A COMPREHENSIVE HELICOPTER ACOUSTIC MODELING TOOL BASED ON SIMULATION AND EXPERIMENT

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Abstract

The paper describes activities currently run in the frame of the MOTUS project. The developed methodology allows to correct an acoustic measurement database from simulation results in order to model the noise emission of a new helicopter (H/C), accounting for the introduction of low-noise technology bricks (*e.g.* rotational speed modification, alternate main rotor blade or Fenestron™ design, engine noise control treatment…). The resulting hemisphere database can then be used to simulate various use-cases, from predicting certification noise levels to computing noise footprints on realistic scenarii, including also Low Noise Procedures. All these results can then be auralized in a subsequent step, to address advanced metrics related to noise annoyance.

1. INTRODUCTION

In May 2015, Airbus Helicopters performed the first flight of H160 introducing its next generation of 6 tons helicopters [1]. The H160 helicopter features numerous innovations, such as the Blue Edge™ main rotor blade, a canted Fenestron™ and an ambitious rotational speed law. This results in an 'A' Sound Efficiency Rating, well better than the competitors in the respective weight class.

Former noise certifications [2,3], as well as research projects, show the continuous effort in lowering the environmental noise footprint of the Airbus Helicopters fleet, either through helicopter design improvements [3-7] or noise abatement trajectories design and implementation [8-11]. Latest progresses in the field of Low Noise Procedures highlight in particular the capability to assess the noise footprint of helicopters on so-called 'realistic' scenarii, taking into account the local topography and demography characteristics. Finally, disruptive designs, such as RACER (Figure *1*) need to be assessed and optimized [12].

Figure 1: The RACER demonstrator.

This paper presents a new methodology developed at Airbus Helicopters in the frame of the French-funded MOTUS project, in a work package related to helicopter acoustic pre-design. This methodology allows the assessment of the acoustic characteristics of candidate helicopter designs. It relies on the knowledge of the noise contributors relative to the helicopter, and the modification of these contributors according to simulation or experimental results.

- Section 2 presents the overall methodology.
- Section 3 details how the noise contributors are modified according to the different design changes.
- Section 4 provides some examples of the application of this methodology.
- Overall conclusion is provided in section 5.

2. DESCRIPTION OF THE METHODOLOGY

The methodology relies on acoustic hemispheres, and starts from a known, consolidated database, representative of the helicopter sound emission at various flight conditions, and derived from field measurements, such as presented in [9-11].

In the present paper, the Airbus Helicopters H130 (Figure *2*) is used as the reference helicopter for the sake of illustration. It is a single-engine helicopter of the 2-tons class, equipped with a 3-bladed rotor, a third generation Fenestron™ and a variable main rotor rotational speed (NR) law. This helicopter is considered as a 'good citizen': it holds a certification level 5.9 dB SEL below the ICAO (Annex 16, Chapter 11) limits, and satisfies the restrictive limitations in force in the Grand Canyon National Park in the United States.

Figure 2: Airbus Helicopters H130.

The external noise of H130 has been characterized through an extensive flight test campaign in the frame of the EU-funded FRIENDCOPTER project [13]. These flight test measurements allowed to derive a comprehensive hemisphere database characterizing the noise emission of the helicopter according to its flight condition [11].

Figure *3* shows the H130 database with the mean A-weighted level over the hemisphere representative of the noise emission for various steady flight conditions. We underline a relative noise increase at negative vertical speeds (*i.e.* in approach) which is attributed to Blade Vortex Interaction (BVI). On the contrary, take-off flight conditions (*i.e.* positive vertical speeds) are shown as quieter compared to approach and flyover. Even though the main rotor power required during take-off is greater, and therefore the required anti-torque as well as the engine power rating, a convection of the tip vortices well below the main rotor plane is assumed. Such an increase of the 'miss-distance' is on the overall beneficial in terms of acoustic emission. Regarding flyover flight conditions (values of the vertical speed close to zero), a relative noise increase is observed with increasing speed. This increase is attributed to the corresponding increase of the main rotor blade tip Mach number.

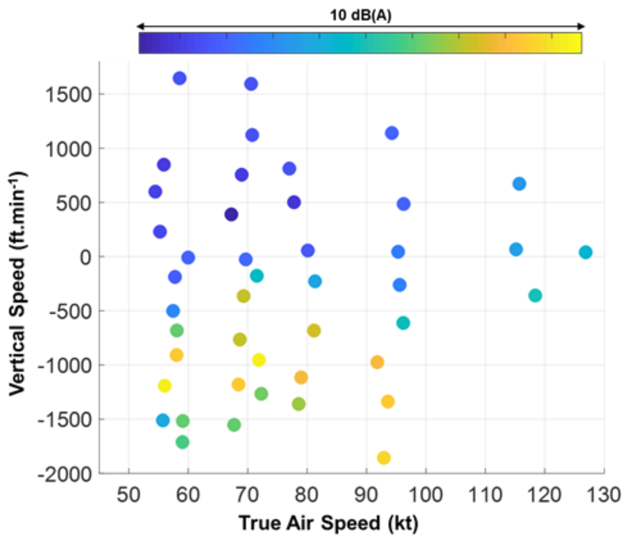

Figure 3: H130 acoustic hemisphere database.

Furthermore, these noise hemispheres can be propagated on any trajectory, using the Airbus Helicopters software CAROT (Compute the Acoustics of a Rotorcraft Over Terrain) [11]. Such computations are done on a daily basis at Airbus Helicopters. Generic trajectories can be simulated over an idealized, homogeneous, flat terrain (Figure *4*), but also on much more representative, so-called realistic scenarii, taking into account local topography and demography, as well as local helicopter traffic data (Figure *5*). Once coupled to an optimizer, low noise trajectories tailored to each specific realistic scenario can be returned.

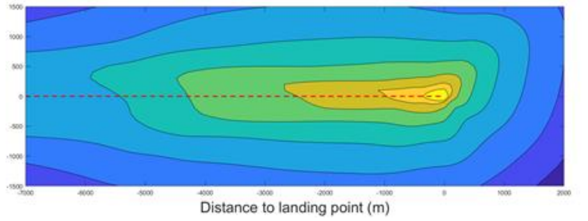

Figure 4: SEL noise footprint (5 dB(A) contours) of a straight approach on a flat homogeneous ground.

