SERRATED TRAILING EDGE NOISE (STENO)

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Table of Contents

1. Abstract

The aim of the STENO project was to investigate the reduction of the aerodynamic noise of a wind turbine by applying serrations (sawteeth) at the trailing edge of the outer part of a blade. At the beginning of the project it was known from wind tunnel experiments performed on two-dimensional (generic) models of wind turbine blades that serrated trailing edges have the potential to reduce boundary-layer trailing-edge (TB-TE or just for short TE) noise by 3-6 dB. TE noise is known to be the most important contributor to the overall (A-weighted) noise level of modern, large wind turbines. To obtain these reductions on a real turbine, it was expected that the shape, orientation and spreading of the serrations had to be optimised as a function of the characteristics of the boundary layer along the rotating blade.

A prediction model developed by TNO/TPD in the parallel JOULE project DRAW [34] was used and extended to the case where the trailing edge is serrated.

The prediction models have been developed and validated using the results of a series of wind tunnel experiments. These experiments were carried out on various models of blade tips in the 2.25x3 m2 closed test section of the Low Speed Wind Tunnel (LST) of the German Dutch Wind Tunnel (DNW) and the 0.4x0.5 m2 anechoic wind tunnel (KAT) of the National Aerospace Laboratory (NLR).

The prediction model has been used to define sawteeth geometries which have been manufactured and mounted on the outer part of one blade of the UNIWEX test turbine of the University of Stuttgart. The measurements of the noise radiated from this blade and of the (untreated) reference blade were carried out using an acoustic parabola.

The analyses of both the UNIWEX and the wind tunnel results have led to the insight that the way the serrations had always been applied during previous (wind tunnel) tests and a (Dutch national) test on a 1 MW turbine is not optimal, i.e. the application of serrations should be applied in such a way that the distortion of the flow streamlines is minimized. If the teeth are applied in this way on a blade of the UNIWEX turbine a noise reduction of 2-3.5 dB is obtained at all frequencies of interest.

With the help of the prediction models developed, the proved noise-reduction capabilities of serrations can be translated into practical guidelines for their optimal application. These guidelines can be followed by blade manufacturers.

2. Partnership

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3. Objectives

The overall objective of the STENO project was the reduction of the turbulent trailing-edge noise, which is the dominant aeroacoustic noise source for state-of-the-art blades, using serrated trailing edges. A second objective was the adaptation and verification of a prediction algorithm for trailing-edge noise with which the aeroacoustic behaviour of wind turbine blades could be guessed a priori.
Serrations were designed and tested in free-field experiments considering different sizes and orientations of the serrations.
The approach comprised three different major activities:

- Wind tunnel measurements:
  The data obtained within the wind tunnel experiments were used for the development and verification of the numerical prediction scheme.

- Scientific preparation, support and evaluation:
  An existing numerical prediction scheme was further developed to cover the application of serrations. The code was used to determine the geometry of serrations to be tested within the free-field measurements.

- Free-field measurements with the UNIWEX turbine using different serrations and applying a measurement scheme which allows a direct comparison.

4. Technical description of the project

The project can be subdivided into three main parts: the wind tunnel measurements, the development of a numerical prediction code and the free-field measurements.
The first part, the wind tunnel measurements, was aimed to provide the necessary fluid flow parameters that were needed later by the numerical code to compute the far-field noise of the serrated trailing edges. In addition, acoustic measurements and measurements of the pressure fluctuations within the boundary layer were conducted for the verification of the numerical prediction scheme.
A numerical model to handle the emitted aero-acoustic far-field noise of serrated trailing edges was implemented. With this code, the serration geometry for the later free-field measurements was determined.
In the third part of the project, the free-field measurements, the results obtained by the numerical simulation were to be verified. Based on the free-field experiences, further improvements of the serration geometry were to be made and tested in further free-field experiments.

4.1 Wind tunnel measurements

The measurements were coordinated with the DRAW project [34],(Development of Design Tools for Reduced Aerodynamic Noise Wind Turbines (JOR3-C95-0083)).
As a consequence, a larger number of models was available and hence, measurements in the LST (Low Speed Wind Tunnel) of DNW-NLR were made possible. Originally, the intention was to carry out all measurements in the KAT (small anechoic wind tunnel). Furthermore, the

models were built in a modular way to be used under different measurement configurations, using a removeable pressure transducer strip.
The wind tunnel experiments had two aims. The flow data were used for the verification/development of the acoustic prediction scheme and for the prediction of the acoustic behaviour of the full-scale tips to be laid-out for the free-field experiments.
Boundary-layer measurements and measurements of the turbulent velocities within the boundary layer were carried out to obtain input data for the later numerical simulation. Acoustic antenna measurements and the evaluation of the unsteady surface-pressure fluctuations within the boundary layer were used to verify the numerical prediction scheme.
On the assumption that the flow does not differ too much between a serrated and unserrated trailing-edge configuration, the measurements were performed with models equipped with unserrated trailing edges.
The wind tunnel measurements are described in more detail in [18, 20].

