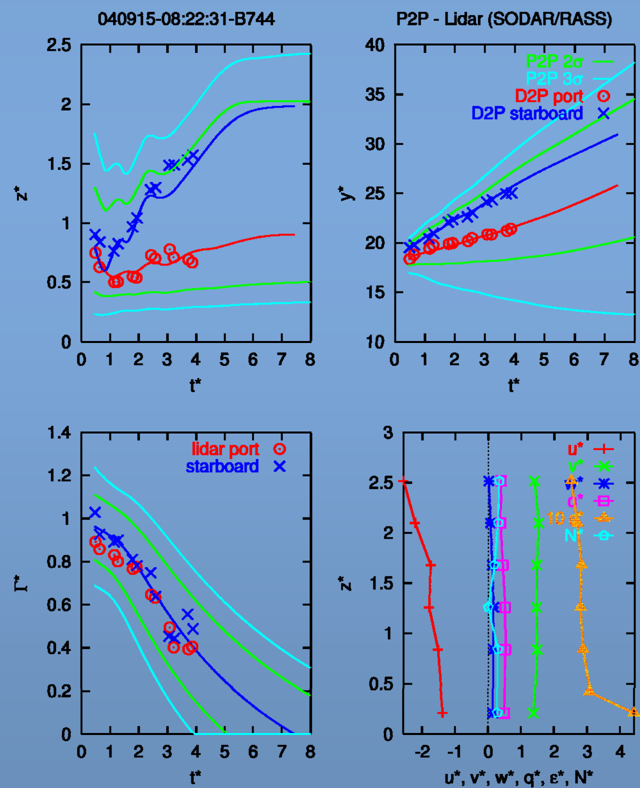
Aircraft wake vortex evolution in ground proximity: analysis and parameterization



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Outline

- Background
- IGE Analysis
- IGE Parametrization
- D2P GE Model
- Conclusions

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Background

- **effects:** **wind, wind shear, turbulence, temperature stratification, <u>ground proximity</u>**

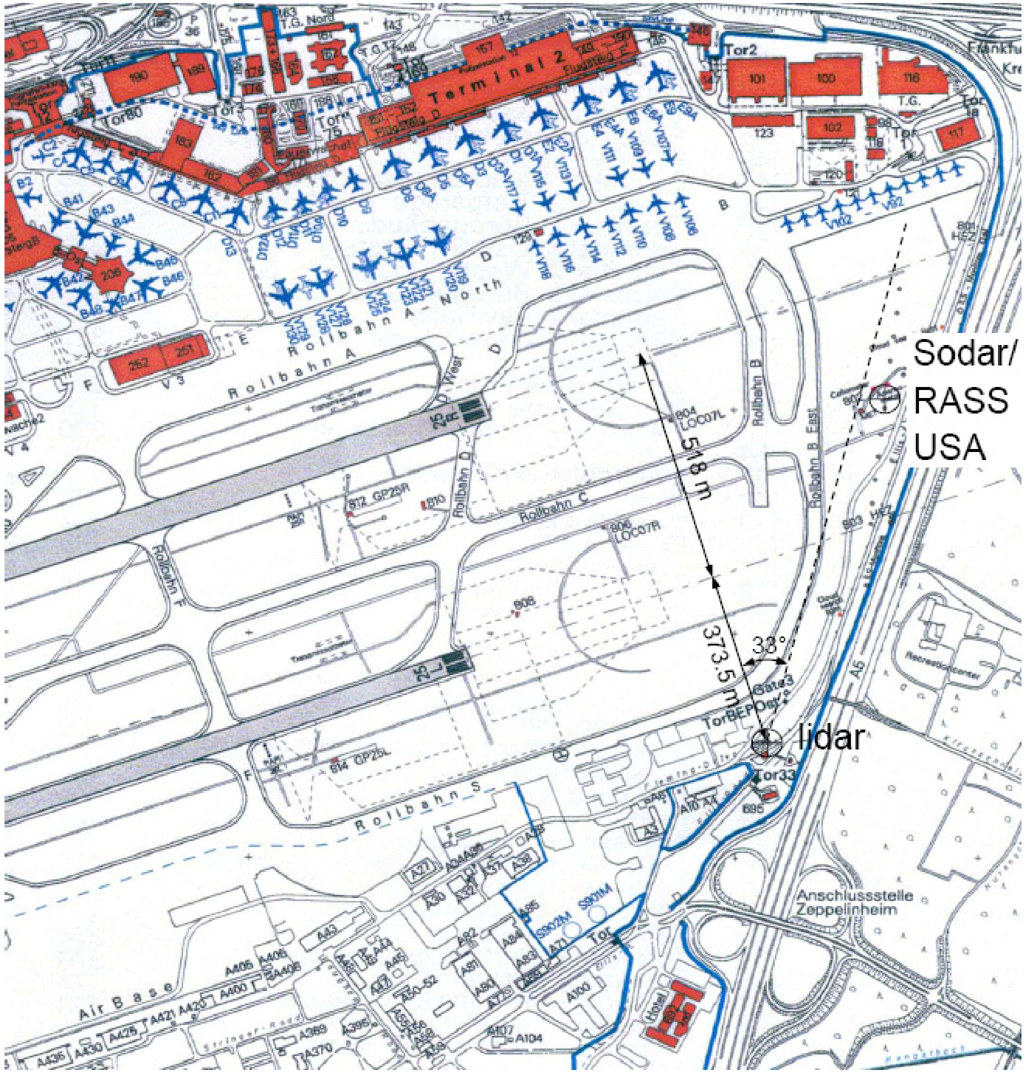
- **P2P input data:** **a/c:** $x_0, y_0, z_0, t_0, \gamma, V, m, b$

  meteo: $u(z), v(z), w(z), \rho(z), q(z), \varepsilon(z), \theta(z)$

[redacted]

Background

- measurement campaign Frankfurt 2004 (Airbus, DFS, Fraport AG)
- 238 a/c (B744, A343, A346)
- *z* = 10 *m*...100 *m*
- *LIDAR*
- *SODAR/RASS*

