FAST TRANSONIC CORRECTIONS FOR PANEL METHODS USING VISCOUS-INVISCID INTERACTION
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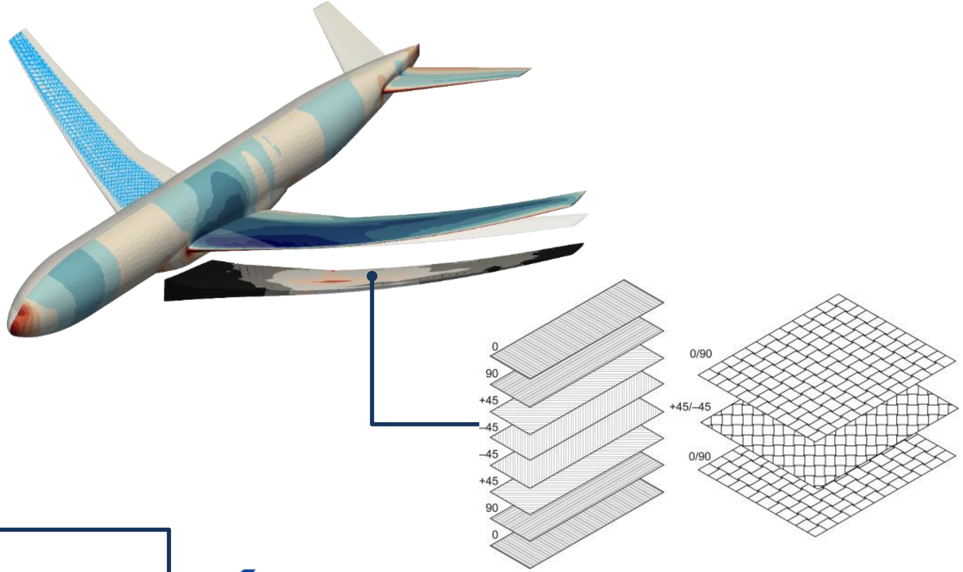
Aeroelastic tailoring