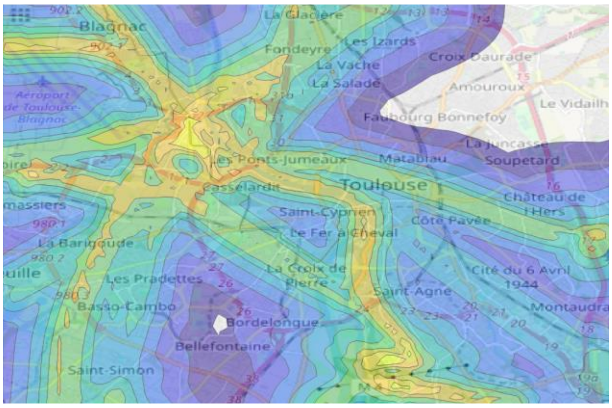

Figure 5: Maximal A-weighted noise level of a realistic traffic, 5 dB(A) contours.

Yet, this methodology still holds some drawbacks:

- It cannot identify the variations of the several noise contributors (main rotor, anti-torque, engines…) according to the flight condition.
- Therefore, the noise assessment (being at sphere level or at ground level) of a design modification is not easily accessible.

The methodology developed in MOTUS goes a step further: once the experimental database is available, the ROSI time domain source separation software, as described in [1], is run in order to get the tonal contributions along time of main rotor and anti-torque, as well as residual noise (subtraction of the main rotor and anti-torque signals to the total one). This results in a set of 3 hemispheres representative of the cited contributors. Figure *6* shows as an example representative hemispheres of the H130 in approach flight condition (total noise, main rotor tonal contribution and Fenestron™ tonal contribution). We can see that the main rotor holds a significant contribution, as expected from this flight condition prone to BVI, highlighting a directivity lobe towards the front of the helicopter. Source separation is therefore considered at Airbus Helicopters as a key asset, which is planned to be further used and improved.

On the top of main rotor and anti-torque tonal noise extraction, the engine noise contribution can be subtracted from the residual noise if information is available (*e.g*. from bench test measurement), resulting in a set of 4 noise hemispheres (main rotor tonal, anti-torque tonal, engine, and end-residual contributors).

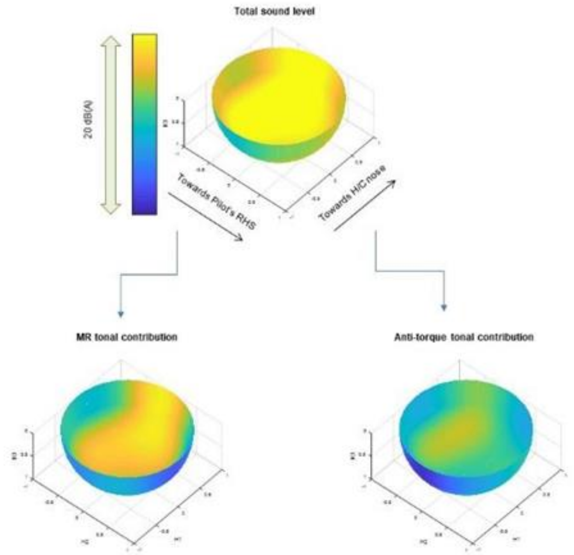

Figure 6: H130 acoustic hemisphere in approach ; main rotor and anti-torque tonal contributions.

This contributors extraction is currently done only on 'flight conditions of interest', as the certification ones, or conditions which are representative of the use of Airbus Helicopters fleet according to available data. It is however planned to automate the extraction on all the available flight conditions, but furthermore on all the available noise databases (*e.g.* H155, EC145…), as well as the databases to come.

Being able to identify the varying contributions of the several noise sources on several flight conditions (and potentially several rotorcrafts) opens the possibility of applying corrections (in terms of noise levels) according to modifications of the latter subsystems, *i.e.* on the corresponding contributors' hemispheres. These corrections, derived either from simulations or experiments, typically account for noise control technology bricks, such as optimized blades (*e.g.* Blue Edge™), Fenestron™ optimization, or engine installation treatments, but also more generic sizing parameters such as rotor radius, mean chord or nominal rotational speed, or virtually any kind of modification.

This allows therefore evaluating the noise of a candidate helicopter *a priori*. The evaluation of these corrections is described in the next section.

Once the corrections are applied, the different contributors are propagated to the ground (on the basis of the simulated scenario), and the total noise level is reconstructed at the simulated receiver positions. In order to allow for that, many features have been added to the Airbus Helicopters computational framework.

- Construction of a database of de-dopplerized noise hemispheres from flight test data. The hemispheres are output in an equivalent 'wind-tunnel' configuration; that is to say that the frequency vector of the tonal contributors is constant whatever the considered directivity.
- Handling of tonal noise hemispheres in the in-house propagation software CAROT, and summation of the different contributors holding different frequency vectors, as assumed uncorrelated sources.
- Re-dopplerization of the tonal hemispheres, according to the computed emission-to-reception vectors over time.
- Chaining of the tool to an auralization software, to get synthesized sound signals at identified observer(s).

In addition to that, an in-house platform allows one to manage and compute all the simulations of the different configurations on various use-cases.

3. SOURCE NOISE SIMULATIONS

This section describes how the noise corrections are applied to the various contributors, as well as how these corrections are evaluated. The retained solution is to apply a so-called 'mask', taking the form of a hemisphere accounting for the considered design change, to the measured noise hemisphere of the relevant contributor. In the case of a rotational speed or blade number change, the modification of the frequency vector of the impacted tonal sources is also taken into account, in addition to the changes in terms of directivity and amplitude.

Currently, a mask can be constructed using 3 levels of accuracy:

- If deemed-accurate directive information is available, the mask is applied as a function of directivity and frequency.
- At a lower accuracy level, the mask is only applied as a representative sphere mean spectrum. That is to say that each directivity of the contributor hemisphere will be impacted equally, according to the mask modification spectrum.
- At the lowest accuracy level, a constant level shift can be applied on the contributor hemisphere. The modification is therefore constant according to directivity and frequency.