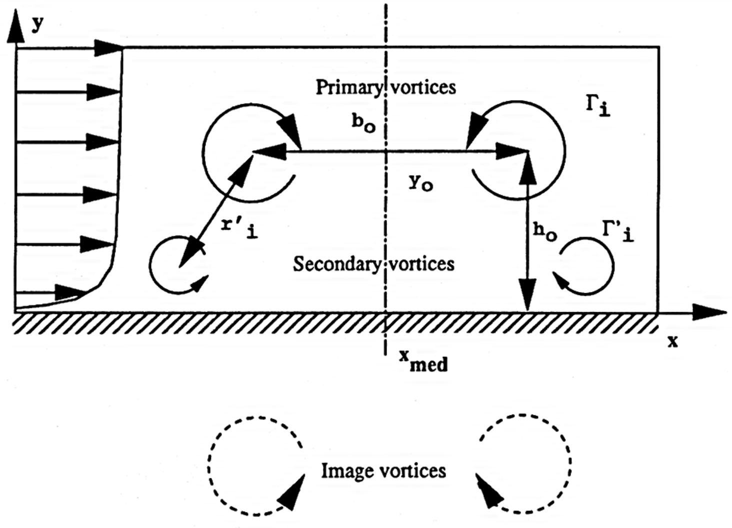


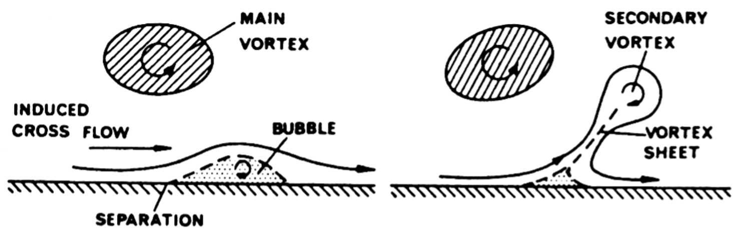
Background

WakeFRA site

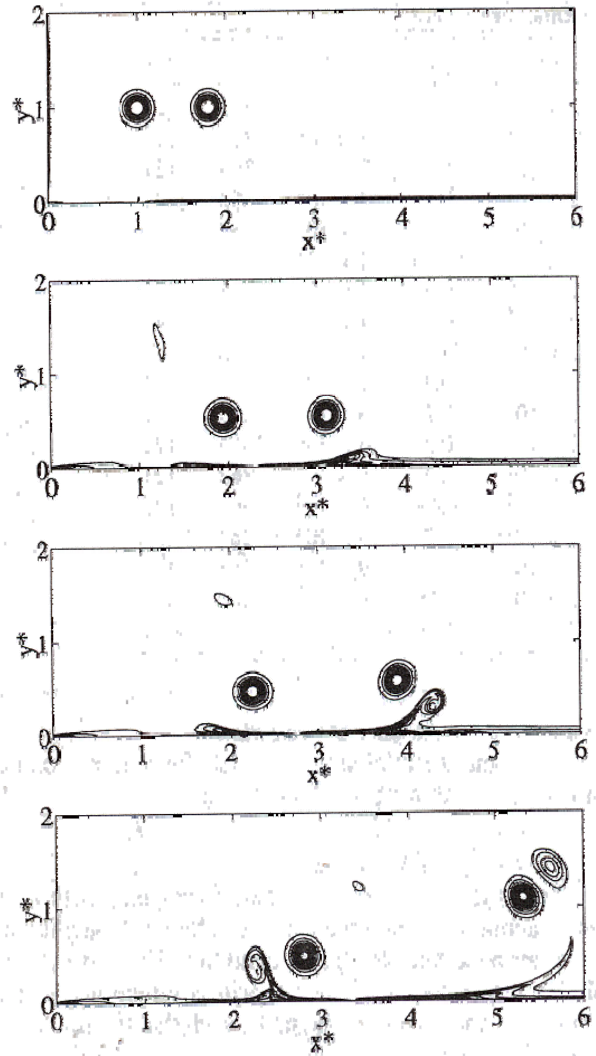
Background

- vortex divergence; describable by means of image vortices
- induced shear layer IGE
- mutual velocity induction





