Wing Geometry Effect on Blade-Vortex Interaction Response Using BEM

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Outline

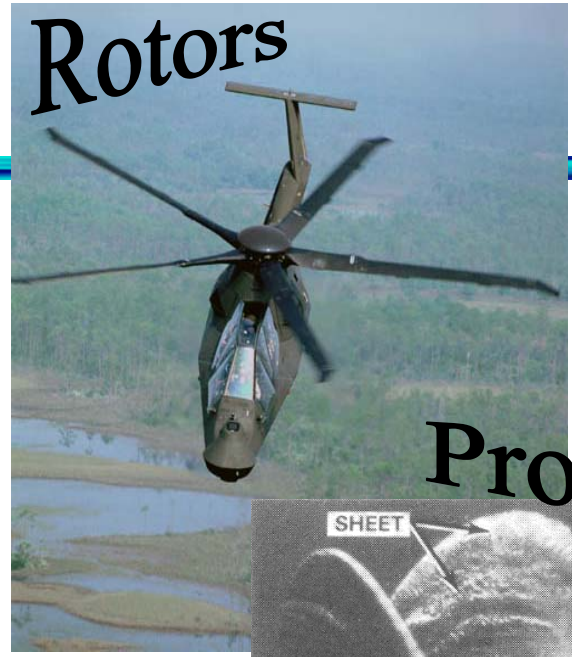
Applications for research

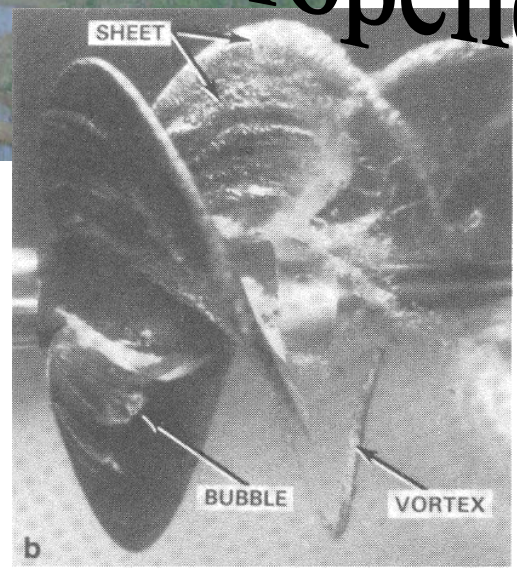
- Rotor BVI problem
- Noise from high-lift wing systems
- Naval propeller shaping

BEM - brief description

Validation of method/classical problems

Wing shape effects





Rotor noise/BVI

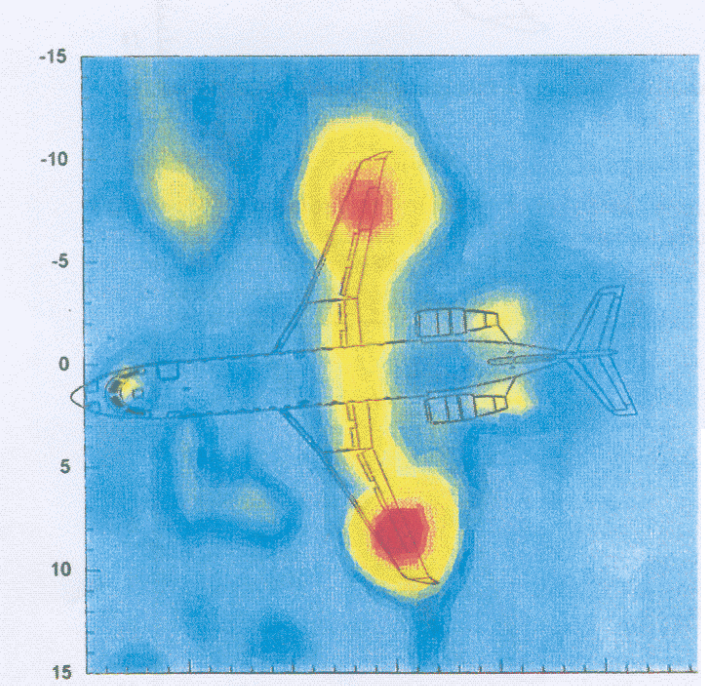
On landing rotor/wake interactions --> beating sound
Blade shaping

XV15 landing (tiltrotor)

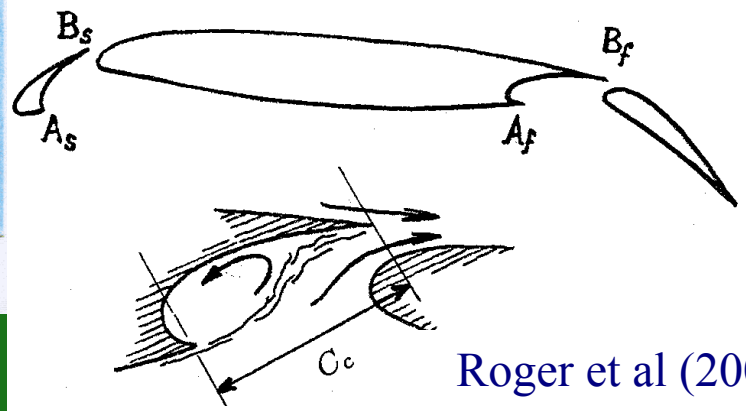
Airframe noise

High-lift wing systems
split flaps, slat tracks,
blown flaps

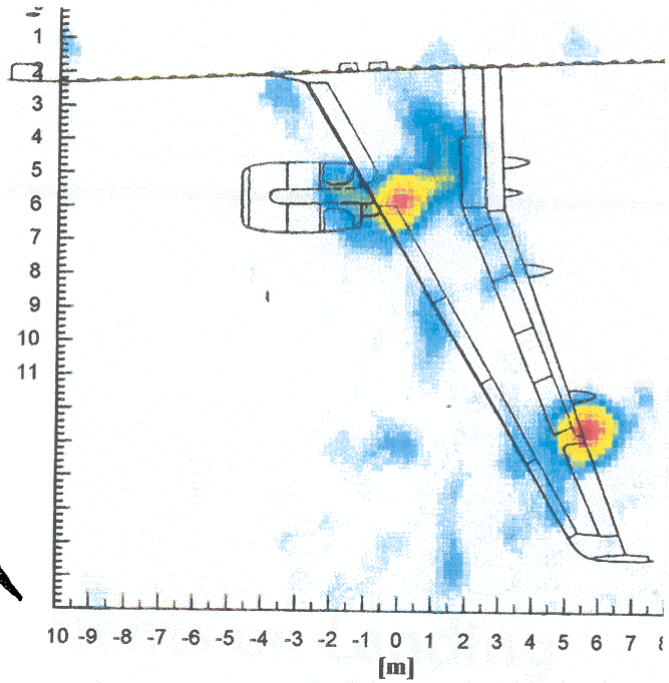
Wing noise



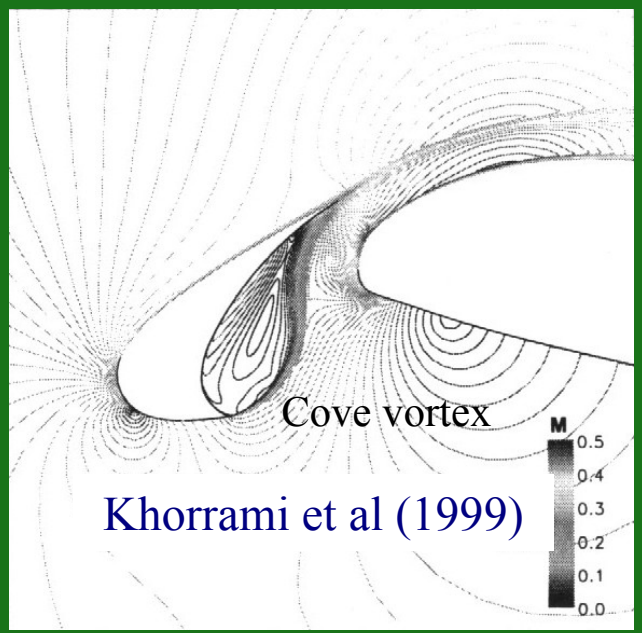
Michel et. al. (1998)



Roger et al (2000)



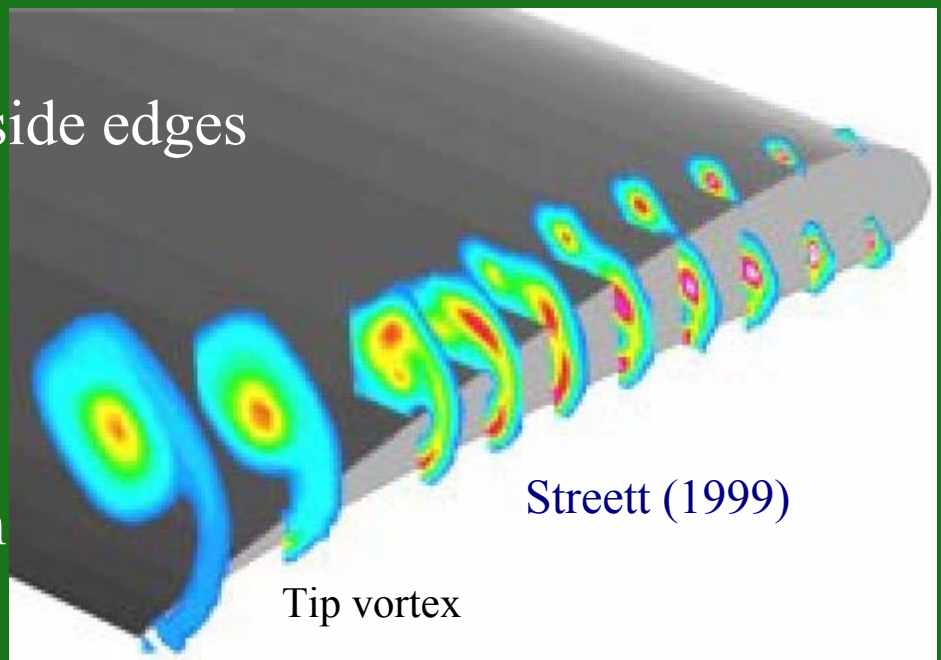
Gaps



Khorrami et al (1999)

