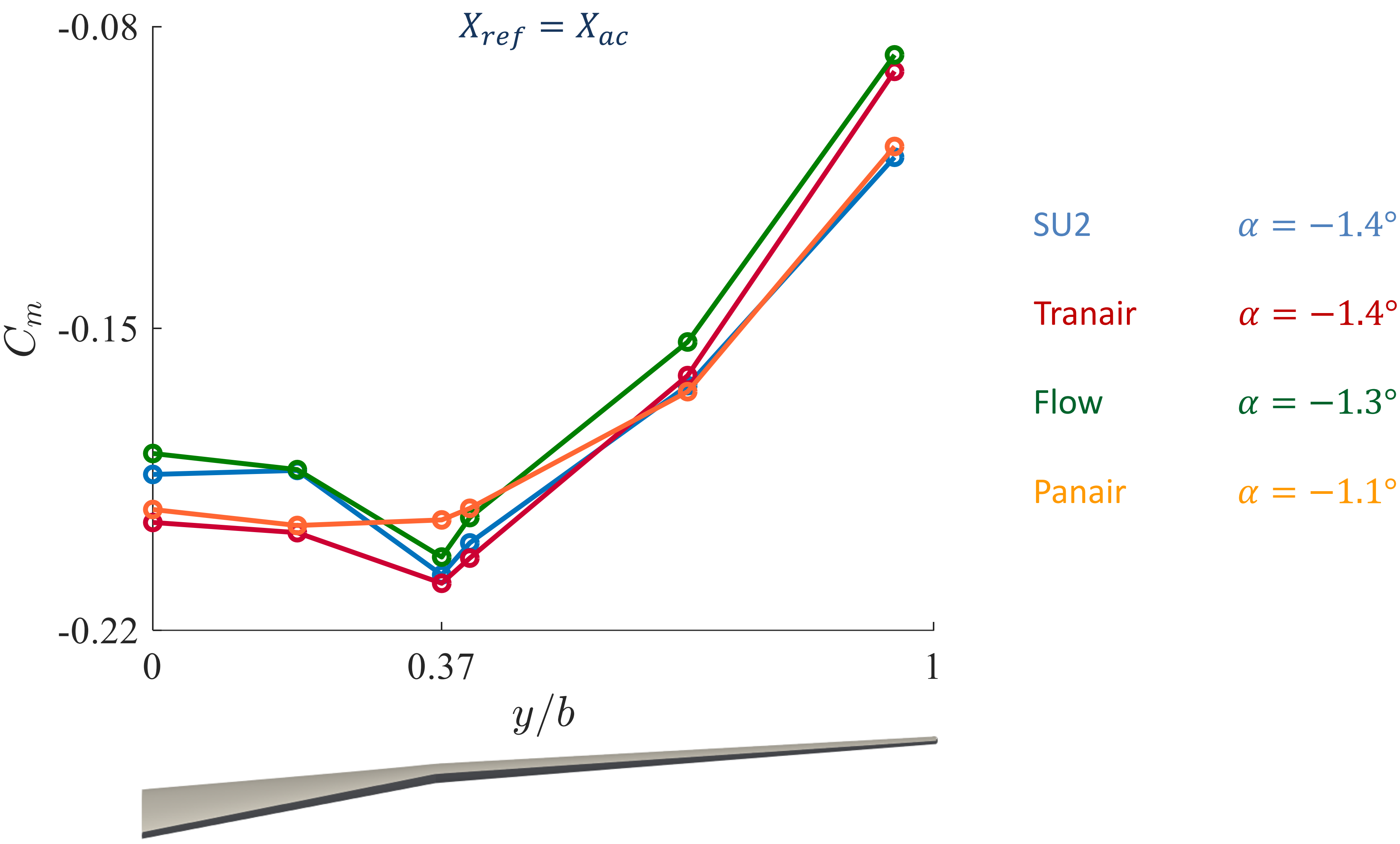
Flow 1×1500 [s]

Panair 1×10 [s]