Optimize shape and laminates

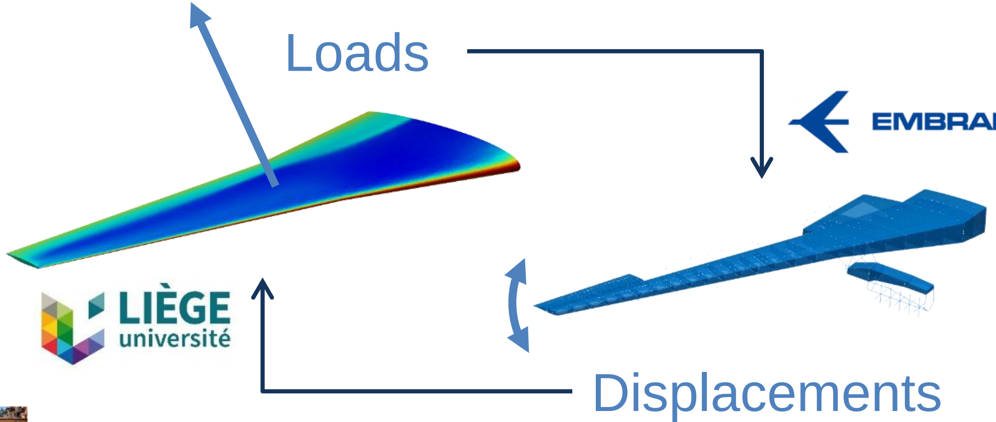
- Decrease fuel burn

Such that

- No failure
- No flutter

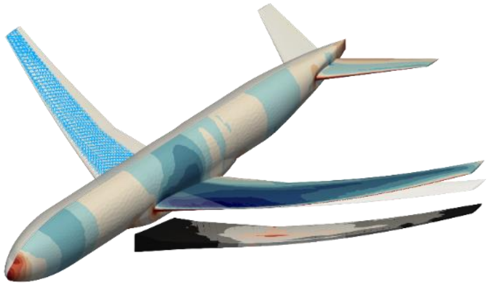


Composite layup – Olhsson



Preliminary aircraft design

Conceptual → **Preliminary (9%)** → Detail



Numerical model

- Global design
- Optimization
- Performance

Results must be obtained **quickly**
Adequate models must be chosen

Unsteady aerodynamic modeling for aeroelasticity

RANS

- Transonic
- Viscous
- Volume discretization
- Days

Euler

- Transonic
- **Inviscid**
- Volume discretization
- Hours

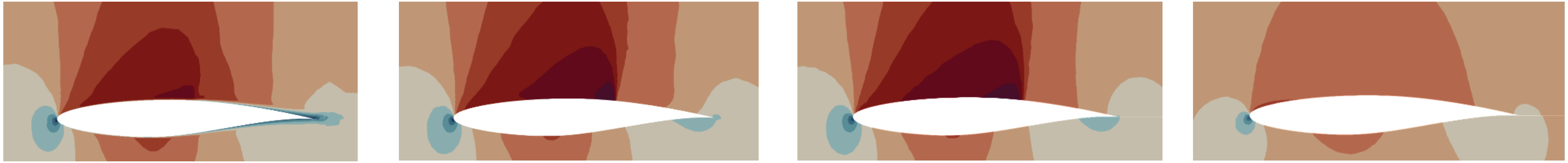
Full potential

- ~**Transonic**
- Inviscid
- Volume discretization
- Hours

Linear potential

- ~~**Transonic**~~
- Inviscid
- **Surface discretization**
- Seconds

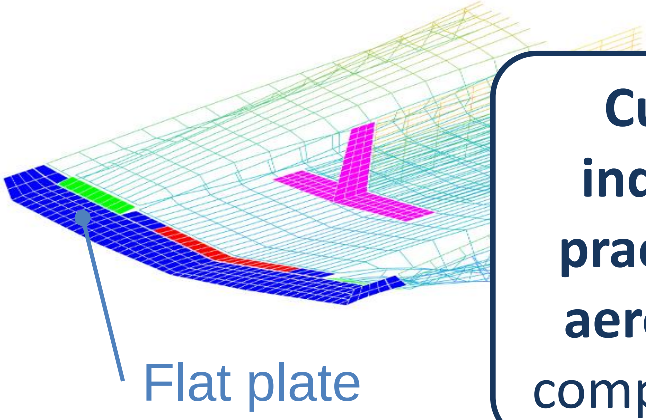
→ Inviscid → Isentropic → Linear



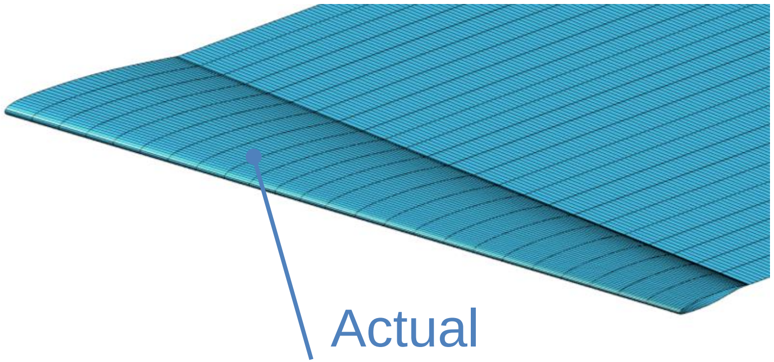
Boundary element methods for linear potential