4.1.1 Measurements in the LST

The LST of NLR in Emmeloord is a closed test section($3m \times 2.25m$) wind tunnel with good flow properties.
In order to simulate the rotating flow properties of the free-field case in the wind tunnel facility with its homogeneous inflow, one of the two wind tunnel models was manufactured with a twist along the spanwise direction [25]. It was determined such that the load distribution along the spanwise direction of the wind tunnel models is almost the same as it would be within a rotating system. The twist angle was set to 1.5^o and was applied at the inner section of the wind tunnel model (LST1). The modular tip part was left untwisted in order to be usable for other measurements.
The models had the airfoil section FX79-W-151A and the tip shape, the so-called Reference tip, which was later used in the free-field measurements. The first model (LST1) had a chord length of $200\ mm$, comparable to those later used in the free-field measurements, and a high aspect ratio, thus leading to good flow conditions. It consisted of the $1400\ mm$ long twisted basic part and the untwisted Reference tip ($200\ mm$). The second model (LST3) had a greater chord length of $800\ mm$ and was $1600\ mm$ long in the spanwise direction. With it's smaller aspect ratio, it was possible to measure higher Reynolds number flows. It also consisted of a basic part and the changeable model tip. Due to the low aspect ratio of the large chord length model, it was not necessary to introduce a twist along the spanwise direction.
Both basic parts of the models had a recess to host the pressure transducer strip. In measurements in which the pressure transducer strip was not needed, the recess was filled with a dummy strip.
In Figure 4.1 the models with their modular design are illustrated.

4.1.2 Measurements in the KAT

This anechoic wind tunnel with an open test section, has the dimensions $0.5m \times 0.4m$. The small test section and the low aspect ratio of the tested (untwisted) models led to a lower flow quality than in the LST.
Its absorption rate is more than 99% for frequencies above $500\ Hz$. The two models (KAT7, KAT8) had a chord length of $200\ mm$ and are illustrated in Figure 4.1.
The 2-d model (KAT7) was compared with the 3-d model (KAT8) to determine the influence of the 3-d flow at the tip area on the integral pressure fluctuations measured at the location of

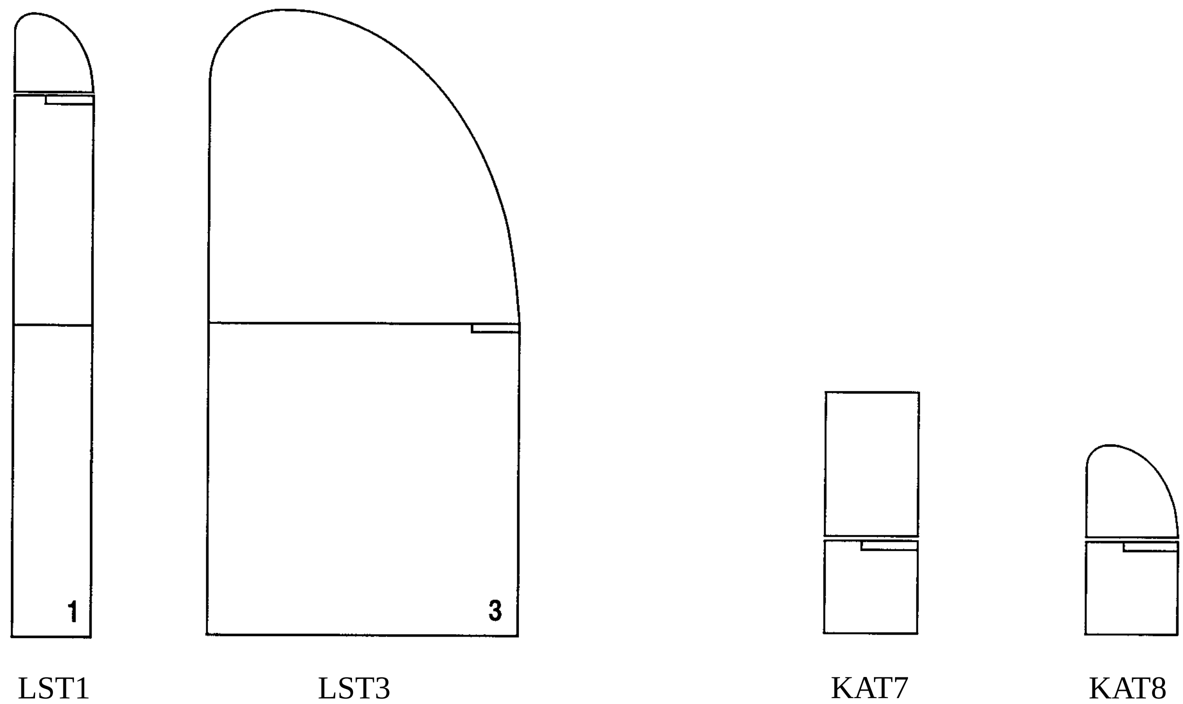


Figure 4.1: STENO models tested in the LST and in the KAT.

the transducer strip. With the acoustic antenna the aero-acoustic noise of the tested models was measured directly.
The measurement of the $k - \omega$ spectra in the KAT made a correlation of the measured pressure fluctuations to the emitted aero-acoustic noise measured by the acoustic antenna possible. However, the deflection of the wind tunnel jet during the experiments restricted the test range to small incidence angles or load distributions respectively.

4.1.3 Measurements performed in the KAT and LST wind tunnel

The following list summarises the measurements done in both wind tunnels. Unless otherwise stated, the measurement was performed in the LST as well as in the KAT.

1. Balance measurements [20] to obtain the loads for different angles of attack, and flow speeds.

2. Flow visualisation with liquid crystals to determine wall streamlines, transition and flow separation

3. Pressure tube measurements to measure velocity profiles at different chord- and span-wise positions and flow configurations, load distributions and flow speeds respectively.