Lift distributions



Moment distributions

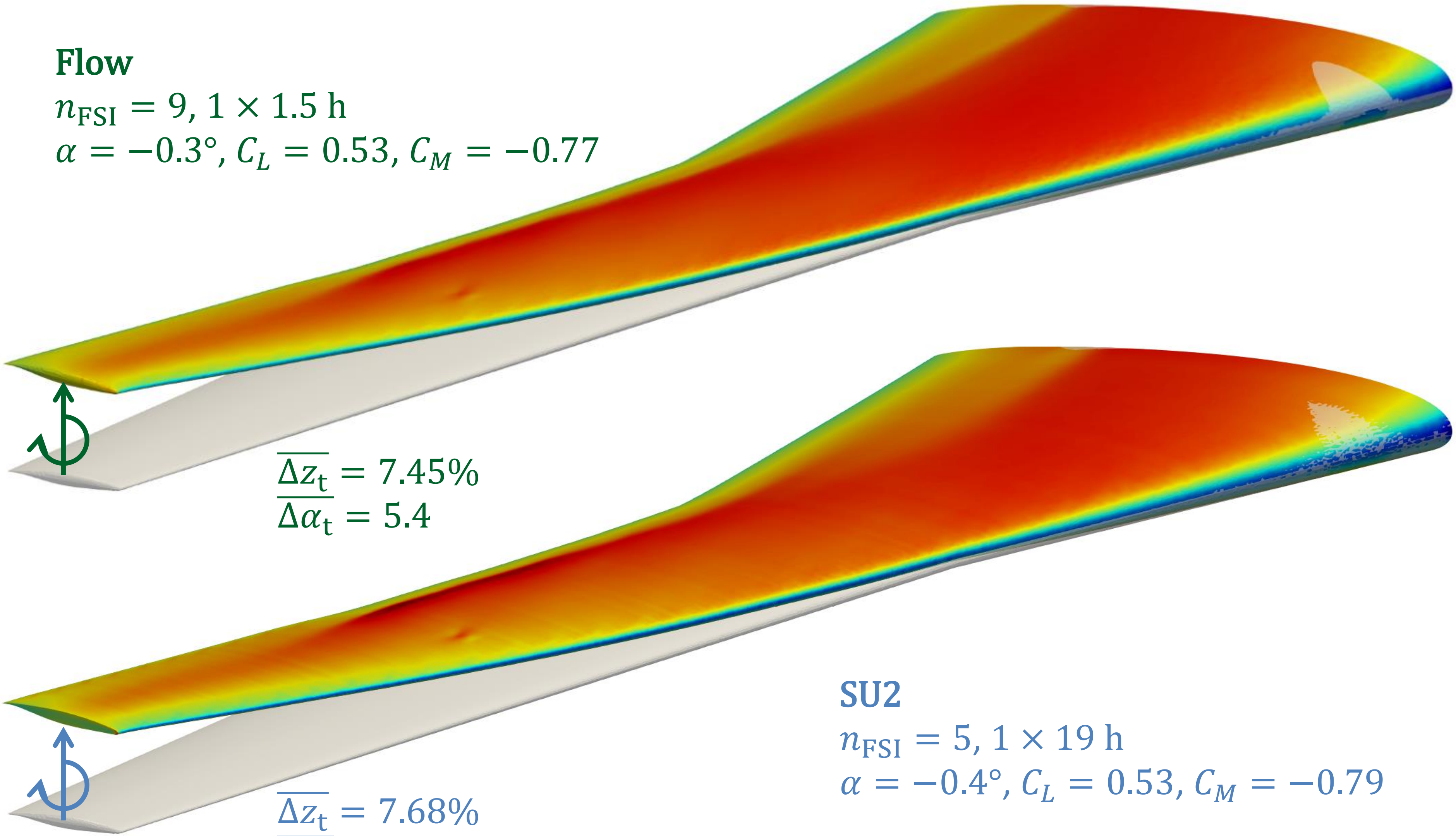


Deformed wing shape

Flow

$n_{\mathrm{FSI}} = 9,\ 1 \times 1.5\ \mathrm{h}$

$\alpha = -0.3°,\ C_L = 0.53,\ C_M = -0.77$