Lattice methods

Panel methods

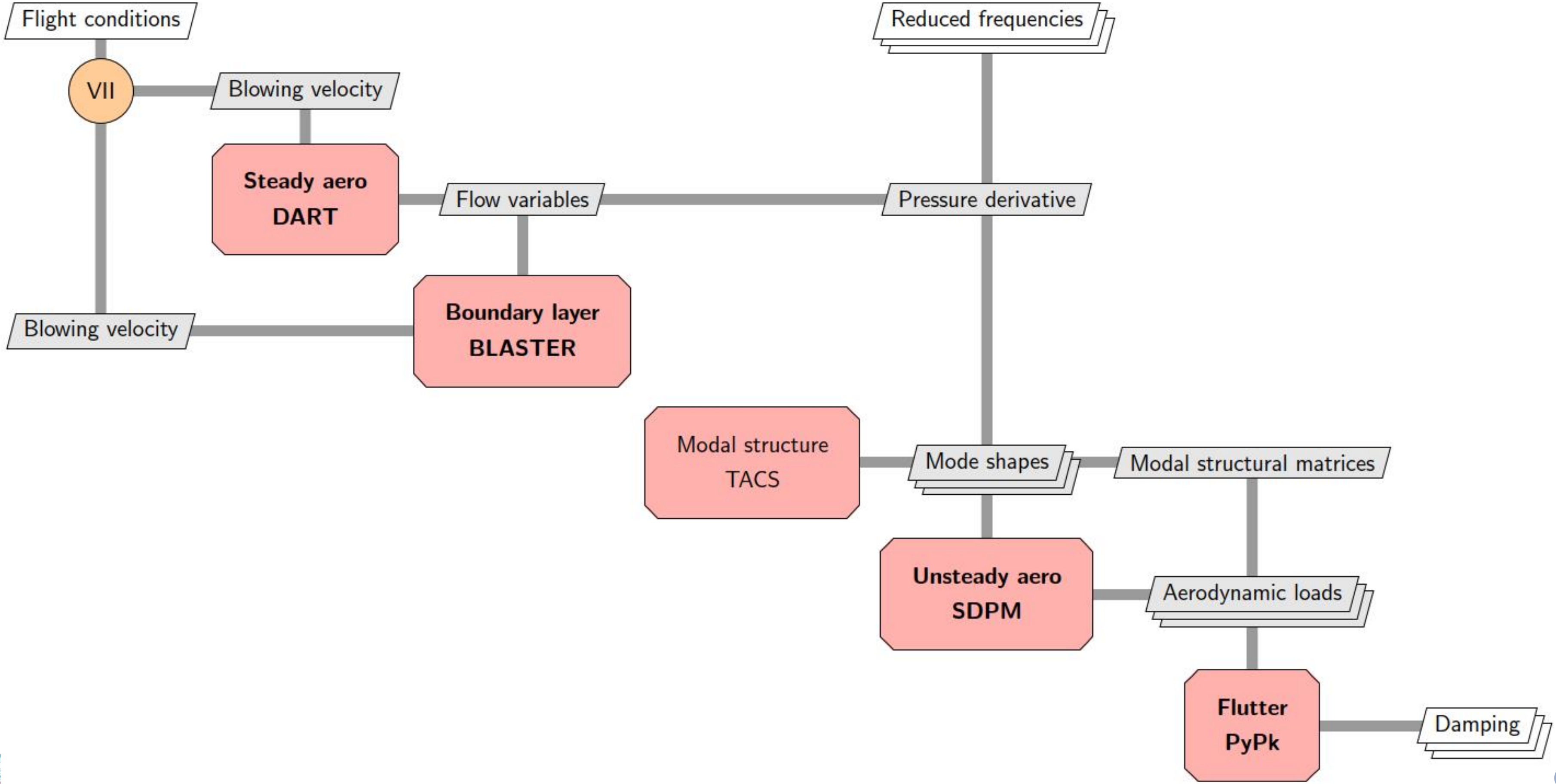


Current industrial practice for **aeroelastic** computations



Panel methods only need to be **corrected** for **nonlinear flow** effects

Overall methodology

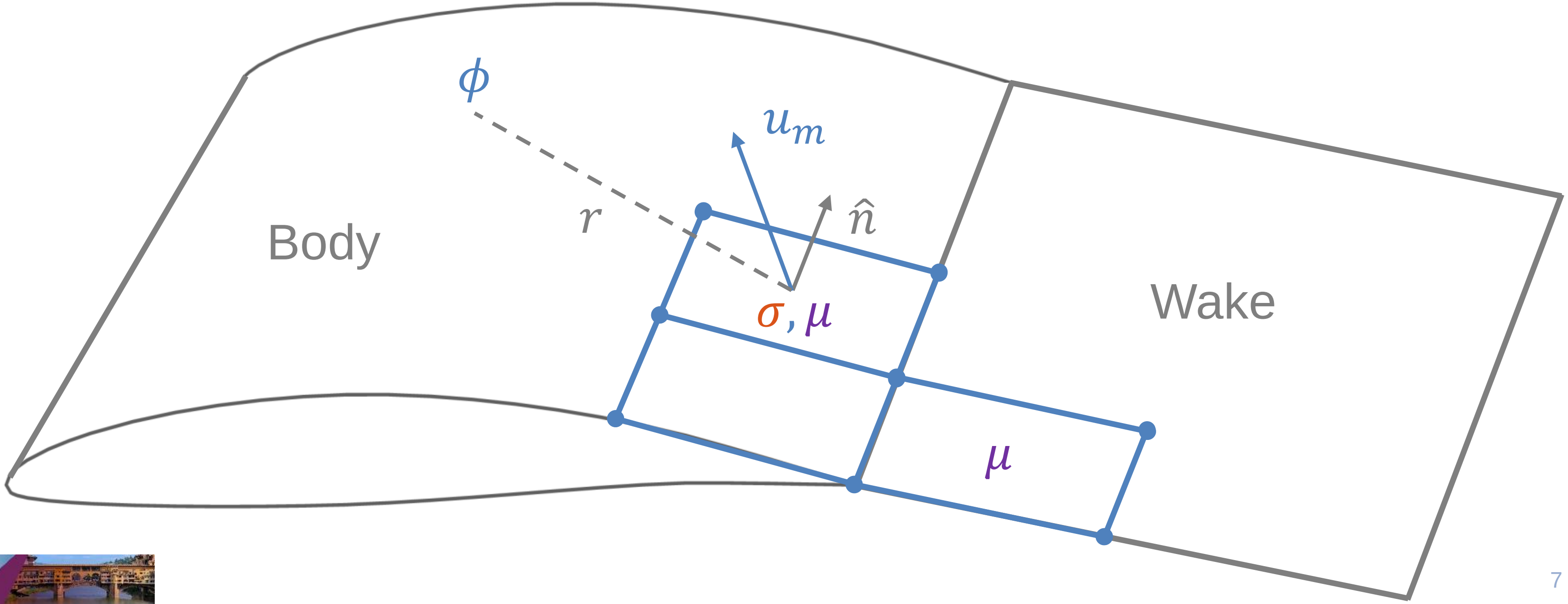


Unsteady source and doublet panel method

Panel discretization

$\sigma = -u_m(\omega) \cdot \hat{n}$

$$\phi(\omega) = -\frac{\sigma}{4\pi}\int_S \frac{E(\omega)}{r}\,dS + \frac{\mu}{4\pi}\int_S \hat{n}\cdot\nabla\left(\frac{E(\omega)}{r}\right)dS = 0 \Rightarrow A(\omega)\mu = B(\omega)\sigma$$