Regions of high vorticity

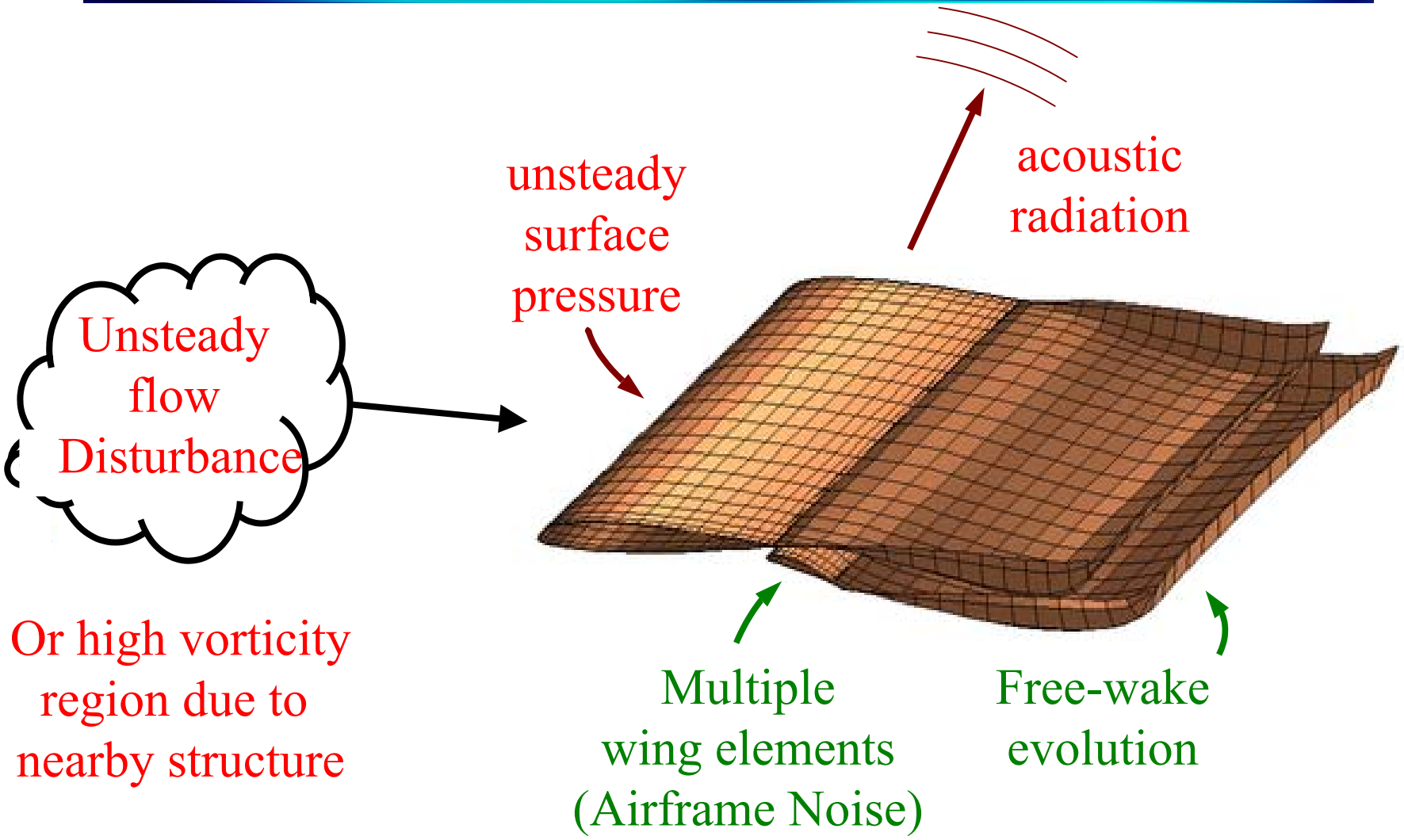
Flap side edges



Streett (1999)

Tip vortex

Underlying Problem



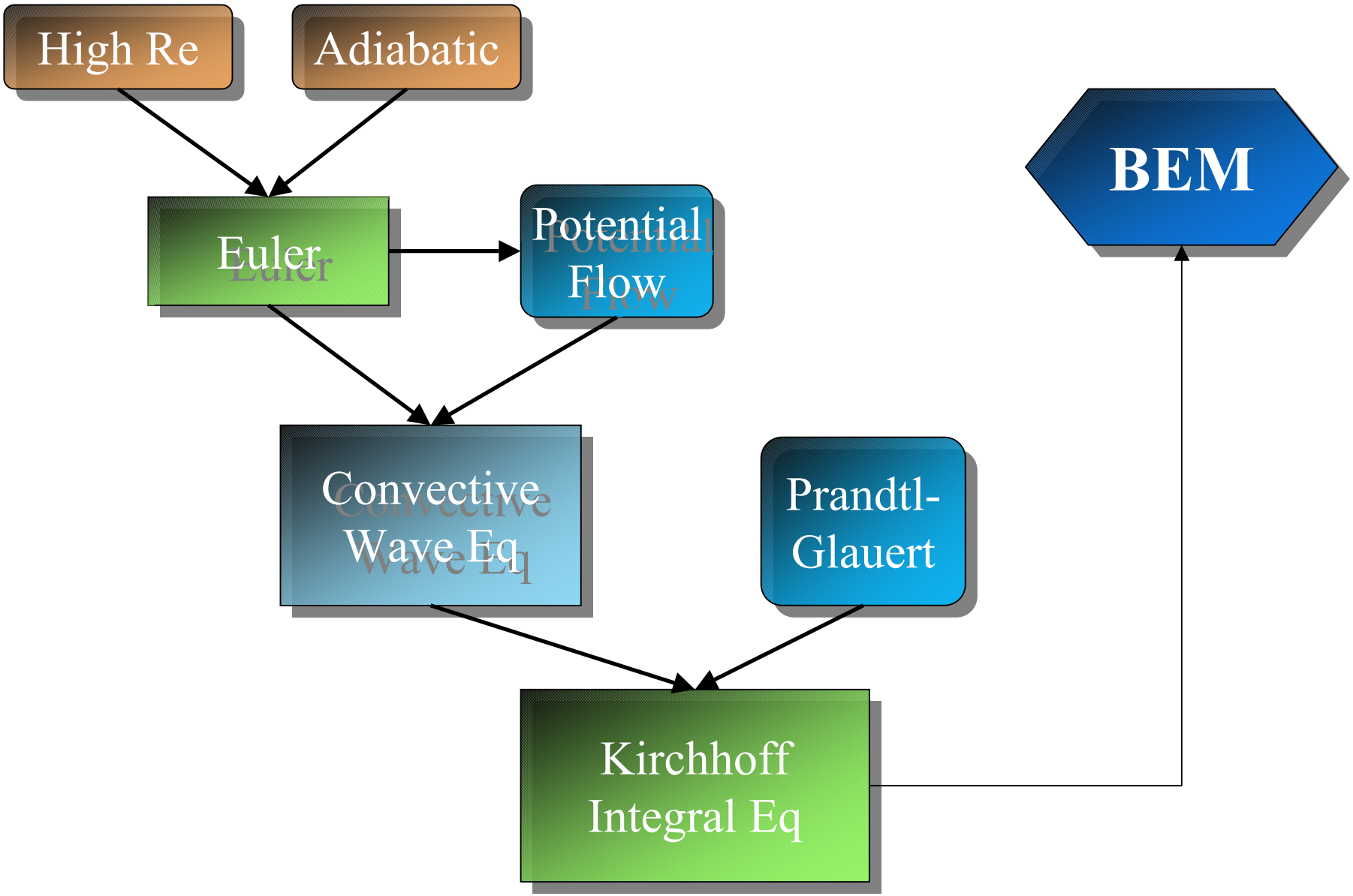
BEM Method

Boundary Element Method (BEM)

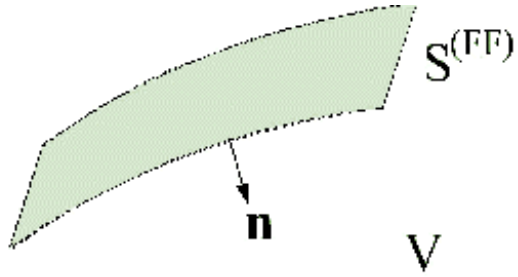
- Widely-used for aerodynamics (High Re, attached)
- Past research on:
  - 2D / 3D steady / frequency / time domain
  - Free wake, boundary layers, separation, transonic