The mask can be obtained either from simulation data or experimental data (*e.g.* in a controlled environment such as a wind tunnel or an anechoic chamber). Typically, this involves computing or measuring the reference and the modified designs as acoustic hemispheres. In the experimental framework, one usually relies on back- or forward-propagation of the measurement data to recover an equivalent noise hemisphere. In a computational framework, the hemisphere is usually computed directly.

A beneficial feature of the retained methodology, when it comes to simulation, is that the focus is to get representative differences between the reference and modified concepts and not absolute levels, which are typically challenging to compute. Indeed, although much progress has been made throughout the years, discrepancies between measurement and simulations are still observed. However, it has been shown [1,7] that design effects (blade planform, Fenestron™ design…) can be fairly well captured in terms of noise gradients with respect to a known reference.

The following subsections describe how the masks are typically derived for main rotor, anti-torque and engine contributors.

3.1. Main rotor modifications

Due to the high costs related to the assessment of main rotor noise design changes at experimental level, Airbus Helicopters mainly relies on simulation data when it comes to main rotor acoustic evaluation. Yet, experimental data can also be used to assess a modification, in case specific flight test data is available (*e.g.* Blue Edge™ dataset).

Main rotor simulation framework at Airbus Helicopters has been developed throughout several years, benefiting from strong collaborations with research centers (ONERA, DLR, IAG), on the basis of several research projects and developments [1,7]. However, main rotor acoustic simulation remains very challenging. Methodologies, mainly based on an aeromechanical solver coupled either to a Free-Wake (FW) [13-15,16] or a CFD solver [17,18], are constantly evolving and gaining in maturity. Typically, the aerodynamic data (either expressed on a solid or porous surface if available) is submitted to an acoustic solver relying on the Ffowcs-Williams-Hawkings analogy, in this case KIM [19]. Currently Airbus Helicopters relies on both the FW method and the CFD one for main rotor noise prediction.

The FW method benefits from lower restitution time and allows for large parametric variations. In this regard, the HOST-MMAP toolchain was recently adapted to the new aeromechanic solver STORM [20]. It benefits from the genericity of this new solver, as well as its powerful Python wrap-up allowing for large parametric variations which would not be possible using a CFD framework due to computational cost. Figure *7* and Figure *8* show respectively the outcome of the STORM-MMAP computation chain as a noise hemisphere, and the source-separated main rotor tonal contribution from experimental data, in approach flight condition. Although the absolute levels are not displayed, the colorbars in these two figures are the same. On the experimental side, a directivity towards the front and left (advancing blade) sides is observed. It matches fairly well with the simulated data ; yet simulation also shows some noise emission on the rear and retreating blade sides of the helicopter, less in accordance with the experimental data.

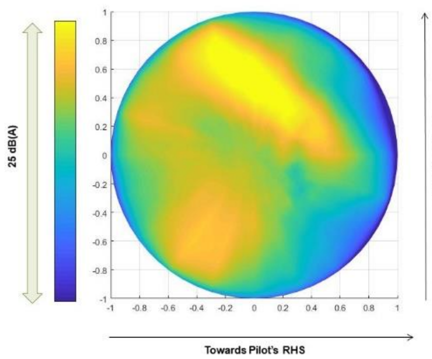

Figure 7: H130 main rotor FW simulated noise hemisphere, in approach.

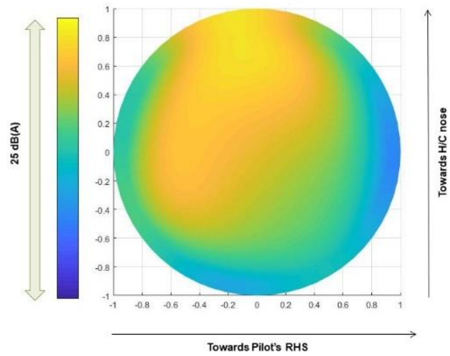

Figure 8: H130 main rotor experimental (source separated) noise hemisphere, in approach.

The CFD method holds a higher expected accuracy, in the sense that it is expected to capture finer effects than the FW method, such as blade tip modification, or tab introduction, the full wake being resolved as illustrated in Figure *9*. Progress has been recently made in the frame of the french-funded ROTOR-NG PETRA PT3 project: an aero-acoustic model of the H130 main rotor has been setup as well as various alternate configurations in designs and flight conditions. The method involves replacing iteratively the low fidelity aerodynamic loads obtained by a rotorcraft comprehensive code (namely CAMRADII [16]) by the high-fidelity aerodynamic rotorblade loads computed by CFD (in this case DLR's FLOWer [17]), as comprehensively described in [18] and [21]. The RANS equations have been closed using the Shear Stress Transport k-ω variant of Menter's model [22]. A 5-stage Runge-Kutta central scheme with artificial dissipation has been used to evaluate numerically the Eulerian terms. The time-dependent URANS solution is obtained using an implicit dual time-stepping approach developed by Jameson [23]. At convergence blade skin pressures are extracted at 0.5° azimuth intervals for acoustics propagation.

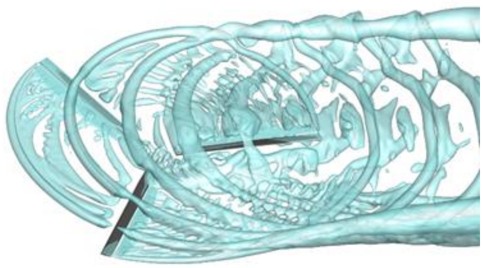

Figure 9: Aerodynamic FLOWER simulation of the H130 main rotor in approach condition (Q-criterion).

Figure *10* shows the noise hemisphere of the H130 in approach as computed by the CFD computation chain. The color scale of the latter figure was shifted by a 5 dB(A) factor in order to be comparable with the experimental and FW plots. This underlines a tendency of underestimation of the noise levels in the current CFD main rotor computation chain.

The hemisphere highlights a directivity towards the front of the helicopter, in accordance with the experimental and FW results. Also, a secondary lobe is visible towards the rear and advancing blade sides, in accordance with the FW results.

