Steady aerodynamics flow analysis for determining the necessary build space of an isolated jet shear layer

Christian Jente

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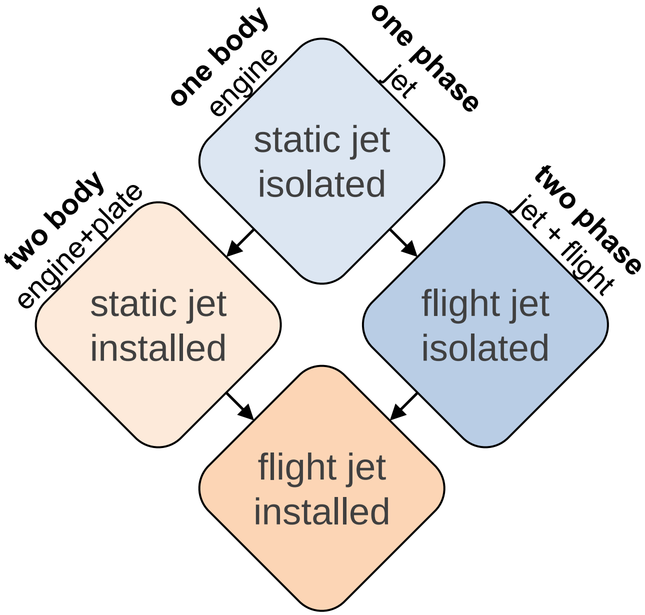
Jet-flap interaction physics are characterized by multi-body, multi-flow, multi-source acoustics



Jet near field – simple geometry, complex parameter set

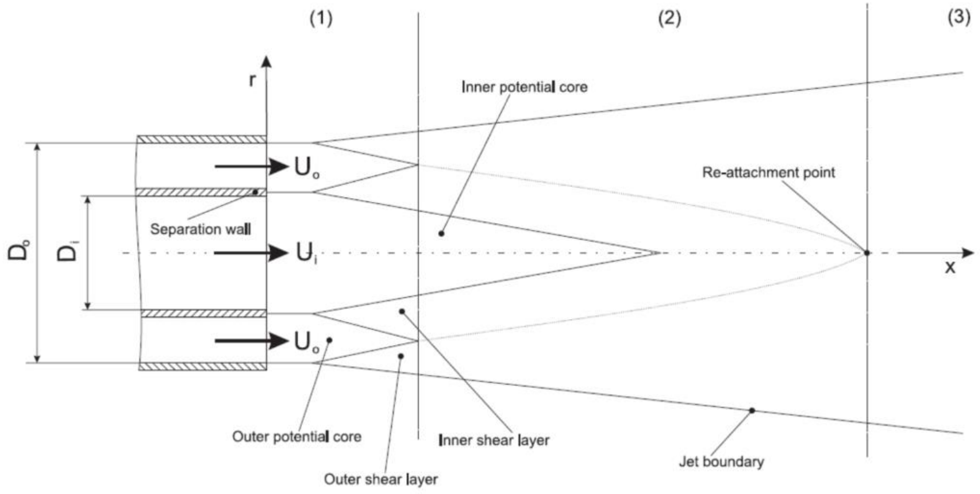


FIGURE 2.7. Sketch of the coaxial jets flow field.

Despite the simplicity of the flow field, the parameters able to affect the flow are numerous. Amongst the most important there are:

- the diameter ratio $\beta = D_o/D_i$;
- the velocity ratio $r_u = U_o/U_i$;
- the inner velocity U_i;
- the inner diameter D_i;
- the shape of the separating wall and its thickness t at the trailing edge;
- the state of the boundary layers and their thicknesses;
- the freestream conditions.

Antonio Segalini: "Experimental analysis of coaxial jets: instability, flow and mixing characterization", p.21-22, doctoral thesis, Università di Bologna, 2010

+ protrusion bypass/core
+ conical flow angle
+ Temperatures
+ …

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Approximation the near-field with thin mixed layer theory

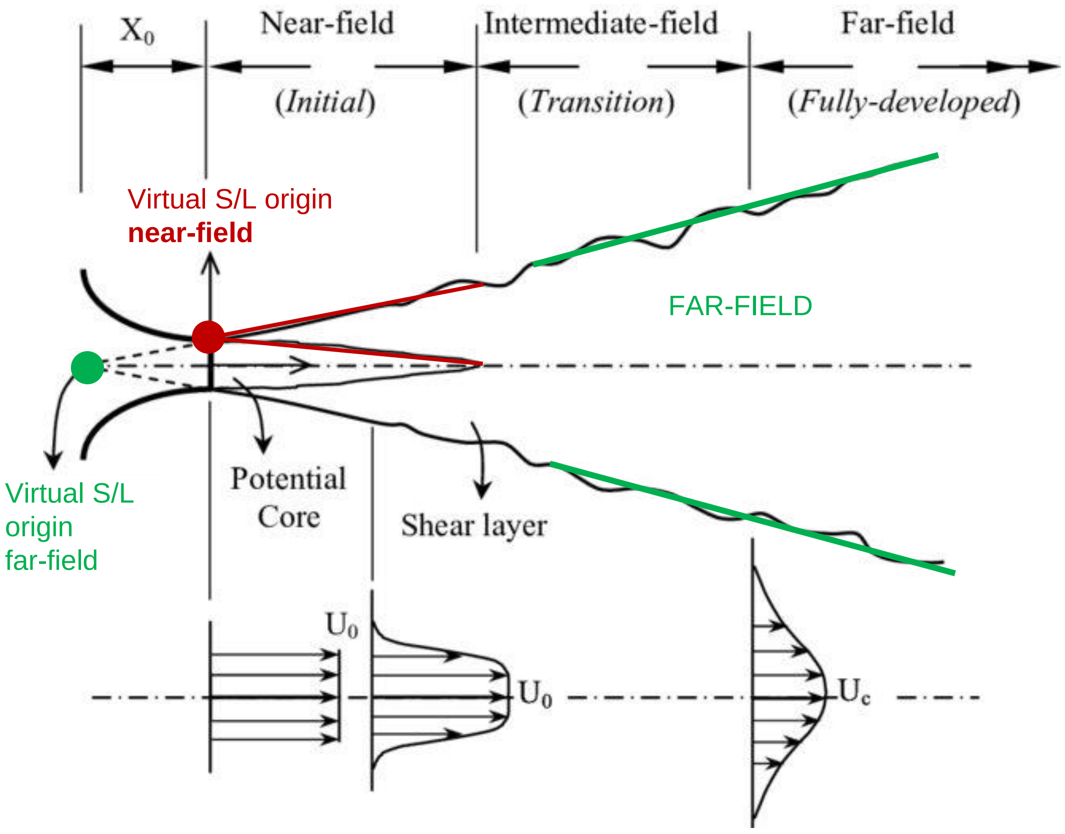
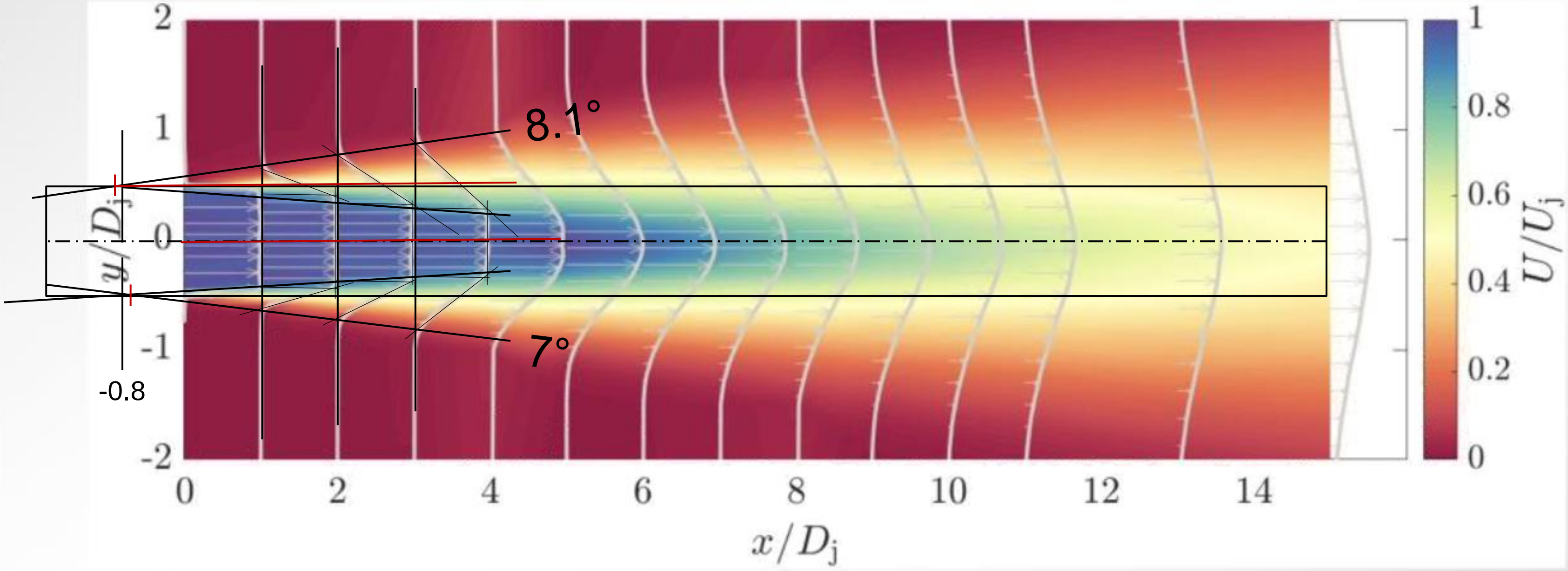


