SEPARATING APART THE CONTRIBUTIONS FROM MULTIPLE TONAL NOISE SOURCES WHICH ARE LOCALIZED TO THE MACH RADIUS

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ABSTRACT

Using classical beamforming methods for localizing unducted tonal turbomachinery noise sources leads to coherent tonal noise sources being localized to their Mach radii rather than their true noise source locations. For certain configurations, the interaction tone noise sources will be localized to a Mach radius of zero. In such instances, the contributions from the rotor, the stator, and even the motor to the noise source appearing on the axis of a beamform map cannot easily be distinguished from one another. Therefore, the contribution of each component to the resulting noise source cannot be determined, and steps cannot be taken toward mitigating these noise sources. Preliminary investigations have been conducted and published, taking steps toward separating these apparent noise sources into their components. This investigation presents further information which is useful in determining the contribution from each rotor blade, each stator blade, and the motor to the beamform peak appearing on the axis. The long term goal of the investigation is to understand the currently available beamforming results of coherent rotating noise sources, gain more information from their beamform maps, and use the newly attained knowledge in order to develop beamforming methods for use in the investigation of coherent rotating noise sources.

1 INTRODUCTION

As the number of turbomachinery applications surrounding us in our everyday lives is increasing, and as competition in the industry is also very strong, the demand for turbomachinery of high efficiency and low noise is on the rise. In order to design such products, and therefore have an edge over the competition, engineers are in need of tools which can help them localize and understand turbomachinery noise sources, and therefore eliminate them at the root of the problem. Phased array microphones and beamforming technology provide a means by which researchers and engineers could gain a vast amount of information regarding where turbomachinery noise sources are located and which noise sources are the most dominant, but first the beamforming results need to be better understood and beamforming methods need to be further developed in order to overcome the difficulties associated with beamforming for turbomachinery applications.

There are many difficulties associated with this task. First of all, the noise sources can be either broadband or tonal. This in itself does not cause too much difficulty, as long as it is kept in mind while processing the results. When taken into consideration that the noise sources are also rotating, are distributed along multiple radial arms (rotors or stators) in the same radial positions, many of the tonal noise sources are of relatively low frequency and also coherent, most turbomachinery applications require a ducted system, turbomachinery produces a pressure rise and hence a windy environment, a large number of noise sources are concentrated in a small area, and background noise is also significant, the problem becomes very complex.

With regard to the difficulties associated with the beamforming of turbomachinery, the following paragraphs provide a glimpse into the advancements which have been made in this area in order to determine the state of the art and to show which areas require further development. Traditional beamforming methods, such as the classical frequency-domain based Delay & Sum (DS) method [1], are better suited to the investigation of stationary noise sources. Advancements to the basic beamforming methods have provided a means of investigating moving sources, including rotating sources [2-4]. These methods are very useful in identifying rotating incoherent noise sources, and therefore play an important role in localizing many broadband noise sources and some tonal noise sources. If the frequencies are high enough, then the noise sources can be pinpointed to various sections of the individual airfoils. From among these methods, this investigation applies the Rotating Source Identifier (ROSI) method [2]. With regard to our intended use, the drawback of these methods is that they are not capable of identifying coherent noise sources, such as interaction tones. Another drawback of the ROSI method is that it is formulated in the time-domain, and therefore advanced beamforming and deconvolution methods cannot be applied in the rotating reference frame when applying this method.

If the frequency under investigation is relatively low (as to be expected for a typical rotation speed of approximately 3000 RPM), advanced beamforming methods can be applied in order to improve the resolution of the beamform maps. This is necessary, since the physical size of these machines is often relatively small and the number of noise sources located within that space is large. There are many beamforming methods that fall into this category, but it is the opinion of the corresponding author that these methods need to be handled with care, as they are usually designed for a specific type of problem and can also trick the user into misinterpreting the results presented in the beamform maps if used incorrectly. It should also be mentioned that many of these advanced beamforming methods work in the frequency domain, while some of the methods that put the results into a rotating reference frame work in the time domain. For our purposes, further research will need to focus on prescribing a beamforming methodology which can help in separating apart and localizing low frequency tonal and broadband turbomachinery noise sources without losing information or leading to the misinterpretation of the results.

