Experimental assessment of low noise landing gear component design

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ABSTRACT

Landing gear related airframe noise is one of the dominant aircraft noise components at approach, so continued research efforts to reduce landing gear noise are essential. This paper describes further development of an advanced low noise main landing gear that was previously designed and tested in the European SILENCER project. The work was carried out under the current European co-financed TIMPAN project (Technologies to IMProve Airframe Noise) using a ¼ scaled landing gear model that was tested in the German-Dutch Wind Tunnel. A variety of gear configurations were tested including a new side-stay design and various modifications to the bogie inclination, wheel spacing, bogie fairings with different flow transparency, leg-door configurations and brake fairings. The farfield noise data from the tests are compared with results from a landing gear noise prediction model, transposed to full scale flight conditions and compared with the full scale test data obtained for the original SILENCER advanced A340 style 4-wheel main landing gear. An optimal combination of tested gear modifications led to a further noise reduction of up to 8 dB(A) in terms of overall A-weighted noise levels relative to the original advanced gear configuration.

1. INTRODUCTION

Due to the advances in aircraft engine noise control, airframe noise is now becoming a major noise component during approach and landing. For wide body aircraft in particular

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the dominant airframe noise sources are the landing gears followed by aerodynamic noise originating from deployed high-lift devices.

Accordingly a number of previous research projects have attempted to reduce landing gear noise through either dedicated wind tunnel experiments or flight tests [1, 2]. Initial noise control solutions involved the application of solid add-on fairings to shield the complex noise generating parts of the landing gear structure from the flow [3–6], but there was evidence that flow displaced by such fairings could be detrimental because of additional noise from adjacent gear components that experienced increased local flow speeds. As a solution of this problem, porous fairings were developed to reduce the amount of displaced flow, whilst still providing a sufficiently low flow velocity in the wake of the fairing not to generate high interaction noise levels with the downstream gear components [7–9].

While add-on solutions could be applied in the short term for current aircraft, it was also realized that low noise gears for future aircraft can best be developed by accounting for noise aspects at the design stage. A similar effort was undertaken in the previous European research project SILENCER ("Significantly Lower Community Exposure to Aircraft Noise") [11]. As a result, a combination of low noise gear component design and the application of porous fairings [7] was considered here so as to realize the maximum possible noise reductions. This work was performed in the European co-financed research project entitled "Technologies to IMProve Airframe Noise" (TIMPAN), with partners from European aircraft industries, research establishments and academia, and focused on further development of the A340 style 4-wheel main landing gear that was originally designed in SILENCER, to achieve increased noise reductions and to avoid the weight penalties associated with some features of that design.

The objective of the TIMPAN study therefore, was to develop operational low noise main landing gear components without weight penalties, taking into account modifications in the gear architecture (e.g. wheel spacing and bogie angle) and to optimize and quantify the benefit from the application of porous fairings for various gear components. As for the SILENCER project, the design had to incorporate the essential constraints defined by gear functionality and safety for a real aircraft application.

2. MAIN LANDING GEAR CONFIGURATIONS

The design developed here was based on the advanced A340 type 4-wheel main landing gear from SILENCER, with a focus on:

- Low noise design of individual gear components known from previous tests to be significant noise contributors (e.g. side-stay, various links, leg-door structure and brakes).
- The optimal arrangement of gear components to minimize the interaction of high speed turbulent wakes with downstream gear structures (e.g. variation of bogie angle, wheel spacing, placement of fairings and additional ramp door).

Fig. 1 presents a comparison between the SILENCER reference configuration and one of the TIMPAN configurations to better understand the design philosophy in TIMPAN.

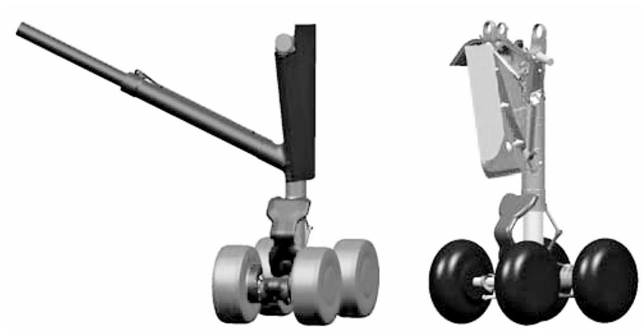


Figure 1: Comparison of SILENCER and TIMPAN main landing gear concepts.

One of the drawbacks of the SILENCER design was the excessive weight of the telescopic side-stay which, however, enabled a very low noise design for the leg-door structure. In TIMPAN therefore, a new side-stay design to avoid the weight penalty also required a new design for the leg-door. As shown in Fig. 1 this is a door which is articulated in such a way as to (once the gear is deployed) protect the complex leg/drag stay structure from the high speed inflow. It should also be noted (Fig. 1) that, for both the SILENCER and TIMPAN gear designs, the torque link is installed in front of the leg and is protected through a fairing, while at the back only a narrow slave link is attached to guide the dressings.

Much effort was directed towards the development of a side-stay which could be almost as quiet as the SILENCER clean circular telescopic stay, the final design being depicted in Fig. 2. Compared with the current A340 design the major advantage is the integration of the down-lock springs into the stay to realize a comparatively "clean" outer profile for the components. In addition, an upstream ramp was provided to shield the area of the upper leg and side-stay and also the wing cavity.

The brakes of the TIMPAN gear were partly recessed and completely separated from the flow by a streamlined fairing, which incorporated a mesh to allow for necessary brake cooling (Fig. 3).

Finally, a low noise arrangement for the bogie components included:

- Variation of the bogie angle from 0° (reference) to −15° toe down.
- Identification of a potentially optimal wheel spacing (Fig. 4) combined with different bogie and torque link fairings (solid and porous, respectively).

The "narrow" wheel spacing shown was defined as a spacing reduced by 50% of the tire width relative to the reference wheel spacing. Similarly a "wide" spacing meant an increase by 50% of tire width.

Examples of the application of solid or porous bogie fairings in combination with solid or porous torque link fairings are presented in Fig. 5.

Figure 2: TIMPAN side-stay design and upstream ramp.

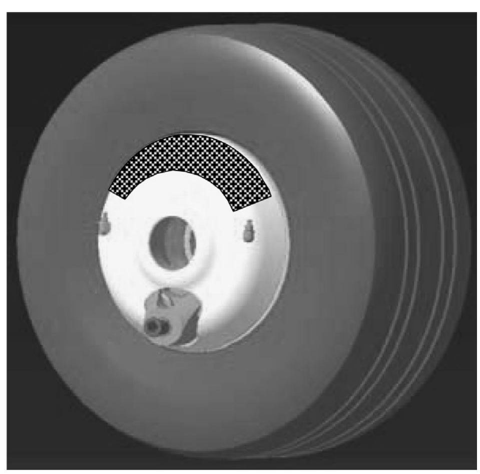


Figure 3: Brake faring with mesh type insert for brake cooling.

Due to budget limitations in TIMPAN, only scale model tests were planned in order to make use of an existing quarter scale mock-up of the SILENCER main landing gear, and new gear components were manufactured at that scale to fit to the existing model. An advantage of testing at quarter scale was that a wide range of configurations could be tested because of the speed with which gear modification could be made.

