A Comparison of Impedance Eduction Test Rigs with Different Flow Profiles

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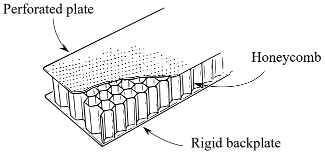
Introduction

- Acoustic liners are the main noise control treatment applied to aircraft turbofan engines and are generally characterized by their acoustic impedance;
- The acoustic impedance is a function of the liner geometry, SPL, grazing flow Mach number, frequency, etc., requiring an experimental characterization;



$$Z(\omega) = \theta(\omega) + \mathrm{i}\chi(\omega)$$

- Eduction Methods are the main experimental techniques used to determine the acoustic impedance of a liner;
- Recently, comparisons between impedance results obtained by different test rigs using different Eduction Methods have identified some discrepancies and raised questions about the possible sources of these discrepancies;
- There is special interest in evaluating the impact of the flow profile characteristics within the test rig on the educed impedance.

Aim and Objectives

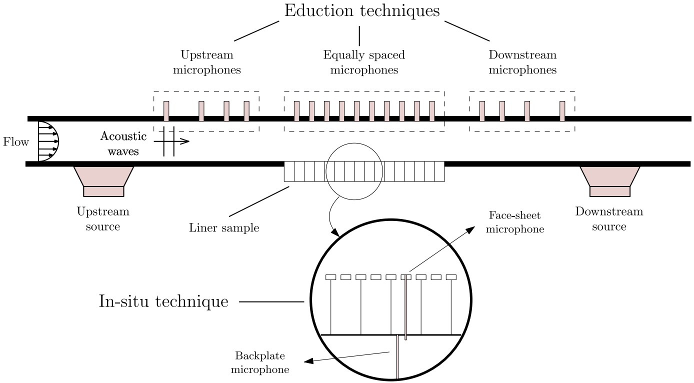
Aim

Comparison between impedance results for the same liner evaluated at UFSC and the NASA test rigs under similar conditions.

- A pair of identical liner samples was 3D printed by the same vendor using the same equipment;
- Tests were performed matching the same SPL and the same centerline or bulk Mach number;
- Eduction methods based on Prony-like algorithms were applied by both UFSC and NASA;
- The Goodrich semiempirical model was used to evaluate the influence of flow profile parameters on the educed impedance;
- Raw acoustic data were shared between the teams to cross-check eduction methods.

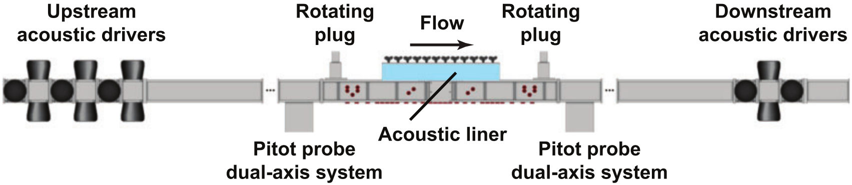
UFSC Liner Impedance Test rig

- Composed of a rectangular cross section duct of 40x100 mm^2;
- 4 compression drivers upstream and downstream of the liner sample can generate sound fields up to 150 dB in both directions;
- External compressed air system sustains grazing flows up to 0.7 averaged Mach.



