Higher Fidelity Transonic Aerodynamic Modeling in Preliminary Aircraft Design

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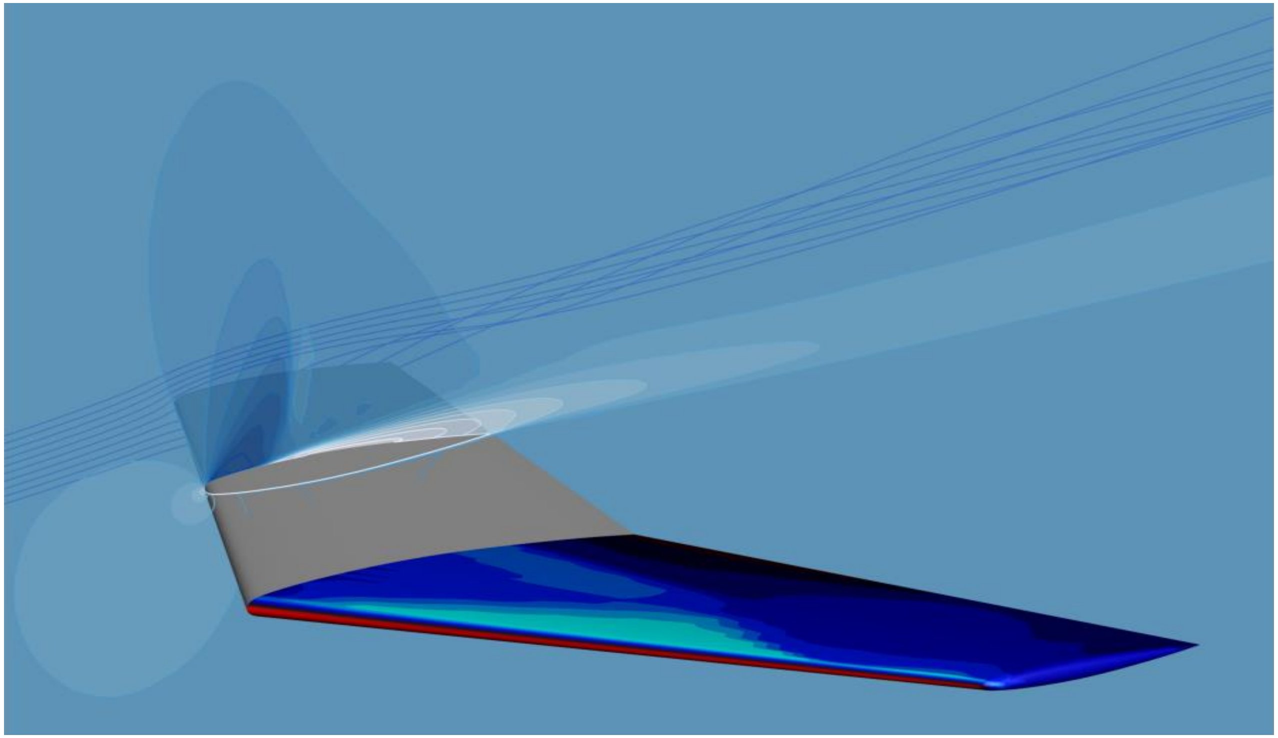


Belo Horizonte, September 2018

Aerodynamics & aeroelastic tailoring

Objective

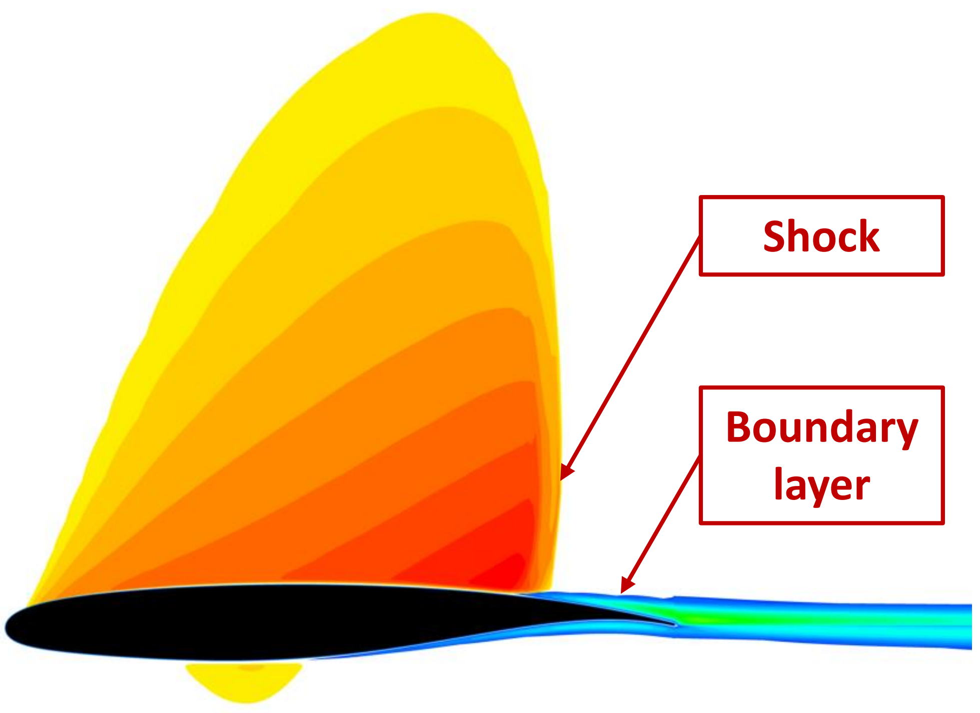
Aerodynamic loads
- Given wing shape

Early preliminary design stage

Fast computations
- Linear solvers

Challenges

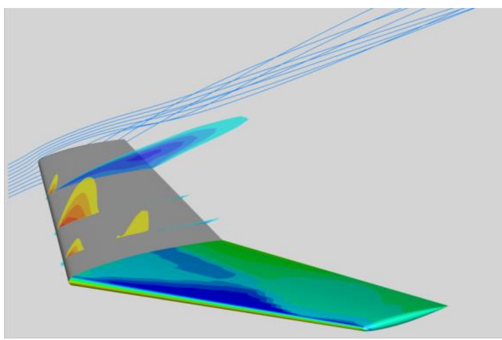
Flow nonlinearities
- Shock and boundary layer



Develop a fast non-linear solver

Overview

Benchmark



Evaluate existing models & methods to efficiently solve transonic flows

Development

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

Outline

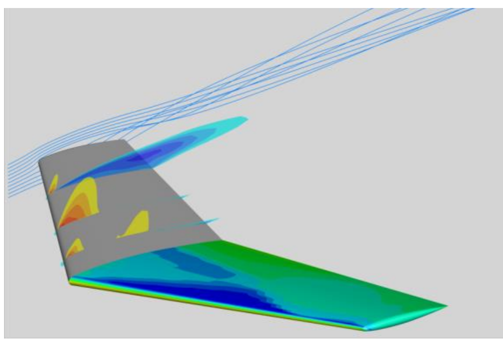
Benchmark
- Levels of fidelity & methods
- Embraer Benchmark Wing 2
- Results
- Analysis

Development
- Methodology
- Panel & field modules
- Challenges
- Transonic computation

