Influence of foam-resin lining on the reflections and scattering of acoustic modes at pylons in a flow duct

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Introduction

In the bypass ducts of aircraft engines, the pylons of the engine installation and the lower bifurcation lead to a separation of the annular duct into two segments. The large dimensions of the bifurcations have a significant influence on the propagation of the acoustic modes that are radiated by the fan, see Figure 1. The degree to which the incident mode is shielded, i.e. the transmission is reduced, or mode scattering occurs, depends to a large extent on the mode propagation angle and the dimensions of the bifurcation relative to the mode wavelength. Since

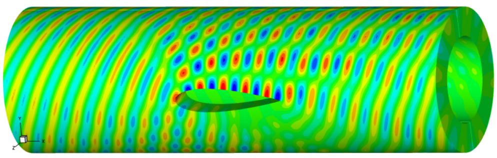


Figure 1: Sound pressure distribution of a mode (8,0) entering an annular duct with a single pylon of symmetrical NACA0021 profile from the left [5].

the effect on the sound field radiated into the free field is of practical interest, various studies have so far mainly investigated the influence on the downstream propagating modes, see e. g. [3], [4], [5]. On the aeroacoustic fan test rig CRAFT [6], on the other hand, the interest lies in investigating the reflections and scattering of the incident modes on a pylon section in the upstream direction. Three pylons, evenly spaced around the circumference, are installed at the end of the fan outlet measurement section to cover the struts that support the cantilevered hub. The pylons have a NACA 63-015A profile and a length corresponding to 1.65 duct diameters. They cause the problem that the modes emitted by the fan are not only reflected and scattered in the upstream direction, but also propagate through the fan and superpose with the mode field directly emitted by the fan into the inlet. As a result, the analysis of the fan noise excitation is compromised. Therefore, a technical means to suppress the mode reflections and scattering at the pylons is sought. In the present study, the suitability of different pylon linings and duct wall linings with foam resin is investigated experimentally.

Experimental setup

The study was carried out at the SPIN (Spinning mode Propagation through INstallations in flow ducts) test bench in the configuration shown in Figure 2. The SPIN test bench consists of an annular duct of 0.5 m diameter and a hub of 0.33 m diameter. It is equipped with a spinning mode generator consisting of two rings, each with 16 loudspeakers, which can excite individual duct

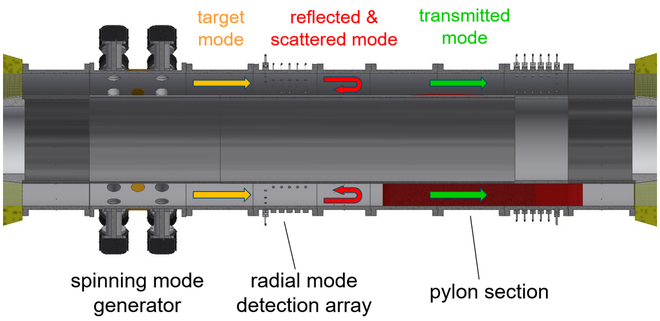


Figure 2: SPIN setup for experimental study of the mode reflection and scattering at the pylon section. Individual modes are emitted by the mode generator and the resulting sound field is analyzed with the mode detection array.

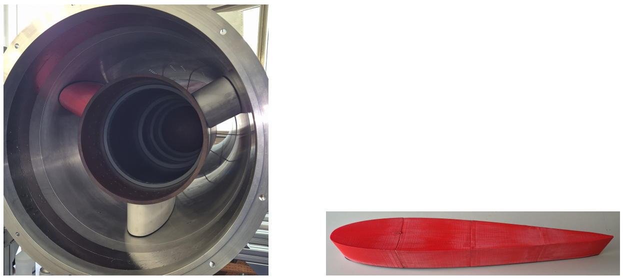
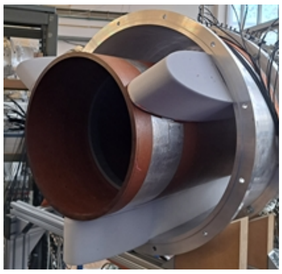


Figure 3: Pylon section in reference configuration. The pylons were manufactured in 3D printing from plastic.