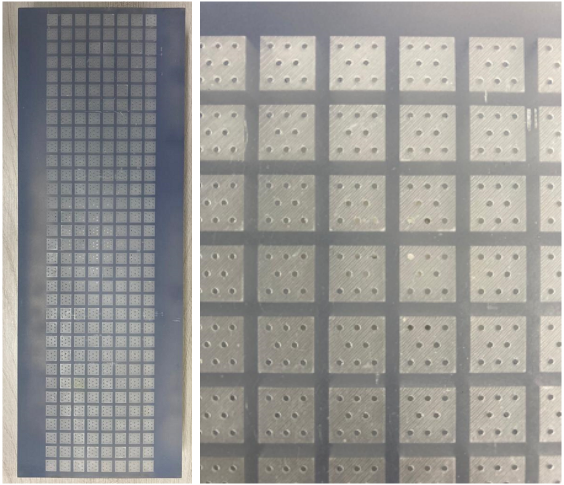
NASA GFIT

- Wind tunnel with a 50.8x63.5 mm^2 rectangular cross section;
- 12 compression drivers upstream and 6 drivers downstream of the liner sample can generate sound fields up to 150 dB in both directions;
- Pressurized and heated air is supplied to the inlet with a vacuum system at the exit to sustain grazing flow velocities up to 0.6 Mach.



Test matrix

- Centerline Mach numbers: 0.0, 0.3 and 0.5
- Bulk Mach number: 0.265
- Incident SPL: 130 dB
- Frequency range: 500 to 2500 Hz with 100 Hz steps
- Test sample
  - Hole diameter 0.99 mm
  - POA of 6.3 % for a single chamber
  - Cavity height 38.1 mm



Impedance Eduction Method

Direct Method - KT Algorithm

- The KT algorithm is applied to the equally spaced acoustic field samples from microphones opposite to the liner sample. By decomposing the acoustic field in damped exponetials, it is possible to obtain the axial wavenumber, ζ, of the lined section
- Considering the Ingard-Myers BC, one may find the eigenvalue problem

$$\alpha_n \tan(\alpha_n H) - \frac{Z_0}{\mathrm{i}kZ}(\mathrm{i}k - \mathrm{i}M\zeta_n)^2 = 0$$

and with the dispersion relationship

$$\alpha_n^2 = (k - M\zeta_n)^2 - \zeta_n^2$$

it is possible to evaluate the liner impedance

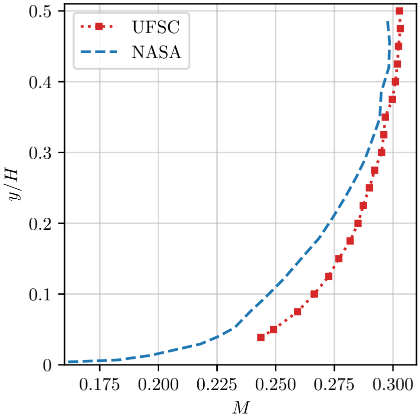
- The Goodrich semiempirical perforate liner impedance model is presented in Yu, Ruiz e Kwan (2008) and is given by

$$Z = Z_{\mathrm{of}} + S_{\mathrm{r}} u_0 + R_{\mathrm{cm}} + \mathrm{i}\left(S_{\mathrm{m}} u_0 - \cot\left(kh\right)\right)$$

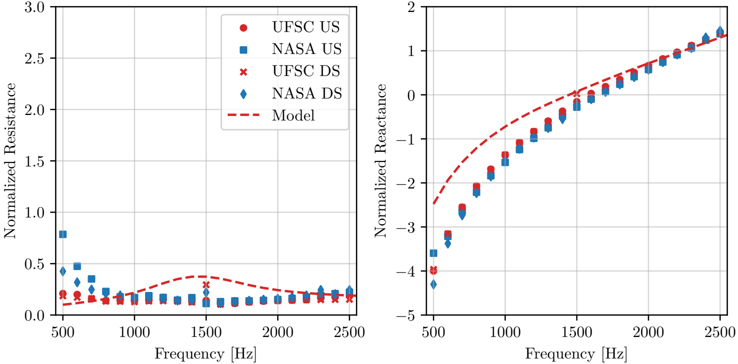
- With the term for the normalized grazing flow induced acoustic resistance being