Turbomachinery interaction tones are most often coherent, since the same noise source appears on each of the rotor or stator blades in a given turbomachinery stage. The phase difference between the sources depends on the number of rotor and stator blades. These coherent noise sources are therefore often evenly distributed around the circumference of the turbomachinery under investigation, at a given radial position. The noise source on the rotor is rotating around the axis, while the noise source on the stator is stationary in an absolute reference frame and vice versa in a rotating reference frame. It has been shown in [5] that coherent noise sources of unducted turbomachinery will be localized to their apparent noise source positions rather than their true noise source positions. These apparent noise sources are localized to the so called “Mach radius” or “sonic radius”, and can be calculated from the theory presented in [6]. The reason for this interesting occurrence is that the wave fronts of the individual coherent noise sources add up constructively and destructively and form newer wave fronts that appear to propagate from an apparent noise source which is located at the Mach radius, when examined using beamforming technology [5]. It was shown in [7] that there are certain worst case scenarios where the noise sources of a rotor, a stator, and a motor can all be localized to the same Mach radius, which is located on the axis. This investigation showed that in evaluating the beamform maps of coherent turbomachinery noise sources, care has to be taken in order to accurately evaluate the noise sources which are located on the beamform maps as the coherent noise sources (rotating or stationary) will all be localized to their Mach radii. In [8], steps were taken toward determining the contribution from each individual coherent noise source with the help of an equation which is analogous to the basic acoustic equation for adding levels. It was determined that in both the rotating as well as absolute reference frame the amplitude of the resulting apparent noise source will be the same. The above presented investigations have presented a theory which explains where coherent unducted turbomachinery noise sources will be located [5, 7], and how to determine the contribution from each individual equal strength source once the motor, rotor, and stator noise sources are separated from one another [8], but it is yet to be presented how the motor, rotor, and stator noise sources are to be separated from one another and how to determine the radial positions of the noise sources, which is key.

The literature provides information regarding ducted phased array microphone systems and beamforming methods [1, 9-13]. As in the investigation of coherent turbomachinery noise sources, these investigations need to take into account acoustic modes (in this case, duct modes), which are key to the understanding of the beamforming results. Though most unducted applications dealt with in the previous paragraphs can be set up in a manner which makes it possible to avoid difficulties resulting from airflow passing over the microphones, placing the microphones in the ducts requires that extra care be taken in setting up, executing, as well as processing the results [1]. Though the research presented in this investigation is for unducted turbomachinery, both cases deal with acoustic modes, and it is hoped that what is learned from unducted turbomachinery will help in further developing the state of the art of beamforming technology with regard to ducted turbomachinery systems and vice versa.

The above stated advancements in the state of the art of beamforming for turbomachinery applications, as well as many others, are continuously bringing us closer to fully understanding turbomachinery noise source maps, but many of these areas have not yet been fully understood. One such area is that of beamforming coherent turbomachinery noise sources which have a Mach radius of zero, which is further investigated here. Though it has been shown that these noise sources are localized to their Mach radii [5, 7], and that once localized to their apparent noise sources, the contribution from each individual noise source on a rotor or stator blade can be determined [8], it has yet to be shown how the 3 noise sources (motor, rotor, and stator) can be separated from one another and how the radial positions of the noise sources can be determined. This investigation looks at preliminary test cases regarding the beamforming of coherent turbomachinery noise sources which are localized to a Mach radius of zero with the help of simulated noise sources, introducing a method for determining the true radial position of the noise sources. One might wonder why such a large amount of effort is invested in determining the true location of noise sources localized to the axis instead of dealing with cases where the Mach radius has a value larger than zero, or cases where the true noise source position can be determined from the measurements. From one point of view, this is a worst case scenario, where three possible noise sources (including coherent noise sources) can be localized to the same point, making it exceptionally difficult to separate the one from the other and then determine its true radial position. From another point of view, preliminary results of counter-rotating open rotor research conducted by the authors has shown that designing these unducted propulsion systems to have a Mach radius of zero could prove very useful and important, but this topic is beyond the scope of the present investigation.

2 INVESTIGATED TEST CASES

This investigation looks at simulated test cases for a turbomachinery stage which consists of a rotor, guide vanes, and the motor which drives the rotor. The reason for using a synthetic test case is that it allows for the investigation of each noise component independently from the others in a controlled environment. Figure 1 provides a schematic of the test case being investigated. The (ξ, η, ζ) coordinate system is fixed in space to the point where the phased array is initially located. The ζ axis passes through the center of the array as well as the axis of the turbomachinery under investigation.