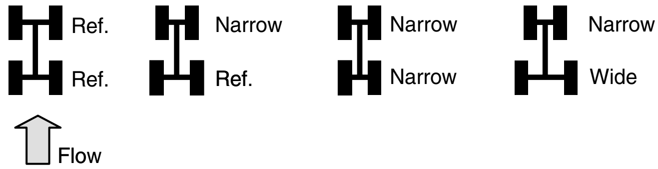


Figure 4: Schematic of selected combinations of forward and rear wheels' spacing.

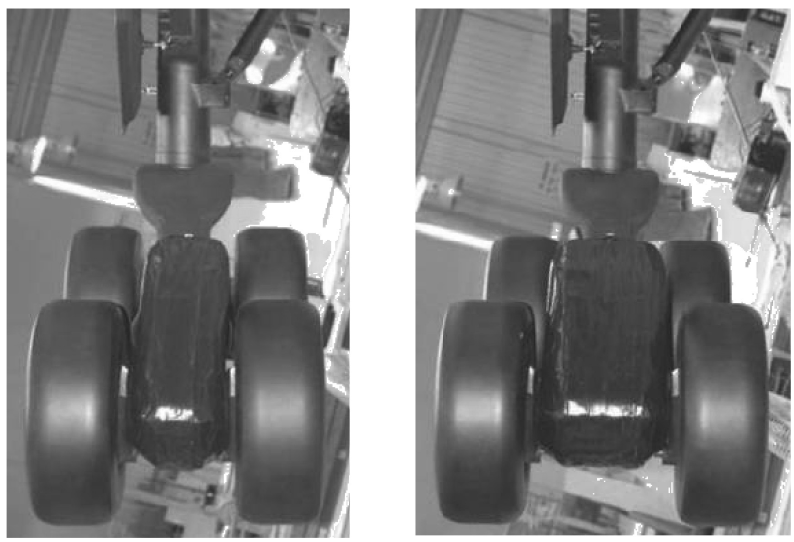


Figure 5: Bogie fairings in combination with torque link fairings for different wheel spacing.

3. EXPERIMENTS

Noise measurements were performed in the DNW-LLF (German-Dutch Wind tunnel – Large Low Speed Facility) in its free-jet configuration with a nozzle cross section of 6 m by 6 m. The maximum wind speed for this tunnel configuration is 78 m/s (152 kts), which is close to the typical landing/ approach speed for current commercial aircraft. The anechoic test-hall, which has a lower limiting frequency of 80 Hz, allows farfield noise measurements to be made outside the flow field at lateral distances up to about 18 m from the landing gear, which is well into both the acoustic and geometric farfield.

3.1. Wind tunnel test set-up

As in SILENCER, the model gear was installed on a side-wall of 7 m length, representing a dummy wing, which forms an extension to one side of the wind tunnel nozzle (Fig 6). In the x-direction (i.e. streamwise) the gear was installed at a distance of about 5 m from the nozzle exit plane. The height of the side-wall was 8 m at the

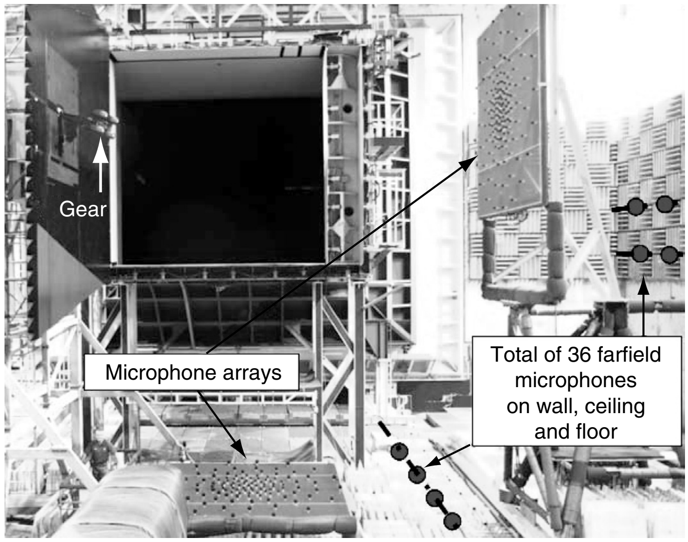


Figure 6: Overview of the measurement set-up in the DNW-LLF 6 m by 6 m open test section.

nozzle and 9 m at its trailing edge (accounting for free jet spreading). Those areas along the wall surface which are exposed to the wind tunnel shear layer flow (upper and lower edge areas), were treated with absorptive material to minimize flow noise generation and radiation from the side-wall. For the same reason the wall's trailing edge features a saw-tooth shape.

The side-wall arrangement was used to simulate the "in-flight" geometric/acoustic environment (reflection geometry from the wing surface) and to eliminate flow noise that could be generated by the support structure. In contrast to the slightly curved aircraft wing lower surface a plain side-wall geometry was used, a simplification that is considered to only have a second order effect on the scattered sound field, especially since the landing gear is an extended cluster of broadband sound sources. In order to simulate the actual in-flight lower wing surface boundary layer thickness, the wind tunnel boundary layer was "peeled off" by means of a scoop installed along the side-wall's leading edge. However, with this test set-up the typical "in-flight" velocity gradient underneath a high-lift wing caused by the circulation flow [10] is not simulated; in the uniform wind tunnel flow therefore, the strength of noise sources located in the upper leg area, close to the wind tunnel side-wall, is increased and the importance of these sources may be slightly overestimated. This effect must be accounted for in the final data interpretation.

Since comparisons were planned between the TIMPAN test data and the previous full scale advanced main landing gear test results from SILENCER [11], the same DNW test set-up was adapted to allow the installation of the new ¼ scale gear mock-up. In particular, during landing/approach the A340 aircraft typically operates at a characteristic angle-of-attack with respect to the inflow direction. Since in the test set-up the flow direction has to be parallel to the surface of the side-wall, this difference between inflow direction and aircraft axis must be accounted for. Based on the gear installation angle of the aircraft (and accounting for deviations of local flow from flight-directions) a slight backward gear-leg orientation was decided upon for the wind tunnel set-up. On the aircraft the main landing gear-leg was laterally inclined with respect to the lower wing surface, so in the test set-up a corresponding inclination angle was realized between the gear-leg and the surface of the side-wall.

In a previous full scale landing gear noise test in DNW-LLF in 1996 [1] the oblique-angled gear bay geometry was accurately reproduced, but no cavity resonances were observed. Since there was apparently no requirement to simulate cavity noise sources in these tests, therefore, the shape of the bay aperture was replicated exactly but a simplified almost rectangular cavity was used; this was lined internally with sound absorbing foam to suppress any potential acoustic resonances caused by the simplified shape.