Transonic correction

Linearized steady pressure coefficient derivative

$$c_p(0) \simeq \frac{2}{\beta}\left(\partial_x^S \mu(0) + \hat{n}_x \sigma(0)\right)$$

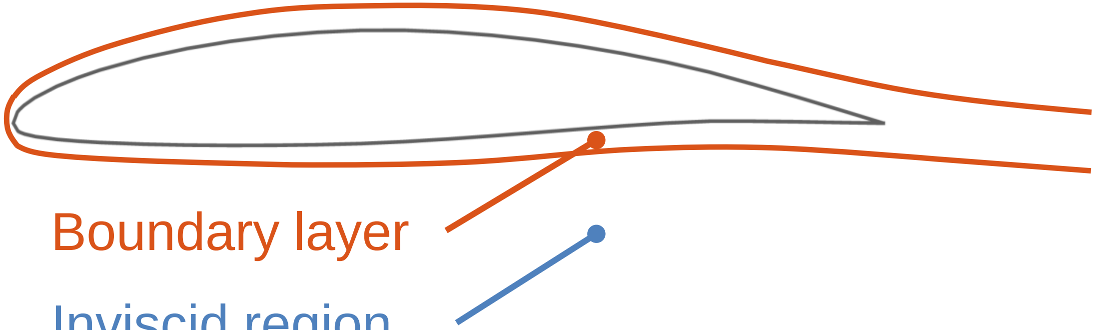
$$\partial_\alpha c_p(0) \simeq \frac{2}{\beta}(\partial N_x^S A^{-1} B \hat{n}_z + \hat{n}_x \hat{n}_z)$$

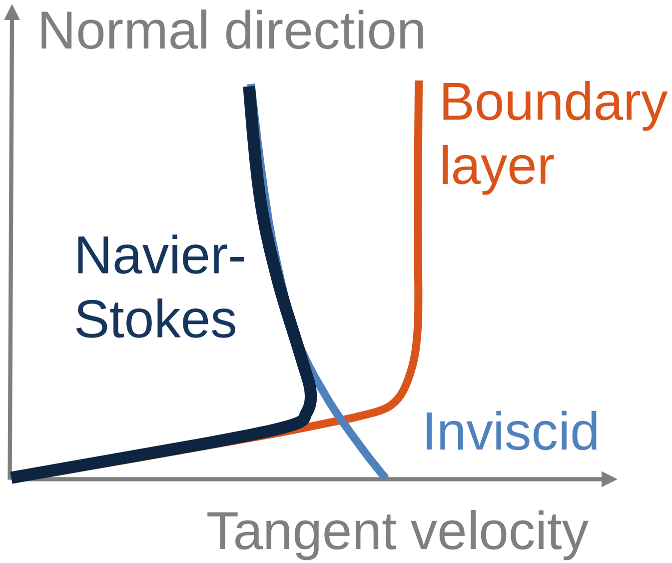
$$\partial_\alpha c_p^{\mathrm{ref}}(0) \simeq \frac{2}{\beta}(\partial N_x^S D^{\mathrm{corr}} A^{-1} B \hat{n}_z + \hat{n}_x \hat{n}_z)$$

