17th AIAA/CEAS Aeroacoustics Conference (32nd AIAA Aeroacoustics Conference)
05 - 08 June 2011, Portland, Oregon

AIAA 2011-2915

Validation of an Integrated Acoustic Absorber in a Turbine Exit Guide Vane

Dominik Broszat*
MTU Aero Engines GmbH, Department Aerodynamics, Aeroelasticity, Aeroacoustics Turbine
Dachauer Strasse 665, D-80995 Munich, Germany
Ulf Tapken, Lars Enghardt
German Aerospace Center (DLR), Institute of Propulsion Technology,
Berlin, Germany
Davide Lengani, Andreas Marn
Graz University of Technology, Institute of Thermal Turbomachinery and Machine Dynamics,
Graz, Austria

Within the scope of previous papers, the general setup of an acoustic turbine test facility at the Graz University of Technology has been presented. In addition, its significance for the validation of acoustic prediction tools and the verification of noise reduction features related to the LPT (Low Pressure Turbine) has been highlighted.

In contrast to the passive noise reduction feature presented last year, the purpose of the present paper is the verification of an innovative integrated acoustic absorber. It considerably extends the available area for acoustic lining in the tailpipe downstream of the LPT by integrating it into the Turbine Exit Case (TEC).

The innovative absorber has been acoustically designed for a maximum area utilization and tested at the above mentioned cold flow LPT rig. In parallel, numerical predictions based on the MTU in-house Linearized Euler (LEE) tool have been performed and compared to the results of the experimental investigations.

The results show a very promising noise reduction potential of the integrated TEC absorber with a relatively broadband attenuation characteristic that allowed for a noticeable effect at all three acoustic operating conditions as well as the first and second Blade Passage Frequency (BPF). In addition, they, again, demonstrate the adequate correlation of the LEE predictions with the experimental data and its qualification as a design tool.

Abbreviations:

BPF	Blade Passage Frequency	LPT	Low Pressure Turbine
EGV	Exit Guide Vane	PWL	Sound Power Level
GTF	Geared Turbofan	STTF	Subsonic Test Turbine Facility
IGV	Inlet Guide Vane	TEC	Turbine Exit Case
LEE	Linearized Euler Equations	VITAL	EnVIronmenTALly Friendly Aero Engine

I. Introduction/ motivation

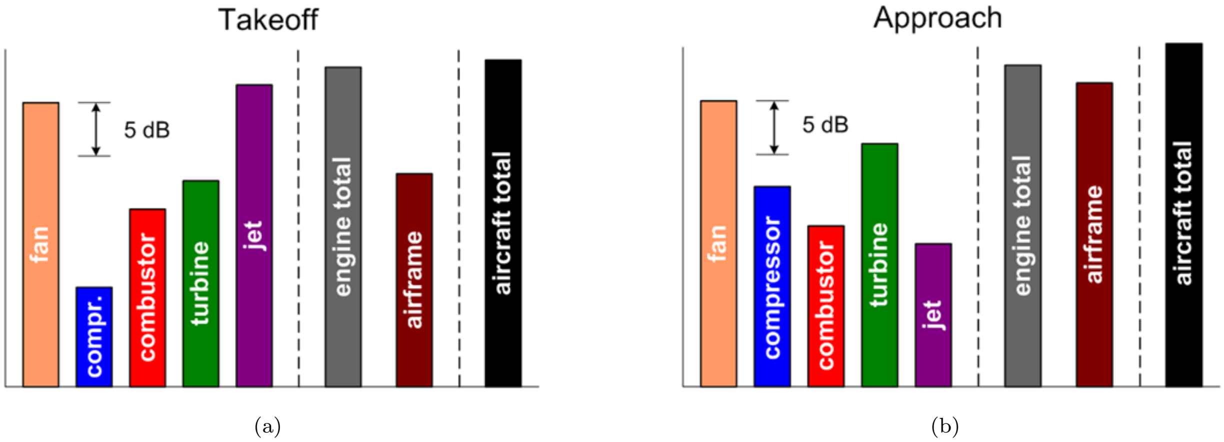
Within the last decades, the noise radiated from aircraft engines has been reduced considerably. This can be attributed to achievements in source noise reduction, configuration or cycle effects, and passive measures to reduce the noise radiated to the far field. The latter refers to a maximization of the acoustically lined area

---

[*] Corresponding author, PhD, AIAA Member, email: dominik.broszat@mtu.de

within the engine inlet and bypass duct. In parallel, both jet and fan noise have been reduced in the course of constantly increasing bypass ratios primarily motivated by the maximization of the propulsion efficiency of the engine.

