Jet-flap interaction noise in model scale and full scale - and the implications for evaluating noise reduction technologies

Christian Jente

Alternative title: The process of down-selecting NRTs for DLR‘s DJINN-WP1 experiment

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1. Is it possible to identify a common spectral shape for JFI?	Perform an experiment at different scale in order to test similarity of spectra
2. What is the typical JFI noise effect?	
3. Is it possible to cluster the JFI effect, e.g. by certain frequencies?	
4. Which part of the spectrum is most relevant in full-scale?	Assign a weighting to the measured spectra to account for human hearing
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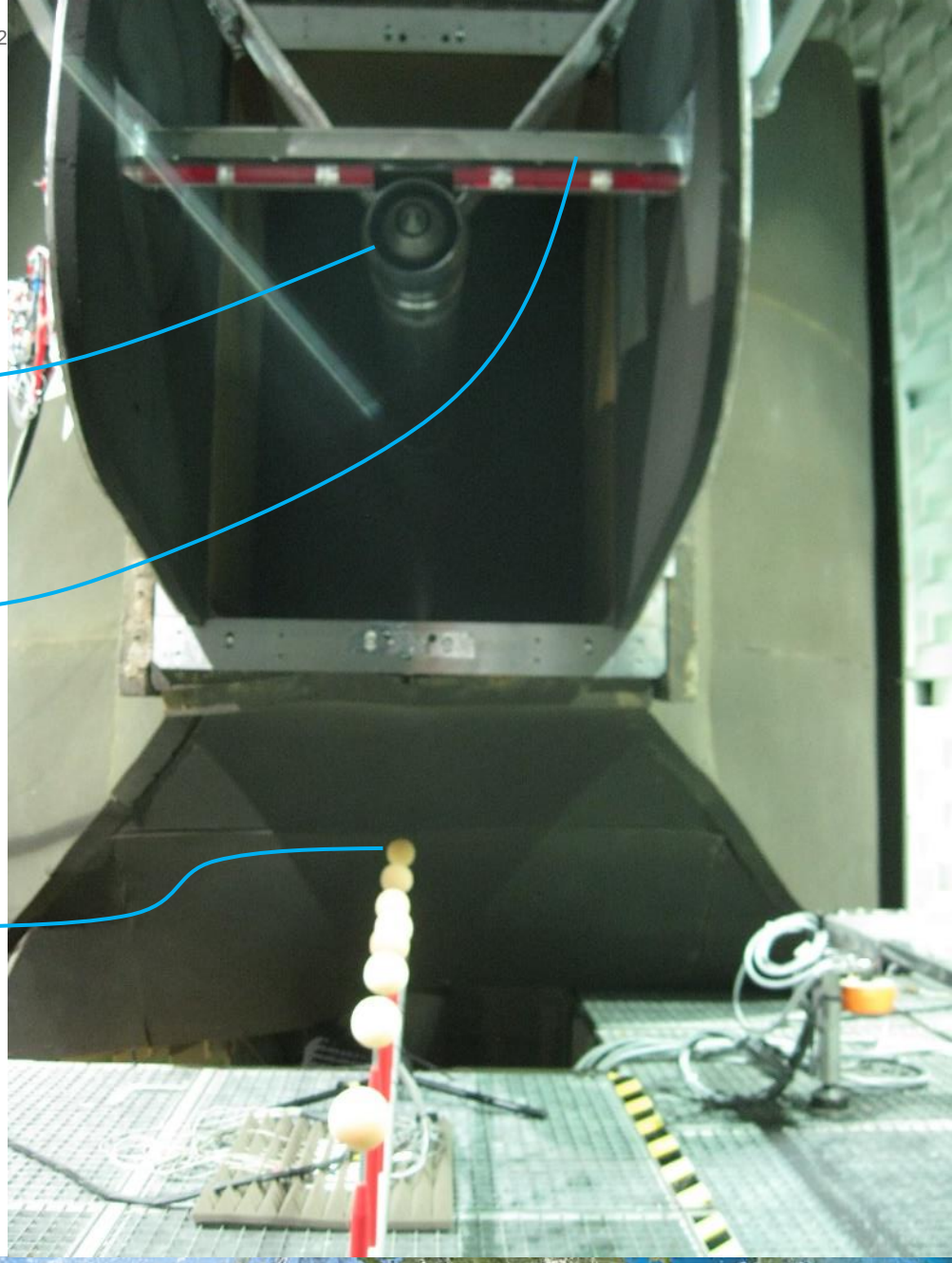
Large-scale experiment at DLR-AWB in 03/2017



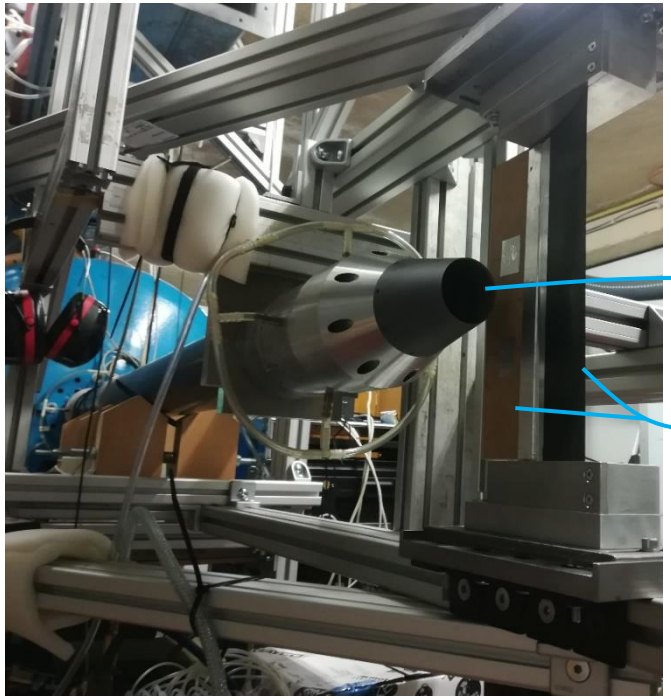
LIST engine
UHBR dual stream
inclined by 14.5°
Same speed jet, Mj=0.6