Image: "A Review of Effects of Initial and Boundary Conditions on Turbulent Jets" Abdel-Rahman 2010

R40 – Plume Mean Flow Data

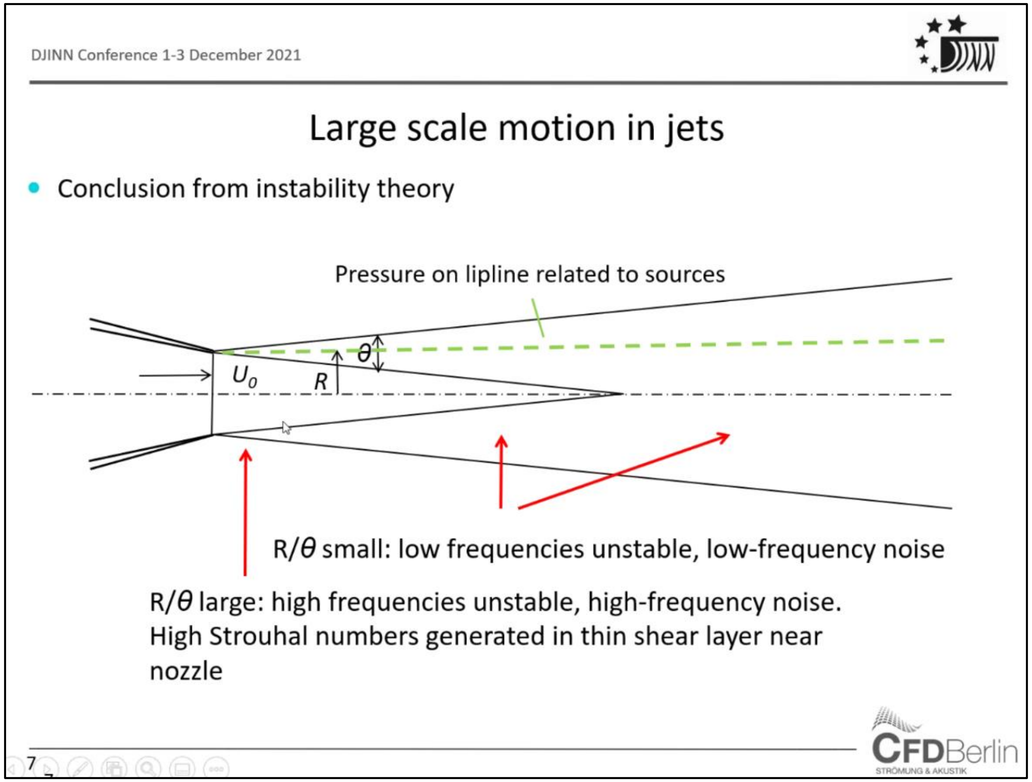
Mj=0.6, Mf=0 Velocity $r_U = U_f/U_j = 0$



$x_{0,NF} = -0.8 * D_j$

Half-jet opening angle = 7.5° (mean)
Jet data deflected by ~0.5° (cause: alignment margin for exp. equipment or: real deflection)

Half jet velocity or „Lipline“ velocity?



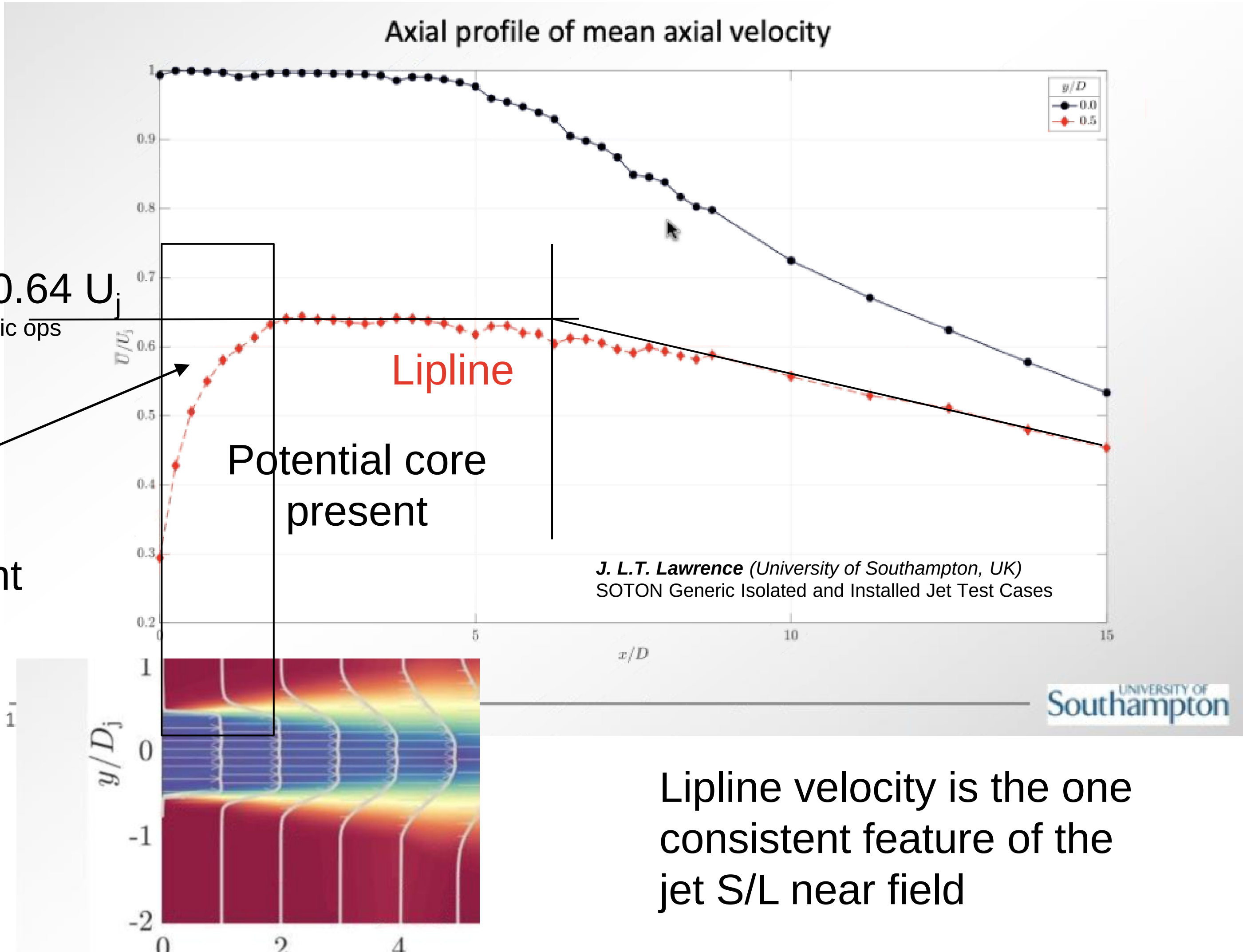
"Lipline is important - it describes the acoustic sources more than anything else."

Ulf Michel, 01.12.2021

U. Michel, M. Schwalbach, F. Thiele, H. Xia , Ch. Ellis *(CFD-Berlin, Germany, Loughborough University, UK)*
Evaluation of a low dissipation and low dispersion finite volume scheme for turbulent jet noise prediction

Half jet velocity or „Lipline“ velocity?

$U_{S/L} = 0.64\ U_j$
Cold jet, static ops



Nothing to worry:
Small area
Large velocity gradient

Lipline velocity is the one consistent feature of the jet S/L near field

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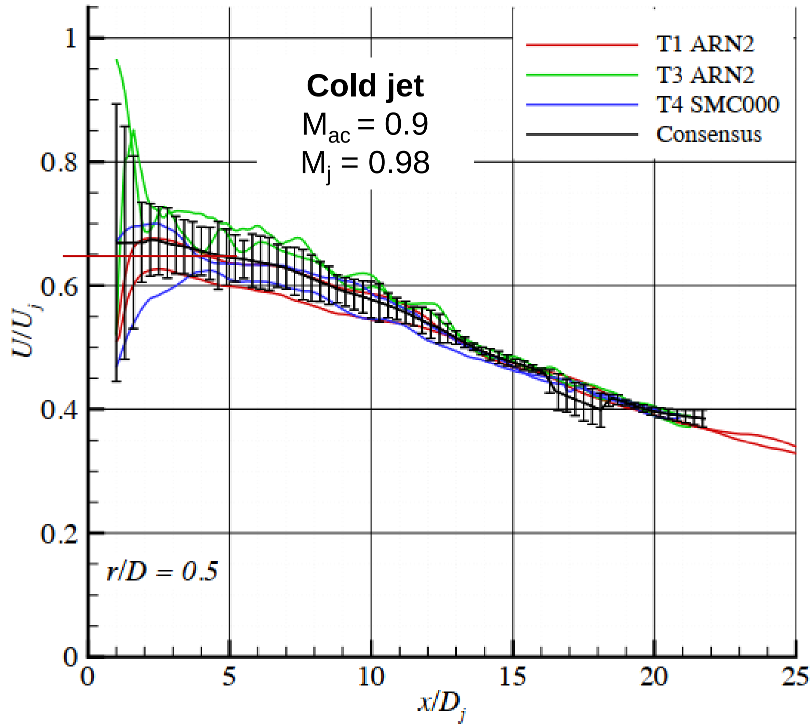
Why not to worry:

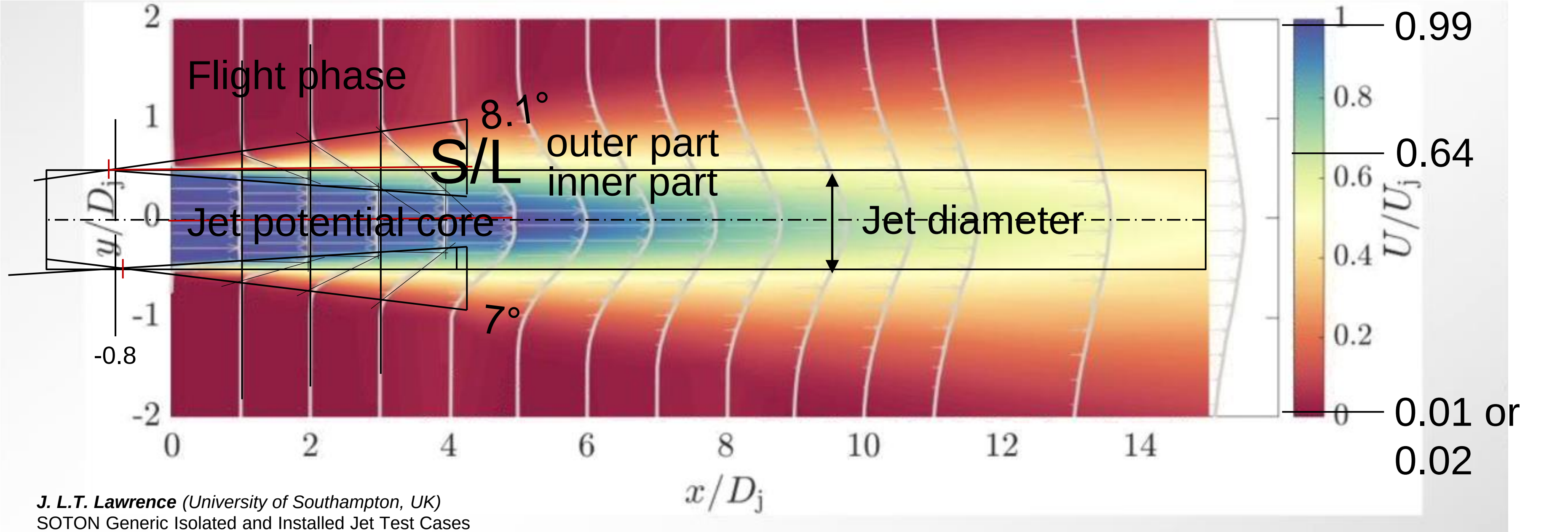


James Bridges and Mark P. Wernet: Establishing Consensus Turbulence Statistics for Hot Subsonic Jets
Figure 19 Setpoint 7: Axial mean on the lipline.

- The lipline velocity of a single stream nozzle is approx. constant in the near-field of the jet

Discretized velocity plot in order to identify jet properties with velocity criteria

- 4 color / 3 line plot which shows the essiential field information:



J. L.T. Lawrence *(University of Southampton, UK)*
SOTON Generic Isolated and Installed Jet Test Cases

A model for the estimation of jet near field S/L properties

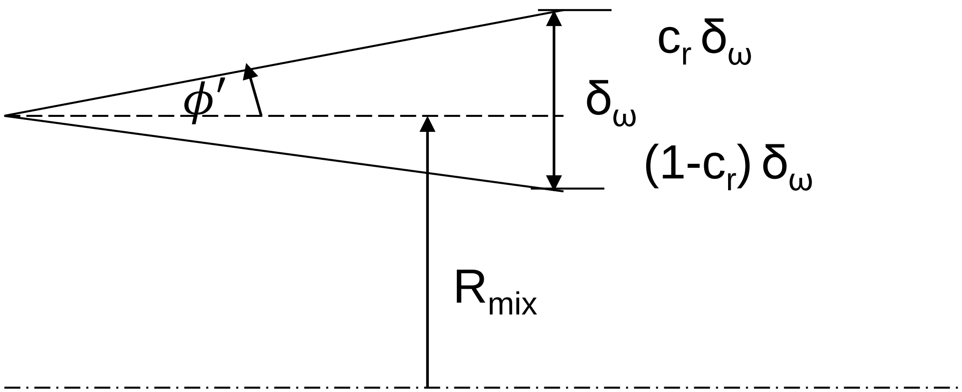
Classical thin mixing layer theory

$$\frac{\delta_\omega}{(L-x_0)} = K \frac{(1-r_U)}{(1+r_U)}$$

+ Calibration for round jet

$$K = \frac{\sqrt{\pi}}{\sigma_0} = \frac{\tan(\phi_0')}{c_r(0)} = \frac{\tan(7.5°)}{0.64} = 0.206$$

Distribution around jet radius



c_r - ratio of outer part of S/L to S/L width δ_ω

c_U – critical S/L „lipline“ velocity/ sum of jet+flight speed

Here you can find the c-functions:

CORRECTION: Velocity Scaling of Shear Layer Noise induced by cold Jet flow with co-flowing Flight stream

Author(s) Name: Christian Jente*, Jan W. Delfs†

Author(s) Affiliations: German Aerospace Center (DLR), Lilienthalplatz 7, D-38108 Braunschweig, Germany

use 0.63 or 0.64 for Jack's data

1. CORRECTION OF TRAPEZOID APPROXIMATION (page 7, equation 16) This formula describes an approximative non-dimensional positioning of the shear layer centroid and not the convection parameter. This formula needs to be renamed as $r_{id}(r_U)$ instead of $c_{id}(r_U)$:

c_r

$$r_{id}(r_U) := \frac{R_c}{\delta_\omega} = \cancel{\frac{2}{3}} \cdot \frac{1-r_U}{1+r_U} + \frac{r_U}{1+r_U}$$

The correct convection velocity parameter $c_{id}(r_U)$ which matches the approximation is then calculated as

c_U

$$c_{id}(r_U) := \frac{U_c}{\Sigma U} = r_{id} + (1 - 2 \cdot r_{id}) \cdot \frac{r_U}{1+r_U}$$

C. Jente / J. Delfs: "Velocity Scaling of Shear Layer Noise induced by cold Jet flow with co-flowing Flight stream", AIAA 2019-2496, doi10.2514/6.2019-2496

+ Click on crossmark link (!)

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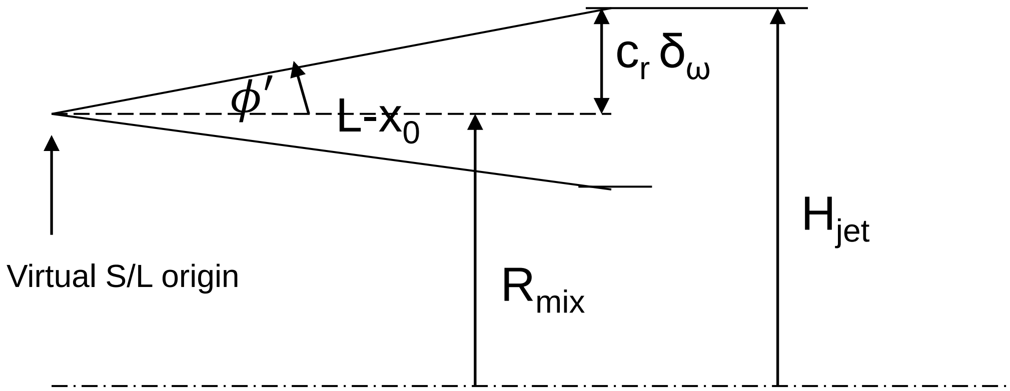
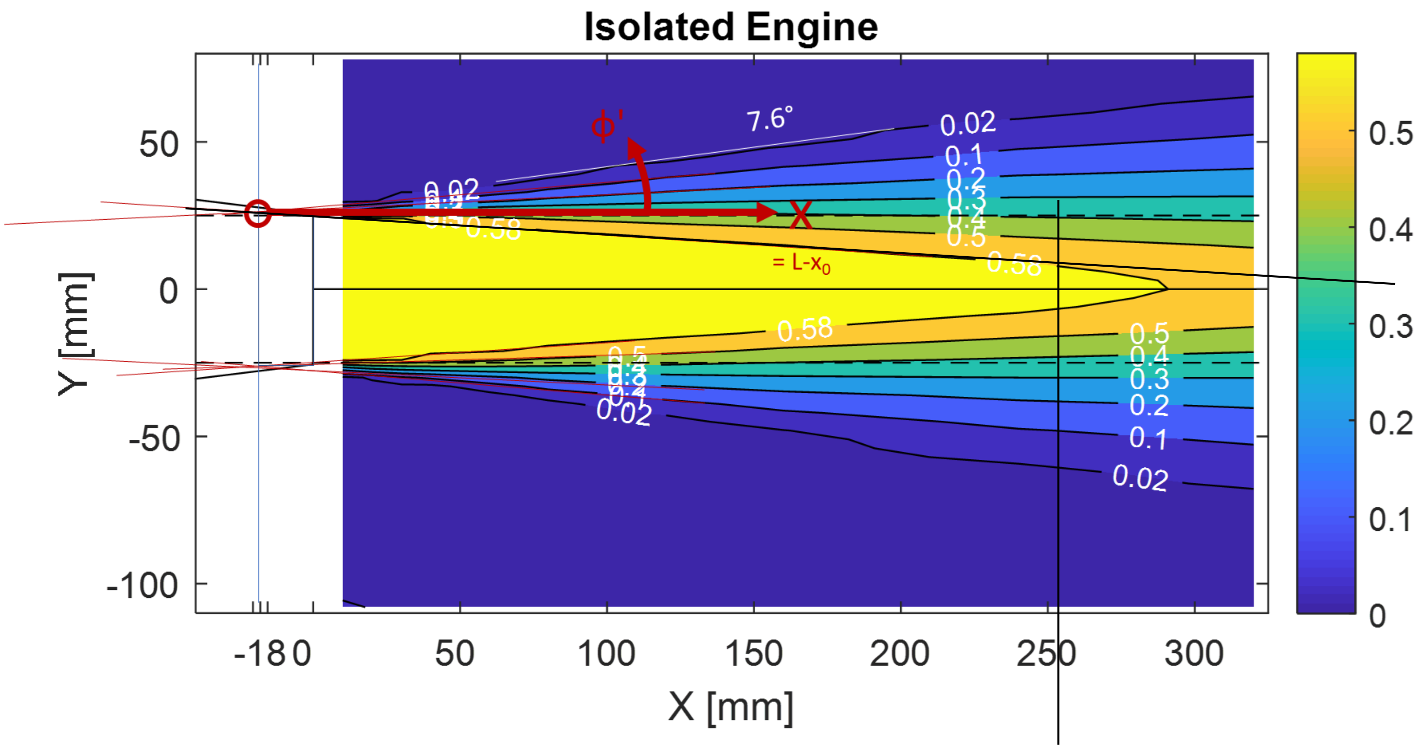
Determination of the half-jet opening angle (for various operations)