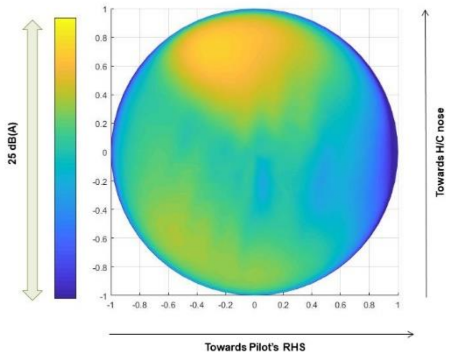

Figure 10: H130 main rotor CFD simulated noise hemisphere, in approach.

Figure *11* shows the experimental, CFD and FW results as sphere-averaged spectra, up to the 40th main rotor harmonic. The FW and experimental results again match fairly well, apart from the {15-25} harmonic number region, which highlights some underestimation of the simulated levels. When it comes to the CFD results, the underestimation observed at sphere level is obviously noticeable. In particular, the discrepancy between simulation and measurement becomes significant at higher harmonic numbers. This needs to be further investigated, but could be attributed to the diffusion of tip vortices prior to interaction with a main rotor blade.

When assessing the flyover condition instead of the approach one, the CFD results match much better with the experimental data than the FW results, as illustrated on Figure *12*. The FW results are far below the measurement levels above main rotor harmonic 10. In this region, CFD results match much better with the experimental dataset. Interestingly, both simulation methods tend to overestimate the main rotor noise in the low frequency region (main rotor harmonics 4 to 10).

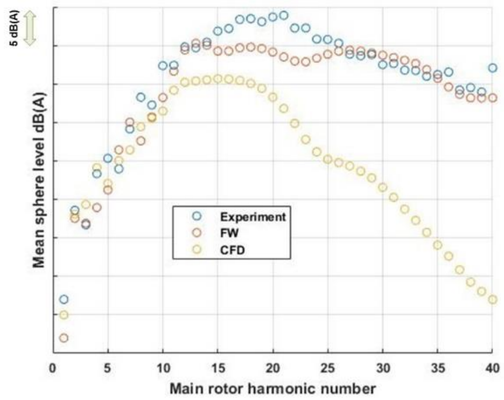

Figure 11: H130 main rotor sphere-averaged A-weighted spectra, in approach.

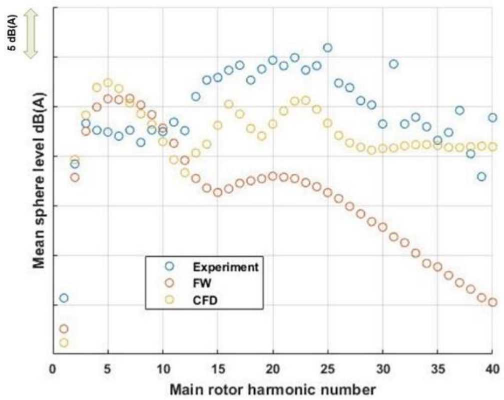

Figure 12: H130 main rotor sphere-averaged A-weighted spectra, in flyover.

Figure *13* and Figure *14* show the acoustic hemisphere representative of the same main rotor, in approach flight condition, at a modified (decreased) rotational speed, corresponding respectively to the FW and the CFD methods, using the same color scales as for the nominal rotational speed. The overall noise level is decreased, as expected, and that the directivity lobe is shifted towards the pilot's left hand side. This shift is attributed to the modification of the interaction patterns induced by the rotational speed modification. Figure *15* displays the subtraction of the sphere-averaged spectrum at reduced rotational speed to the spectrum at nominal rotational speed. A positive value therefore indicates a noise reduction thanks to the rotational speed decrease. The spectra are expressed along main rotor harmonics, but the corresponding frequencies are different on the two configurations, due to the rotational speed modification. Both methodologies predict strong noise reduction above main rotor harmonic 12, a frequency domain where much (A-weighted) acoustic energy is located according to Figure *8*. On top of that, the shapes of the FW and CFD noise reduction spectra show similarities, although the FW results attribute more effectiveness to the rotational speed decrease in terms of noise reduction. This underlines the benefit of the MOTUS methodology, which focuses on the noise gradients between the explored configurations and the reference, instead of the absolute levels, which in that case are significantly different between the two methodologies.

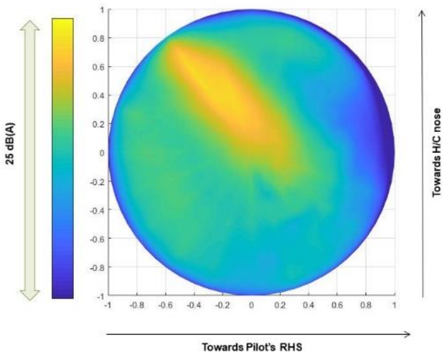

Figure 13: H130 main rotor FW simulated noise hemisphere, in approach, at reduced rotational speed.

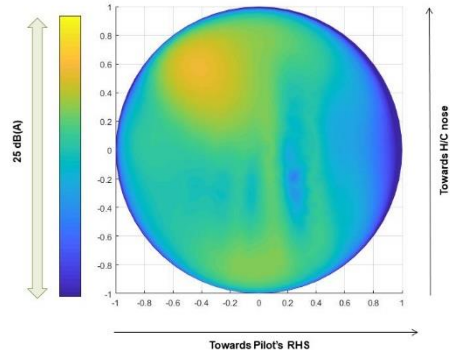

Figure 14: H130 main rotor CFD simulated noise hemisphere, in approach, at reduced rotational speed.

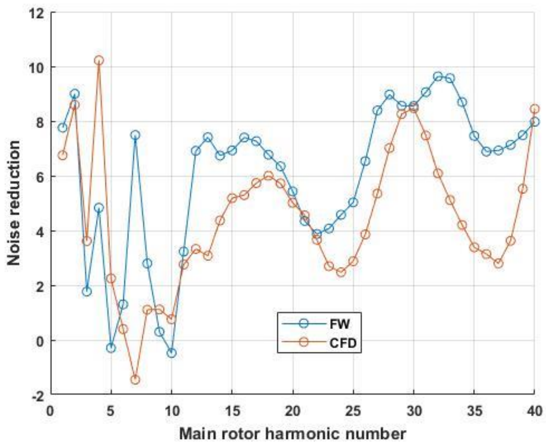

Figure 15: Effect of the rotational speed reduction on the main rotor sphere-averaged noise spectra according to the 2 computation chains.

