12th ERCOFTAC NPC Meeting

Helicity of Passively Generated Vortices from Vortex Generators

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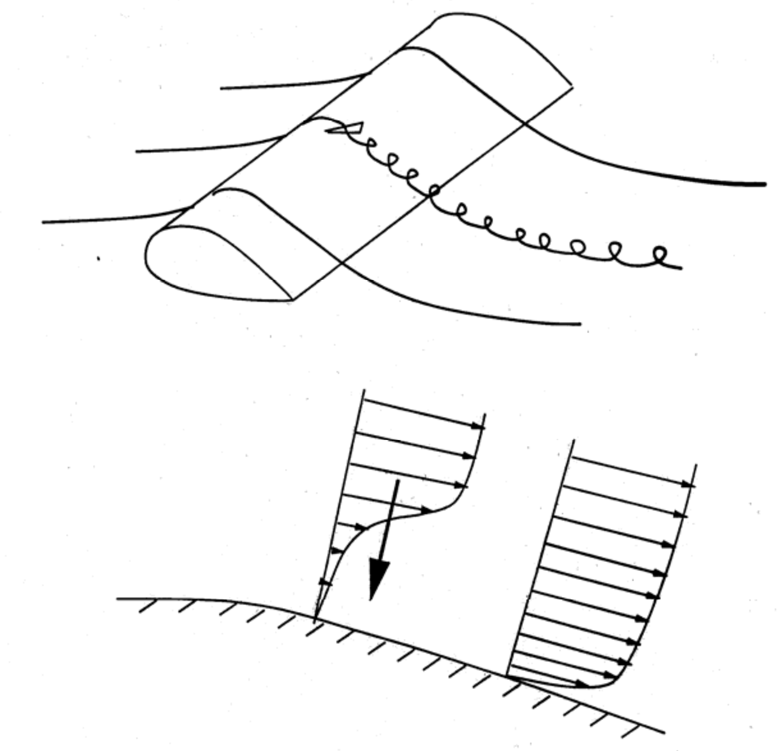
What is a vortex generator?



Schematic explanation of how a VG works:

- Generation of longitudinal vortices

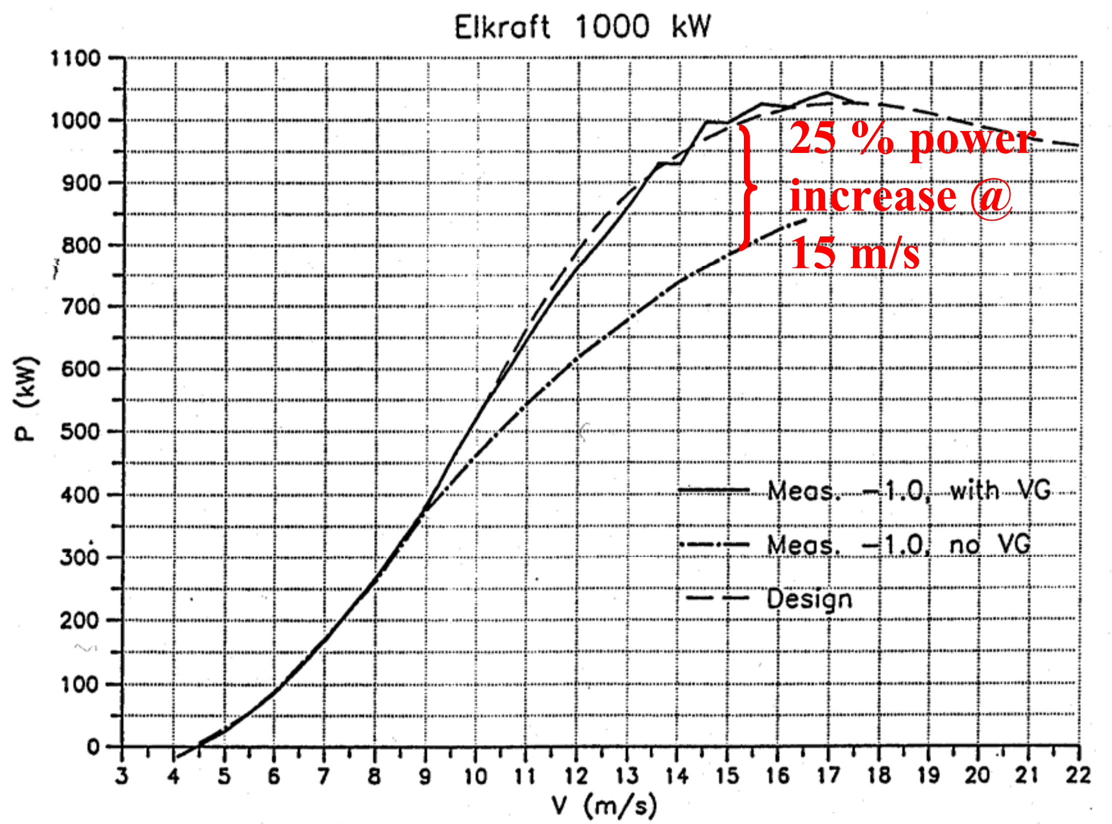
- Overturn of the b.l. flow via large scale motions

- Redistribution of streamwise mom’m in b.l.

