Transition to turbulence control by means SVG

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Linné Flow Centre, KTH − Royal Institute of Technology

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European Research Council

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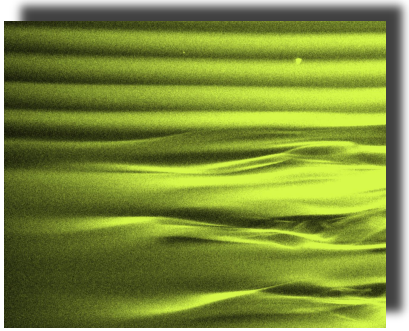


ERCOFTAC Workshop, October 13 (2016), KTH, Stockholm

KTH VETENSKAP OCH KONST

FLOW

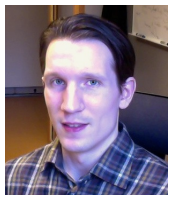
2010 (Nov.) – 2015 (Oct.)

- **A**dvanced **F**luid **R**esearch **O**n **D**rag reduction **I**n **T**urbulence **E**xperiments
- Research programme – ERC, with the objective to study flow control methods for skin-friction drag reduction
- In particular passive flow control
  - No energy input

- **AFRODITE group members:**

PhD students | Postdoc | Researcher | PI



Affiliated researchers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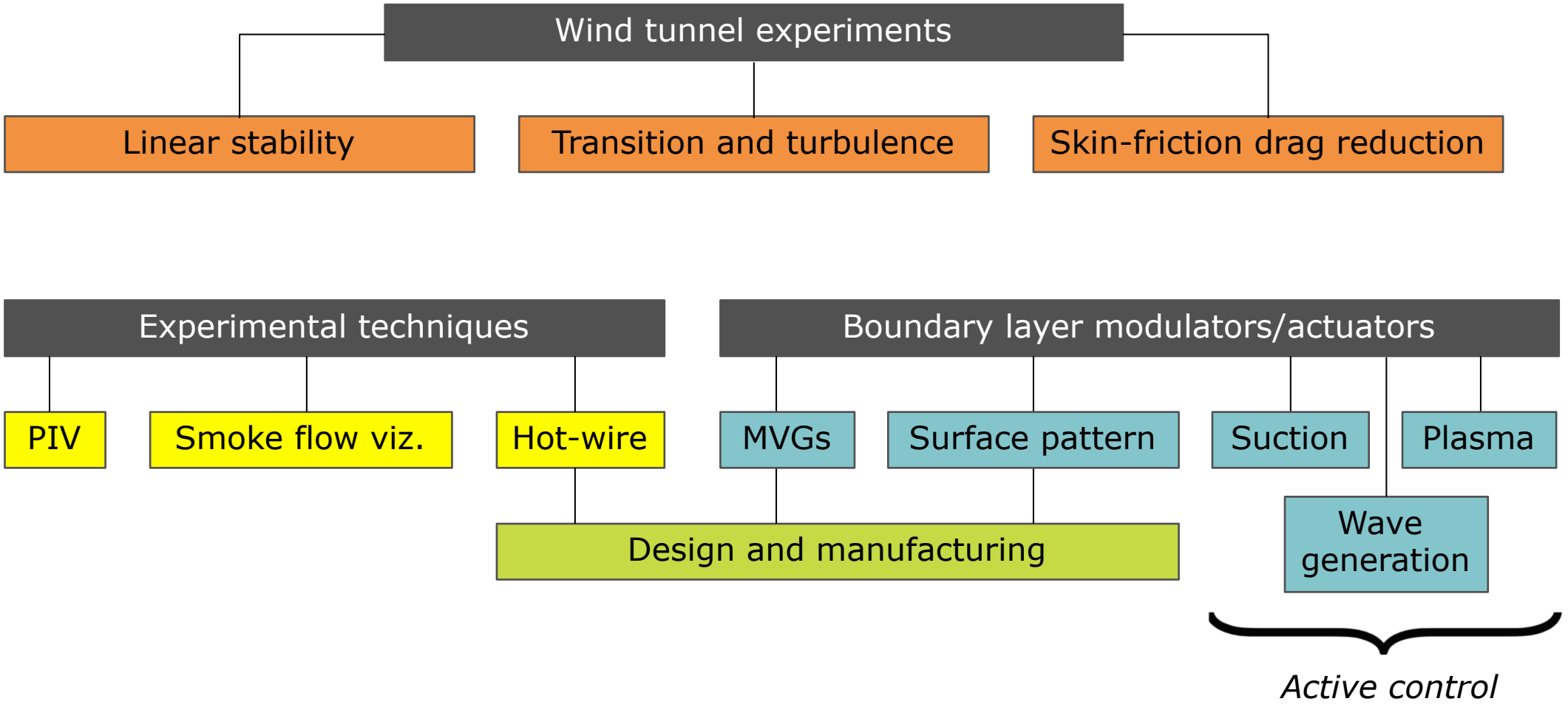

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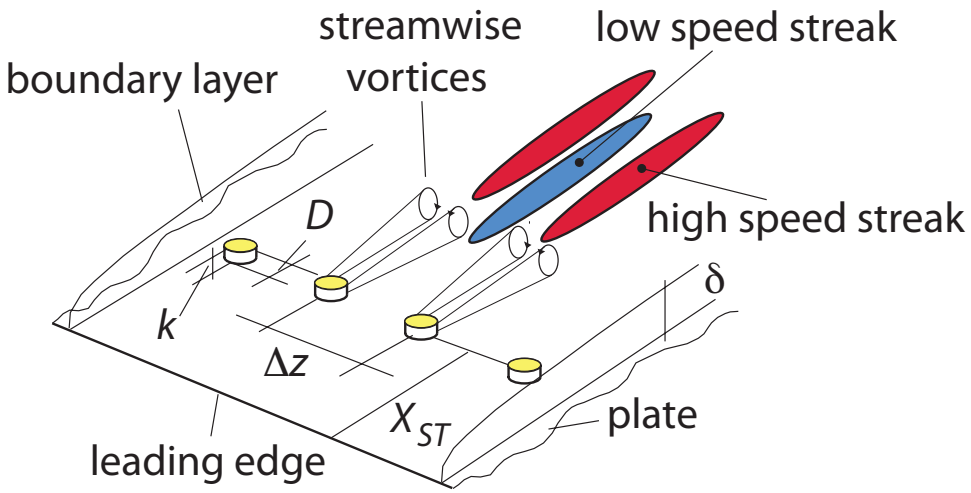
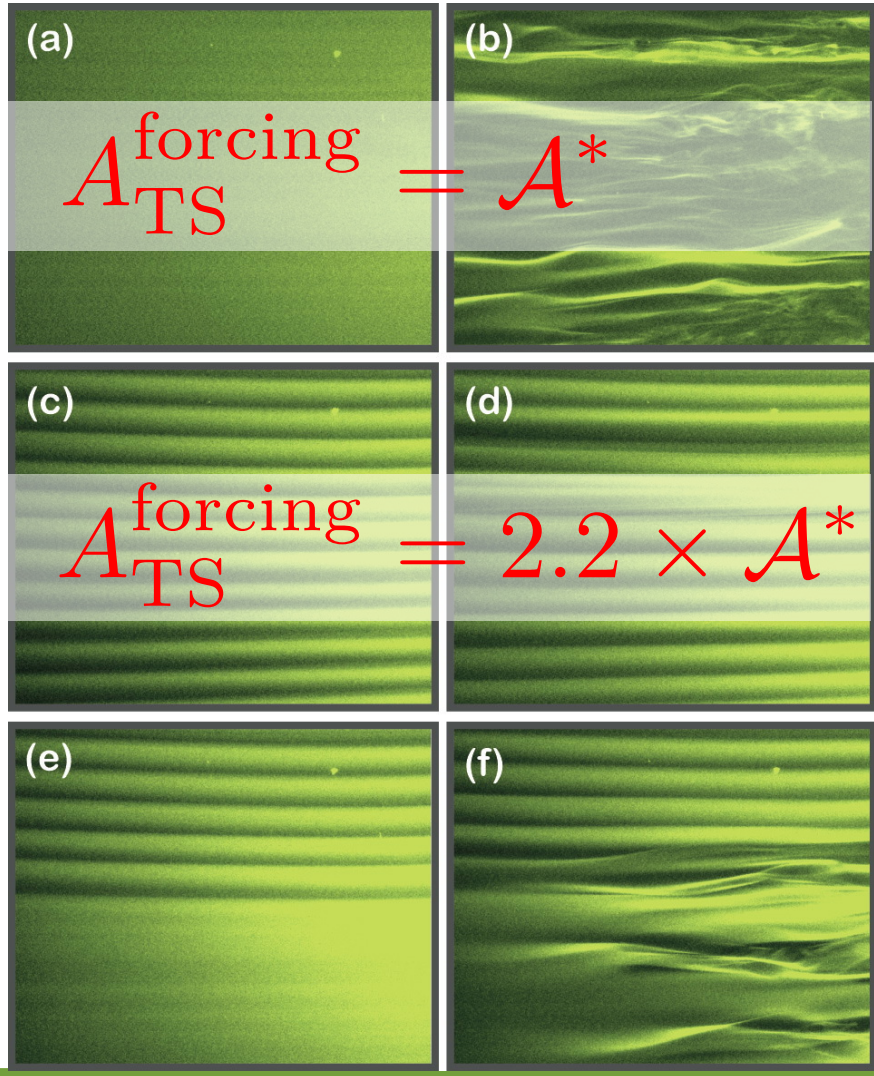
First proof-of-concept of transition delay using the SVG method