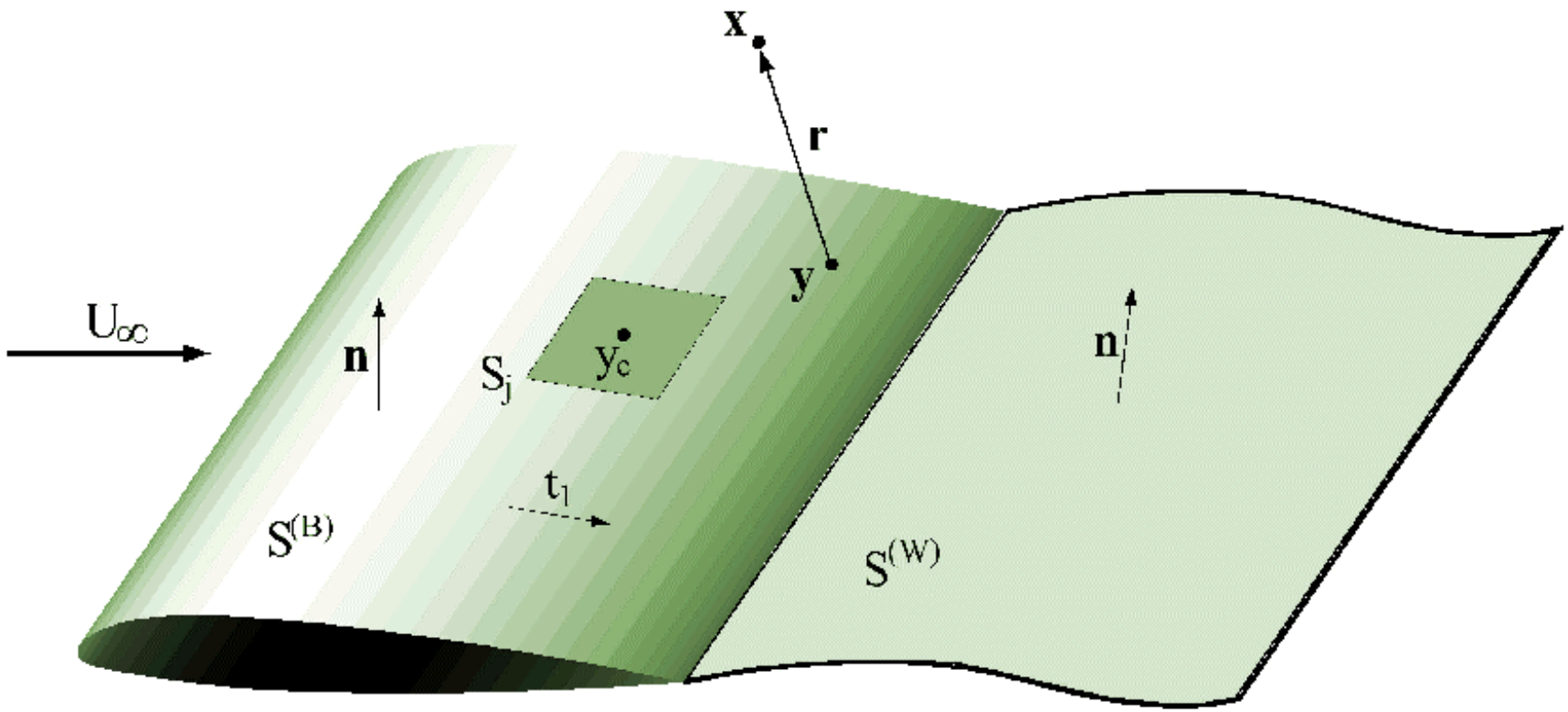
- Current Capabilities:
  - 3D Multi-element, Time domain, Compressible
  - Acoustic Evaluation
  - Free wake, Free vortex evolution
  - Accurate **fixed-wake** model using steady **free wake**

Method


High Re
Adiabatic
Euler
Potential Flow
BEM
Convective Wave Eq
Prandtl-Glauert
Kirchhoff Integral Eq

Method

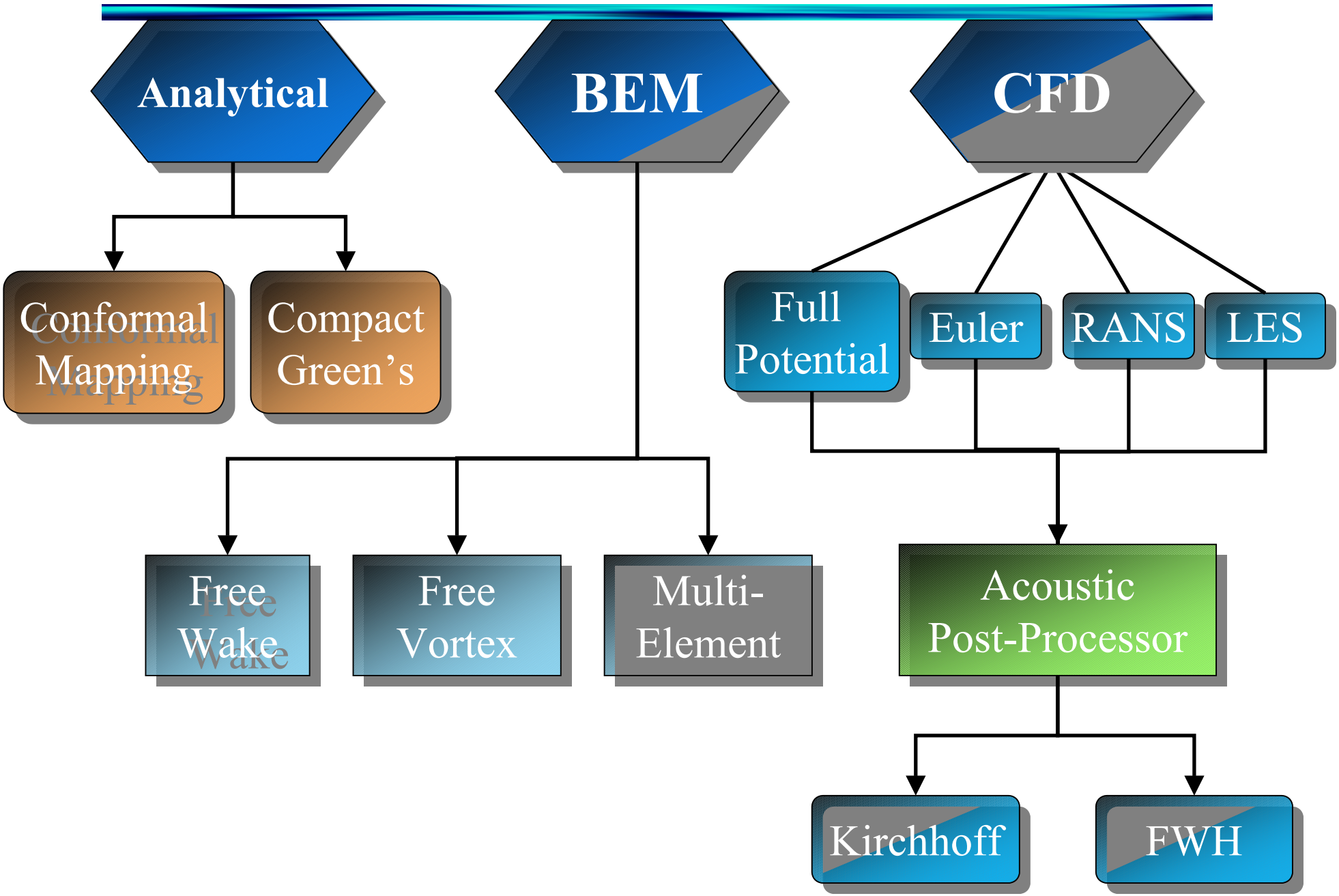




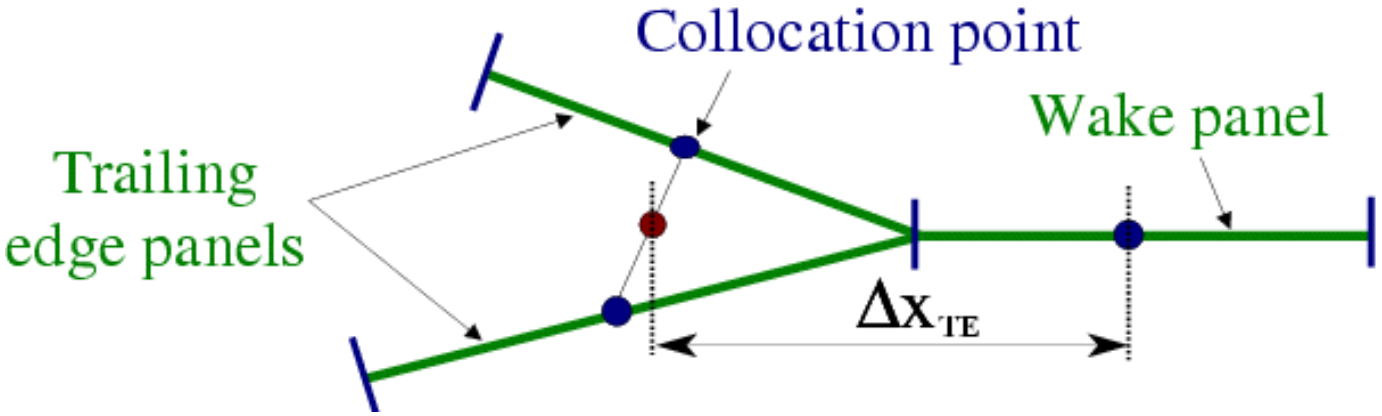
$$\mathbf{v} = \nabla\phi + U_\infty \hat{i}$$

$$\phi(\mathbf{x},t) = \int_S \left[G_S \frac{\partial \phi}{\partial n} + G_D(\mathbf{x},t|\mathbf{y},\tau)\phi(\mathbf{y},\tau) + G_R \frac{\partial \phi}{\partial \tau} \right]_{\tau^\star} dS_y$$