4. Hot wire measurements (cross-wires) for the RMS (root mean square) values of the turbulent boundary-layer velocity fluctuations at different chord positions and at the tip edge.

5. Five-hole rake measurements to measure the velocity profile at several downwind positions behind the trailing edge.

6. Measurements of the $k-\omega$ spectra using the transducer strip which delivers integral unsteady pressure fluctuations at the surface. They are used for the correlation of the turbulent boundary-layer flow fluctuations to the far-field noise.

7. Acoustic antenna measurements (only done in the KAT) to determine the radiated aero-acoustic noise of the tested models.

The measurements performed are summarized in Table 4.1

Model	Balance measurements	Flow visualisation	Pressure tube	Hot wire	Five hole rake	$k-\omega$ spectra	acoustic antenna
LST1	x	x	x	x	x	x	
LST3	x	x	x	x	x	x	
KAT7	x	x	x	x	x	x	x
KAT8	x	x	x	x	x	x	x

Table 4.1: Measurements performed in the wind tunnels with the different models

4.1.4 Results

The results obtained within the wind tunnel measurements were used as input for and for the verification of the numerical prediction code. The experimental data were made available to the project partners. Hardcopies as well as the distribution of larger data sets with data files were used.
In the following, some major results of the wind tunnel measurements are presented.

1. The measurements provided information about the convective velocity, the length scale and the intensity of the boundary-layer turbulence to be used in the numerical code. Evaluation of the data obtained with the three transducer arrays adjusted in chordwise direction yielded that

   - Increasing the geometrical incidence angle led to higher intensities at lower wave numbers and to lower intensities at higher wave numbers at the suction side of the models.
   - The maximum intensity level increased with an increasing geometrical angle of attack.
   - The convective speed of the most intense turbulence varied along the incidence angle. The ratio of the convective speed to the undisturbed tunnel speed varied between $0.5-0.6$, for $C_L = 0$ to $0.3-0.4$, for $C_L = 1.0$.
   - Increasing the Reynolds number led to higher intensities for lower wave-number disturbances and lower intensities at higher wave numbers.

2. Tip flow measurements:
   Within the flow visualisation measurements, the boundary-layer measurement and the five-hole rake measurements, it was found that the region of 3-d flow is limited to a small region, about 50% chord length, at the very tip of the Reference tip used.

4.2 Prediction methods for the effect of trailing edges

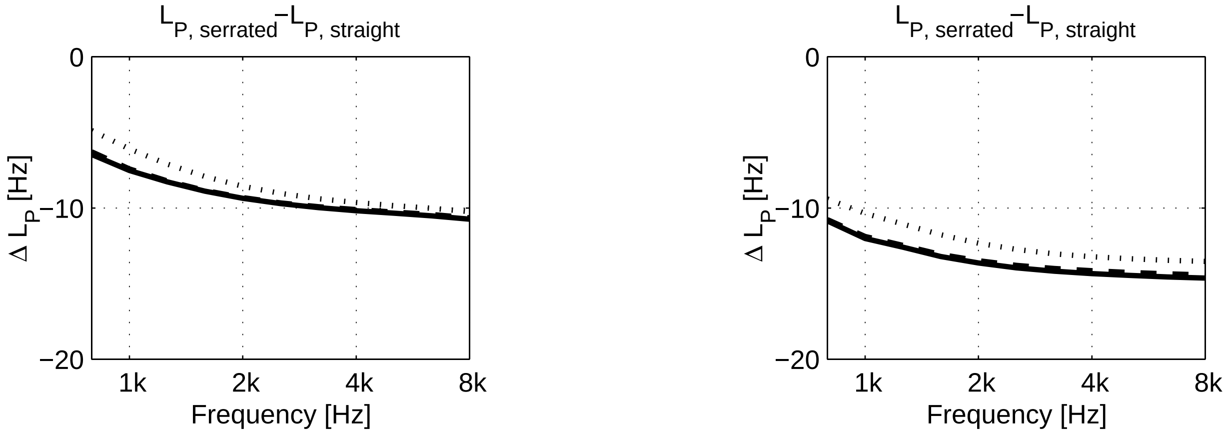
The second main part within the STENO project covered the development of a prediction scheme for serrated trailing edges.
Based on a prediction code for the trailing-edge noise, developed within the DRAW project, an extension for the application of serrated trailing edges was introduced, which is described in detail in the first subsection.
Then an alternative boundary-element algorithm was introduced to predict the far-field noise generated by the diffraction of an incoming subsonic surface-pressure wave at a trailing edge of any arbitrary geometry. Unfortunately, the algorithm turned out to be very computing intensive and thus unusable to compute the far-field noise of a complete wave-number-frequency spectrum. However, the alternative algorithm was used to verify simplifications made in the radiation efficiency using Howe's [26] approach.
For both codes, the $k - \omega$ spectrum of the unsteady surface-pressure fluctuations was needed. Although they were measured within the wind tunnel experiments, these data were only used to verify an algorithm that calculates the $k - \omega$ spectra from some boundary-layer parameters. Since the flow in the LST was representative for the realistic flow around the UNIWEX-blade, the boundary-layer data measurerd in the LST were used for the prediction of its acoustic properties, i.e. for the lay-out of the serrations.
Furthermore, theoretical investigations were drawn on the influence of a skewed wave-number vector for serrated trailing edges. The first free-field measurements had revealed additional high-frequency noise and skewing of the wave-number vector was one possible explanation to be investigated [28]. This was done within the national Dutch research project AORA [30].
Using the developed prediction code, the most efficient geometry of the serrations tested within the free-field measurements at the UNIWEX turbine were specified.