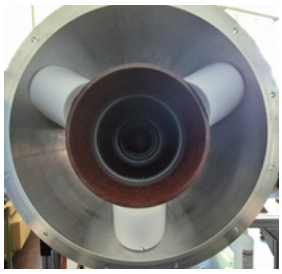
modes of azimuthal order $m = \{-7 \ldots +7\}$ and radial order $n = \{0, 1\}$ with high dominance my means of measured modal transfer functions [1]. By radiating the target mode onto a test object, its reflection, scattering and transmission characteristics can be measured accurately. For the present study, the three pylons of the CRAFT fan test stand were built as test objects on a 1:1 scale using 3D printing, see also Figure 3. A microphone array of 98 1/4" high quality G.R.A.S. condenser microphones was placed between the mode generator and the pylon section to detect incoming, reflected and scattered modes. 33 microphones were arranged uniformly in a ring. Furthermore, there were 5 rings with 13 microphones each, arranged on a non-uniform grid that was optimized for Compressed Sensing based Azimuth Mode Analysis [2]. With the complete array, a standard Radial Mode Analysis could be carried out up to 2.3 kHz. Using Compressed Sensing, the radial mode amplitudes of four dominant azimuthal orders could be determined directly up to 4 kHz, and the amplitudes of all remaining mode orders could be estimated [2]. It should be noted that a second array, which can be used to measure the mode transmission on the opposite side of the test object, was not used.

Table 1: Test matrix.

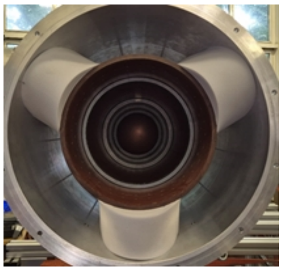
target mode (m_t, n_t)	$\min(f)$ in Hz	$\max(f)$ in Hz	number of frequencies
(0,0)	806	3398	24
(1,0)	632	3086	18
(3,0)	806	3104	30
(3,1)	2235	4088	30
(4,0)	1069	2745	23
(7,0)	1846	3677	9



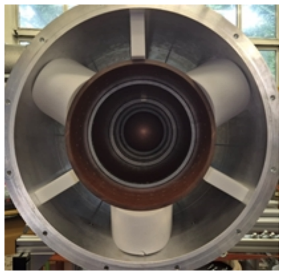
(a) PSOFT



(b) PBL30

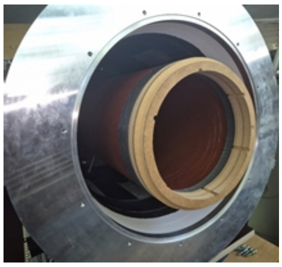


(c) PBL45

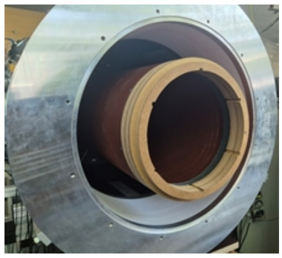


(d) PBL30-S30

Figure 5: Pylon made of foam resin or in a hard-walled version with foam resin lining of various thicknesses and arrangements.



(a) D80



(b) D200

Figure 6: Duct segment with foam resin liner of depth 100 mm and axial lengths of 80 mm or 200 mm.

Measurements were carried out for the seven target mode orders given in Table 1. At the highest analysis frequency of 4088 Hz, modes of the azimuthal orders up to $|m| = 16$ and of radial orders up to $n = 1$ were cut-on. The reflection and scattering of the modes depends sensitively on their angle of propagation, which in the case of no flow can be calculated as $\theta_{m,n} = \arccos(\alpha_{m,n})$. Since the mode cut-on factor $\alpha_{m,n}$ increases rapidly with increasing frequency from the value 0 at the cut-on threshold and then approaches 1 asymptotically, the test frequencies were chosen to be non-equidistant in steps of 85, 80, 75, 65, 55, ... degrees. This scheme was applied to the target mode as well as to the reflected and scattered modes.

