

Assessment of Aircraft Formation Flight Safety via High-Fidelity Vortex Particle-Mesh Simulation

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The Vortex Particle-Mesh (VPM) method

Vorticity - Velocity

$$\boldsymbol{\omega} = \nabla \times \mathbf{u} \quad \Rightarrow \quad \nabla^2 \mathbf{u} = -\nabla \times \boldsymbol{\omega}$$

Incomp. Navier-Stokes

FFT-based
Poisson solver

$$\frac{D\mathbf{x}_p}{Dt} = \mathbf{u}_p$$

✓ Low dissipation and dispersion errors

$$\frac{D\boldsymbol{\omega}_p}{Dt} = [\boldsymbol{\omega} \cdot \nabla \mathbf{u} + \nu \nabla^2 \boldsymbol{\omega}]$$

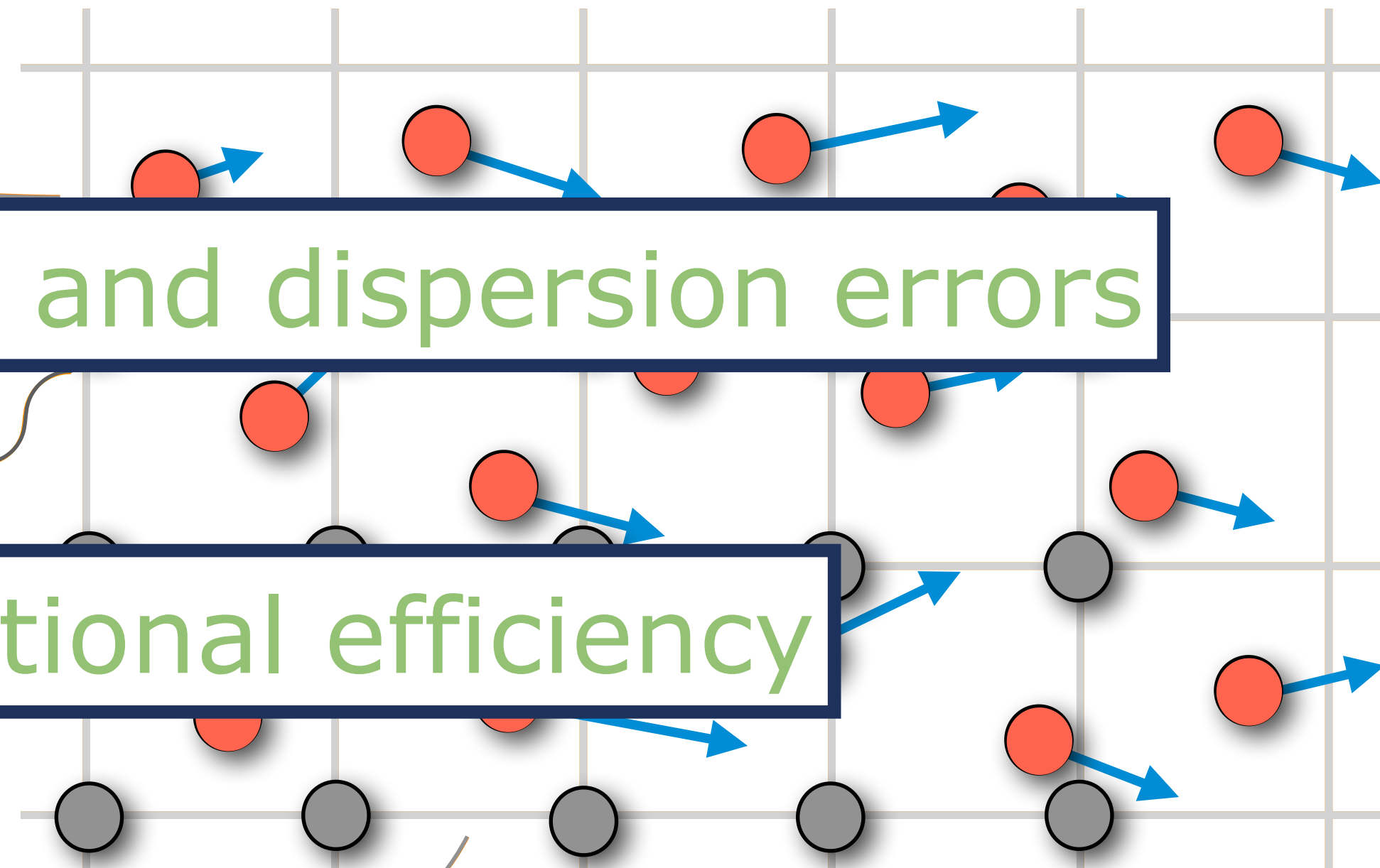
Finite differences

✓ Computational efficiency

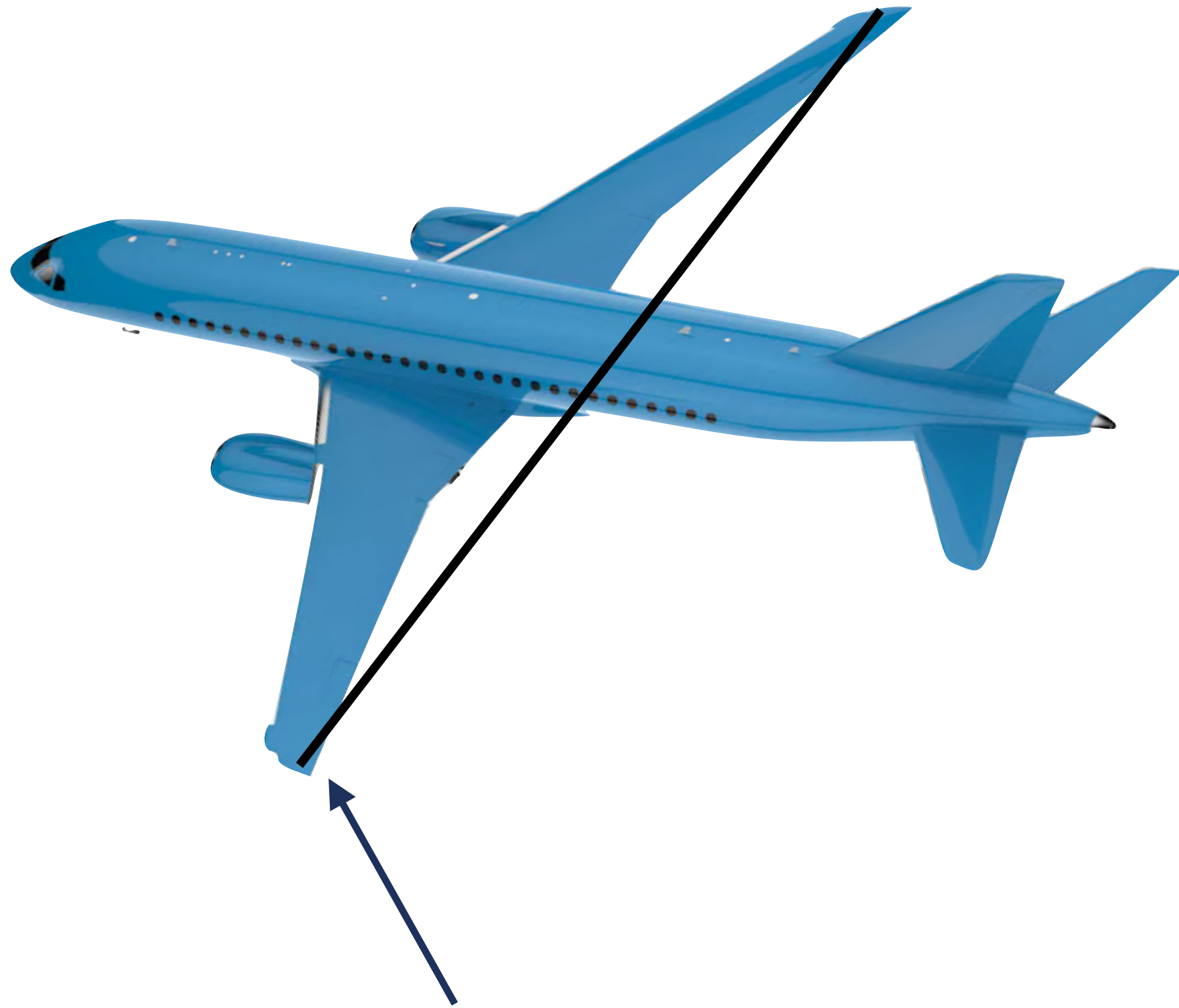
Reprojection

$$\nabla \cdot \boldsymbol{\omega} = 0 = \nabla \cdot (\tilde{\boldsymbol{\omega}} + \nabla A) \quad \text{with} \quad \nabla^2 A = -\nabla \cdot \tilde{\boldsymbol{\omega}}$$