- Half jet opening angle



$$\tan(\phi'_{jet}) = \frac{H_{jet} - R_{mix}}{L - x_0} = c_r \underbrace{\frac{\delta_\omega}{L - x_0}}_{K \frac{1 - r_U}{1 + r_U}}$$

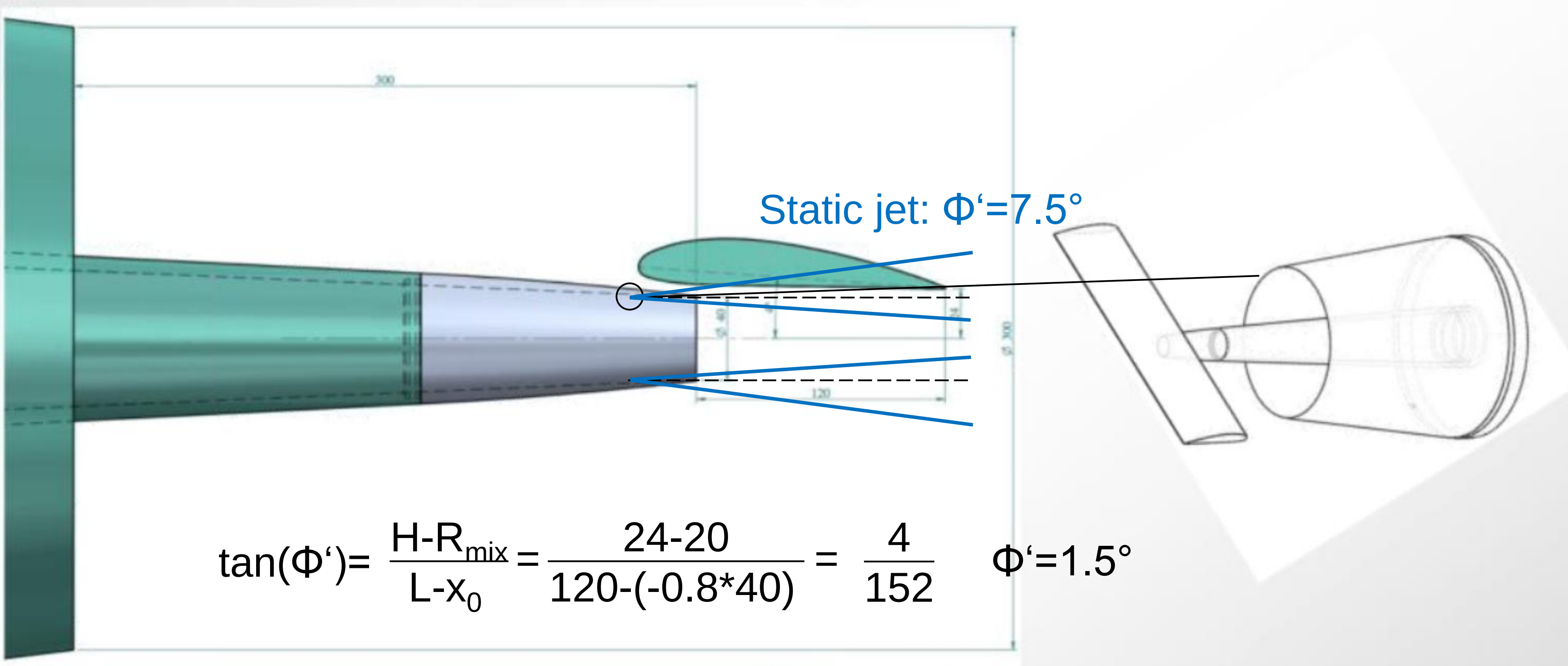
Streamwise Mach number scan of an isolated jet (M=0.6) originating from the DLR-DJ50 engine



Model is good until x/D~5 (!)

Potential core length will be overestimated

R40_NACA4415_C150_A4_H24_L120 CAD



$$\tan(\Phi') = \frac{H-R_{mix}}{L-x_0} = \frac{24-20}{120-(-0.8*40)} = \frac{4}{152} \qquad \Phi'=1.5^\circ$$

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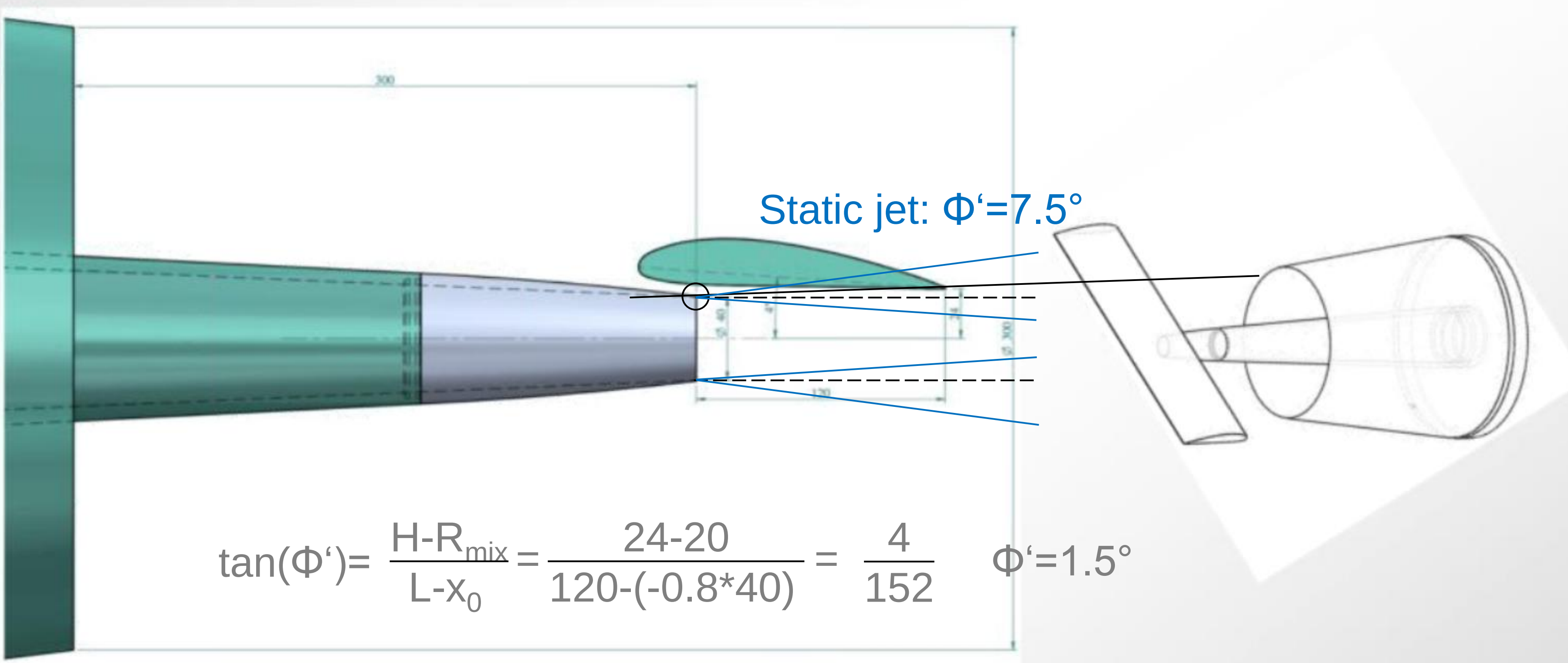
R40_NACA4415_C150_A4_H24_L120 CAD



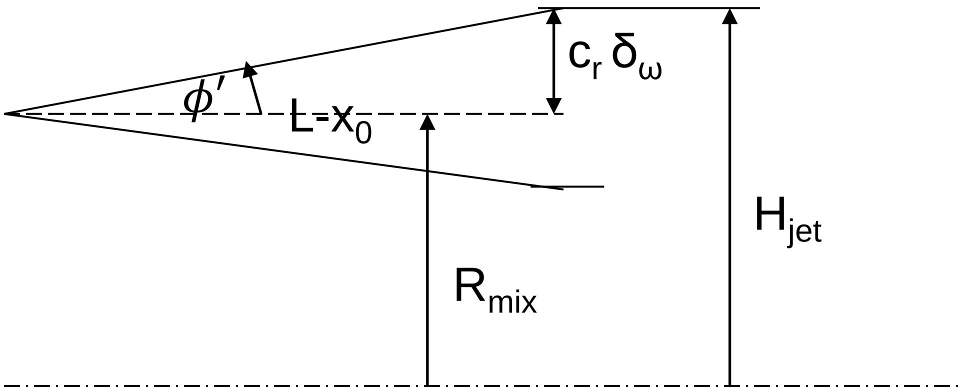
$$\tan(\Phi') = \frac{H-R_{mix}}{L-x_0} = \frac{24-20}{120-(-0.8*40)} = \frac{4}{152} \qquad \Phi'=1.5^\circ$$