The position of each turbomachinery noise source is defined in this coordinate system. Each noise source can be defined if the ζ coordinate, the radial position r, the initial angle θ, the rotational frequency n, amplitude, frequency, and initial phase are known. The phased array can also be repositioned in the (ξ, η, ζ) coordinate system by a value $\Delta \underline{r}$ and rotated about its own y axis by angle ΔΨ. The (x, y) coordinate system is fixed to the center of the array and will be seen in the beamform maps. The synthetic array is of the same design as the Optinav Inc. Array 24: Microphone Phased Array System. It has a diameter of 1 m, and the microphones are distributed along logarithmic spiral arms.

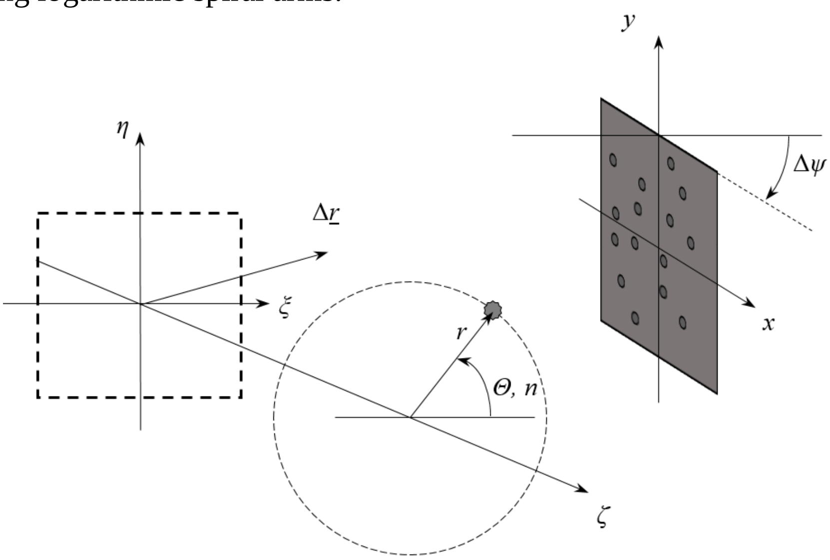

Fig. 1. Coordinate system of the test case under investigation.

The noise sources of the rotor blades, guide vanes, and the motor are represented by coherent monopole noise sources of equal amplitude. At present a single noise source is placed on each blade tip and one is placed on the axis of the motor. The noise sources radiate at a specified frequency of 3000 Hz and are in-phase. Future investigations will look at distributed sources and other more complex noise sources. The rotor under investigation has 15 blades and rotates at -200 revolutions per second. There are also 15 stationary guide vanes, and, unless otherwise stated, the diameter of the rotor and the guide vane is 0.4 m. The resulting interaction tone radiates from both the rotor and the guide vane at a frequency of 3000 Hz. The motor also radiates at 3000 Hz, which can be imagined to be a harmonic of the motor noise. The test case was designed to have a relatively high frequency, in order to avoid resolution issues in the results, and therefore would be difficult to realize in real life. Unless otherwise stated, the phased array is located in its initial position of (0, 0, 0), facing the ζ direction and the turbomachinery noise sources are located in the ζ= 0.3 m plane.

3 NOISE SOURCE GENERATION

The synthetic acoustic signals were created using an in-house program implemented in GNU Octave [14]. The program is capable of generating pressure time series at predefined microphone positions in case of multiple stationary as well as rotating tonal, monopole noise sources. It operates in the following manner: First, the program generates the required harmonic wave with the specified frequency, amplitude, and phase at equally distributed time instances. This is the emitted noise as observed from a set of coordinates fixed to the source. Then the position of the source is calculated as a function of time, taking its initial angular position, radius, angular velocity, and distance from the array plane into account. The propagation time delays are then calculated for each emission time instant using the instantaneous distances between the source and the receiving microphones and the speed of sound. The decrease in amplitude due to the spreading of the wave front is also taken into consideration. In this way, the instantaneous pressure values are obtained for a set of microphone arrival times. However, the arrival times are no longer equidistantly spaced in the case of moving sources. This is resulting from the Doppler-effect. For further processing, the data is interpolated for a specified sampling frequency, using piecewise cubic interpolation in order to form a uniformly distributed time series. To improve the interpolation, the sound generation steps are carried out with a sampling frequency that is three times larger than that of the final sampling frequency. Care has been taken to avoid extrapolation. This method is repeated for all sources, after which the results are summed for each individual microphone position, creating the sound file of that channel of the phased array. In preliminary tests, the method has reliably produced the required sound samples with a signal-to-noise ratio of over 60 dB.