+ remeshing



Aircraft representation: Lifting lines

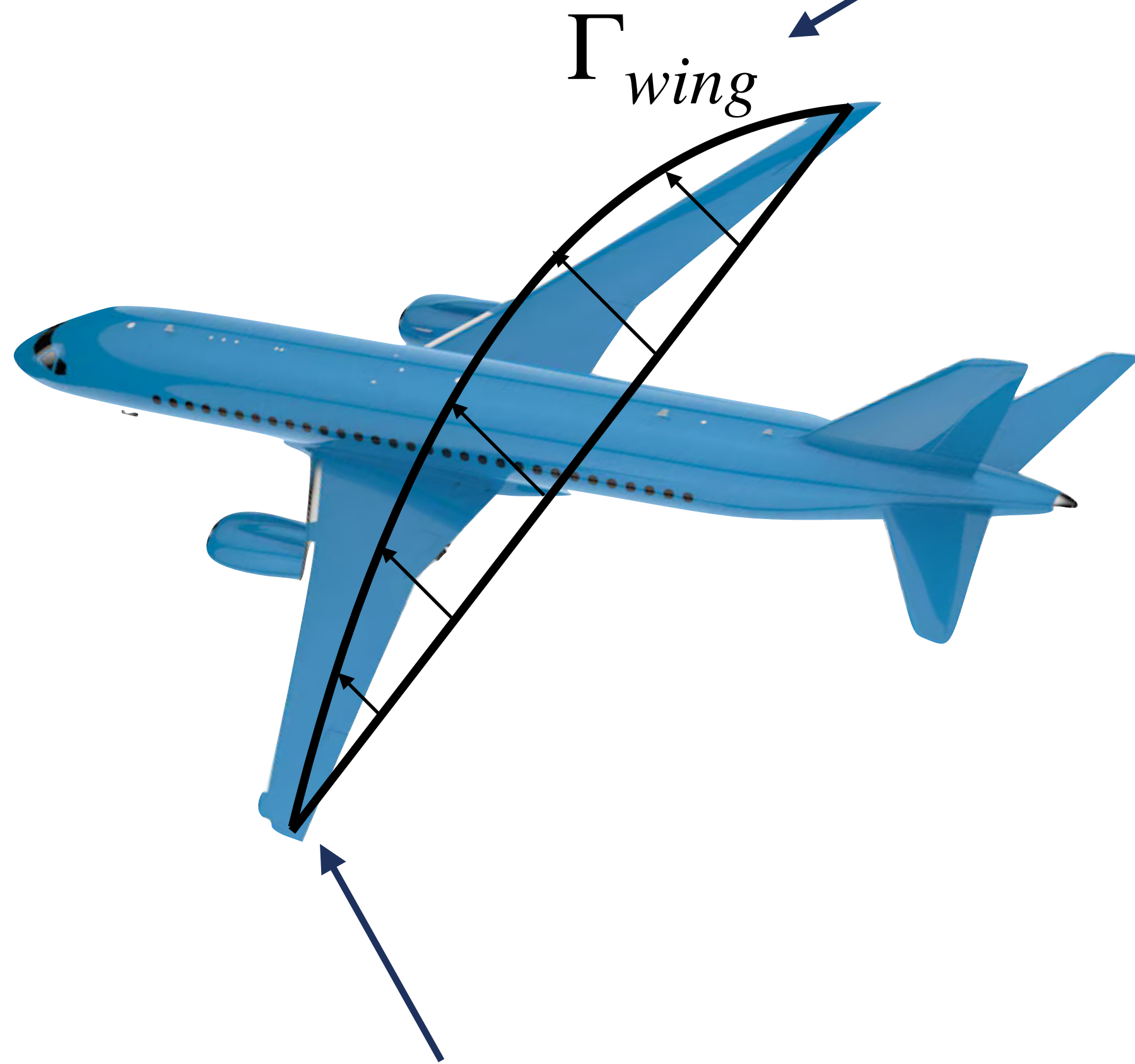


1: The wing is modelled via a line

Aircraft representation: Lifting lines

2: The circulation on the line is computed with the upstream flow and the wing characteristics:

$$\Gamma(y) = \frac{1}{2} \frac{U_e^2}{U_0} c(y) C_l(y, \alpha)$$



1: The wing is modelled via a line

Aircraft representation: Lifting lines

2: The circulation on the line is computed with the upstream flow and the wing characteristics:

$$\frac{1}{2} U_0^2$$

These lines also:

- Include drag by shedding dipoles into the flow:

$$\mu(y) = \frac{1}{2} \frac{U_e^2}{U_0} c(y) C_d(y, \alpha)$$

- Model control surfaces by modifying the wing polar locally

is
particles
flow field

1: The wing is modelled via a line

3: The circulation distribution is converted to a vortex sheet

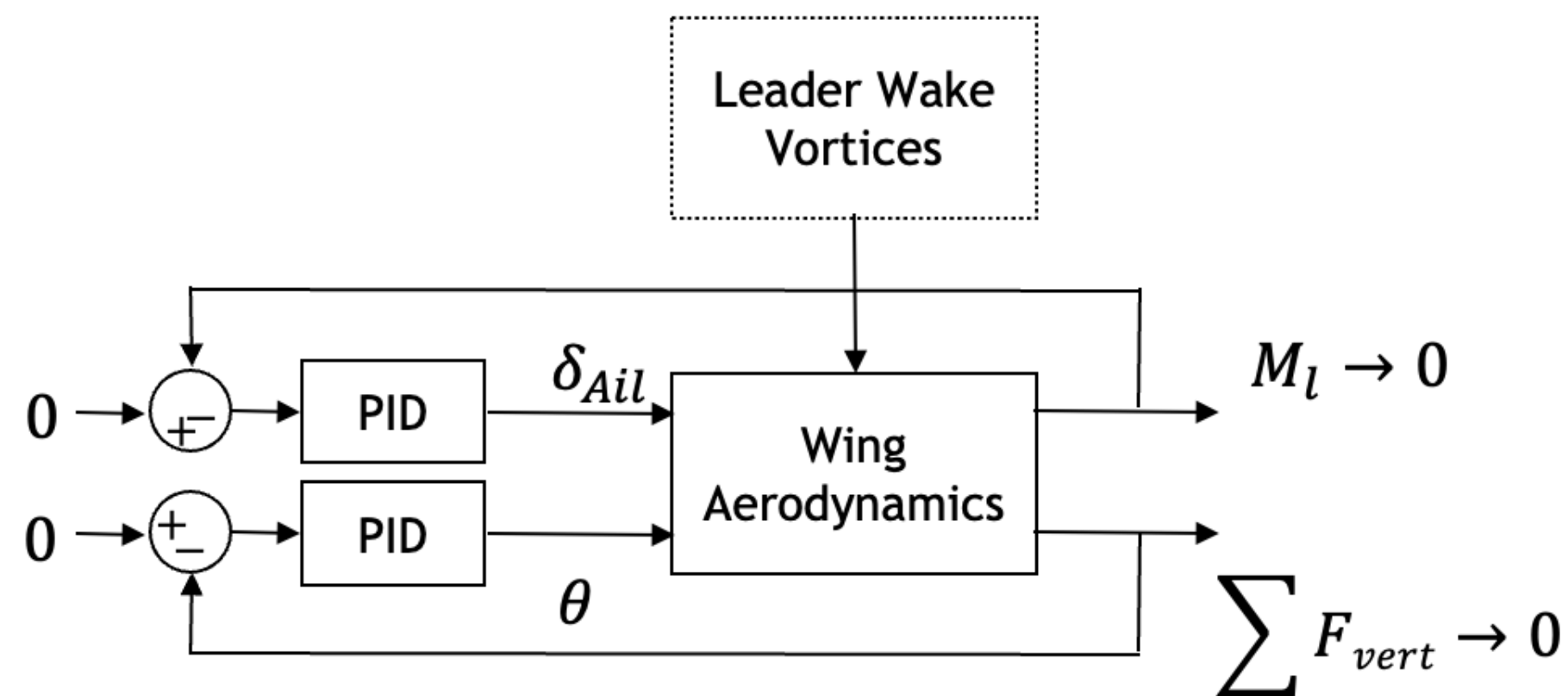
Chord shapes and control

The chords of the aircraft have an hyper-elliptic shape

$$c(y) = c_{root} \left(1 - \left| \frac{2y}{b} \right|^n \right)^{\frac{1}{n}}$$

- b [m] is the wing span
- c_{root} [m] is tuned to get the required wing area S [m²]
- n [-] is tuned to get the required vortex spacing b_0 [m]

The aircraft are controlled in aileron deflection and angle of attack to maintain zero roll and zero vertical force



The vortex circulation will be imposed by these controllers