Configurations with foam resin lining of the pylons and at the duct wall

For the reduction of the reflections and scattering at the pylons, Basotect® foam resin was selected. The advantages of the material are the high absorption over a wide frequency range and the good machinability to cover even curved structures. Figure 4 shows the frequency-dependent absorption coefficient for different layer thicknesses. Note that the absorption coefficient was measured with an impedance tube for normal sound incidence. To provide an orientation regarding a suitable layer thickness, the fundamental tone of the CRAFT reference fan at 50% of the design speed is marked as the lowest frequency of interest. In the selection, it must be considered that the pylons cannot be equipped with linings of arbitrary thickness, since the increased profile thicknesses lead to an increased blocking of the flow duct and thus to a throttling of the fan, which can result in an impairment of the usable aerodynamic fan map. The foam material was used in different variants. In the first variant, the pylon was completely replaced by the foam material, see Figure 5(a). This variant represents an idealization because the pylons in the CRAFT fan rig have cutouts for the supporting struts. It should also be noted that implementing this variant on the fan rig would be very time-consuming, since the test stand would have to be extensively disassembled. A much simpler approach is to cover the existing pylons with a foam layer. The variants PBL30 and PBL45 shown in Figure 5(b) and (c) implement this with a layer thickness of 30 mm and 45 mm respectively. As an alternative to PBL45, in the PBL30-S30 variant, in addition to the PBL30, the absorber material was inserted in the form of splitter plates in the middle between every two pylons, see Figure 5(d), with the idea of better damping the incident spinning modes in this way. At CRAFT, a further variant could be to install a sound-absorbing duct segment directly upstream of the pylon section. A space of about 100 mm is available for this, so that the segment labeled D80 in Figure 6(a) could be integrated with a foam lining of

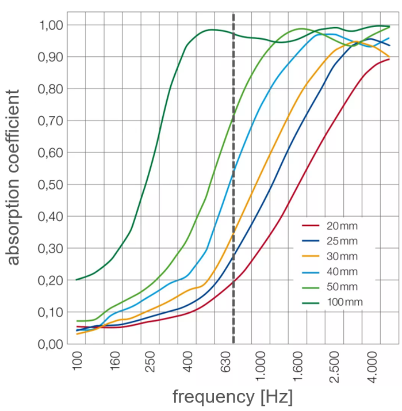


Figure 4: Absorption coefficient of Basotect® for different layer thicknesses [7]. The dashed line marks the fundamental tone of the CRAFT fan at 50% of the nominal speed.

80 mm axial and 100 mm lateral dimensions. The duct segment D80 was prepared for the tests from an existing liner with 200 mm axial depth by taping a partial area. To evaluate the liner potential, the segment D200 shown in Figure 6(b) was also measured. The lined duct segments were tested in combination with the installed pylon variant PBL30.

Results

Impact on reflection

Figure 7 shows the reflection coefficient of the target mode $(m_t, n_t) = (3, 0)$ as a function of the mode propagation angle for the pylon soft variants PSOFT, PBL30, PBL30-S30 and PBL45 compared to the acoustically hard variant PHW. The reflection coefficient is defined by $\Sigma_n P^-_{m_t,n}/P^+_{m_t,n_t}$, where, with respect to the sound radiation direction of the mode generator, $P^\pm_{m,n}$ is the sound power of the downstream (+) or upstream (-) propagating mode (m,n) as a result of the Radial Mode Analysis using the microphone array. In words, the reflection coefficient is the ratio of the summed power of the reflected modes to the power of the target mode. As expected, a very high reflection occurs at very large angles of propagation of the target mode, since the mode wavefront hits the pylon side almost perpendicularly. At a propagation angle of 85°, i.e. close to the cut-on frequency of 806 Hz, the mode is reflected to a very high degree in all pylon variants. For the hardwall pylons PHW, the reflection coefficient decreases to -20dB only for mode propagation angles below 30°, i.e. at frequencies above 1600 Hz. In all soft versions, however, the reflection coefficient already lies near -20dB and even lower for mode propagation angles of less than 60° (corresponding to frequencies above about 950 Hz). Reflection coefficients of less than or equal to -20dB are considered acceptable for the measurements at the CRAFT test stand, i.e. they represent the target value. The PSOFT variant performs best overall, not least in its effect on very small mode propagation angles (i. e. high frequencies). Looking at PBL30, increasing the layer thickness to PBL45 or adding the splitter plate to PBL30-S30 does not provide any clear advantage. Combining the PBL30 configuration with a ligned D80 or D200 duct segment placed in front of it has a disadvantageous effect on reflections, see Figure 8. The obvious explanation lies in the sudden impedance change at the liner wall where there is a transition from a hard to a soft surface, to which modes with large propagation angles in particular react sensitively.