However, due to these noise reductions of the main contributors to engine noise, other components have recently gained increasing importance, within the rear arc especially the low pressure turbine (LPT). This is especially true in operating conditions where the noise floor of the other engine components is fairly low, e. g. at approach power, such that the LPT can become the dominating noise source within the high frequency range (compare figure 1). Related to current engine developments, this fact gains even more importance in the case of geared turbofan (GTF) designs where fan noise is even more reduced compared to conventional applications, and thus the relative weighting of the LPT increases.



(a) (b)

Figure 1. Contributors to aircraft noise at takeoff and approach (schematic) according to Ref. 1

Motivated by two aspects, namely the validation of the analytical and numerical tools, as well as the verification of noise reduction measures in the LPT domain, an acoustic 1 ½ stage LPT test rig (STTF) has been established at the Graz University of Technology in Graz, Austria within the EU funded project VITAL (EnVIronmenTALly Friendly Aero Engine).

Within the scope of a previous related paper,[2] the general setup of this acoustic test facility (compare figure 2) has been described in more detail. This rig, representative of the last stage of a commercial LPT, has been used in several test campaigns studying the acoustic interaction of relatively rotating blade rows. It consists of one LPT stage (V1 - B1) plus an Inlet (IGV) as well as an Exit Guide Vane (EGV or TEC).

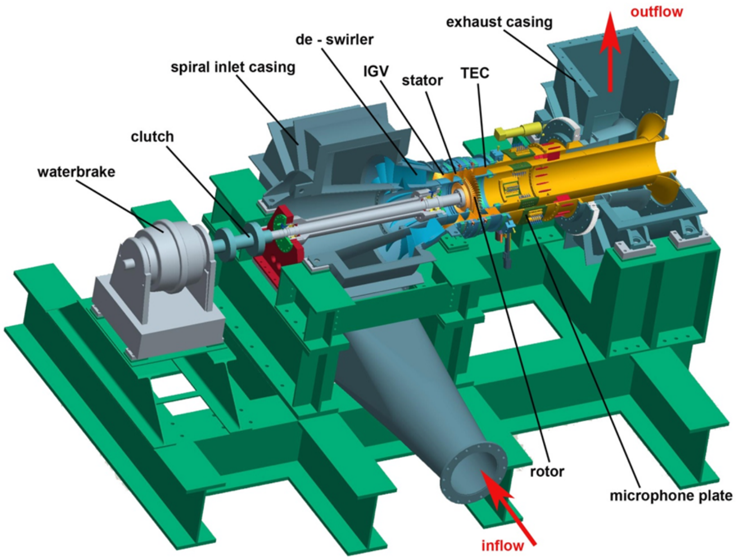


Figure 2. General arrangement of STTF acoustic rig

In addition, the aerodynamic and acoustic measurement positions and the corresponding analysis processes have been explained. Complementary to these experimental investigations, analytical as well as numerical computations of the tonal noise generation of this test rig have been carried out using two MTU in-house tool, a semi-empirical/ analytical code and a Linearized Euler code.

Whereas the two measurement campaigns covered in 2009's paper[2] aimed mainly at the validation of these two prediction tools by means of a reference configuration and a distance variation of the stator and rotor rows, the campaign dealt with in last year's[3] as well the current paper investigate the effect of acoustic measures to reduce the noise generation or propagation at/ through the TEC.

