UK FLUIDS 2025 LIVERPOOL

Flow transition over surface gaps in 2D incompressible laminar boundary layers

Víctor Ballester Ribó[1], Jeffrey Crouch[2], Yongyun Hwang[1], Spencer Sherwin[1]

[1]Department of Aeronautics, Imperial College London, UK
[2]The Boeing Company, USA

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IMPERIAL BOEING

Motivation

Figure: Wing of a Boeing 737-800

Setup

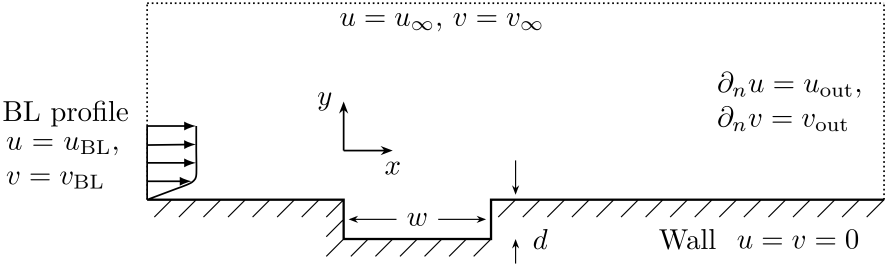


Figure: Domain setup for the steady-state finder

- **Aim:** Study the stability of the system as a function of the depth d and width w of the gap.
- 2D incompressible NS
- $\mathrm{Re}_{\delta*} = 1000 \implies \mathrm{Re}_x = 3.38 \times 10^5$

Stability results

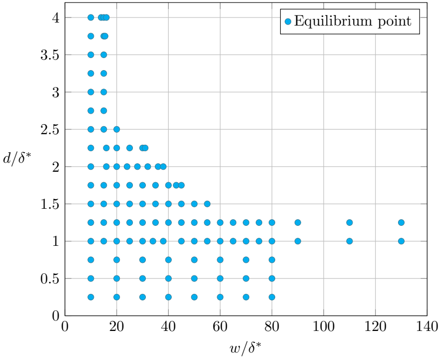
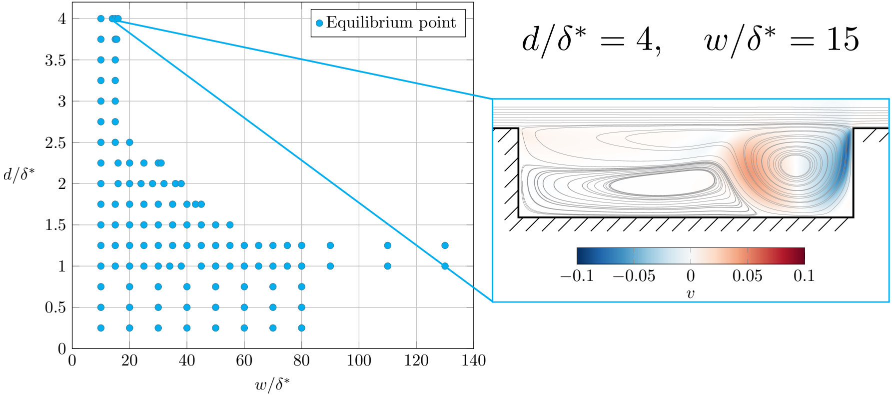


Figure: Classification of the stability of points downstream of the gap.

Stability results



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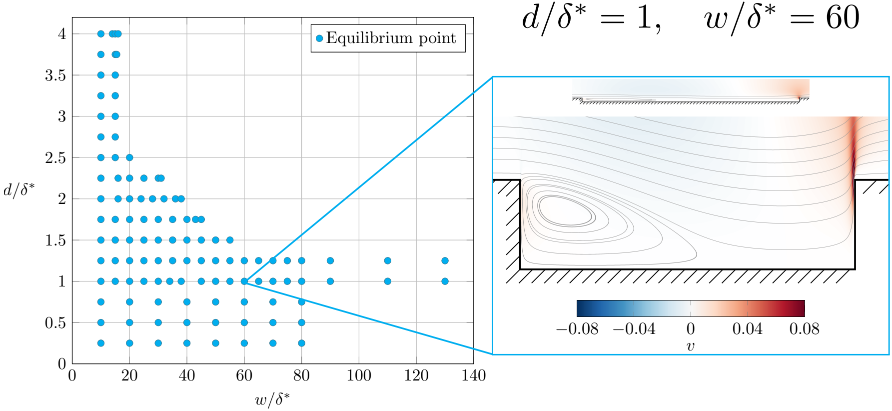