- Resistance to positive pressure gradient

- Decreased risk for stall

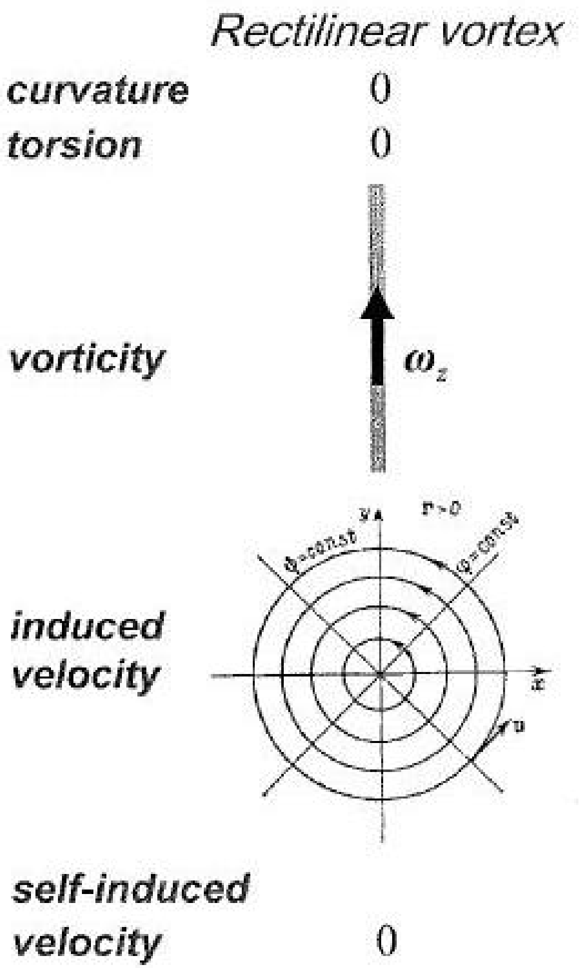
Example of application of VGs on wind turbine wings: ELKRAFT 1000 kW wind turbine at Avedøre



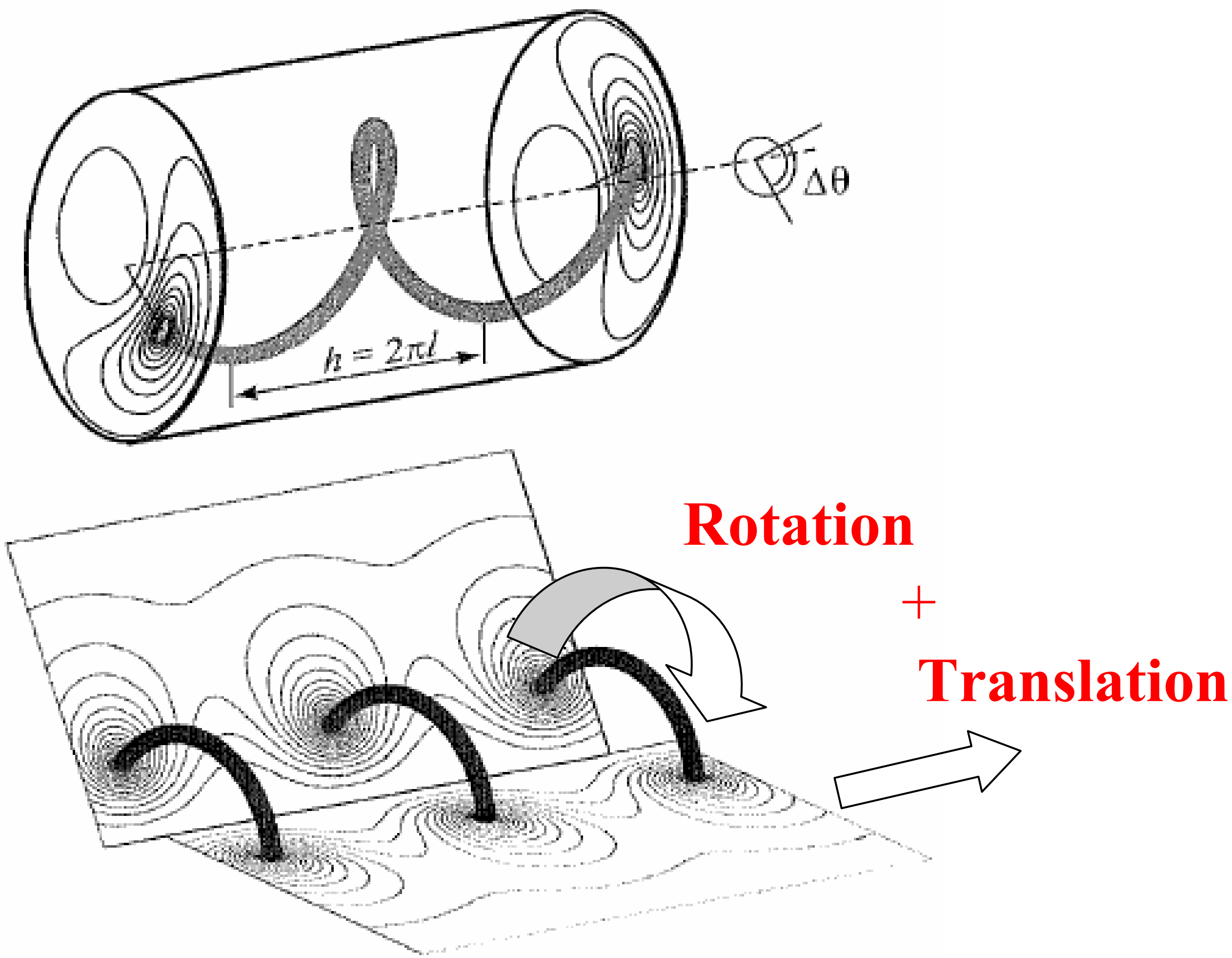
From: [3] S. Øye, The effect of Vortex Generators on the performance of the ELKRAFT 1000 kW Turbine, 9th IEA Symp. On Aerodynamics of Wind Turbines, 1995.