In contrast to the passive noise reduction feature presented in last year's paper which successfully and considerably reduced the interaction of the (last) rotor and the TEC, the current technology acts as an acoustic absorber (or 'liner') on the propagating sound field generated upstream of the TEC. Even if this approach might only be seen as a fall-back solution to recover an increased noise contribution from the turbomachinery section, the usage of acoustic treatment in the hot section might be required due to other boundary conditions or aspects as e. g. the fulfillment of a number of competing design targets of the LPT component, or to meet overall system level noise requirements.

Obviously, in this area, the integration of acoustic liners is quite challenging with respect to the material properties of the treatment. In addition, the available installation space is normally very limited in modern weight optimized designs, especially the in many cases more effective lining area at the outer duct wall. To increase the acoustically effective area, the current technology extends it into the area in between the TEC struts, both at the hub and tip walls. If the proper implementation into the TEC design can be achieved, this represents a considerable increase in lined area and is expected to correspond to a noticeable noise reduction of the LPT. With this background, at first, the verification of the acoustic potential was pursued in an (acoustically) representative environment.

II. Design of the integrated acoustic absorber in the TEC

II.A. Definition of design concept, objectives and acoustic dimensioning

In this specific application, an acoustic absorber had to be integrated into the TEC structure. To maximize the acoustically effective area, both the hub and tip wall area in between the TEC struts have been modified to accommodate the acoustic liner as indicated schematically in figure 3. This allocation yielded an area ratio of the treated area (at the walls) to the throat area in between the TEC struts of approximately AR = 2.1.

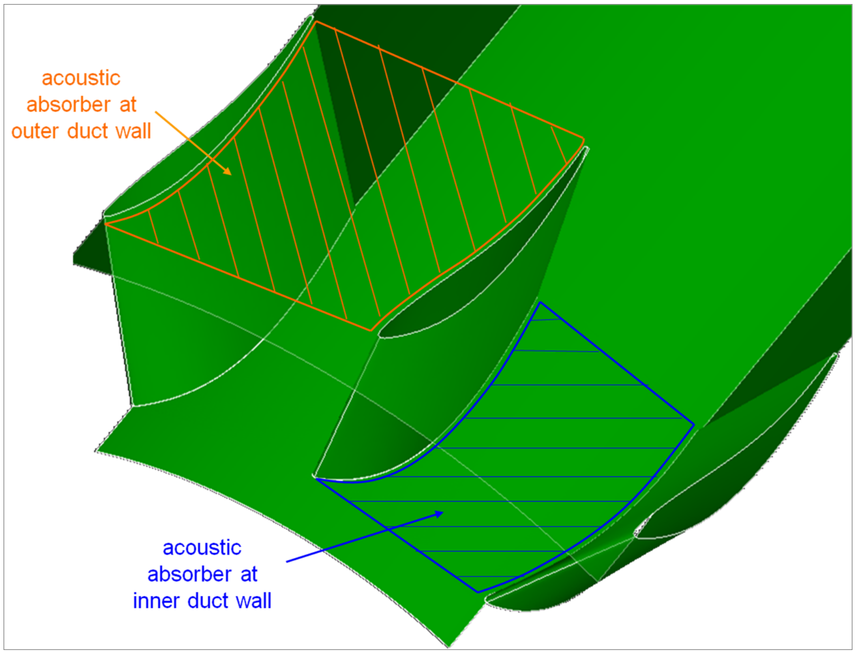


Figure 3. Schematic sketch of acoustic absorber in between TEC struts

According to the specification, the integrated absorber was to be designed for its maximum effectiveness at the BPF (blade passage frequency) at the rig operating conditions corresponding to the acoustically relevant certification points approach and cutback/ flyover, and, if possible, also the sideline condition. In addition, a limited absorber efficiency was targeted at 2 BPF as summarized in table 1.

Table 1. Noise reduction objectives of the integrated acoustic absorber

parameter	unit	Approach	Cutback	Sideline
effectiveness 1BPF	[dB]	-3.0	-3.0	-1.5
effectiveness 2BPF	[dB]	-1.5	-1.5	± 0

To achieve this, a classical $\lambda/4$ absorber setup has been selected due to its favorable variability of the design for either a maximum peak absorption or a more broadband absorption characteristic. It consists of a partitioned cavity of a dedicated cell depth, a rigid backing wall, and a porous facing sheet allowing for the communication with the main flow.