Don‘t know virtual S/L origin of near field?

$$\tan(\Phi') = \frac{H-R_{mix}}{L-\cancel{x_0}} = \frac{24-20}{120} = \frac{4}{120} \qquad \Phi'=1.9^\circ \text{ (good initial guess)}$$

Determination of the half-jet opening angle (for the flight stream problem)

- Half jet opening angle



$$\tan(\phi'_{jet}) = c_r K \frac{1 - r_U}{1 + r_U}$$

$$r_U = \frac{U_f}{U_j} \sim \frac{0.1}{0.6} = 0.1667$$

AIAA 2019-2496

$$c_r(r_U = 0.1667) = 0.6$$

Outer part = 60% δ_ω

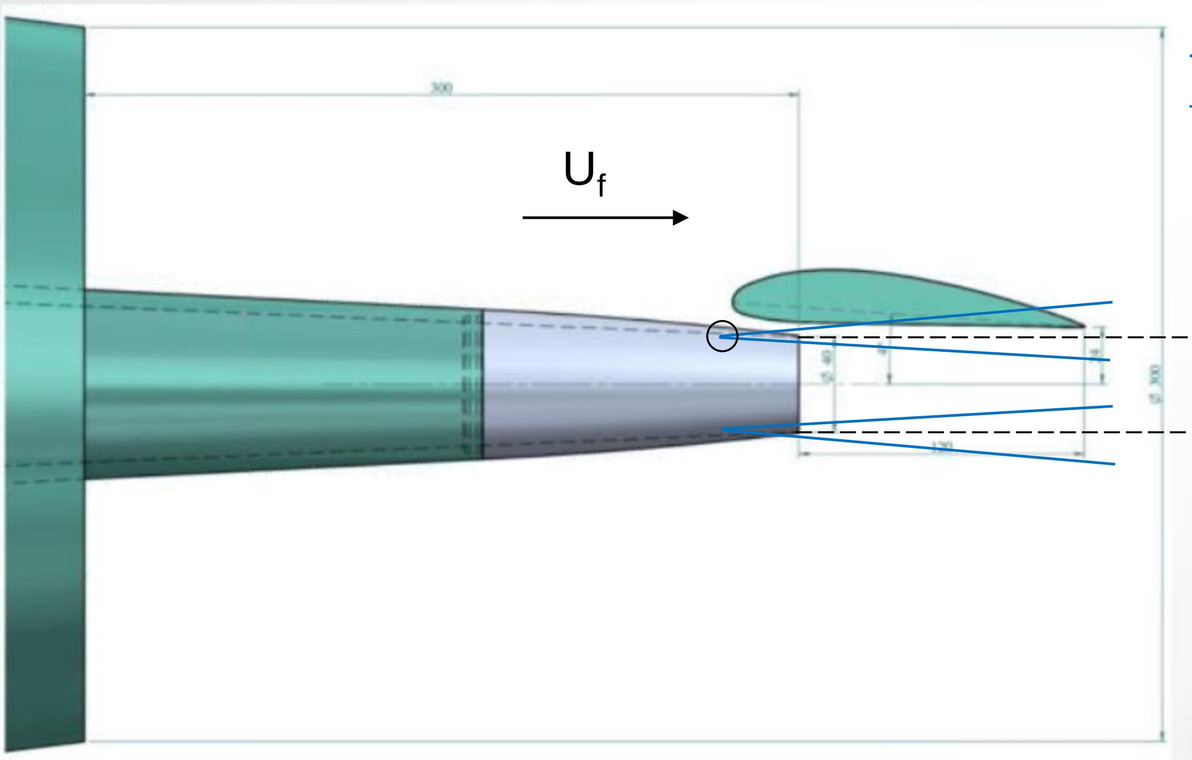
Inner part = 40% δ_ω

$$\mathrm{K} = \frac{\tan(7.5°)}{0.64} = 0.206$$

(as before)

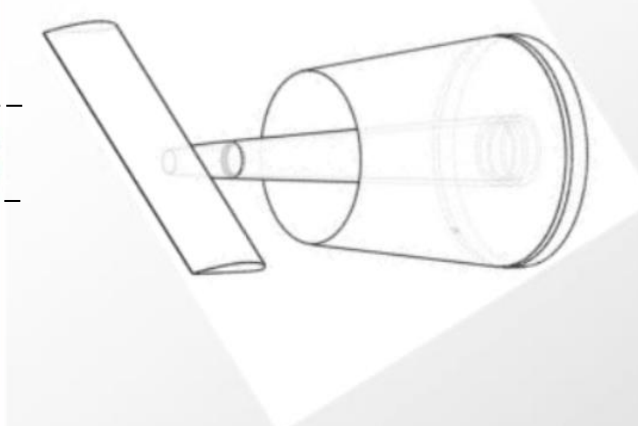
$$\phi'_{jet}(r_U) = 5.0°$$

R40_NACA4415_C150_A4_H24_L120 CAD

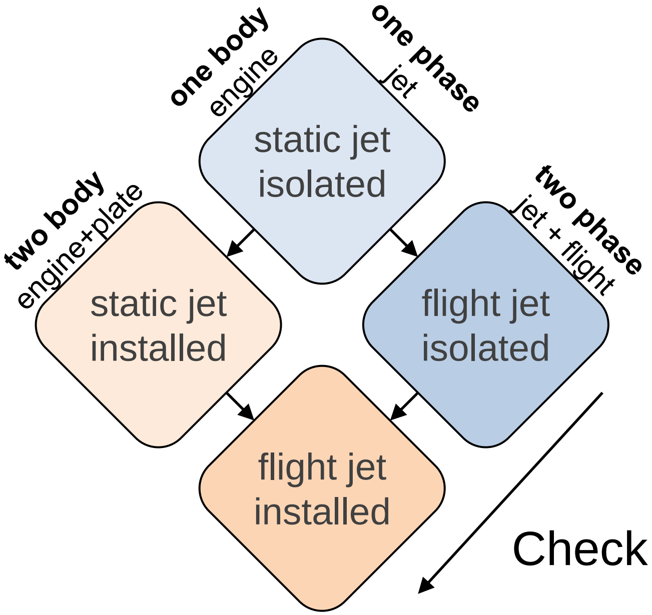


Theoretical min. requirement for undisturbed flight jet:

Flight jet: Φ'=5°



Jet-flap interaction physics are characterized by multi-body, multi-flow, multi-source acoustics



Check effect of flight speed

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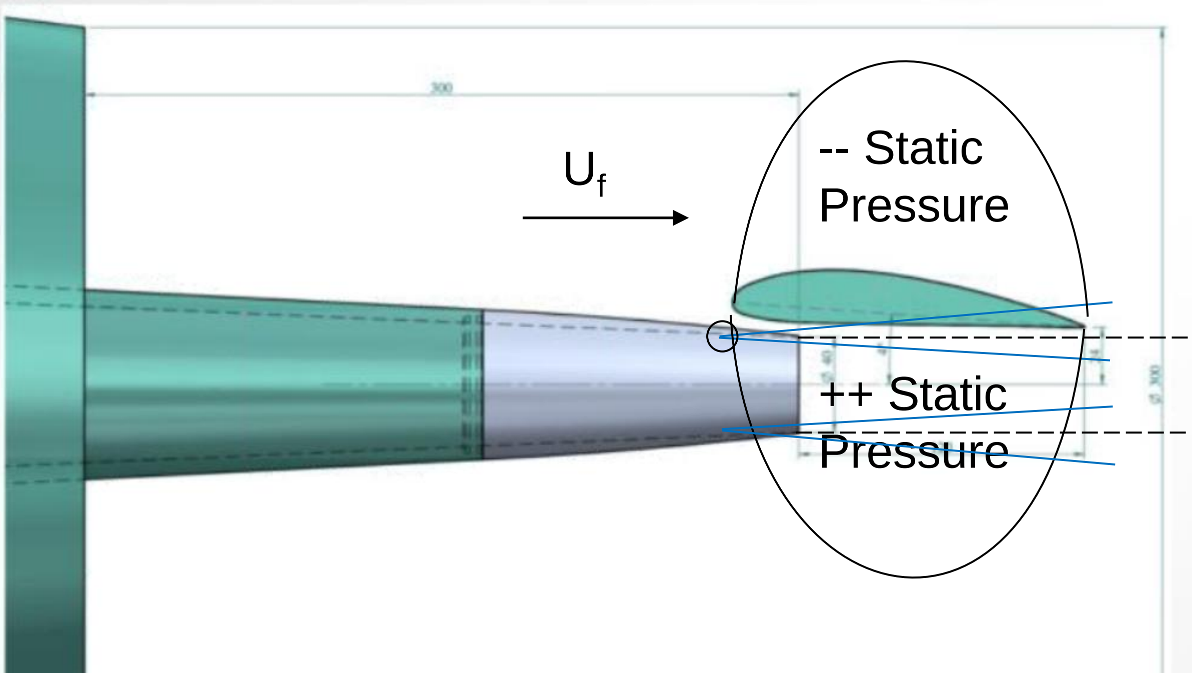
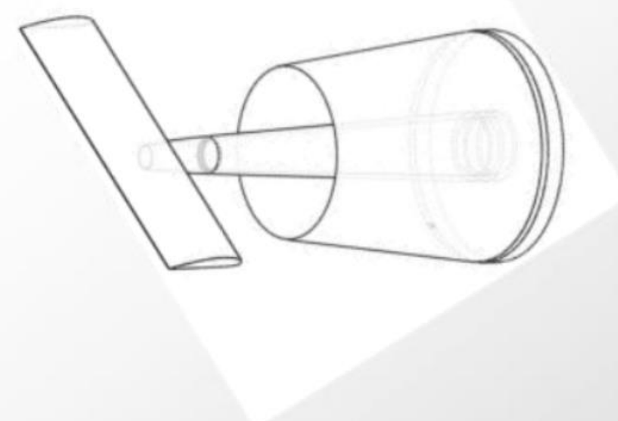
R40_NACA4415_C150_A4_H24_L120 CAD



