

Modelling Surface Porosity and Transpiration for Disturbance Control with a Harmonic Navier Stokes Approach

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Acknowledgments: Airbus (AGI), Dr. Stephen Rolston



HLFC system on A320 fin

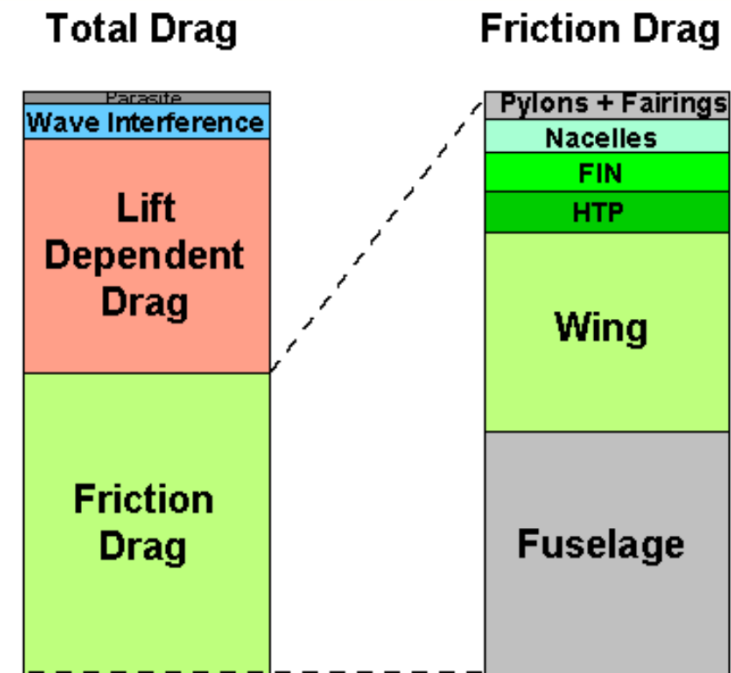
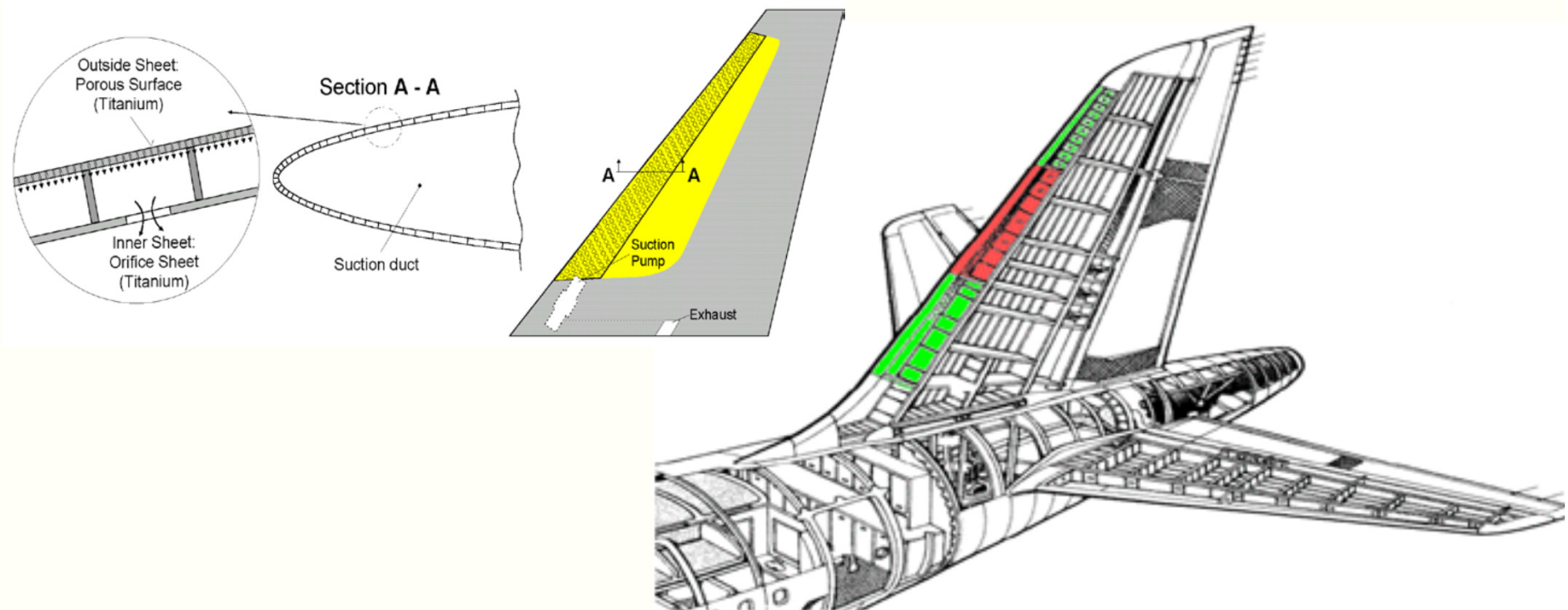


Fig. 1 Drag breakdown of a typical transport aircraft

Ref: The Need of Large-Scale HLFC Testing in Europe
Geza Schrauf

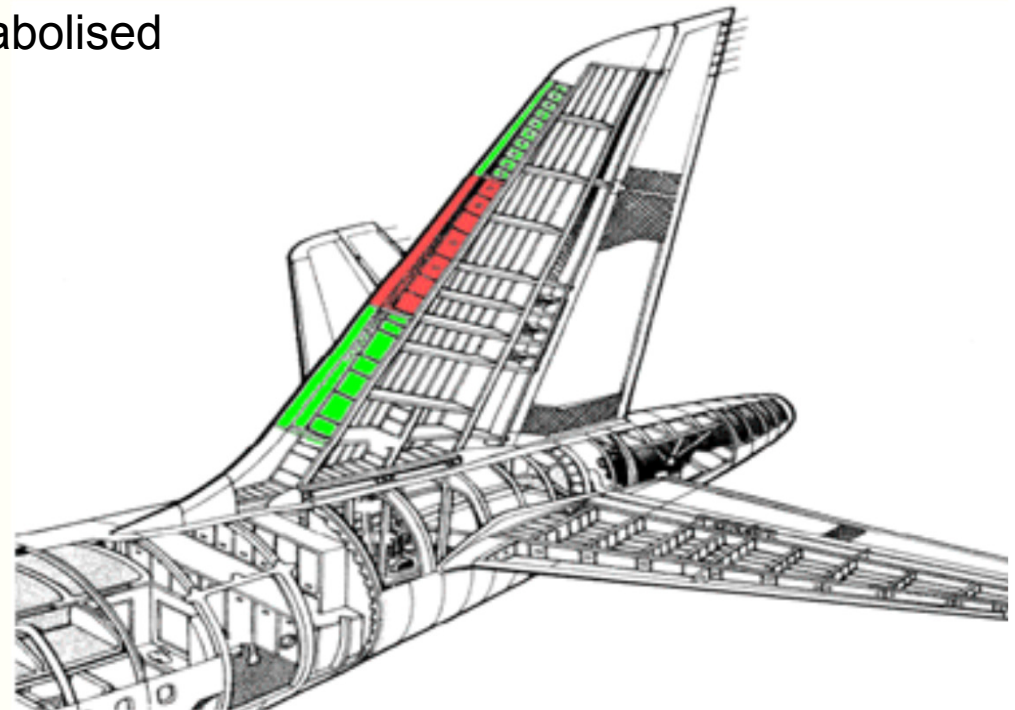
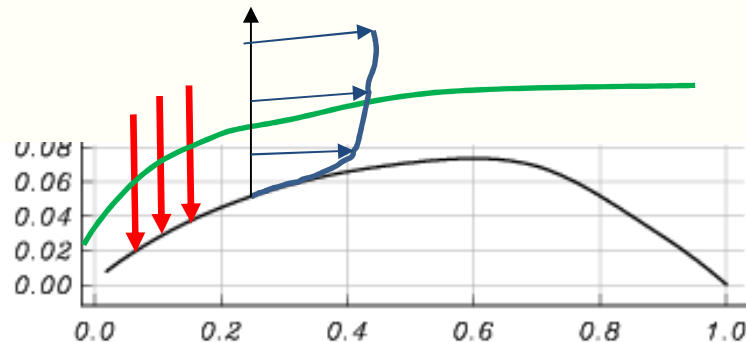


Sketch of the A320 tail with the middle leading edge box taken from Schrauf, G., Horstmann, K H.: Simplified hybrid laminar flow control. ECCOMAS 2004, Jyväskylä, Finland, 24-28 July 2004.