Background



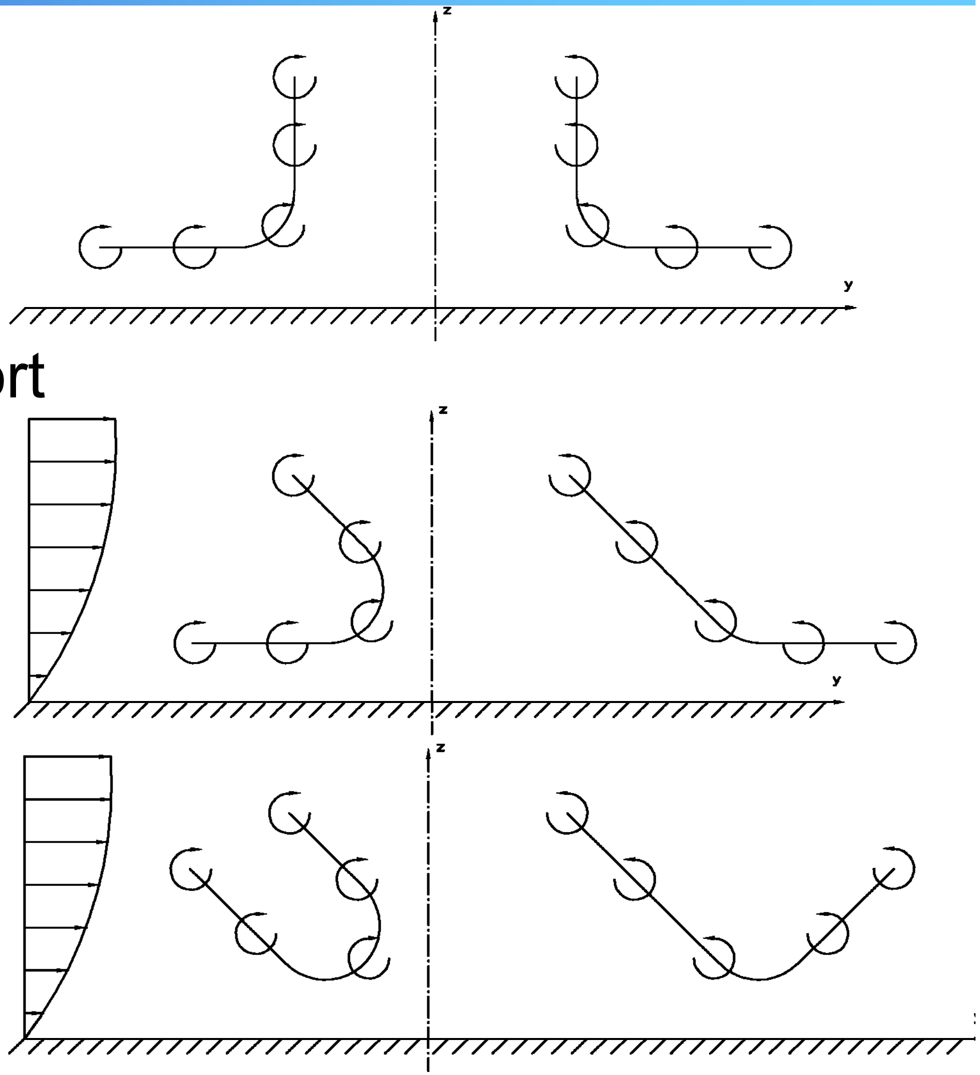
state of the art

- self-similar circulation decay[2]
- no effect of: initial height, vortex separation, circulation, turbulence[2]

[1]Corjon A., Poinsot T. (1997): Behavior of Wake Vortices near Ground, AIAA Journal, Vol. 35, No. 5, pp. 849-855.
[2]Proctor F., Hamilton D.W., Han J. (2000): Wake Vortex Transport and Decay in Ground Effect: Vortex Linking with the Ground, AIAA Paper 2000-0757.

Background

- 2D trajectory
- divergence NGE
- additional lateral transport due to crosswind
- rebound IGE



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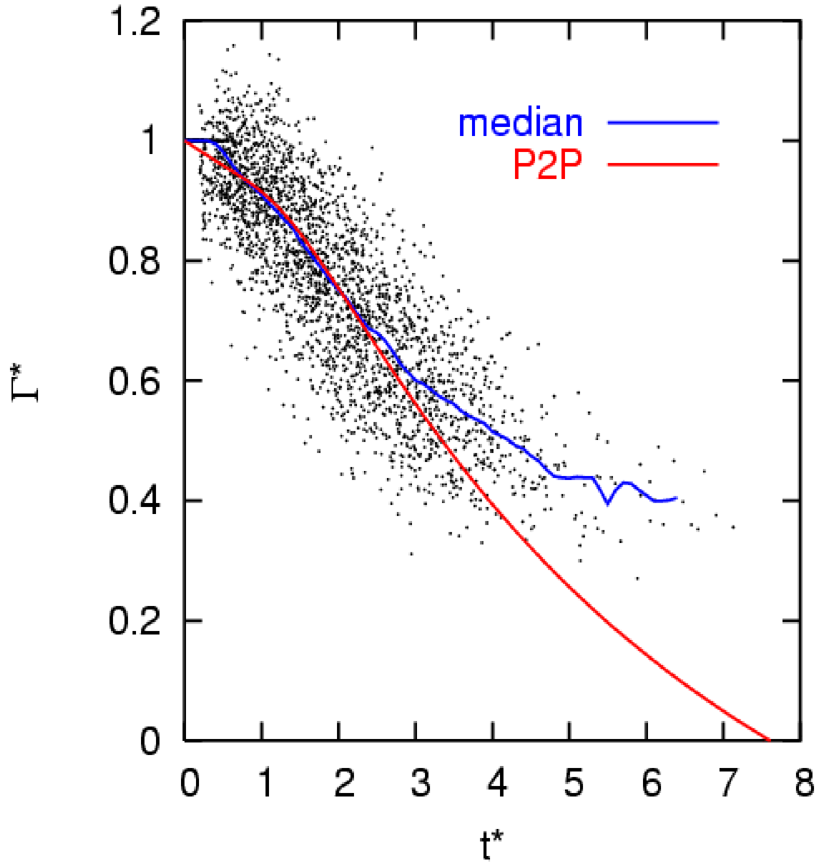
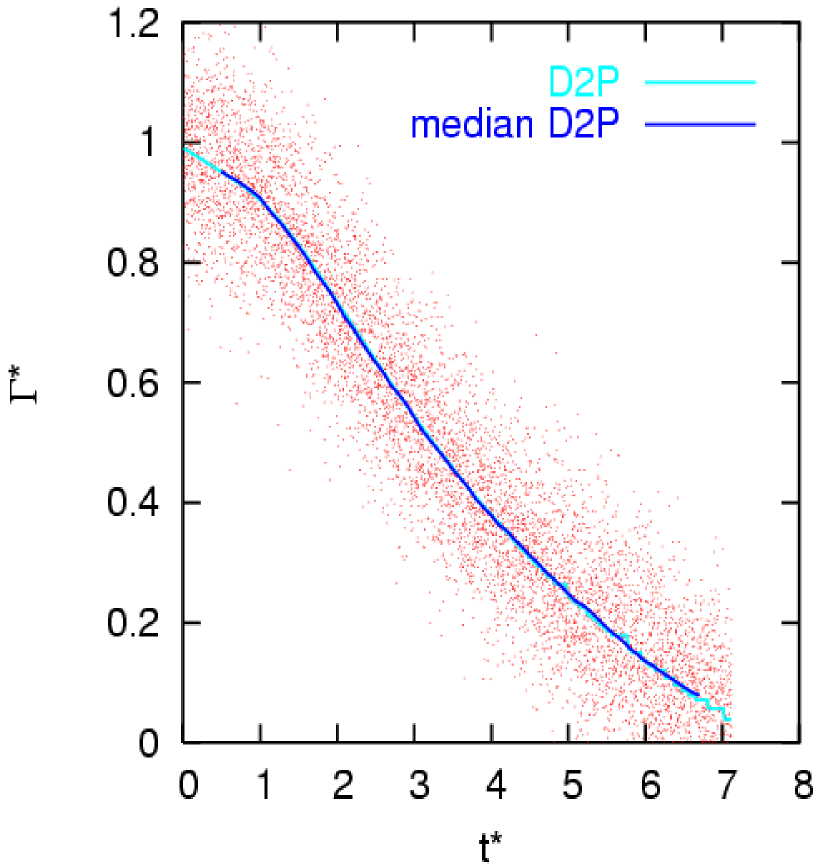
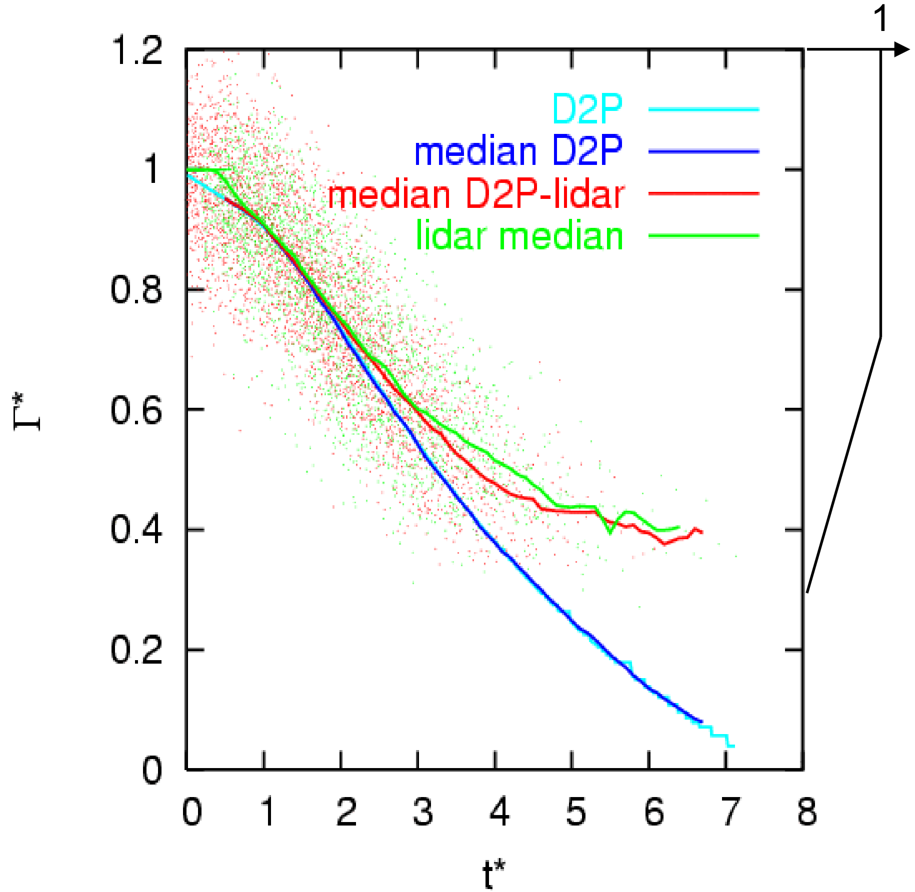
IGE Analysis