- Streamwise streaks were generated by means of circular roughness elements, at the time doomed to fail! (Fransson et al. 2006 *Phys. Rev. Lett.*)





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First observation: Kachanov & Tararykin 1987

- Kachanov & Tararykin **1987**: Steady streaks forced by wall blowing (≈5%). Linear 3D streaky TS waves less amplified than in Blasius, or even stable, *Izv. SO AN SSSR. Ser. Tekh. Nauk.*

TRANSITION DELAY WAS HOWEVER NEVER OBSERVED!

Further experimental observations

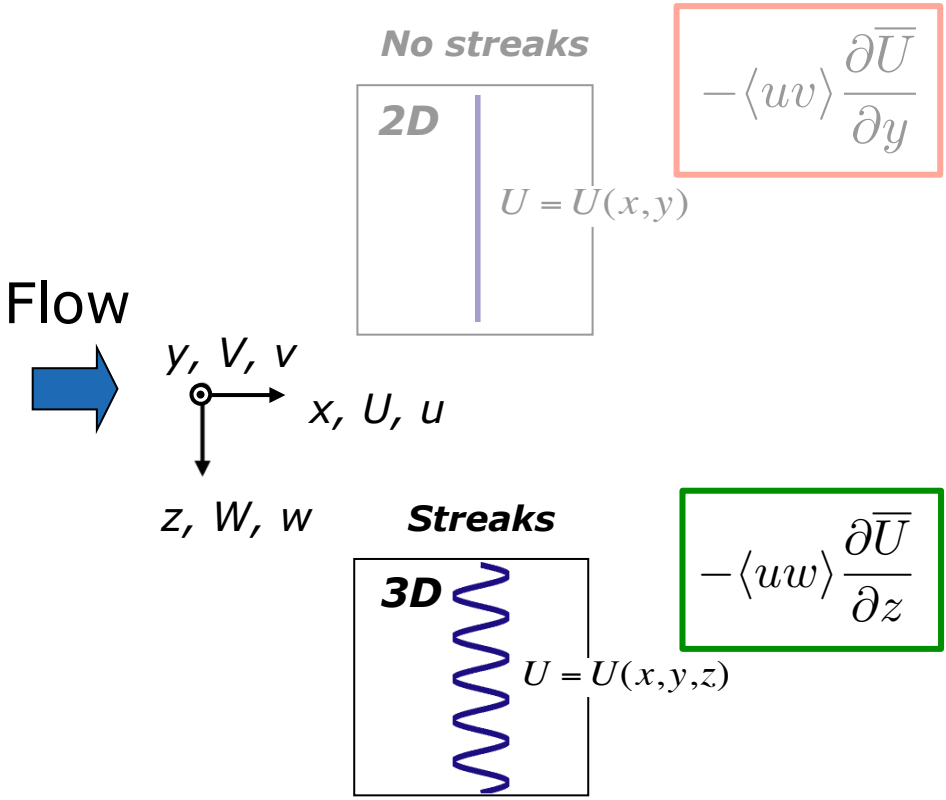
- Bakchinov, Westin, Lingmann, Kozlov & Alfredsson **1995**: Unsteady induced streaks by FST damp the growth of TS waves. Transition location was however advanced. *J. Fluid Mech.*

$$\frac{\mathrm{d}E_{\mathcal{V}}}{\mathrm{d}t} = \underbrace{-\int_{\mathcal{V}} \langle u_i u_j \rangle \frac{\partial U_i}{\partial x_j} \mathrm{d}\mathcal{V}}_{\text{Production}} \underbrace{- \frac{1}{Re} \int_{\mathcal{V}} \frac{\partial u_i}{\partial x_j} \frac{\partial u_i}{\partial x_j} \mathrm{d}\mathcal{V}}_{\text{Dissipation}}$$

Kinetic disturbance energy equation

Mechanism of stabilization

- Cossu and Brandt **2004** *Eur. J. Mech. B:* Linear stability analysis on DNS base flow fields



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AFRODITE (Nov. 2010 – Oct. 2015)

European Research Council
Established by the European Commission

- JFM 2012: Fransson* & Talamelli (MVGs)
- PRL 2012: Shahinfar, Sattarzadeh, Fransson* & Talamelli (MVGs)
- JFM 2013: Shahinfar, Fransson*, Sattarzadeh & Talamelli (MVGs)
- JFM 2014: Shahinfar, Sattarzadeh & Fransson* (MVGs)
- PRE 2014: Sattarzadeh, Fransson*, Talamelli & Fallenius (MVGs)
- JFM 2014: Downs & Fransson (humps)
- POF 2014: Sattarzadeh & Fransson* (MVGs)
- JFM 2015: Siconolfi, Camarri & Fransson* (free-stream vortices)
- AIAAJ 2015: Ferro, Downs* & Fransson
- EXIF 2015: Sattarzadeh & Fransson* (MVGs)
- POF 2015: Tinti & Fransson* 2015 (suction)
- JFM 2015: Siconolfi, Camarri & Fransson* (MVGs)
- PRE 2016: Sattarzadeh & Fransson* (*pair-of-oblique waves*)
- – 2016: Downs, Fallenius & Fransson* (wavy-surfaces, under review)
- – 2016: Sattarzadeh & Fransson* (*suction, under review*)