DLR-F16
high-lift wing
inclined by 14.5°
flap at δ_F=25°

B&K 4136 flyover mics
Type: pressure response
(corrected)
Mic 1 (at 71°+14.5°) closest to 90°

Acknowledgement: German national project LIST

DLR

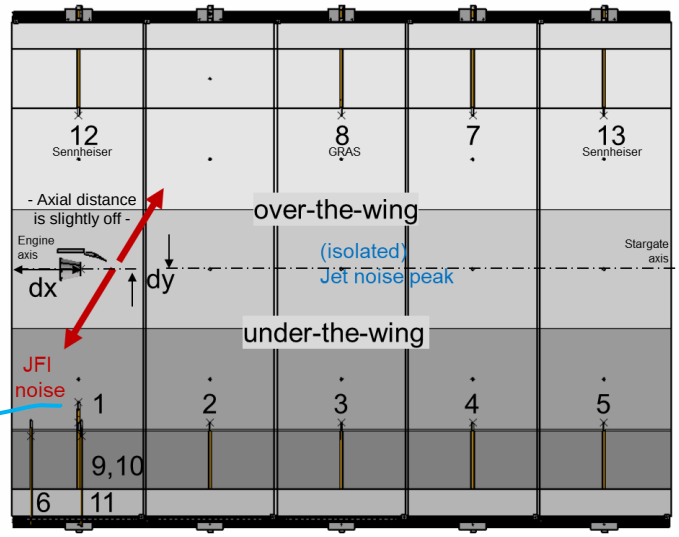


The small-scale experiment at JExTRA in 07/2021

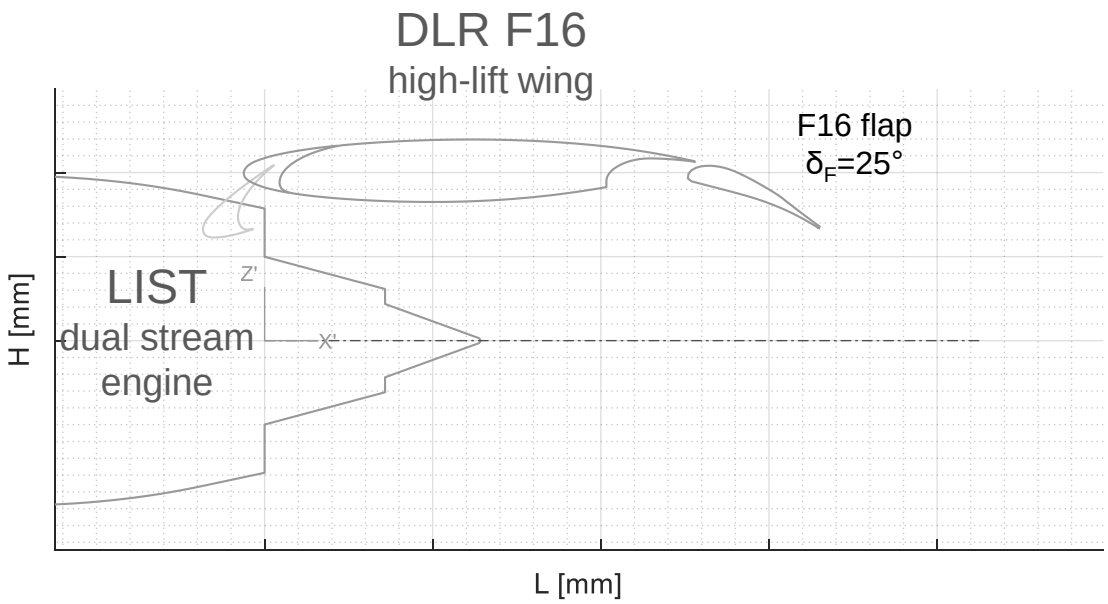
DJ50 engine
single stream | not inclined | Mj=0.6