IGE Analysis



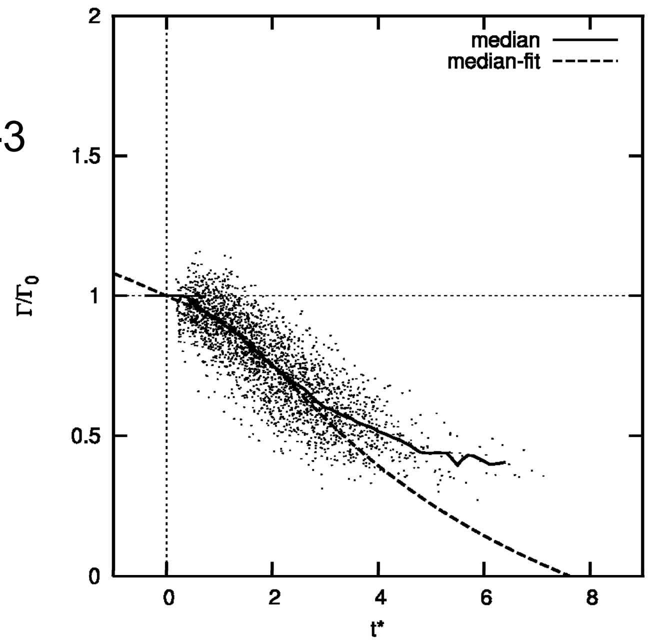


IGE Analysis

- D2P:

$$\Gamma^* = \frac{\Gamma}{\Gamma_0} = \left[A - \exp\left(-\frac{R^{*2}}{\upsilon_1^*(t^* - T_1^*)} \right) - \exp\left(-\frac{R^{*2}}{\upsilon_2^*(t^* - T_2^* - T_g^*)} \right) \right] \cdot k$$