4.2.1 Prediction of the performance of a serrated trailing edge

Using the parameter values determined via the measured $k - \omega$ spectra, the pitot-tube measurements and hot-wire measurements, it is possible to predict the reduction induced by a serrated trailing edge. It appears that the length of the teeth that is needed for a considerable reduction scales with the boundary-layer thickness. Furthermore, it appears that the reduction saturates at a tooth length of approximately 5 to 10 times the boundary-layer thickness. Figure 4.2 shows the results of these predictions for geometries of 40 mm long and 20 mm wide and 40 mm long and 6 mm wide teeth respectively at airfoil loads of $C_L = 0.00$, $C_L = 0.25$ and $C_L = 0.50$ respectively.
These figures show that both serration geometries yield considerable reductions of the radiated noise. They furthermore show that the reduction is only weakly dependent on the airfoil load. Only at $C_L = 0.5$ does the performance of the serrations deteriorate by maximum 2 dB.
Based on these results, it was decided to apply serrations with a length/width ratio of 2 and 6 and a length of approximately 40 mm to be tested within the first round of free-field measurements.

4.3 Free-field measurements

In the third part of the STENO project, the predictions made with the developed numerical algorithm were to be verified under free-field conditions.
Originally, two measurement rounds were planned. For the first round geometries suggested by applying the prediction code were tested. Large discrepancies were found in the aero-acoustic



(2:1 configuration) (6:1 configuration)

Figure 4.2: An analytical estimate of the reduction of the far-field noise induced by application of a serrated trailing edge. (—— $C_L = 0.00$, - - - $C_L = 0.25$, · · · · $C_L = 0.50$)

noise emission between the first round free-field measurement results and the numerical predictions. In the second round, further developed geometries were tested, based on consultation among the project partners after the first round. Together with the additional wind tunnel measurements in the Dutch AORA [30] research program and theoretical considerations using the prediction scheme, the second free-field campaign with the UNIWEX turbine confirmed the considerations that had been made. However, a third campaign was initialised to verify and improve the experience of the Dutch research project AORA and the second measurement campaign. This led to a cost neutral extension of the project by an additional four months granted by the commission.

First, the experimental set-up used within the free-field measurement rounds is described. Two different evaluation procedures for the acoustic measurement data were developed and will also be presented. After the definition of the measurement conditions, the different tested serrations are described together with the results obtained.

4.3.1 Experimental set-ups

The experimental set-ups are based on former research projects [1]. The so-called 'hybrid rotor' configuration was used, i.e. one rotor blade of the turbine is equipped with the experimental blade-tip while at the other rotor blade a Reference blade-tip was mounted allowing for a direct comparison of the two blades.

The experimental blade tips are designed as gloves to be slid on the outer part of the original UNIWEX rotor blades [22]. The gloves had been fixed with fibre reinforced tape. Since the investigation of different serrations had been foreseen, the blade tips were designed in a modular way allowing the exchange of the serrations. All steps and transitions were smoothed with plasticine to avoid additional turbulence and noise. The Planform of the tips was the one of a rather silent dutch industrial blade, already used in former investigations, the airfoil was a FX79-W-151A.

To measure the far-field noise emitted by the tested serrations a parabola microphone with $1.8\ m$ diameter was used. The parabola was placed upwind at a horizontal distance of $24\ m$.

The axis of the parabola was adjusted to the downgoing blade tip when the turbine rotor was in a horizontal position. The dimension of the sensitive area of the parabola, outside of which the attenuation is $\geq 3\ dB$ less than at the axis of the parabola depends on the frequency to be measured and, therefore, the size of the spot seen by the parabola is frequency dependent.
The acoustic signal was recorded continuously and evaluated using a window technique. The correlation with the non-acoustic data monitored by the UNIWEX data acquisition system was achieved by a synchronisation signal.

4.3.2 Data evaluation

During the free-field measurements acoustic and non-acoustic data such as wind speed, rotor rpm, pitch angle etc. were recorded. The non-acoustic data were monitored by the UNIWEX data acquisition system and stored on disk. The acoustic signals were contiuously recorded on a DAT rcorder. During the later evaluaion the relevant acoustic time windows were sorted out and evaluated independently by ECN and ICA applying different procedures.
The non-acoustic data were used to sort the acoustic time windows into different classes (wind speed, rpm, pitch angle and flow-speed, incidence angle resp.). In the ECN procedure the selection of the time windows was done manually by an experienced engineer and they were correlated with the mean values of the non-acoustic data from the respective measurement file of typically 3 min length. The sound pressure recorded in the selected windows were treated with an analog frequency analyser to obtain the A-weighted Sound-Pressure-Level-spectra. In the ICA procedure the mean values of each time window were used and the selection and correlation was done by a computer based algorithm. For the establishment of the SPL-sectra a digital frequency analyser was used. Comparison showed, that for standard cases both procedures delivered the same results.