DLR-F16 flap
+wooden plate as substitute for wing
not inclined | flap at δ_F=25°

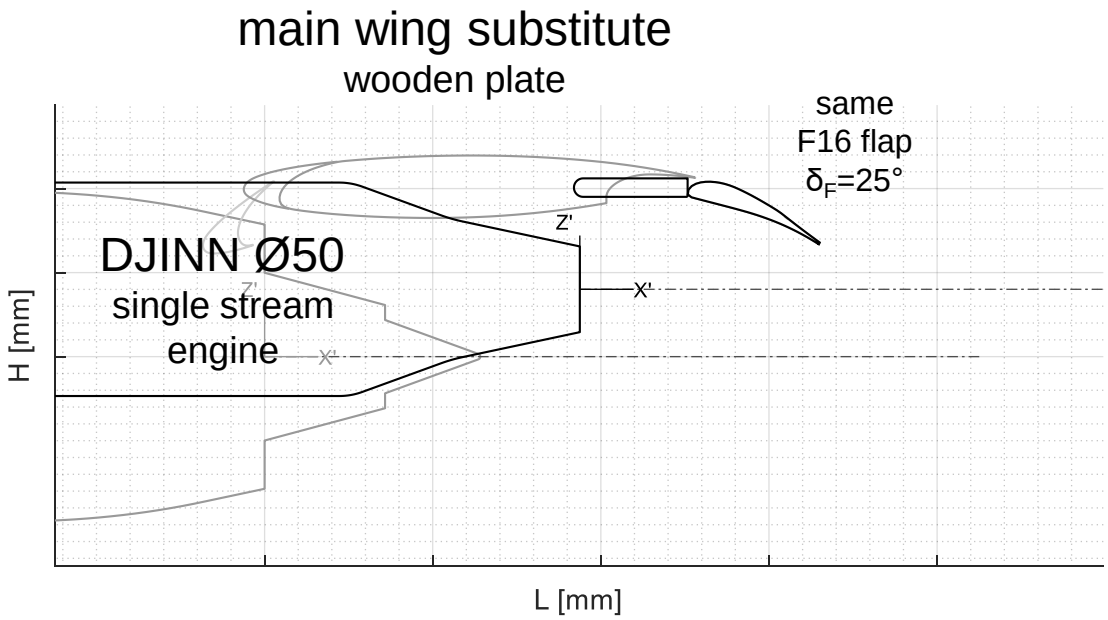
MK301 mics
Type: free-field
(not corrected)
Mic1 at 89°



Mid-scale exp, at DLR-AWB during LIST in 03/2017

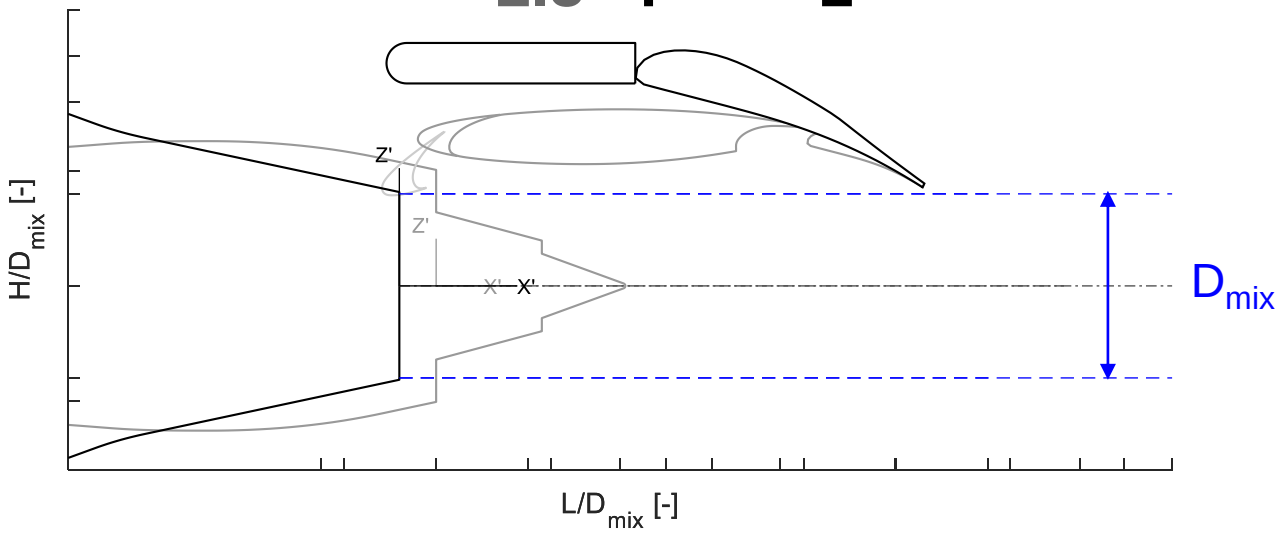


Small-scale exp, at DLR-JExTRA during DJINN in 07/2021

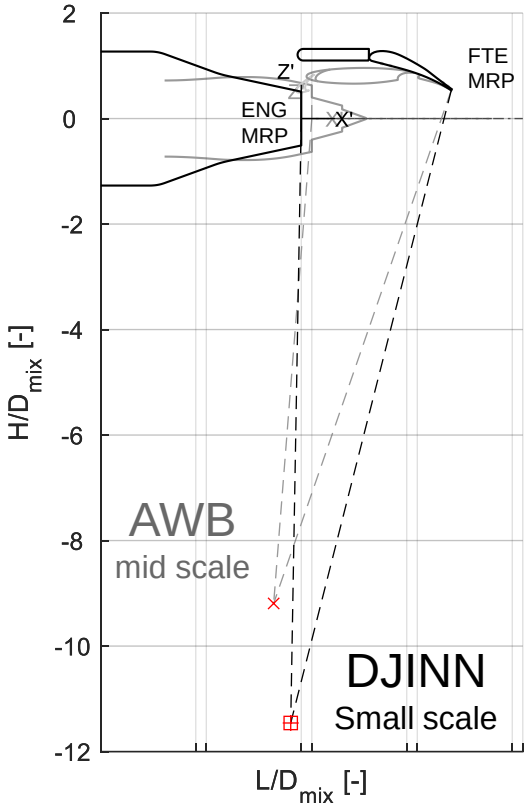


Scaled JFI experiment: AWB vs **JExTRA**

2.5 : 1



Scaled JFI Experiment
- Microphones



Distance R

- Same R/D_{mix} is required (multi-source problem)
- Microphones are typically installed where mounting is physically possible
- The evaluation has to live with compromises; distance offsets must be corrected