Conclusion
- Summary

Overview

Benchmark



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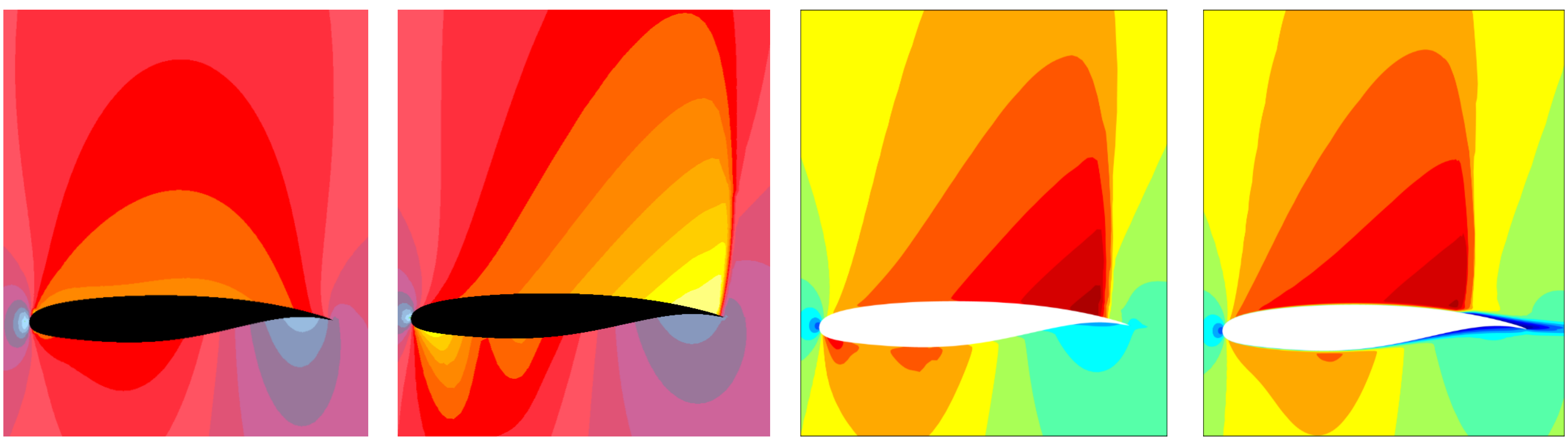
Levels of fidelity

Linear Potential Equation	Full Potential Equation	Euler equations	RANS equations
• Subsonic • Supersonic • Attached • Linear	• Subsonic • Supersonic • Weak transonic • Attached	• Subsonic • Supersonic • Transonic • Attached	• Subsonic • Supersonic • Transonic • Mildy separated

Non-linearity → Non-isentropicity → Viscosity →



Numerical discretization

Models	Methods
Linear • Linear Potential Equation (LPE)	Boundary Element Method (BEM)
Nonlinear • Full Potential Equation (FPE)	Field Panel Method (FPM)
• Euler equations • RANS equations	Field Method (FM)

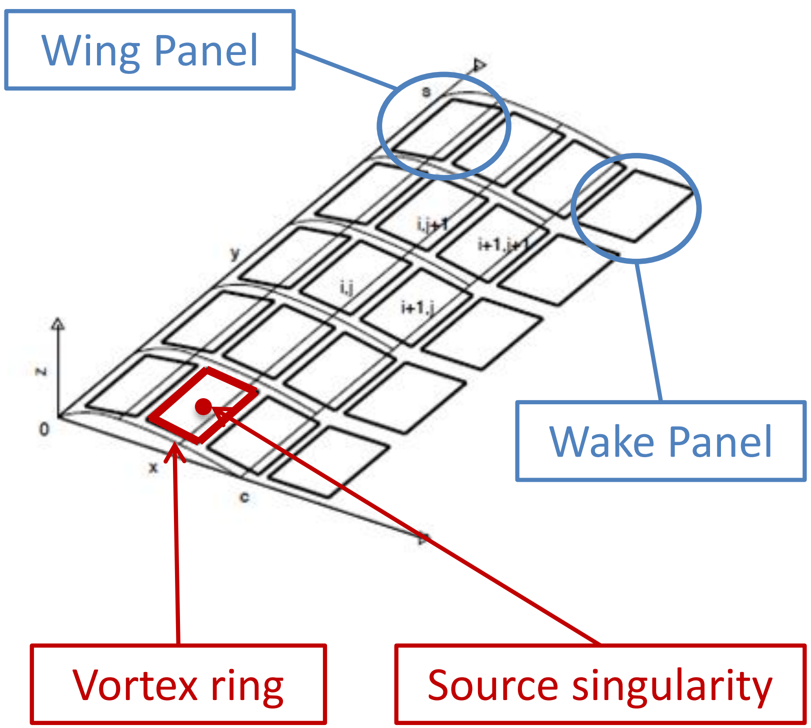
Methods

Boundary Element Method

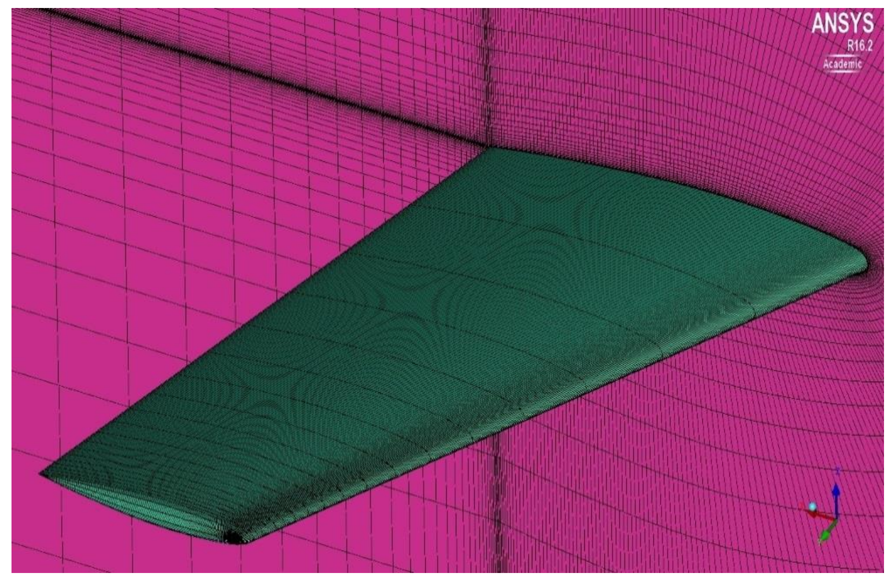
- Only boundary is discretized
- Linear equations only