3.2. Anti-torque modifications

Similarly to main rotor noise, anti-torque (being conventional tail rotor or Fenestron™) noise, also assumed tonal, can be assessed on the basis of CFD. Due to the complexity of the geometry, especially considering the Fenestron™ (Figure *16*), the design change can also be investigated using a mock-up in a controlled environment. In the frame of the MOTUS project, both strategies are being used.

Figure 16: H130 Fenestron™.

When it comes to numerical methods, the current CFD framework is based on FLOWer simulations of the isolated tail parts and Fenestron™. The RANS equations are closed using the k-ω Wilcox model [24]. A 5-stage Runge-Kutta central scheme with artificial dissipation is used to evaluate the Eulerian terms. The time-dependent URANS solution is obtained using an implicit dual time-stepping approach [23]. Up to 6 revolutions are computed in order to converge the solution and pressure signal is extracted at 1° azimuth intervals for the last revolution for acoustics simulation.

As the model is currently being set up, only first results are shown hereafter. Figure *17* and Figure *18* display respectively the source-separated Fenestron™ tonal contribution extracted from experimental data, represented by a noise hemisphere, and the corresponding simulated hemisphere. Due to the clockwise rotation of the H130 main rotor, the Fenestron™ thrust side is located on the left of the figures, and the blowing side on the right. In order to well compare, the simulated noise levels have been shifted by a factor of -5 dB(A). That is to say, that contrary to the main rotor, the CFD simulation tends to overestimate the Fenestron™ tonal contribution. These results are currently analyzed, but several potential root causes presented hereafter are suspected.

- The current acoustic processing is based on porous surface data located at the inlet and outlet of the Fenestron™ vein. It is suspected that rotor wake vortices cross these surfaces and therefore induce unphysical additional noise. The processing of the solid surface data (pressure data on the surfaces such as rotor, stator, shroud…) is expected to help in assessing the porous surface positioning, but will also allow to track the Fenestron™ main noise sources at sub-component level (*e.g.* rotor/stator interaction noise).
- A mismatch between the numerical rotor pitch angle and the estimated experimental pitch has been recently discovered. Computations with a more appropriate pitch angle are currently running which may improve the comparison between experiment and simulation.
- On top of that, the extraction of Fenestron™ noise from experimental data is in itself a complex task. It is likely that the experimental sphere is underestimated thus increasing the gap between experiment and simulation.

Despite the above points, the experimental and numerical noise hemispheres show fairly comparable directivities. In particular, the shroud 'masking' effect, which allows to significantly reduce the anti-torque noise under track (directly below the helicopter) [2] is clearly observed. Two directivity lobes are located on the blowing and thrust sides on both spheres, although the experimental sphere holds higher levels on the thrust side, whereas the simulated one holds higher levels on the blowing side.

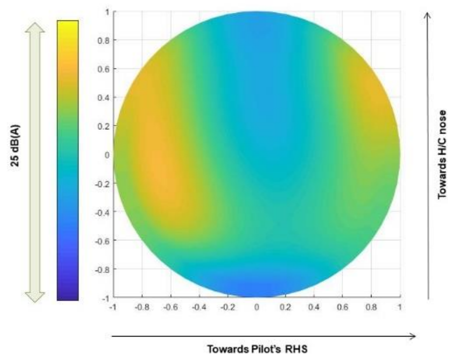

Figure 17: H130 Fenestron™ experimental (source separated) noise hemisphere, in flyover.

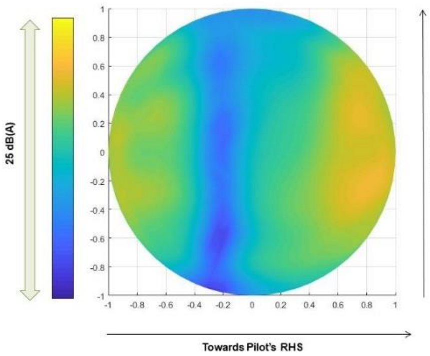

Figure 18: H130 Fenestron™ CFD simulated noise hemisphere, in flyover.

Additionally, experimental data are also being used to assess noise reduction of various noise control solutions. As for the main rotor, anti-torque modifications can also be assessed through specific field test campaigns. For example, Fenestron™ acoustic surface treatment influence has been tested in the frame of Bluecopter [7] project, and specific processing of such database can be used to retrieve hemispheres masks for such noise control treatments. Using similar principles, the influence of a conventional tail rotor compared with a Fenestron™ can be extracted from previous research project measurement (*e.g.* EC145 CLEANSKY database).

Finally, laboratory testing can also be leveraged to assess experimentally Fenestron™ design changes. In the 80's, a 1/3rd scale Fenestron™ mock-up was designed and built in order to study, especially in wind-tunnel, the specific operation of this innovative anti-torque system. This fenestron mock-up was extensively used to study and characterize its aeromechanic behavior, but also to build-up a comprehensive database for simulation. This Fenestron™ mock-up was then updated more recently and used to design the H160 Fenestron™, also including canting investigations. The Fenestron™ mock-up will now also be used for acoustic characterization. Within the frame of the MOTUS project, it will be tested in ONERA anechoic chamber in Toulouse (France), to investigate acoustic effects of various design parameters, including integration of noise control solutions such as acoustic surface treatments. This experimental acoustic characterization will also allow generating noise hemispheres of anti-torque noise source in various configurations, that will further be included in the global methodology presented herein to assess noise control benefits at helicopter level.

3.3. Engine modifications

Engine noise is typically the third main noise contributor on the helicopter. Extracting its contribution to total noise from experimental data is much more difficult, as it is typically broadband.