Polar angle θ

- Max JFI noise at forward arc/overhead
- choose angle wrt to this, e.g. $\theta_{ENG}=90°$

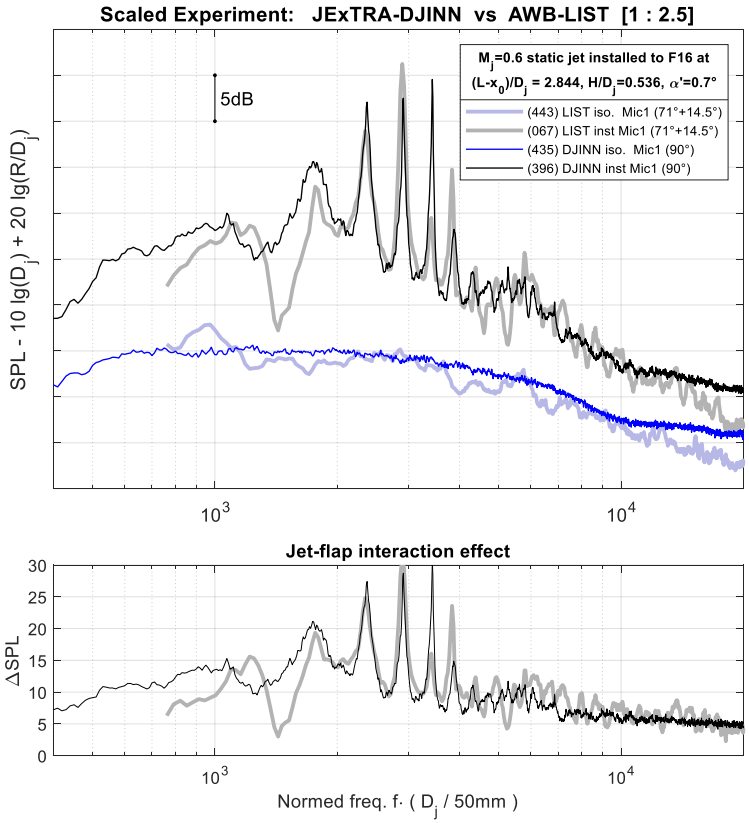
AWB vs. JExTRA Cross-comparison
shortcomings

	AWB	JExTRA	Comment	
Wind tunnel type	closed-circuit	open-circuit	AWB with minimal co-flow	🟡
Comp. location	remote	close	Temp. behaviour different	🟡
Engine	dual stream	single stream	Positioning analogy required	🔴
Eng. Int $(L-x_0)/D_{mix}$	2.844	>2.844	guess value for $x_{0,DJ50}$	🟡
Eng. Int. H/D_{mix}	0.536	0.536	Good position	🟢
Expected Flap	DLR-F16 1:1	DLR-F16 1:2.5	Skewed contours	🟡
main wing	3-element	2-element	avoid flight operations	🟢
Clean chord c/D_{mix}	2.4	3	roughly same reflection area	🟢
Mic type	Pressure resp.	Free-field	free-field correction for AWB	🟡
Mic Pos. R/D_{mix}	9.2	11.5	Fix with far-field geometric damping	🟡

- Lots of effort was put into making the experiments comparable
- the premises for the comparison are nevertheless not ideal and in some points questionable

Mid scale vs. small scale experiment

1. Is it possible to identify a common spectral shape for JFI?



Frequency axis:

- JFI tones and JFI broadband noise characteristics collapse for the same normed frequency.
- Both of the scaled experiments show the same acoustic behavior.

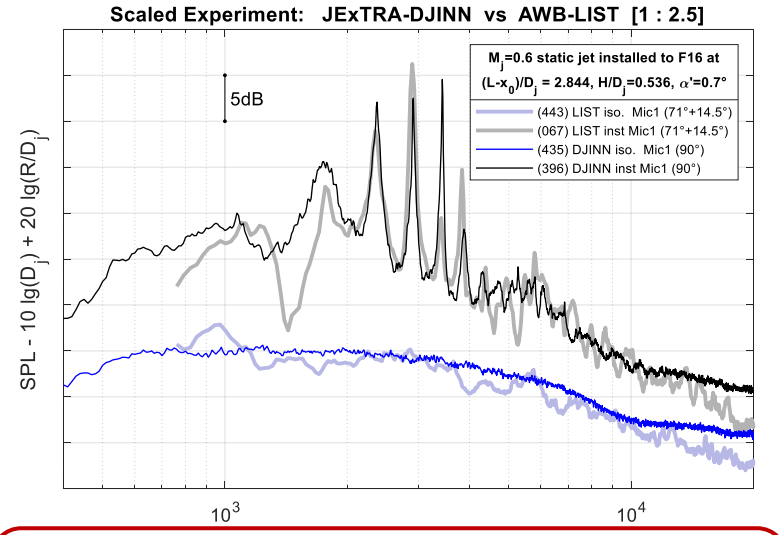
Normed SPL / ΔSPL_{JFI} axis:

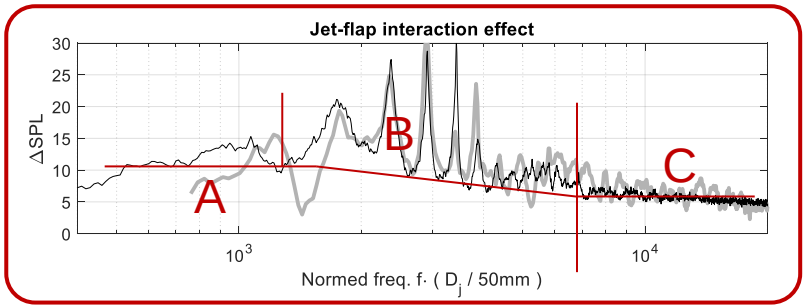
- There is great overall agreement in SPL.
- Tiny differences can likely stem from the shortcomings of the experiment.