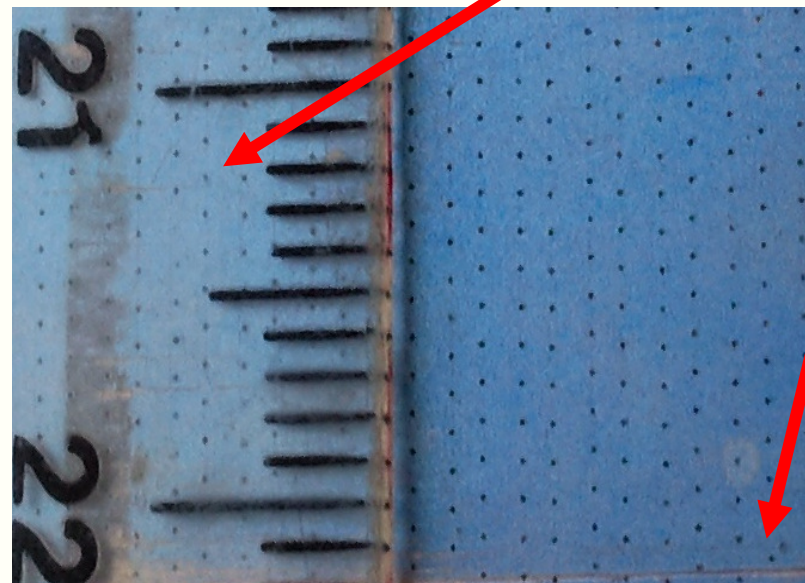
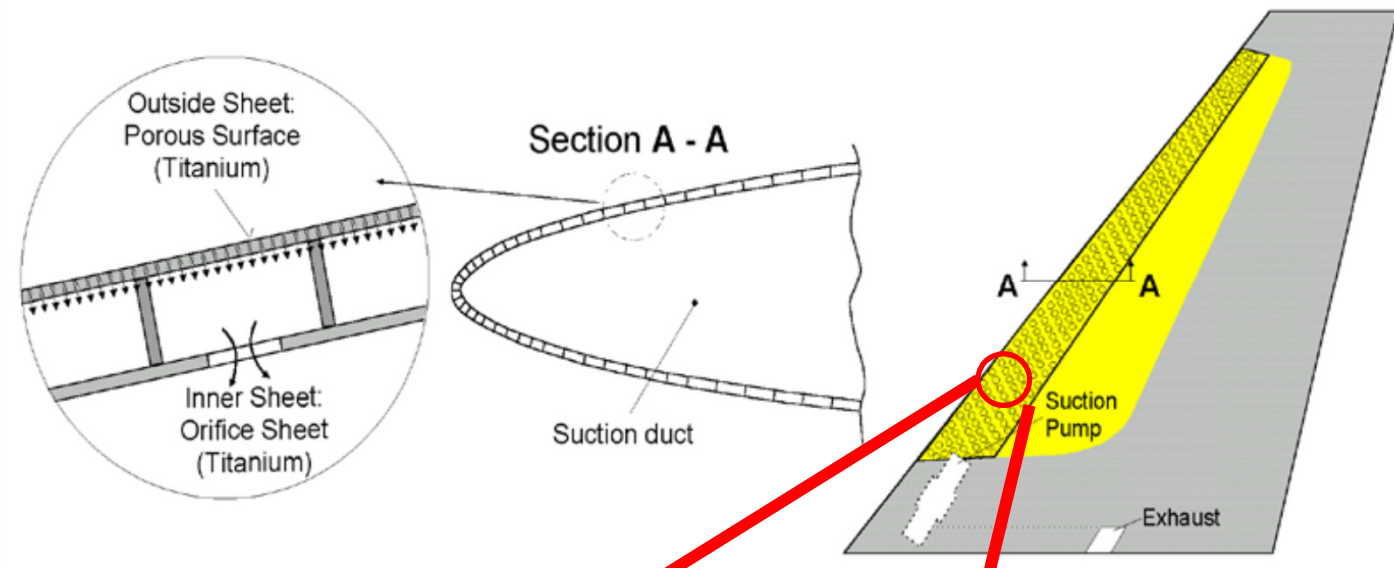
Existing Hybrid Laminar Flow Control (HLFC) Analysis is underpinned by:

1. Computation of Steady Boundary-Layer flow with a prescribed **Surface Transpiration $C_q(s)$** .
2. Instability Analysis : Either Local Linear Stability Theory (LST) or Linear Parabolised Stability Equations (LPSE) Theory.

2.5D Boundary-Layer Equations



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Laser drilled Titanium
skin

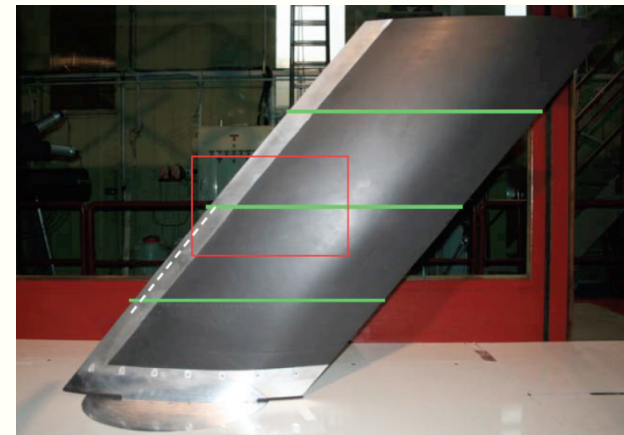
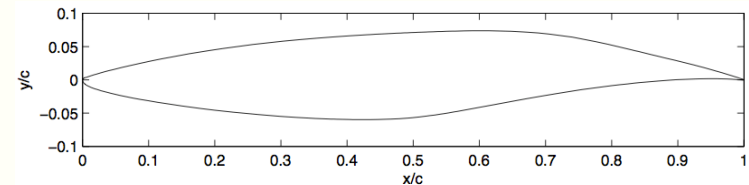
The “AERAST” Swept-Wing Model

- * $t/c = 12\%$
- * Sweep = 40° , chord = 0.8 m, span = 1.2 m
- * $\alpha_{\text{root}} = -2.15^\circ$; tip-down linear twist = 1.5°
- * Surface roughness ~ 0.5 microns; hand-polished leading edge ~ 0.06 microns

Simply used as a typical Swept Wing Data Test Case.

AERAST Model Airbus Manufactured for DRE control of CF vortices ~ 2009 :
AERAST Project 10029 DTI funded

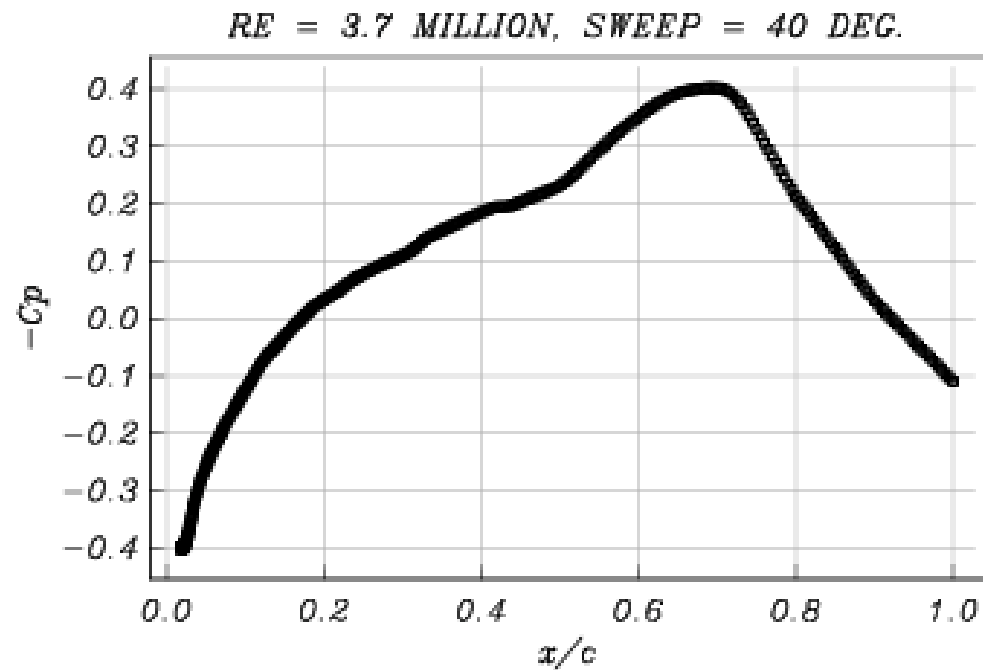
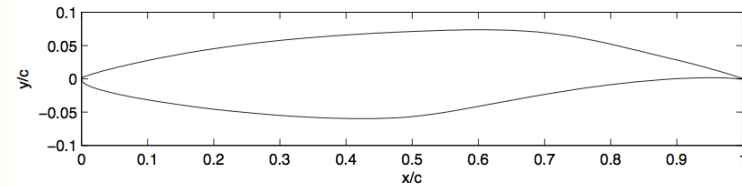
Airbus DiPaRT 2019



26-28 Nov. 2019

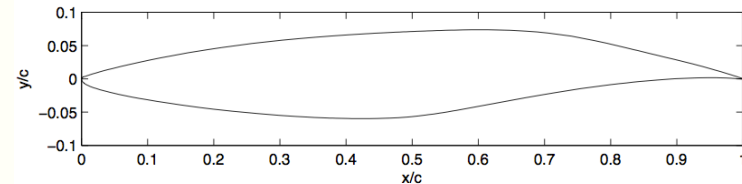
AERAST Surface Pressure Distribution

- * $Re_c = 3.7$ million at $\alpha_{root} = -2.5$ deg. Favorable pressure gradient to $x/c = 0.7$