Impermeability/know downwash


Analytical
BEM
CFD
Conformal Mapping
Compact Green's
Full Potential
Euler
RANS
LES
Free Wake
Free Vortex
Multi-Element
Acoustic Post-Processor
Kirchhoff
FWH

Trailing Edge Condition



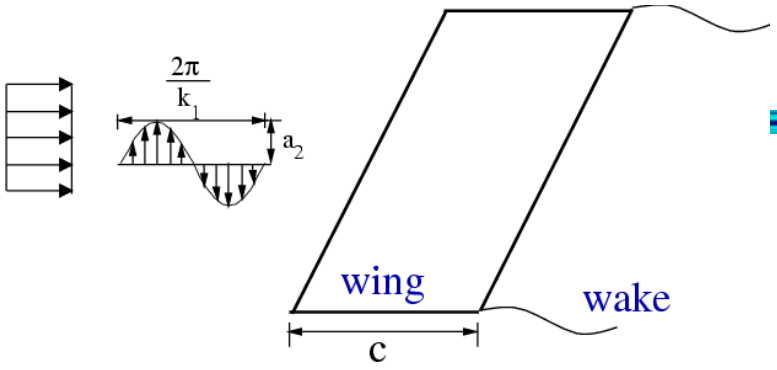
Kutta Condition:

$$\Delta p_{\mathrm{TE}} = 0 \quad \Rightarrow \quad \Delta \phi_{\mathrm{TE}}^{(\mathrm{B})} = \Delta \phi_{\mathrm{TE}}^{(\mathrm{W})}$$

0^{th} order BEM:

$$\Delta \phi_{TE}^{(W)} = \left[\phi_{(TE+)}^{(B)} - \phi_{(TE-)}^{(B)} \right]_{t - \Delta x_{TE}/U_\infty}$$

Sears Problem



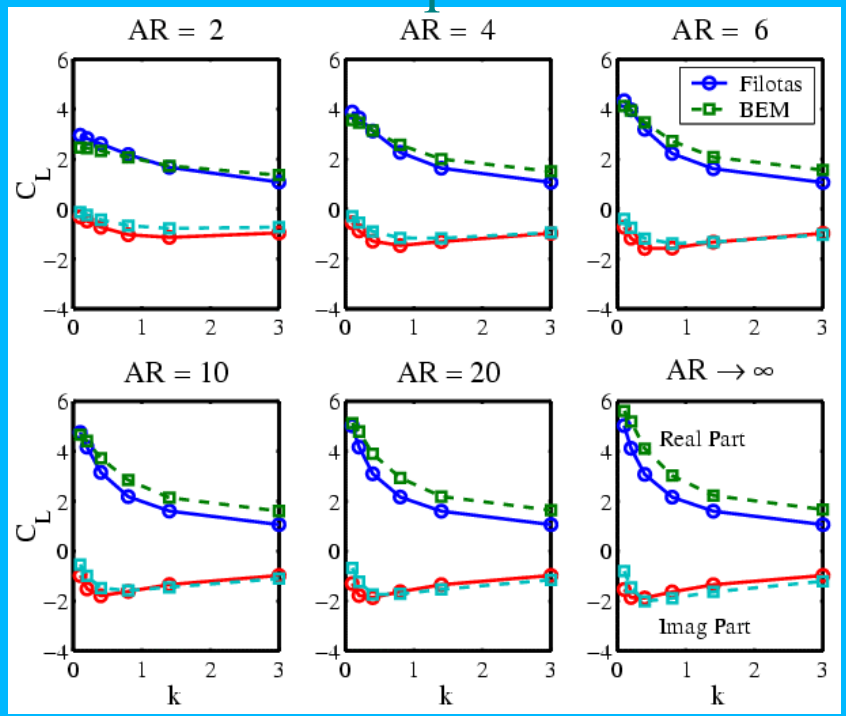
Downwash velocity

$$\mathbf{v}(x_1, x_3, t) = A(k)e^{-ik(t-x_1)}\hat{j}$$

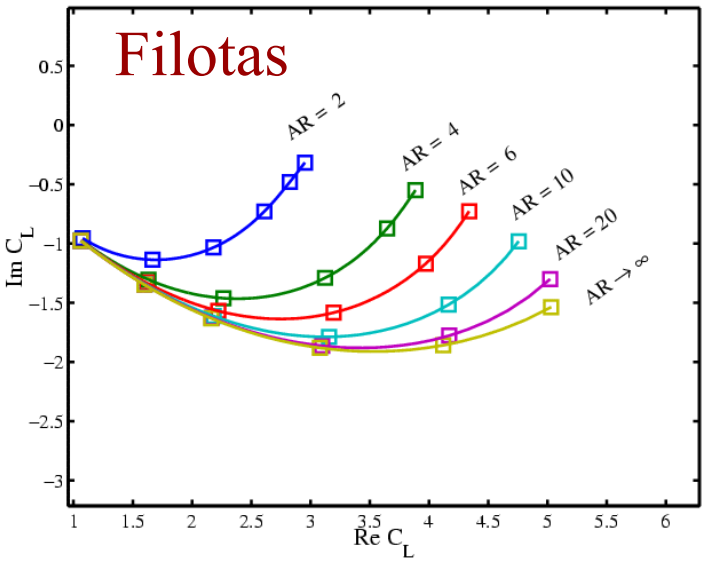
Large aspect ratio, Filotas solution

$$C_L = \frac{L}{\frac{1}{2}\rho_\infty U_\infty^2 S_A} = 2\pi A(k) S_B(k, AR) e^{-ikt}$$