The engine noise contribution can be estimated from residual noise (*i.e.* total experimental noise minus the main rotor and anti-torque contribution), for example assuming that, at high power rates, engine noise constitutes the main part of the residual noise. An alternate solution is to use an engine noise contribution derived from controlled environment measurement (*e.g.* if bench data is available).

Once the engines contribution is available in the form of a noise hemisphere, engine modifications can then be estimated using a mask. The modification can be for example representative of a change of nozzle ejector shape or the introduction of acoustic surface treatments.

In the frame of GORDON (DGAC-funded project with Safran Helicopter Engines), engine noise contribution is being investigated for various flight conditions and on various helicopters. Noise hemispheres are being extrapolated from bench acoustic measurements on installed engine configurations. Engine noise reduction techniques are investigated numerically and through comparison with tests when possible.

Simulations include a RANS flow computation, which is then injected in an aero-acoustic code to get the noise radiation. Far-field noise is obtained by the use of infinite elements.

On Figure *19*, we insert a standard liner on the H130 nozzle ejector to reduce exhaust noise, and then consider an improved liner version. The directivity results, given at 800 Hz on a sphere, put into evidence the noise level decrease in presence of the liners (spheres are expressed in the same coordinate system as the displayed geometry).

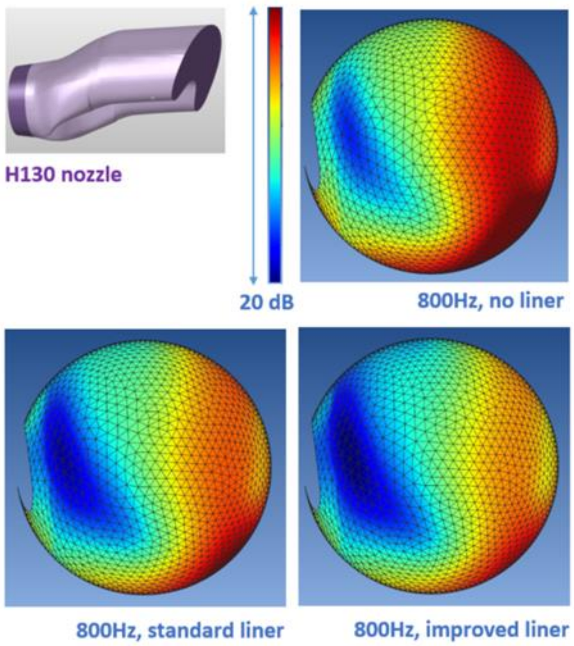

Figure 19: Radiation response of H130 nozzle to aero-acoustic modal excitation at 800Hz for 3 different configurations.

Figure *20* shows the noise mask which is derived from the numerical computations, which is applied to the extracted engine noise contribution hemisphere.

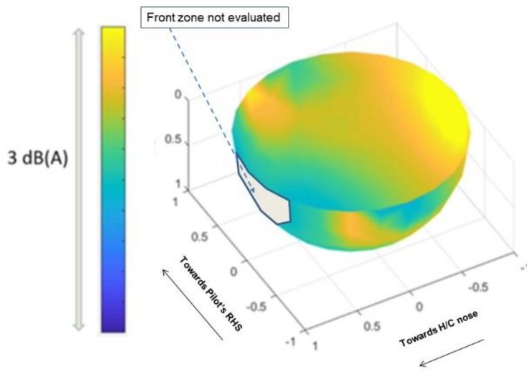

Figure 20: Noise mask resulting from the engine liner application at frequency 800Hz.

4. APPLICATIONS

This section highlights several applications of the developed computational framework. In particular, we detail the effects of a modified (decreased) rotational speed and of an alternate helicopter design (modification of the number of blades, main rotor radius, mean chord, nominal rotational speed…) in approach flight. For the take-off flight condition, we focus on the effects of the substitution of the Fenestron™ with a conventional tail rotor and on the application of surface acoustic treatments to Fenestron™ and engine exhaust.

The modifications displayed in the present section are assessed for the sake of illustration of the presented methodology and are not representative of current designs or design proposals, in particular when it comes to the interaction with other disciplines (performance, loads…).

Table *1* gives an overview of the different tested design modifications that are detailed in this section. As throughout this paper, the Airbus Helicopters H130 has been used as the reference H/C configuration.

Table 1: Overview of the tested configurations.

		Sources		
Flight phase	**Name**	**Main Rotor**	**Anti-torque system**	**Engine**
Approach	Modified NR	NR reduction	NR reduction	Ref.
Approach	New H/C design	Modified rotor (mean chord, radius, nb. of blades, NR...)	Modified Fenestron™ (NR)	Ref.
Take-off	Conventional TR	Ref.	Conventional tail rotor	Ref.
Take-off	Acoustic treatments	Ref.	Acoustic Treatment	Acoustic treatment

First, the toolchain makes it possible to evaluate the benefits of the different design changes on ICAO certification noise levels. The predicted reductions, in terms of SEL associated to the ICAO Annex 16 Chapter 8 certification take-off (resp. approach) procedure, are given in Figure *21* (resp. Figure *22*) for the 3 certification microphones. Negative values represent an acoustic gain (noise reduction) relative to the H130 reference configuration. SEL is used as an alternate noise metric herein in order to get an insight of noise reductions without taking into account the tonal correction introduced by the use of EPNL.

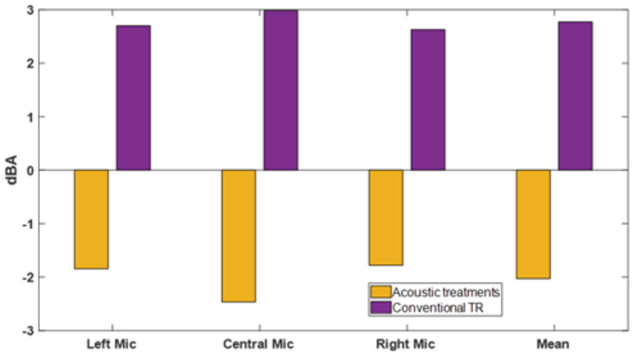

Figure 21: Noise gains (SEL) compared to reference H/C in take-off.

