Experimental analysis of the effect of suction and step height on boundary-layer transition

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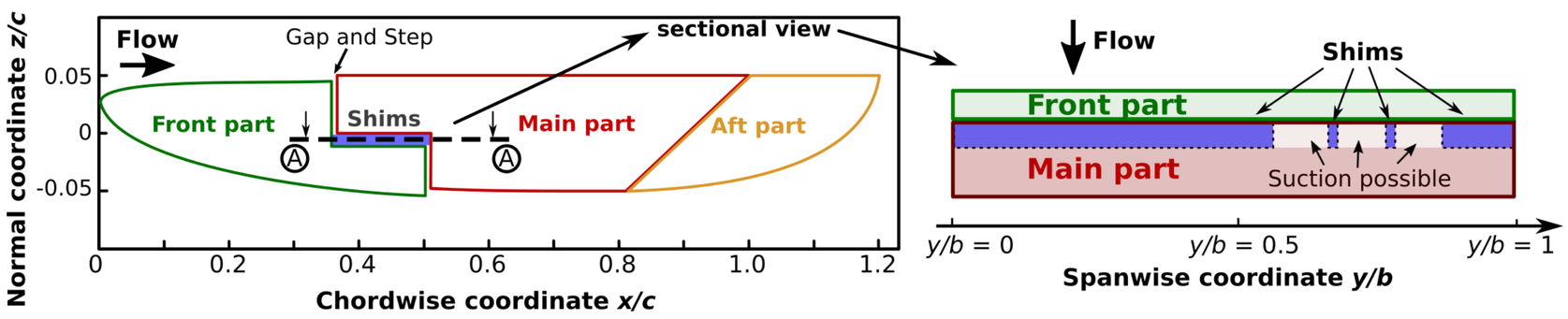
Introduction

Laminar flow on transport aircraft is challenging to maintain in the presence of surface imperfections such as steps and/or gaps, which can occur at structural joints. A substantial stream-wise delay of laminar-turbulent transition, however, can be achieved by suction. This work focuses on the influence of suction on transition in the presence of forward-facing steps (FFS) and backward-facing steps (BFS) (step Reynolds number Re_h) in combination with stream-wise gaps (gap Reynolds number Re_{gap}). Systematic experimental investigations were performed in the low-turbulence Cryogenic Ludwieg-Tube Goettingen for large Reynolds numbers (chord Reynolds numbers up to $Re_c = 16 \cdot 10^6$), Mach numbers $0.35 \leq M \leq 0.77$ and various streamwise pressure gradients quantified by β_H (Hartree parameter).

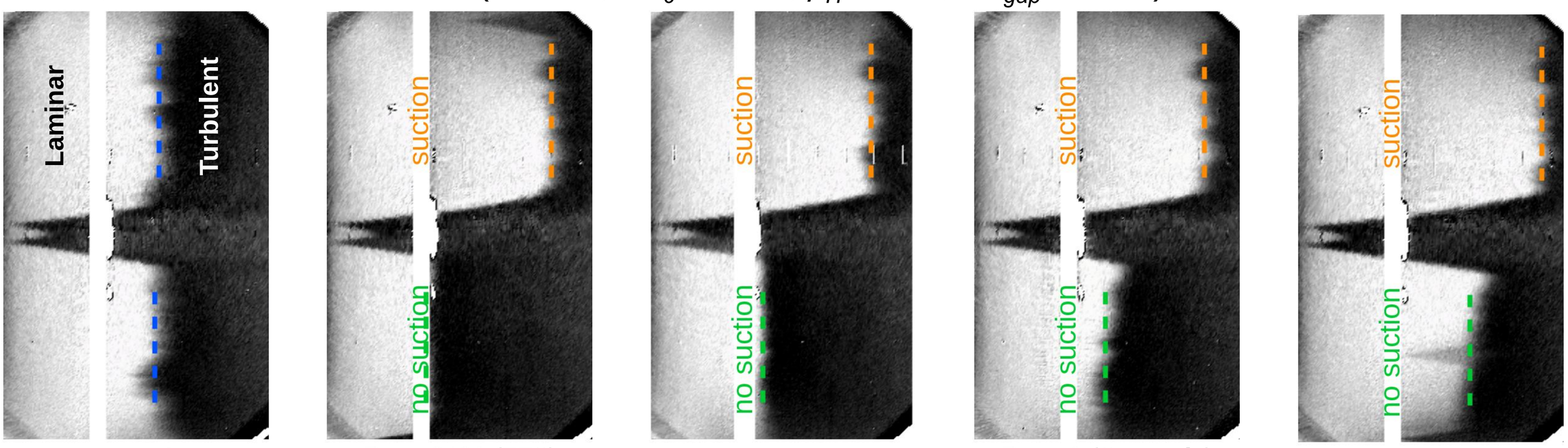


Simplified sketch of the wind-tunnel model. *Left:* cross-section *Right:* sectional view in the A-A plane.