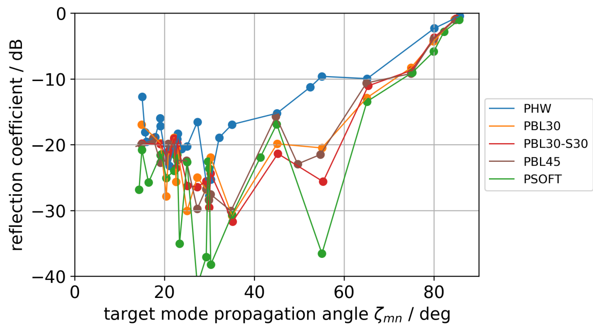


Figure 7: Reflection of target mode (3,0) at pylons in acoustically hard version, soft version and with different foam layers on the surface and in between.

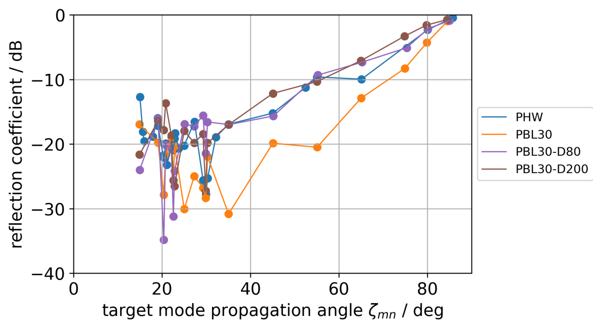


Figure 8: Reflection of target mode (3,0) at combination of foam ligned duct segment and pylons with 30 mm foam layer.

Impact on scattering

Figure 9 shows the scattering of the target mode $(m_t, n_t) = (3, 0)$ at the sound-reflecting pylon configuration PHW. The scattering coefficients for all azimuthal orders m_s are shown, which result from the scattering at the V=3 pylons according to the relationship $m_s = m_t \pm jV$ with $j = 1, 2, 3, \ldots$. The scattering coefficient is calculated as $\Sigma_n P^-_{m_s,n}/P^+_{m_t,n_t}$, i.e. for each azimuthal scattering order, the sound powers of the individual radial orders are summed and set in relation to the sound power of the incident target mode. Obviously, the scattering in the mode m_s is particularly high near its cut-on frequency. This is plausible since the admittance of a mode near the cut-on frequency is very high [1]. The cut-on frequencies of the modes are marked by triangles on the frequency axis. Slightly above the cut-on frequencies, the scattering coefficients remain in the range from -8 to -16dB and then drop to values around -20dB and below. In the following, the envelope of the maximum scattering coefficients of all modes is used for comparisons to provide a better overview. Figure 10 shows the effect of the soft pylon variants. As with the reflections, the goal for the CRAFT fan test facility is to reduce all scattering coefficients to at least -20dB. The PSOFT and PBL45 configurations fulfill this requirement across all frequencies, except near the cut-on frequency of the mode (-3.0). For the configurations PBL30 and PBL30-S30, this applies with further restrictions at the

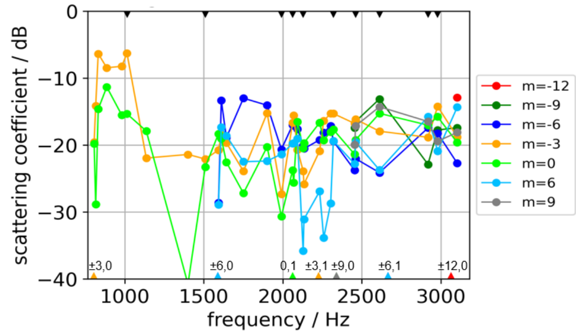


Figure 9: Scattering of target mode (3.0) at the rigid pylon in upstream modes of orders $m_s = m_t \pm j3$ with $j = 1, 2, 3, \ldots$.