For the acoustic design, at first a preliminary design based on simple analytical equations has been conducted which has then been refined by more refined analytical/ empirical correlations. These take into account e. g. the length correction of the resistive sheet, the effect of a simplified flow model on the acoustic propagation, and determine in the end the effective impedance of the acoustic absorber. This has then been converted into an absorption coefficient and a corresponding acoustic damping.

After defining the optimum acoustic characteristic, this has then been converted into a required cell depth of the back cavity and a desired facing sheet resistance. For the facing sheet, a material named 'Feltmetal'[4] has been selected. It is a porous material for acoustic applications consisting of sintered metal fibers attached to a perforate plate or wire mesh for enhanced structural stiffness. In addition to this, it combines high acoustic absorption factors with a low non-linearity factor and high temperature and corrosion resistance.

II.B. Verification of acoustic effectiveness at lab scale

After defining the geometric dimensions of the acoustic absorber and selecting the corresponding materials, laboratory tests have been conducted using a Kundt's tube to confirm the acoustic design under no flow conditions. Figure 4 shows a comparison of the predicted versus the measured absorption curve.

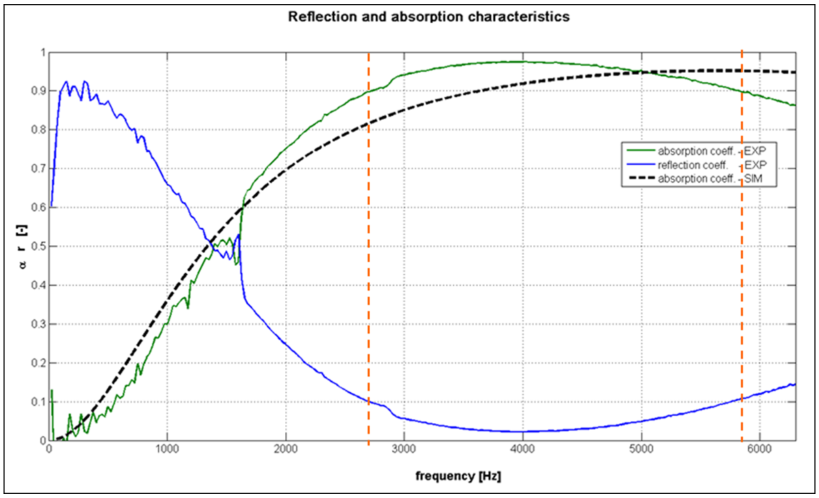


Figure 4. Comparison of absorption coefficient determined by Kundt's tube vs. predictions

The slight shift of the peak absorption value is probably attributed to inaccuracies in the manufacturing of the lab scale material sample. However, in general, the same relatively broadband absorption characteristic can be observed, yielding an absorption coefficient $\alpha \geq 0.9$ for the frequency range between 2700 Hz and 5800 Hz. This target frequency is, of course, shifted under flow conditions to achieve peak absorption at the design frequencies.