Scaled experiments which are geometrically scaled by a factor of 2.5 have the potential to show the same results.

Mid scale vs. small scale experiment

2. What is the typical JFI noise effect?





A In this experiment, there is a large low-frequent JFI-offset (~10dB „broadband“) which is superposed by tonal components.

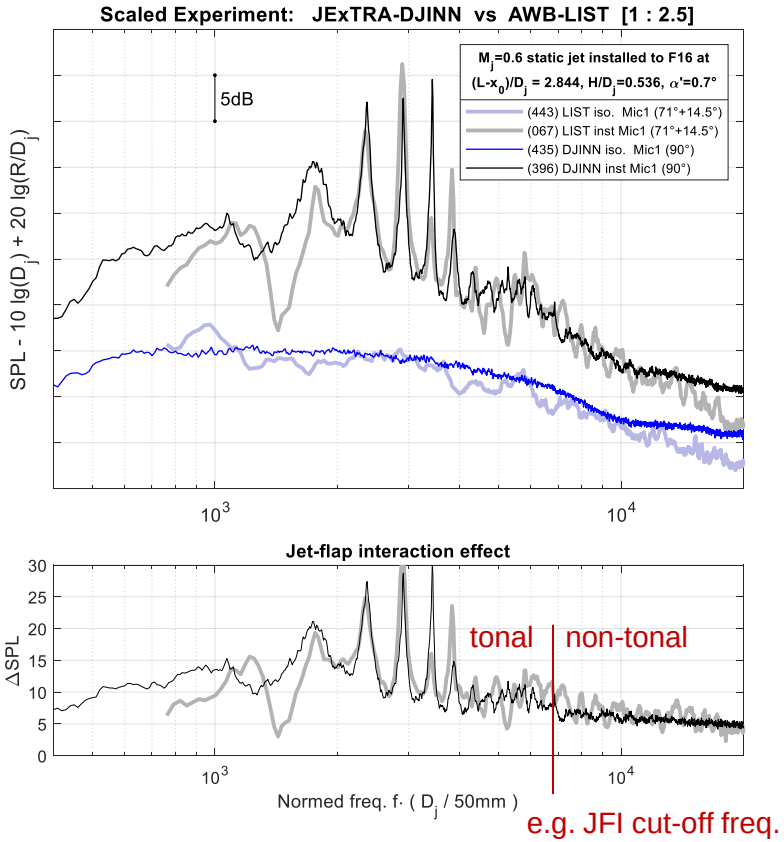
B The tonal components (up to 30dB) are only present within a certain range of the spectrum and can be characterized by cut-on and cut-off criteria. [1]

C There is also a high-frequent JFI effect (here 5-6dB). It is often smaller than the effect for lower frequencies and may be therefore overlooked.

[1] Peter Jordan, Vincent Jaunet, Aaron Towne, André V. G. Cavalieri, Tim Colonius, Oliver Schmidt, and Anurag Agarwal. Jet–flap interaction tones. Journal of Fluid Mechanics, 853:333–358, 2018.

Mid scale vs. small scale experiment

3. Is it possible to cluster the JFI effect frequencies?



A clustering could occur wrt. the cut-off criterion into low freq. tonal and high-freq. non-tonal JFI noise.

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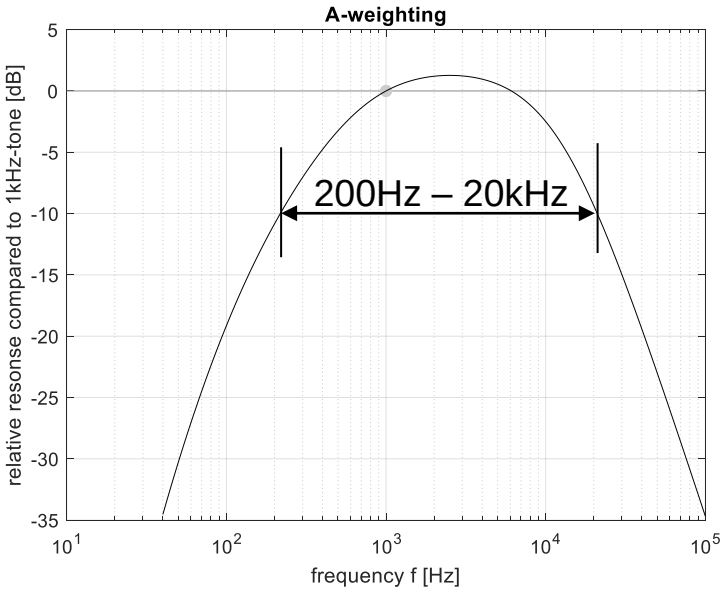
Which part of the spectrum is most relevant in full-scale?