4.3.3 Definition of the measurement conditions

The wind tunnel experiments at NLR had been performed at different blade loadings since this made a comparison between the differnet wind tunnels possible.
These data were the basis for the numerical simulations done by TNO/TPD. Since it was one intension of the free-field experiments with the UNIWEX turbine to verify the given numerical results, measurements have been performed under the same conditions and therefore blade loads. This strategy was followed in the first round of measurements testing the straight 2:1 serrations. It turned out during the examination of the first round results that testing the serrations and their aero-acoustic behaviour under various angles of attack would be the better strategy. A sweep over a certain range of incidence angles also performed within the first measurement campaign was then used for all other measurement campaigns within STENO.
The rpm of the turbine was set to 50, resulting in a tip speed of approximately $42.7\ \frac{m}{s}$ at the blade position were the full chord length of $200\ mm$ was reached, hence a Reynoldsnumber of approximately $0.6 \cdot 10^6$. The rpm of the turbine was kept constant by an automatic controller increasing or decreasing the rotor moment at the generator side according to the varying wind speeds. Therefore, the pitch setting could be kept constant during the measurements and minor changes in the angle of attack occured only due to variations in wind speed.
The lift coefficients investigated were $C_L = 0; 0.25; 0.5; 0.75; 1.0$.
Table 4.2 shows the minimum and maximum incidence angles achieved for each investigated serration. They depend on the weather situation and normally low and high angles of attack could not be measured on the same day.

Serration	α_{geo} minimum	α_{geo} maximum
Straight 2:1	-1^o	14^o
Straight 6:1	-3^o	14^o
Curved 2:1	-3^o	14^o
Curved 3:1	-2^o	14^o
Bend 2:1	-1^o	14^o
Bend 3:1	-3^o	14^o

Table 4.2: Angle of attack sweeps measured for each tested serration

Serrations with different total lengths, aspect ratios and geometries in the cross section profile (straight, bent, curved) were tested under free-field conditions. The short (40 mm) serrations 2:1 (basis:length) and 6:1 have been suggested by the prediciton code. The longer (60 mm) 3:1 serrations were supposed to improve the low frequency performance and the bending/curving should prevent the flow from the pressure side to the suction side between the teeth.
The following figure shows the schematic concept of the serrations.

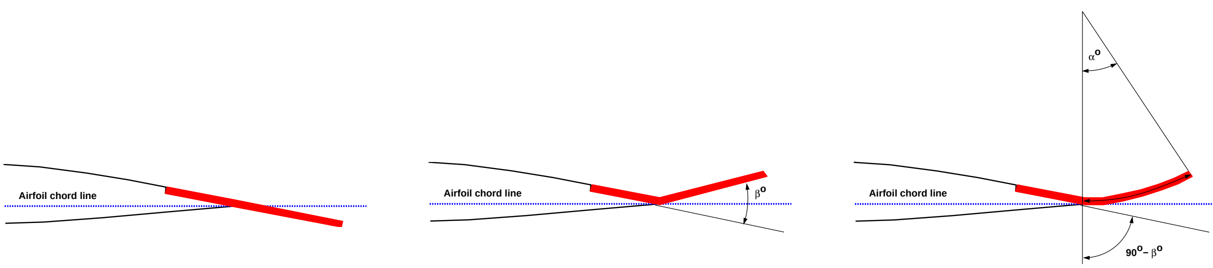


Figure 4.3: Concepts of the tested configurations.

5. Results and Conclusions

Due to the limited space in this report only selected results will be presented. For more details see [12]. The absolute sound pressure level spectra typically had higher levels at lower frequencies (630 - 1250 Hz) and lower levels at higher frequencies. This led to the effect that small reduction in the low frequency region combined with high increase in the high frequency domain still resulted in an overall SPL-reduction. The straight 6:1 and 2:1 serrations delivered rather similar results. The same is true for the 2:1 bent and curved serrations. Therefore only the 2:1 straight and bent and the 3:1 bent serrations are presented here.

5.1 Straight 2:1 serrations

Straight 2:1 serrations were measured against the Reference blade and evaluated by ECN and ICA. The differences in the emitted sound-pressure level are plotted as surface plots (Fig. 5.1) over the frequency and the geometrical incidence angle. Frequencies below $630\ Hz$ are not reliable due to disturbing background noise measured by the ground parabola, the sensitivity area of which becomes larger for decreasing frequencies to be measured. Frequencies higher than $6\ kHz$ are of minor interest, since their sound-pressure level is too low.