Field Method

- Whole field is discretized
- Linear and nonlinear equations



Adapted from *Workshop on Aerodynamics* – G. Dimitriadis

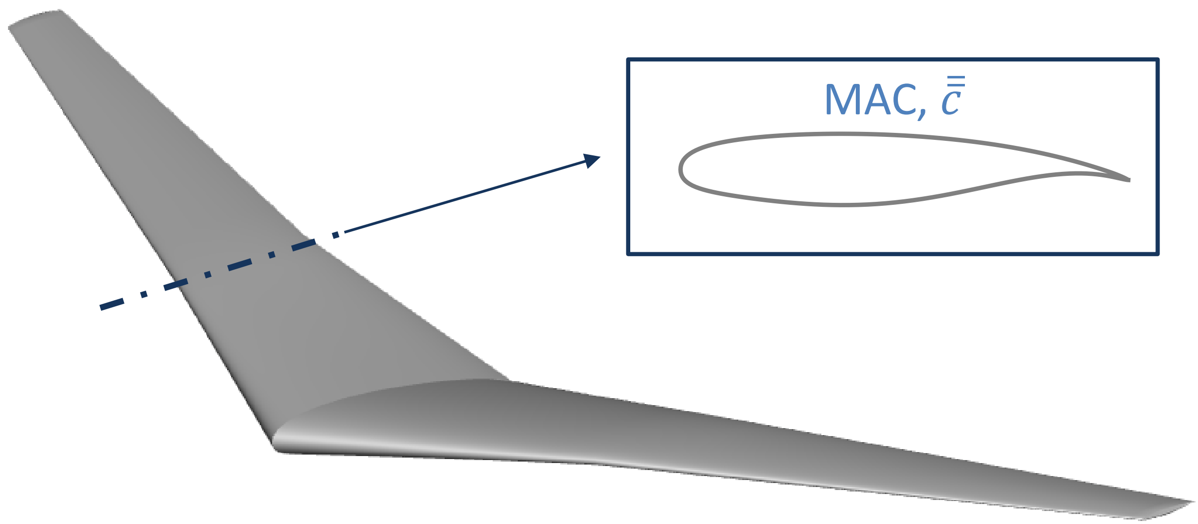


Evaluated models & methods

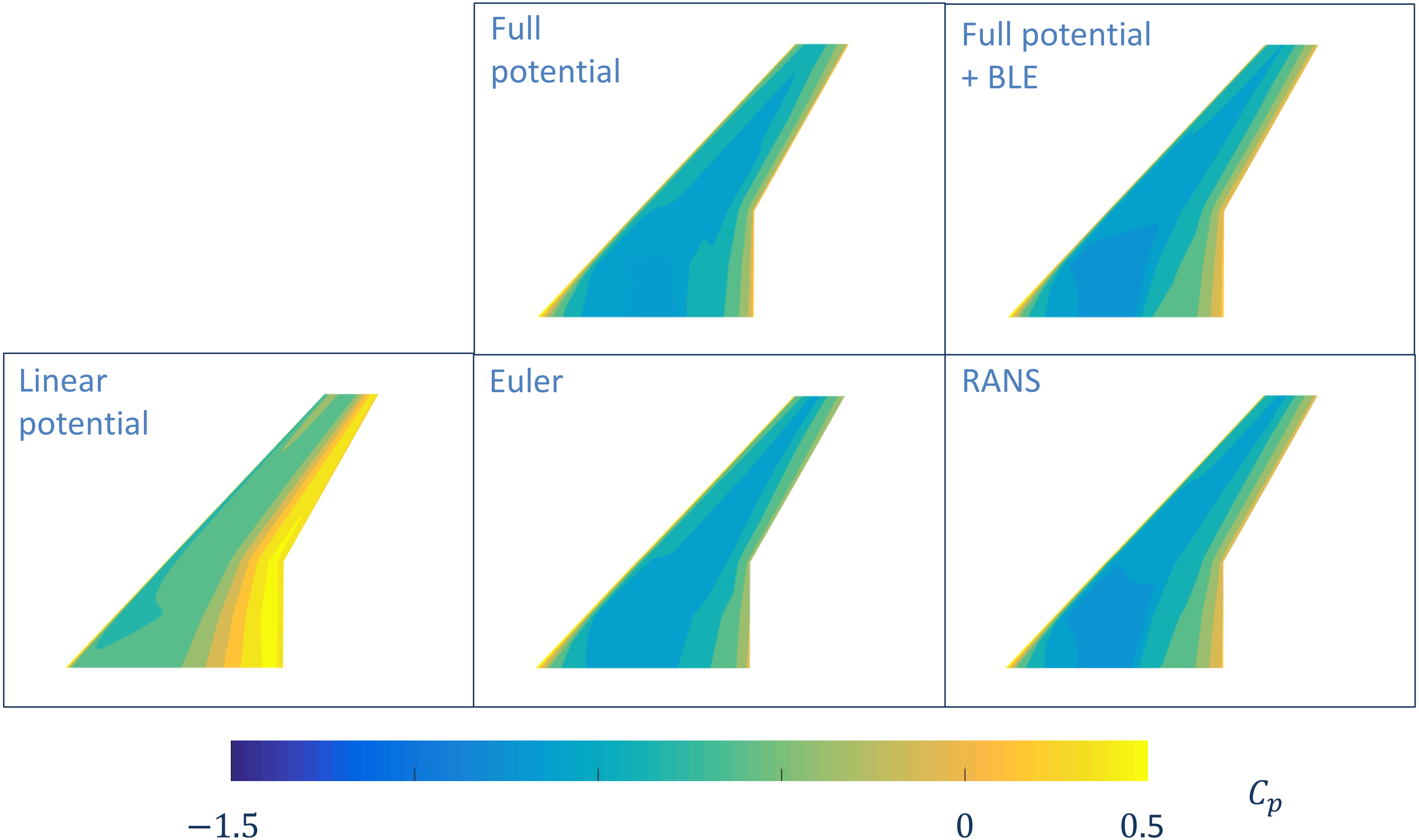
Models	**Software**	**Methods**	**Legend**
Linear Potential Equation	*Panair*	Panel (doublet/source)	Red
Full Potential Equation	*Tranair++*	Finite element	Orange
Full Potential Equation + Boundary Layer Equations	*Tranair++*	Finite element	Green
Euler equations	SU^2	Finite volume	Blue
RANS equations	SU^2	Finite volume	Violet

Embraer Benchmark Wing 2

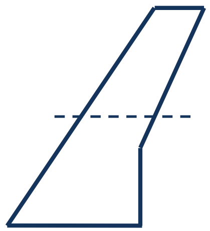
	M	C_L	FL	Re
Cruise	0.78	0.47	350	$\sim 20 \times 10^6$