III. Experimental validation at the STTF rig

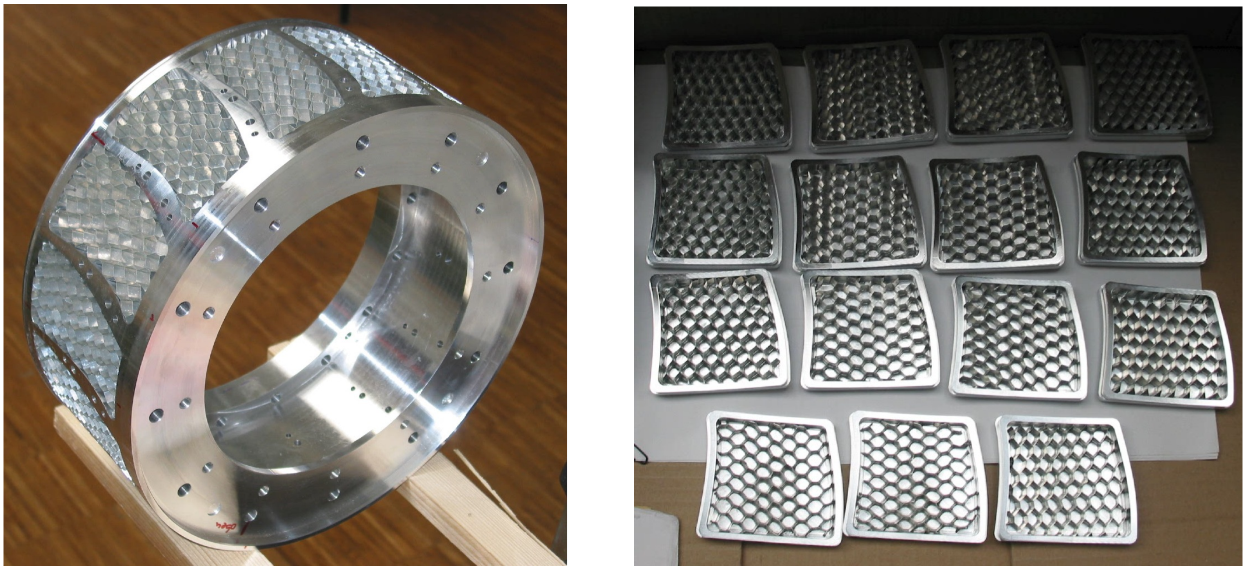
III.A. Acoustic pre-test predictions

For the selected absorber design, steady RANS and LEE (Linearized Euler Equations) calculations have been performed as described in Ref. 2 to predict the acoustic power levels (PWL) of the relevant mode orders at the three acoustic operating conditions. To account for the absorber effect on the propagating sound field, the full set of linearized calculations involving all airfoil interactions (IGV ↔ B1, V1 ↔ B1, B1 ↔ EGV) as well as noise generation mechanisms (wake, potential field) had to be considered. As described in more detail in 2009's paper, the linearized computations are in all cases coupled solutions from the origin of noise generation to the downstream end of the test rig to compare with the experimental results. This implicitly includes scattering effects at downstream blade rows with respect to azimuthal mode order and frequency, in the general case.

In this specific case, also the effect of the acoustic liner was modeled by means of an impedance boundary condition applied to the relevant panels at the inner and outer duct walls.

III.B. Test campaign and acoustic analysis

Whereas for the inner duct wall pockets have been milled into the supporting structure to accommodate the honeycomb cells, separate acoustic absorber boxes have been designed for the areas between the struts at the outer duct wall (compare figure 5).



(a) (b)

Figure 5. Absorber pockets at inner duct wall (a) and absorber boxes for outer duct wall (b)

These were then connected to the structural frame of the TEC by bolting. In both cases, the cell structure consisted of an overexpanded aluminum honeycomb material that combined an adequate flexibility to adapt to the curvature of the absorber pockets (especially at the inner duct wall) with a good temperature resistance under rig testing conditions. As mentioned above, the porous facing sheet consisted of a specific acoustic material that also contributed to the stiffness of the acoustic absorber.

Figure 6 shows a rear view of the fully assembled integrated TEC absorber and demonstrates again that the maximum available area in between the struts has been employed for the acoustic treatment.

For the experimental verification, this modified TEC module has been integrated into the modularly designed STTF rig. After final assembly, this configuration has then been tested at the three operating conditions corresponding to the acoustic certification points approach, cutback, and sideline. After an exact adjustment of the corresponding flow parameters, the pressure time series have been recorded at all microphone positions by a circumferential traverse of the cylindrical acoustic test section downstream of the TEC (compare also Ref. 2).