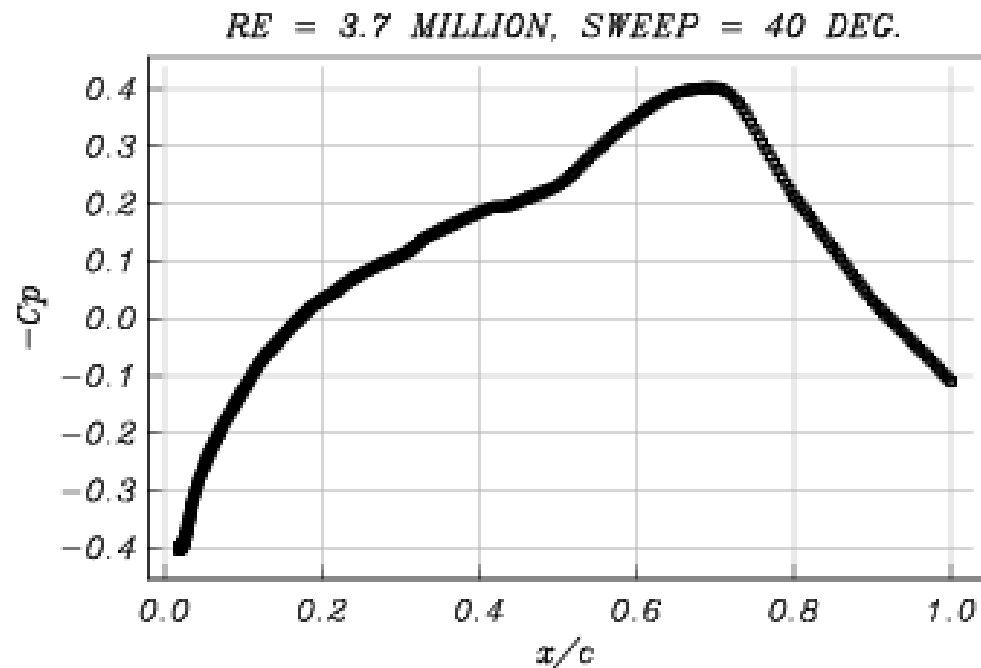
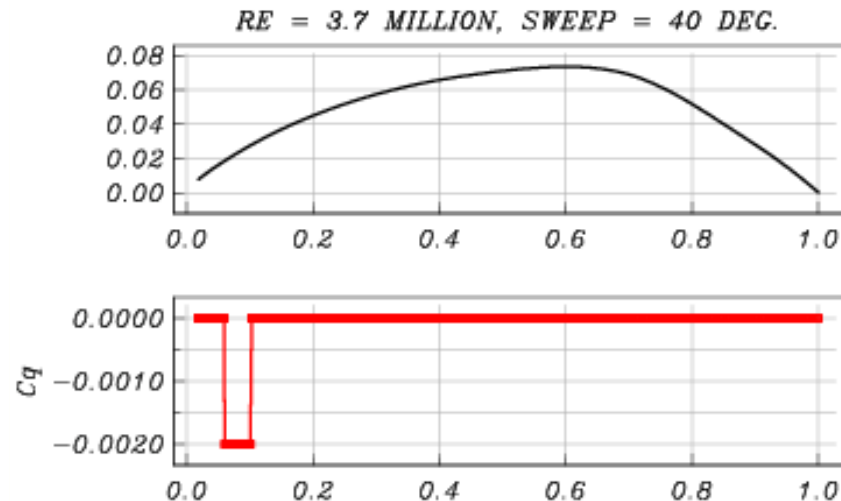


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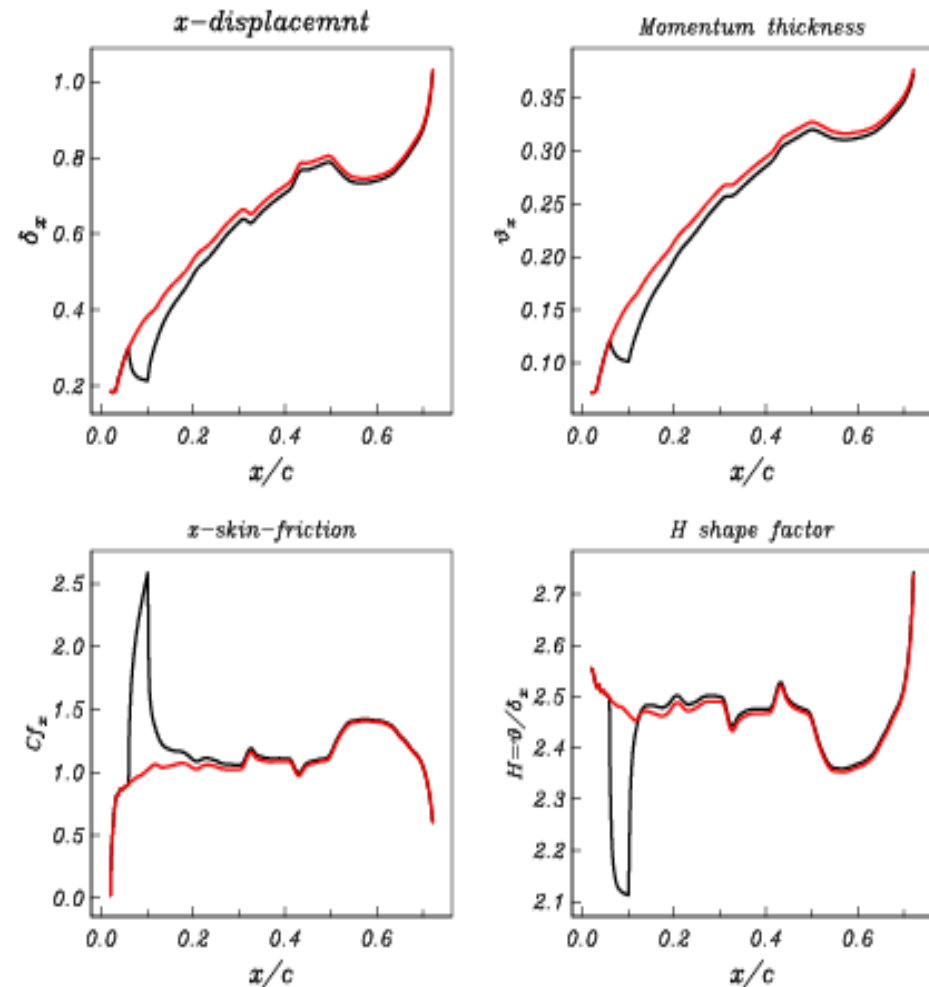
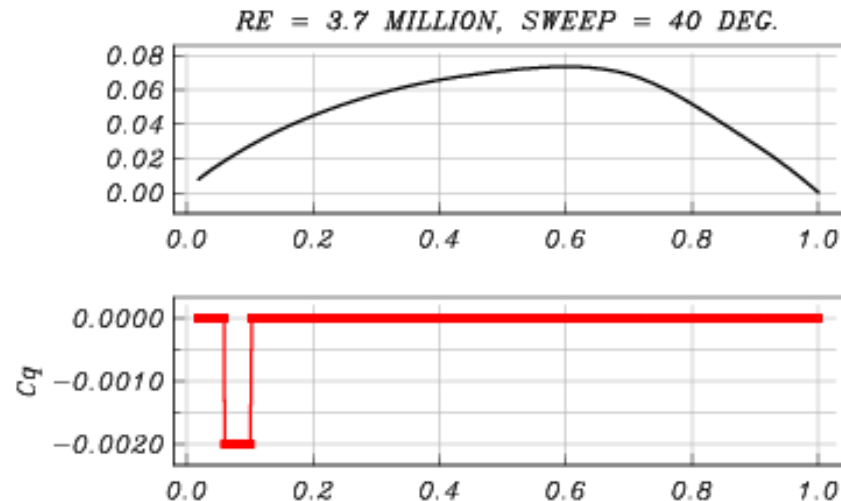
Upper Surface shown, with extent of surface Transpiration, C_q



Steady solutions: (skin friction, Shape factor, momentum thickness etc.)

Comparison of boundary-layer integral quantities from computations **with** and **without** surface transpiration.

- 1) **RED** : No surface suction
- 2) **BLACK** : With surface suction.