What is a helix?

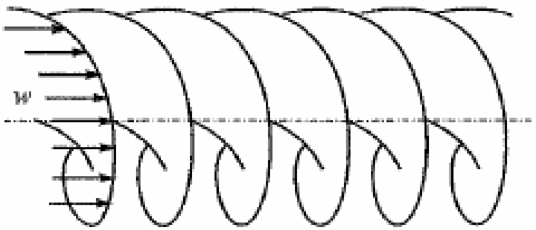
Pitch → ∞



In reality the flow has 2-D structure !!!



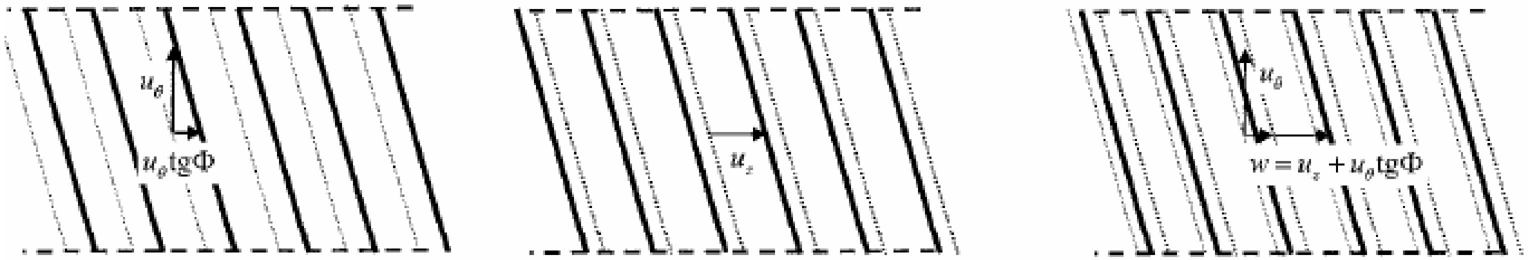
Kinematic interpretation of the helical symmetry