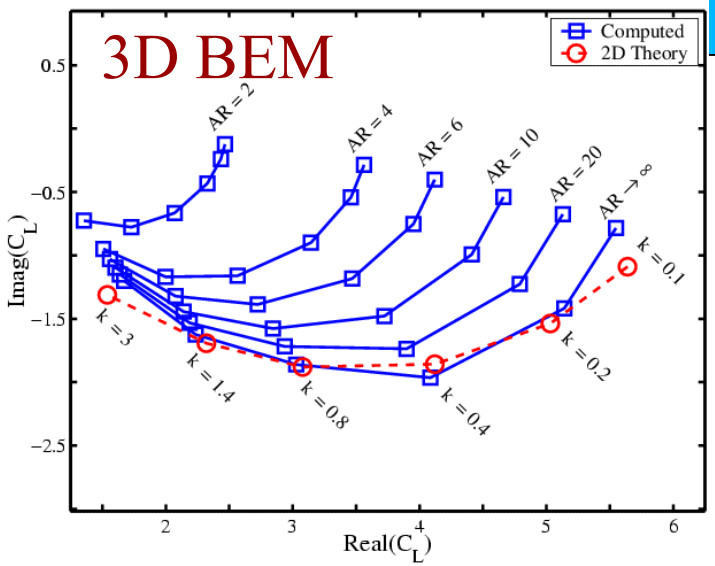
Comparison



Filotas

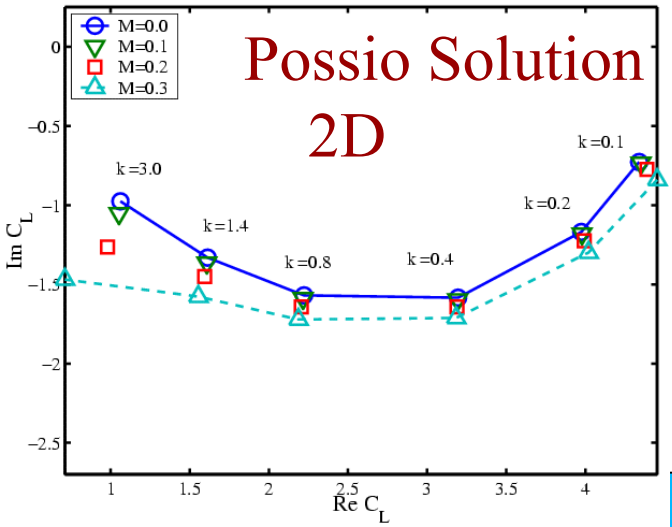


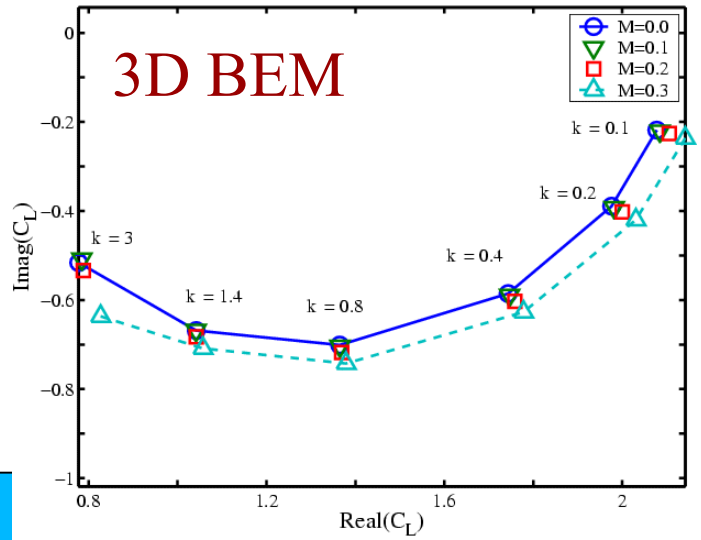
3D BEM



Extrapolation (1/N) using N=10,12,14

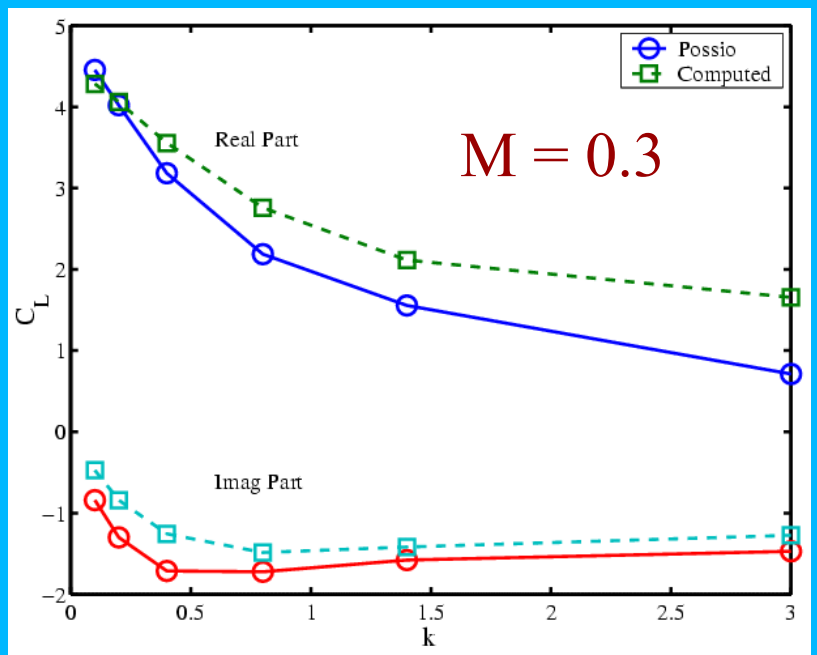
Compressible Problem





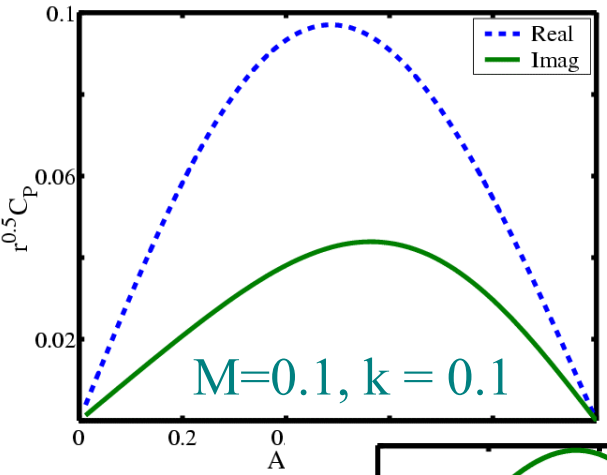
Computations for AR=6.0 (Difference due to 3D effects)