4 PROCESSING OF THE DATA

The simulation data is processed by in-house beamforming software, which was also implemented in GNU Octave [14]. The files that were processed have a sample length of 2 seconds and a sampling frequency of 44100 Hz. Fourier transformations are carried out on 2048 elements at a time, with use of a Hanning window and a 50% overlap. Two types of algorithms are used: the classical frequency-domain based Delay & Sum (DS) method [1], which can localize stationary sources in an absolute reference frame, and the Rotating Source Identifier (ROSI) method [2], which can localize sources which are stationary in a rotating reference frame. The diagonal elements of the cross-spectral matrices are not removed, as previous investigations have shown that diagonal removal has no positive influence on the results in case of synthetic noise sources. Beamforming is done for narrowband and third-octave band frequency bins. The results provide beamform maps, which display the magnitudes and the positions of the strongest sources located in the investigated plane for a given frequency range.

The magnitudes of the beamform map sources are presented as levels which are calculated from sound pressure squared values which have been corrected for sound intensity attenuation with regard to distance. The values are therefore given with regard to the source position. The results are converted to and presented as power spectral density (PSD) results. The reference value used in the calculation of the levels is $2x10^{-5}$ Pa.

5 RESULTS

5.1 Axially aligned, single noise source investigation

A large portion of this investigation looks at the basic test cases described in chapter 2, where a rotor, guide vanes, and a motor are investigated from the axial direction. First, the three sets of noise sources are looked at individually, since this provides us with some useful information regarding the processing of noise sources which are localized to their Mach radii and a set of reference data to which further cases can be compared when the three sets of noise sources are looked at simultaneously.

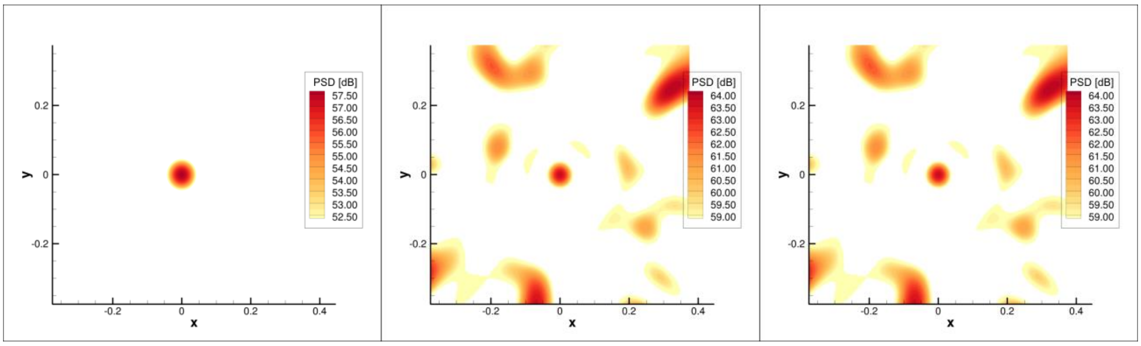

Fig. 2. DS beamform maps of turbomachinery noise sources investigated from the axial direction (narrowband, ζ=0.3 m): motor (left), rotor blades (middle), guide vanes (right).

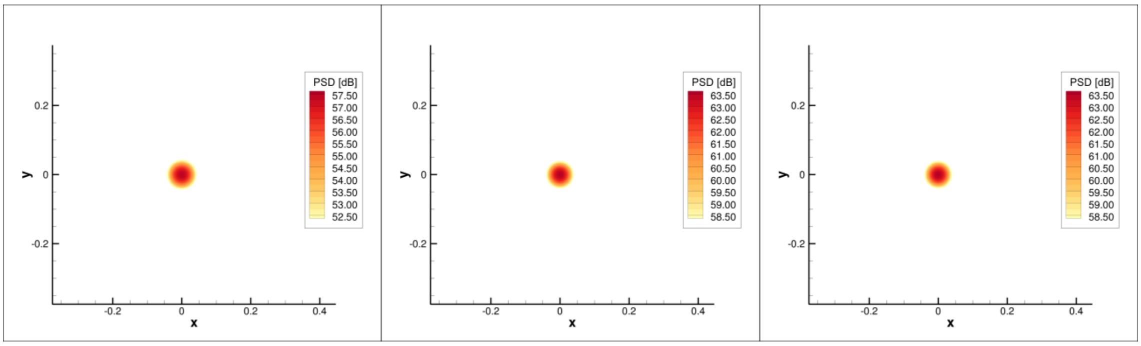

Fig. 3. ROSI beamform maps of turbomachinery noise sources investigated from the axial direction (narrowband, ζ=0.3 m): motor (left), rotor blades (middle), guide vanes (right).

