Global Linear Stability Analysis of the Jet in Crossflow

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KTH Mechanics

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DNS: Jet in Crossflow

- Fully spectral code with fringe region
- Parabolic jet profile imposed as boundary condition
- R=3 & Re=165

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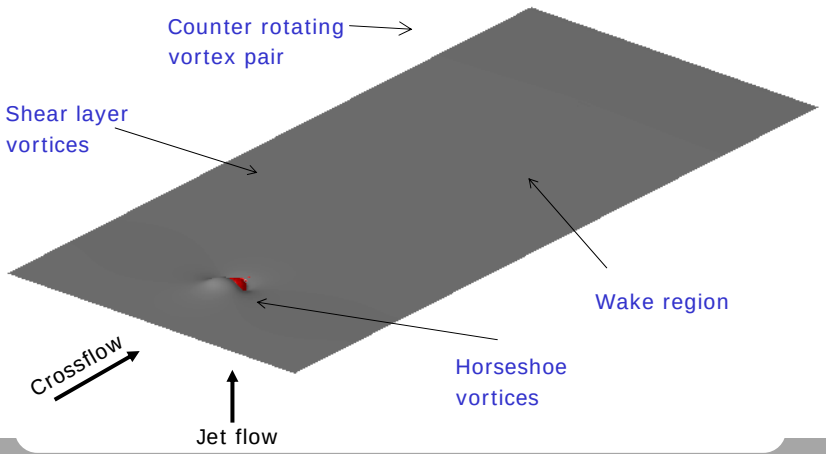

contours of u
contours of λ_2

Observations from DNS

- Unsteady structures:
  - Shear layer vortices
  - Wake vortices
- Self-sustained global oscillations

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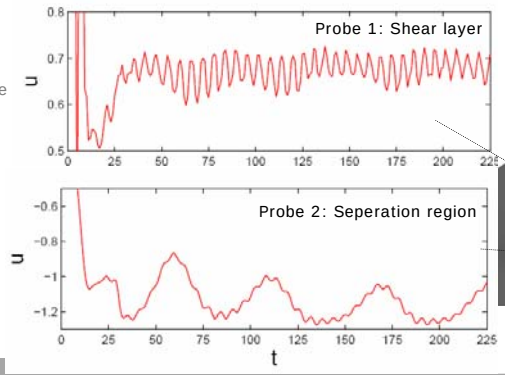

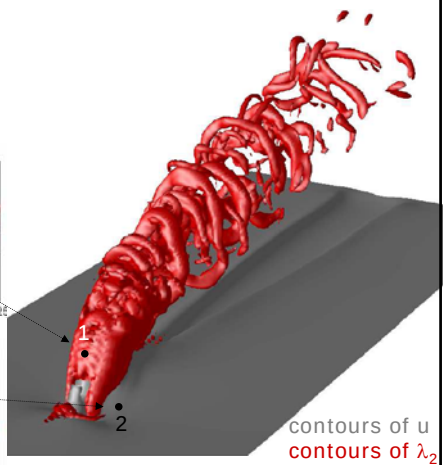

contours of u
contours of λ_2

Steady-State Solution

- Selective frequency damping (SFD):
  SFD: Åkervik et al (2006)
- Steady structures:
  - Horseshoe vortices
  - Counter-rotating vortex pair (CVP)

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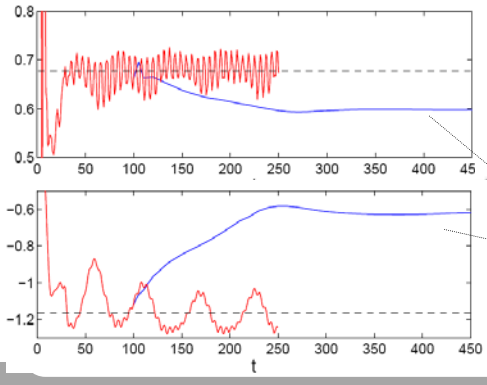
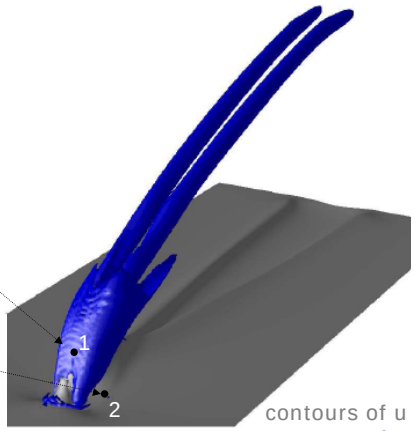