Comparison

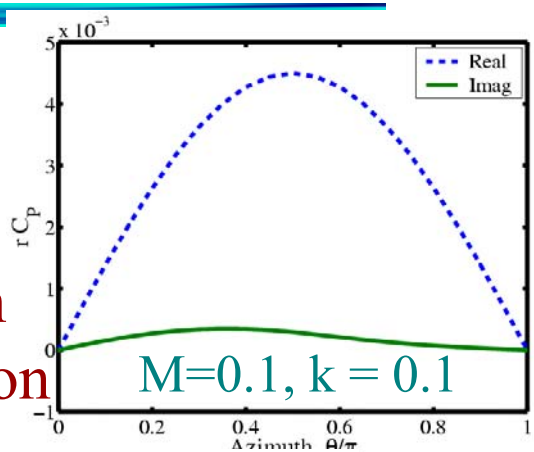


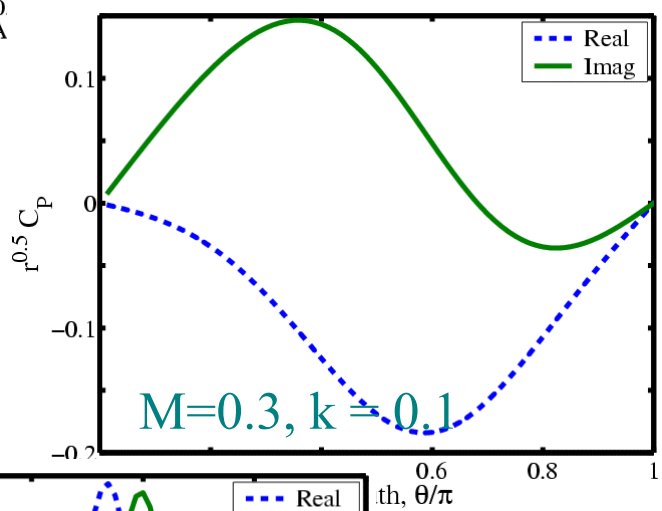
Far-field for Sears

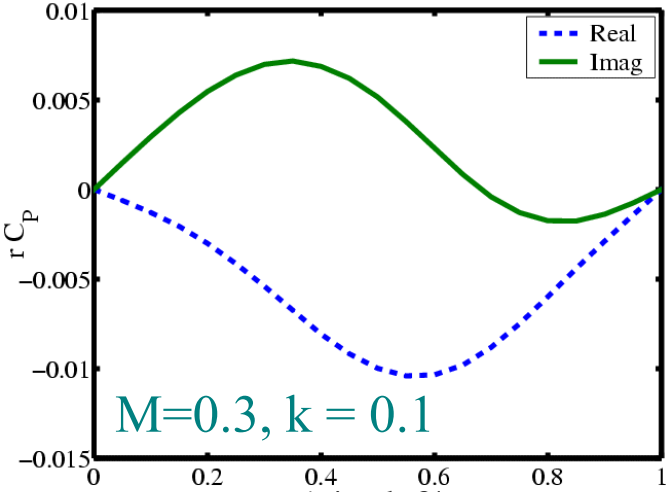
2D propagation
Possio/Atassi

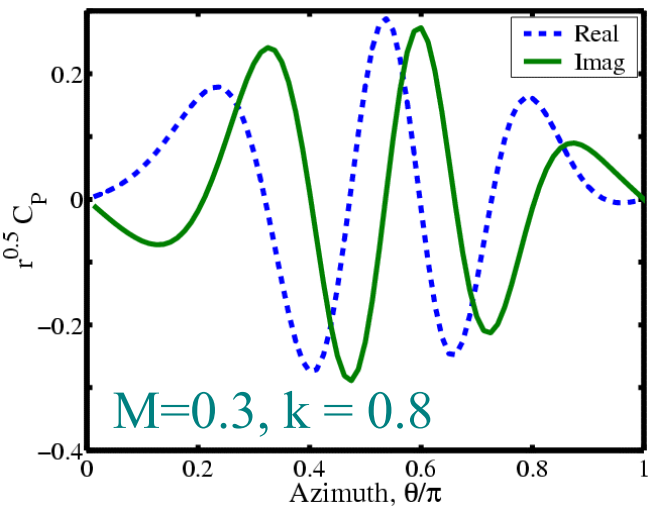


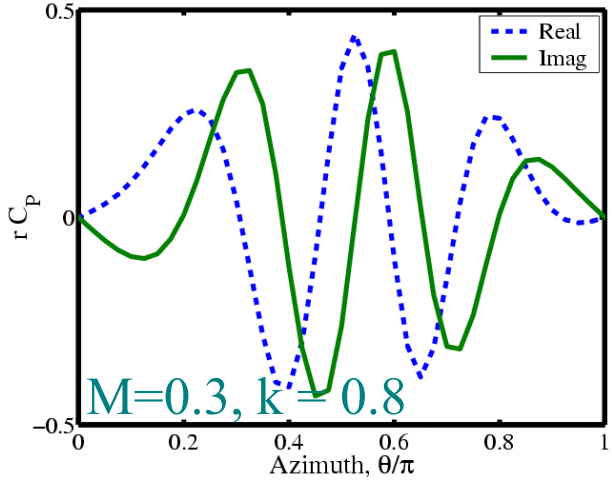
3D propagation
BEM Computation



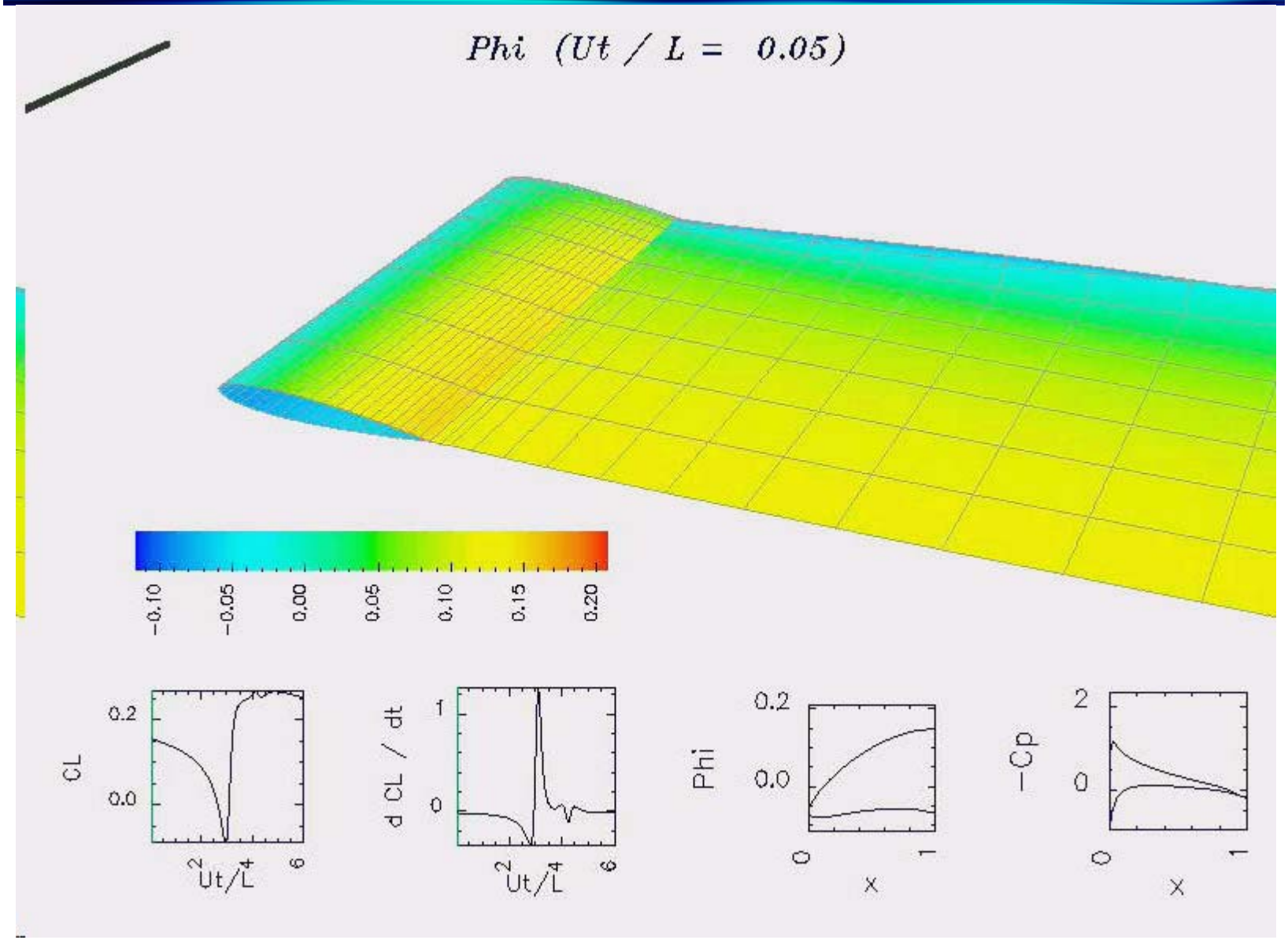








Blade-Vortex Interaction Problem

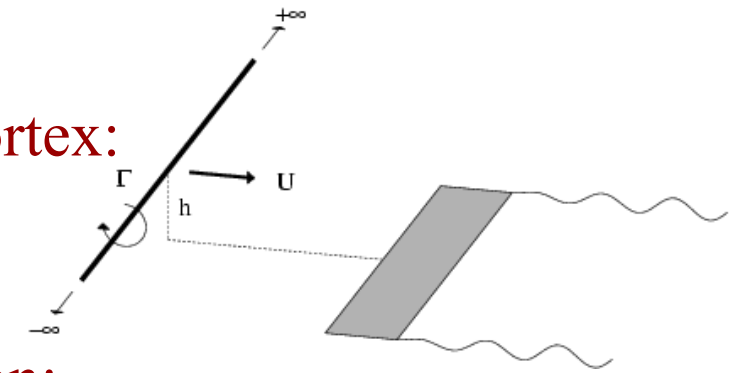


BVI Validation

Analytic frequency response

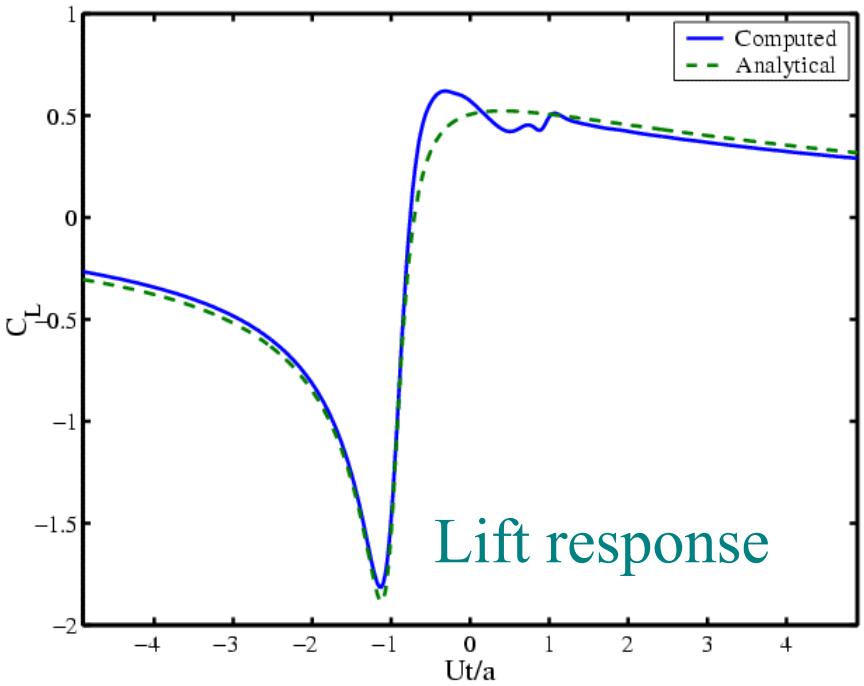
Thin, Flat, unloaded, two-dimensional line vortex:

$$C_l(k) = \frac{i}{2}\Gamma \, \mathrm{sgn}(k) e^{-i|k|h} S(k)$$

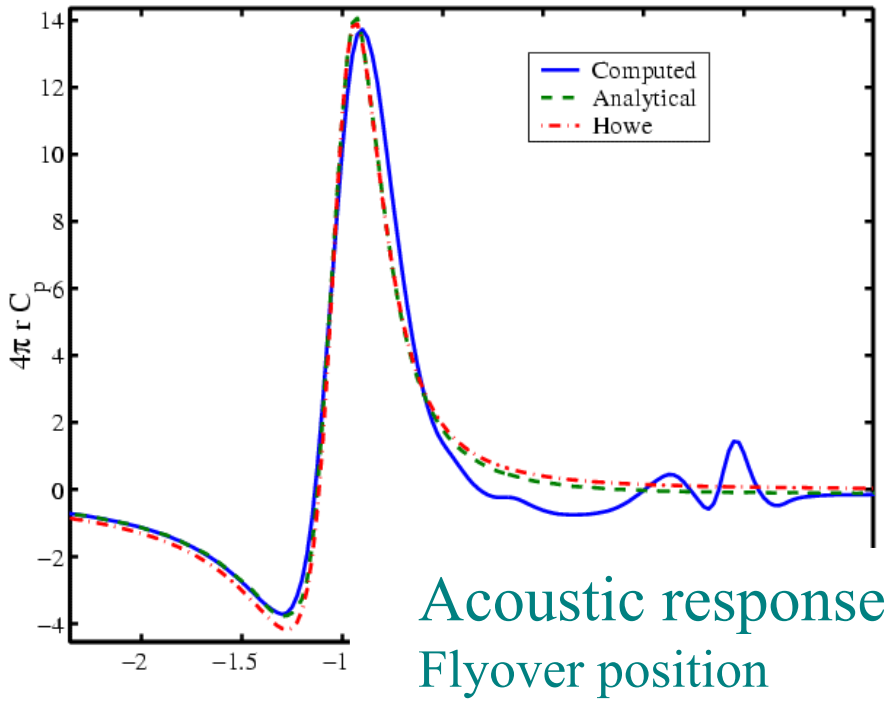


Low Mach number acoustics from Curle's equation:

$$C_p(\mathbf{x},t) \approx \frac{M \; AR \; \cos\theta_P}{4\pi r} \left(\frac{\partial C_L}{\partial t}\right)_{t-Mr}$$