- 25R: T_g^* = 1.23 und υ_2^* = 2,81·10^{-3}



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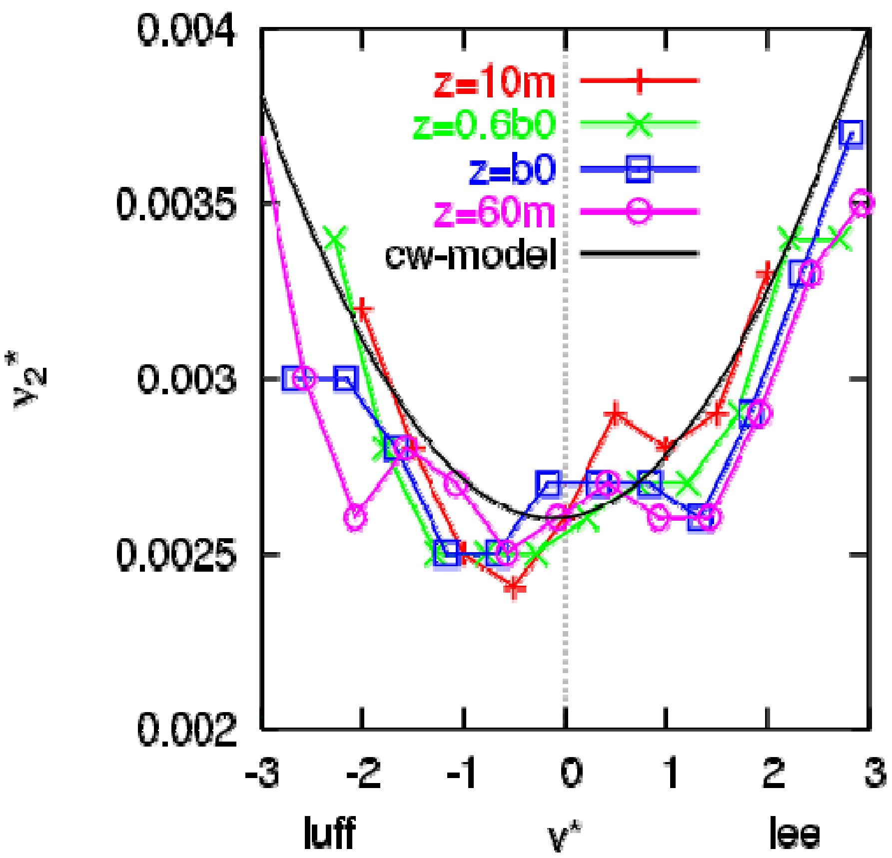
IGE Parametrization

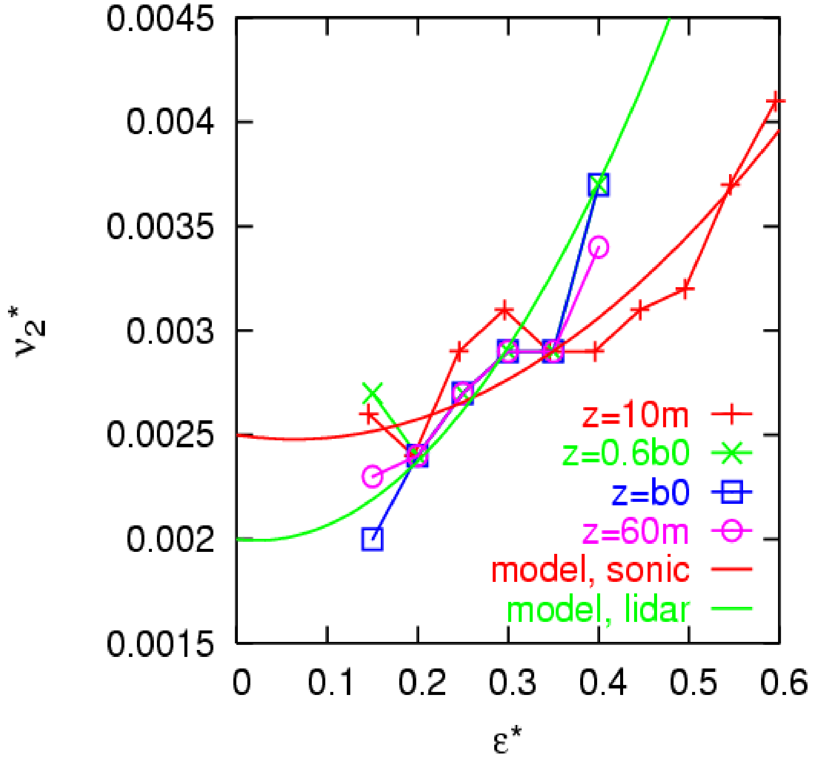


decay rate based on crosswind

$$\upsilon^{*}_{2,port(starb)} = 0.0026 - (+) 3.27 \cdot 10^{-5} v^{*} + 1.45 \cdot 10^{-4} v^{*2}$$

[1] Holzaepfel, F., Meiko Steen, 2007, Aircraft Wake-Vortex Evolution in Ground Proximity: Analysis and Parameterization, AIAA Journal, Vol. 45, No. 1, American Institute of Aeronautics and Astronautics, pp. 218-227