3.2. Measurement techniques and data analysis

A similar measurement set-up to the previous SILENCER test was used, i.e. two phased microphone arrays to produce noise maps of the gear from a ground view and from a side view, and four rows of far-field microphones (with the rows distributed in the flow direction) installed close to the wall (2 rows), the floor (1 row) and the ceiling (1 row), respectively (Fig. 7). In this way noise radiation both towards the "ground" and in the sideline directions were measured. Each row comprised nine microphones, positioned at angular increments of nominally 10°, and covering a range of polar angles of $60° < \varphi_x < 125°$ (Fig. 7). All farfield measurement positions were equipped with 1/2 inch diameter LinearX M51 type electret freefield microphones. Acoustic data were acquired up to a frequency of 40 kHz.

The analysis and reduction of the farfield noise data focused on comparisons of the noise level spectra and radiation directivities for each of the different landing gear configurations and flow velocities. From this basic information, the measured data may ultimately be extrapolated to the operational conditions specified for approach noise certification. However, to obtain the true source characteristics for the landing gear, the wind tunnel acoustic data have to be corrected for wind tunnel background noise, the effects of shear-layer refraction [12] (including wave convection), microphone directivity, atmospheric absorption [13] and for the effect of convective amplification (assuming dipole type sources). The shear-layer refraction correction was based on Amiet's two-dimensional (2D) solution which is proven to work well for sound propagation toward the wall mounted microphones. Strictly speaking, a 3D solution is required to correct for shear-layer refraction of sound propagating toward the floor or ceiling mounted microphones, which were being applied for the first time in landing gear noise tests. Since such a solution was not implemented at the time the data analysis was carried out, the standard 2D solution was used to also correct the data obtained from the floor and ceiling mounted microphones. In the meantime, Amiet's 2D solution was analytically extended to 3D, and 2D vs 3D comparisons have been made for

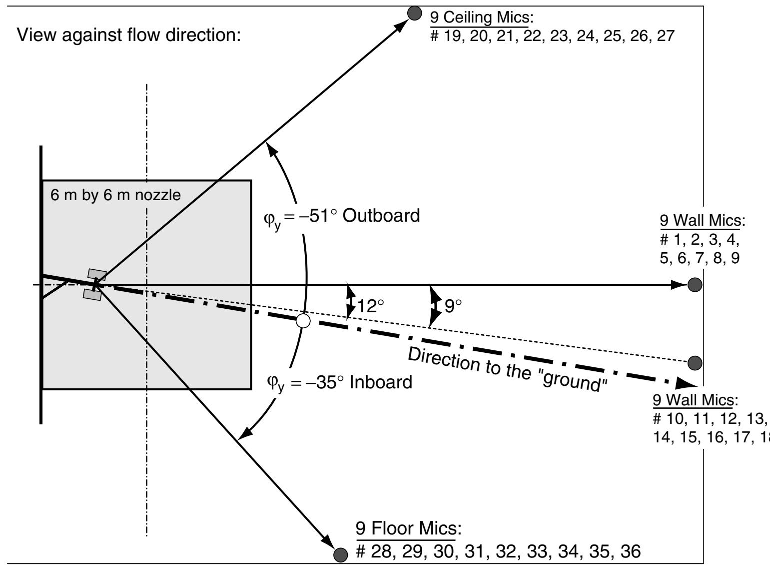


Figure 7: Selected farfield microphone positions on the wind tunnel side wall, the ceiling and the tunnel floor.

selected laterally located microphone positions. This demonstrated that, for the test geometry under consideration, the 2D solution provides sufficiently accurate shear-layer corrections.

All farfield noise data were normalized towards a constant propagation radius and will be presented in terms of 1/3-octave band levels.

To visualize local flow conditions at selected gear components, tufting tests were performed. Pictures from two different view angles were recorded by means of two video cameras.

4. TEST RESULTS

To ensure the quality of the data, the test started with a background noise measurement for the clean side-wall, i.e. without gear and closed gear cavity. The test matrix comprised a total of 47 gear configurations, resulting from different combinations of individual gear component designs. Whereas previously reported measurements were carried out at 3 different speeds, in order to save measurement time here the majority of configurations were tested at 2 speeds only (i.e. 78 and 62.5 m/s).

To enable an extrapolation of noise data to other speeds and scales, or to account for small speed variations in the experiments, appropriate scaling laws must be defined.

From previous landing gear noise tests it is known that dipole type noise source mechanisms dominate, and so the following velocity scaling of levels and frequencies pertain:

$$\Delta L = 10 \cdot \log(v/v_{ref})^6 \tag{1}$$

based on an arbitrary reference speed v_{ref}, and for measured frequencies f and flow velocities v the relevant non-dimensional Strouhal number St can be calculated as

$$St = \frac{f \cdot s}{v} = const. \tag{2}$$

where s is a characteristic length scale or scale factor.

For the previous tests in SILENCER the length scale was taken as s = 1 m so, taking account of the scale of the TIMPAN gear, the length scale used here is s = 0.25 m. This allows easy comparison of data from the full scale and model scale tests.

To finally present source noise levels and directivities, taking account of the model scale factor and source size, all data are referenced to a constant propagation distance r_{ref} based on spherical sound attenuation relative to the measurement distance r through

$$L_{ref} = L + 20 \cdot \log(r/r_{ref}) + 20 \cdot \log(s_{ref}/s) \tag{3}$$

The data from microphones at similar streamwise (φ_x) positions but slightly different azimuthal angles in the range of $3° < \varphi_y < 12°$ (corresponding to the two rows of microphones on the test hall wall) were averaged and considered to represent the noise characteristic for radiation towards the "ground". This was considered reasonable since the respective spectra show similar and systematic variations for all tested gear configurations in the order of less than 1 dB.

In order to check the validity of the scaling laws to account for the effect of flow speed on broadband landing gear noise, spectra are presented in a non-dimensional form based on Eq. (3) to normalize levels and Eq. (2) to calculate Strouhal numbers from measured frequencies.

Prior to any comparison of noise spectra for different gear configurations within these tests, it is useful to check how well the noise spectrum of the original full scale advanced main landing gear compares to the noise spectrum of the 1/4 scale gear in its reference configuration after transposition to full scale using Eqs. (2) and (3). This comparison is depicted in Fig. 8 and shows good overall agreement, except for the peak at about 1 kHz; it is interesting to note that a similar peak occurs in both sets of data, but with a much higher level for the scale model gear. The comparison of broadband noise levels at other frequencies is excellent in the forward arc but the model gear is about 1 to 2 dB noisier than the full scale gear in the rear arc.