Figure 2 shows narrowband DS results for a turbomachinery test case which is located in the ζ=0.3 m plane (see description in chapter 2). First only a motor is investigated, which is the first of the three figures (located on the left side). As expected, the noise source appears at its true position, on the axis. The beamform map for the rotor is located in the middle, and the one for the guide vane is located on the right. As described in [5,7] the apparent noise sources of coherent noise sources of turbomachinery are localized to their Mach radii, which for this case is on the axis (0, 0, 0.3), instead of their true positions, which is circumferentially distributed at a radius of 0.2 m in the ζ=0.3 m plane. The beamform maps and the magnitudes of the two apparent noise sources located on the axis are similar, as would be expected according to [8].

In Fig. 3 a similar set of beamform maps can be seen, but in this case the results are produced by applying the ROSI method. It can be seen that the results contain less sidelobes. The results for the rotor and the guide vane show the apparent noise source as localized to the Mach radius, and the levels are similar to those seen in the DS results, as expected according to the results in [8].

Taking a look at the third-octave band results for the same investigations, it can be seen that the DS results in Fig. 4 are very similar to the DS results attained using narrowband processing (see Fig. 2), except for the peak values being slightly larger here. Comparing the DS results (Fig. 4) to the ROSI results in Fig. 5, it can be seen that the amplitudes of the apparent noise sources are almost the same, as would be expected according to the investigations published in [8].

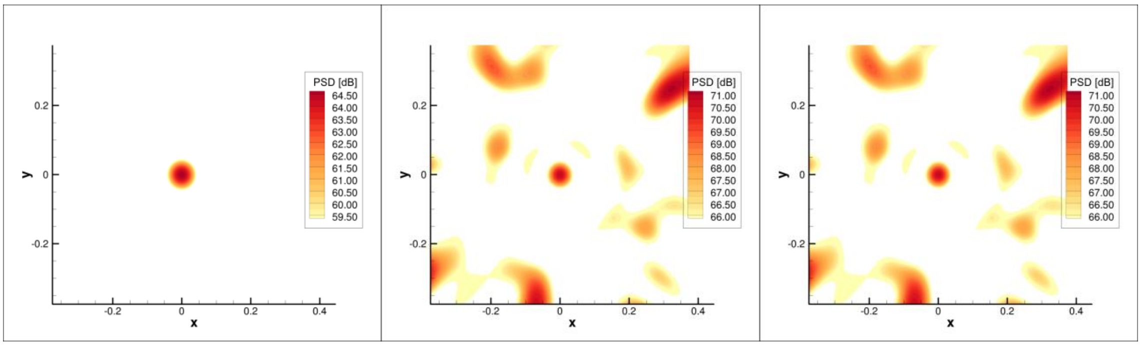

Fig. 4. DS beamform maps of turbomachinery noise sources investigated from the axial direction (third-octave band, ζ=0.3 m): motor (left), rotor blades (middle), guide vanes (right).

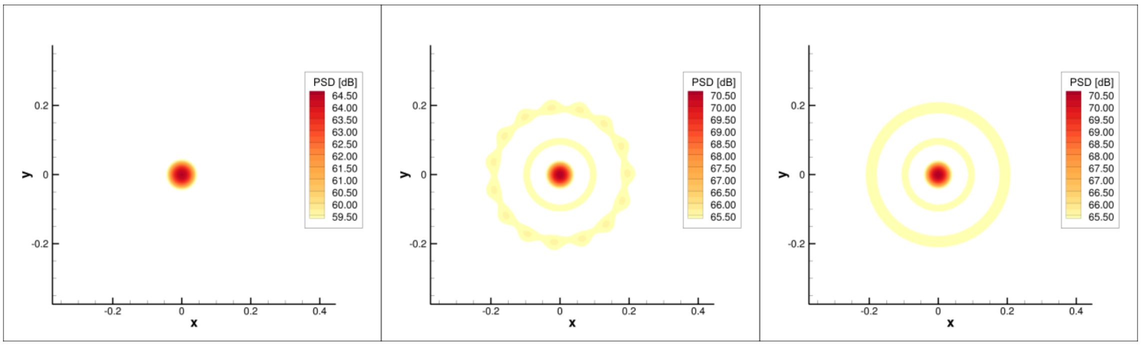

Fig. 5. ROSI beamform maps of turbomachinery noise sources investigated from the axial direction (third-octave band, ζ=0.3 m): motor (left), rotor blades (middle), guide vanes (right).