IGE Parametrization



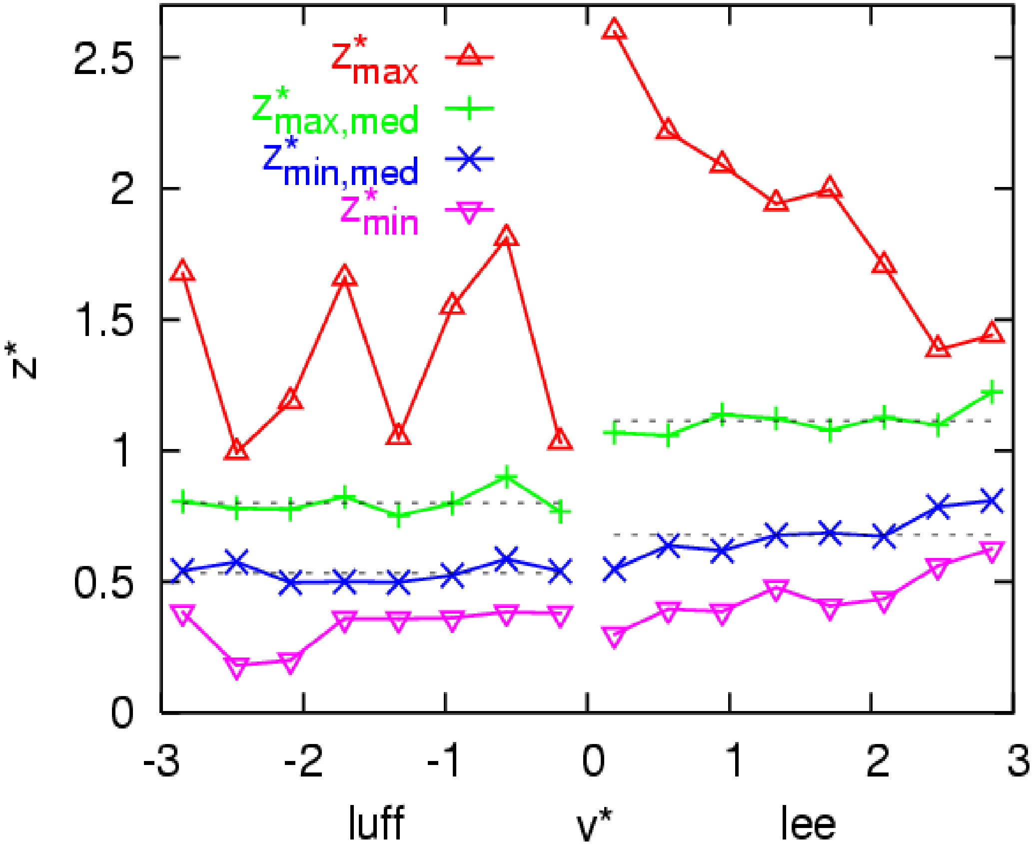
decay rate based on EDR

USA: $$\upsilon_2^* = 0.002 - 0.00053\varepsilon^* + 0.012\varepsilon^{*2}$$

lidar: $$\upsilon_2^* = 0.0025 - 0.00066\varepsilon^* + 0.00516\varepsilon^{*2}$$

IGE Parametrization

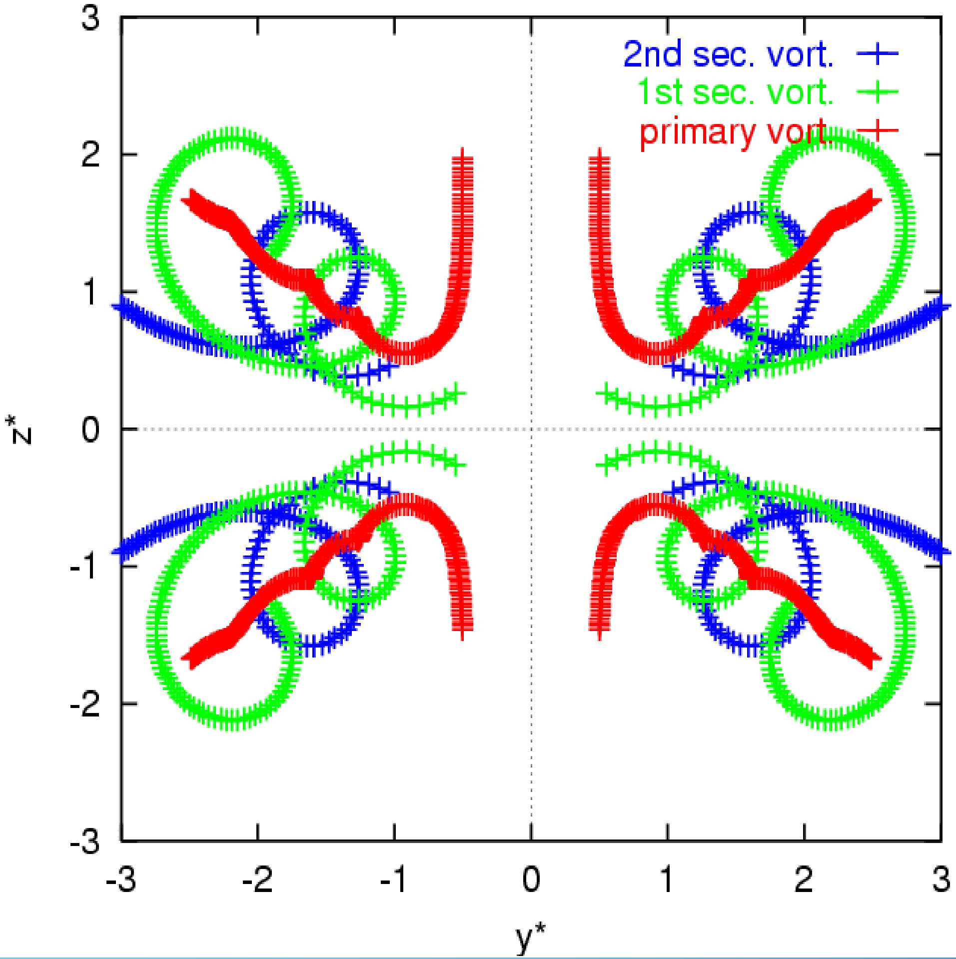
min/max rebound height – statistics



[1] Holzaepfel, F., Meiko Steen, 2007, Aircraft Wake-Vortex Evolution in Ground Proximity: Analysis and Parameterization, AIAA Journal, Vol. 45, No. 1, American Institute of Aeronautics and Astronautics, pp. 218-227

IGE Parametrization

previous trajectory model[1]