Procedure

1. Compute pressure derivative $\partial_\alpha c_p^{\mathrm{ref}}(0)$ from steady CFD
2. Solve for diagonal correction matrix D^{corr}
3. Compute doublets: $\mu(\omega) = A^{-1} B \sigma\left(\omega, u_{m_{x,y}}\right) + D^{\mathrm{corr}} A^{-1} B \sigma(\omega, u_{m_z})$

Viscous-inviscid interaction





Steady full potential eq.

Unsteady boundary layer eqs.
+approx. inviscid

Non-iterative p-k flutter solution method

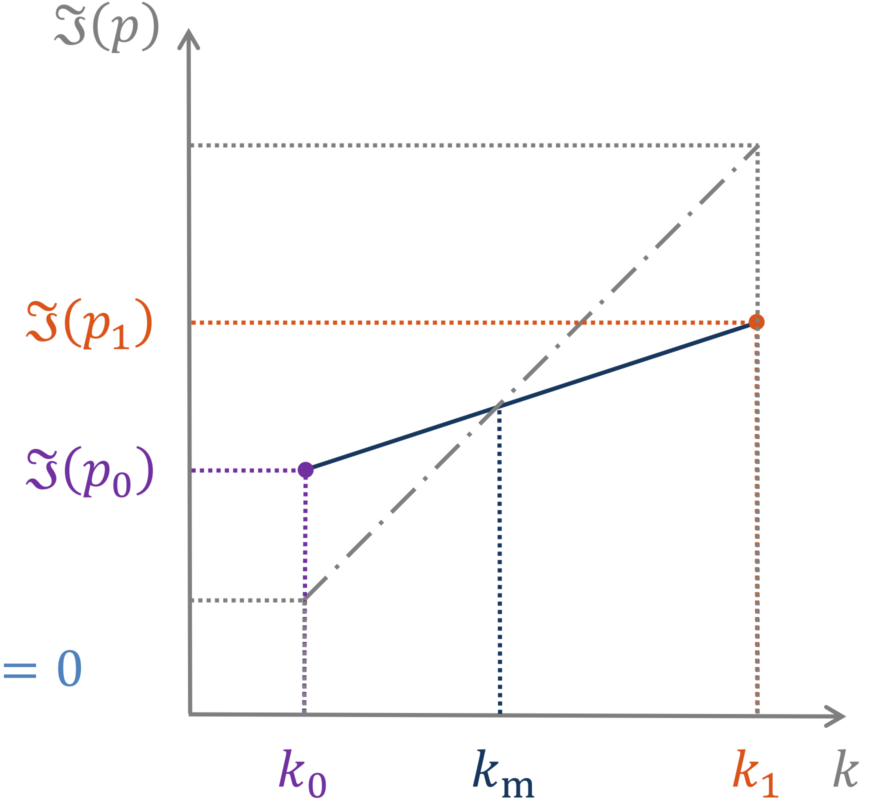
Flutter equation

$$\left(\frac{u_\infty^2}{l_{\mathrm{ref}}^2}p^2 M + K - \frac{1}{2}\rho_\infty u_\infty^2 Q(k)\right)q = 0$$