Investigating the third-octave ROSI beamform maps displayed in Fig. 5, an interesting difference can be seen when comparing them to the narrowband beamform maps provided in Fig. 3. As with the DS beamform maps, the amplitudes are slightly larger for the third-octave results as compared to the narrowband investigations, but what is interesting from our point of view is the ring which appears around the apparent noise source for the case of the rotor and the guide vane. For the motor (left side portion of the figure), no such ring appears. Therefore, this ring is most likely not associated with a noise source which is truly located on the axis in the form of a sidelobe. The ring appears at the radial position where the rotor and guide vane noise sources are truly positioned, and therefore seems to hint at the true location of the noise sources. For the rotating coherent noise sources (middle portion of the figure), the ring consists of 15 individual noise sources, the number of actual noise sources being investigated here, which also agrees with the number of spaces located between the individual noise sources. For the stationary coherent noise sources (right side portion of the figure), a solid ring appears on the beamform map. This information is interesting for us with regard to determining the true noise source locations and will be discussed below.

5.2 ROSI in revealing the radial position

It is interesting to see that the narrowband ROSI investigations of a set of rotating coherent noise sources localizes the apparent noise source to the Mach radius, without necessarily providing any information as to the true locations of the noise sources, while a third-octave band investigation of the same case seems to hint at the true location of those sources. This section aims at shedding light on why this occurs.

First of all, sidelobes should be discussed, since one might assume that the rings which are seen above are standard sidelobes. In Fig. 6 a third-octave investigation of three different sets of rotating noise sources can be seen. All the sets are similar to the rotating noise source investigated above, except that the radius of each set of noise sources is different. In the figure on the left, the radius is 0.2 m, while in the middle it is 0.3 m, and on the right it is 0.4 m. It can be seen that choosing the radius of the initial case as having a radius of 0.2 m was in a sense an unfortunate choice, since one of the main sidelobe rings has approximately the same radius. On the other hand, it also provides us with a worst case scenario. It can be seen that in each case the radial ring of second largest magnitude, after the apparent noise source localized to the Mach radius, is always the one on which the noise sources were truly located, regardless of whether or not that ring is shared with other sidelobes. Therefore, it can be stated that the rings should be further investigated. The same is true for the case of the stationary noise sources displayed in Fig. 7. The difference between the two sets of results is that the set of data which investigates rotating noise sources in a rotating reference frame (Fig. 6) produces concentrated sources along the circumference, while the set of data which looks at stationary noise sources in a rotating reference frame provides a solid ring (Fig. 7). Before this can be understood, the ROSI method needs to be explained in a bit more detail.

The ROSI beamforming method is an extension of the DS method for rotating source models. The main difference between the two methods is that the ROSI method applies a so called deDopplerization step in order to place the rotating noise sources into a rotating reference frame and hence make them stationary. The positions and velocities of the possible noise sources are accounted for by correcting the arrival time and amplitude of each data point with regard to each receiver position. The corrected source signals are then processed with a beamforming method which agrees with the DS method [2]. When the ROSI method is applied to a set of data, it takes a sound file which is associated with a given microphone and processes it for every initial circumferential position of every radial position of the investigated plane. In every investigation point on that plane, it resamples the data to correct for the rotation of the source. The data from each microphone is then delayed and summed in order to arrive at a beamforming level which is placed on that point of the beamform map.

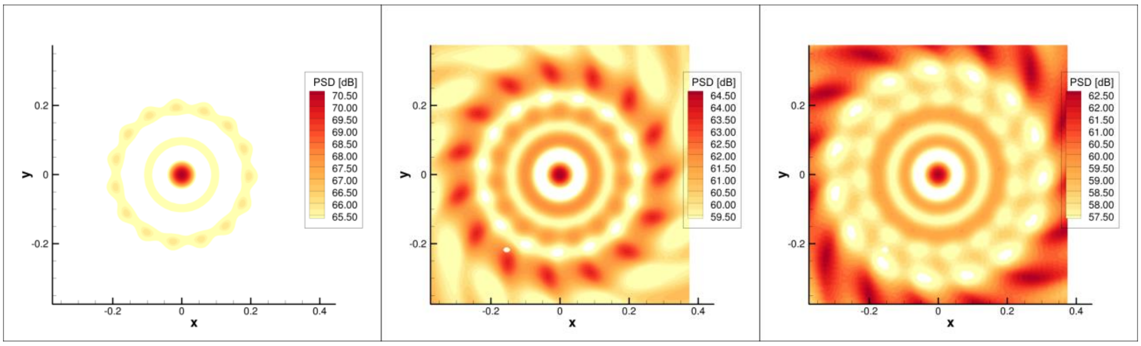

Fig. 6. ROSI beamform maps of rotating noise sources investigated from the axial direction (third-octave band, ζ=0.3 m). Radius: 0.2 m (left), 0.3 m (middle), 0.4 m (right).