- Chord length c = 200 mm
- Additional aft part to reduce disturbances
- Temperature-sensitive paint (TSP) for transition detection
- Passive suction through the gap driven by pressure difference between upper and lower side

TSP Results

($M = 0.6$, $Re_c = 8 \cdot 10^6$, $\beta_H = 0.04$, $Re_{gap} \sim 8000$)



smooth (no suction)

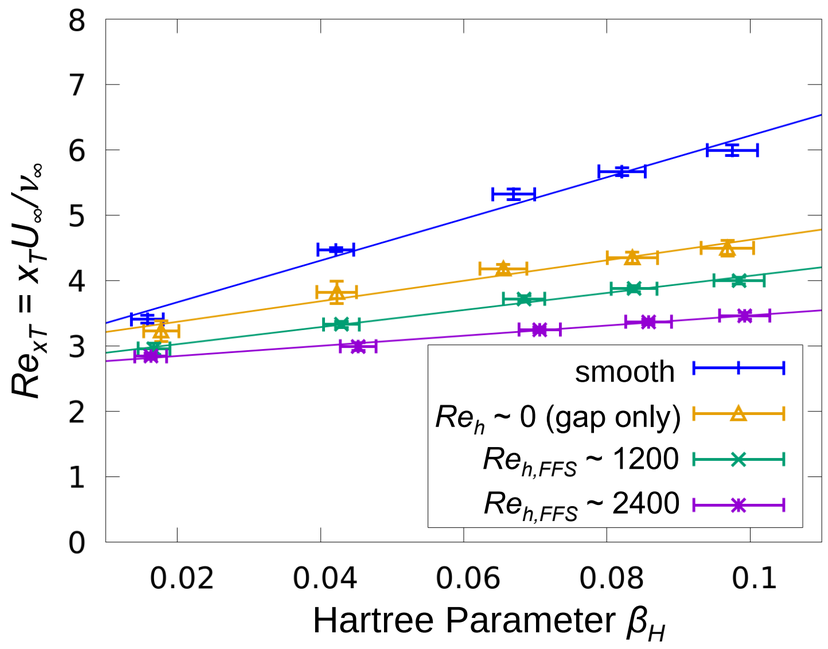
$Re_h \sim 2400$ (**FFS**) $q \sim 1.13$

$Re_h \sim 1200$ (**FFS**) $q \sim 1$

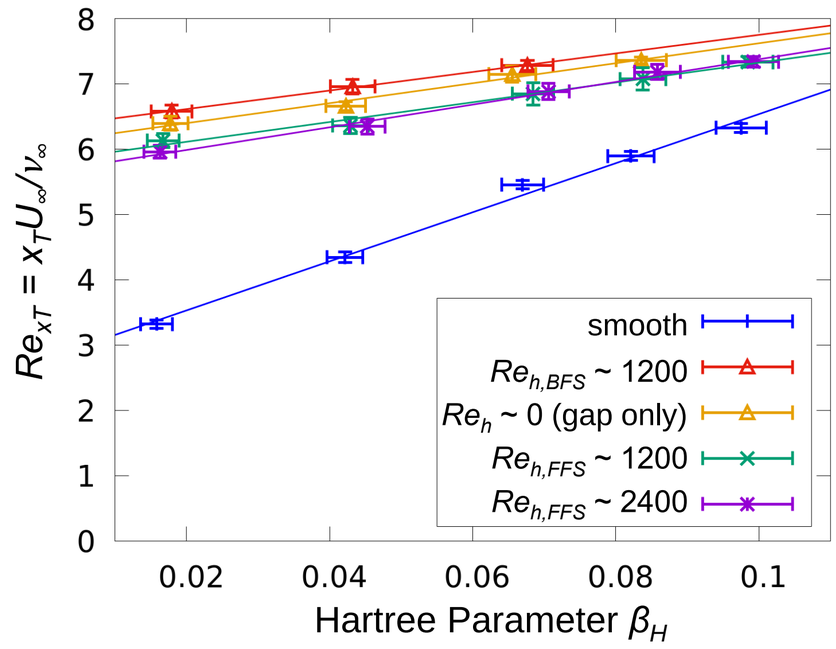
$Re_h \sim 0$ (**Gap only**) $q \sim 0.96$

$Re_h \sim 1200$ (**BFS**) $q \sim 0.62$
(*Transition with no suction influenced by internal gap flow*)

No suction



Suction



Suction rate $q = \frac{v \cdot d_{gap}}{\delta^* \cdot U_\infty}$ with average suction velocity v, gap width d_{gap}, displacement thickness δ^* and freestream velocity U_∞.

Transition Reynolds number with freestream viscosity ν_∞ as function of Hartree parameter for $Re_c = 8 \cdot 10^6$ and $M = 0.6$.

Conclusions

- Varying step heights (-30, 0, 30, 60 µm) in combination with a streamwise gap and a smooth configuration were examined for laminar-turbulent transition location by means of TSP.
- Suction significantly delays transition and even overcompensates the adverse effect of step and gap.
- For no-step and backward-facing step configurations, transition location was detected further downstream despite considerably lower suction rates.

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