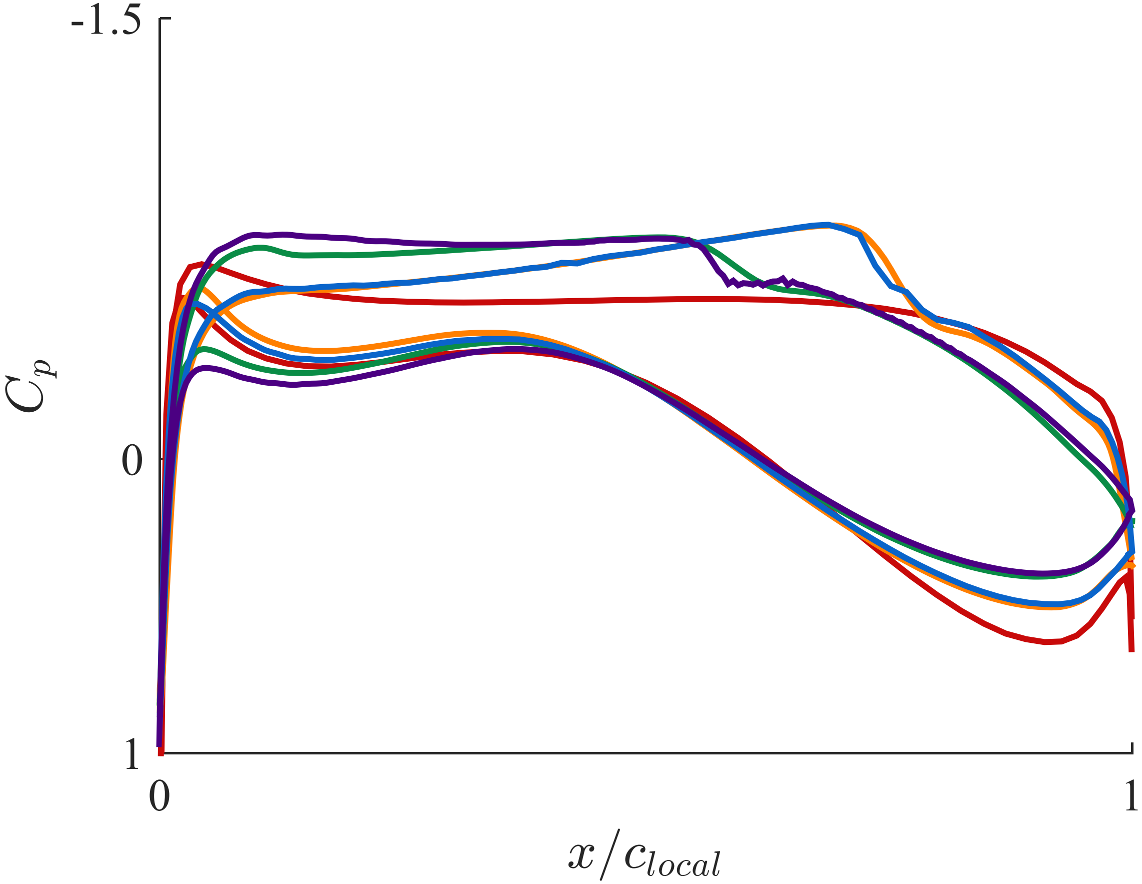
Pressure contours



Pressure distributions

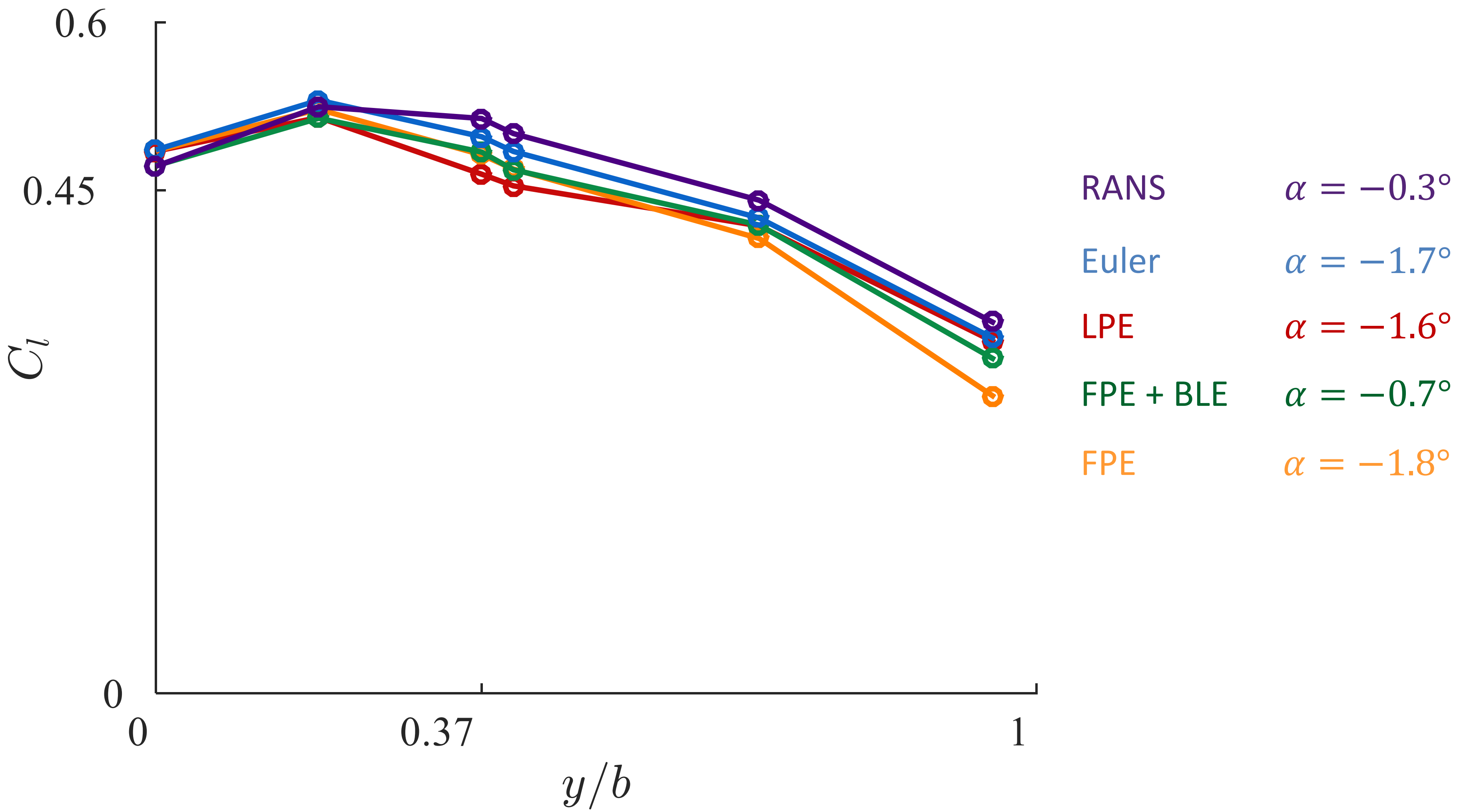


$$\frac{y}{b} = 0.406\ (\bar{\bar{c}})$$

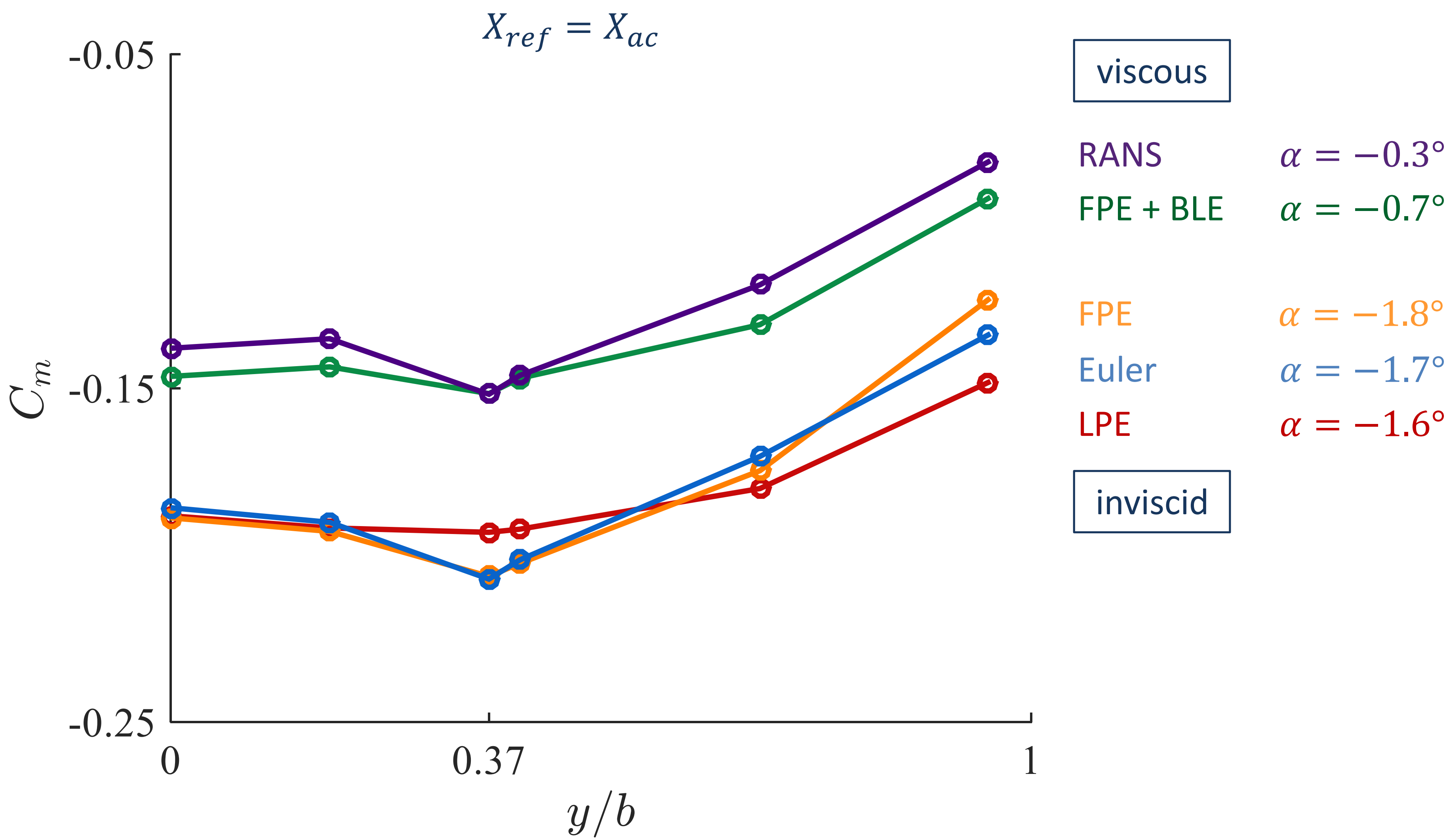


Model	~CPU time
Linear potential	1×10 [s]
Full potential	1×600 [s]
Euler	6×3 [h]
Full potential + BLE	1×900 [s]
RANS	32×24 [h]

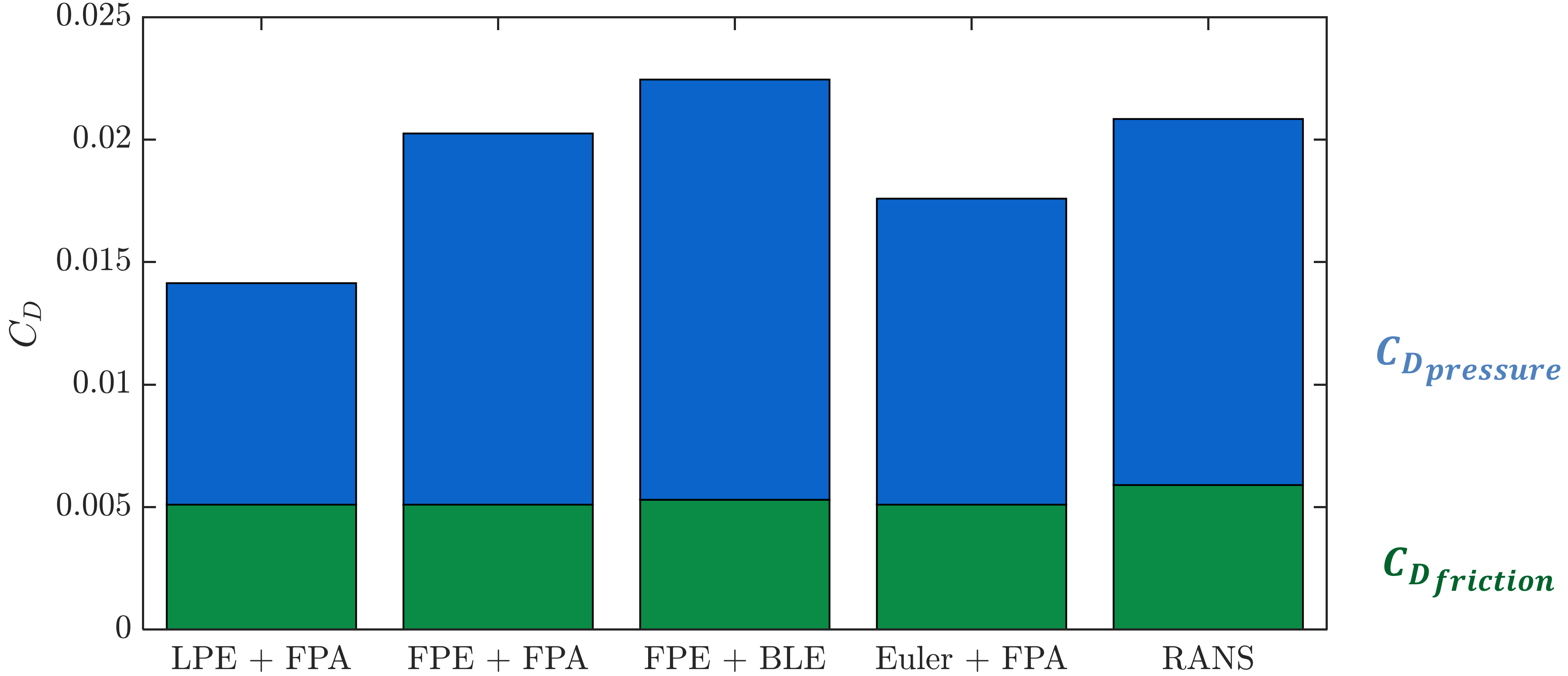
Lift distributions



Moment distributions



Near-field drag breakdown



$\alpha = -1.6°$ $\alpha = -1.8°$ $\alpha = -0.7°$ $\alpha = -1.7°$ $\alpha = -0.3°$

FPA: Flat Plate Analogy

Analysis

Physics

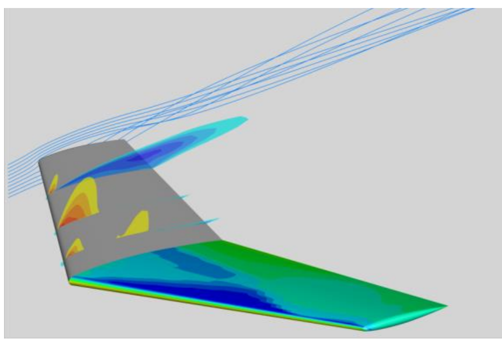
- **Shocks** completely change the physics and **must** be taken into **account**
- The **boundary layer** significantly impacts **shock location** and **strength** and should be modeled
- The **friction drag** can be accurately computed by the **FPA**

Modeling

- The **Linear Potential** Equation is **not accurate** enough for transonic flows while **Euler** and **RANS** equations are too **costly**
- The **Full Potential** Equation gives **meaningful results** for **little runtime,** especially when corrected by the **Boundary Layer** Equations
- The **Full Potential Equation** alone can be used for **routine computations** and supplemented by a **boundary layer** model to **adjust** the **solution**