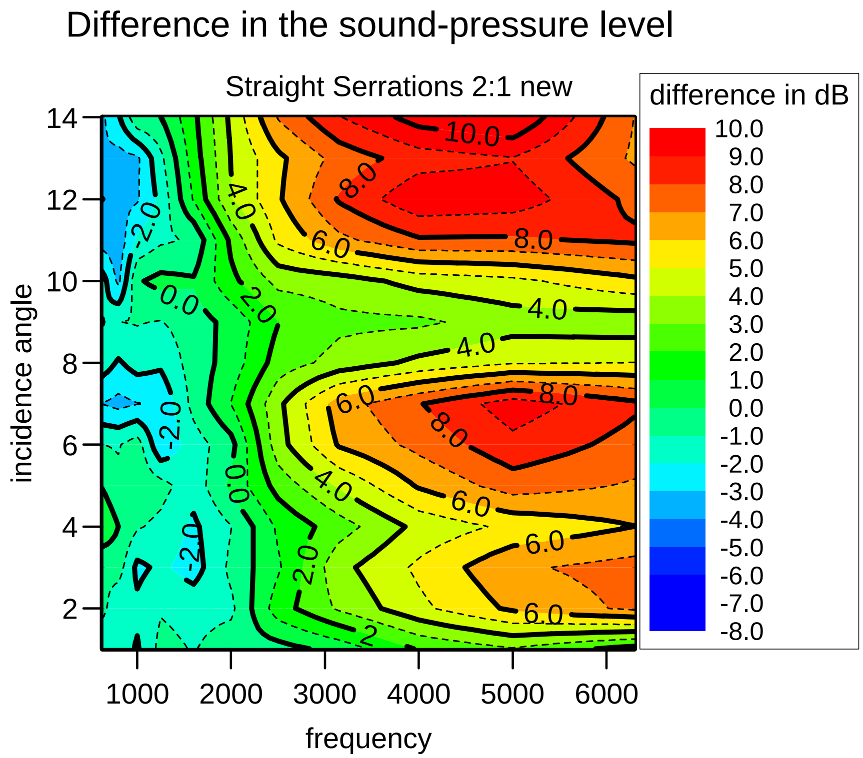


Figure 5.1: Surface plot Straight Serrations 2:1

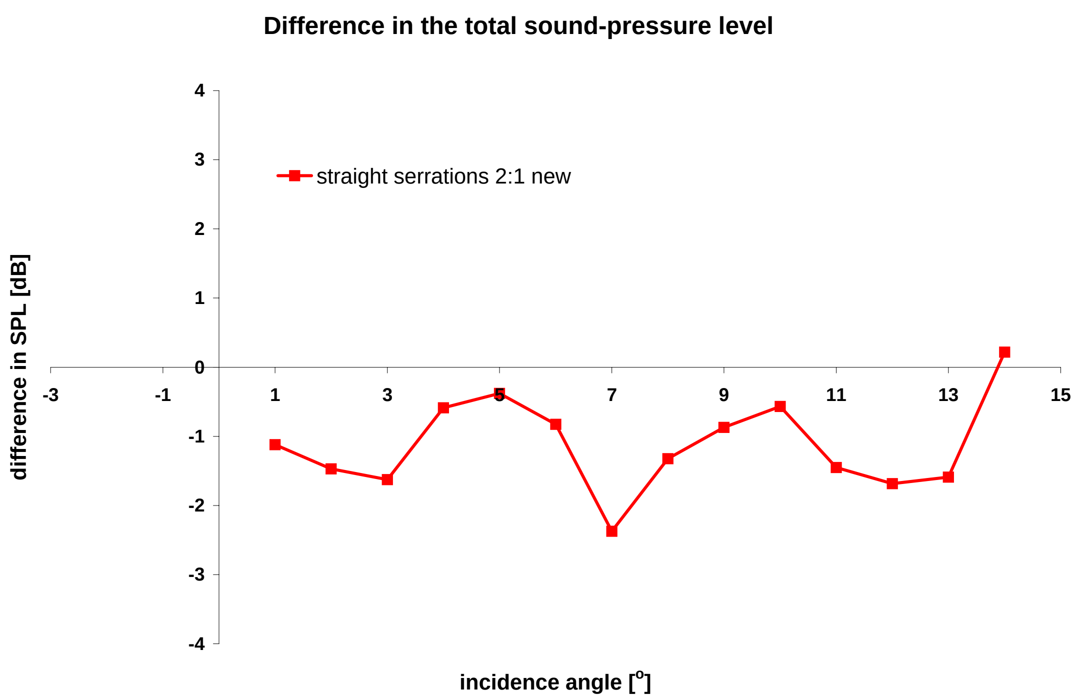


Figure 5.2: Difference in the total SPL. Straight Serrations 2:1

At low and moderate frequencies, a noise reduction of up to $2\ dB$ can be achieved. In contrast to the theoretical and numerical predictions with a noise reduction of about $10\ dB$, however, high-frequency noise increased for medium and high incidence angles. Since the overall emitted aero-acoustic noise is dominated by the lower frequency range, the small reduction revealed there led to an absolute noise reduction of up to $2\ dB$, depending on the angle of attack. In Figure 5.2, the resulting overall emitted noise benefit, which is limited to a certain range of incidence angles, is plotted.
One possible explanation for the discrepancy between the theoretical and measured results was the flow from the pressure side to the suction side between the teeth.

5.2 Bent 2:1 serrations

The bent serrations exhibit better aero-acoustic noise properties. The difference in the total sound-pressure level only increased slightly, but the high-frequency noise decreased as well, confirming qualitatively the theory. A disturbing single tone at 2^o so far could not be explained, it is, however, untypical for TE-noise and probably has a different reason. Qualitatively, there is no difference to the curved 2:1 serrations. A disturbing single tone occurs at 2^o angle of attack. Altough it is not strong as was the case for the curved 2:1 serrations, it still occurs in the dominant $1\ kHz$ band, thus also being found in the absolute sound-pressure difference.