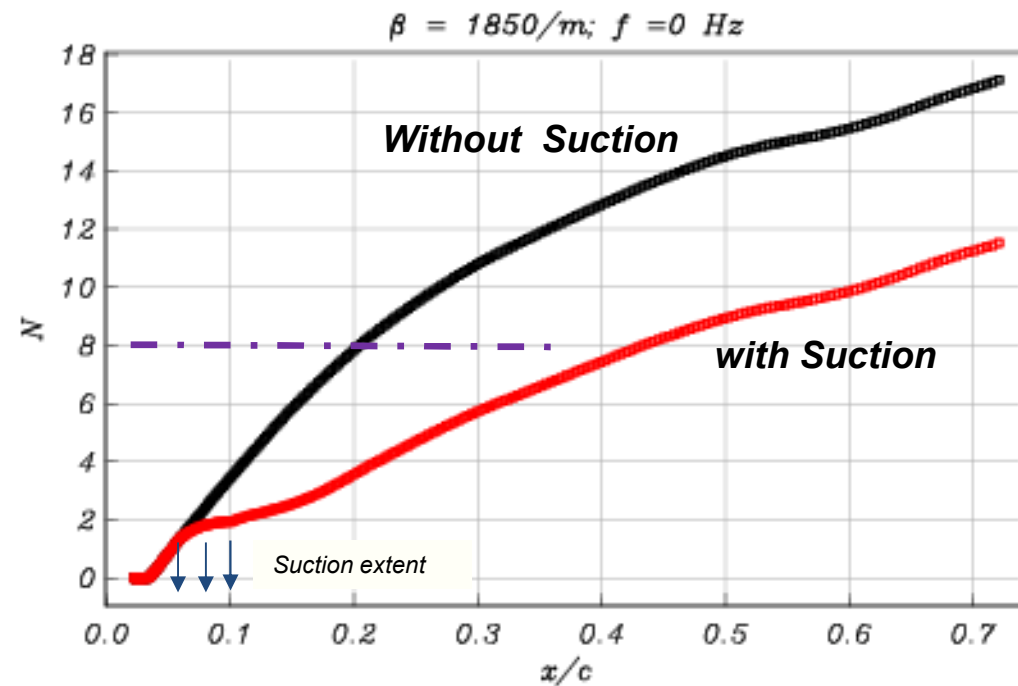
Instability Results: N-Factors

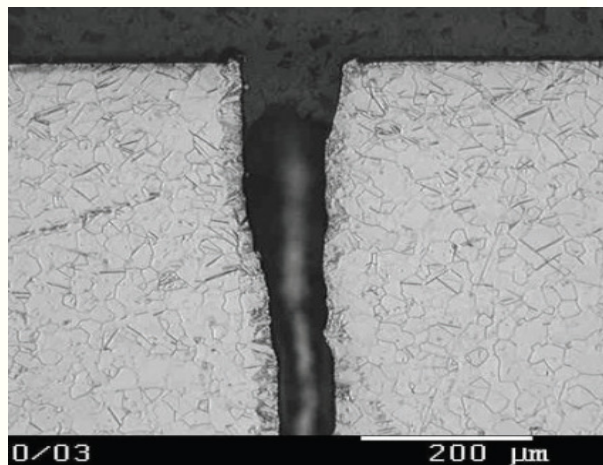
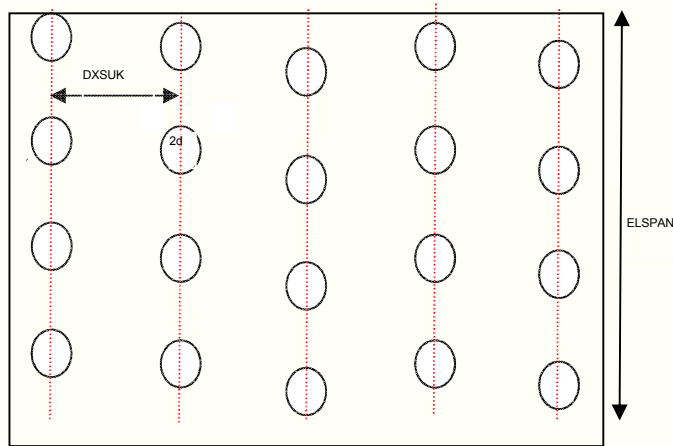
LPSE, Dominant Crossflow, Zero
frequency Stationary
Disturbance.

Beta=1850/m wavenumber or
CF wavelength ~ 3.4 mm

UNIFORM SUCTION
 $0.06 < x/C < 0.1$

$C_q = V_{\text{surf}} / Q = 0.002$





Titanium skin, laser drilled surface, Transverse cut through suction panel (Schrauf).

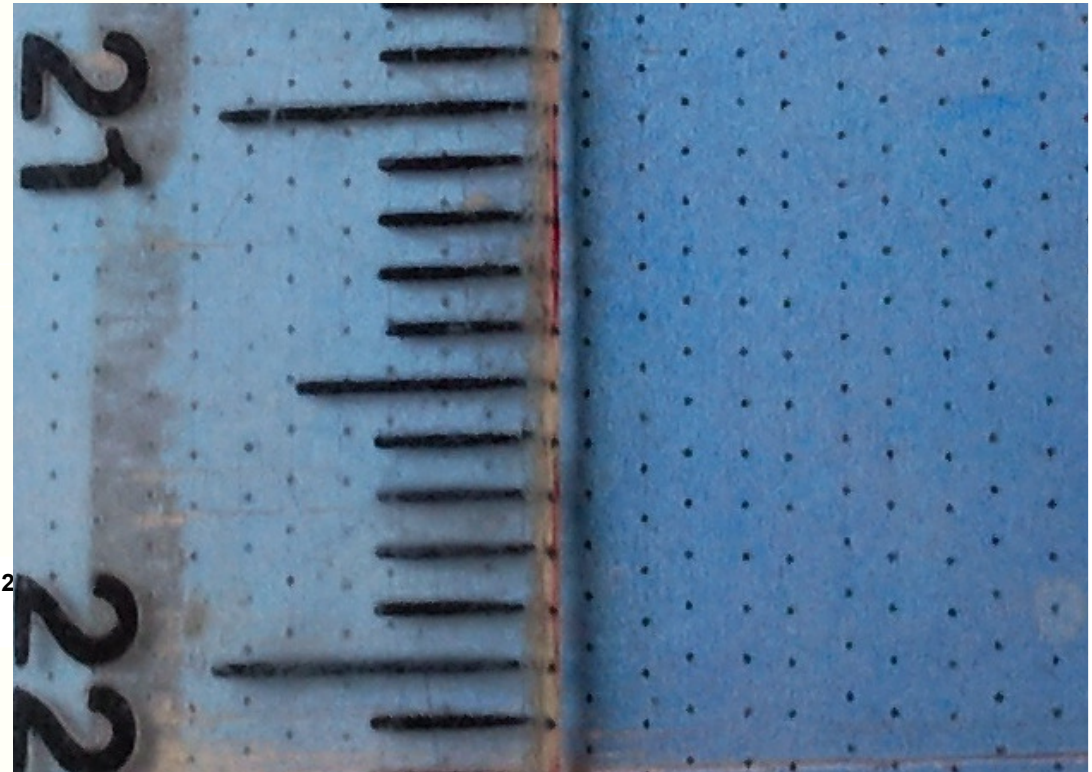
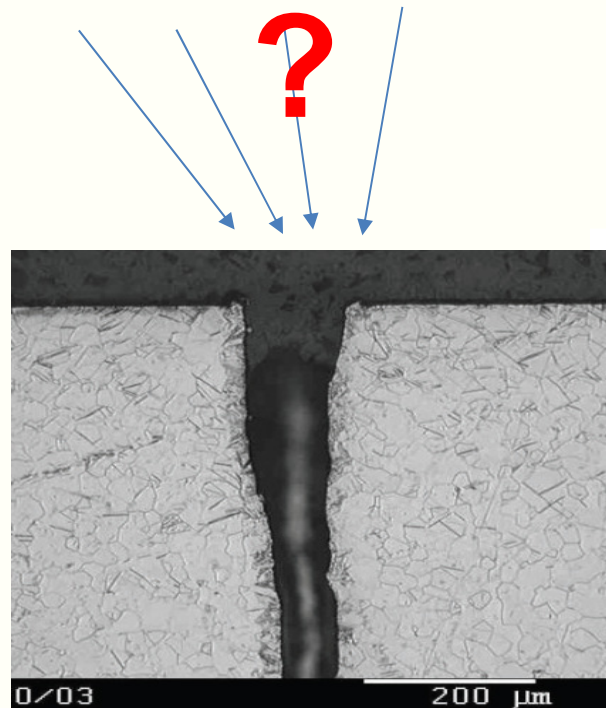


Figure 2

~ 1 hole/mm
~ 0.1mm diameter



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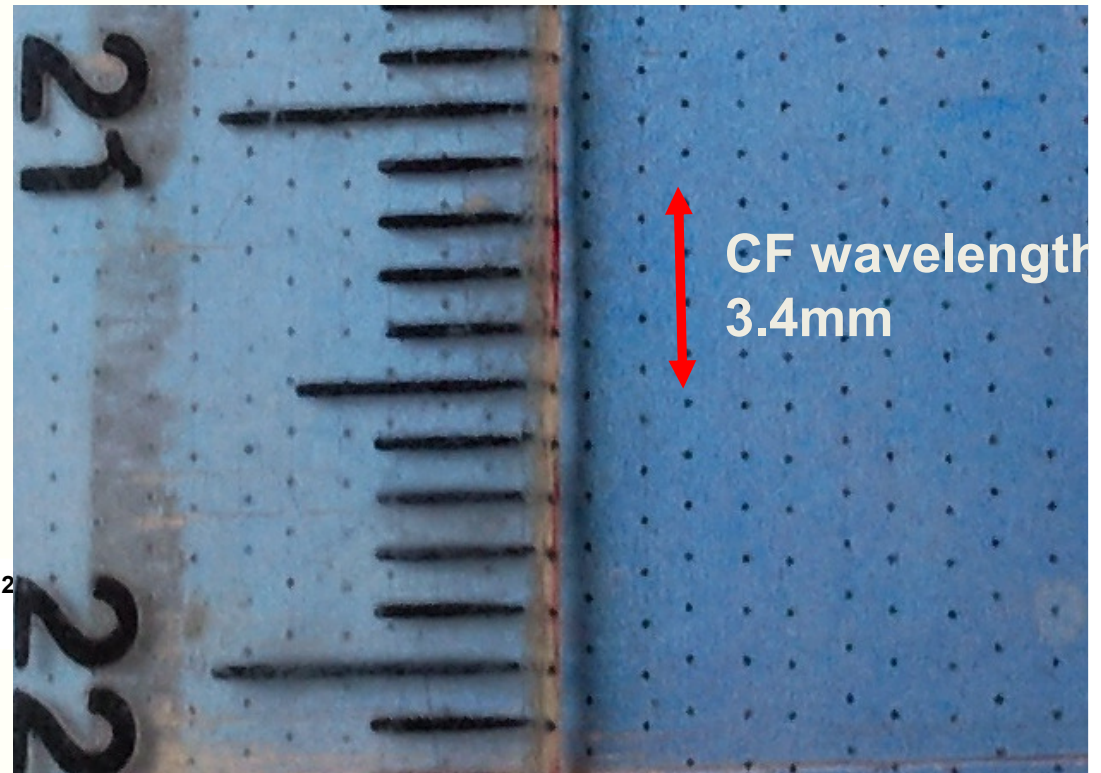


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MATH/PHYSICS MODEL : Unsteady Navier-Stokes Eqns.