- 3 plenary talks
- 3 seminar invitations
- 39 conference presentations

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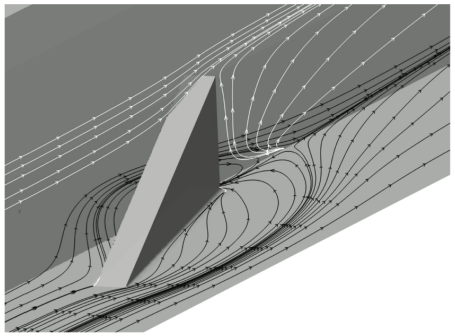
FLOW

AFRODITE results

- **Miniature vortex generators (EXP & DNS)**



- **Wavy surfaces (EXP)**

- **Free-stream vortices (DNS)**

- **Pair of oblique waves (EXP)**

initial POW

nonlinearly forced streaks

4 ways to generate SVG

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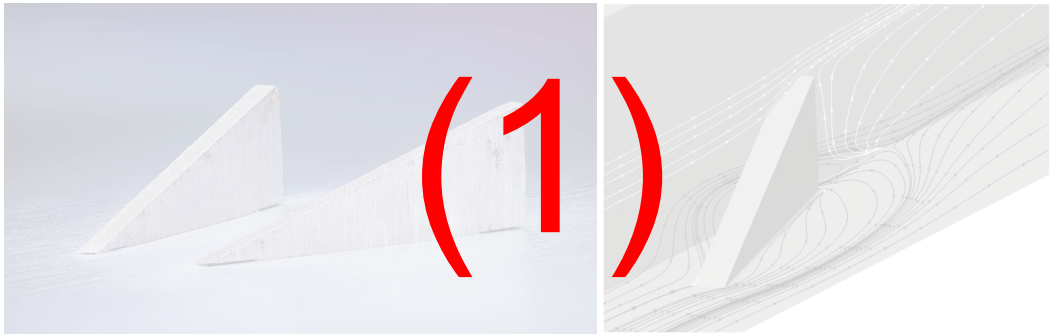
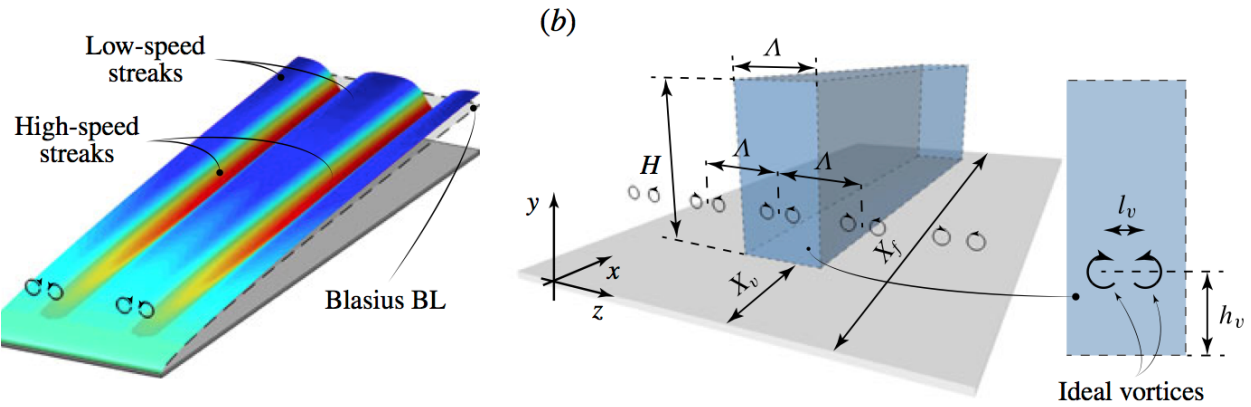
AFRODITE results

- Miniature vortex generators (EXP & DNS)



- Wavy surfaces (EXP)

- **Free-stream vortices (DNS)**



- Pair of oblique waves (EXP)

initial POW

nonlinearly forced streaks

4 different ways to generate SVG

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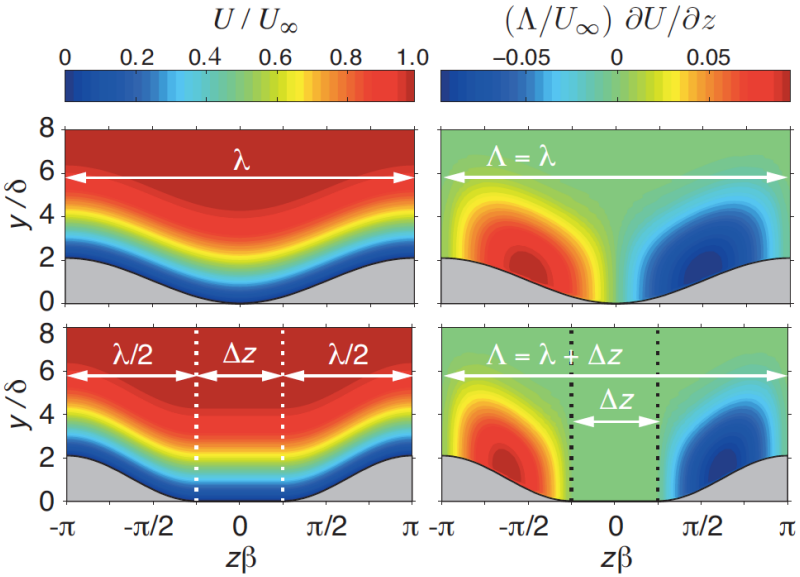
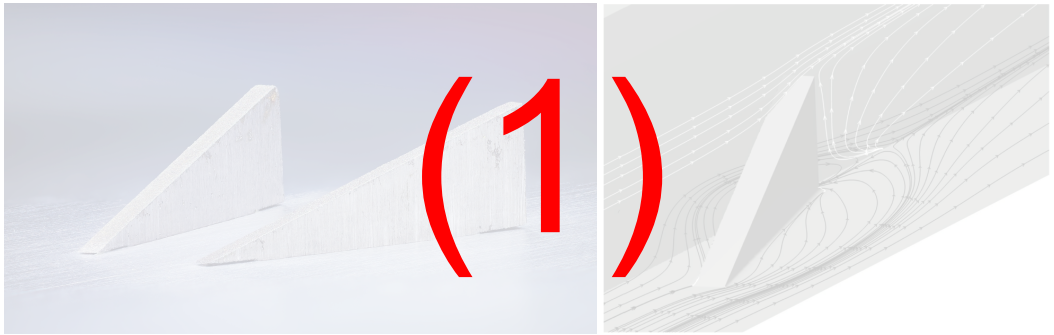
FLOW