Flight jet: Φ'=5°



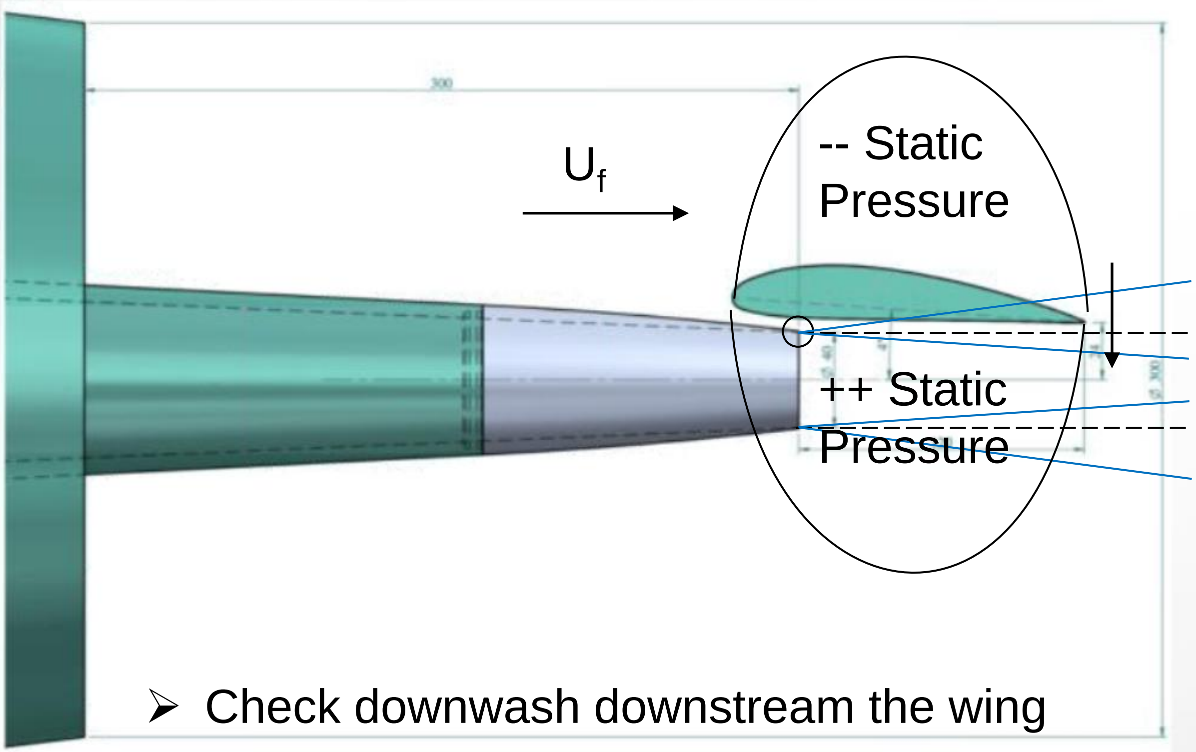
Flight velocity causes circulation around wing

This induces static overpressure on pressure side of wing

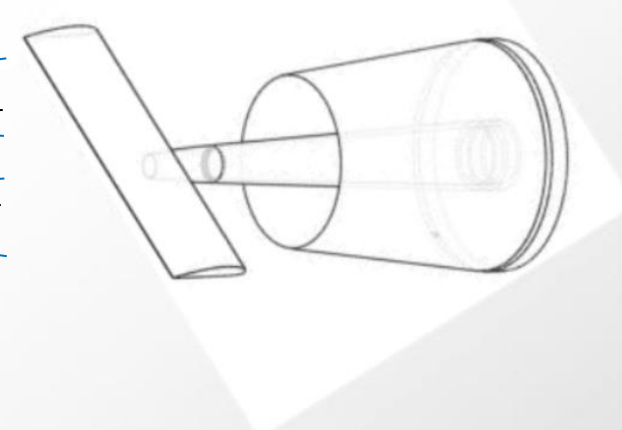
- Jet not fully expanded „below wing"
- Restrict resolution of static pressure in RANS to P_{AMB} ±500Pa

J. L.T. Lawrence *(University of Southampton, UK)*

R40_NACA4415_C150_A4_H24_L120 CAD



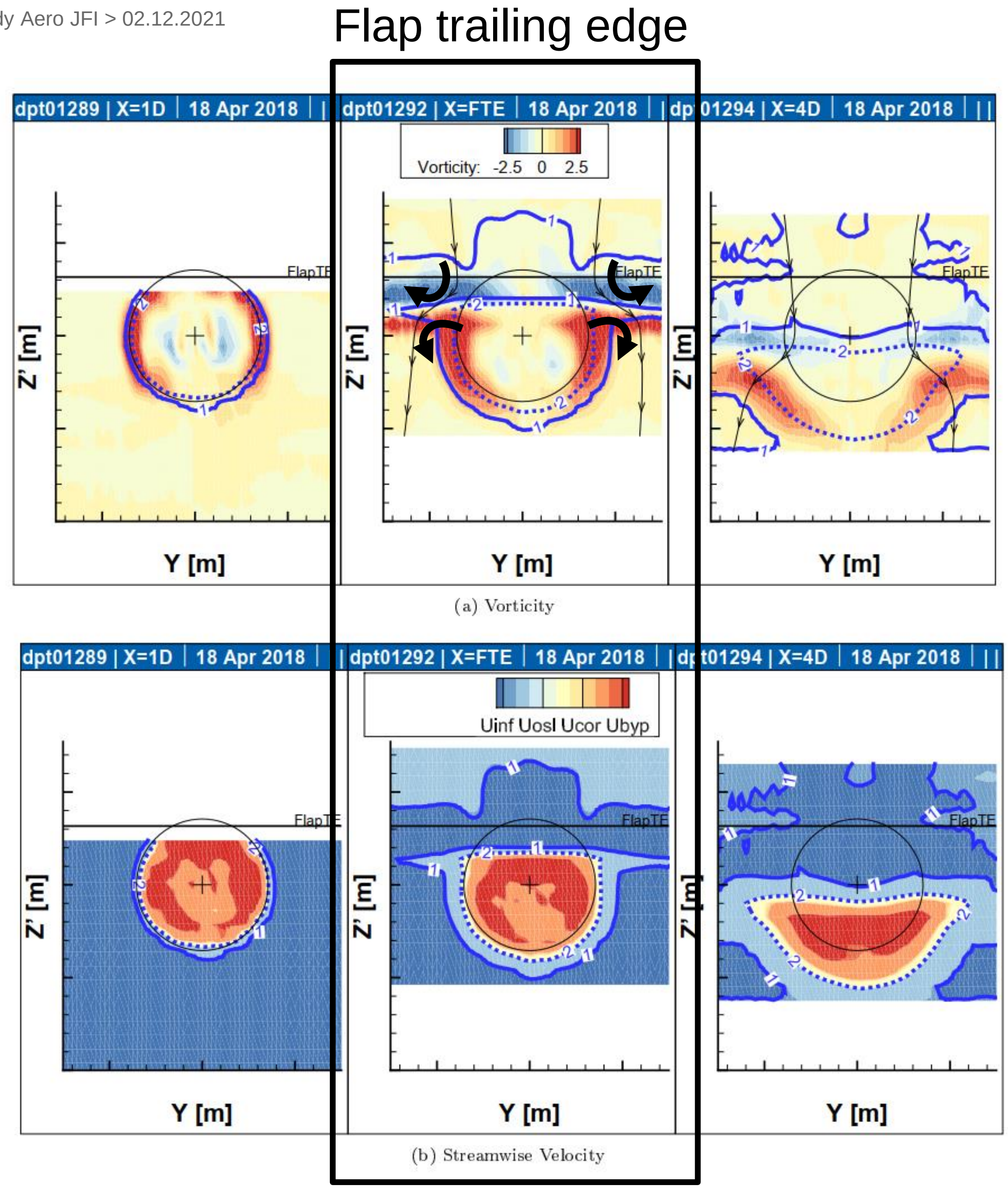
Flight jet: 0°<Φ‘<7.5°



➢ Check downwash downstream the wing

Analysis of spanwise flow field

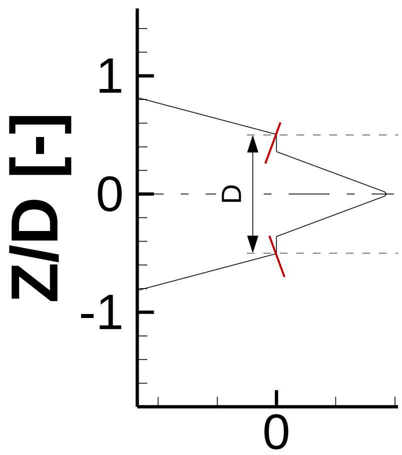
- Spanwise to jet, just downstream flap TE
- Make streamline with Y-velocity and Z-velocity
- Resolve jet S/L
  - Does the downwash help the jet to bend?
  - Do you find a vortex pair which redistributes the flow?

