PROBAND Deliverable

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STREP PROBAND

Improvement of Fan Broadband Noise Prediction: Experimental Investigation and Computational Modelling

Deliverable D1.6a

Publishable Final Project Results

Report: Proband-DLR-WP1-Task 1.0

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Consortium: DLR (D, Co-ordinator), Rolls-Royce (UK), SNECMA (F), ECL (F), FLU (F), ONERA (F), UPMC (F), ISVR (UK), UCAM (UK), TUB (D), VKI (B), UR3 (I), KTH (S), NLR (NL), CLI (F), ACAT (D)

Summary of final project results

Workpackage 2 (WP2) was dedicated to the development and validation broadband noise prediction methods. Once validated on non rotating airfoils in WP2, these methods were to be applied to fan configuration in WP3 and WP4. As a consequence, WP2 had a major role in the whole project. Moreover it was structured as a self-containing piece of work, where analytical and CFD model developments could be compared to each other and to experimental data. Thus most of the project partners had an activity WP2. This intense activity led to a number and variety of new results:

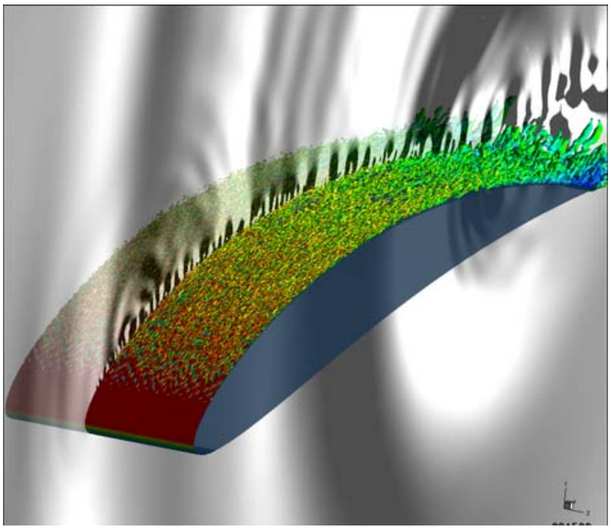


Figure 1: Resolved turbulent boundary layer structures - λ_2 iso-contours coloured with velocity magnitude - and slice with acoustic waves (greyscale)(self noise configuration at AoA = 7° (⇔ 15° exp), U_0=70 m/s; h=0). **[Partner TU Berlin]**

- Tip clearance noise was measured and its sources physically characterised in an experimental approach.
- Self noise was measured in the same experiment, thus the two sources could be quantitatively compared.
- New post-processing tools (based wavelet analysis) helped to shed a new light onto the flow physics.
- A new tip clearance noise model was developed.
- For the first time a tip clearance noise model was successfully applied to experimental flow data.
- An existing self noise model was considerably improved to be applicable in flow configurations that are relevant for real flight conditions.
- An additional model was developed and validated in order to apply the trailing edge noise model to RANS outputs.
- An existing interaction noise model was modified in order to be applied to fan-OGV geometries in WP3 and WP4.
- A new statistic model was developed that can predict the density variance in CFD codes that are not fully unsteady.
- A non rotating single airfoil tip clearance configuration was computed by LES. Mean and RMS flow as well as velocity, wall pressure and far field pressure spectra could be compared to experimental data.
- A non rotating single airfoil Trailing Edge configuration was computed by LES. Mean and RMS flow as well as velocity, wall pressure and far field pressure spectra could be compared to experimental data.
- All CFD codes used in PROBAND were tested on a common test case that consists of a symmetric non lifted airfoil in the far wake of a rod. The ability of the codes to

predicting broadband noise could be quantitatively evaluated. More over, this test case allowed many partners to improve their CFD codes and in particular their turbulence models. It helped them to define the optimal conditions for broadband noise predictions in the turbomachinery context.

Workpackage 3 (WP3) was to provide a parametric study on broadband noise sources in a laboratory-scale fan rig. Advanced measurement and analysis techniques to achieve this were to be developed on this fan rig. The predictions of the broadband noise of the laboratory fan rig were to be evaluated numerically using RANS/semi-analytic methods and validated LES/DES models.