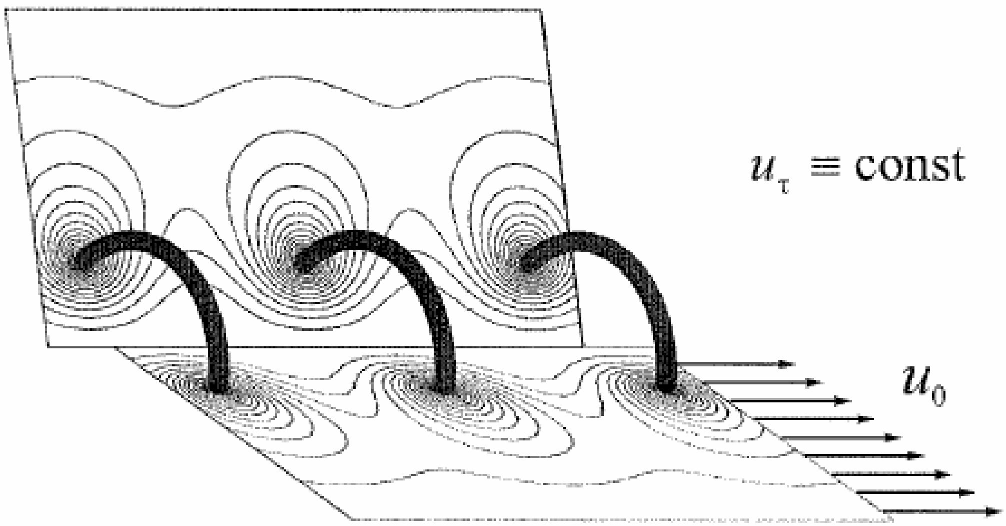


By analogy with the vortex theory of screw propeller by Sydney Goldstein

$$w \equiv u_0 = u_z + r u_\theta / l \qquad \mathrm{tg}\Phi = r/l$$

sheet rotation — *sheet translation* — *total motion*



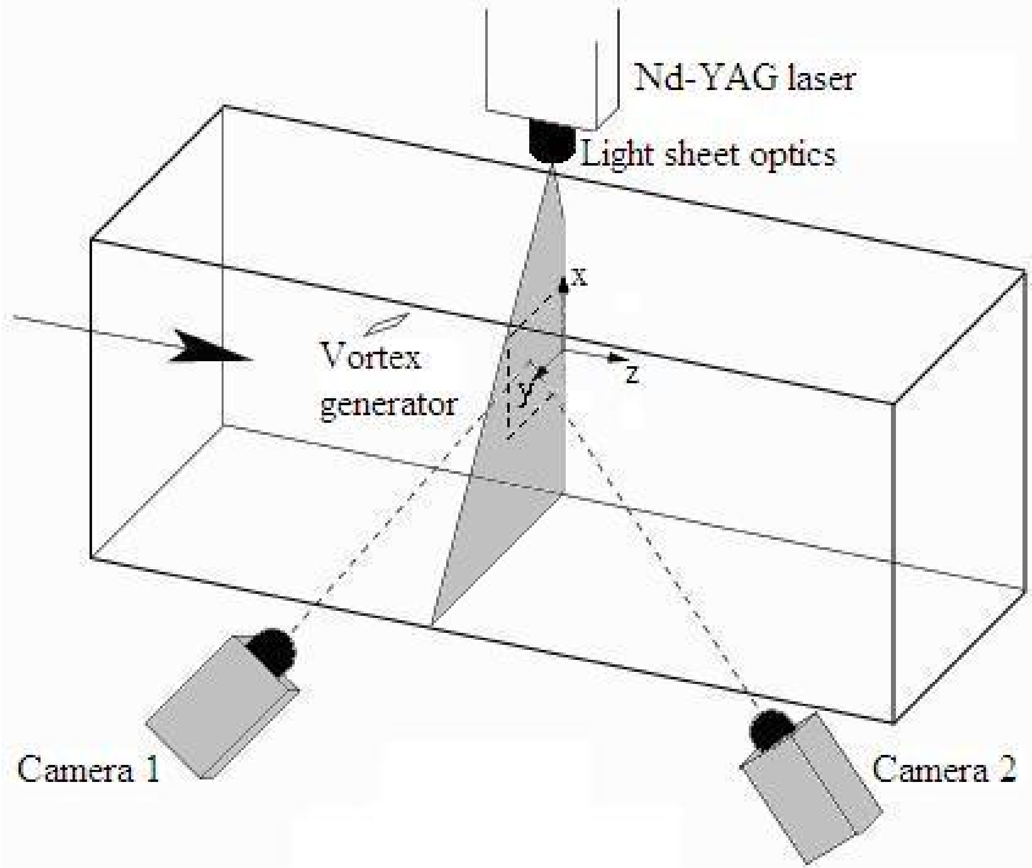


$$u_\tau \equiv \mathrm{const} \quad \text{or} \quad u_z + r u_\theta / l = u_0 \equiv \mathrm{const}$$

u_0 -

may be interpreted as total uniform motion of fixed plan of 2-D motion

Experimental Setup



$U_{\infty} = 1\ ms^{-1}$

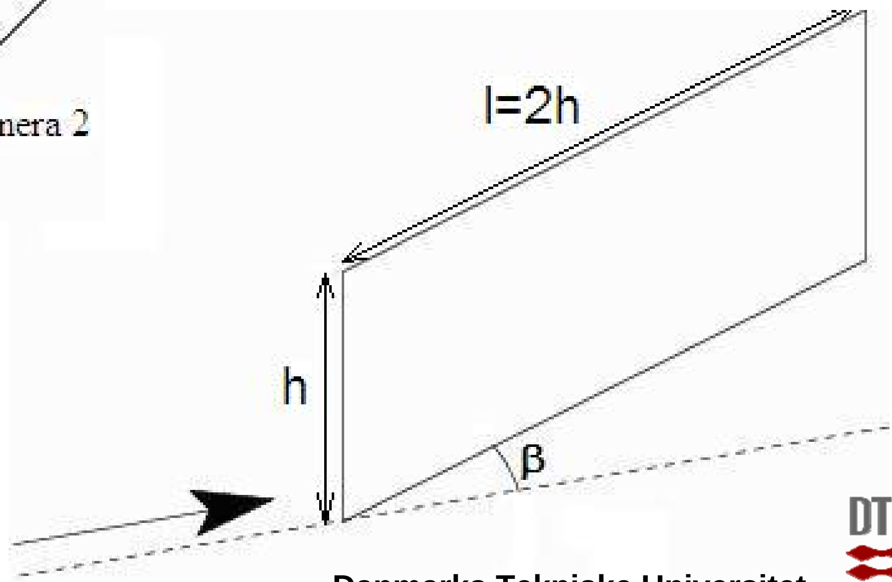
Stereoscopic Particle Image Velocimetry (SPIV)