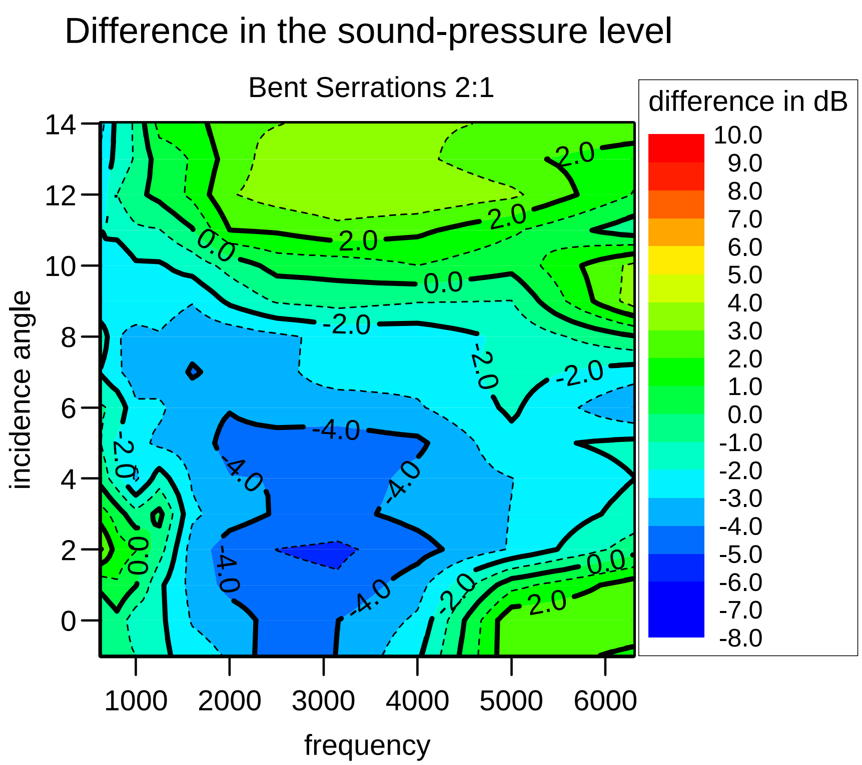


Figure 5.3: Surface plot Bent Serrations 2:1

For rather high incidence angles, the bent serrations tend to be less noisy than the curved serrations, but qualitatively, the plots are the same. There might be an interaction between the fluid flow and the teeth, such that, for the curved serrations under very high angles of attack, when

flow separation at the suction side might occur, the tooth tips are wet by the turbulent boundary layer of the suction side causing additional noise, which might not be the case for the bent serrations.
The reason for the tonal noise component within the $1\ kHz$ frequency band is difficult to explain, since it can be observed in almost all measured configurations with varying strength. This phenomenon probably can only be explained, if further investigations regarding the fluid flow in the presence of the serrations are made.
It turned out that the bent 2:1 serrations have almost the same aero-acoustic noise properties as the curved 2:1 serrations and thus the additional curvature is not necessary for this configuration. Furthermore, the bent 2:1 serrations show slightly better noise characteristics for very high incidence angles.

5.3 Bent 3:1 serrations

Bent serrations, without the additional curvature of the tooth plane were also tested for longer serrations with an aspect ratio of 3:1. The geometrical angle α was set to 0^o and β was again adjusted to 10^o as was the case for the bent 2:1 serrations (comp. Figure 4.3).
In Figure 5.4, the revealed total sound-pressure difference is illustrated over the geometrical incidence angle.