Nearly all of the important deliverables and milestones for the work associated with the first test campaign on the fan rig at DLR have been completed on time or with only minor delays. Analysis of data from configuration 1 and the prediction of the noise using the semi-analytic model have been completed. Agreement between experiment and prediction is generally good. Extensive acoustic and aerodynamic data were collected according to a test matrix defined previously. The second test campaign has also now been completed after an 8 month delay due to manufacturing delays and installation difficulties. This test has focussed on the effect on the broadband noise of increasing the gap between rotor and stator and doubling the number of stator vanes (while halving the chord). The data from this test has been analysed in detail. Preliminary predictions of the broadband noise from this test have been made using the semi-analytic method and have been shown to closely predict the effects of increased fan loading, number of stator vanes and the effect of increasing the gap between rotor and stator. Finally, a new method for analysing the turbulent rotor wake has been proposed and found to give unprecedented insight into its characteristics.

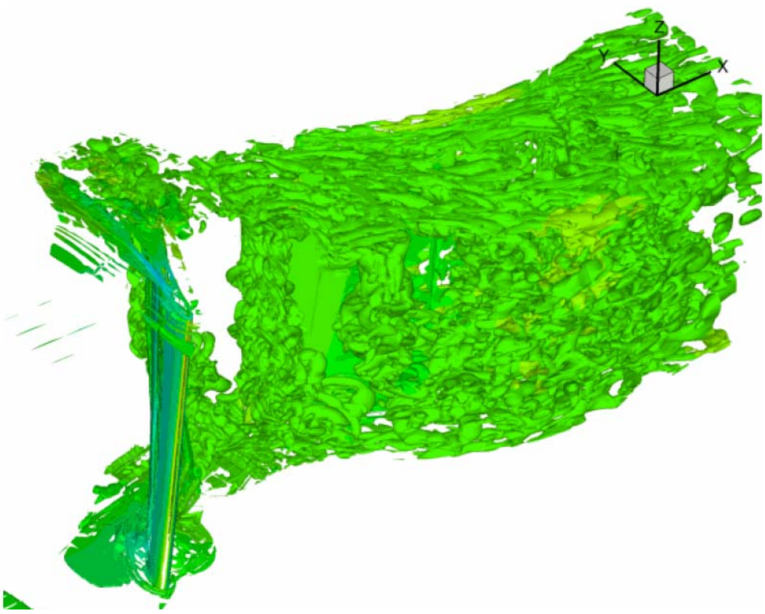


Figure 2: Example 1 of LES simulation results:
Instataneous turbulent flow structures. **[Partner DLR]**

Rolls Royce has continued investigations into the discrepancies observed in earlier work between RANS predictions of the DLR low speed fan stage and measurement. There was an over-prediction of the overall fan performance and comparisons with the DLR hot-wire measurements had shown under-prediction of the rotor hub secondary flow. Rolls-Royce have undertaken a variety of studies aimed at establishing the cause of this discrepancy, including the use of inflow boundary conditions measured by KTH, which corresponded to higher turbulence level and length scale than in initial calculations. Use of the KTH inflow conditions, the inclusion of k-ε and k-ω turbulence models, and the inclusion of a rig centre body upstream of the rotor. In all three cases, the change in the predicted turbulence levels were found to be small compared to the discrepancy sought between measurement and prediction. The source of the discrepancy is currently thought to be some other loss mechanisms not accounted for in the simulation.

DLR has taken the decision to revert from DES to LES. Possible discrepancies between the modeled geometry and the actual physical blades were assessed by scanning actual blade geometry, including the root. Alongside the influence of blade geometry on the quality of the CFD results the impact of the accuracy of the inflow boundary conditions on the simulation results was also investigated. The performance characteristics of the fan stage were re-computed using RANS using the revised rotor blade geometry and the more accurate inflow boundary conditions. The degree of agreement between the measured fan characteristics and the computed values is improved. The impact of the more accurate inflow boundary conditions is however seen to be marginal.