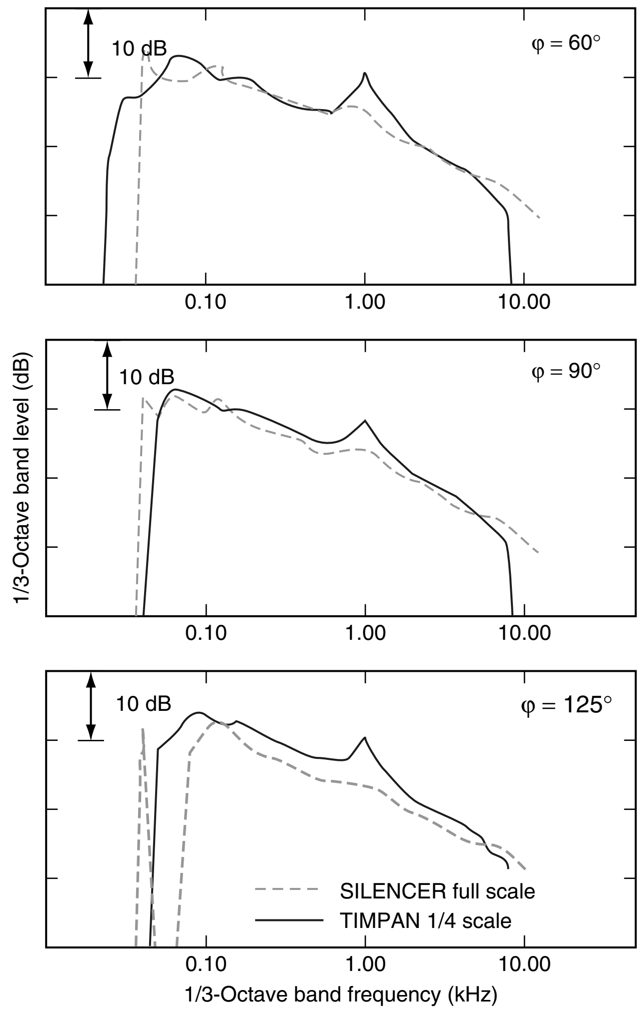


Figure 8: Comparison of normalized 1/3-oct. band level spectra for the TIMPAN ¼ scaled model gear in its reference configuration with the spectrum for the original full scale SILENCER advanced gear at different polar radiation angles.

Further investigation of the apparent "tone" at 1kHz showed that the frequency scales with Strouhal number, and appears to correspond to the vortex shedding frequency from the dressings based on a Strouhal number of 0.2 calculated using the diameter of the electric wire material used to simulate those components. Any noise reduction potential derived from the ¼ scale model reference gear must therefore account for this particular model effect.

4.1. Noise characteristics

4.1.1. Normalized noise level spectra

In Fig. 9 noise spectra are shown for the SILENCER reference configuration and the quietest TIMPAN configuration, respectively. This latter gear configuration combines the following features:

- Negative bogie angle (toe down),
- Narrow wheel spacing (both forward and rear wheel sets),
- Porous bogie and torque link fairings,
- TIMPAN brake fairings,
- Articulated TIMPAN door with 45° ramp and
- TIMPAN side-stay design.

It is apparent from Fig. 9 that the data reduction procedure, presented for the reference configuration only, provides a reasonable collapse of the data for all three radiation directions, i.e. in the forward arc ($\varphi_x = 60°$), for the aircraft in the overhead position ($\varphi_x = 90°$), and in the rear arc ($\varphi_x = 125°$), respectively.

Fig. 9 also shows that, compared to the SILENCER reference configuration, a broadband noise reduction potential of up to about 10 dB was obtained for the quietest TIMPAN gear design. This noise reduction potential is most pronounced for the important forward arc radiation direction. The noise reduction achieved at very low Strouhal numbers is rather limited, but is still a useful 2 to 4 dB.

4.1.2. Normalized noise level directivities

From the comparison of spectra presented above it is obvious that there are some Strouhal number effects on the noise directivity characteristics. Noise level directivities will therefore be presented for three different Strouhal number ranges, with integrated sound energies in the ranges: $2 < St \le 5$, $5 < St \le 20$ and $20 < St \le 63$.

This normalized data representation inherently accounts for small differences in actual test speeds. Corresponding examples of noise directivities are presented in Fig. 10 for the SILENCER reference configuration and the TIMPAN low noise configuration respectively. While the SILENCER configuration exhibits an almost omnidirectional noise radiation characteristic for the whole Strouhal number range of interest, the corresponding directivities for the low noise configuration feature an increasing gradient in sound pressure level with increasing Strouhal number, i.e. low levels in the forward arc and high levels in the rear arc radiation direction. Accordingly, the TIMPAN low noise configuration provides an increasing noise reduction potential for higher Strouhal numbers and forward arc radiation direction.

In an attempt to explain these changes in directivity, array source plots can usefully be inspected, with results from the sideline view microphone array being most interesting (Fig. 11). In these graphs the solid black line indicates the position of the wall. While for the reference configuration (upper part of Figure 11) the bogie area is seen to be the predominant source of noise, with the gear in its low noise configuration (lower part of Figure 11) the highest noise levels originate from the leg-door/side-stay

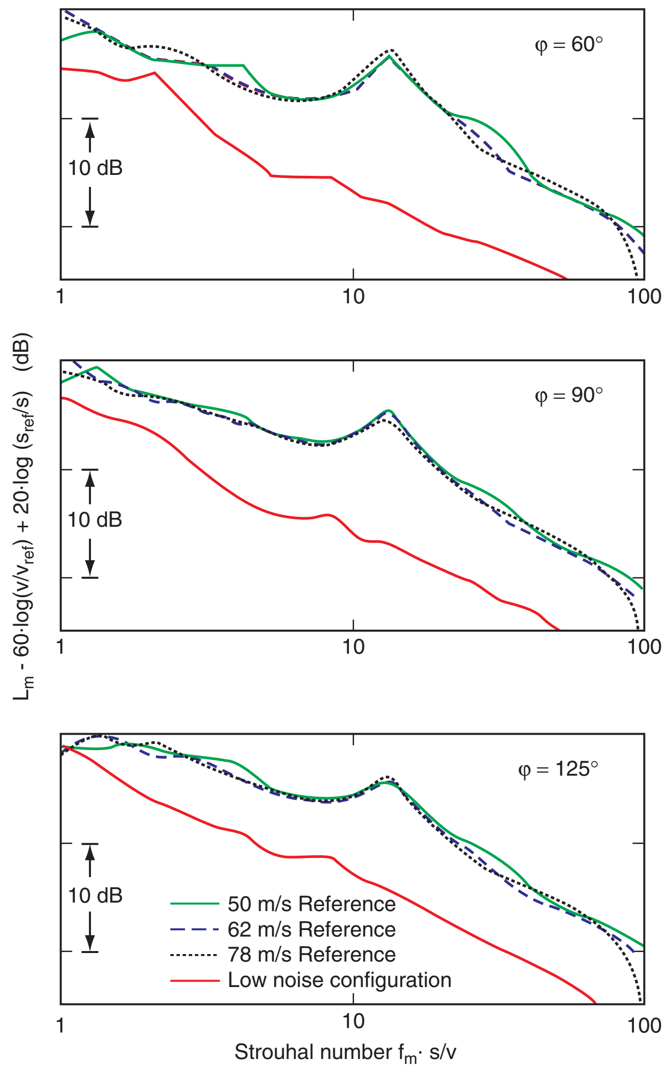


Figure 9: Comparison of normalized 1/3-oct. band noise spectra for the reference and the TIMPAN low noise configuration at different polar radiation angles.

area (Note: maximum levels are much lower for ID 55). From this data it is clear that the TIMPAN low noise design was successful in dramatically reducing bogie related noise sources, but needs further attention regarding an effective low noise design of the leg-door/side-stay structure.