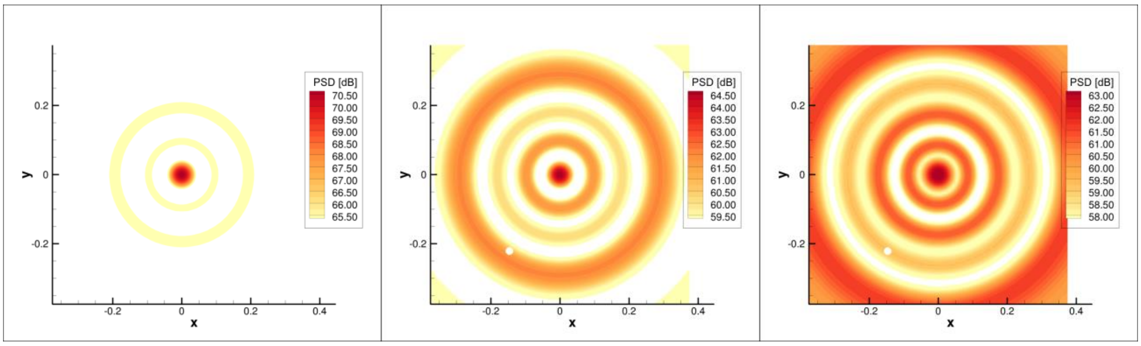

Fig. 7. ROSI beamform maps of stationary noise sources investigated from the axial direction (third-octave band, ζ=0.3 m). Radius: 0.2 m (left), 0.3 m (middle), 0.4 m (right).

If no noise sources are located in the investigated position, or in its vicinity, then the data is altered by the correction to some entirely different form for each microphone. When the data is delayed and summed, since there will be little to no correlation between the various microphones, a small beamform level will be calculated. If a noise source is truly located in that position, then the sampled sound file will be corrected for in an appropriate manner for every microphone, arriving at a set of data which is very similar. Hence, when delaying and summing the files, if the noise sources are not coherent with other sources in the investigated plane, then a large beamform level will be calculated for the beamform map in that position. If the noise source is coherent with other noise sources located within the investigated plane, then the phased array interprets the sound as if the noise source were located at its Mach radius position (due to the sound adding up constructively and destructively), and therefore the data which is to be delayed and summed will only be highly correlated at the Mach radius position, and hence the apparent noise source will be placed there [5, 7].

What happens for investigated points which are near a true noise source, such as along the same circumference but between two true noise sources? The resampled data created by the ROSI method will be relatively well correlated, but not entirely coherent, since the true noise sources are near to the investigated point in the space as well as frequency domains, but will not be corrected in exactly the same manner for each microphone position. Therefore, for some frequency bins which are near the true radiated frequency the data will be relatively well correlated, but not 100%. Since this repeats as we travel around the circumference, the noise sources will also have a somewhat coherent character.

In order to understand this better, imagine a set of purely tonal noise sources distributed along a given circumference. Take a point between two of the noise sources, which is located along the circumference. It can be understood that the noise source which is slightly ahead of the investigated point in the direction of rotation will have a slightly higher/lower frequency due to the Doppler shift than expected for the point under investigation, while the one which is slightly behind it will have a slightly lower/higher frequency, depending on the angle between the source and the given microphone for the current location under investigation. If the sound file is then corrected by the ROSI method as if the noise source were truly located between the two noise sources, then the resulting data will not be the same, but will still be somewhat well correlated for all the microphones, and this will result in a noise source being placed on the beamform maps between and around the true noise source positions. Since the data which is corrected for by the ROSI method will also be somewhat coherent, an apparent noise source will also be placed at the Mach radius position for frequency bins which are near the true radiation frequency, but not necessarily agreeing with the investigated frequency. Therefore, the noise sources localized to the true radial positions are actually showing the empty areas between the true noise sources for frequencies near the radiation frequency. In processing a third-octave band worth of data, the method which is applied first calculates each narrowband within the larger band range and then sums up the results. Therefore, even if the ring at the true radial position described here does not appear in the bin of the frequency under investigation, since it is relatively strong in the bins which surround it, it will appear among the dominant sources in the third-octave band results. This is what can be seen in Fig. 6. With regard to other sidelobes, they appear in many of the bins within the third-octave band, but will usually not be as strong as those described here, and therefore this noise source will often be one of the dominant noise sources within the third-octave band under investigation.