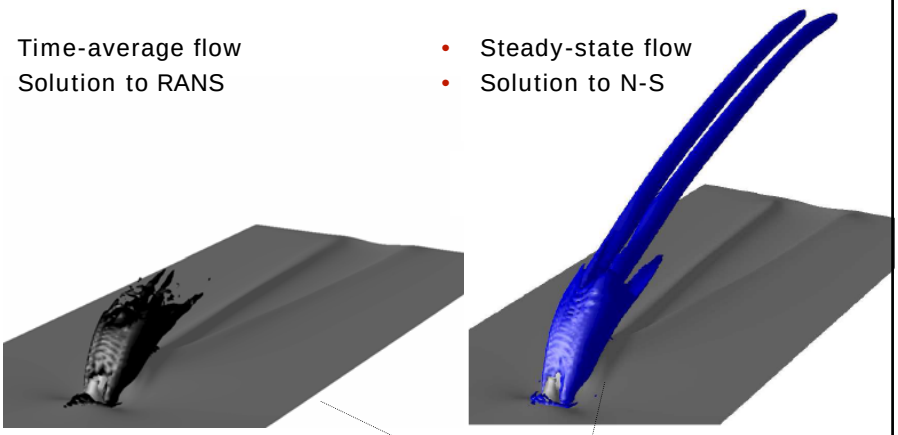


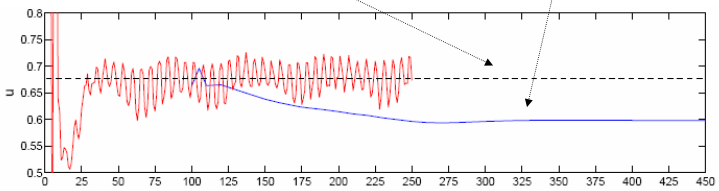
contours of u
contours of λ_2

Choice of Baseflow

- Time-average flow
- Solution to RANS

- Steady-state flow
- Solution to N-S





Unsteady DNS
Time-averaged flow
Steady-state flow

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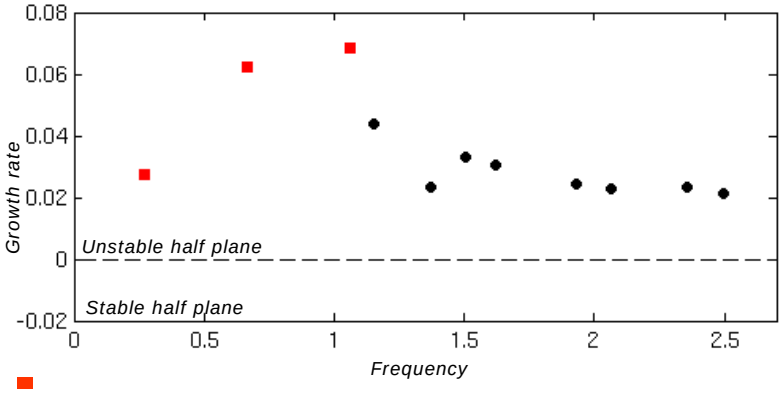
Spectrum of JCF

- Unstable eigenmodes of the linearized Navier-Stokes
- Computed using PARPACK by the time-stepper technique



Symmetric modes ■
Antisymmetric modes ●

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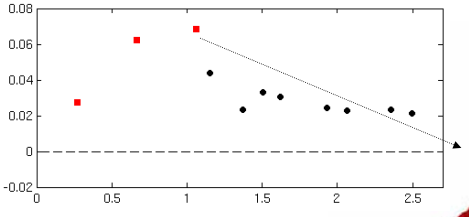
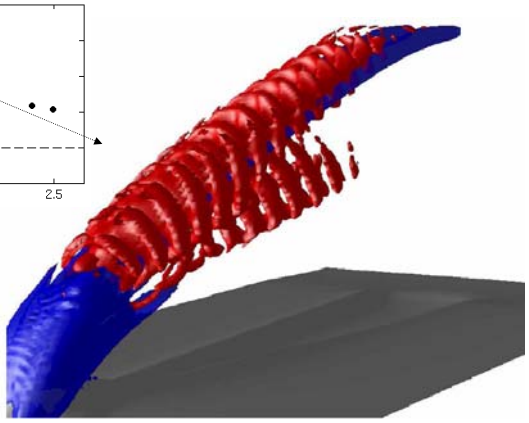
Most Unstable Mode