$\overline{\Delta z_{\mathrm{t}}} = 7.45\%$

$\overline{\Delta \alpha_{\mathrm{t}}} = 5.4$

SU2

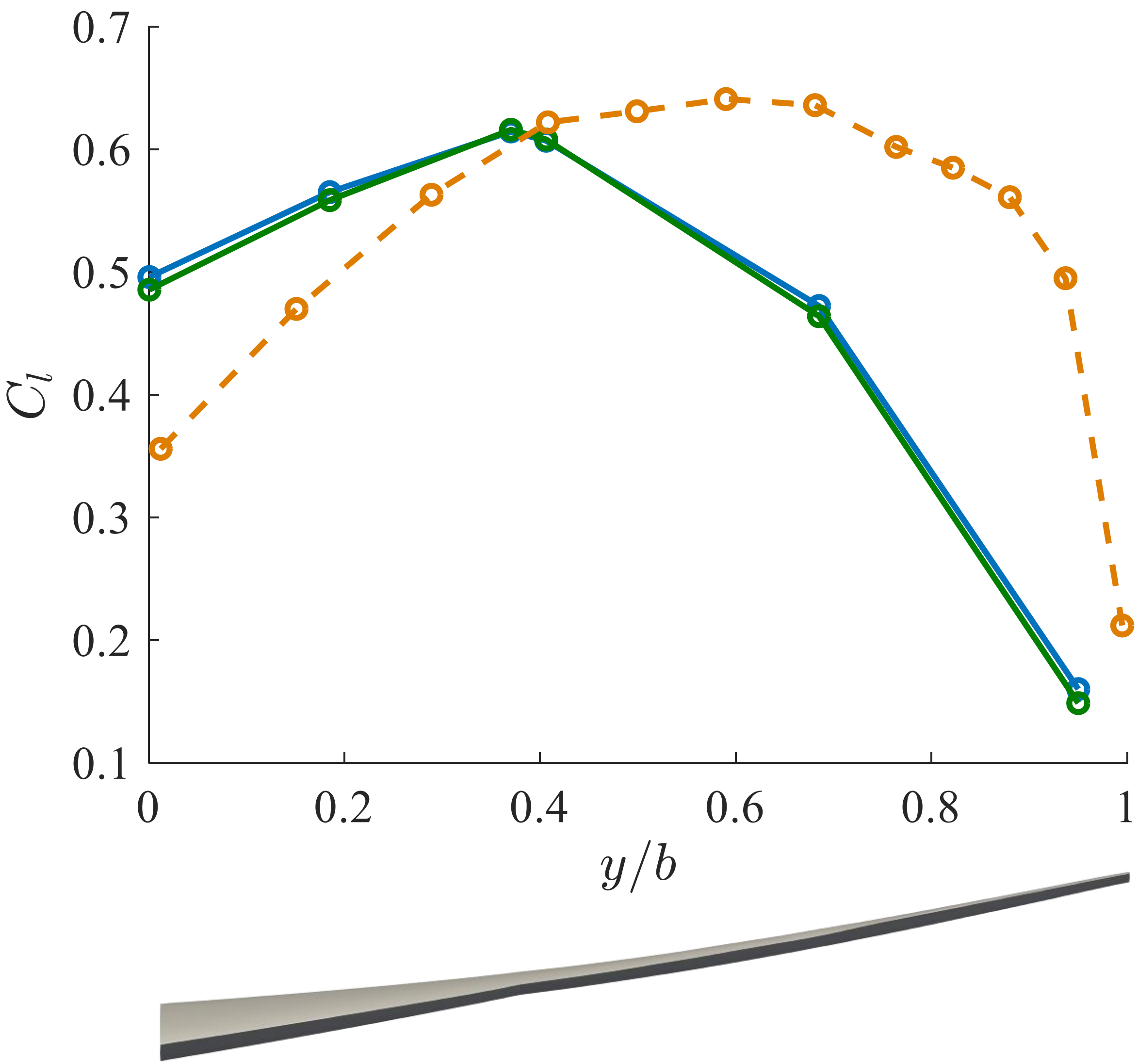
$n_{\mathrm{FSI}} = 5,\ 1 \times 19\ \mathrm{h}$