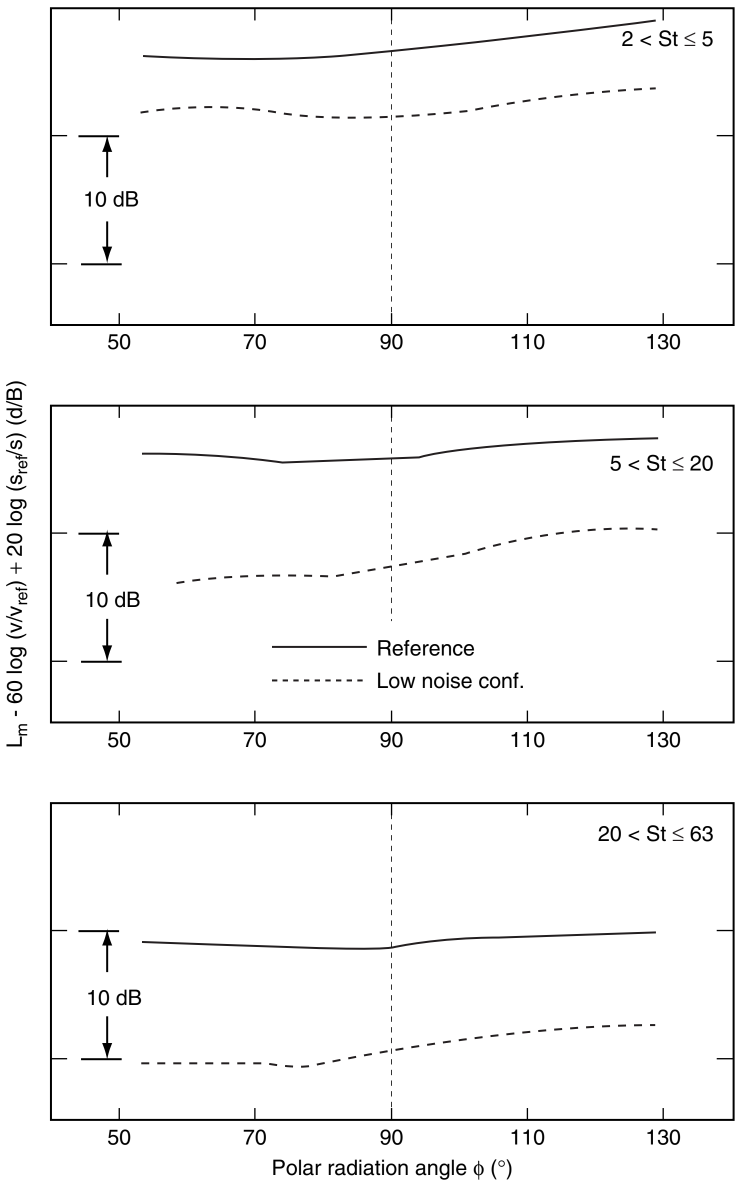


Figure 10: Comparison of polar directivities of normalized 1/3-oct. band noise levels in different bands of Strouhal number for the reference and the TIMPAN low noise configuration.

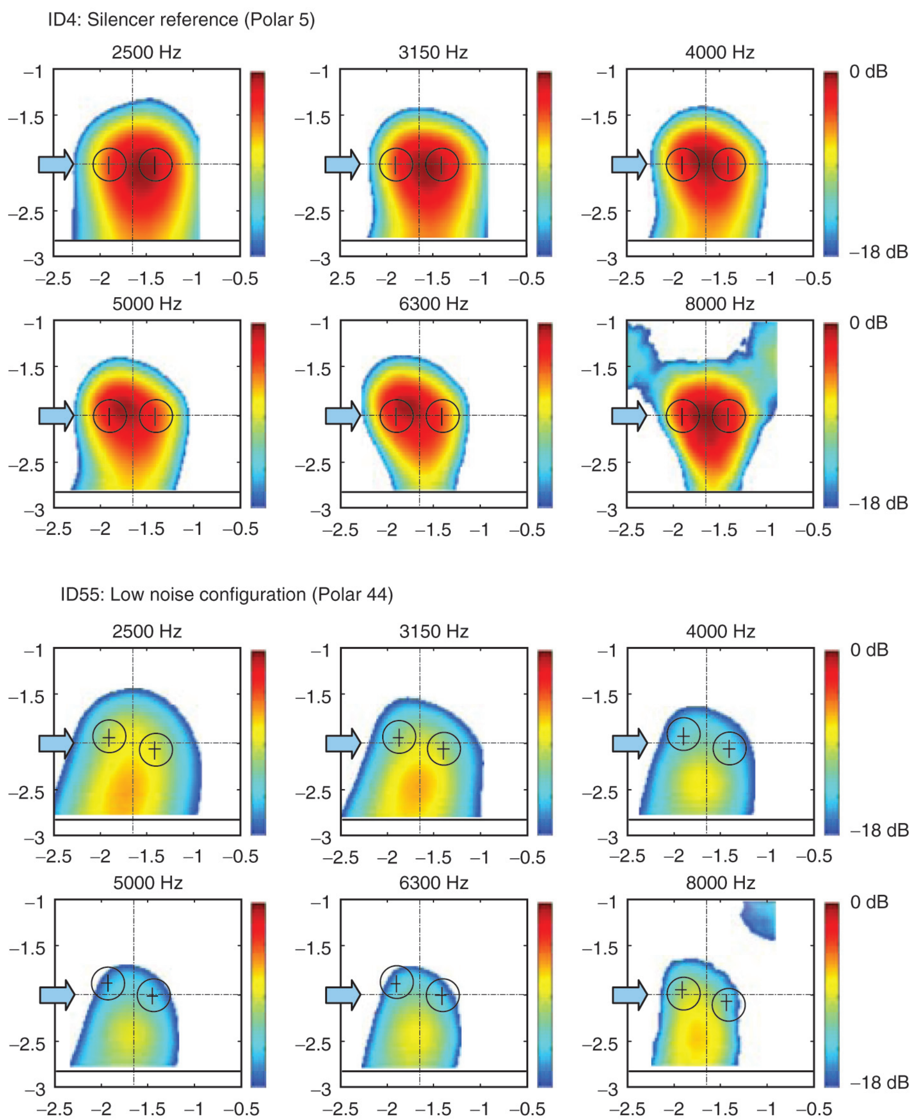


Figure 11: Comparison of noise source distributions from a “side view” for the reference configuration and the TIMPAN low noise configuration and different 1/3-oct. band frequencies, respectively (wind speed from left to right; same level scales for the two configurations at identical frequency but autoscaling for different frequencies).