Overview

Benchmark



Evaluate existing models & methods to efficiently solve transonic flows

Development

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

Potential equation

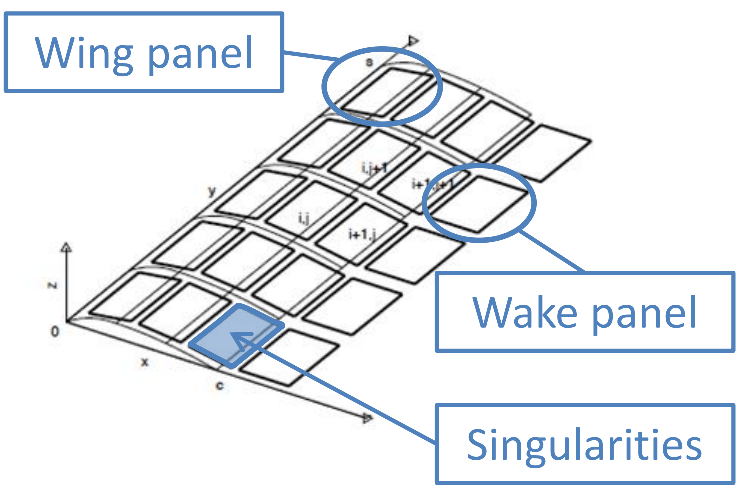
$$\sigma = 0 \quad \leftarrow \quad \Delta\phi = \sigma \quad \rightarrow \quad \sigma = -\frac{\nabla\rho}{\rho} \cdot \nabla\phi$$

Linear Potential Equation

Flow

- Linear
- Subsonic or supersonic
- **NOT transonic**

Solver – Boundary Element Method



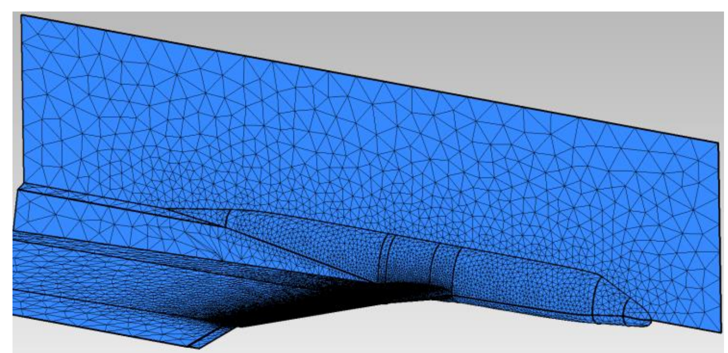
Full Potential Equation

Flow

- Nonlinear
- Subsonic, **weak transonic** or supersonic

Solvers

- Finite Element/Volume Method
- Field Panel Method

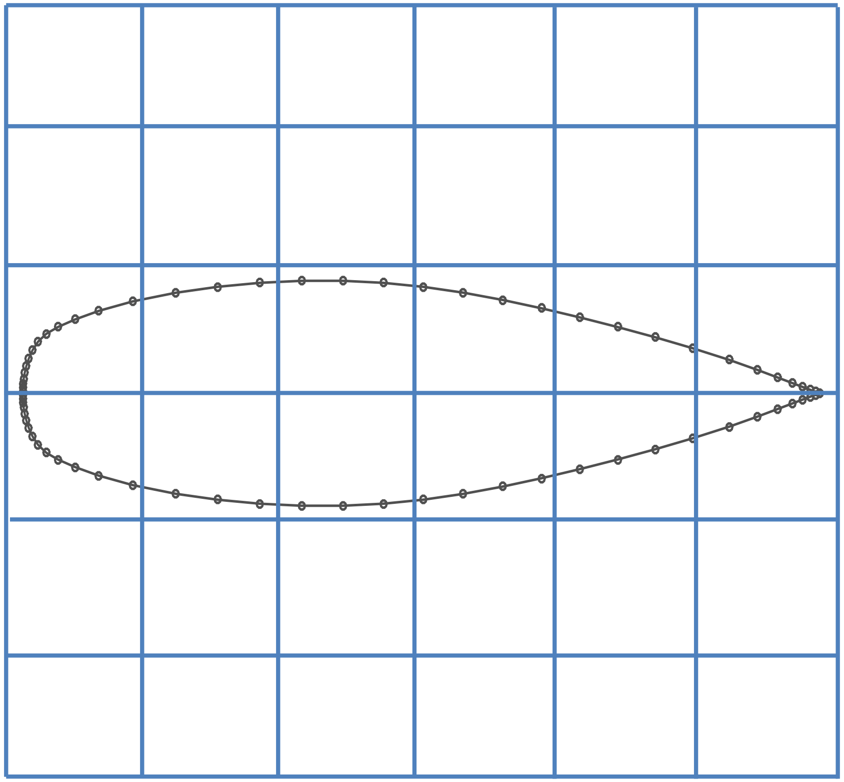


Field Panel Method

Combination

Boundary Element Method
- $\Delta\phi = 0$
- On the wing surface

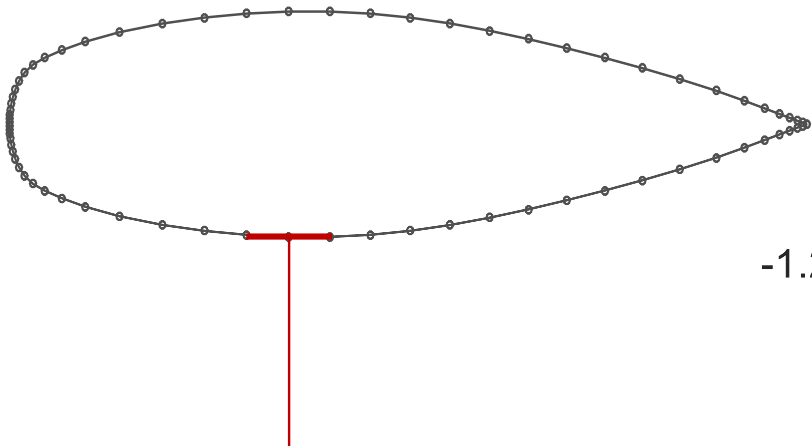
Field Method
- $\sigma = -\frac{\nabla\rho}{\rho} \cdot \nabla\phi$
- In the field



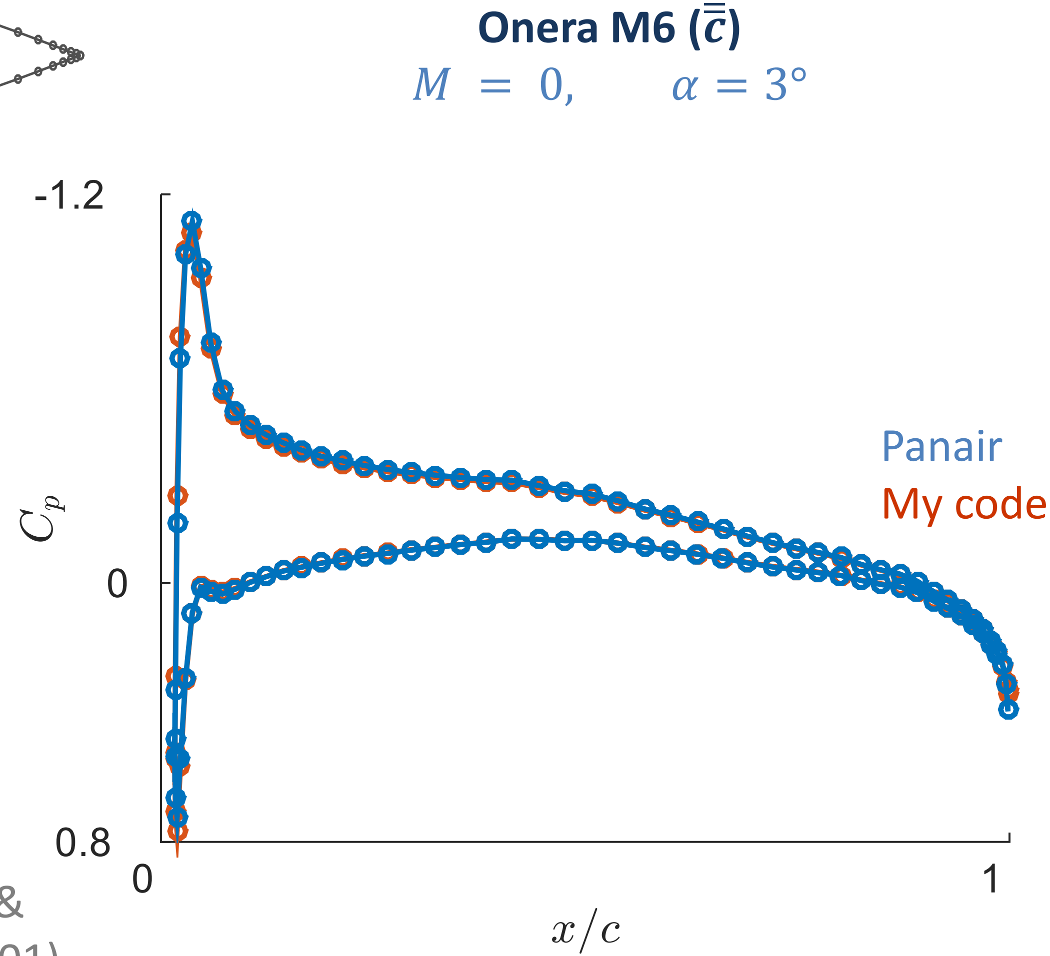
Advantages
- Cartesian grid
- Aerodynamic Influence Coefficients