DLR have also undertake additional work on the design of the computational mesh for the first LES computation where it became evident that the resolution of three rotor blades and two stator blades (as was done in the original DES computations) would not be feasible in the LES computations The decision was therefore taken to scale the rotor-stator geometry to change the blade-count-ratio from the physical value of 3:2 to 1:1.

ONERA have developed a model for predicting fan broadband noise. The work is a first attempt at using a LES code called *elsA*, developed by ONERA for providing the unsteady surface pressure inputs to the model. The DLR-Berlin low speed fan are simulated using LES to validate predictions against test results. A grid in 2.5D with more than 12,000,000 nodes has been generated. Twenty locations along the vane chord are selected for the input data to the acoustic code. The predicted sound power levels in the exhaust duct were compared to DLR test data with overall reasonable agreement.

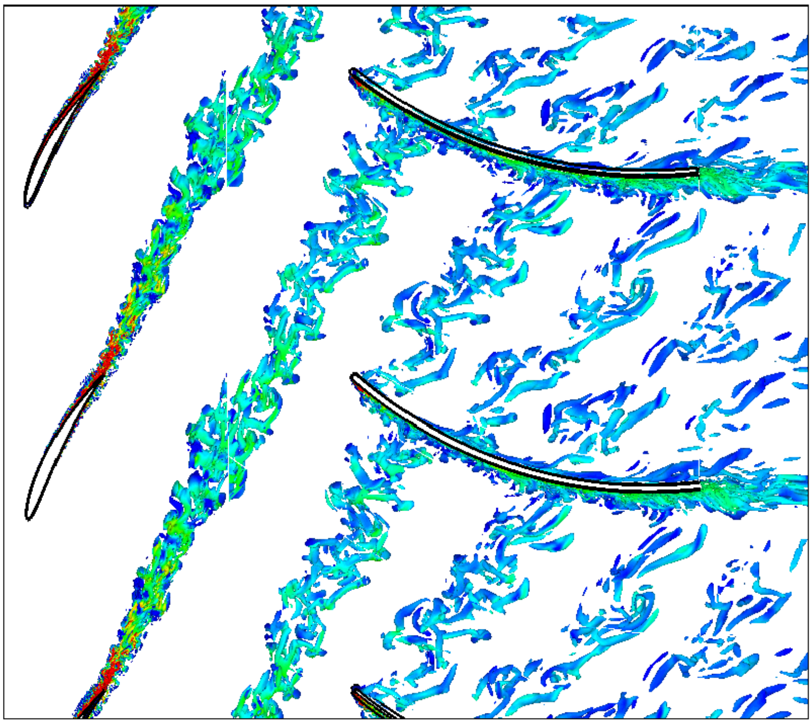


Figure 3: Example 2 of LES simulation results: Interaction between blades and vanes. **[Partner ONERA]**

Workpackage 4 (WP4) was dedicated to the acquisition of detailed broadband noise and turbulence measurements on an Industrial Fan-OGV stage rig at representative flow conditions, and to the demonstration and validation of broadband noise models and CFD methods against this data. The WP4 work built on the model developments and validation in WP2 and on the evaluation of the methods against the low speed fan stage tested in WP3.

The rig test was designed and planned successfully between the partners involved. The Integrated Programme Team was established and worked well on ring and probe design. The rig test was completed successfully in November 2007.

The data acquisition task was done successfully, covering aerodynamics, forward and rear arc noise data, noise data for beamforming analysis, OGV surface pressure, and hot-wire traverses. Noise, aerodynamics and OGV surface pressure data have been made available to partners and used for comparison with noise models and CFD analysis. The hot-wire data is though not available due to a problem in the data recording

The rig test provided the opportunity to obtain a consistent set of aerodynamic and noise data on an industrial fan rig over range of fan speeds and working lines.

Using the beamforming techniques applied to the intake microphone ring, it was shown that broadband noise sources were present on both rotor and stator. By means of the azimuthal mode spectra, it was made plausible that the dominant sources of broadband noise were on the stator. Further application of the beamforming method is required to refine the technique.