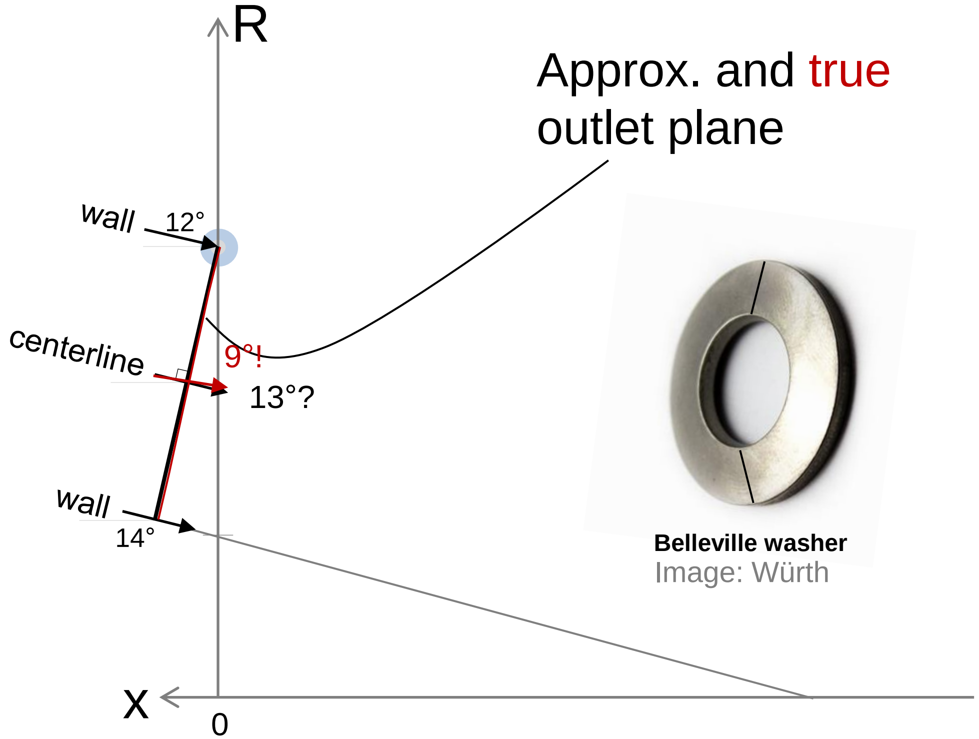


(a) Vorticity
(b) Streamwise Velocity

Christian Jente, Michael Pott-Pollenske, Dirk Boenke, Alexander Buescher and Iris Goldhahn: „Experimental Investigation of Jet-Flap-Interaction Noise Sensitivity due to varying flap parameters at a UHBR Engine/High-Lift-Wing installation“
DOI: 10.2514/6.2018-3788

Where is the lipline (better: mixed jet radius) for other engine types?

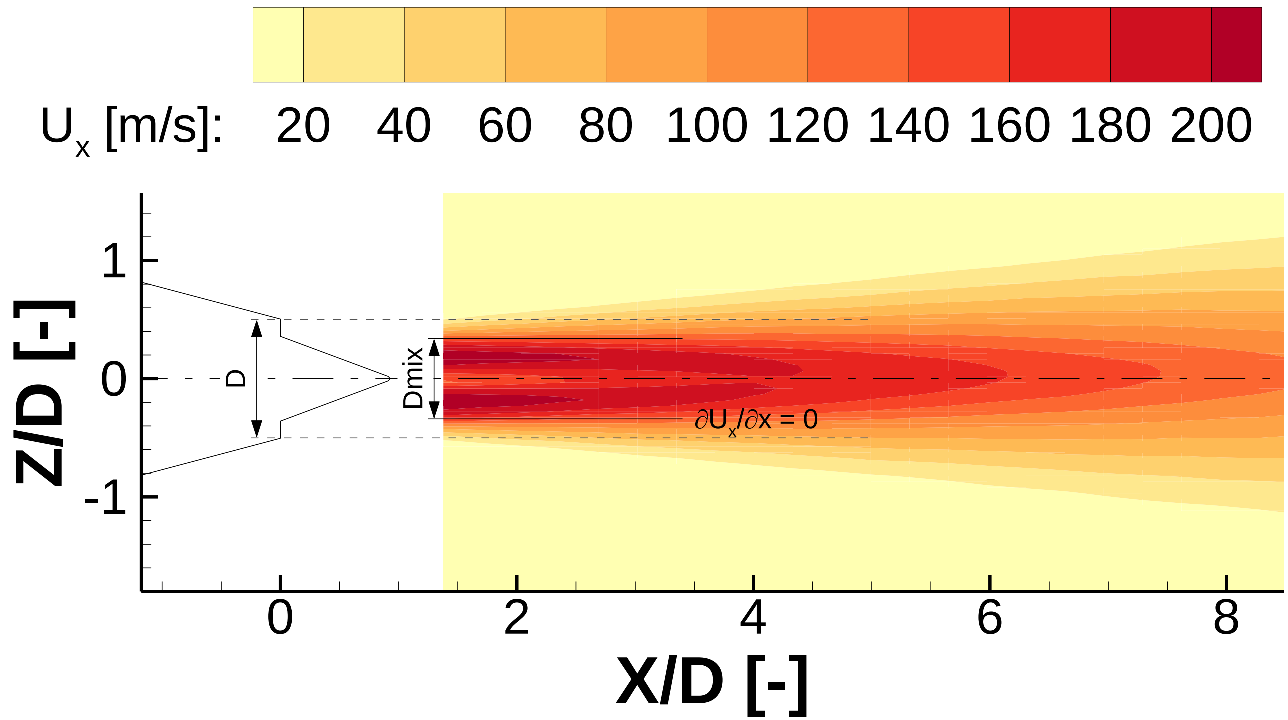




Belleville washer
Image: Würth

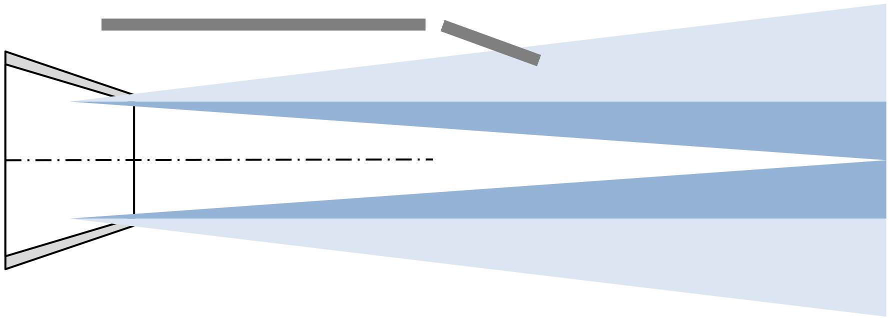
Find S/L properties for different engine

$U_\infty = 0$, $U_{jet} = 214$ m/s (378)

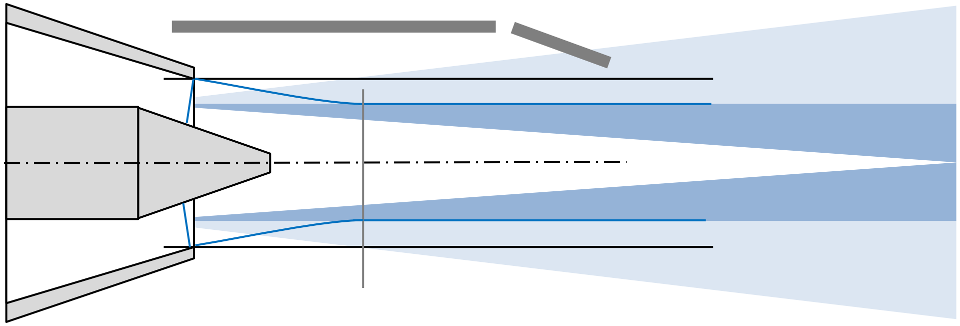


C. Jente / J. Delfs: “Velocity Scaling of Shear Layer Noise induced by cold Jet flow with co-flowing Flight stream”, AIAA 2019-2496, doi10.2514/6.2019-2496