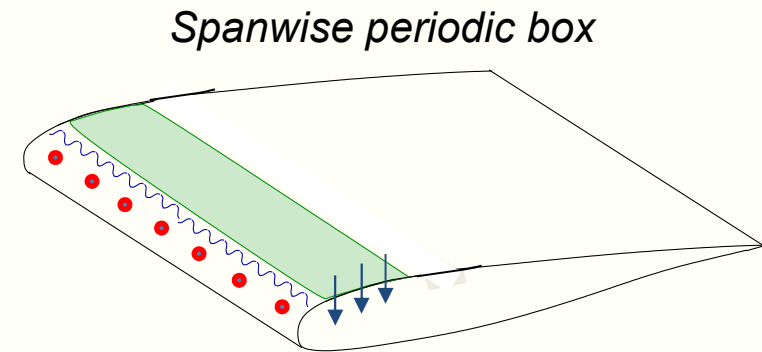
Ansatz: $q(x, y, z, t) = \underbrace{Q(x, y)}_{\text{Steady B-L solve}} + \sum_{m=-M}^{+M} \sum_{n=-N}^{+N} q_{(n,p)}(x, y) e^{i(m\beta z - n\omega t)}$ Consider stationary Crossflow, i.e. $\omega = 0$.

Numerical Discretisation: Pseudo-Spectral and 4th-order Finite differencing.
Truncate $\mathbf{m=1}$, follows:

Two coupled nonlinear sets of equations:

$$[L]^{(0,n)} q^{(0,n)} = \sum_{m=-1}^1 u_j^{(m)} \frac{\partial u^{(0,n-m)}}{\partial x_j}, \quad n = 0, 1$$

Solve by Direct Matrix/Iteration of RHS, nonlinear forced terms.



DREs (Distributed Cylindrical Roughness Elements) generate an initial Cf disturbance.
DRE wavelength = 3.4 mm,

Suction boundary conditions:

$$v^{(0,0)}(x, 0) + v^{(0,1)}(x, 0) e^{i\beta z} = Cq(x, z)$$

MFD + (0,1) CF ← FFT

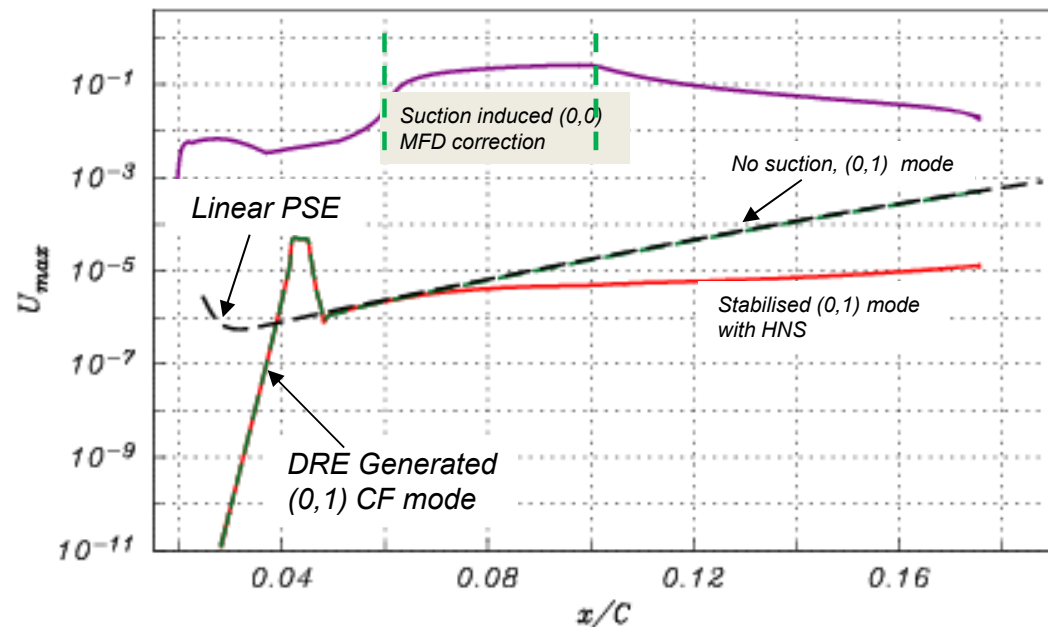
DRE boundary conditions:

$$q^{(0,n)}(x, 0) = -\bar{H}(x, z) \left. \frac{\partial Q}{\partial y} \right|_0 ;$$

$q = (u, v, w) - \text{disturbances}$

Uniform Suction in NL-HNS,
replicates B-L solution
computed by steady B-L
solver (CoBLc)

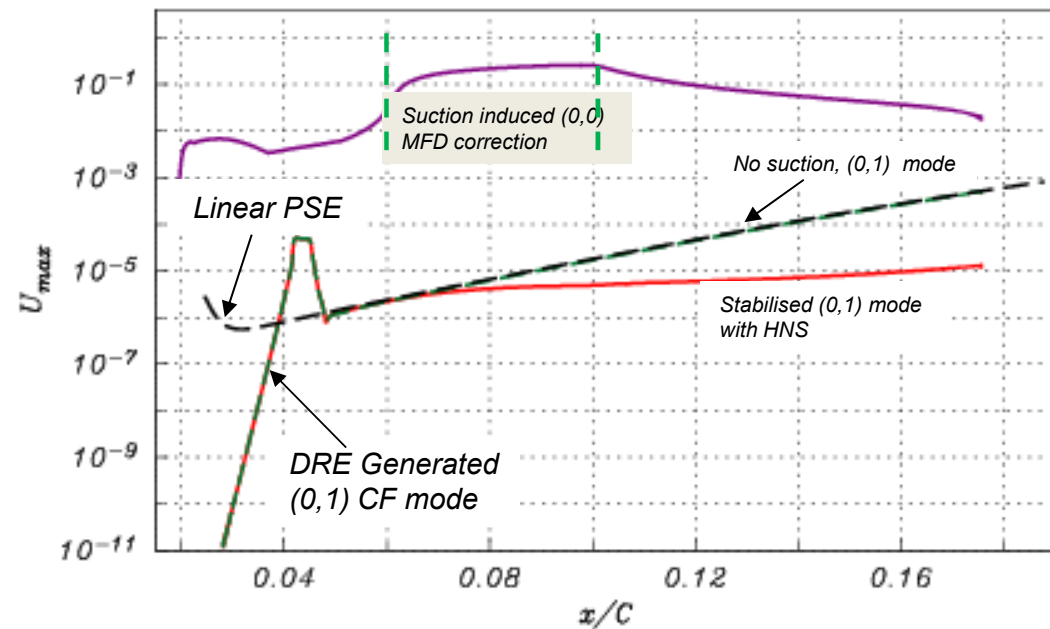
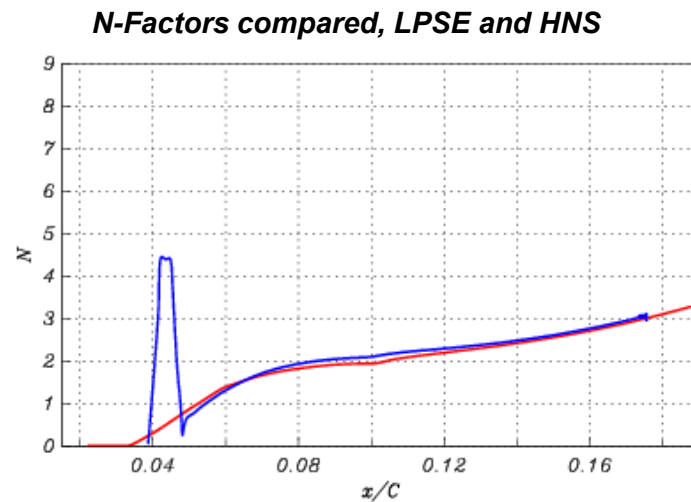
UNIFORM SUCTION
 $0.06 < x/C < 0.1$



1. **Suction in BL-Sover** – followed by Linear HNS to generate CF mode, with DRE.
2. **No suction in BL-SOLVER.** All done with **NL-HNS**. Surface suction BC in (0,0) Mean-flow Distortion, DRE too.