$$R_{\mathrm{cm}} = \frac{M}{\sigma\left(2 + 1.256\frac{\delta^*}{d}\right)}$$

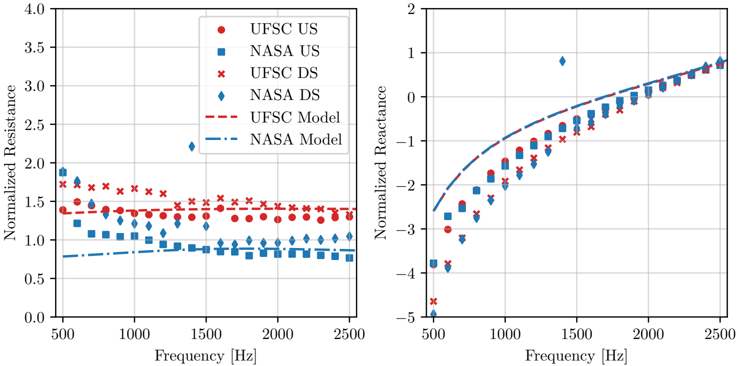
depending not only on the average Mach number, but also the flow profile represented by the boundary layer displacement thickness.



- Different flow profiles were observed in each test rig, the boundary layer displacement thickness was evaluated as $\delta^*_{\mathrm{UFSC}} = 1.02\,\mathrm{mm}$ and $\delta^*_{\mathrm{GFIT}} = 2.60\,\mathrm{mm}$.

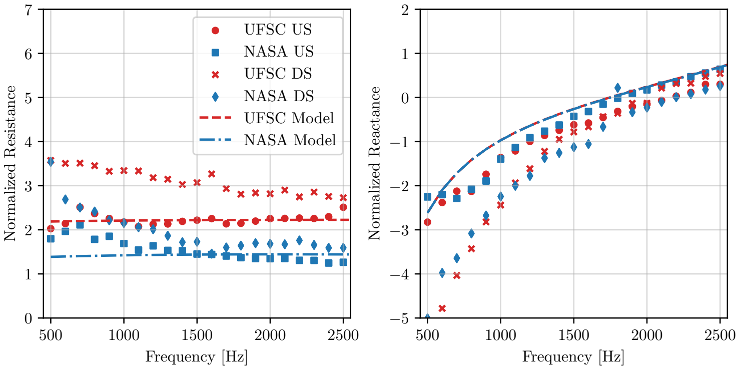


- Good agreement was observed for most frequencies;
- These results show the similarity between samples and the manufacturing process.



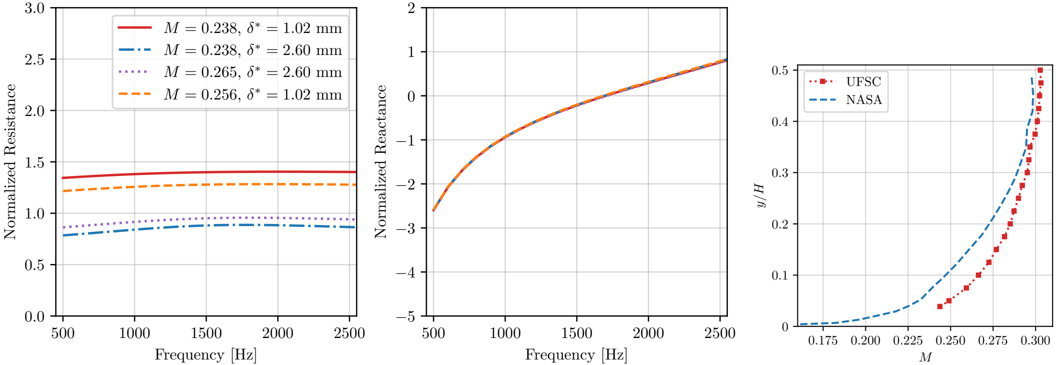
- Very good agreement was observed for the educed reactance with flow;
- Educed resistance with flow is consistently higher for the UFSC facility;
- The semiempirical model captures the change in resistance when accounting for each rig flow profile parameters.