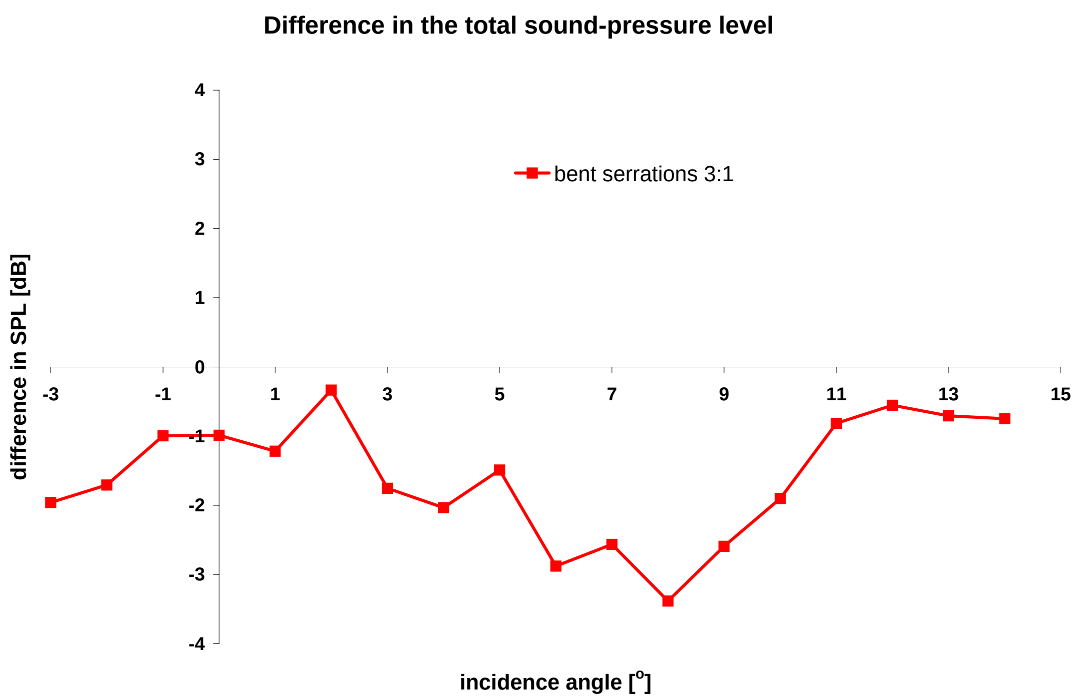


Figure 5.4: Difference in the total SPL. Bent Serrations 3:1

In principle, there is no difference to the result obtained with the shorter bent 2:1 serrations. Only the single tone component for 2^o incidence angle within the $1\ kHz$ band is less strong as was the case for the bent 2:1 serrations, but still exists. The differences in the aero-acoustic sound-pressure level emitted is also plotted within a surface plot over the frequency and the geometric angle of attack, Figure 5.5. The plot is comparable to the results gained with the bent 2:1 serrations, but there are still some differences. The tonal component in the $1\ kHz$ band is smeared over a certain incidence angle range within -2^o up to 3^o with a small peak at 2^o resulting in the peak within the total sound-pressure difference. The maximum noise reduction for moderate frequencies $2\ kHz$ - $4\ kHz$ and lower incidence angles is increased by about $2\ dB$ in comparison to the shorter 2:1 serrations. Hence, the longer serrations seem to be more effective. However, a second additional single tonal component was measured for an incidence angle of 8^o with a frequency of $2\ kHz$. The reason for this single tonal component is not clear yet. Beside an interaction of the fluid flow and the serrations causing additional turbulence, it is very likely that an improperly fixed tape at the transition from the experimental blade to the regular UNIWEX blade might be identified as the reason for this single whistling tone. This could be found out by simply remeasuring the bent 3:1 serrations.

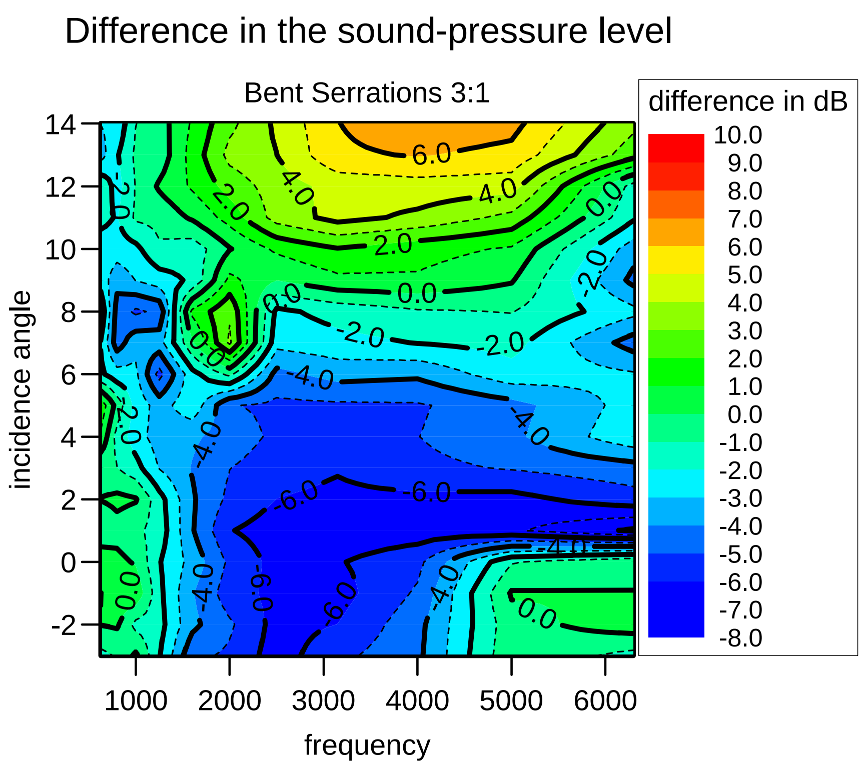


Figure 5.5: Surface plot Bent Serrations 3:1

At higher incidence angles, a noise steady increase in the medium frequency bands can be examined in contrast to bent 2:1 serrations for which this was limited to incidence angles above 14^o. The longer teeth are bent with the same angle β. Thus, it is likely that, for very high incidence angles, the tip of the teeth are more wet by the boundary-layer flow of the suction side than it was the case for the shorter serrations. This flow through the serration plane in the tip region of the teeth might cause additional noise.

The larger maximum reduction in the aero-acoustic noise emitted within the moderate frequency range makes the longer bent 3:1 serrations preferable to the bent 2:1 serrations.

However, the same reduction achieved within the noise dominant $1\ kHz$ band making both serrations comparable again. This limited success and the occuring tonal noise components within the $1\ kHz$ band are more or less independent of the tested serration geometry, and might have its basis in an as yet unknown reason. Without this effect, the longer teeth would show the better noise reduction properties.

6. Exploitation plans and anticipated benefits

In principle there are two exploitable results, the predicition model for the aerodynamic noise from airfoils with serrated trailing edges and guidelines to modify the straight serrations in order to obtain better noise reduction.

The prediction model will be applied in the follow-up project DATA (JOR3-CT98-0248). In this project the design of silent airfoils shall be conducted also applying the prediction code for serrated trailing edges. TNO/TPD besides this may also apply the code within industrial projects. Handling of the code so far is restricted to the developer.

The know-how with respect to the bending of the serrations will be used as well in the above research project. Aerpac, the industrial partner within the STENO project is interested to apply the new serrations to commercial blades, as soon as their effectiveness is proved for commercial turbines. Aerpac sees realistic possibilities for an application especially in the market of inland turbines.

With the reduction of 3,5 dB as obtained in the free-field experiments it should be possible to increase the area for the erection of turbines and therefore the number of turbines by a factor of two due to the reduced minimum distance from dwellings.

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