- Anti-symmetric
- Localized wavepacket wrapped around CVP





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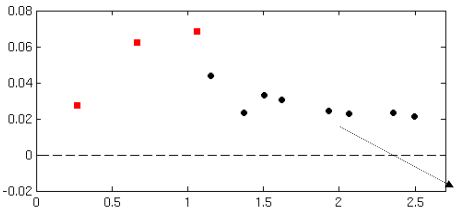
Streamwise velocity (baseflow)

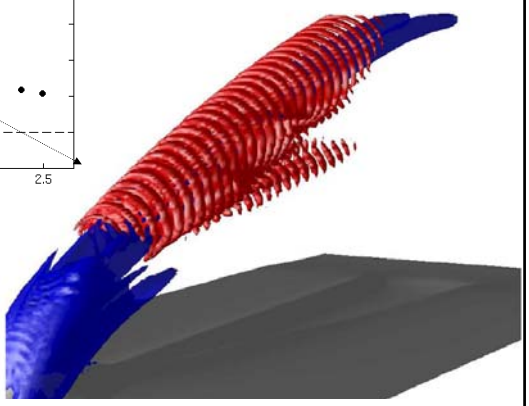
λ_2 Vortex (baseflow)

λ_2 Vortex (global mode)

High-Frequency Mode

- Symmetric
- Localized wavepackets sitting on the CVP





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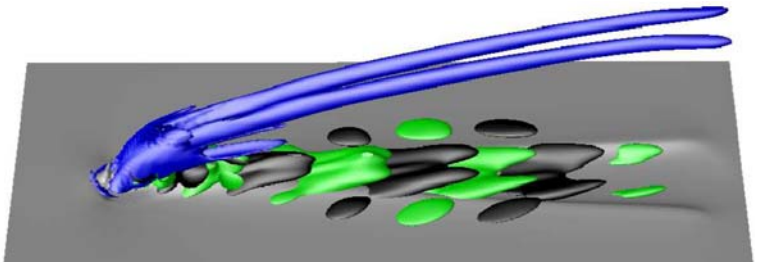
Streamwise velocity (baseflow)

λ_2 Vortex (baseflow)

λ_2 Vortex (global mode)

Low Frequency Mode

- Antisymmetric
- Wake instability



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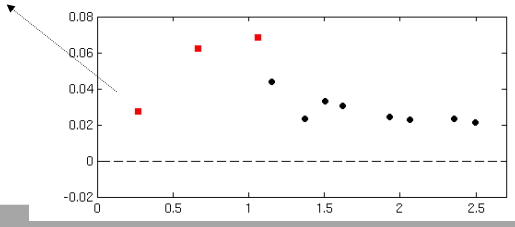
Streamwise velocity (baseflow)

λ_2 *Vortex (baseflow)*

Spanwise velocity (global mode)



Impulse Response

- Symmetric initial Gaussian condition
- Triggers most unstable symmetric mode

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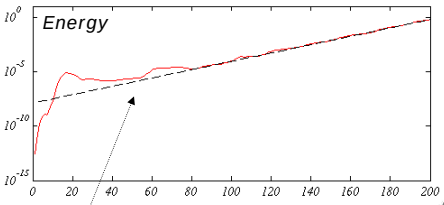

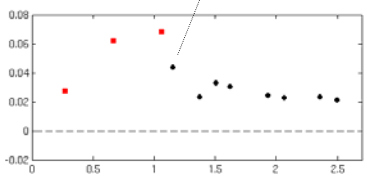

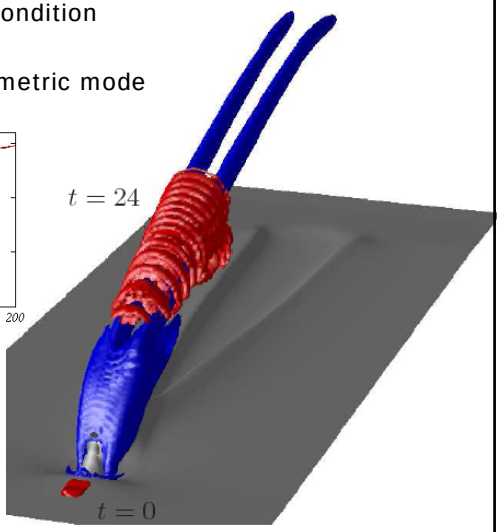

Outlook & Conclusions

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- We found self-sustained synchronized oscillations at R=3:
  - Observed in Direct Numerical Simulation
  - Linear impulse response of steady-state base
  - Linear 3D global stability analysis

- Future work:
  - Bifurcation analysis: Find critical velocity ratio
  - Sensitivty to forcing (adjoint global modes)
  - Optimal disturbances