Disadvantages
- Memory requirement
- Not well documented

Incompressible prediction (PM)

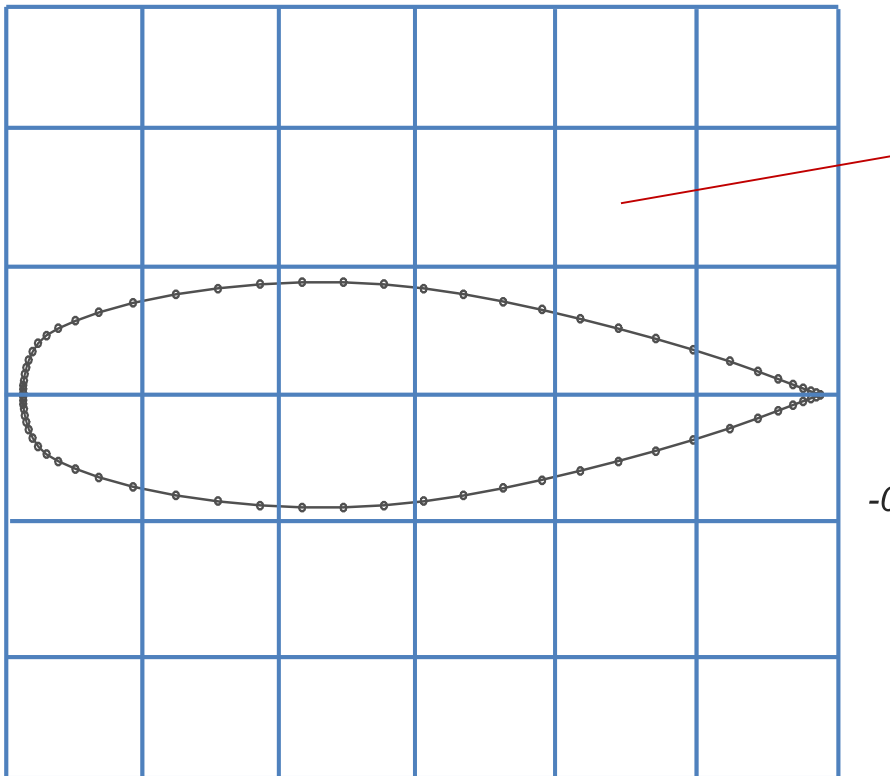


1. $\boldsymbol{\tau = -u_{n,\infty} - u_{n,\sigma}}$
2. $\boldsymbol{\mu = A^{-1} B \tau}$
3. $\boldsymbol{u_i = f(\tau, \mu)}$
4. $\boldsymbol{c_p = g(u_i)}$



Method implemented following Katz & Plotkin, *Low-Speed Aerodynamics* (2001)

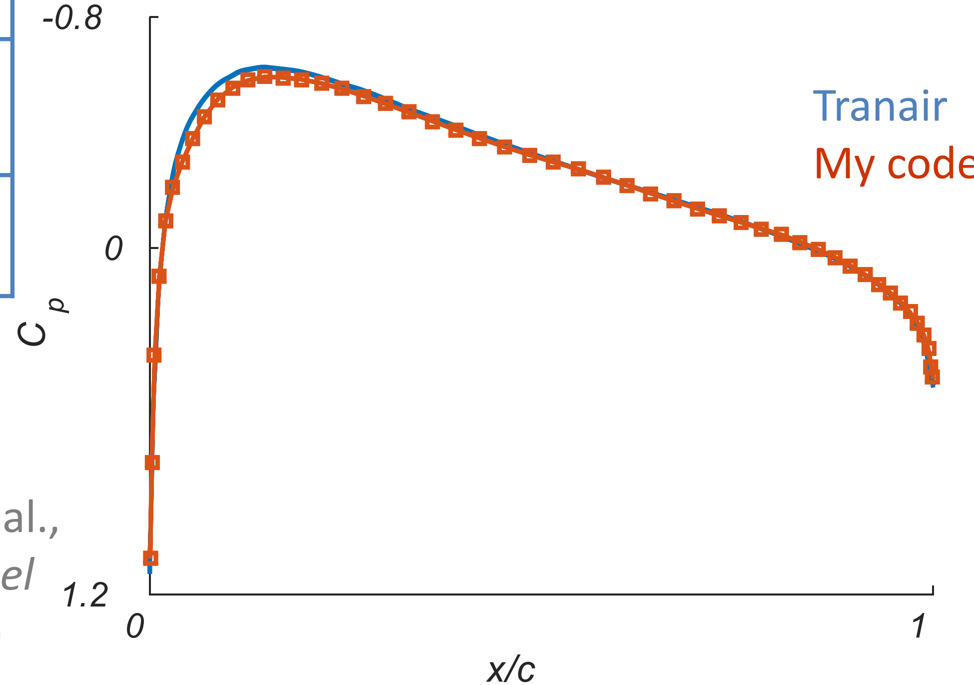
Compressible correction (FM)



1. $\phi = A_f \mu + B_f \tau + C_f \sigma$
2. $\rho = h(\partial_i \phi)$
3. $\sigma = -\dfrac{\partial_i \phi \partial_i \rho}{\rho}$
4. $u_{n,\sigma} = C_b \sigma$