3C of velocity in plane

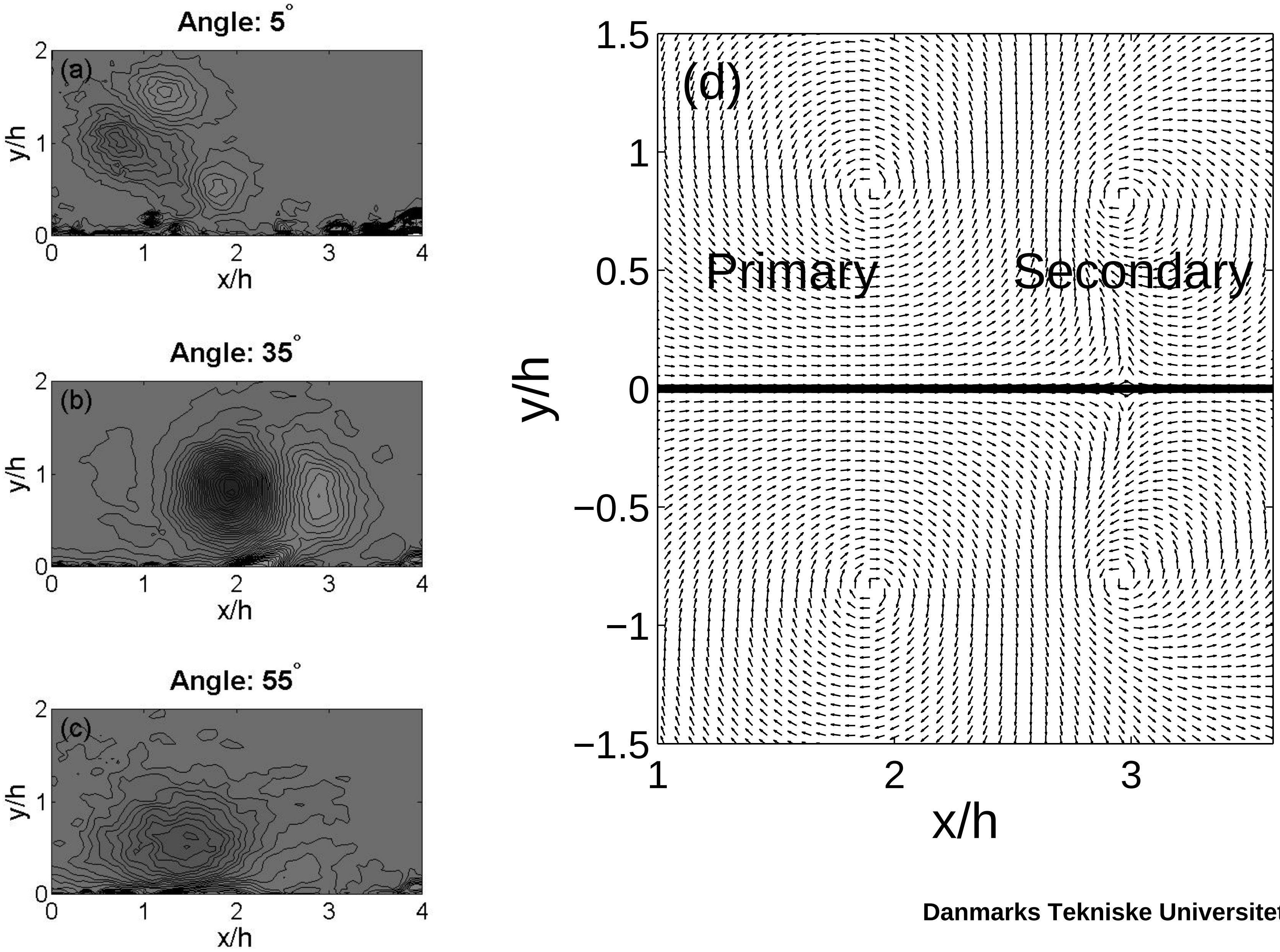
Vortex generator: Rectangular vane

h = 25 mm

Parametric study, β variable



Primary and secondary vortices



Condition of helical symmetry

VORTICITY FORMULATION:

The vorticity vector

$$\omega_r = 0; \quad \omega_\theta = r\omega_z/l$$

is always directed tangentially to the helical lines

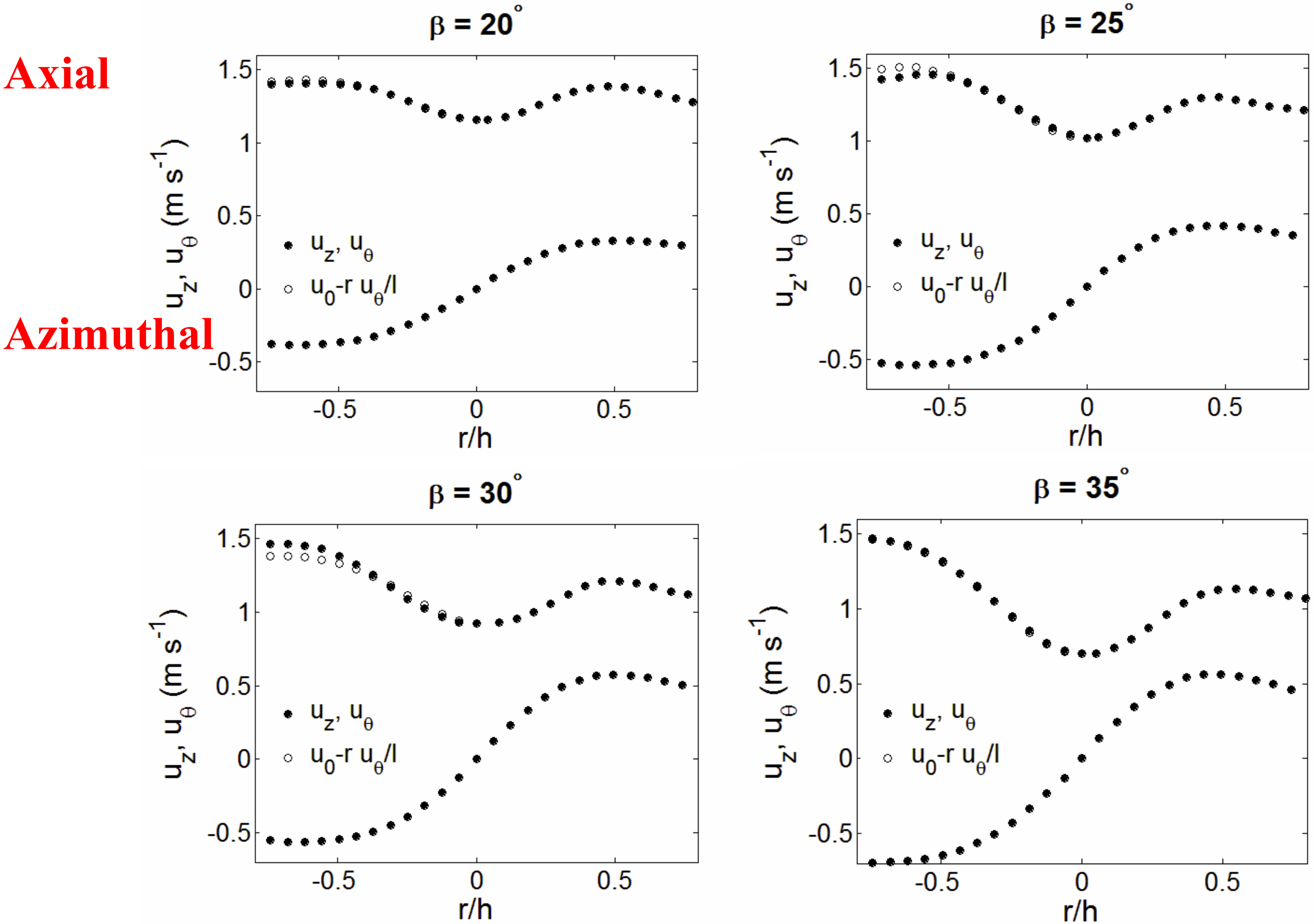
$$x = r\cos\theta;\ y = r\sin\theta;\ z = l\theta$$

VELOCITY FORMULATION:

An equivalent condition for the velocity is

$$u_z + \frac{r}{l}u_\theta = u_0 \equiv \text{const.} \quad \text{or} \quad u_z = u_0 - \frac{r}{l}u_\theta$$

Testing of condition: $u_z = u_0 - \frac{r}{l} u_\theta$



1D columnar/axisymmetric vortex model

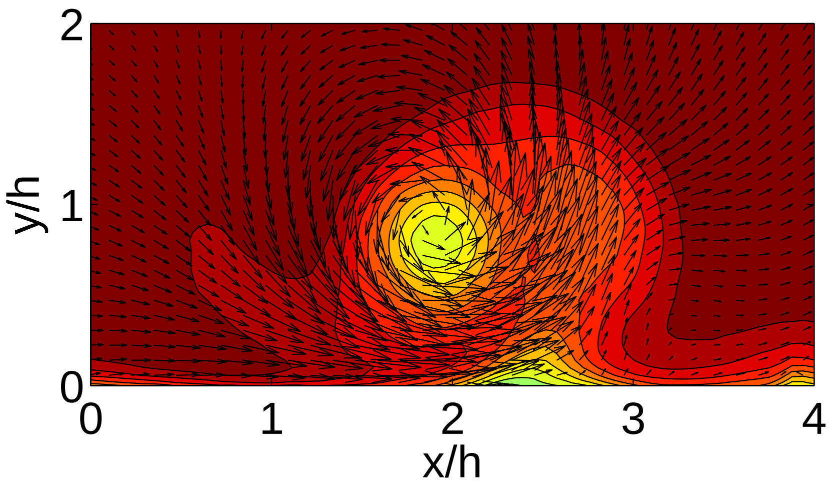
$$\begin{cases} \omega_z = \dfrac{\Gamma}{\pi\varepsilon^2}\exp\left(-\dfrac{r^2}{\varepsilon^2}\right) \\[2ex] u_\theta = \dfrac{\Gamma}{2\pi r}\left[1-\exp\left(-\dfrac{r^2}{\varepsilon^2}\right)\right] \\[2ex] u_z = u_0 - \dfrac{\Gamma}{2\pi l}\left[1-\exp\left(-\dfrac{r^2}{\varepsilon^2}\right)\right] \end{cases}$$

constant for Lamb-Oseen vortex

Alekseenko, Kuibin & Okulov (2007) Theory of concentrated vortices. Springer

Fitting of vorticity: $\omega_z = \frac{\Gamma}{\pi\varepsilon^2}\exp\left(-\frac{r^2}{\varepsilon^2}\right)$

