Development of the secondary crossflow instability

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Development of the crossflow instability I

Laminar

Disturbances

amplitude

Receptivity

Primary modes

Secondary mechanisms

Breakdown

Turbulence

Turbulent

Crossflow instability
Co rotating steady and unsteady vortices due to sweep and favourable pressure gradient.

Poll (1985)
Development of the crossflow instability I

Secondary instability*
High frequency instability due to shear layers of mean flow.

Type I: Instability with frequency $f$, found in regions with large $DU/DZ$ gradients.

Type II: Instability with frequency $2f$, found in regions with large $DU/DY$ gradients.

*Selection of literature
Computational: Malik and Chang (1994), Malik et al. (1999)
Open questions

• Where and when is the breakdown process initiated?

• What are the characteristics of the secondary instability close to breakdown?

• Can the secondary crossflow instability be forced by wall and freestream forcing?
Current experiment

Tu = 0.02%

Re = 1.5 x 10^6
Current experiment
Current experiment
Coordinate systems
Secondary instability excitation

- Injection and suction with speaker to excite secondary instability (Kawakami 1999).
- Small speaker placed at back of plate.
- Sound emitted through 0.5 mm hole.
- Frequency of exciter equal to the frequency of the secondary instability occurring in the natural flow.

\[ f_{exc} = f_{sec} = 2000\text{Hz} \]
Stationary crossflow waves
Secondary instability
Traveling waves
Growth of traveling waves
Structure of the secondary instability I

Kawakami (1999)

Serpieri and Kotsonis (2016)
Structure of the secondary instability II

Bonfigli and Kloker (2007) $\gamma = 12^\circ$
Serpieri and Kotsonis (2016) $\gamma = 21^\circ$

Malik et al. (1999): $U_{ph} = 0.84 U_\infty$
Kawakami (1999): $U_{ph} = 0.78 U_e$
Serpieri and Kotsonis (2016): $U_{ph} = 0.80 U_e$

$U_{ph} = 0.83 U_\infty$

$\gamma = 14^\circ$

$\gamma = 12^\circ$
$\gamma = 21^\circ$

$\lambda = 7.48 \text{mm}$
Open questions

• Where and when is the breakdown process initiated?

• What are the characteristics of the secondary instability close to breakdown?
XZ scan
XZ scan
Power spectra development inside wedge

![Graph showing power spectra development inside a wedge.]
Power spectra development outside wedge
Onset of wedge structure III

- 0.9-2.3kHz
- 4-10kHz

Graph showing the variation of $A^x$ with $x_s$ (mm) and $x/c$.
Wedge structure in literature

Dagenhart and Saric (1999)

Breakdown initiation White and Saric (2000)

Streamwise Flow → Crossflow

- Low Shear - Naphthalene Remains
- High Shear - No Naphthalene
- Low Shear - Naphthalene Remains
- High Shear - No Naphthalene

Secondary Instability Mode

Location of Naphthalene Wedge Initiation
Onset of wedge structure I
Onset of wedge structure II
Onset of wedge structure III

![Graphs showing U/U_e, u'/U_e(%), dU/dZ (1/s), and u'_BP/U_e (%)](image)
Open questions

- When/where and how is the breakdown process initiated?

- What are the characteristics of the secondary instability close to breakdown?
Onset of wedge structure
Secondary instability structure

\[ x_s = 61\,\text{mm} \quad x/c = 0.34 \]
\[ x_s = 123\,\text{mm} \quad x/c = 0.38 \]
\[ x_s = 153\,\text{mm} \quad x/c = 0.40 \]

\[ \frac{u_{ph}}{U_e} (\%) \]

\[ 0 \quad -0.05 \]

\[ Y (\text{mm}) \quad Z (\text{mm}) \]

\[ Y (\text{mm}) \quad Z (\text{mm}) \quad x_s (\text{mm}) \]

\[ U_\infty \quad \text{at} \]
Conclusions

• Where and when is the breakdown process initiated?

• What are the characteristics of the secondary instability close to breakdown?
Conclusions

• Where and when is the breakdown process initiated?
  - In the region where secondary instability fluctuations are large in the middle of the vortex.
  - Secondary instability spreads in wall-normal and span wise direction.
  - High frequency fluctuations increase as soon as wedge appears.

• What are the characteristics of the secondary instability close to breakdown?
Conclusions

• Where and when is the breakdown process initiated?
  - In the region where secondary instability fluctuations are large in the middle of the vortex.
  - Secondary instability spreads in wall-normal and span wise direction.
  - High frequency fluctuations increase as soon as wedge appears.

• What are the characteristics of the secondary instability close to breakdown?
Conclusions

• Where and when is the breakdown process initiated?

• What are the characteristics of the secondary instability close to breakdown?
  - Structure spreads out over entire crossflow vortex.
  - Structure seems to break up in the spanwise direction due to wedge structure.
Questions?
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Bordulin et al. (2017)
Development of the crossflow instability

**Laminar**

- **Disturbances**
  - Receptivity
  - Primary modes
  - Secondary mechanisms
  - Breakdown

- **Turbulent**
  - Turbulence

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**Secondary instability**

High frequency instability due to shear layers of mean flow turbulence.

**Primary instability**

Co-rotating steady and unsteady vortices due to sweep and favourable pressure gradient.

**Type I**

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*Selection of literature*  

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*Disturbances*

- Free stream turbulence
- Sound
- Roughness

*Receptivity*
Different velocity measures

Raw hot wire signal $E$ (V)

**King’s Law**

$$E^2 = A + BU^n$$

Mean velocity $U$ (m/s)

Fluctuating velocity $u'$ (m/s).

Integration of PSD

Bandpass filtered velocity $u'_{BP}$ (m/s).

Phase-averaged velocity $u'_{exc}$ (m/s).

Analog filter

(2-10000 Hz)

Digital filter

Phase-averaging algorithm

Exciter signal (V)
Dominating secondary instability