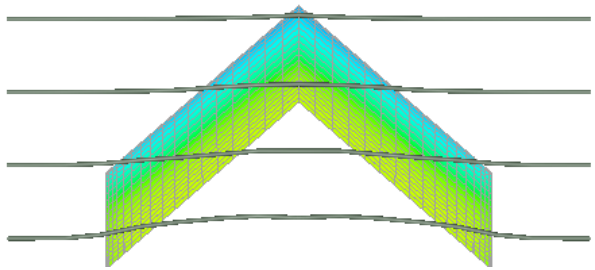
Lift response



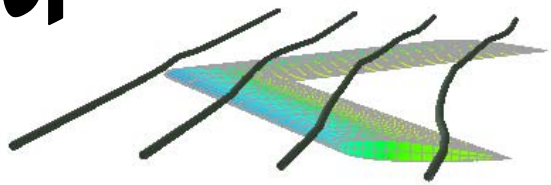
Acoustic response

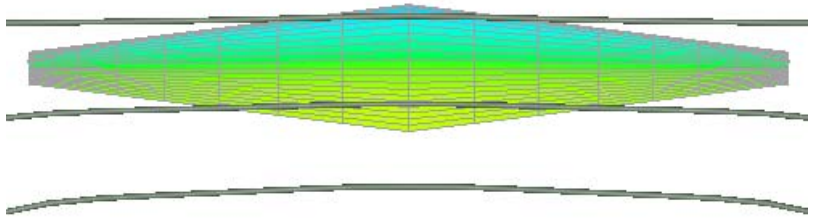
Flyover position

Wing geometry effect

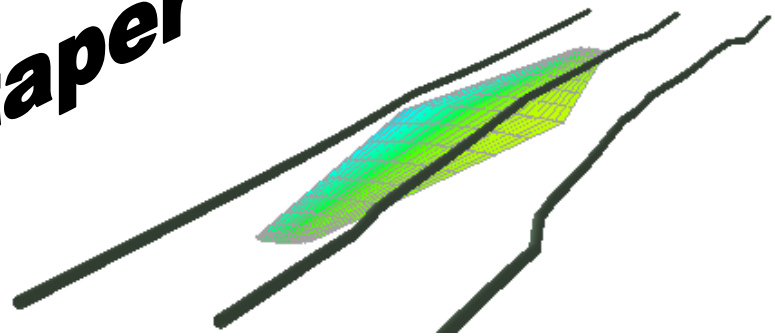


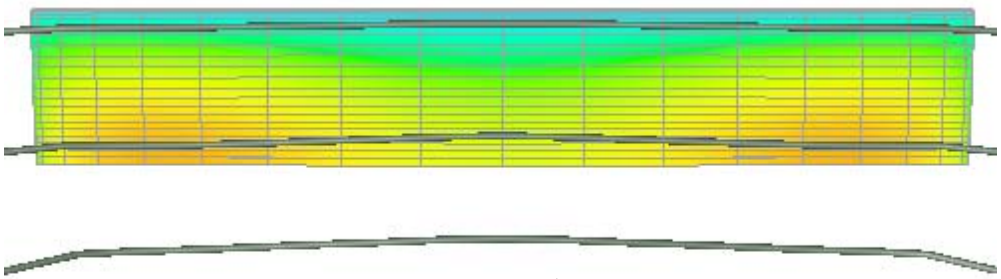
sweep



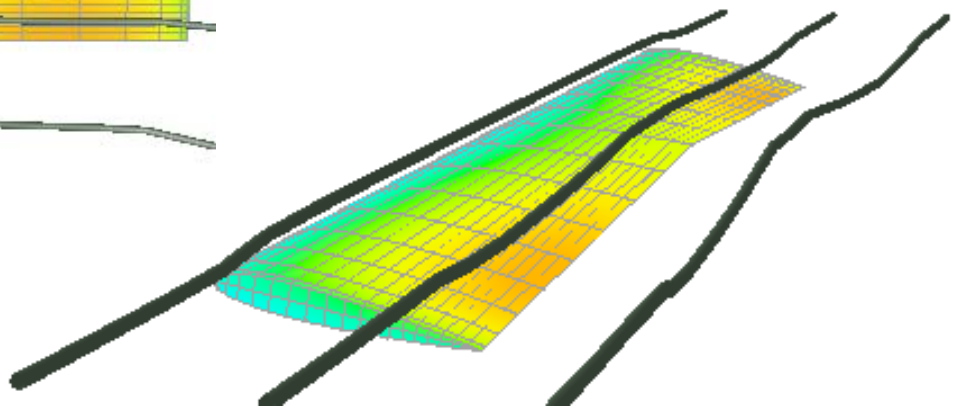


taper

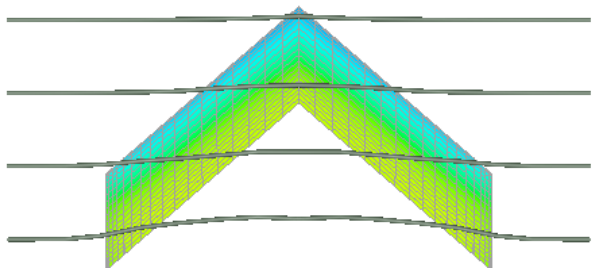


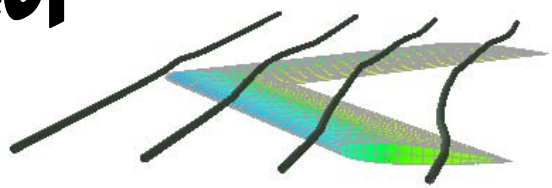


twist



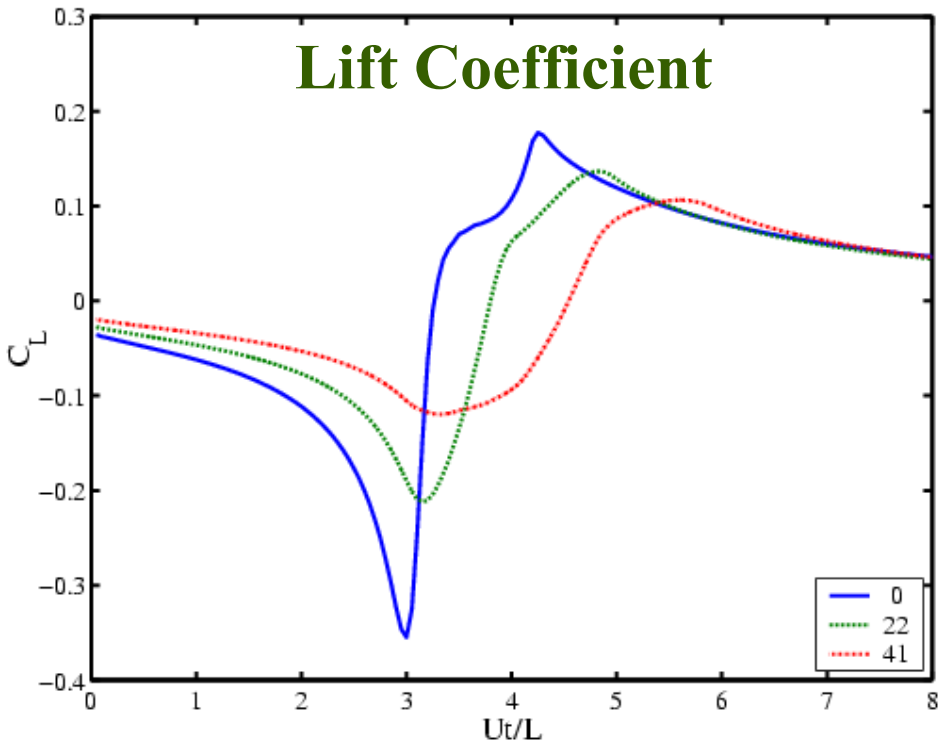
Sweep Effect

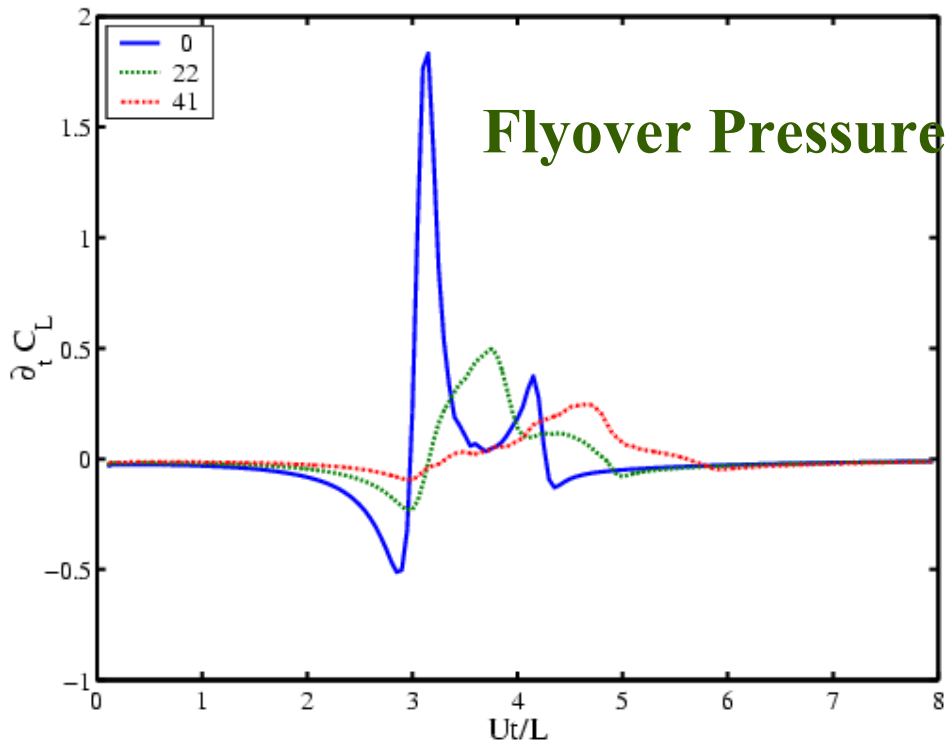




Increased **sweep**

$\Rightarrow$ LE interaction spreads out

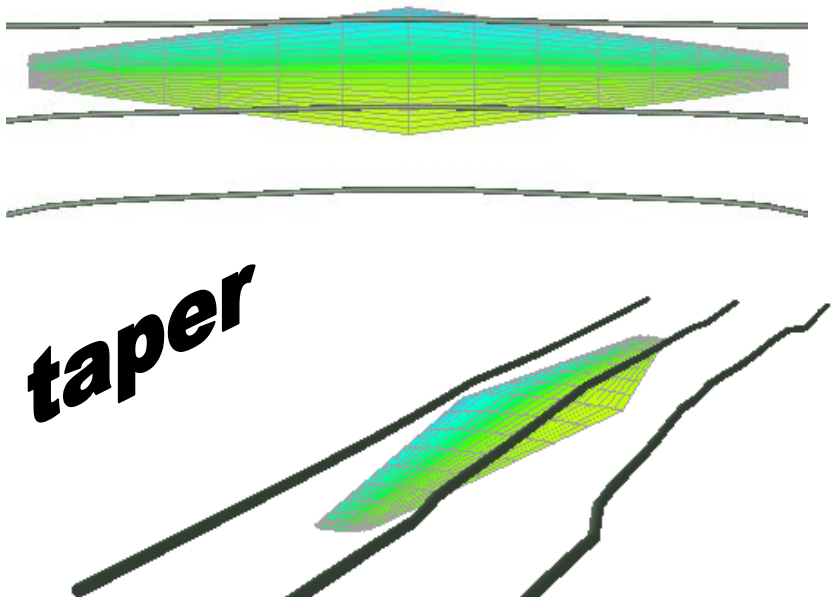


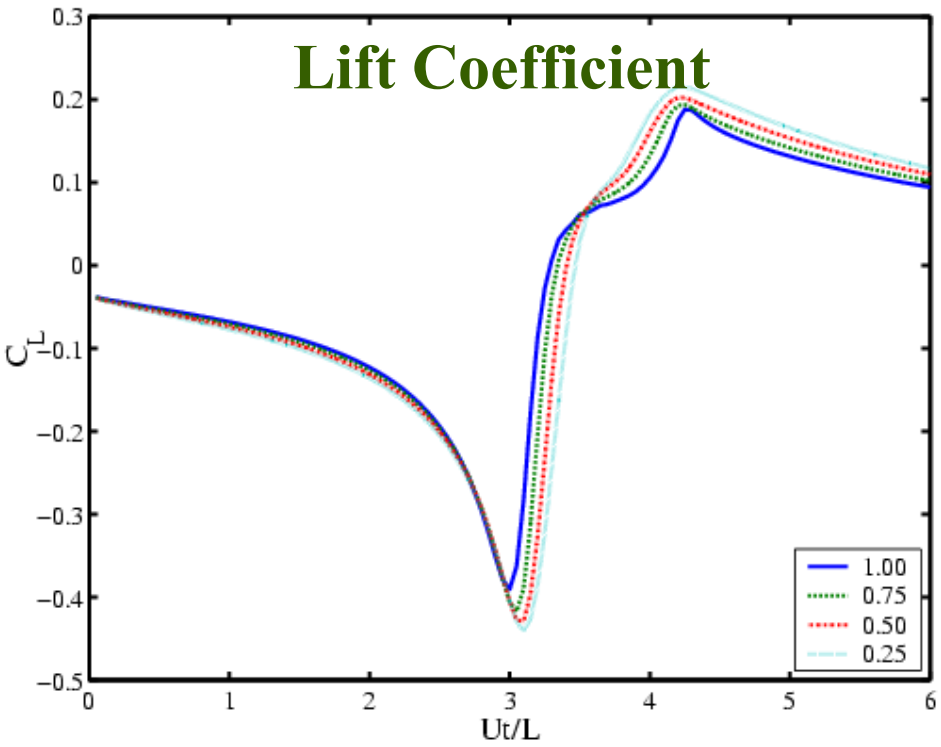