$\beta = 35^\circ$



1D columnar/axisymmetric vortex model

$$
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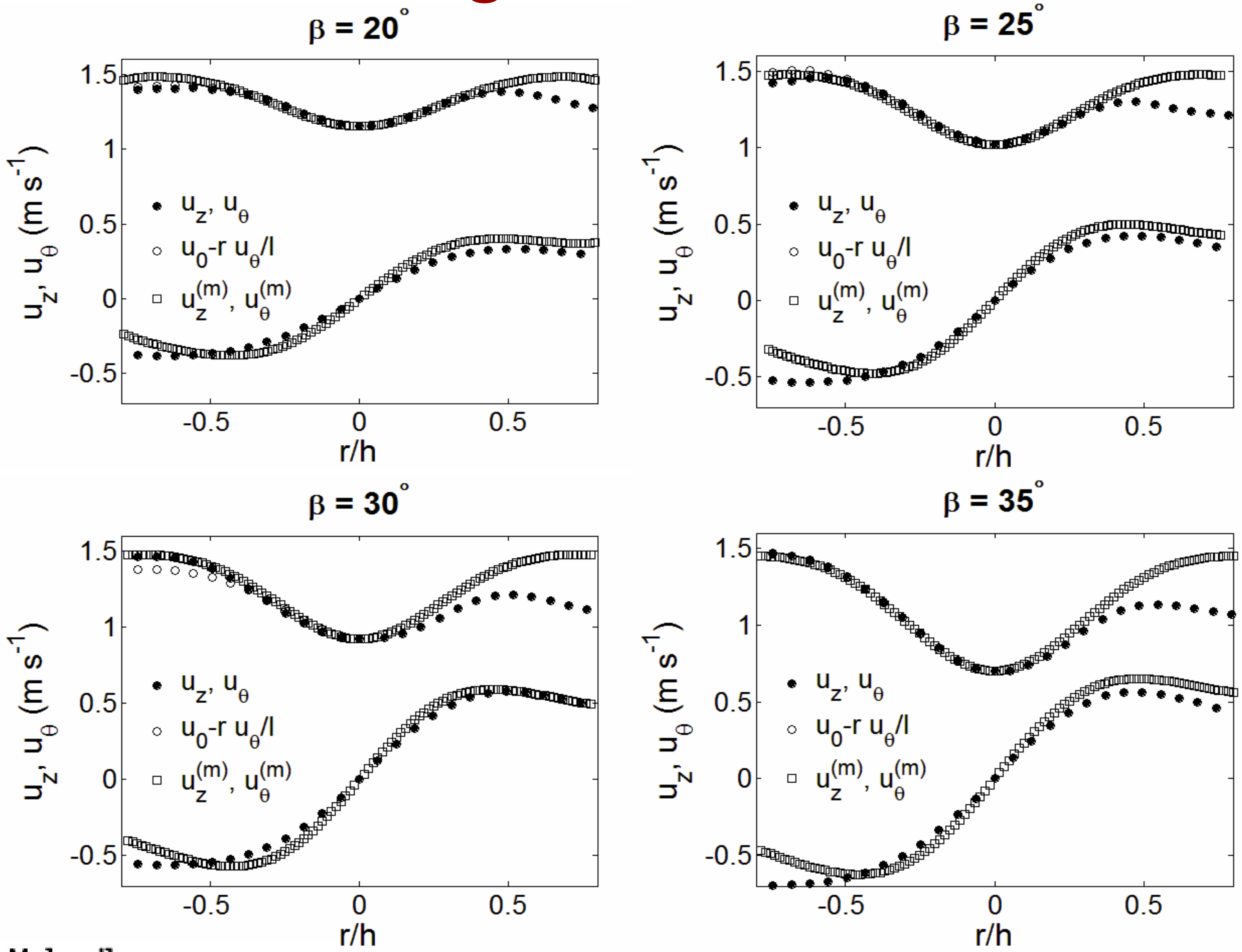
u_z = u_0 - \dfrac{\Gamma}{2\pi l}\left[1-\exp\left(-\dfrac{r^2}{\varepsilon^2}\right)\right]
\end{cases}
$$