AFRODITE results

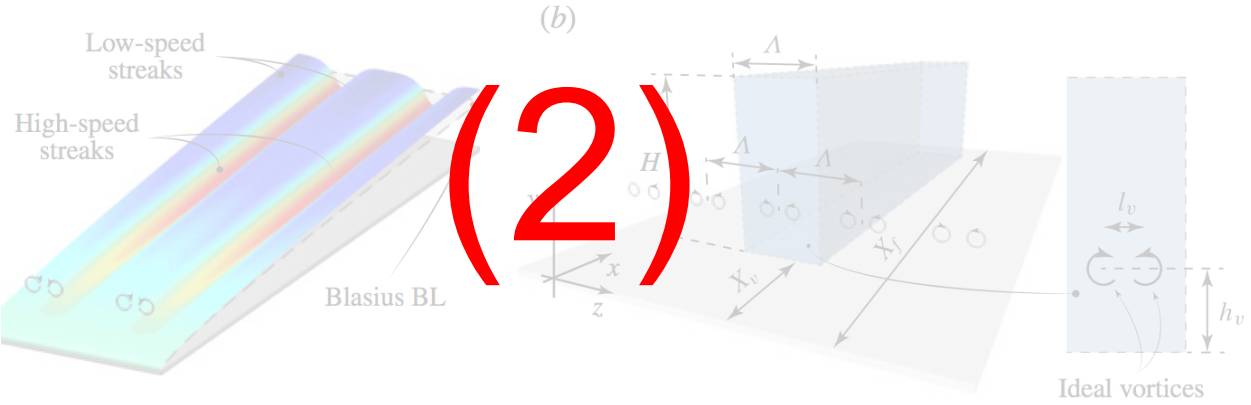
- Wavy surfaces (EXP)



- Miniature vortex generators (EXP & DNS)



- Free-stream vortices (DNS)



- Pair of oblique waves (EXP)

initial POW

nonlinearly forced streaks

4 ways to generate SVG

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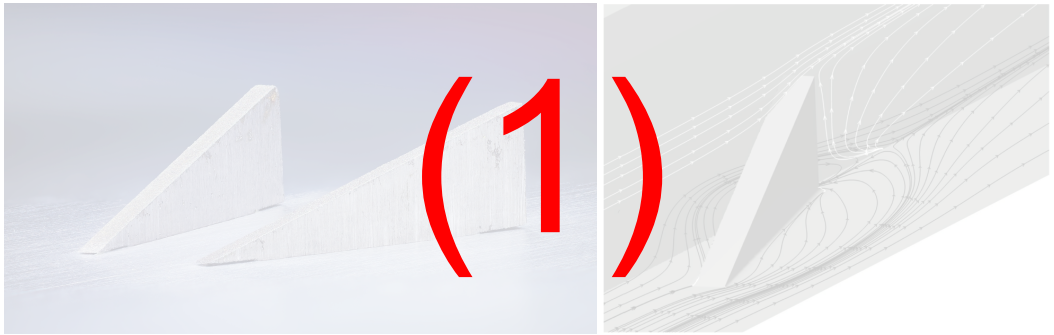
AFRODITE results

- Miniature vortex generators (EXP & DNS)



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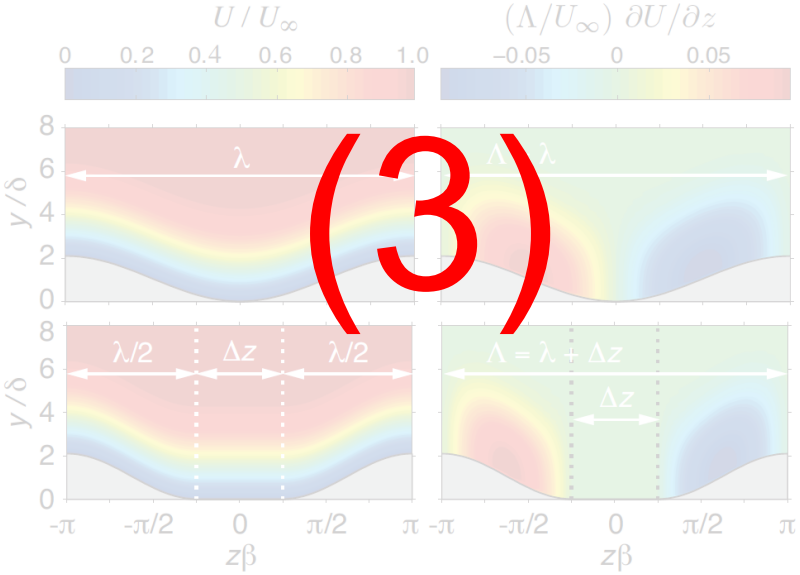
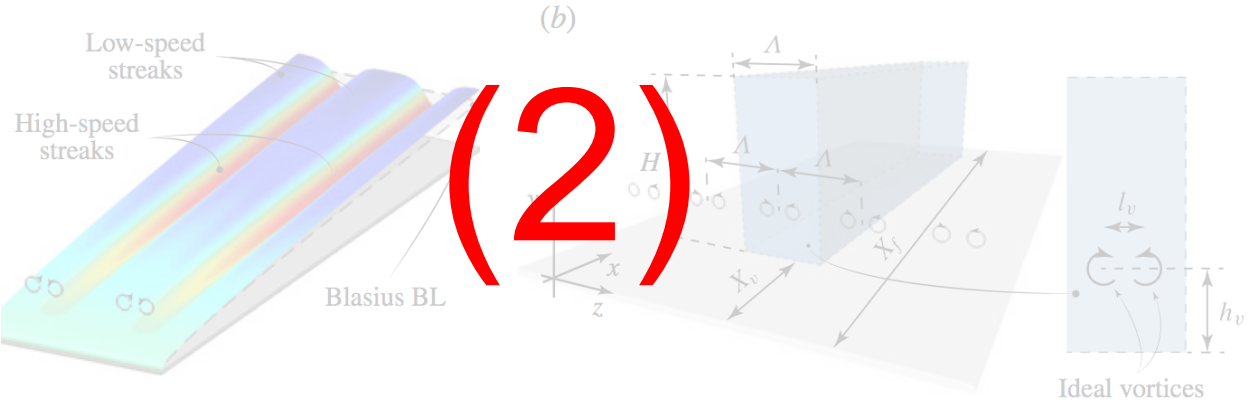
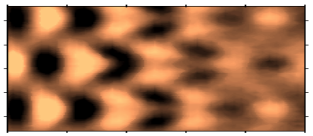
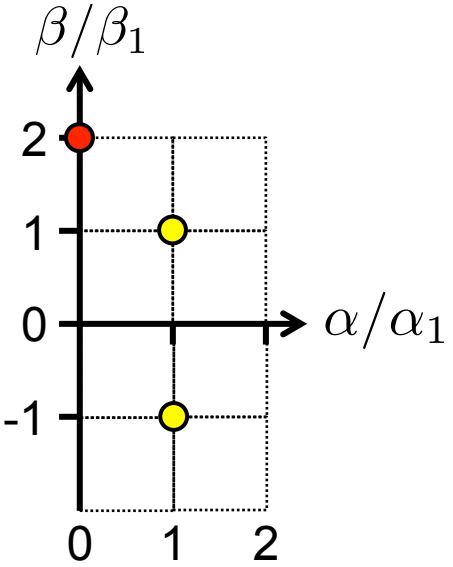


- Free-stream vortices (DNS)