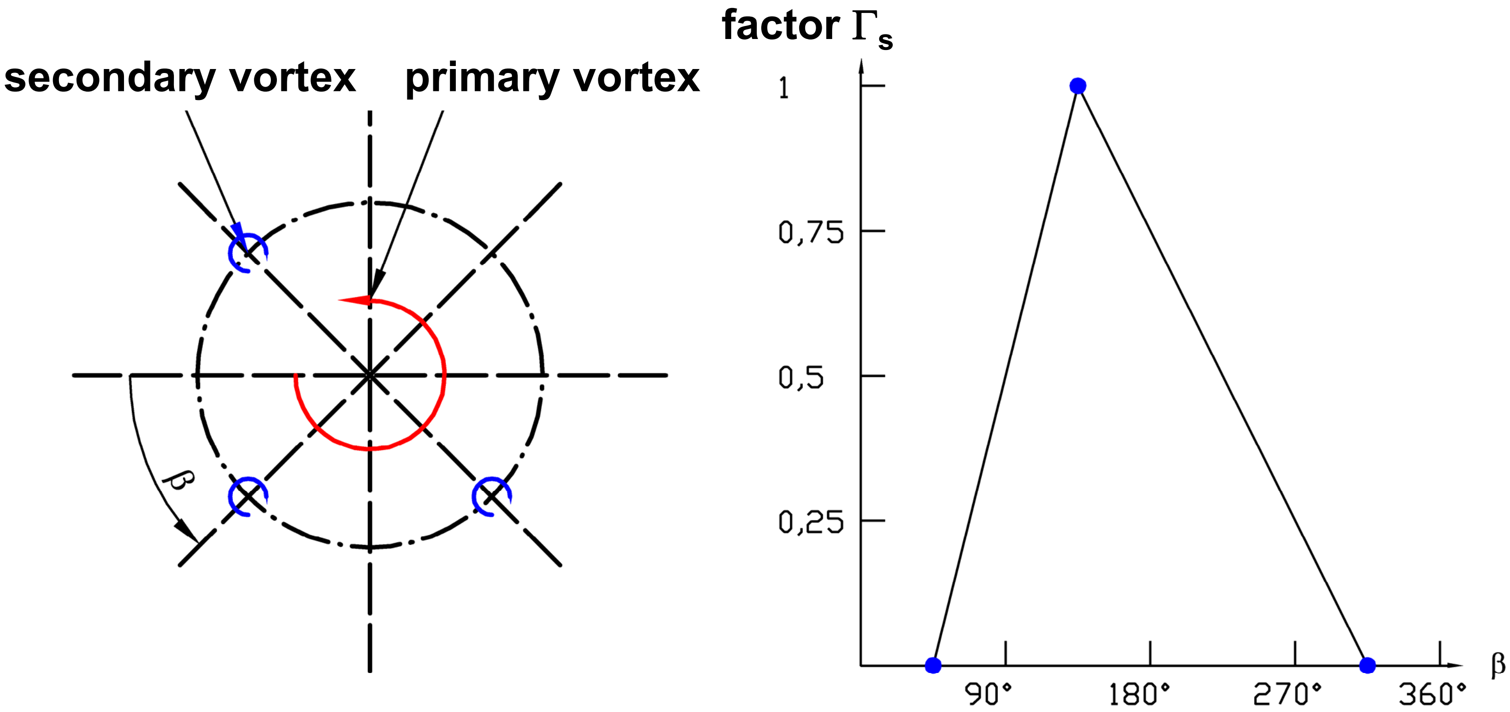


- **Image vortices at z = 1.5 b_0**
- **GE vortices + images at z = 0.6 b_0**
- **after rotation of 180 deg another pair of secondary vortices + images**
- $\Gamma^*_{s,\max} = 0.4\, w^*$

[1]Robins, R.E., Delisi, D.P., and Greene, G.C. (2001):, Algorithm for Prediction of Trailing Vortex Evolution, Journal of Aircraft, Vol. 38, No. 5, pp. 911-917.

IGE Parametrization

- strength variation pf secondary vortices



IGE Parametrization

ground effect model

decay model

$$T_2^* = t^*(z^* = 1)$$

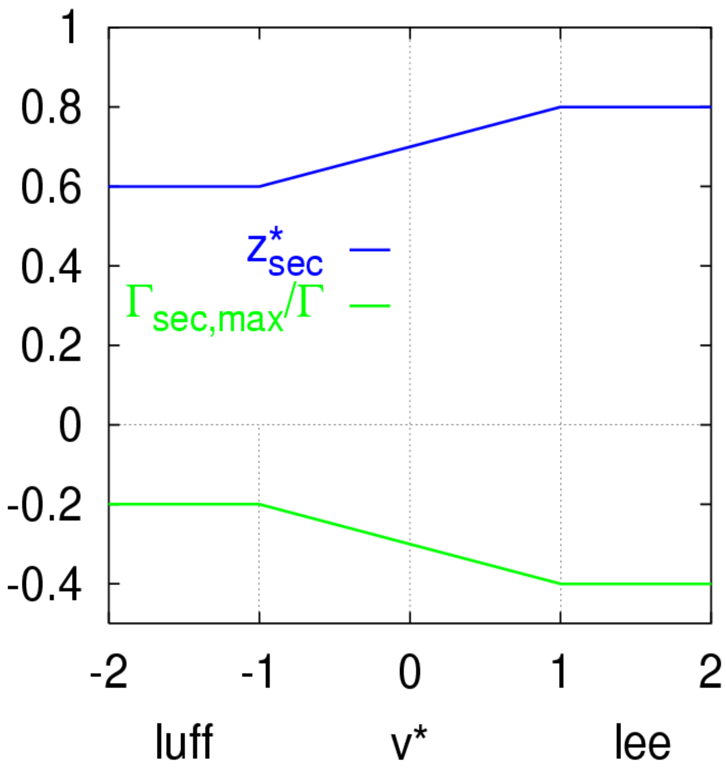
CW: $\upsilon^*_{2,p(s)} = 0.0026 - (+) 3.27 \cdot 10^{-5} v^* + 1.45 \cdot 10^{-4} v^{*2}$

EDR lidar: $\upsilon^*_2 = 0.002 - 0.00053 \varepsilon^* + 0.012 \varepsilon^{*2}$

EDR USA: $\upsilon^*_2 = 0.0025 - 0.00066 \varepsilon^* + 0.00516 \varepsilon^{*2}$