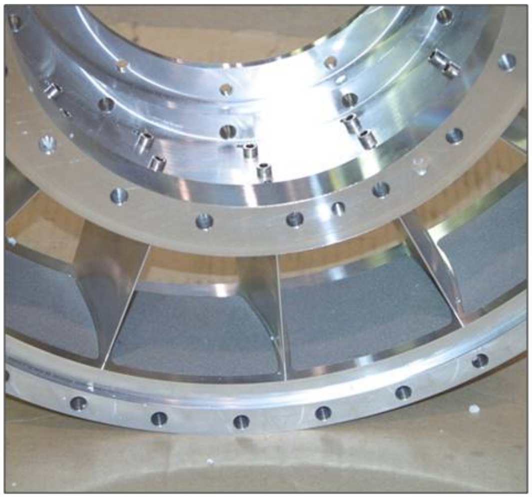


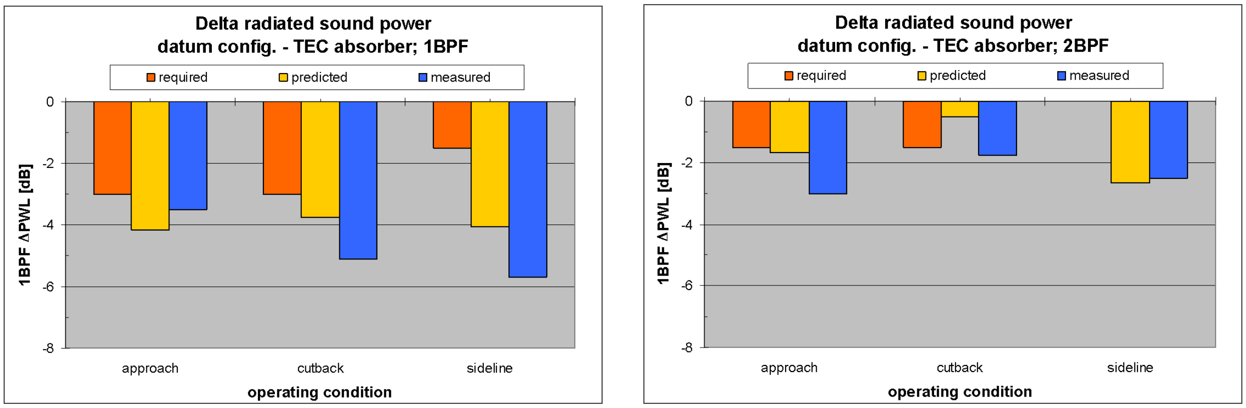
Figure 6. Rear view of the integrated acoustic absorber in the TEC

The recording and the adaptive resampling step (to account for variations in the rotor speed by means of a rotor trigger signal) have been conducted by the Graz University of Technology, the subsequent analysis of the test data has been performed by DLR using their well-known mode analysis technique (compare e. g. Refs. 5, 6).

IV. Comparison of experimental and numerical results

In this section, the correlation of the results of the experimental and numerical study will be assessed. In addition, the acoustic effect of the integrated acoustic TEC absorber will be evaluated with respect to the achieved noise reduction relative to the reference configuration.

On an overall basis, figure 7 co-plots the measured and predicted 1 BPF (7(a)) and 2 BPF (7(a)) PWLs at the three acoustic operating conditions in terms of the PWL reduction relative to the (hard wall) reference configuration, i. e. the acoustic power reduction or insertion loss of the integrated absorber. In addition, the targeted or required noise reduction -as specified in table 1- has been added.



(a) 1 BPF Power Levels

(b) 2 BPF Power Levels

Figure 7. Comparison of experimental and numerical results of acoustic absorber relative to requirements

These plots clearly indicate, on the one hand, the good correlation of the experimental and numerically predicted results, on the other hand the very promising noise reduction effect of the integrated acoustic absorber. At the approach condition at 1 BPF, the LEE tool shows a slight overprediction of the noise reduction potential whereas at almost all other conditions the experimental results even exceed the predicted attenuation. Furthermore, the targeted noise absorber effectiveness has been clearly met at all conditions. Not only at the approach and cutback, but also the sideline condition, a considerable attenuation of between

3.5 dB and 5.7 dB has been experimentally determined at 1 BPF. In addition, the achieved 2 BPF PWL reductions range between 1.8 dB and 3.0 dB.