$\alpha = -0.4°,\ C_L = 0.53,\ C_M = -0.79$

$\overline{\Delta z_{\mathrm{t}}} = 7.68\%$

$\overline{\Delta \alpha_{\mathrm{t}}} = 6.0$

New lift distributions

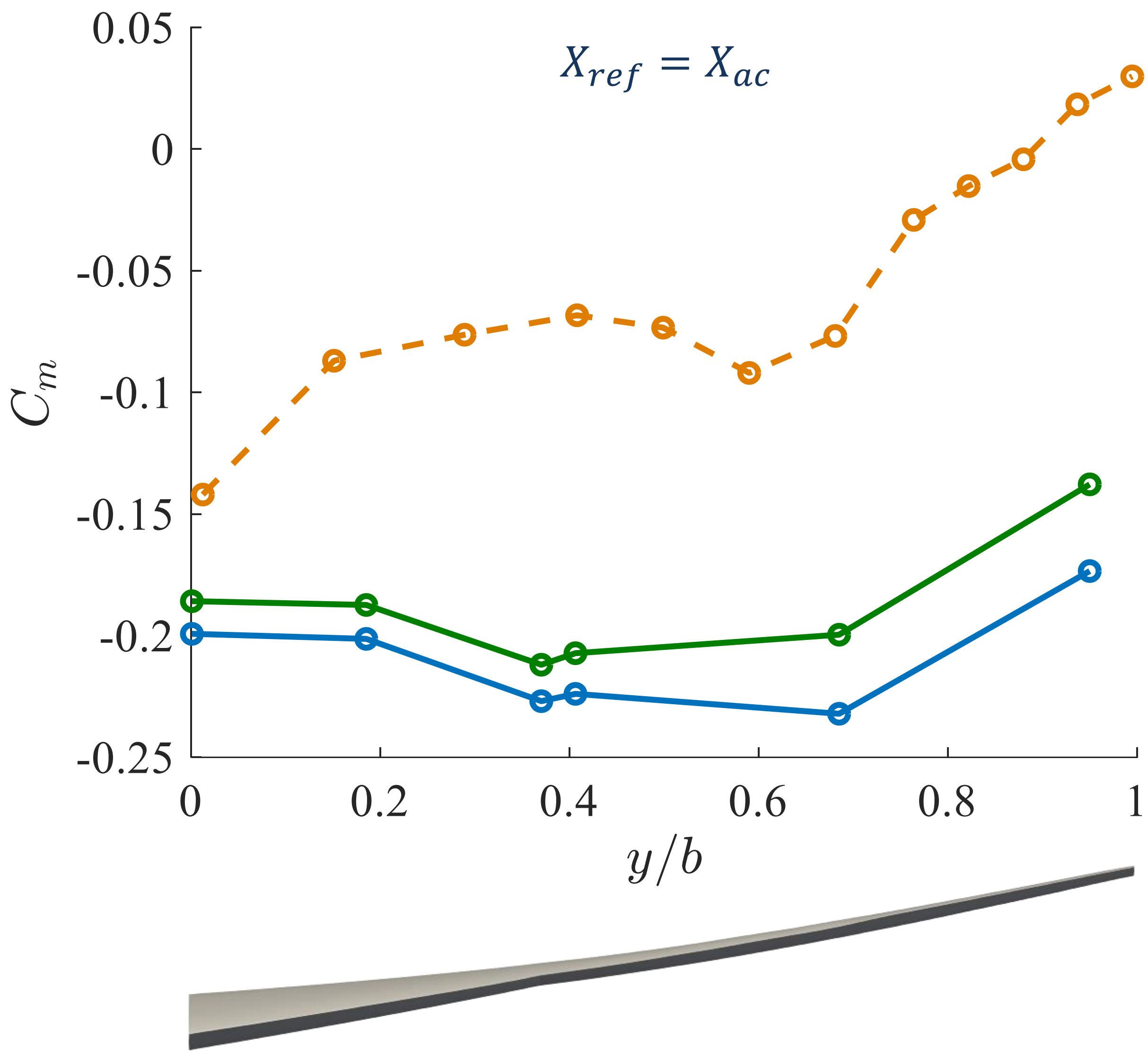


SU2 $\alpha = -0.4°$

Flow $\alpha = -0.3°$

NASTRAN $\alpha = 5.6°$

New moment distributions



SU2 $\alpha = -0.4°$

Flow $\alpha = -0.3°$

NASTRAN $\alpha = 5.6°$

Conclusion and perspectives

Summary

- Development of **Flow** and **CUPyDO**
- **Full Potential** equation offers a **good tradeoff** between accuracy and cost compared to Euler or Linear Potential equations