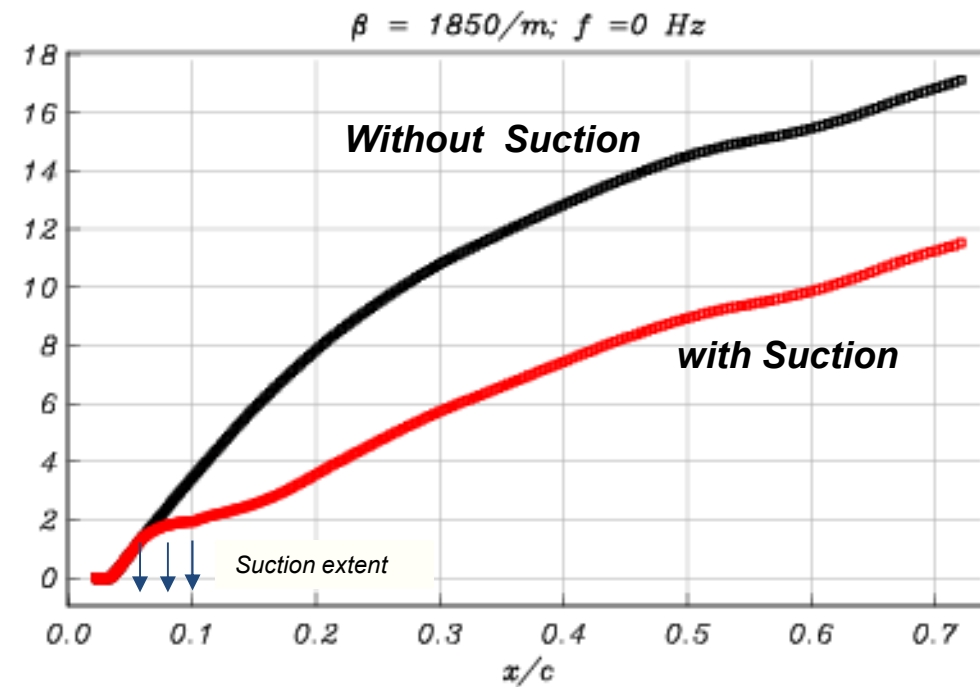
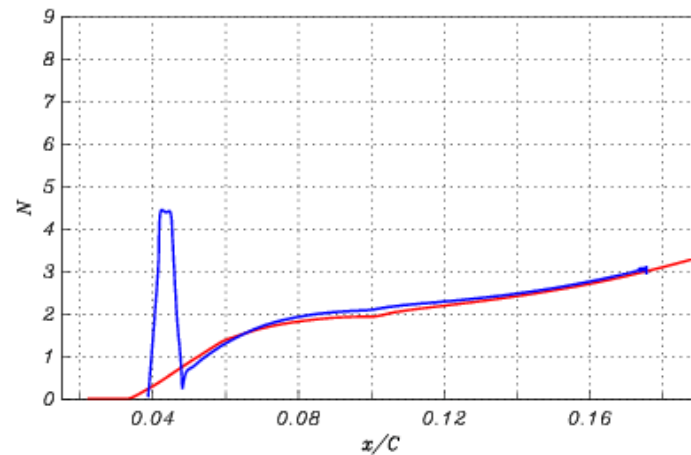
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UNIFORM SUCTION
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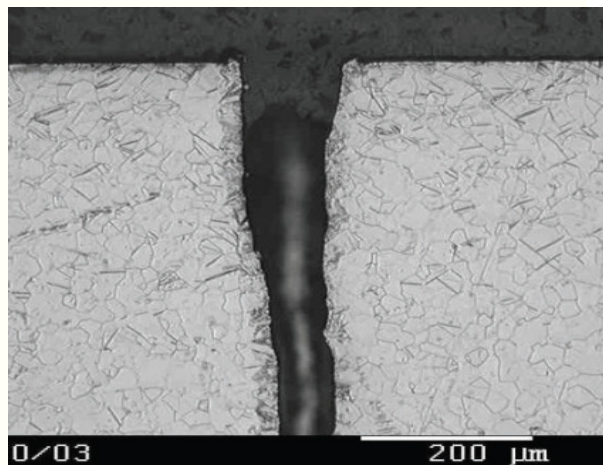
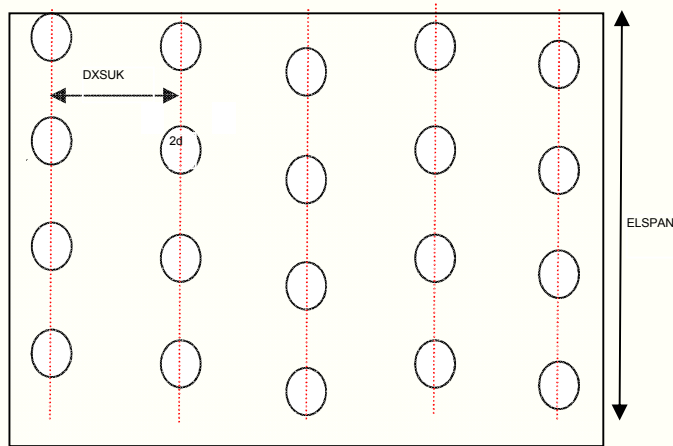


**LPSE, Dominant Crossflow, zero
frequency Stationary
Disturbance.**

Beta=1850/m wavenumber or
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Distributed Porosity



Titanium skin, laser drilled surface, Transverse cut through suction panel (Schrauf).

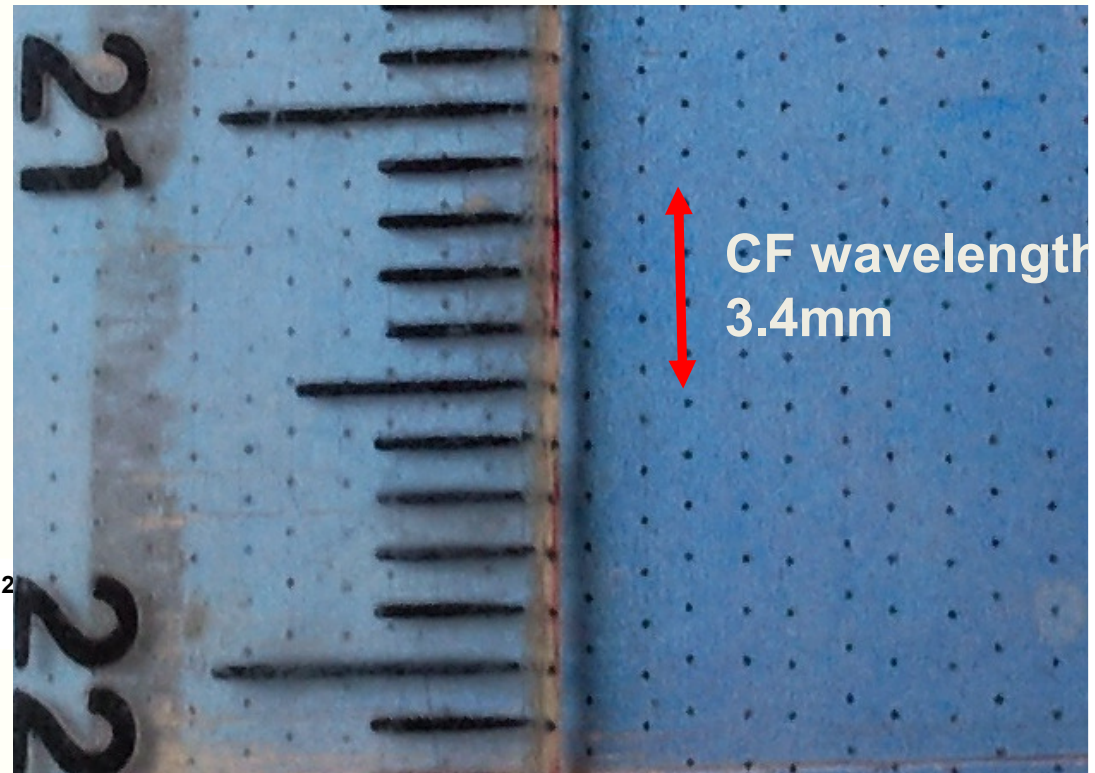
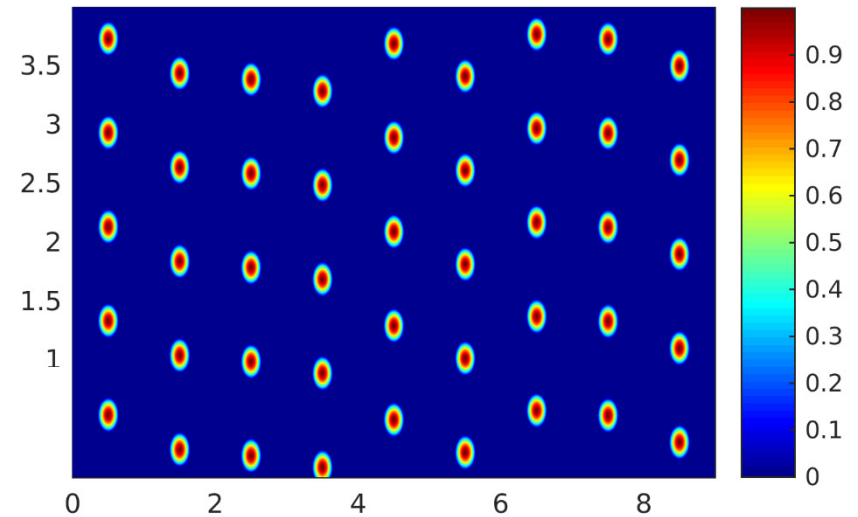
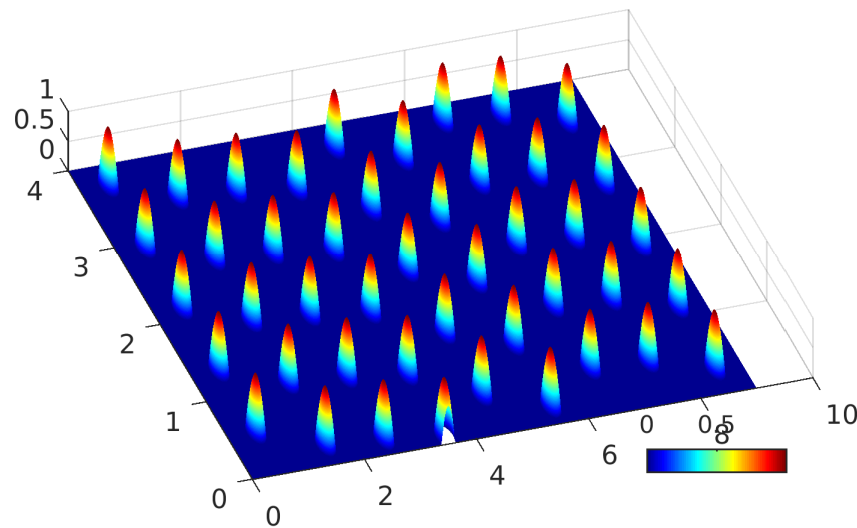