- **Pair of oblique waves (EXP)**





initial POW

nonlinearly forced streaks

4 ways to generate SVG

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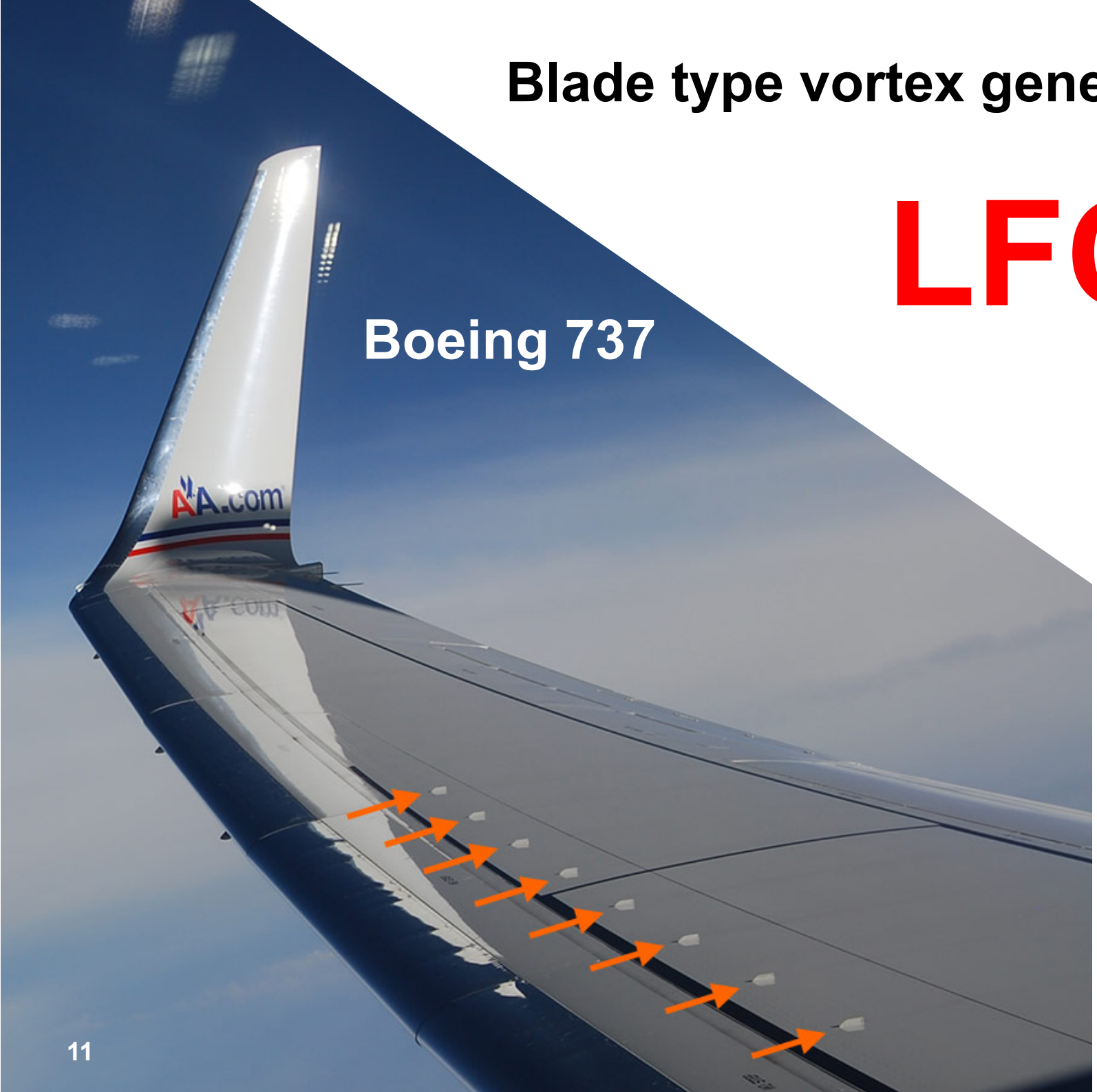
Blade type vortex generators not new



LFC?

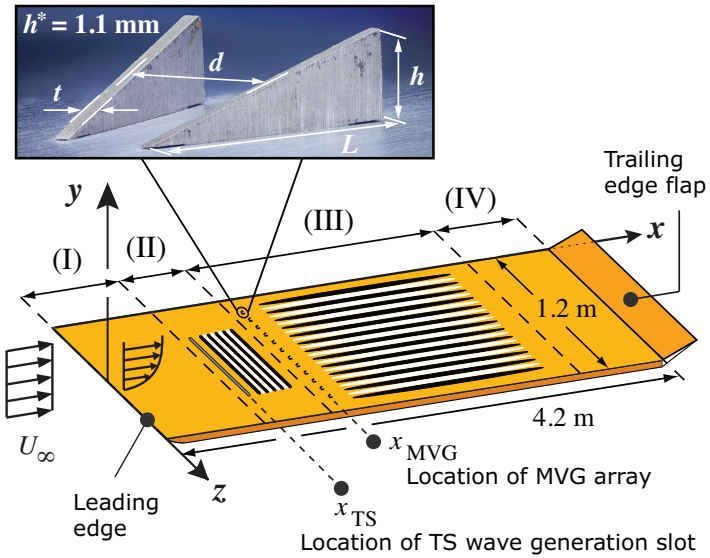
(1)

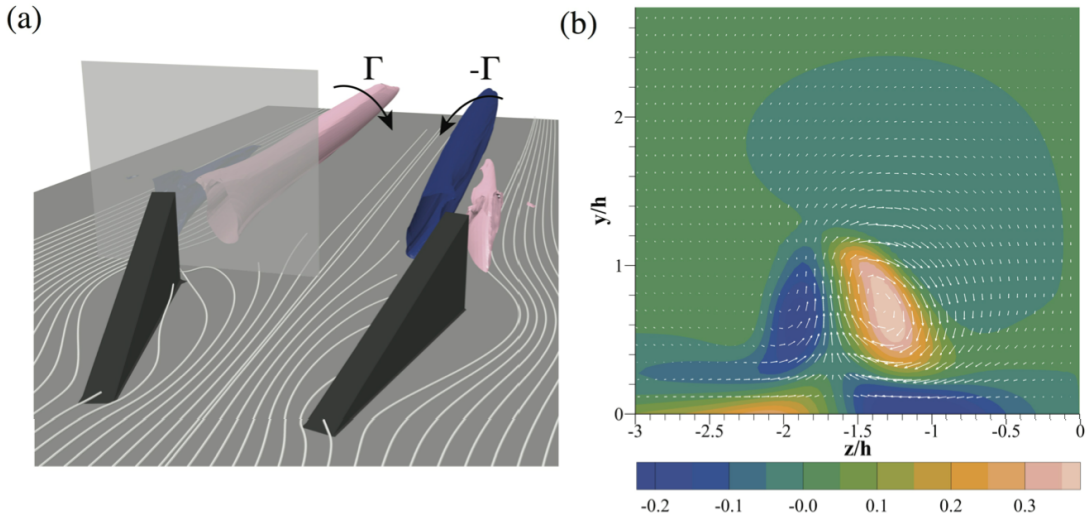
Experimental setup in MTL

- 2D periodic disturbances: TS wave
- Streaky base flow by means of MVGs
- Realistic flow configuration (dist. Gen. upstream of MVG array)

MTL wind tunnel, KTH

PRL 2012: Shahinfar et al.