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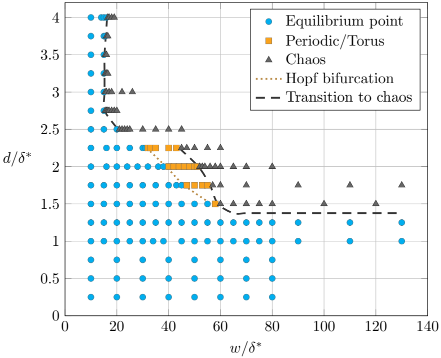
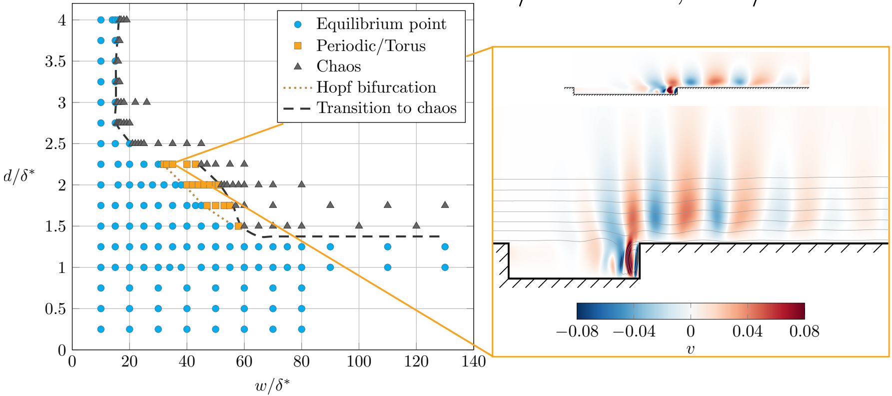


Figure: Classification of the stability of points downstream of the gap.

Stability results

$$d/\delta^* = 2.25, \quad w/\delta^* = 35$$



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Framework for the LST (TS-wave transition)

- We linearize the flow around a steady baseflow:

$$\mathbf{u}(x, y, t) = \mathbf{U}(x, y) + \tilde{\mathbf{u}}(x, y, t).$$

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- We add a distrubance of characteristic amplitude A_0 upstream of the gap and we track its evolution through

$$A(x) := A_0 \mathrm{e}^{n(x)} \implies n(x) = \log\left(\frac{A(x)}{A_0}\right).$$

$n(x)$ is called the n-*factor* and it is used to predict transition in the BL.

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- To compare between gaps, we define $n_{\mathsf{ref}}(x)$ as the n-factor of a reference case (flat plate) and we compute

$$\Delta n_{\mathsf{gap}} = n_{\mathsf{gap}} - n_{\mathsf{ref}}.$$

Perturbed system setup

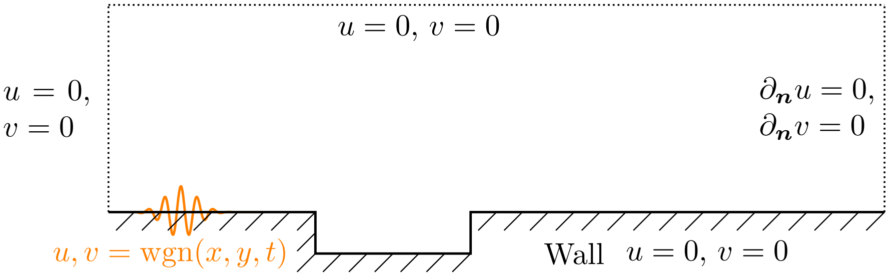
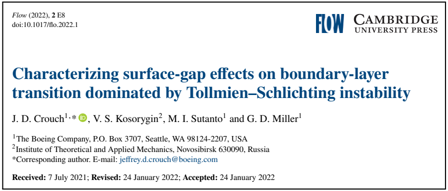