This conclusion is supported by the results from the far-field sideline measurements. Fig. 12 presents a comparison of normalized landing gear noise directivities under the line of flight and for both outboard and inboard sideline radiation directions, for both the SILENCER reference configuration and the TIMPAN low noise configuration. For the reference configuration there is very little difference in the polar directivities for the different sideline directions, but for the quieter gear build the noise reduction is greatest for overhead ("ground") and outboard radiation directions, while the levels for inboard radiation direction remain relatively high. From the data acquired for other builds, it is apparent that this observation is not associated with any particular gear build, but is found in all relatively quiet configurations. This supports the conclusion that the leg-door/ side-stay area is the remaining dominant source region compared to the bogie area for the SILENCER reference configuration, and that the leg door projects noise

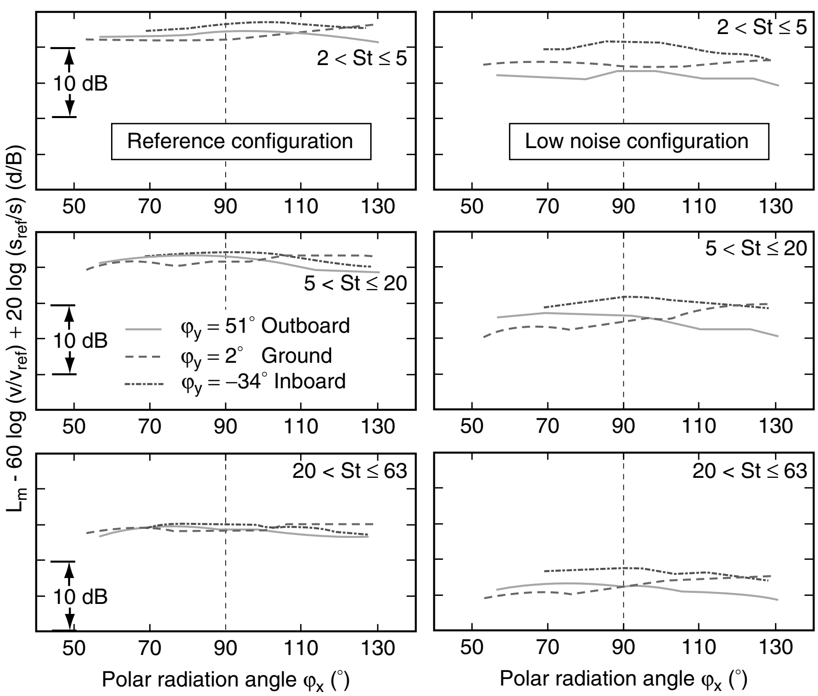


Figure 12: Polar directivities of non-dimensional 1/3-oct. band noise levels in different bands of Strouhal number for the reference, the TIMPAN low noise configurations and different azimuthal (sideline) radiation angles φ_y, respectively.

produced on the upper part of the gear towards the in-board direction. Thus noise originating from the bogie area features is almost omnidirectional, whilst noise from the leg-door structure is much more directional.

Any efforts to further reduce the noise radiation from this gear design must obviously focus on the leg-door/side-stay components. However, the skewness of the azimuthal directivity is not considered a problem with respect to aircraft noise impact on the ground because the directivities presented here are referenced to a constant radiation radius; in a flyover situation noise levels experience a geometrical reduction in level in the sideline direction, amounting to about 3 dB for a 45° azimuthal angle, and compensating for the observed “source” level increase shown in Fig. 12.

4.2. Noise reduction potential

The effectiveness of different noise reduction measures was determined through the computation of level differences from corresponding tests relative to a suitable reference configuration, i.e. the level difference from two gear configurations with one component change at a time, but limitations in testing time meant that not all treatments could be tested individually.

From this exercise, a rank ordering of the effectiveness of various methods of noise reduction was obtained. This exercise is limited by the fact that not all changes could be tested for the same reference configuration, so that the effectiveness of a noise control measure is dependant on whether it was tested on a relatively noisy configuration or a relatively quiet configuration, and no conclusive rank ordering of treatments can be provided. Still, some important general low noise design guidelines can be identified based on this procedure as discussed below.

4.2.1. Bogie and torque link fairings

The combined application of a bogie fairing and a torque link fairing (note: for this gear the torque link is installed in front of the main leg) seems to be a prerequisite for a low noise gear. Furthermore it was found that a porous design for both of these fairings is a very effective noise reduction feature. Fig. 13 depicts the effects of these individual solid or porous fairings. For porous fairings, the flow displacement is significantly reduced while still achieving a low enough wake flow velocity.

In this context it should be mentioned that different wheel spacing did not have a notable effect on noise, although this design parameter has some effect on the flow through the bogie structure.

4.2.2. Bogie inclination angle in combination with a bogie fairing

A successive increase in toe down bogie angle led to a successive decrease in noise (see Fig. 13). However, the noise-wise optimal toe down bogie angle might not have been captured in TIMPAN. This parameter needs a dedicated optimization cycle, keeping in mind that the final optimal angle might only be relevant for the gear architecture under consideration. It is expected that the effect on noise of this design parameter is due to the shielding effect of the bogie fairing with respect to the flow incident on the rear axle.

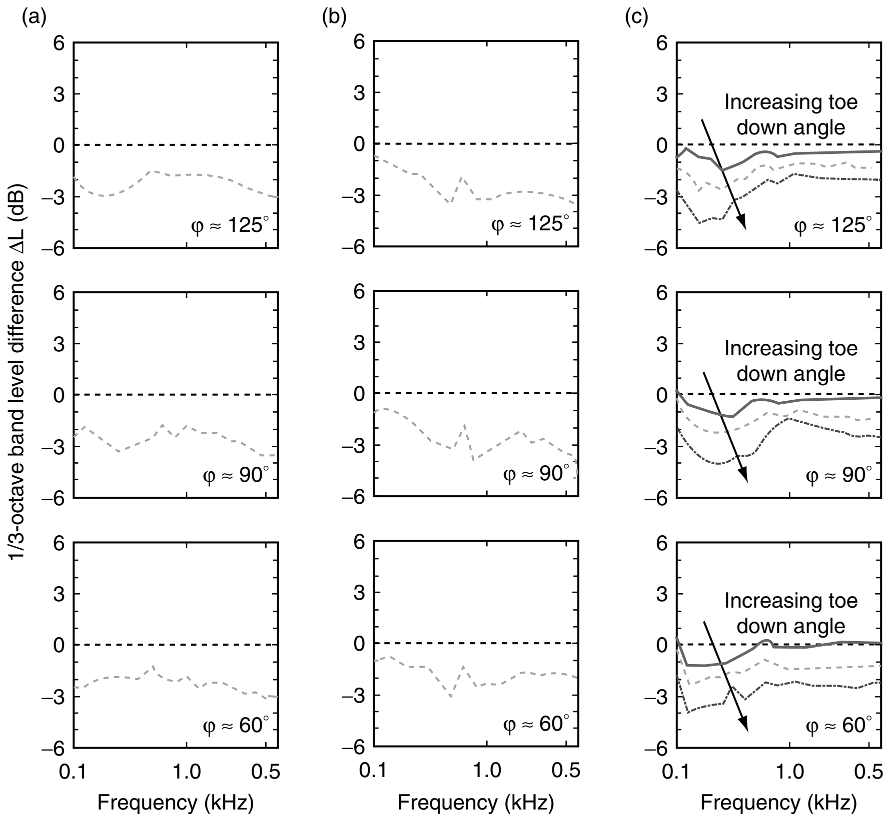


Figure 13: Effects of (a) porous bogie fairing and (b) porous torque link fairing w.r.t. solid fairings and (c) of bogie inclination angle.