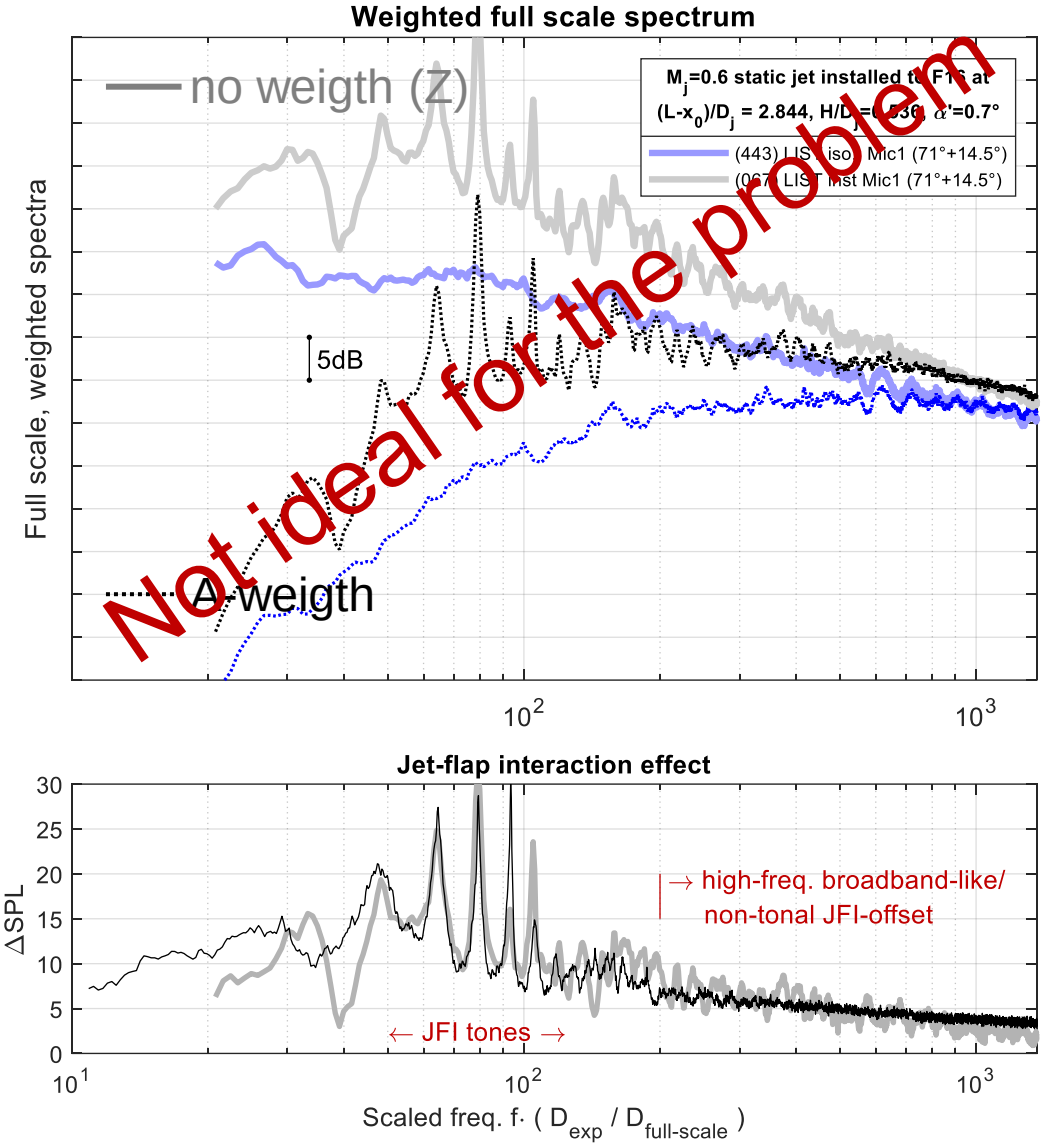
- **scaling to full-scale will produce the same spectral shape**
  (as shown in the model scale experiment)

- But: what if very low model-scale frequencies are scaled to full scale – and they are not audible - could they distort the evaluation criteria for selecting NRTs?
  - e.g. 200 Hz (in 1:40 model scale) = 5 Hz (full scale)

- Check this by applying a weighting which resembles the human hearing for varying frequencies
  - very low and very large frequencies cannot be perceived
  - 1-4kHz is perceived very well