Figure: Domain setup for the perturbed system

Previous Work



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Characterizing surface-gap effects on boundary-layer transition dominated by Tollmien–Schlichting instability

J. D. Crouch[1,*], V. S. Kosorygin[2], M. I. Sutanto[1] and G. D. Miller[1]

[1]The Boeing Company, P.O. Box 3707, Seattle, WA 98124-2207, USA
[2]Institute of Theoretical and Applied Mechanics, Novosibirsk 630090, Russia
*Corresponding author. E-mail: jeffrey.d.crouch@boeing.com

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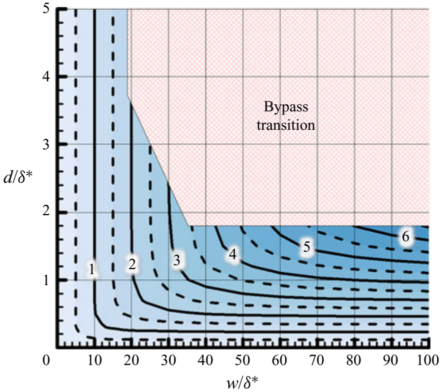

Figure: $\Delta n_{\text{gap}} = n_{\text{gap}} - n_{\text{ref}}$ for different gap dimensions

Crouch JD, Kosorygin VS, Sutanto MI, Miller GD. Characterizing surface-gap effects on boundary-layer transition dominated by Tollmien–Schlichting instability. Flow. 2022;2:E8.

e^N-method results

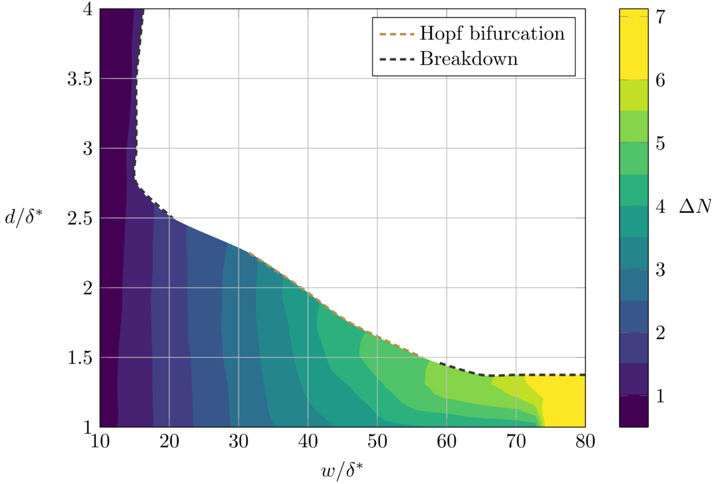

Figure: Interpolated $\Delta n_{\text{gap}} = n_{\text{gap}} - n_{\text{ref}}$ in the globally-stable region.

e^N-method results

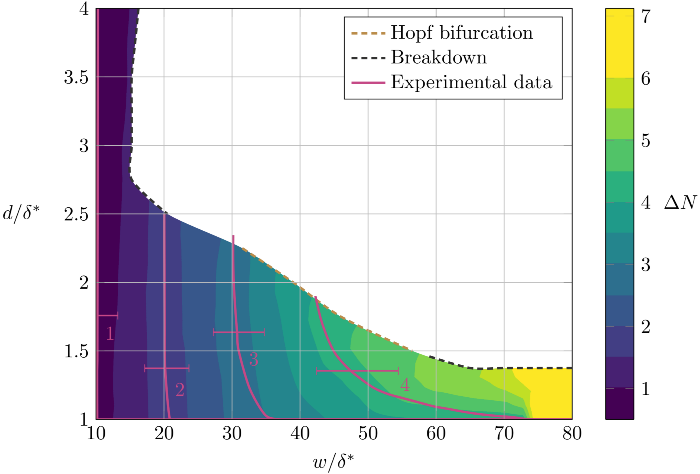

Figure: Interpolated $\Delta n_{\text{gap}} = n_{\text{gap}} - n_{\text{ref}}$ in the equilibra region. Magenta lines indicate the contour levels of the experimental data.

Future Work

- Go to higher Ma (compressible regime).

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- Account for spanwise effects (quasi-3d simulations).