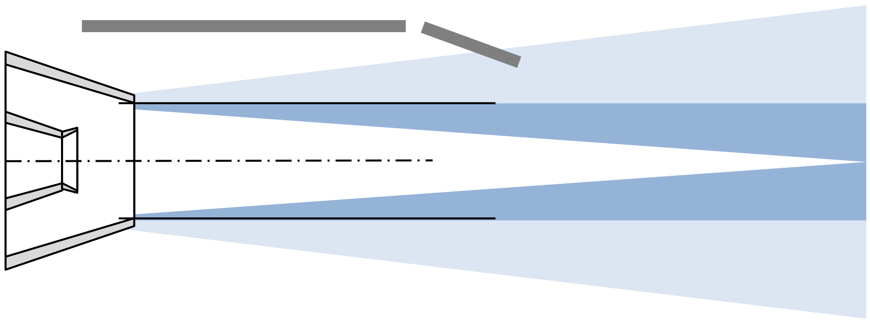
Single stream, round jet



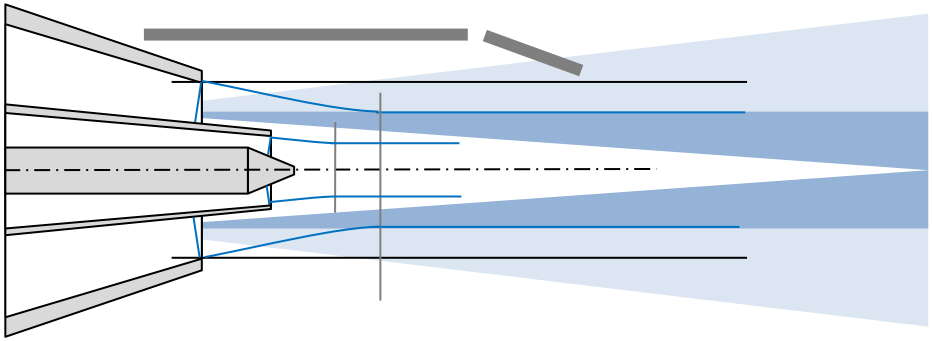
Single stream, Annular flow



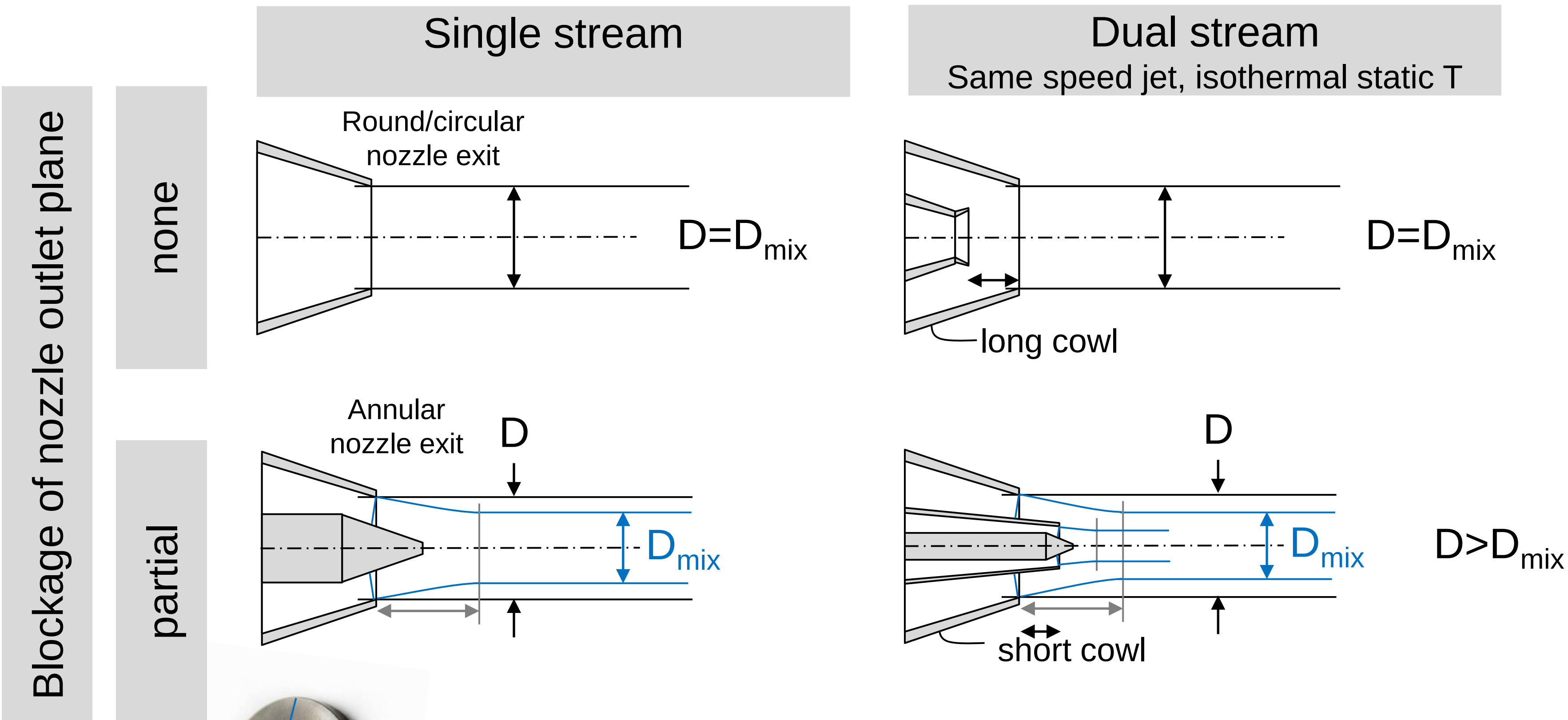
Long cowl engine



Short cowl engine



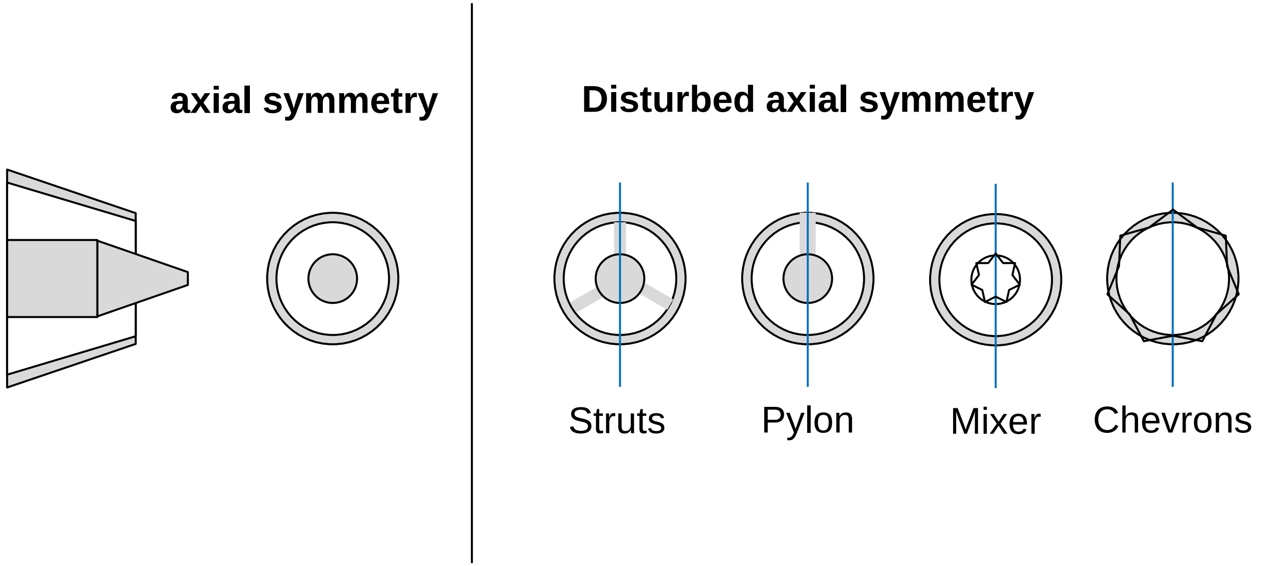
Characterization of mixed jet diameter for different axis-symmetric flows



Belleville washer
Image: Würth

$$D_{mix} \sim 2 \cdot \sqrt{\frac{\Sigma A_{noz}}{\pi}}$$

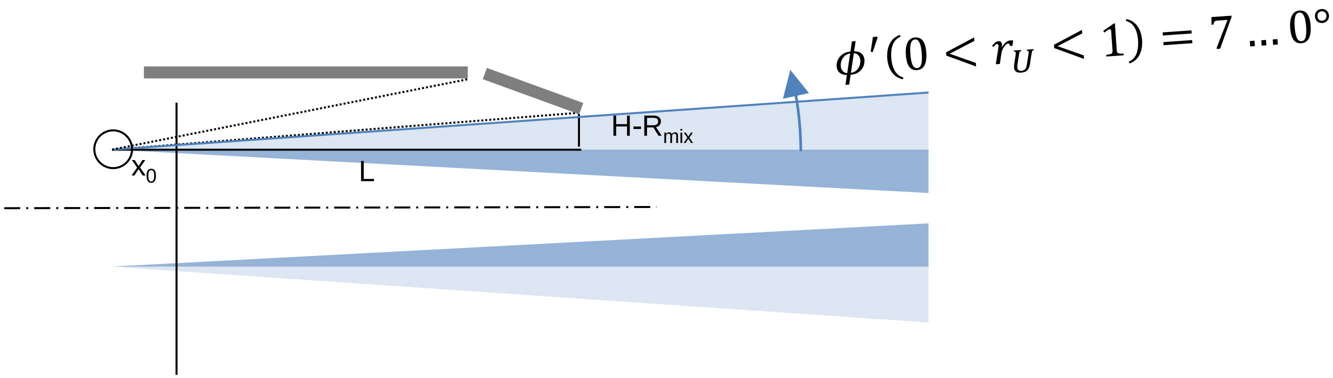
When the streamwise plane is not sufficient



- Measure spanwise jet planes and try to extract relevant information from there

Learnings

Questions?



- We can replace various engine types with near-field Jet shear layer properties

- We can express both isolated jet space requirement and wing geometry in the same coordinates

- We can formulate a **meas. hypothesis** by identifying a theoretical interaction scenario:
no interaction | interaction with outer part of S/L | interaction with jet
Close engine integration — Radical engine integration

Acknowledgements

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UNIVERSITY OF Southampton

The main aerodynamic analysis are here showcased with the help of experimental results which were measured by the team around Jack Lawrence at the ISVR Anechoic Doak Lab located at the University of Southampton.

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Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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