It is observed that the installation of a conventional tail rotor instead of the Fenestron™ anti-torque system shows a significant degradation of the certification noise levels in take-off. In particular, the highest increase is observed at central microphone, which is attributed to the absence of the Fenestron™ masking effect, as detailed in Section 3.2.

In addition, Figure *21* shows an average acoustic gain of roughly 2 SEL dB(A) thanks to the implementation of surface acoustic treatments applied to both Fenestron™ and engine exhaust. This technology thus proves to be of great interest in reducing the noise emission, especially in the flight phases, such as take-off, in which the engines and the anti-torque are the main contributors to the total noise.

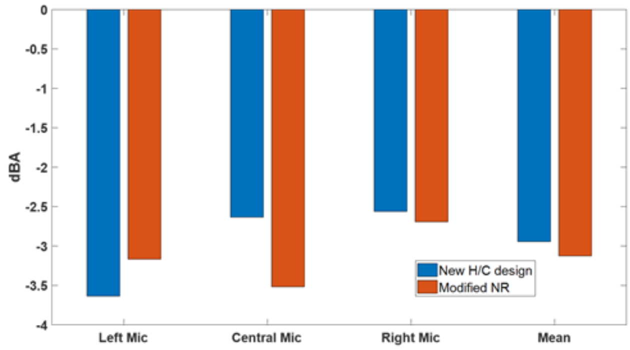

Figure 22: Noise gains (SEL) compared to reference H/C in approach.

Regarding the approach condition, the acoustic gains associated with the proposed design changes are given in Figure *22*. For the new H/C design, we can see that the highest reduction is predicted on the left microphone (*i.e.* on the advancing blade side for a H130 helicopter), which is consistent with the location of the main rotor directivity lobe (towards the front and the left). As explained in Section 3.1, modifying the main rotor design will thus modify the interaction patterns, resulting in a shift of the directivity lobe. More generally, the new H/C design configuration shows a mean reduction of roughly 3 dB(A) over the three certification microphones. It is also observed that similar average gains can be achieved thanks to the implementation of a modified (decreased) rotational speed.

In addition to the certification noise levels, the design changes can also be evaluated through the computation of the noise footprint of different realistic scenarii representative of single missions or even at traffic scale, following the work in [11]. Figure *23* (resp. Figure *24*) depicts an iso-SEL contour associated with a typical take-off (resp. approach) procedure projected on Marseille airport. We observe that for both take-off and approach the design changes contribute significantly to reducing the size of the contour. Thanks to the coupling of the toolchain with geo-referenced data, further studies can focus, for example, on the reduction in terms of the number of people impacted in various locations.

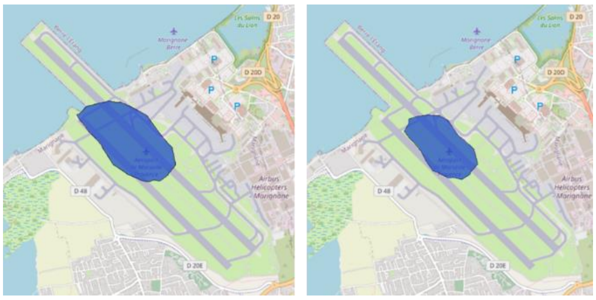

Figure 23: 80dB SEL contour in take-off for reference H/C (left) and H/C with surface acoustic treatments (right).

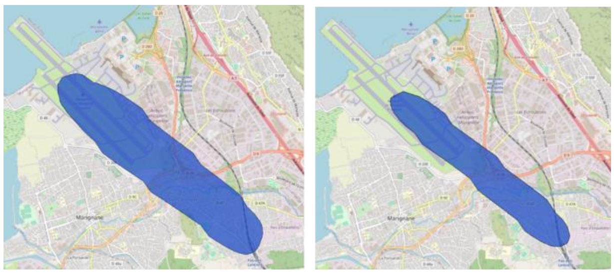

Figure 24: 80dB SEL contour in approach for reference H/C (left) and new H/C design (right).

In the frame of lowering the environmental noise footprint of helicopters, a proven efficient technology is the design and use of Low Noise Procedures (LNP), as detailed in [11]. One of the main advantages of LNP is that it is applicable to all helicopters, including those already in service. In addition, LNP can be combined with the various design modifications presented in this paper. Figure *25* shows the SEL noise footprint associated with the modified H/C with a reduced rotational speed flying the reference procedure and the same modified H/C using a LNP. We observe that incorporating the investigated design changes on the top of LNP can significantly reduce the noise level on the ground, hence the number of people impacted.

Figure 25: 80dB SEL contour in approach for an H/C with a modified rotational speed on reference procedure (left) and a LNP (right).

Finally, the acoustic content resulting from the propagation of the modified noise hemispheres along a given trajectory can be auralized so as to get a realistic fly-by signal. The auralization process relies on the GENEPASS [25] software to synthesize a sound signal at a given observer position. First, the propagated noise hemispheres are re-dopplerized within the propagation tool CAROT and the noise spectra of tonal and broadband contributions are calculated at a given receiver position. In a second step, GENEPASS accounts for the ground effect and the atmospheric turbulence in the synthesis of the signal. The different design changes can therefore be evaluated directly by a panel of listeners to perform a subjective assessment. After listening, the configurations are ranked from the quietest to the noisiest in order to identify the most efficient technologies to reduce the helicopter noise annoyance.

5. CONCLUSION

This paper shows the methodology currently put in place at Airbus Helicopters, allowing for the noise assessment of candidate helicopter designs, on the basis of experimental and numerical results. It leverages on the source separation capability available at Airbus Helicopters, which permits the evaluation of the major tonal noise sources of a helicopter (*e.g.* main rotor and anti-torque) from experimental data. Engine noise is derived from residual signal and/or bench test measurements.

Corrections (in the forms of masks) are then applied to their corresponding sources. The mask corrections are derived from experimental or numerical assessment.

- When it comes to main rotor, numerical evaluation is the preferred option. Simulations shown in the present paper (either from FW or CFD solvers) show comparable characteristics to measurement data.
- Regarding anti-torque, design changes can be assessed on the basis of either of simulations and test data.
- Engine modifications (in particular in terms of installation) are finally implemented. The present paper provides an example on the basis of simulation data.