Overall, the integrated acoustic absorber has shown a very promising noise reduction potential even above the expectations in the design phase. Whether this might also be partly due to the integration into the TEC structure, will be the subject of follow-on research. One possible effect could be the absorption directly at the source of the noise generation B1 ↔ TEC, which is one important contributor at the approach condition where -in this application- the V1 ↔ B1 interaction is designed cut-off. Another effect might be related to the interaction with scattering effects on incident acoustic modes from upstream airfoil interactions.

V. Summary and plan for follow-on work

To considerably increase the available area for acoustic treatment in the tailpipe downstream of the LPT, an integrated acoustic absorber within the TEC structure has been designed by MTU Aero Engines. For the validation of its acoustic effectiveness, a cold flow rig test has been conducted at the Graz University of Technology building on the experience of the previous campaigns presented in last years' papers.

Therefore, at first, a design study of the absorber patches and their integration into the TEC structure has been carried out. Following, corresponding materials have been selected and the acoustic absorption of the lining has been verified at lab scale. Finally, the integrated absorber has been manufactured and tested at the 1 ½ stage LPT rig. Detailed acoustic measurements have been conducted using a well-proven mode analysis technique and been compared to numerical predictions of the acoustic effect using MTU's in-house LEE tool.

The results show a very promising noise reduction potential of the integrated TEC absorber with a relatively broadband attenuation characteristic that allowed for a noticeable effect at all three acoustic operating conditions as well as the first and second BPF. In addition, they, again, demonstrate the adequate correlation of the LEE predictions with the experimental data and its qualification as a design tool.

Concerning follow-on work, the integration of the TEC absorber into a real aircraft engine will be investigated within the EU-funded Clean Sky JTI (Joint Technology Initiative). In this context, the additional requirements and boundary conditions for an integration of this technology into an engine environment will be within the focus, i. e. structural requirements, hot stream environment, available installation space, containment etc.

In addition, additional acoustic investigations are planned to deepen the understanding of this specific noise reduction feature. Part of these will be e. g. the verification of the predicted acoustic impedance under flow conditions and the comparison to a conventional acoustic liner to investigate the effect of its integration into the bladed duct.

Acknowledgments

This work has been carried out in the framework of the European research project VITAL (EnVIronmenTALly Friendly Aero Engine) under grant AIP4-CT-2004-012271. The support of the European Union is gratefully acknowledged. In addition, the authors would like to thank the Aeroacoustics group of EADS Innovation Works Germany for the design and procurement of the TEC absorber.

Follow-on work on the integration of this technology into a demonstrator engine is currently being conducted under the Clean Sky JTI in the SAGE 4 ITD (Integrated Technology Demonstrator).

References

[1] Batard, H., "Aircraft noise reduction: AIRBUS industrial needs in terms of new materials for nacelle liners," *Journées scientifiques de l'ONERA*, 2003.

[2] Broszat, D., Korte, D., Tapken, U., and Moser, M., "Validation of Turbine Noise Prediction Tools with Acoustic Rig Measurements," *AIAA-2009-3283*.

[3] Broszat, D., Kennepohl, F., Tapken, U., Enghardt, L., Lengani, D., and Marn, A., "Validation of an Acoustically 3d-designed Turbine Exit Guide Vane," *AIAA-2010-3806*.

[4] Technetics, "What is Feltmetal," `http://techneticsfl.com/What%20is%20Feltmetal.html`.

[5] Enghardt, L., Tapken, U., Neise, W., Kennepohl, F., and Heinig, K., "Turbine blade/ vane interaction noise: Acoustic mode analysis using in-duct sensor rakes," Vol. AIAA-2001-2153, 2001.

[6] Enghardt, L., Tapken, U., Kornow, O., and Kennepohl, F., "Acoustic mode decomposition of compressor noise under consideration of radial flow profiles," Vol. AIAA-2005-2830, 2005.