JFM 2015: Siconolfi, Camarri & Fransson

(1) Miniature vortex generators

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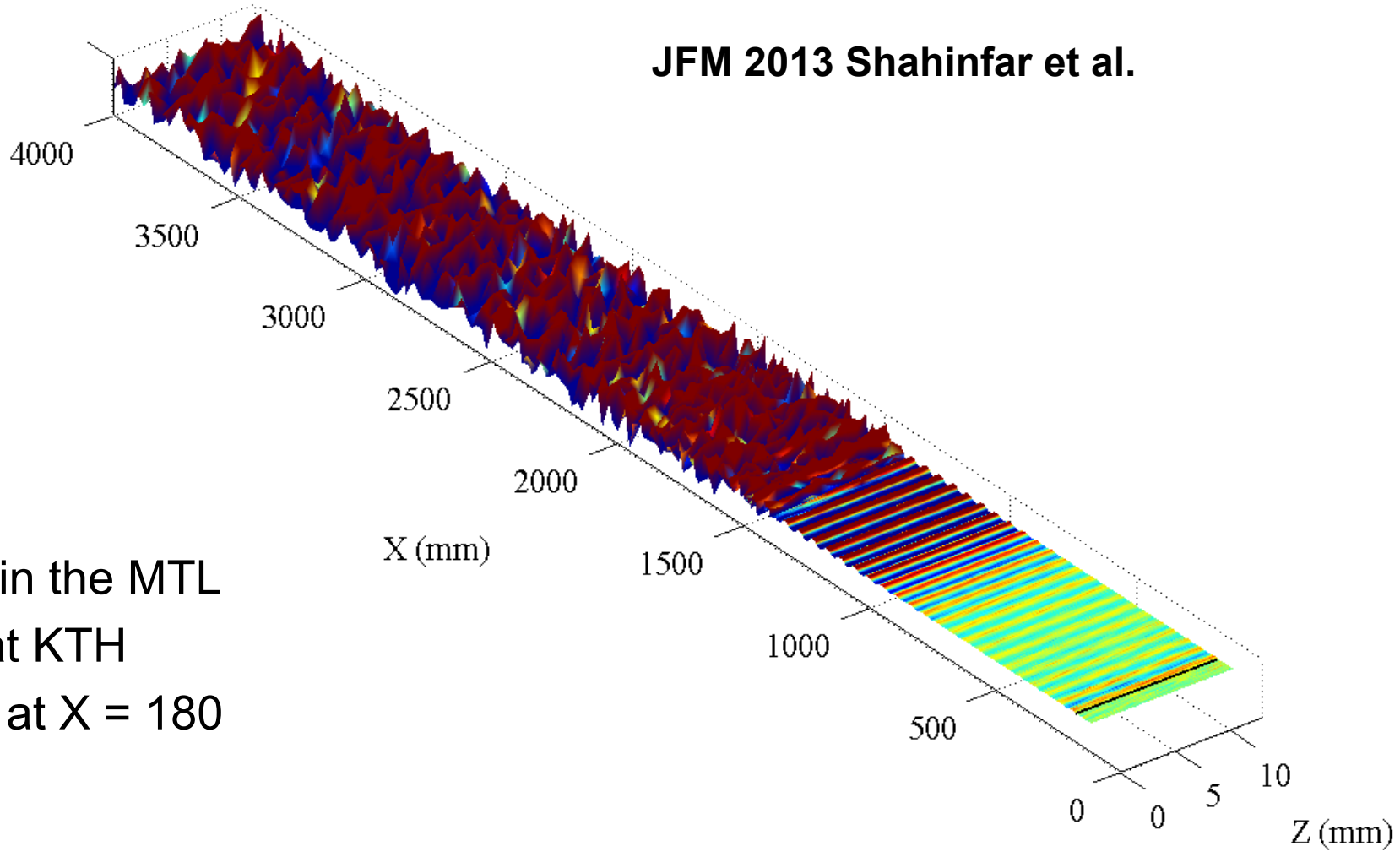
TS wave transition without MVGs

PRL 2012 Shahinfar et al.

JFM 2013 Shahinfar et al.



- Experiments in the MTL wind tunnel at KTH
- TS wave slot at X = 180 mm

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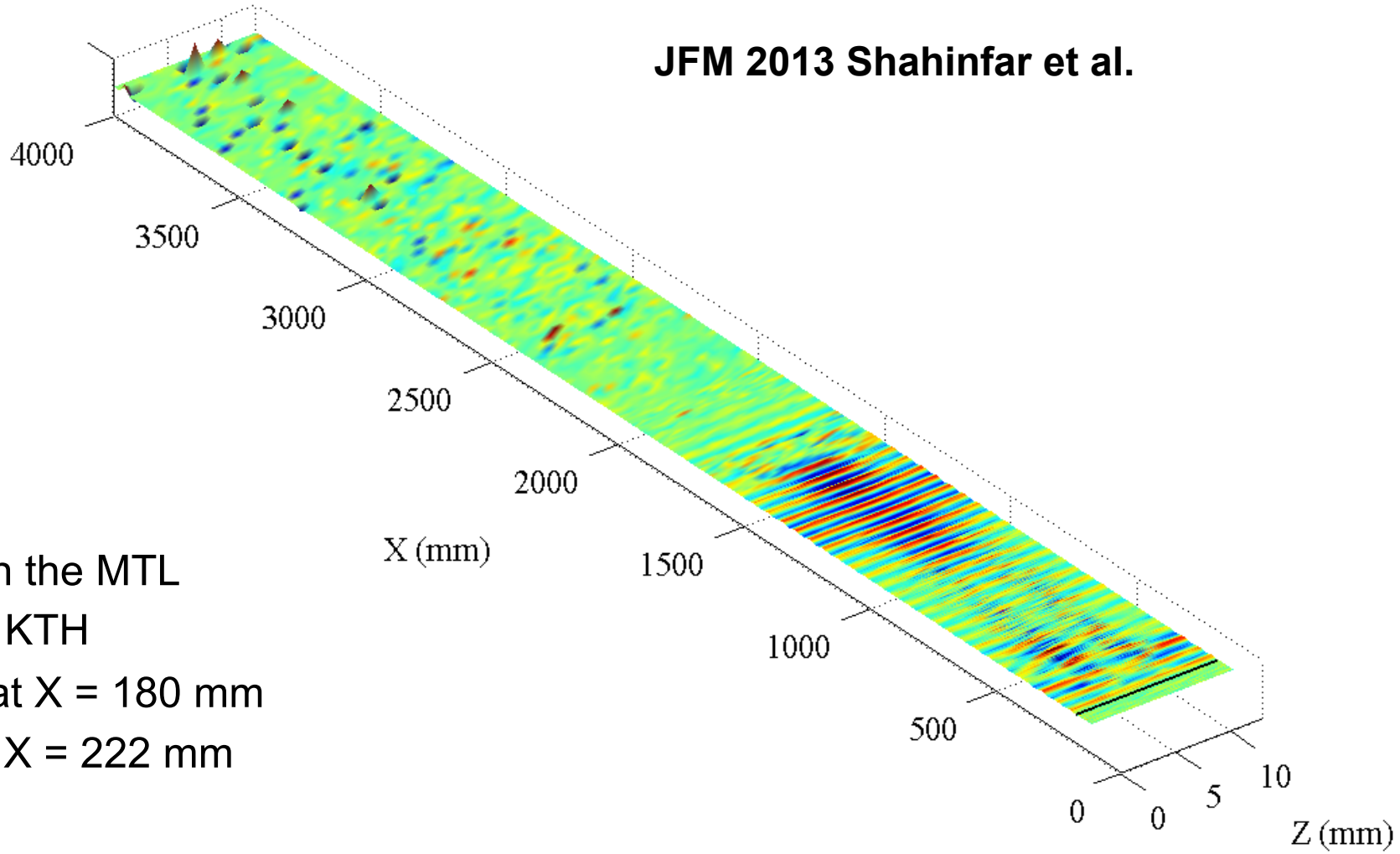
TS wave transition with MVGs

PRL 2012 Shahinfar et al.