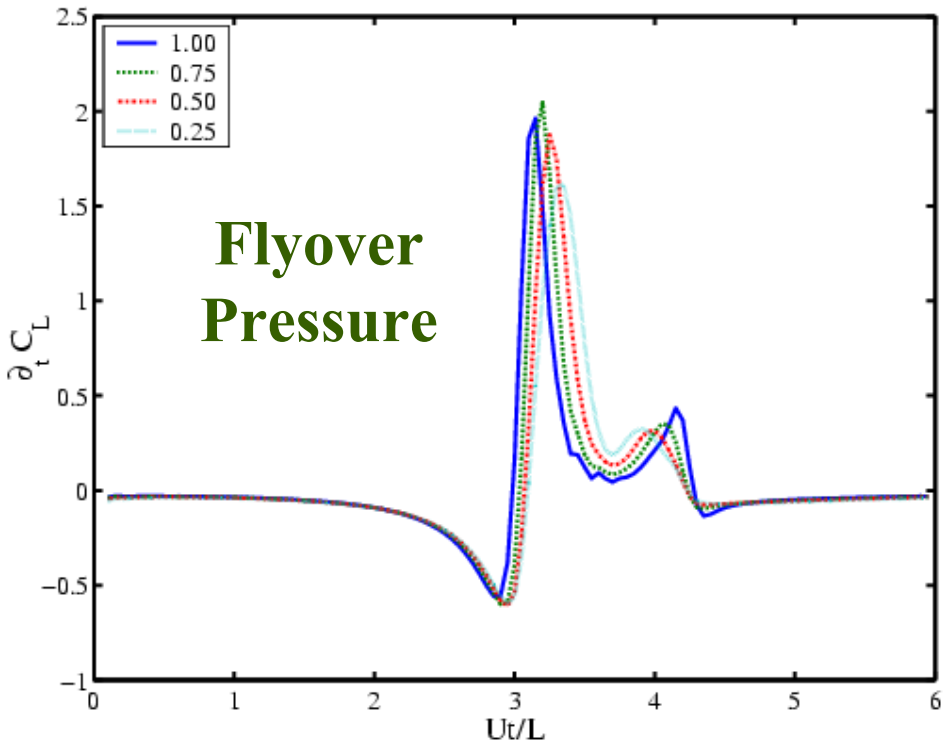
Taper Effect

Increased **Taper**

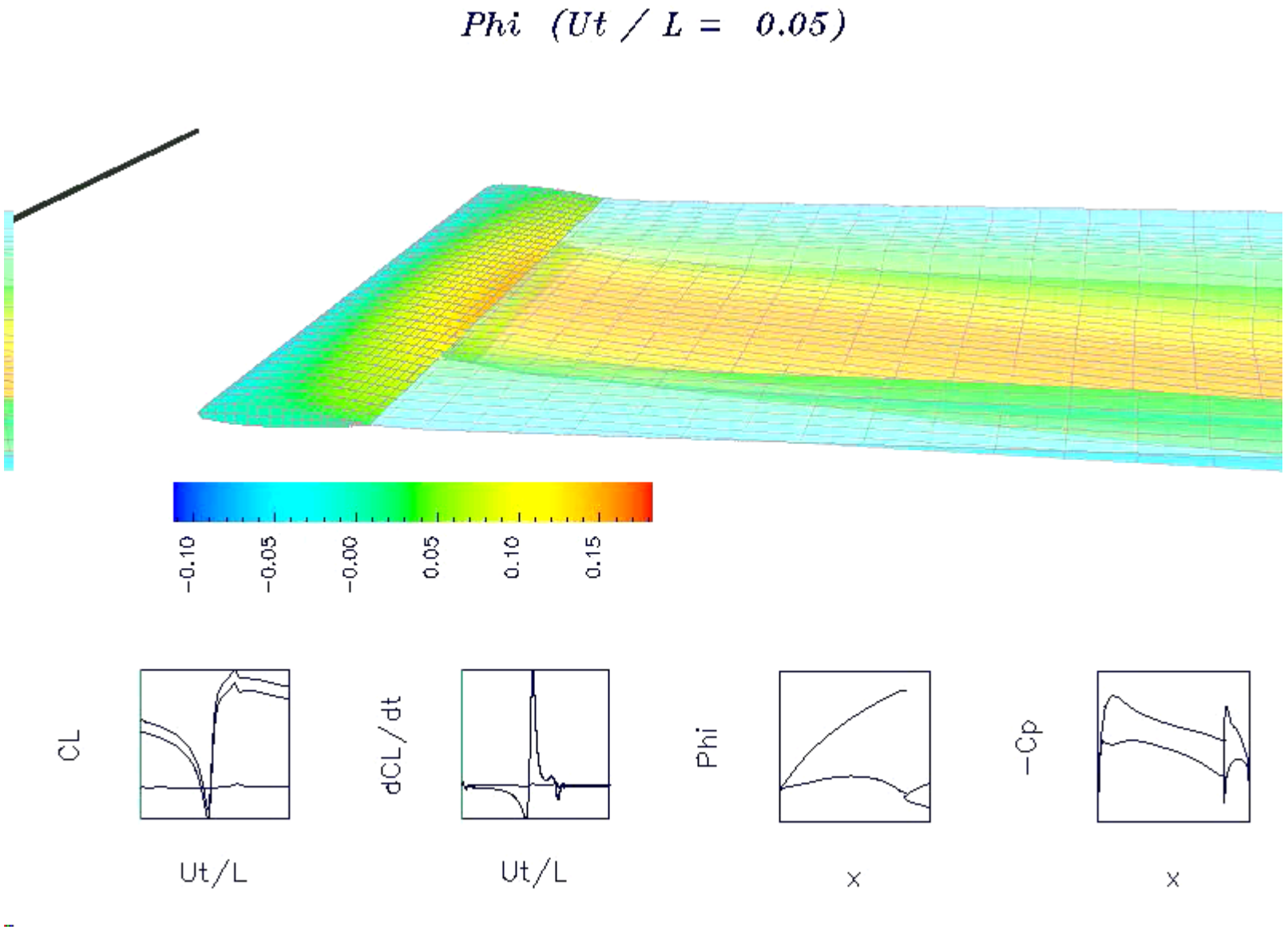
$\Rightarrow$ slightly **decreased** acoustics







Part span flap



Conclusions

- 3D **BEM validated**
  - Free Wake Evolution
  - **BVI** with Free Vortex Evolution
  - Efficient method for predicting sound from complex wing/blade gometries

- Wing geometry effect
  - Thickness, Camber, Sweep → **decrease** sound
  - Angle of Attack, Flap Deflection → **increase** sound
  - Full-span flap not important sound source

➢ Flap side-edge; Flap and slat gaps, Slat cove

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  - Technical support on this presentation