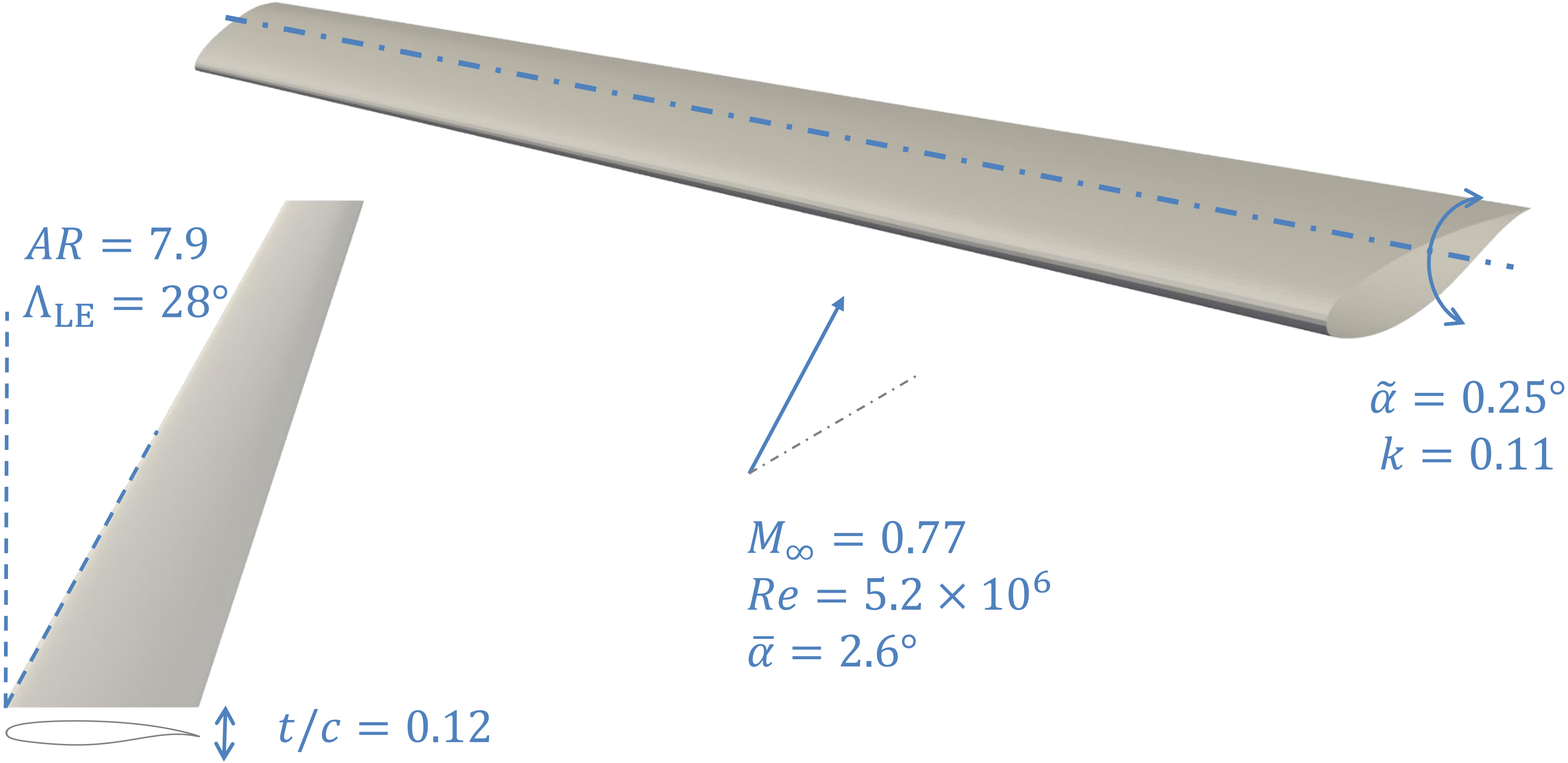
$$p = gk + ik$$

Algorithm

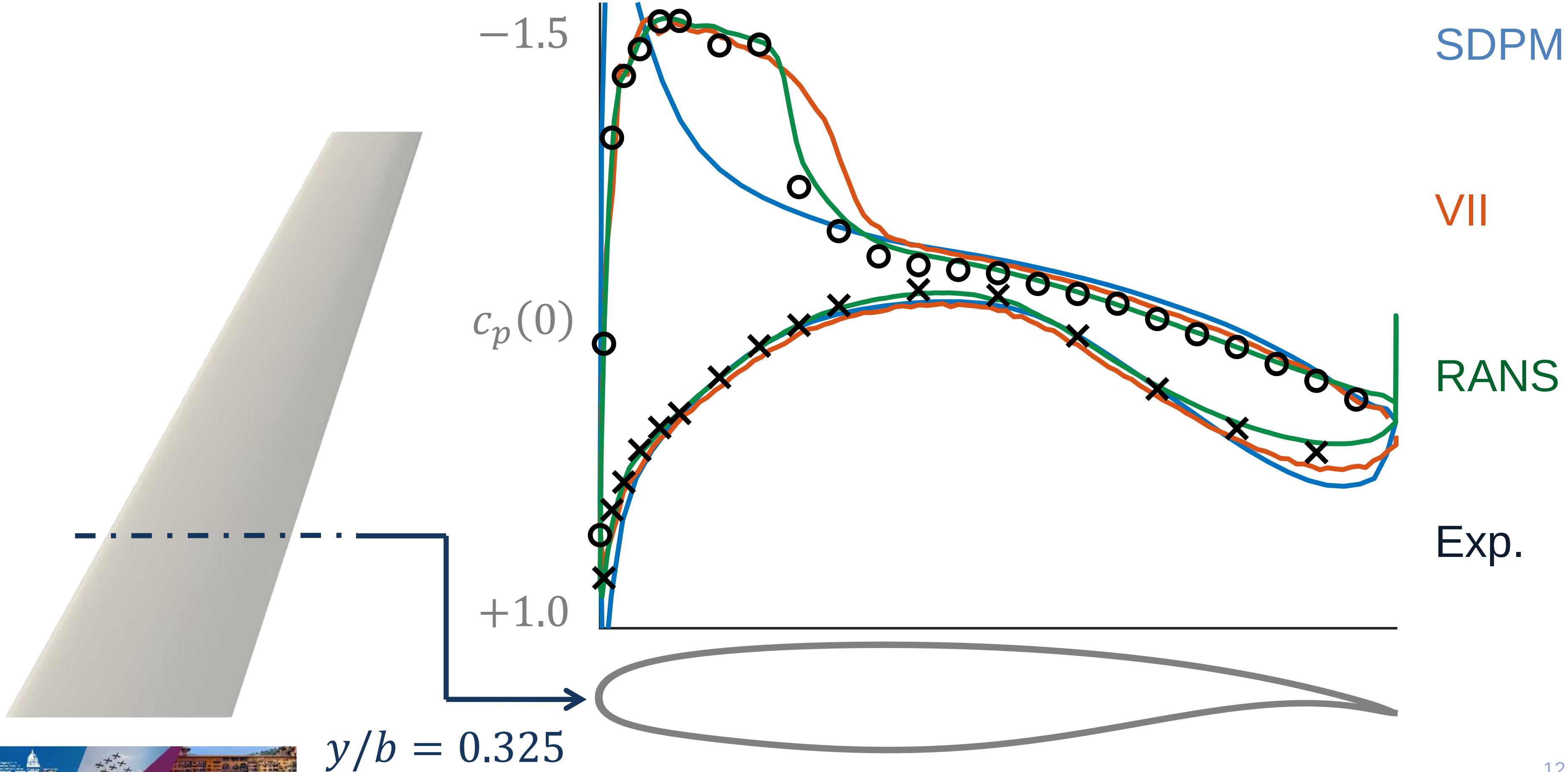
1. Compute $Q_i(k_i)$ for a set of k_i
2. Solve eigenvalue problem for p_i
3. Interpolate k_{m} such that $\Im(p_{\mathrm{m}}) - k_{\mathrm{m}} = 0$