4.2.3. Brake fairings

The type of brake fairings tested in TIMPAN, incorporating partially recessed brakes, are considered an optimal solution with respect to noise. Such fairings are important because otherwise noise from the brakes will significantly degrade the noise benefits from other noise reduction treatments.

4.2.4. Leg-door/side-stay design

The TIMPAN side-stay in combination with the articulated leg-door design was shown to be reasonably quiet, though not quite as good as the SILENCER telescopic side-stay. This situation can significantly be improved by application of a ramp to reduce high frequency noise originating from the upper leg area and the side-stay joints, and also avoids flow interaction with the cavity aperture.

As a final result in this study the optimal combination of all tested gear modifications (see Section 4.1 for configuration details) provided a noise reduction of 8 dB(A) in

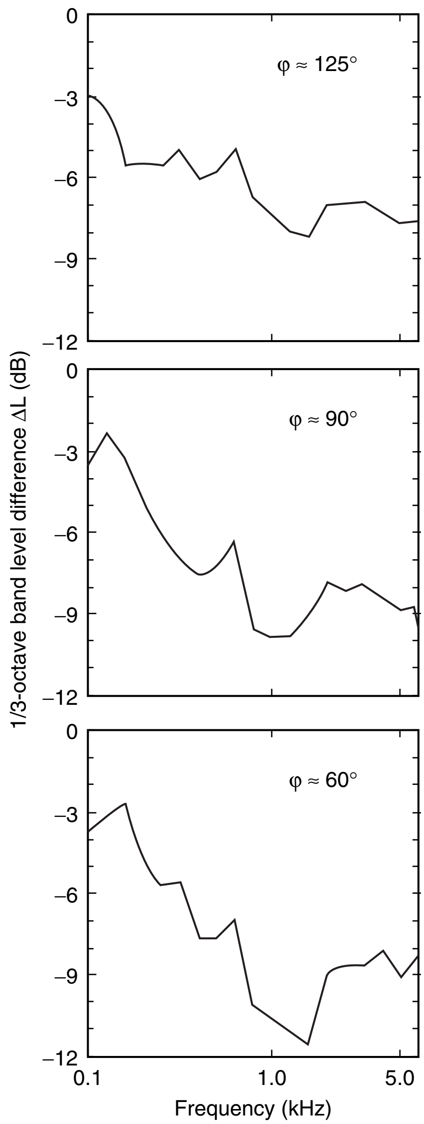


Figure 14: Noise reduction potential vs full scale frequency of the TIMPAN low noise configuration in comparison with the reference configuration.

terms of the OASPL (Overall Sound Pressure Level) compared to the noise of the SILENCER reference configuration. The highest noise reductions were achieved for high frequencies radiated into the forward arc (Fig. 14). This is the most important radiation direction because convective amplification enhances the forward arc noise once this "stationary source" noise characteristic is transposed to flight conditions.

5. NOISE PREDICTION

Prior to the tests, predictions of some of the key configurations were made using a semi-empirical landing gear noise prediction model [14]. Carrying out predictions prior to testing is beneficial as it confirms that the tests will provide useful results and also guides the priorities for the experimental programme. Comparing predictions with measured data after the test is obviously beneficial for validating the model, but also helps in interpreting and extrapolating from the data.

The prediction model has been validated in a considerable number of previous tests, but a major difficulty here was that the gear modifications to be tested (e.g. variation of wheel layout and bogie angle, ramp fairing, etc.) were expected to cause major changes to the flow distribution. As no CFD predictions were available it was necessary to make a number of assumptions about the extent to which each modification either increased or decreased the local flow over each gear component, so for example it is known that the blockage from wheels increases the flow over the brakes which increases their importance as a source. Other assumptions included the following: Installing a porous fairing reduced flow over shielded components with no increase over other components; installing a solid bogie fairing shielded some components completely but also increased external flow over the wheels and mid-leg region; installing the ramp fairing shielded parts of the upper leg and side-stay but increased flow on some leg components.

On the basis of these assumptions Fig. 15 shows a comparison of the predicted and measured benefits of installing either a solid bogie fairing or a porous bogie fairing, combined with a toe-down bogie angle so as to ensure that components of the rear axle are shielded and also a ramp fairing to shield the upper leg. The reference build for this

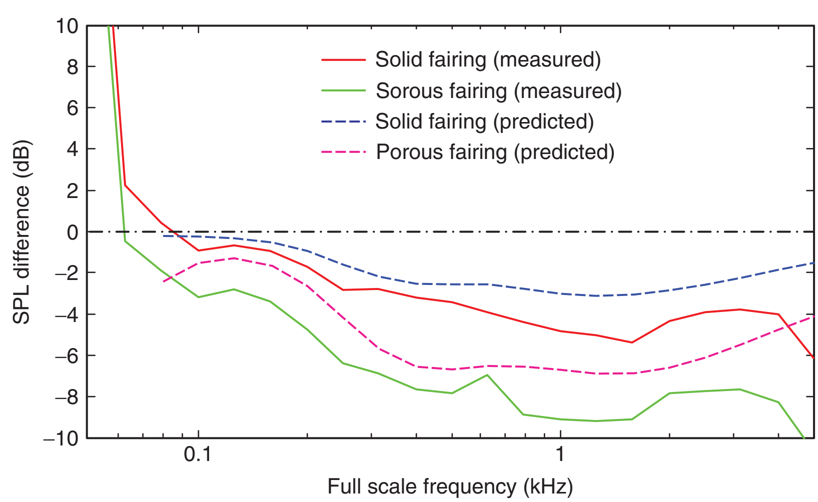


Figure 15: Predicted and measured effect of installing either a solid or porous bogie fairing and ramp fairing on the standard gear with the TIMPAN folding side-stay.

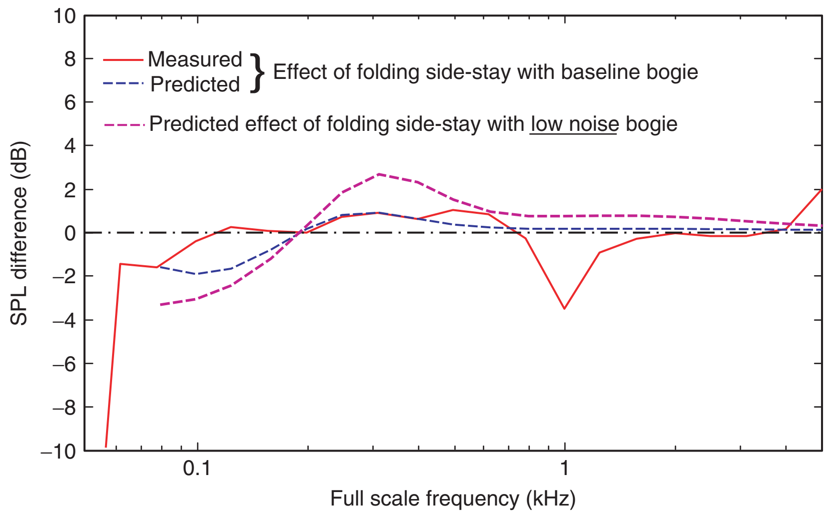


Figure 16: Noise increase due to changing from the SILENCER telescopic side-stay to the TIMPAN folding side-stay with the bogie in its reference configuration or its low noise configuration, respectively.

comparison comprises the standard advanced gear bogie combined with the new folding side-stay. The benefit of having a porous fairing rather than a solid fairing is fairly well predicted, and a key to this prediction is that a solid fairing significantly increases the flow over other components. Without this assumption the solid fairing would be predicted to be as effective as the porous fairing since they shield the same regions.

