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

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Abstract

It is rather difficult to characterize the geometry of multi-body multi-flow problems, such as jet-flap interaction. Even the 1D similarities are not obvious. Therefore, a clear measurement hypothesis cannot be formulated and measurement results are harder to interpret.

The solution to this problem is the study of the near field geometry of the isolated jet shear layer. Its geometry can be modelled with the help of the virtual shear layer origin, mixed jet radius and half-jet opening angle. This information is very practical when introducing a second body to the problem. Even though the flow might change a lot, the theoretically necessary space for isolated jet flow can be determined. This superposition allows to make a qualitative guess on possible interaction scenarios, and theoretical jet impingement areas. It is also easier to track deviations from the superposition.

The experimental measurement with a spanwise oriented rake in the streamwise plane is cost-effect for symmetric problems: A small streamwise resolution allows for fast measurement times while significant data properties are gathered.

Cross-comparison with other engine models

The streamwise flow of the isolated shear layer describes the geometric space requirements of the jet.

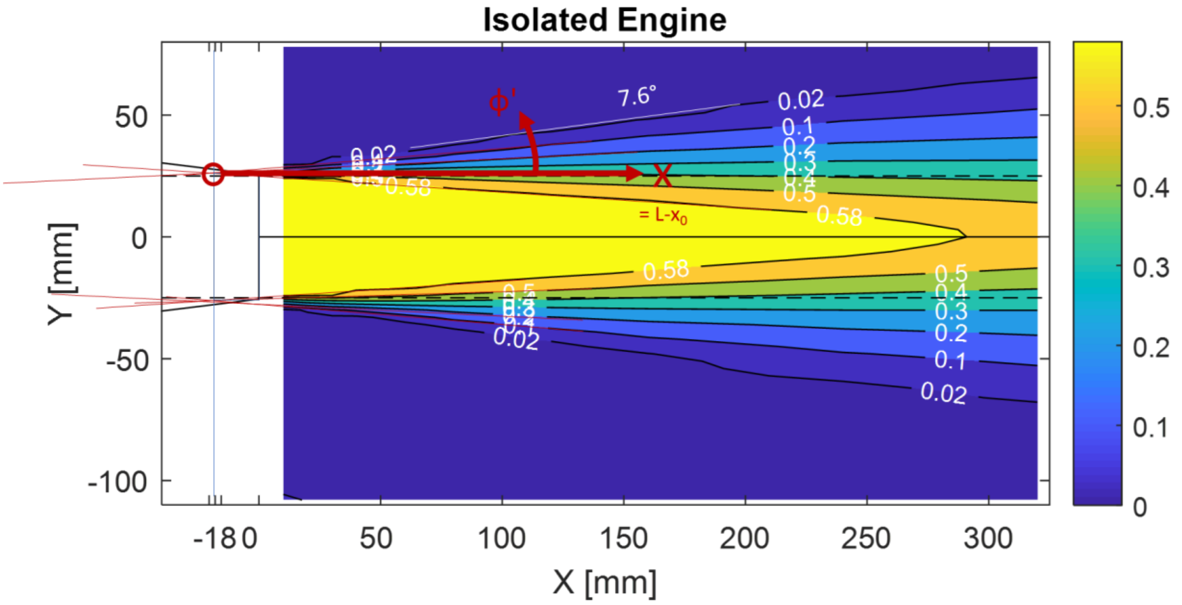

Fig. 1 Streamwise Mach number scan of isolated DJ50 engine

The streamwise flow scan helps to determine actual in-experiment flow properties (e.g. Fig. 1): The virtual shear layer origin of the jet near-field is located at jet mixed radius (around the nozzle lip line, here R=25mm) and can be determined by extending the velocity isolines towards the engine (the red lines in Fig. 1 which result in $x_0 = -18$mm). The virtual shear layer origin determines the position of an idealized engine without any internal or external (nacelle) boundary layer and zero trailing edge thickness. It deals well with the challenge

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of including non-zero, but realistically small boundary layer thicknesses as well as manufacturing limits for the trailing edge.

The mixed jet radius can be determined with the help of the velocity isoline which runs parallel to the engine axis within the near field (where the jet potential core is still present). This velocity is a characteristic S/L velocity and should be searched around $U_c \sim 0.65$ Uj [1][2] for round jets at static operation.

The engine model with its realistic short-comings can be replaced by a geometric model for a jet S/L like flow and thus allow the cross-comparison to other engine models and facilities.

Theoretical space requirement for jet flow in multi-body problems

Jet shear layer like flows are characterized by their half jet opening angle. The lowest resolved speed setting (here: M=0.02, must be tested out) is an indicator for the jet opening angle. It can also be determined by Powerpoint analysis, as in Fig. 1. The depicted half-jet opening angle is 7.6° for the static jet in Fig. 1. The half-jet opening angle decreases when a co-flow (flight speed) is added. If jet velocity and co-flow are at the same speed, there is only a small wake or 0° opening angle. In fact, there is some work available [1] that approximates the half-jet opening angle only with help of the velocity ratio r_U:

(outer) shear layer velocity ratio $$r_U = U_\infty / U_j \qquad (1)$$

The realistic jet and its theoretical space requirement can be specified with reference to a new coordinate system. The origin is located at $[x_0, R_{mix}]$ and the polar coordinate system contains an angle (e.g. the half-jet opening angle depending on the velocity ratio).

Even though the introduction of a plate or aerofoil at [L, H] may (drastically) change the flow field, the superposition of the theoretical isolated jet shear layer space requirement with the reality of the build geometry is still a good and presumably the only tool for a qualitative analytical prediction of an interaction scenario.

The space requirement and restriction are listed in equations (2) and (3):

Space restriction by wing $$\tan(\phi'_{build}) = \frac{H-R_{mix}}{L-x_0} \qquad (2)$$

Space requirement by flow $$\tan(\phi'_{jet\ S/L}) = f(r_U)\left[= \frac{H_j(x)-R_{mix}}{x-x_0}\right] \qquad (3)$$

Definition of experiment

If unknown, planning can be conducted with x0=0 and φ'=7° to 8°. Yet, the experimental reality can be determined with a total pressure rake in the isolated jet S/L near field. The DLR pressure rake resolves the flow field well enough with only a few streamwise rake movements (5-10). Hence, the estimated rake measurement times should be small (not greater than 2 mins per operation). The testing of close to all operations should be targeted.

A comparably low measurement time and a rather large benefit in test results can make the measurement of the streamwise plane at Y=0 and Z=0 the most cost-effective one for both, jet noise and jet-interaction noise problems.

However, if the measured information does not contain symmetric information (pylon, influence of struts etc.), the advantages of correcting tiny rake-to-nozzle alignment errors are lost and spanwise flow information is crucial for the evaluation of flow properties.

References

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