Figure 2

~ 1 hole/mm
~ 0.1mm diameter

Distributed Porosity (DP) : I

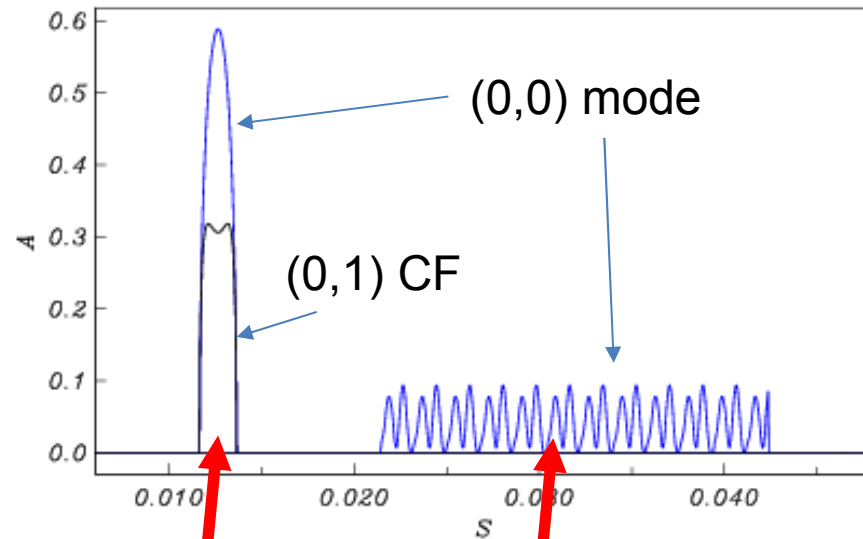


~ 1 hole/mm
~ 0.3mm diameter

**Cosine shaped radial form of
Vsurf.**

Distributed Porosity (DP) : I

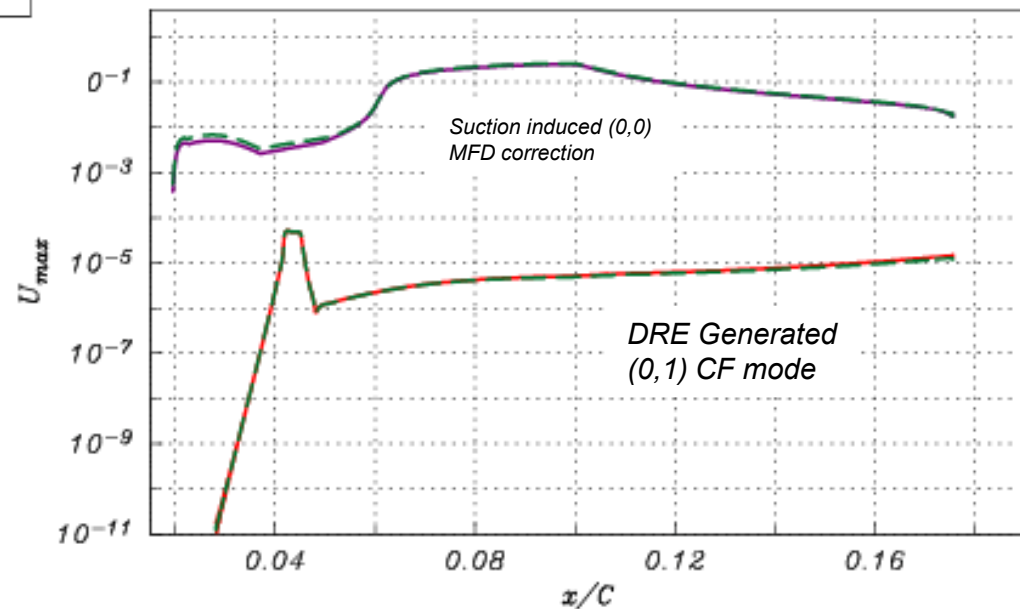
FFT of wall forcing



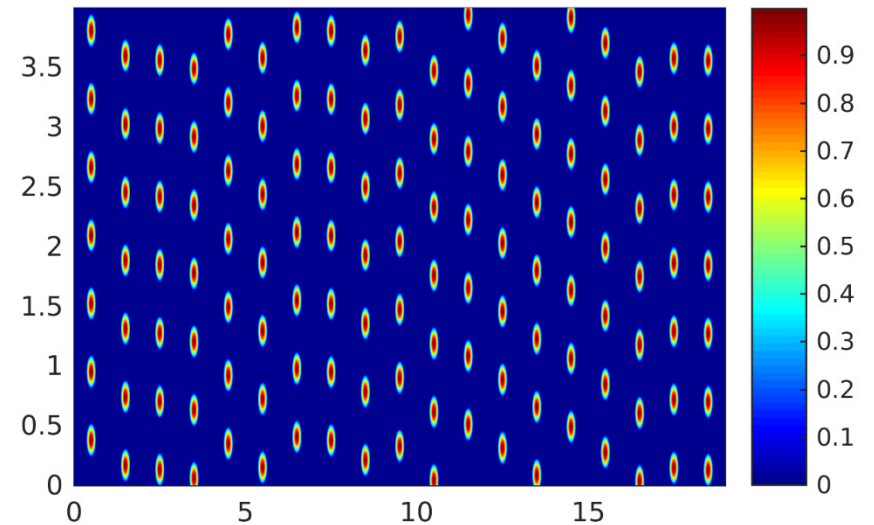
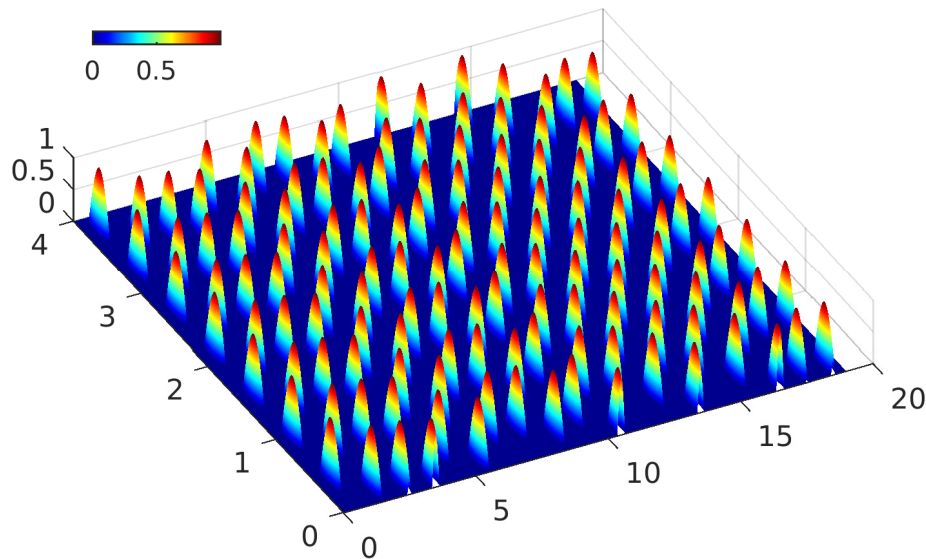
DRE