JFM 2013 Shahinfar et al.



- Experiments in the MTL wind tunnel at KTH
- TS wave slot at X = 180 mm
- **MVG array** at X = 222 mm

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J. Fluid Mech. (2015), *vol.* 764, R2, doi:10.1017/jfm.2014.731

JFM RAPIDS
journals.cambridge.org/rapids

Boundary layer stabilization using free-stream vortices

(2)

L. Siconolfi[1], S. Camarri[1] and J. H. M. Fransson[2,†]

[1]Dipartimento di Ingegneria Civile ed Industriale, Università di Pisa, I-561 26 Pisa, Italy

[2]Linné Flow Centre, KTH-Royal Institute of Technology, SE-100 44 Stockholm, Sweden

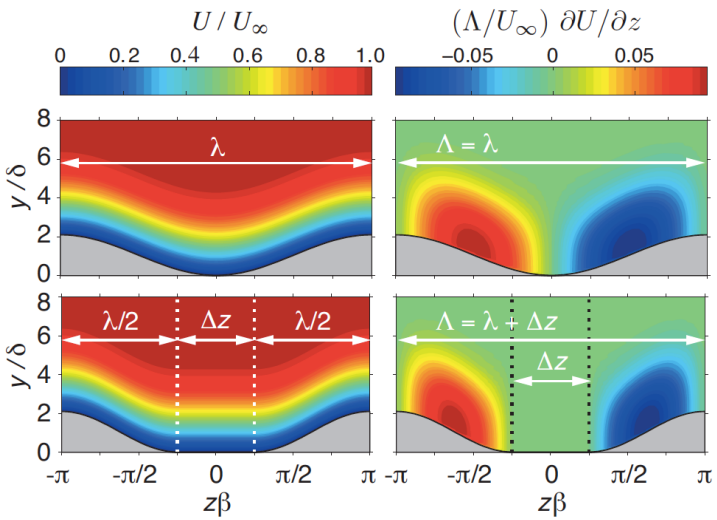
(Received 8 October 2014; revised 8 December 2014; accepted 16 December 2014)

Wavy surfaces not new

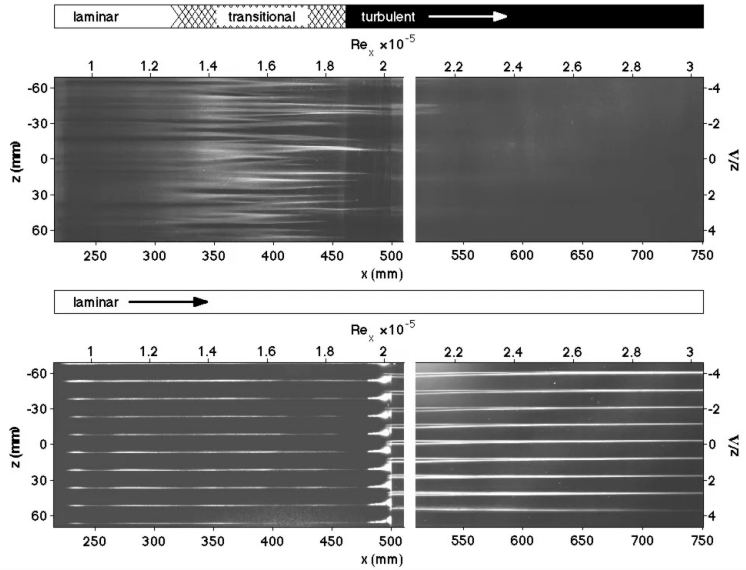
Proof-of-concept for LFC

***Wavy surfaces*: Downs, Fallenius & Fransson 2015 (under review)**

$$U_\infty = 6 \text{ m s}^{-1} \qquad F = 183 \qquad Re_x^{\text{end}} = 3.05 \times 10^5 \qquad x_{\text{TS}} = 160 \text{ mm}$$



Smoke flow visualization



$$\beta = 0$$

$$\beta = 0.30$$

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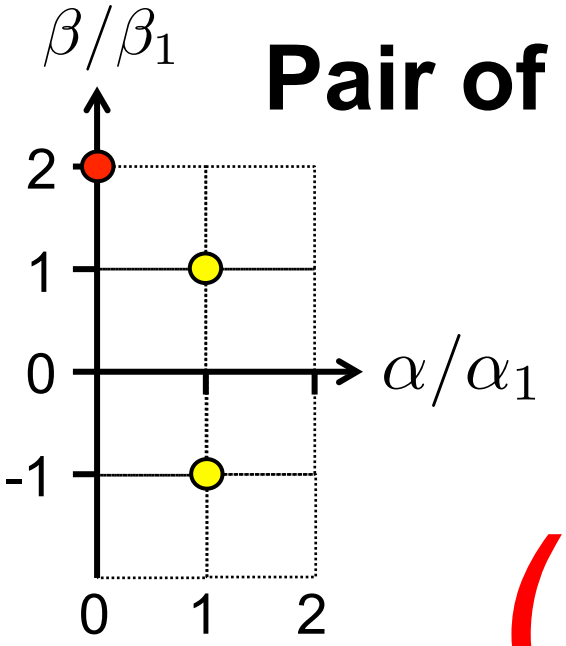
Pair of o… (POW)