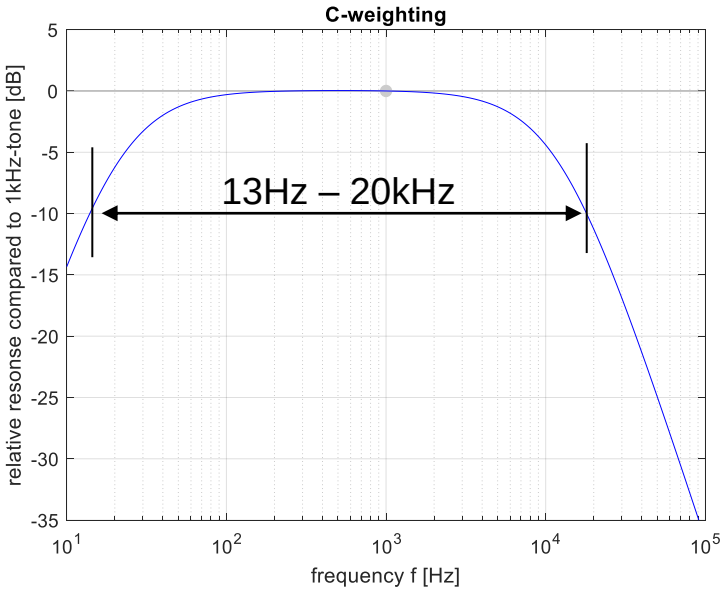
A-weigthed spectra



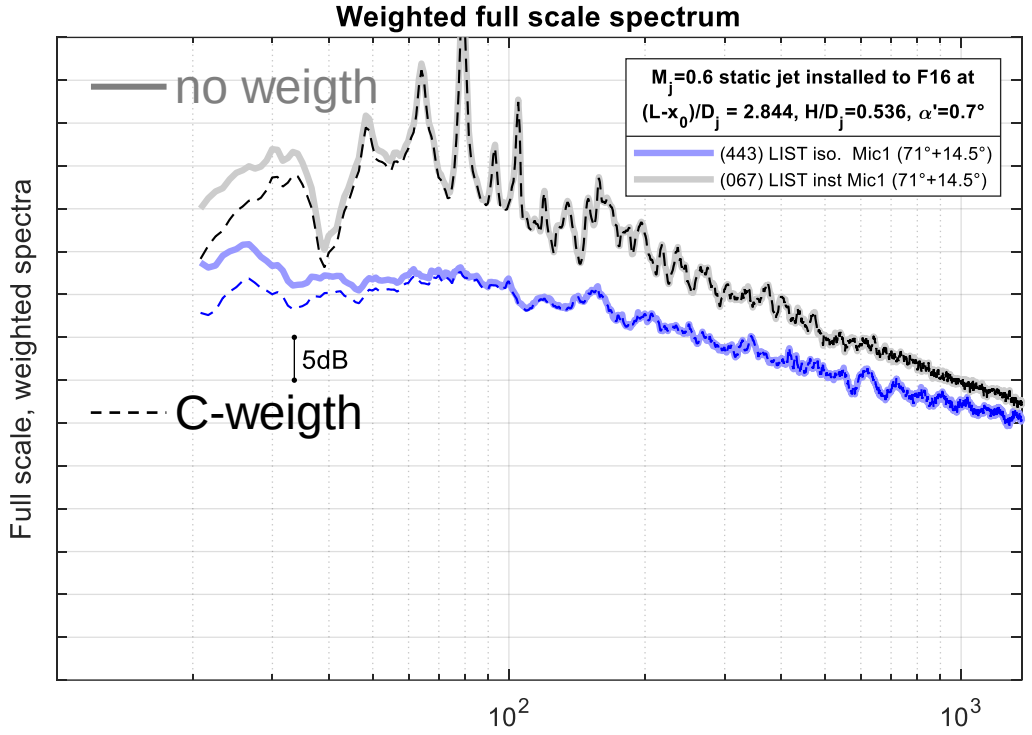


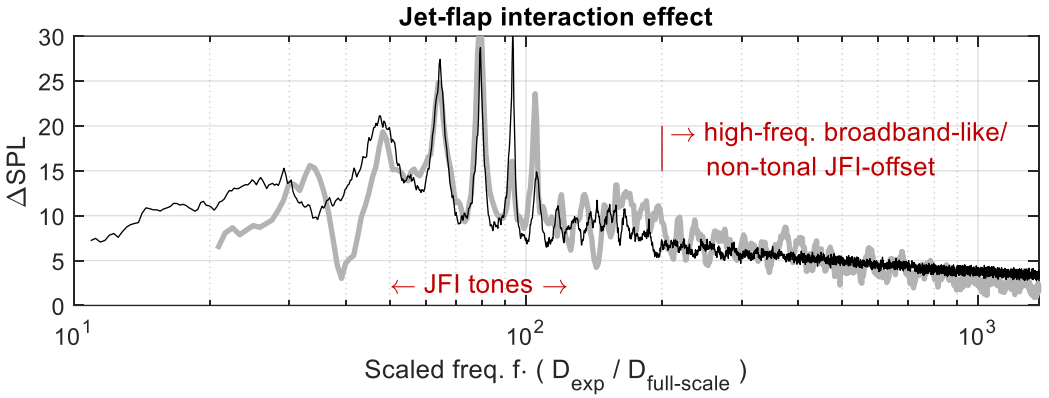
- First idea which comes to mind: use A-weigthing
- 2 points of critique
  - dBA meant for low SPL
  - A-weighting can be used to „hide“ low-freq. noise (not the author‘s intention!)

C-weighted spectra



- models the ear's response for higher SPL
- C-weighting is suited for JFI noise / much better than A-weighting





Which part of the spectrum is most relevant in full-scale?

Esp. low-freq., but also high-freq.

- **scaling to full-scale will produce the same spectral shape** (as shown in the model scale experiment)

- But: what if very low model-scale frequencies are scaled to full scale – and they are not audible, could they distort the evaluation criteria for selecting NRTs?
  - e.g. 200 Hz (in 1:40 model scale) = 5 Hz (full scale)

  There is no real „what if“; the design criterion (lower freq.) for a test facility and the typical model size are often in good range of full scale requirements

- Check this by applying a weighting which resembles the human hearing for varying frequencies
  - very low and very large frequencies cannot be perceived
  - 1-4kHz is perceived very well