The noise model may also be used to extend the range of the database by predicting builds that could not be included in the test program. So for example Fig. 16 shows the additional noise produced by changing from the telescopic side-stay to the TIMPAN folding side-stay when the bogie is either in its baseline configuration or is in its low noise configuration. The measured data confirm that this has only a small effect when the bogie is in its baseline configuration, but the prediction model shows by how much the relative importance of the side-stay is increased when the bogie noise is reduced, a characteristic that is borne out by Fig. 11.

6. TRANSPOSITION OF NOISE DATA TO FLIGHT CONDITIONS

Measured noise data were finally transposed to flight conditions to estimate the potential impact of the new main landing gear design on the noise certification level (Effective Perceived Noise Levels) at approach for a generic long range twin engine aircraft. The low noise main landing gear configuration evaluated in-flight combines the following features:

- –15° bogie angle (toe down),
- Narrow wheel spacing (both forward and rear wheel sets),

- Porous bogie and torque link fairings,
- TIMPAN brake fairings,
- Articulated TIMPAN door with 45° ramp and
- TIMPAN side-stay design.

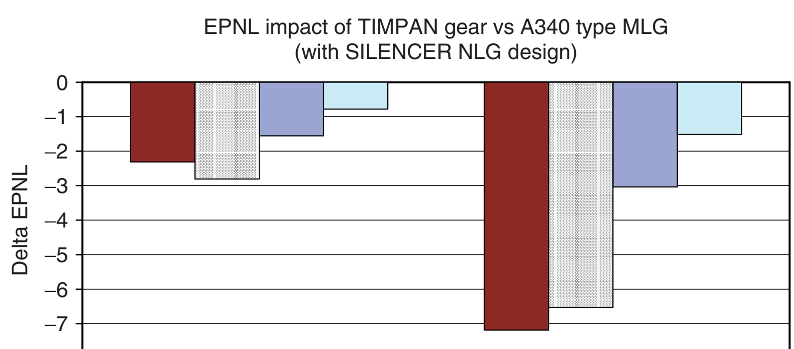
The estimation of approach noise levels is based on Airbus' total aircraft noise prediction code, accounting for landing gear source noise reduction in terms of level differences obtained from the wind tunnel tests after transposition to full scale conditions. This prediction code has been validated previously through comparisons with flight test data [15]. The code predicts the levels from each airframe and engine noise source separately.

The following parameters have been taken into account to conduct noise impact calculations for a long range twin engine aircraft configuration as defined in TIMPAN:

- Landing gear configurations: A340 baseline reference landing gears or with SILENCER advanced nose and main landing gear design [11];
- Aircraft configuration: 23° slat, 32° flap and landing gears down;
- Conventional approach trajectory: –3° glide slope;
- Flight parameters: Speed V_C = 145 kts, aircraft angle of attack = 3°;

At this stage neither a potential impact on the aerodynamic aircraft performance nor on aircraft weight was taken into account for this noise estimation.

Fig. 17 presents the estimated impact on the EPNL for the TIMPAN low noise main landing gear design in comparison with the SILENCER advanced gear design and the



	TIMPAN baseline (silencer MLG2)	TIMPAN low noise configuration (ID55)
MLG noise	–2.3	–7.2
LG noise	–2.8	–6.5
Airframe noise	–1.6	–3.0
Total A/C noise	–0.8	–1.5

Figure 17: Impact on EPNL for approach conditions of the TIMPAN low noise main landing gear design vs the SILENCER (reference) gear design and the original A330/A340 gears, respectively.

A330/A340 baseline main landing gear design, respectively, on (i) main landing gear source noise level, (ii) total landing gear source noise level, (iii) airframe noise, and (iv) total aircraft noise level. Accordingly, A340 main landing gear noise is reduced by more than 7 EPNdB due to the TIMPAN low noise features. This corresponds to an additional 5 EPNdB noise reduction in comparison with the previously developed advanced SILENCER main landing gear design [11].

For the TIMPAN low noise main landing gears, the overall landing gear noise (including SILENCER nose landing gear design) is reduced by 6.5 EPNdB when compared to A330/A340 original landing gear noise levels. This demonstrates that the objectives of the TIMPAN research project to reduce landing gear noise levels by 6 EPNdB relative to the year 2000 technology has been achieved.

Finally, total aircraft noise can be reduced by 1.5 EPNdB at approach when applying the TIMPAN low noise features on A330/A340 main landing gears for otherwise identical noise levels related to both high-lift devices and the engines.

7. SUMMARY

In the European co-financed research project TIMPAN the "advanced low noise design" of an A340 type 4-wheel main landing gear, as developed in the former European SILENCER project, was further investigated with the objective of developing gear components which are as quiet or even quieter than the SILENCER design, but with less weight penalty. A number of design options were developed to fit on an existing 1/4 scale SILENCER advanced gear for noise testing in the DNW-LLF. A variety of different gear configurations were tested for two wind speeds, respectively, including a new side-stay design, different toe down bogie inclinations, modified wheel spacing, bogie fairings with different flow transparency, and updated leg-door and brake designs.

Acoustic farfield data were acquired for frequencies up to 40 kHz to account for the model scale factor. Comparing the normalized noise spectra and directivities for the reference configuration in these model scale tests with data from the original full scale SILENCER test shows reasonable agreement.

An optimal combination of all tested gear modifications led to a noise reduction of up to 8 dB(A) in terms of overall A-weighted noise levels relative to the SILENCER reference gear configuration. The main contributions to this noise reduction originated from an increase in toe down bogie inclination angle, porous fairings for the front of the bogie and the torque link, improved brake fairings, and a low noise side-stay and alternative leg-door design in combination with a ramp.

In contrast to the SILENCER reference configuration, the polar directivity of the TIMPAN low noise configuration is characterized by high noise levels at high frequencies in the rear arc direction. Source location with microphone arrays and supported by the analysis of sideline noise level directivities, indicated that the leg-door/side-stay structure is the dominant residual noise source area for the TIMPAN low noise main landing gear configuration, whilst the bogie area was the dominant noise source region for the SILENCER reference gear configuration.

The test data are broadly in line with predictions made using a semi-empirical prediction model, although the use of this model is limited by the lack of accurate information about the changes in local flow over each component.

Finally, measured noise data were transposed to flight conditions to estimate the overall approach noise reduction for a generic long range aircraft. The TIMPAN low noise main landing gear configuration provides more than 7 EPNdB main landing gear source noise reduction, which results in a total aircraft noise reduction of 1.5 EPNdB for otherwise unchanged high-lift devices and engine noise levels.

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