The highlights of the RANS / semi-analytic model validation work are

- steady and unsteady RANS predictions of the fan stage were demonstrated to give good prediction of the overall fan stage performance
- use of RANS predicted wake turbulence intensity and length scale in the semi-analytic broadband noise wake interaction model, developed and validated in WP2 and WP3, has given good prediction of the trends of broadband noise variation with fan speed and working line variation
- application of the fan-tip noise model developed in WP2 to the industrial fan stage rig was not successful due to the extent of transonic flow on the blade
- the wake-OGV interaction model has been demonstrated as ready for industrial use

LES simulation methods have been applied to the industrial fan stage using thin section models of the blades and also full annulus height fan and fan-OGV/ESS models. The simulations have been compared where possible to the fan rig test data but the lack of the hot wire data meant that no comparison of turbulence level was possible. Model developments have also been studied for use in turbomachinery LES simulation

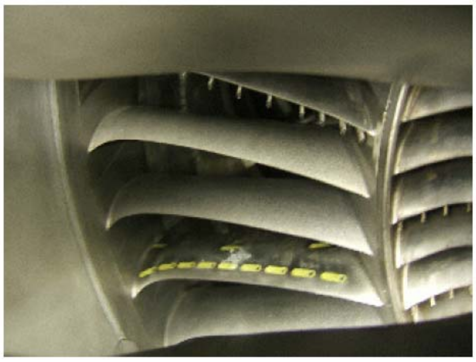
- URANS-LES matching technique
- turbulence forcing techniques for LES
- special periodic boundary conditions

The overall conclusions of the LES simulations are

- the calculations demonstrate the potential capability of LES and DES to predict fan stage turbulence and braodband noise
- computing resource requirement is still very substantial for application of LES and DES to industrial configurations (initialisation run times, mesh requirement at high Reynolds number)
- LES and DES capability has though been demonstrated for application to model geometries (supported by WP2 and WP3 work) for studies of noise generation flow physics and noise reduction measures

(a) Fan rig installed in anechoic chamber

(b) Fan-OGV gap hot wire probe



(c) Inlet flow hot-wire probe

(d) Bypass OGV with Kulites

Figure 4 : Views of the PROBAND WP4 test hardware.
[Partners Anecom Aero Test, Rools-Royce UK, VKI]

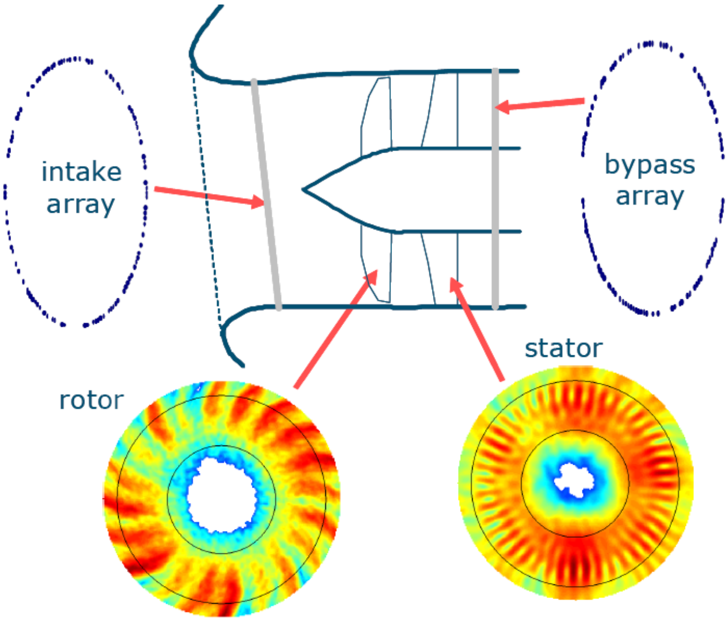


Figure 5 : Typical broadband noise source maps on rotor (obtained with intake microphone ring) and stator (obtained with bypass microphone ring). **[Partner NLR]**