Once the contributors are known, the helicopter total noise is propagated and re-synthetized on ground.

- Certification noise (or equivalent) is thus accessible. On top of that, the relative benefit of each implemented technology brick becomes visible, as well as the combination of the technology bricks.
- Noise footprints, which can be assessed on the basis of realistic scenario, can be computed. This furthermore makes possible to evaluate the combination of the assessed technology bricks with Low Noise Procedures.
- Finally, the sound signal can be re-synthetized on any simulated location, so that a subjective assessment is possible, but also to demonstrate the benefit of candidate technology bricks in terms of noise reduction.

The methodology will be further used at Airbus Helicopters, in various contexts. Potential enhancements, in particular in the frame of broadband noise identification, and disruptive design assessment (*e.g.* Urban Air Mobility), are already identified.

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7. REFERENCES

1. Guntzer F., Gareton V., Pinacho J.P., Caillet J., “Low noise design and acoustic testing of the Airbus Helicopters H160-B”, European Rotorcraft Forum 45th Annual Forum Proceedings, Warsaw, Poland, September 2019.
2. Gareton, V., Gervais, M., Heger, R., “Acoustic Design and Testing of the Eurocopter EC145T2 and EC175B – a harmonized Franco-German Approach”, European Rotorcraft Forum 39th, Moscow, September 2013.
3. Niesl, G., Arnaud, G., ‘Low Noise Design of the EC135 Helicopter,’ Presented at the 52nd Annual Forum of the AHS, Washington DC, June 1996.
4. Gervais, M.; and Gareton, V.: “Analysis of Main Rotor Noise Reduction due to Novel Planform Design – The Blue Edge™ Blade”, 37th European Rotorcraft Forum, Gallarate, Italy, Sept. 2011.
5. Rauch, P.; et all.: “Blue Edge™: the Design, Development and Testing of a new Blade Concept, Experiment”, Proceedings of the American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 2011.
6. Allongue, M.; Marze, H. J.; Potdevin, F.: “The Quiet Helicopter « From Research to Reality »”, American Helicopter Society 55th Annual Forum, Montreal, Canada, May 25-27, 1999.
7. Schneider, S., Heger, R., Konstanzer, P., “Bluecopter™ Demonstrator: the State-of-the-Art in low Noise Design”, 42nd European Rotorcraft Forum, Lille, France, September 2016.
8. Marze, H.-J., Gervais, M., Martin, P., Dupont, P., “Acoustic Flight Test of the EC130 B4 in the Scope of the FRIENDCOPTER Project”, 33rd European Rotorcraft Forum, Kazan, Russia, September 2007.
9. Gervais, M., Gareton, V., Dummel, A., Heger, R., “Validation of EC130 and EC135 Environmental Impact Assessment using HELENA”, American Helicopter Society 66th Annual Forum, Phoenix, USA, May 2010.
10. Guntzer, F., Gareton V., Gervais, M. Rollet, P. “Development and testing of optimized IFR noise abatement procedures on EC155”, American Helicopter Society 70th Forum, Montreal, Canada, May 2014.
11. Pierre Dieumegard, Frédéric Guntzer, Julien Caillet, Sonia Cafieri, "A realistic rotorcraft noise footprint computation for Low-Noise trajectory optimization", Vertical Flight Society 78th Forum, Ft. Worth, Texas, USA, May 2022.
12. Pierre Dieumegard, Frédéric Guntzer, Julien Caillet, “Rotorcraft Low Noise Trajectory Design: a focus on RACER”, Towards Sustainable Aviation Summit, Toulouse, France, 2022.
13. Benoit B., Dequin A.-M., Kampa K., Gruenhagen W., Basset P.-M., Gimonet B., "HOST: A General Helicopter Simulation Tool for Germany and France“, 56th American Helicopter Society Annual Forum, Virginia Beach, Virginia, USA, May 2000.
14. Beaumier P., Delrieux Y., “Description and validation of the ONERA Computational Method for the Prediction of Blade-Vortex Interaction Noise”, Aerospace Science and Technology Journal, AST Vol.9 issue 1, Elsevier.
15. Reboul, G., Falissard, F., “On the Use of CFD for Improvement of Low-Fidelity Blade-Vortex Interaction Prediction Code”, Proceedings of the Vertical Flight Society 75th Annual Forum and Technology Display, Philadelphia, Pennsylvania, May 2019.
16. Johnson, W., “Technology drivers in the development of CAMRADII”, AHS Conference, San Francisco, California, 1994.
17. Kroll, N., Eisfeld, B. & Bleeke, H., “The Navier-Stokes code FLOWer”, Notes on Numerical Fluid Mechanics, vol. 71, pp. 58-71, 1999.
18. Kowarsch, U., Öhrle, C., Keßler, M. & Krämer, E., “Aeroacoustic simulation of a complete H145 helicopter in descent flight”, J. of American Helicopter Society, 61(4), 2016.
19. Rahier G., Prieur J., “An efficient Kirchhoff integration method for rotor noise prediction starting indifferently from subsonically or supersonically rotating meshes", AHS 53th Forum, Virginia Beach, USA, May 1997.
20. Casolaro D., “STORM, the new Airbus Rotorcraft simulation tool based on 60 years of cumulated experience in digital flight physics”, European Rotorcraft Forum 48th Annual Forum Proceedings, Zurich, Switzerland, September 2022.

21. Roca León, E., Desvigne, D., Embacher, M., "Understanding Flight-test data with CFD Rotor simulations: an application case on the H175 helicopter", 48th European Rotorcraft Forum, Winterthur, Switzerland, 6-8 September, 2022.

22. Menter, F.R., "Two-equation eddy viscosity turbulence model for engineering applications", AIAA J. Vol 32, 8,pp. 1598-1605, 1994.

23. Jameson, A.J., "Time dependent calculation using multigrid, with application to unsteady flow past airfoils and wings", AIAA paper 91-1596, 1991.

24. Wilcox, D.C.: "Turbulence Modeling for CFD", DCW Industries, Inc., 1994.

25. https://www.arbois-med.com/annuaire-post/genesis/