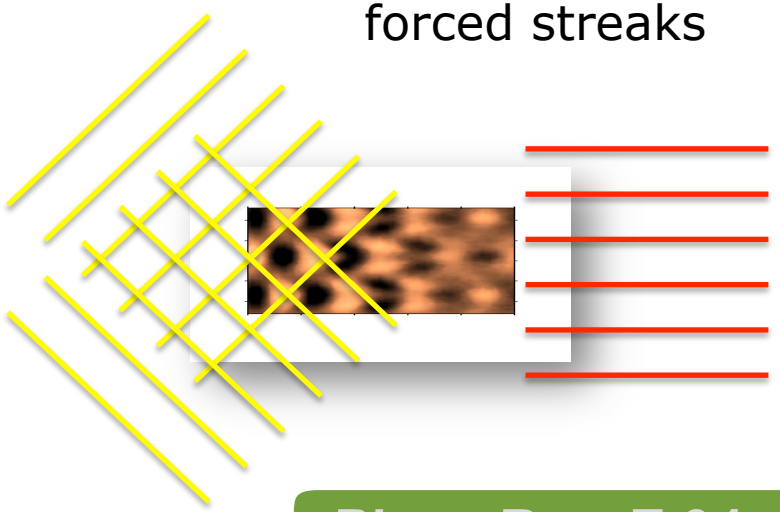
Generating streaks by POW

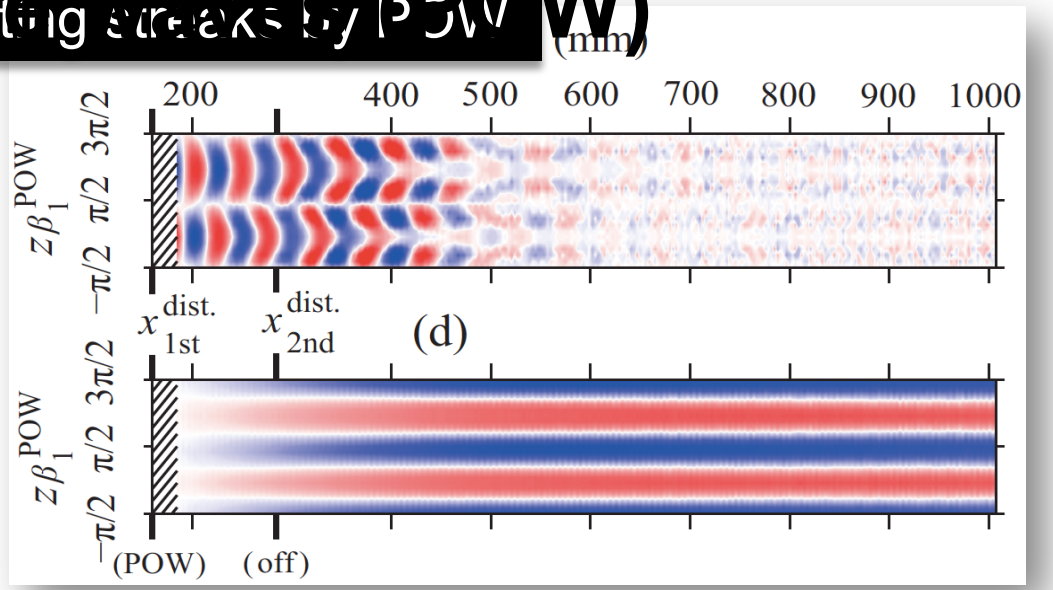


initial POW

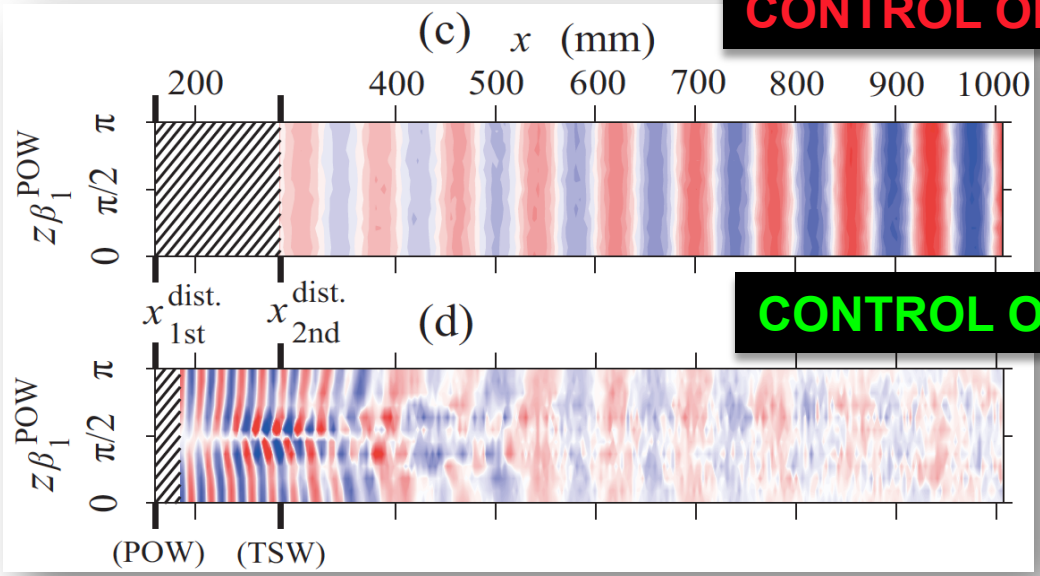
nonlinearly forced streaks

(4)





CONTROL OFF



CONTROL ON

Phys. Rev. E 94, 021103(R) (2016)

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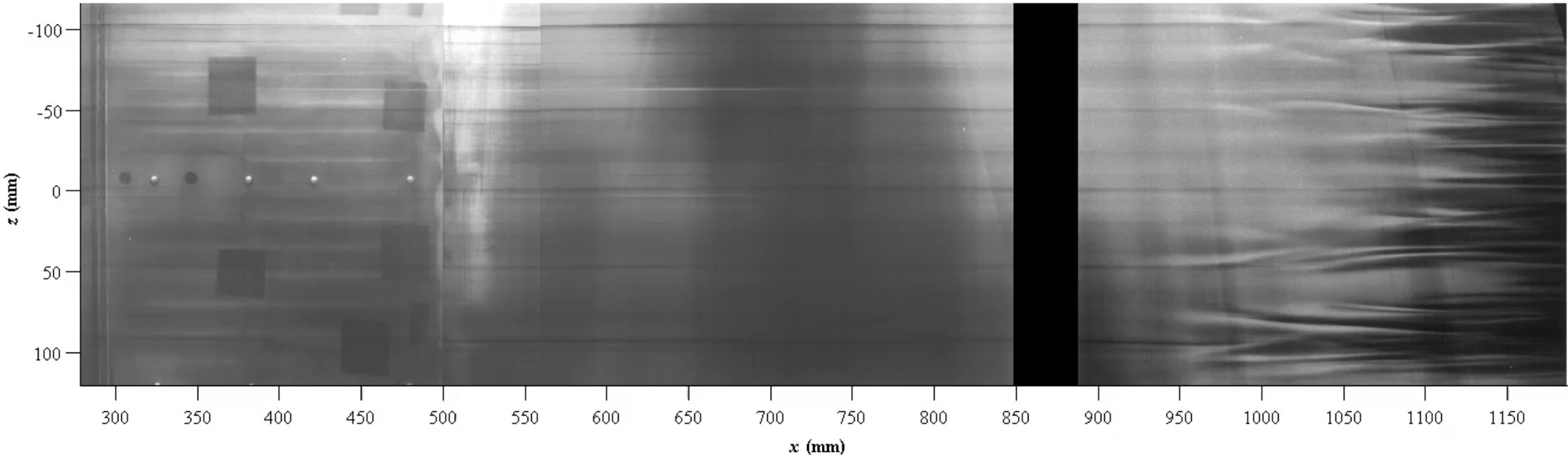
FLOW

Pair of oblique waves: smoke visualization



F_{TS} = 146
x_{TS} = 160 mm
x_{POW} = 285 mm
Re_x^{end} = 480 x 10^5

(4) Pair of oblique waves **Phys. Rev. E 94, 021103(R) (2016)**

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Conclusions

- The SVG method for LFC is robust
  - Circular roughness elements
  - Miniature vortex generators
  - Free-stream vortices
  - Wavy surfaces
  - Pair of oblique waves

- The SVG method has a lot of potential and certainly deserves further attention.

- This is not an ended chapter, it is only the beginning…

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