In the case of stationary noise sources distributed along a given circumference, the radiation frequency of the noise sources is the true radiation frequency (in this case 3000 Hz), and the ROSI method resamples the data, adding a Doppler shift to the signal. Once again, the results show some level of coherence for the points between the noise sources. Since the method corrects for the rotation of the sources, it distributes the results around the circumference evenly, resulting in a solid band on the beamform maps. This is what can be seen in Fig. 7.

These results are important, since they show a way of determining the true radial positions of rotating and stationary coherent noise sources experienced in turbomachinery applications. In this section it was shown that this method provides information for the case of a single set of noise sources (motor, rotor, or guide vane). If the true radial position is determined, then from the beamform peak level, L_B, which is located at the Mach radius, the contribution to the beamform peak level from each equal strength coherent in phase noise source, $L_{B,one}$, can be determined with the help of the equation presented in [8], which is analogous to the basic acoustic equation for adding levels. As given in Eq. 1, if one finds the L_B associated with the noise source under investigation, and one knows the number of sources, x, then one can calculate $L_{B,one}$. Therefore, we now know how to determine where the noise source is radially located and how large of a contribution each coherent source makes to the beamform peak located at the Mach radius.

$$L_B = L_{B,one} + 20\log_{10}(x) \tag{1}$$

5.3 Multiple noise sources

As a result of studying the beamform maps of turbomachinery applications, it is now known that incoherent noise sources will be localized to their true noise source locations by the DS method for stationary sources or the ROSI method for rotating sources. For coherent sources, the noise source will be localized to the Mach radius by both the DS and ROSI methods, with wideband processing providing a hint as to the true radial positions of the sources. Now that the elements in a single set of noise sources (motor, rotor, or guide vane) have been localized and the contribution to the beamform peak has been determined, the next step would be to localize and determine the contribution of each in a case where multiple noise sources are looked at simultaneously.

A few cases were looked at, but will not be presented in detail. Applying the method to the case of three noise sources (motor, rotor, guide vane) located in the same plane, not enough information is available to separate the three noise sources localized to the axis from one another. For noise sources which are coaxial and relatively closely spaced (having 1/4 rotor diameter distance between the motor, the rotor, and the guide vane), the DS and ROSI methods lack the resolution needed to separately analyze the various planes from the axial direction. In a case where larger distances are characteristic of the distance between the planes containing the noise sources, the above stated investigation method combined with investigations from the radial direction seem promising in providing enough information for determining the contribution from each plane as well as determining the radial distribution of the noise sources.

6 SUMMARY

In this investigation the presented findings provide a means by which the radial position and the contribution of each coherent noise source to the beamform map can be determined for a single set of coherent noise sources (rotor or guide vane). This method cannot yet be applied to a general case, where multiple sets of noise sources are located in one plane or coaxial and relatively closely spaced. This will be the subject of future investigations, though it is likely that the approach still needs to be further developed in order to accomplish this task.

Though not the subject of the paper and not emphasized throughout the text, the authors feel that the true value of the outcome of this paper is beyond the scope of this investigation. Many earlier investigations have stated that it is not possible to determine the true positions of coherent noise sources using currently available beamforming methods. In a way, the presented results support this thought, but show that this is not necessarily a limit of the beamforming methods, but due to the fact that the results of beamforming investigations of coherent noise sources are not yet truly understood. It is shown that investigating these results in greater detail, more information can be extracted from the results, leading to the localization of the coherent noise sources. The investigation also shows that taking into consideration the extra information provided by the Doppler shift could be very useful in the further investigation of coherent noise sources. Until now, investigations which have applied a Doppler correction to moving sources seem to have used the information in order to correct data in a given microphone position, and then neglected to take into consideration the extra information provided by correcting the data during the analysis of the results. Further investigations will focus on better understanding the beamforming results of coherent noise sources, taking into account the extra information attained from the Doppler Effect, after which the newly gained knowledge and experiences will be applied in the development of advanced beamforming methods designed for the investigation of rotating coherent noise sources.

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