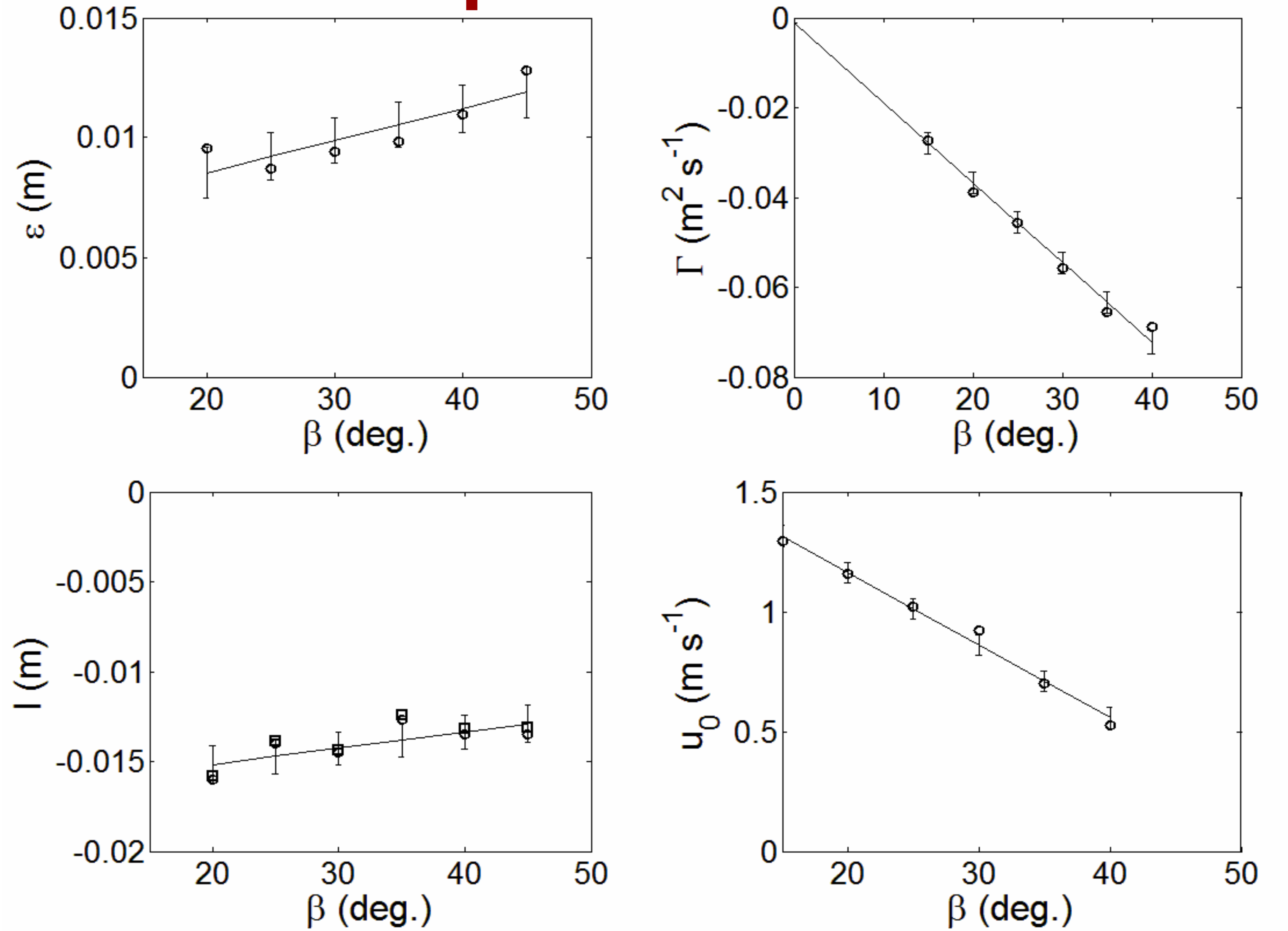
$$
\begin{cases}
S = F_{mm}/F_m L, \quad l = -F_{mm}/F_m = -LS & \text{if } u_0 = 0 \\
l = -F_{mm}/(F_m - u_0 G) = -LS/(1-u_0 G/F_m) & \text{if } u_0 \neq 0
\end{cases}
$$

Alekseenko, Kuibin & Okulov (2007) Theory of concentrated vortices. Springer

Testing of vortex model



Device angle dependency of parameters



Conclusions

- The longitudinal vortex generated by the passive vortex generator possesses helical symmetry.

- The primary vortex is accompanied by a secondary counter-rotating vortex, giving rise to perturbations

- A 1D columnar vortex model has been applied, decouplied from the b.l. flow and surrounding vortices, describing the flow successfully and providing the circulation Γ and vortex size ε

- The helical pitch l was found through the swirl flow parameter, concurring well with results from least squares fitting of the data

- The parameters Γ, ε, l and u_0 were all found to vary linearly with the device angle β

Additional work

- Further development of model for helical vortex, stability studies and investigation of non-linearities

- Parametric study to investigate flow processes for different h/δ and h/l.

- Study of the dynamics of vortices generated by passive devices

  - Apply snapshot POD to SPIV data to distinguish dominant energy modes in the flow

  - LDA measurements to capture dominant frequencies in the flow

- Spin-off: Noise free power spectra (HW and burst mode LDA)

- SPIV measurements of effect of vortex generators in a more realistic setting (LM Wind tunnel, Lunderskov)

- CFD modeling of effect of vortex generators

Thank you!

Questions?

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