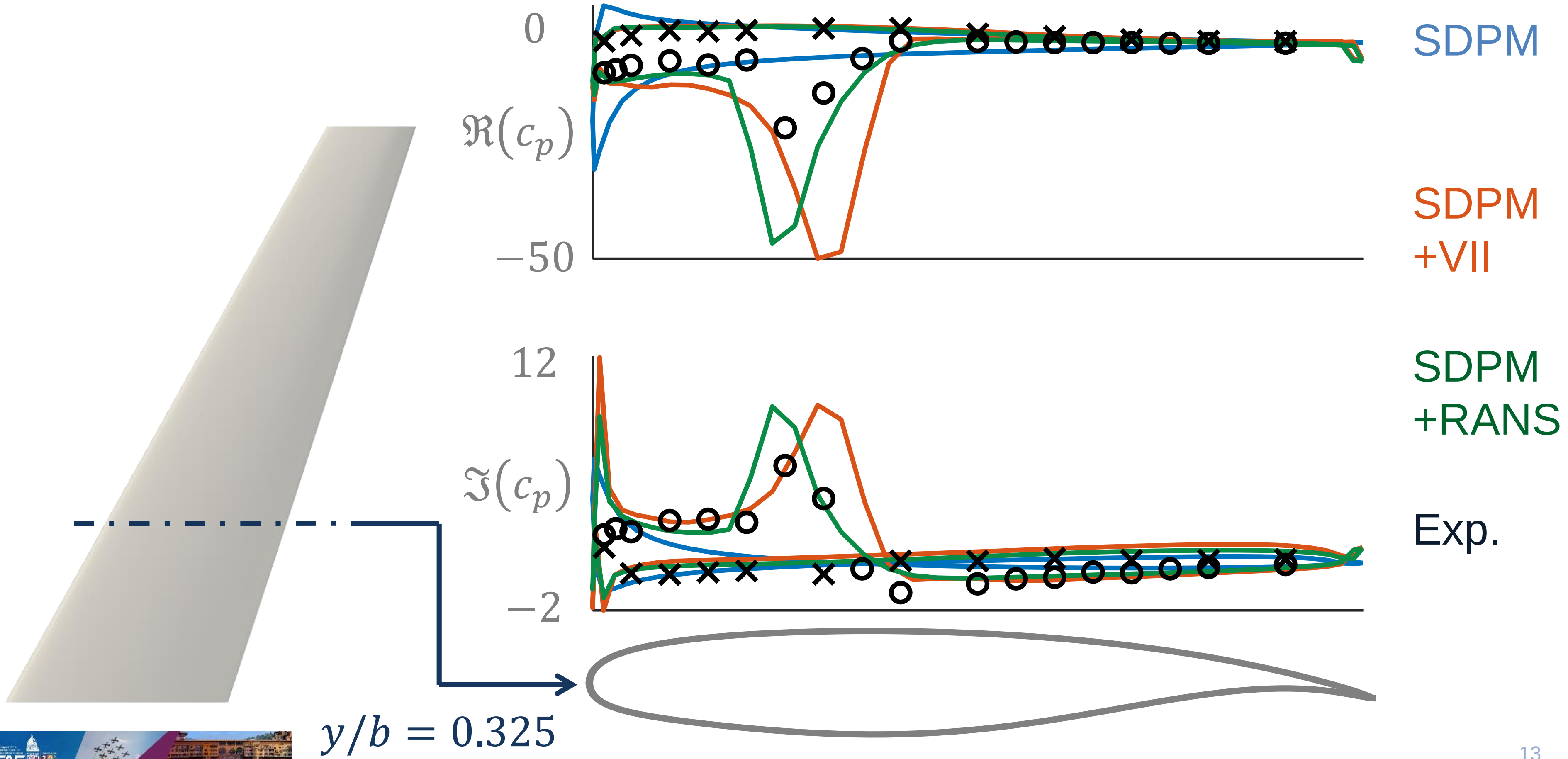
Aerodynamic case – LANN wing



Steady pressure coefficient



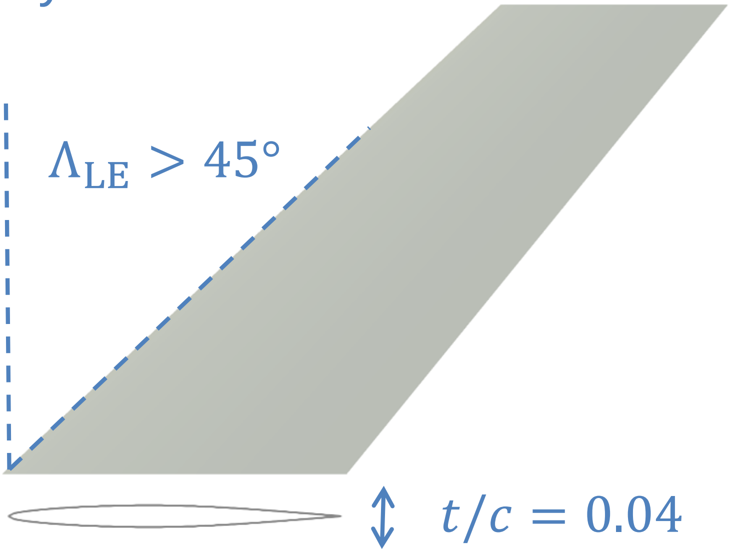
Unsteady pressure coefficient



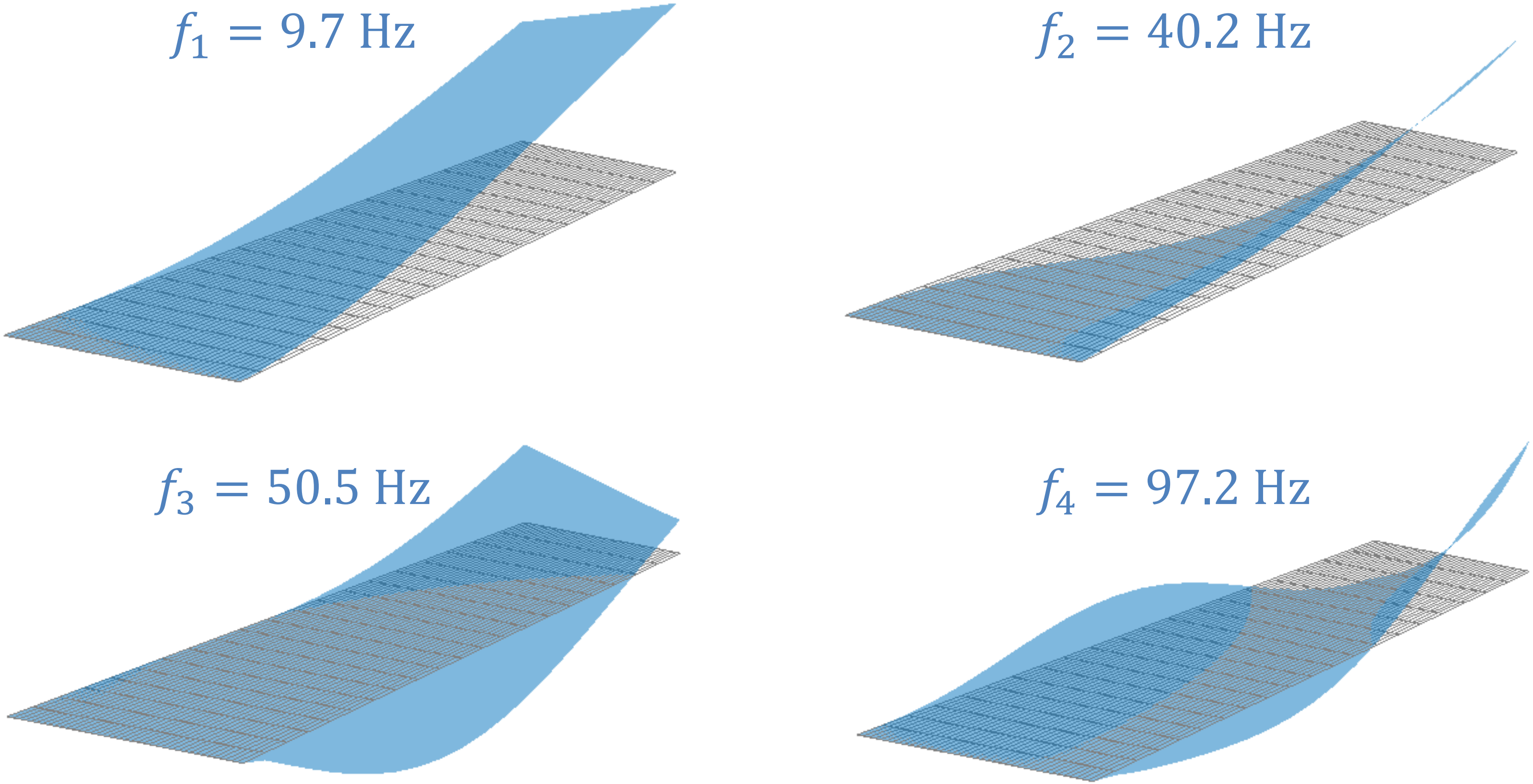
Aeroelastic case – AGARD 445.6 wing

$$M_{\infty,1} = 0.50$$
$$M_{\infty,2} = 0.68$$
$$M_{\infty,3} = 0.90$$
$$M_{\infty,4} = 0.96$$