$$\upsilon^*_2 = 0.003$$

secondary vortex parameters



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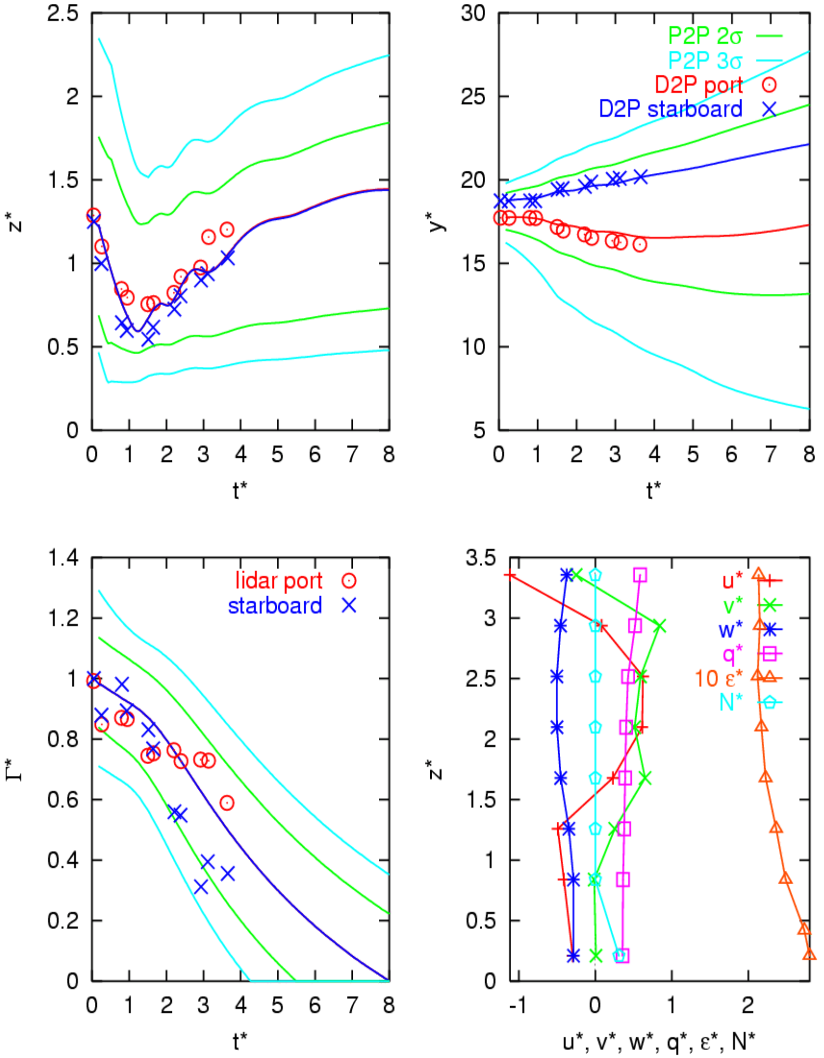
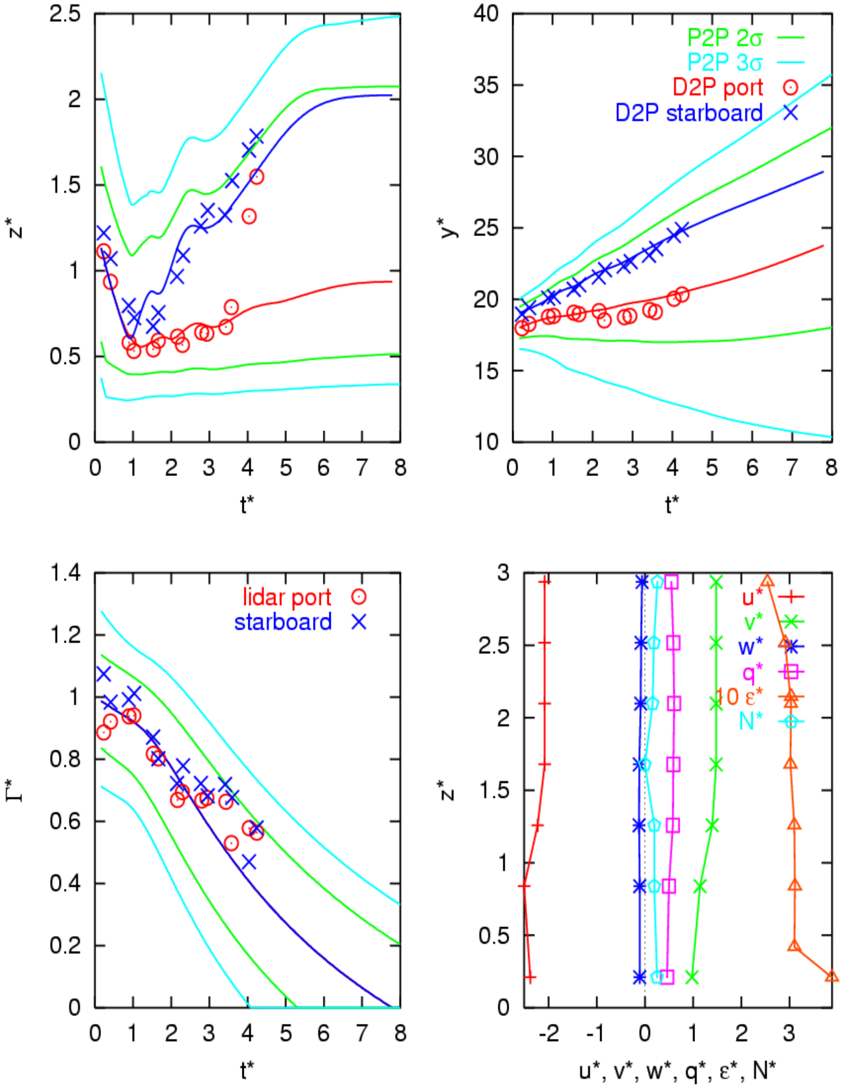
D2P GE Model



v*~0

D2P GE Model



$v^* \approx 1$

D2P GE Model

deterministic performance GE model

	RMS $\Delta\Gamma / \Gamma_0$	RMS $\Delta z / b_0$	RMS $\Delta y / b_0$
	37%	40%	13%
OGE model: median	0.145	0.199	0.462
90th perc.	0.251	0.278	0.974
v_2^* =0.003: median	0.0910	0.118	0.404
90th perc.	0.136	0.224	0.860
EDR (lidar): median	0.0903	0.118	0.404
90th perc.	0.127	0.225	0.858
EDR (USA): median	0.0877	0.120	0.404
90th perc.	0.126	0.226	0.860
CW: median	0.0905	0.118	0.402
90th perc.	0.129	0.225	0.860

110 approaches on 25R

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Conclusions

- correlation between ambient turbulence and GE decay
- weak impact of crosswind and turbulence on decay
- pronounced asymmetric rebound characteristics dependent on crosswind
- common normalization appropriate
- rapid decay OGE faster than IGE-decay
- GE evolution better predictable than OGE (y - 58%, z - 69%, Γ - 29%)
- fair GE predictions based on simply crosswind

Thank you for your attention!

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