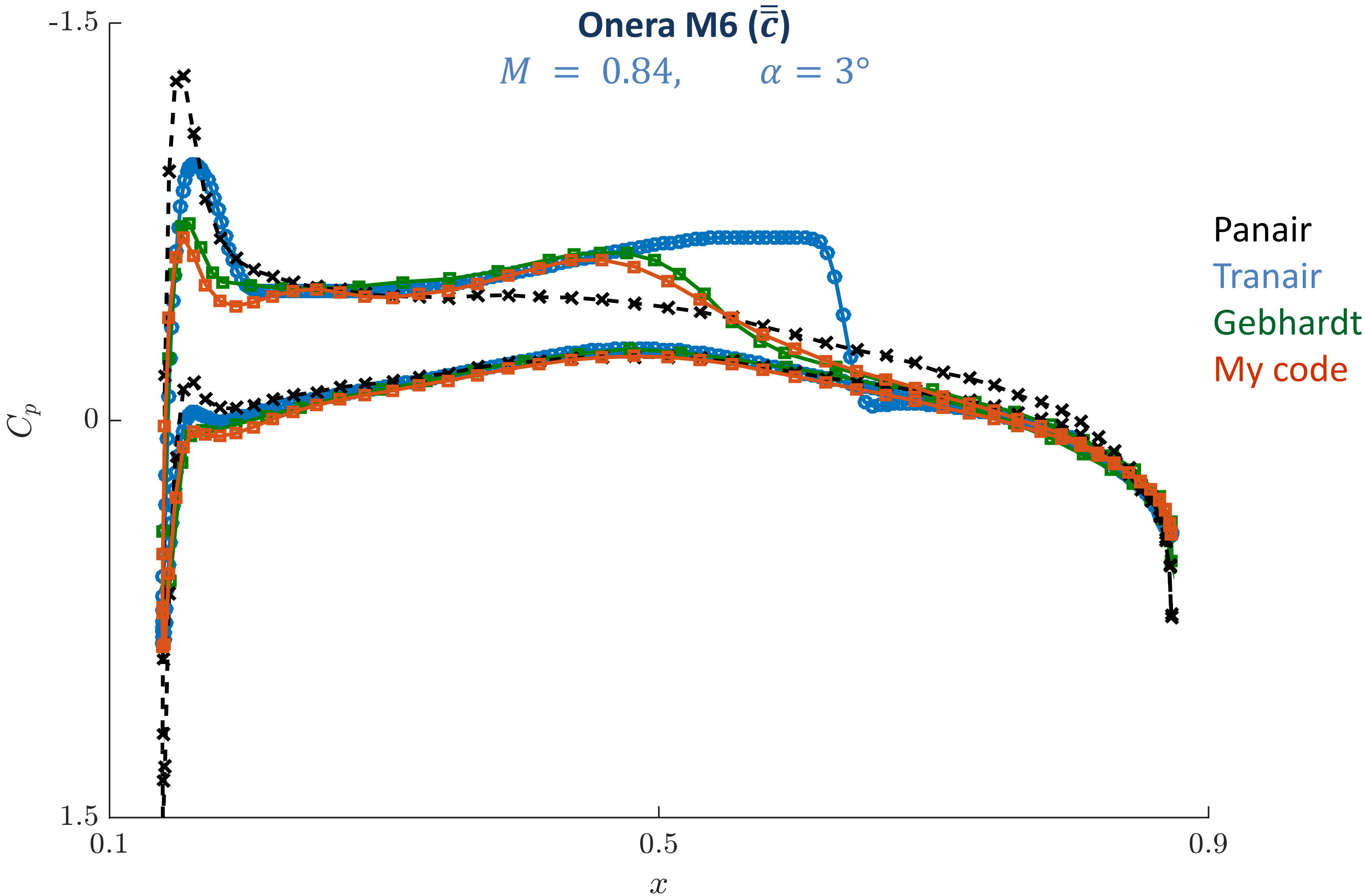
NACA 0012 ($\bar{\bar{c}}$)

$M = 0.7, \quad \alpha = 0°$



Method implemented following Gebahrt et al., *An Implicit-Explicit Dirichlet-Based Field Panel Method for Transonic Aircraft Design* (2001)

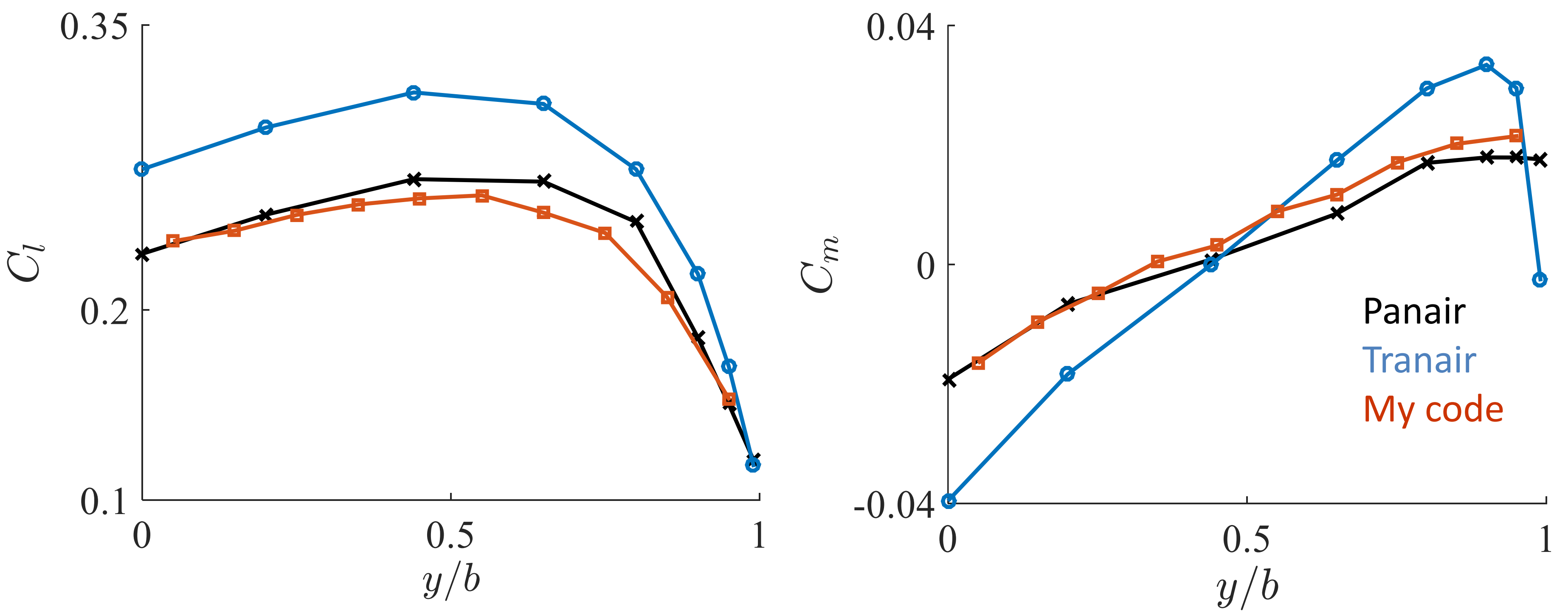
Transonic computation - pressure



Transonic computation – lift & moment

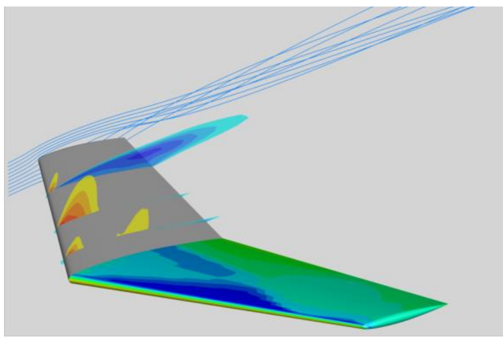
Onera M6

$M = 0.84, \quad \alpha = 3°$



Summary

Benchmark



- Comparison of different levels of fidelity
- FPE + BLE achieves best efficiency

Development

- Development of the FPM
- Incompressible and subcritical flow results are very good
- Transonic results are not yet satisfactory

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Steady Transonic Aerodynamic Modeling

Adrien Crovato – Belo Horizonte, September 2018