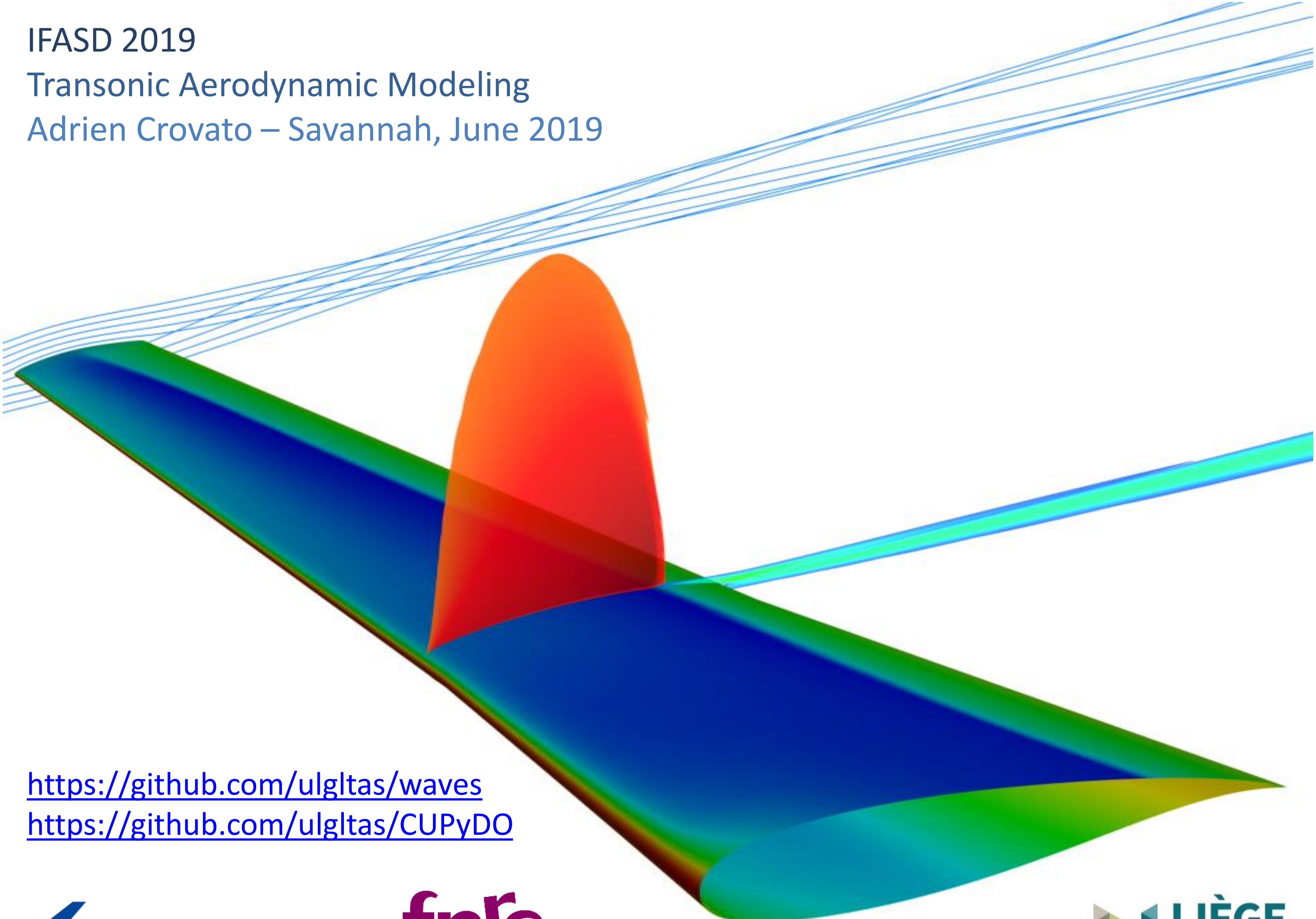
Next steps

- Optimize Flow (**Quasi Newton** and **line search methods**, other **inner solvers**, **Intel** compilers, …)
- Enhance Flow (**adaptive gridding, unsteady** and **viscous coupling** capabilities)
- Investigate **camber** and **transonic correction** methods for NASTRAN
- Investigate **multi-fidelity FSI** computations

IFASD 2019

Transonic Aerodynamic Modeling

Adrien Crovato – Savannah, June 2019



https://github.com/ulgltas/waves
https://github.com/ulgltas/CUPyDO

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