$$\alpha = 0°$$



Modes shape



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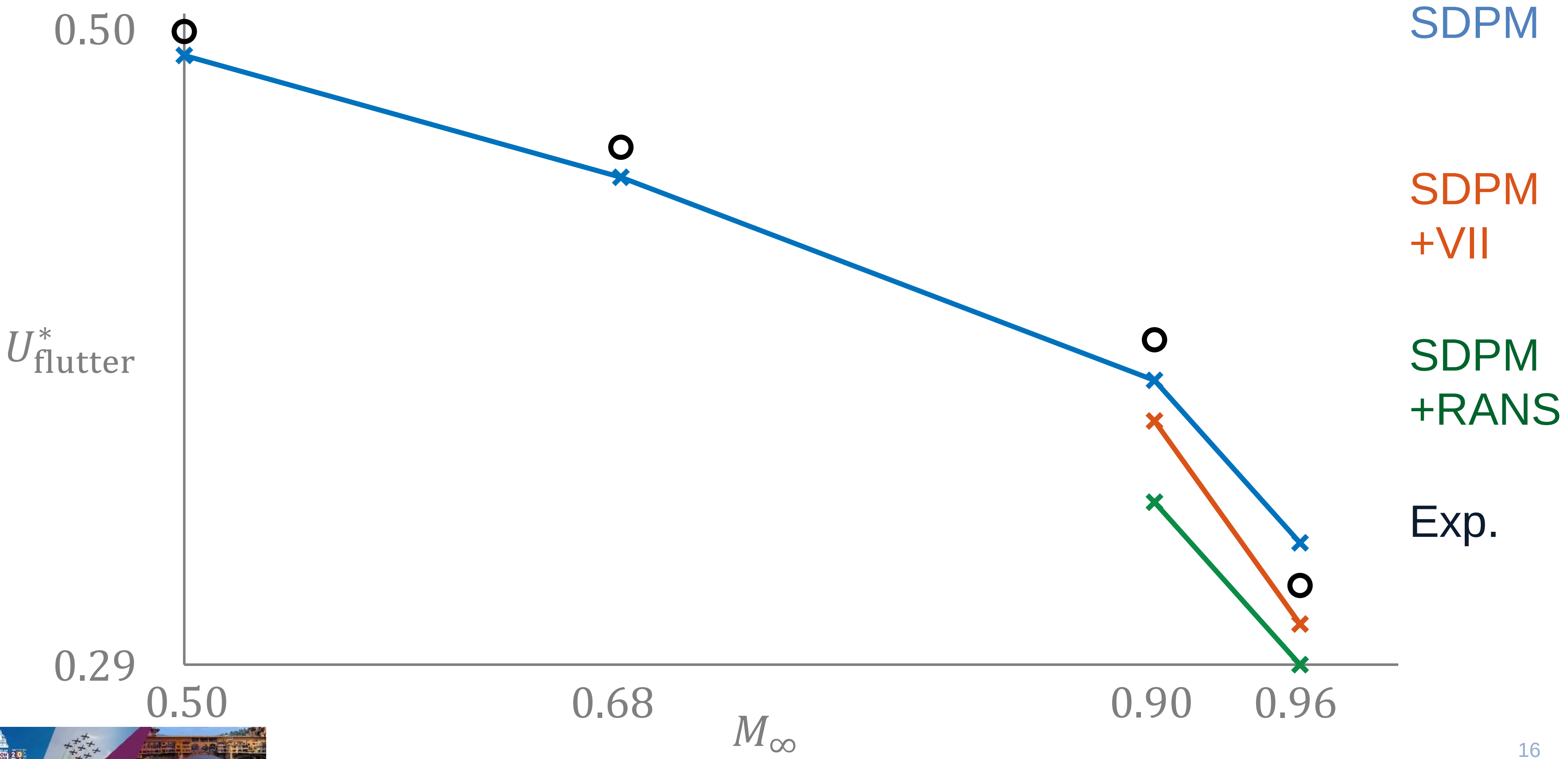
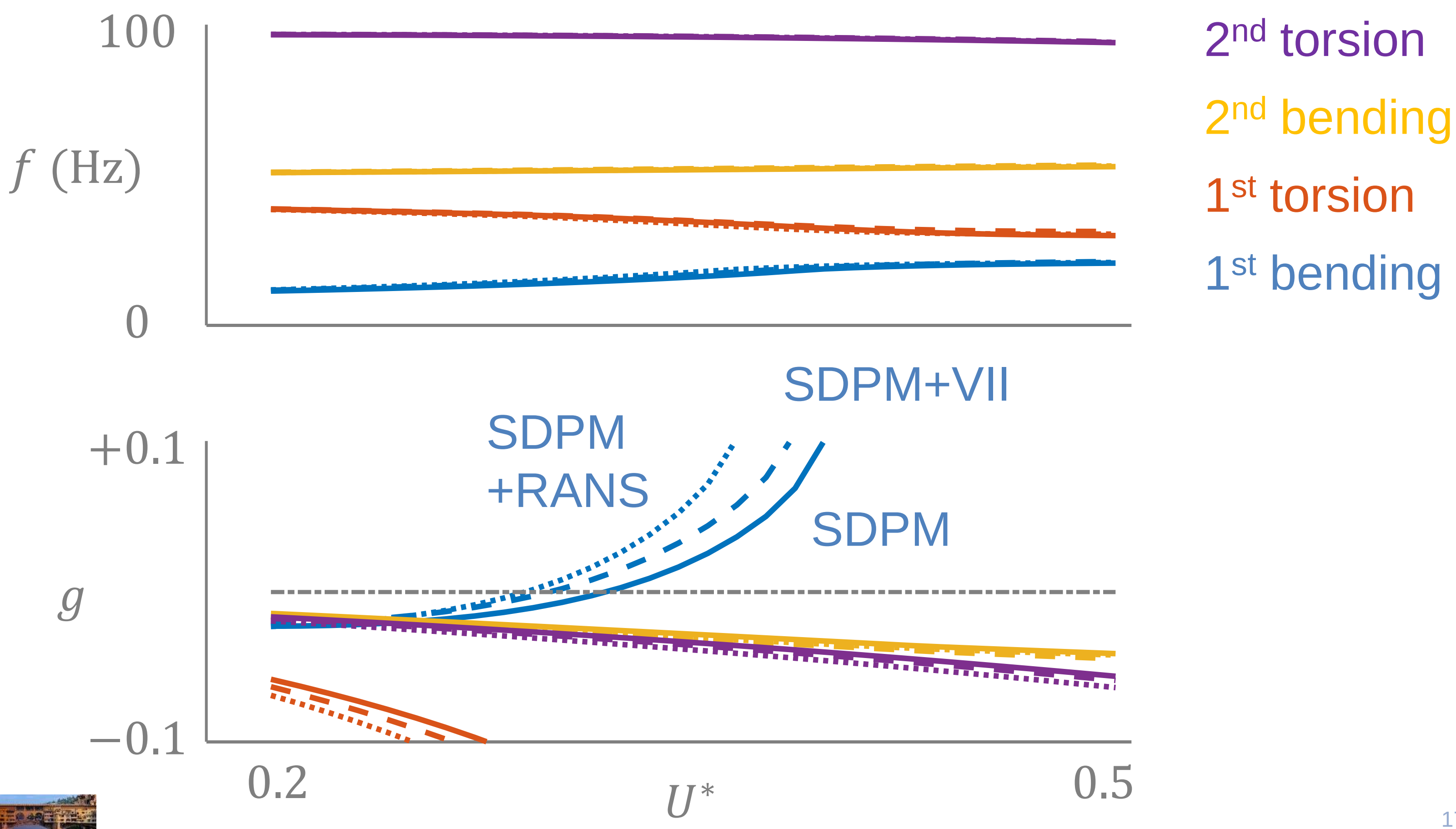


Modes migration



Conclusion

Main points

- **Developed correction methodology** whereby steady **viscous-inviscid interaction** is used to **correct** an unsteady **panel method** for nonlinear **transonic and viscous flow** effects
- **Demonstrated** the methodology on **aerodynamic** and **aerostructural** cases
- **Discrepancies** mainly due to **quality** of **reference** steady **results**

Next steps

- **Integrate** the methodology into **optimization** framework to calculate **flutter constraints**