  A-weighting can lead to wrong conclusions for JFI Noise

  C-weighting is a suitable weight for the problem

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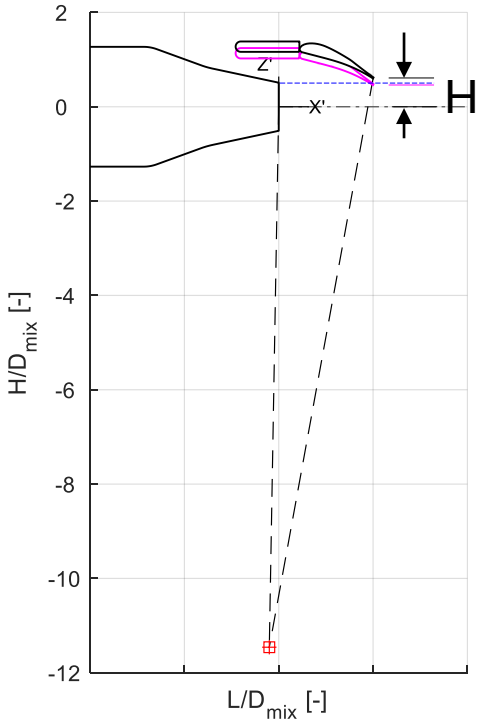
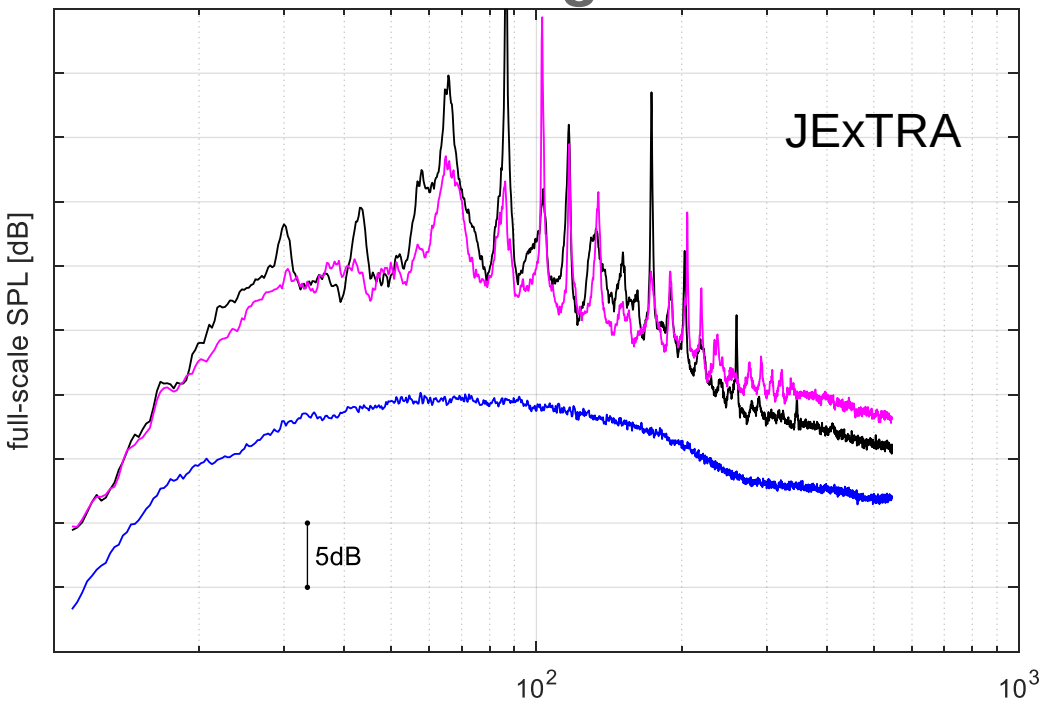
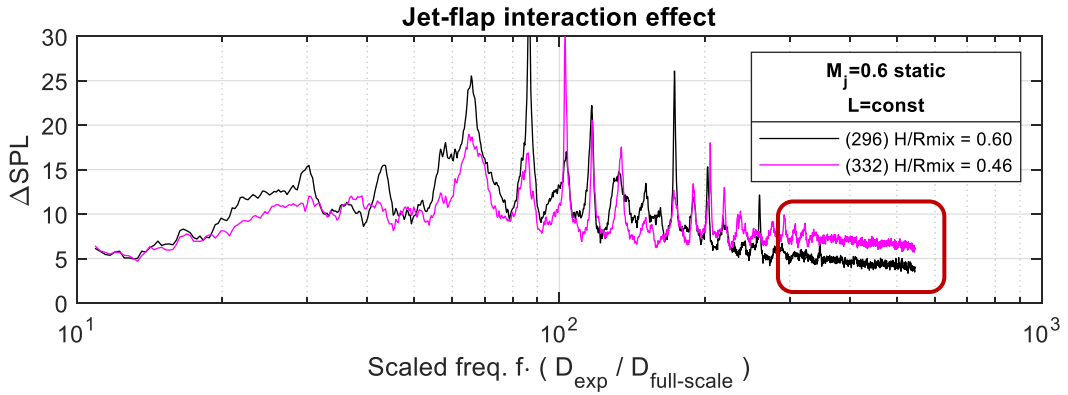
What is the sensitivity of JFI noise wrt. engine integration height?

- Lower height, especially „radical“ engine integration H<R_{mix} causes greater impact of high-frequent broadband-like noise







What are the conclusions for down-selecting NRTs?

- The JFI effect consists of both, low-frequent and high-frequent noise components.
  - The low-freq. effect is larger in ΔSPL.
    - The DJINN objective is to achieve a reduction of 5dB in this range.
  - The high-freq. effect is smaller in ΔSPL.
    - While almost negligible for even rather close engine integration, the effect increases significantly with very close (radical) engine integration.

- DLR decided for their WP1 campaign to select NRT candidates which perform well in either frequency range and to add a radical engine integration ($H<R_{mix}$) in addition to the commonly defined close engine integration ($H>R_{mix}$) .

Questions?

Acknowledgements

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on the basis of a decision by the German Bundestag

DLR

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DLR Braunschweig AS-TEA for hosting of test campaign and test conduction of AWB mid-scale test.

DLR