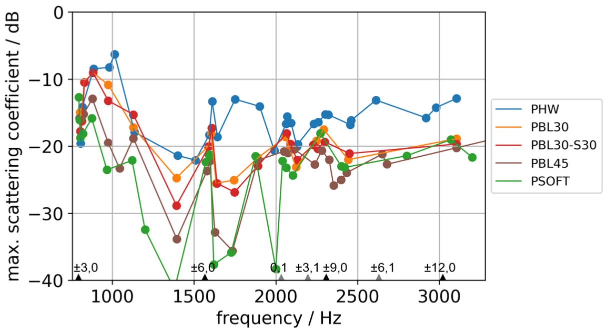


Figure 10: Maximum scattering of target mode (3,0) in upstream modes at pylons in acoustically hard version, soft version and with different foam layers on the surface and in between.

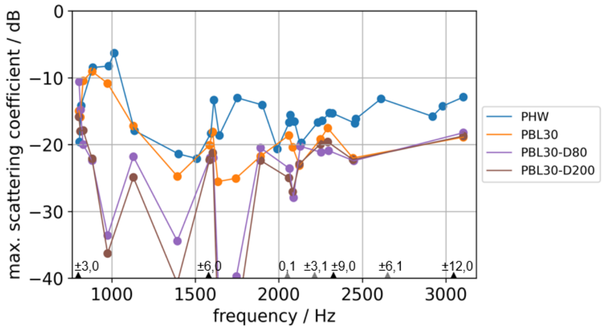


Figure 11: Maximum scattering of target mode (3,0) in upstream modes at a combination of foam ligned duct segment and pylons with 30 mm foam layer.

cut-on frequencies of most of the other scattering modes. The comparison of PBL45 and PBL-S30 shows that it is also more favorable for the scattering reduction to apply additional foam material onto the pylons instead of placing it between the pylons. The combination of PBL30 with a lined duct segment leads to a satisfactory reduction of the scattering over the entire frequency range, cp. Figure 11. Compared to the PSOFT variant they perform better near the cut-on frequency of the mode (3,0). This behavior can be well explained by the fact that the incoming target mode is damped when passing through the liner, then partially reflected more strongly (see Figure 8), and the scattered modes are damped again when passing through the liner on the way back to the microphone array. No effect can be seen with regard to the length of the liner, possibly because the D80 segment already reduces the scattered modes to levels close to the noise level.

Conclusion

The aim of the present study is to reduce the reflection and scattering of downstream incident modes at three evenly spaced pylons located in the outlet duct of a fan test bench in the upstream direction by at least 20 dB in a sound power rating. Using the example of mode (3,0), it was shown that the greatest difficulty in achieving this goal arises at large mode propagation angles, i.e. near the cut-on frequency, since the wavefronts then impinge almost perpendicularly on the longitudinal side of the pylon and the mode is strongly reflected. This effect can be best reduced by a foam version or foam lining of the pylons, with the impact increasing with decreasing mode propagation angle. The installation of a foam-lined duct segment directly upstream of the pylon section leads to an increase of the reflections and is therefore not an option for the fan test bench. The scattering of the incident mode into other modes occurs more strongly near their cut-on frequencies due to their high admittances. This effect can be largely reduced by 20 dB by using a foam version or foam lining of the pylons. For the fan test bench, the replacement of the pylon bodies, which are provided with central recesses for supporting struts, by foam versions with an additional foam layer of 30 mm, is the optimal solution. The feasibility of maintaining the aerodynamic fan map despite the enlarged pylons still has to be finally verified.

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