Results - M = 0.5 - 130 dB



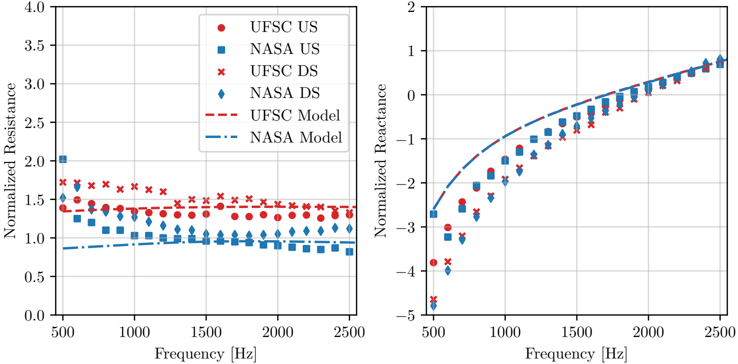
- Similar results to the M = 0.3 case.

Results - Parametric analysis

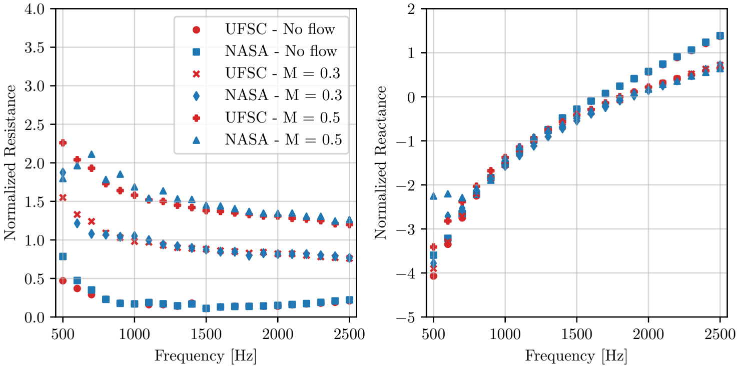


- The effects of average Mach number and flow profile are evaluated.
- Results show that the dominant effect is the flow profile, while the difference due to the average Mach is smaller.

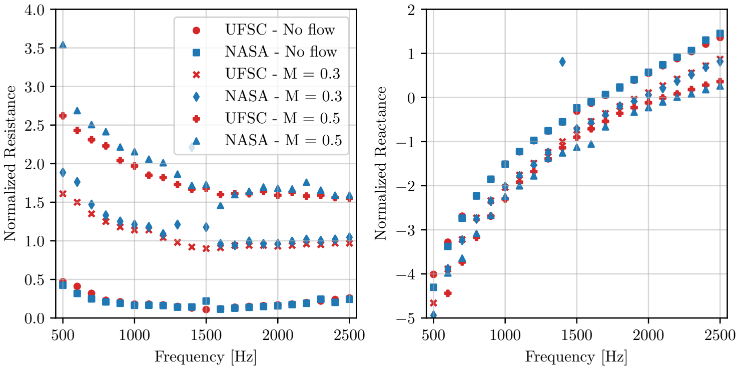
Results - Bulk M = 0.265 - 130 dB



- The same bulk Mach number was targeted at both test rigs to validate the parametric analysis;
- The discrepancy in the educed resistances was still observed;
- This suggests that the flow profile is an important parameter when comparing educed impedances.



- Impedance results using the UFSC and NASA implementations of the Eduction Method with the same dataset compare favorably;
- Results provide high confidence in the implementation of the Eduction Methods by each institution and point to the flow profile differences as the main source of discrepancies



- Results are similar for the downstream source.

Concluding Remarks

- Impedance results obtained by each institution for the no flow case were very similar, indicating identical samples;
- Higher values for the resistance were obtained in the UFSC test rig, when matching the same bulk Mach number or the same centreline Mach number.
- Analysis made with the semiempirical model indicates that the differences are caused by the different flow profiles, represented in the model by the boundary layer displacement thickness.
- Impedance educed using each institution's implementation of the Eduction Method showed great similarity, indicating that the differences previously observed are not caused by the eduction methods.

Acknowledgments

Thanks for your attention!