Due to suction

Uniform suction & DP compared
Both with NL-HNS



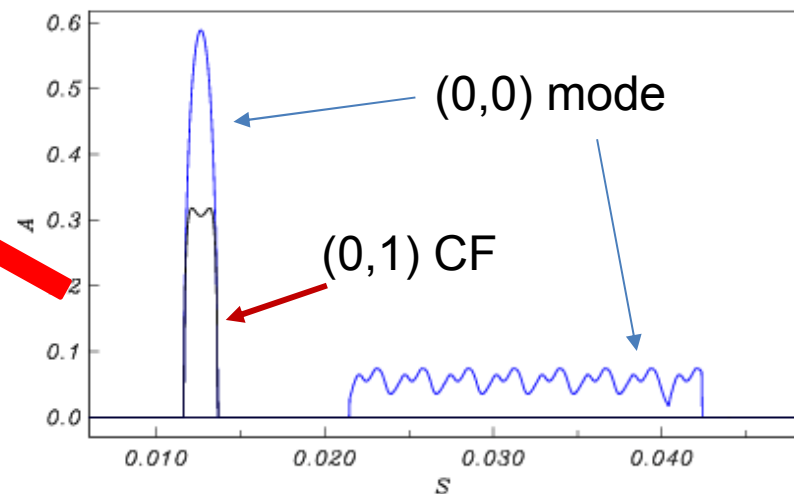
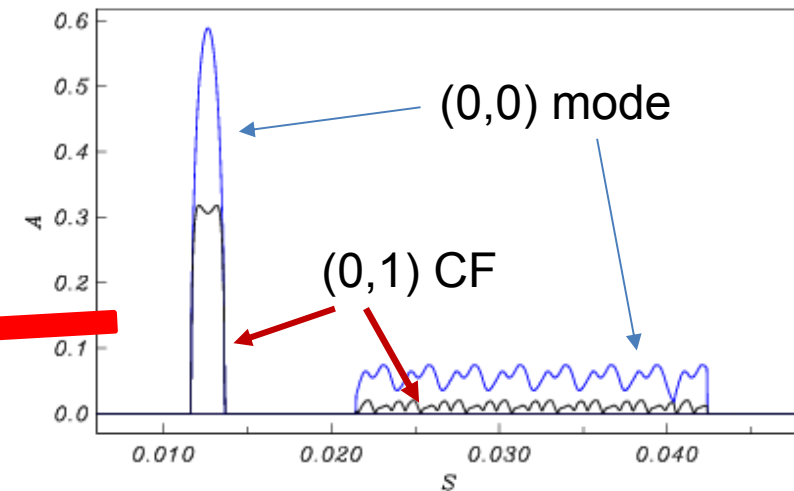
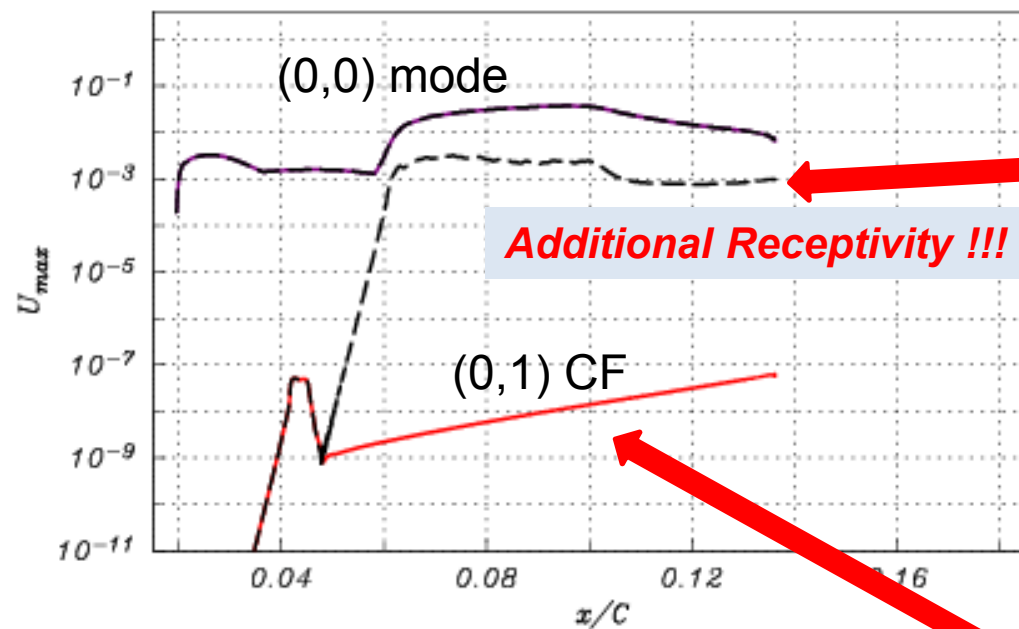
Distributed Porosity (DP) : 2



~ 2 holes/mm
~ 0.3mm diameter

**Cosine shaped radial form of
Vsurf.**

Distributed Porosity (DP) : 2



Conclusions

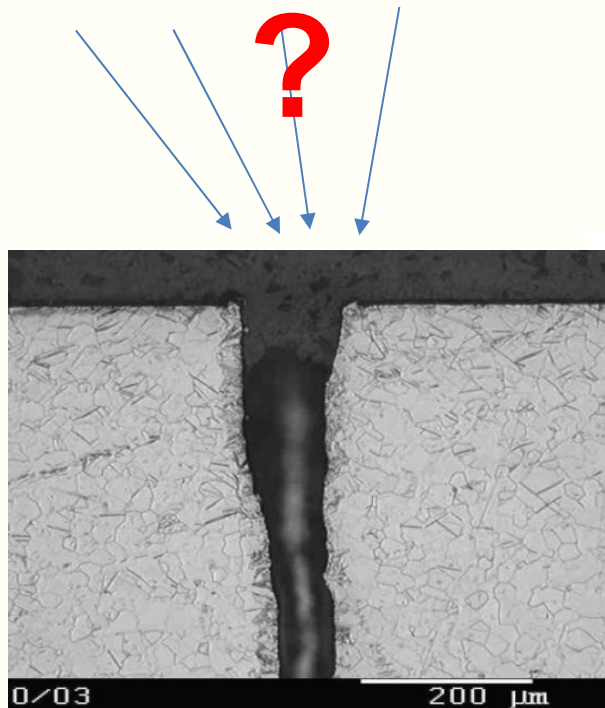
Nonlinear HNS allows a number of issues to do with HLFC to be investigated, ranging from:

1. Approach replicates the conventional method of BL-solution followed by LPSE say. Hence vindication of correctness of model.
2. Porous surface acting as an effective distributed rough surface
3. A site for further destabilisation of instabilities – if porous surface is not optimal? Hole distribution, Diameter, Porosity perspective.
4. Receptivity issues arising from porous surfaces.

Methods development and Enhancement of Harmonic Navier-Stokes (HNS)solver to explore:

- Uncertainty quantification analysis, to account for variability in suction panel, porosity and blockage. Hole porosity, analysis of dependency on engineering-manufacturing imperfections. Hole diameter variation, distribution for optimal layout.
- Determination of optimal suction distribution for total sucked volume constraint. Other constraints investigated, suction extent or varying chamber dimensions.
- Slotted suction and/or coupled to distributed suction investigations/optimisation studies.
- Receptivity due to ‘effective surface roughness’ effects (positive and negative displacements), caused by porous surface.
- Most Appropriate Boundary condition and transpiration form to be used at the “suction hole(s)”

Difficult Modelling problem



Titanium skin, laser drilled surface, Transverse cut through suction panel (Schrauf).

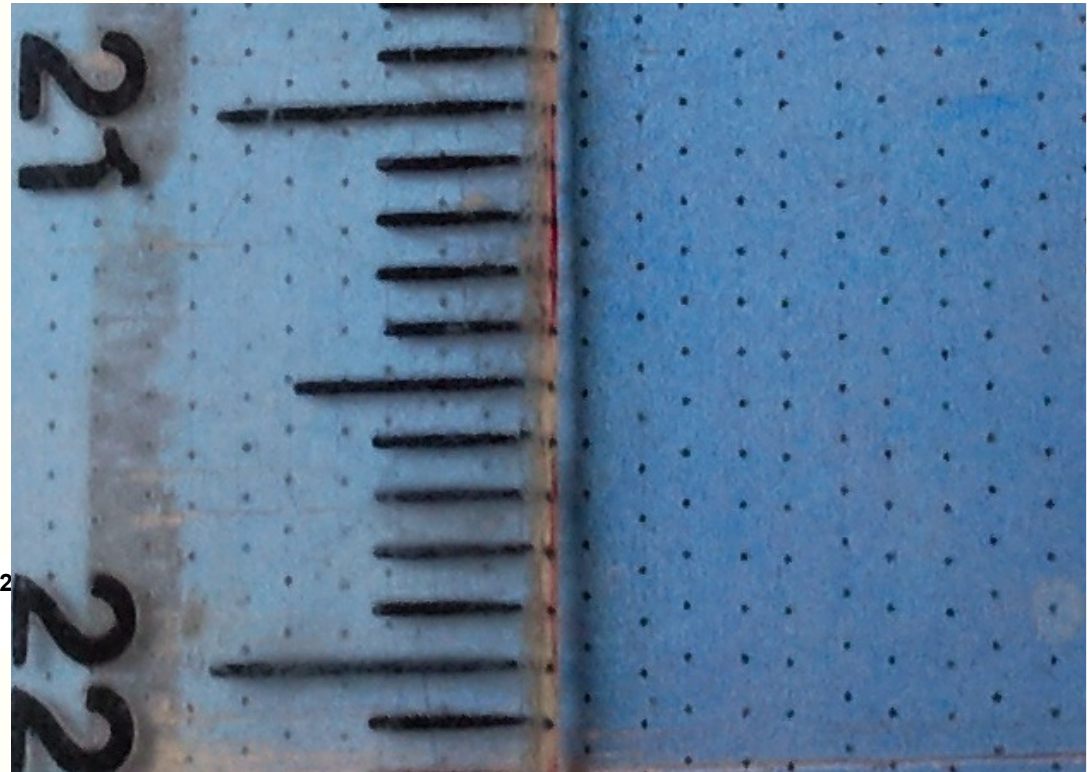


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