DEMONSTRATION AND TESTING OF THE PILOT ACOUSTIC INDICATOR ON A HELICOPTER FLIGHT SIMULATOR

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Abstract

This paper presents the results of the demonstration campaign of the Pilot Acoustic Indicator (PAI), which is the outcome of Clean Sky Green Rotorcraft 5 (GRC5) project MANOEUVRES Work Package (WP) 4. The PAI is an instrument conceived to present information on the current and expected noise emission levels to the rotorcraft pilot, to allow him/her to adequately react to incipient high noise conditions and effectively fly low acoustic impact procedures, such as in terminal manoeuvres. In-flight noise estimation is based on the interpolation within a pre-calculated database of acoustic hemispheres interrogated through the retrieval of a limited set of current rotorcraft state parameters. Noise information is subsequently synthesized in an index for cockpit display, through a dedicated Human Machine Interface (HMI). Within MANOEUVRES WP4 a PAI demonstrator has been developed and integrated in AWARE, the industrial research flight simulator developed in-house by Leonardo Helicopters, and a simulated flight PAI demonstration campaign has been performed, with the purpose to assess the capabilities of the proposed noise monitoring instrument in real-time operations, to evaluate the impact on the Test Pilot of the presence of the PAI in terms of workload and Situational Awareness and finally to collect the Test Pilot impressions, opinions and suggestions. Outcomes are reported in the final part of the paper.

1. INTRODUCTION

Among the various aspects of the environmental emissions of aircraft, noise can be considered to be the most directly annoying for overflown communities, and thus can be deemed as one of the key factors to improve for broadening the public acceptance of flying machines.

The situation is particularly delicate when it comes to rotorcraft, since they are more prone to fly their missions at limited altitudes due to air traffic control constraints and also because their unique vertical take-off and landing capabilities permit operations from helipads located in densely populated urban areas.

Having an on-board instrument conveying information on the emitted noise footprint would be advantageous for the pilot for different reasons. For a start, he/she could monitor in real time the intensity and evolution of produced noise and apply, when possible, the suitable corrective actions to maintain it within acceptable limits. Additionally, such an instrument would allow the assessment of the noise impact of different manoeuvring strategies in training/verification/evaluation activities, without the need to fly at low altitudes over an ad-hoc prepared, ground-deployed acoustic acquisition infrastructure.

In this regard, the Clean Sky - Green Rotorcraft 5 (GRC5) project MANOEUVRES[1] concerns an innovative approach geared towards quieter rotorcraft manoeuvres, especially during terminal flight phases. A major topic in the project concerns the design, development and testing of a novel in-flight measurement system for rotor blade flapping that will be able to provide reliable rotor state information to feed an algorithm that, together with other data retrieved from the helicopter avionics, will enable the run-time estimation of the emitted noise. The present paper illustrates how MANOEUVRES Work Package (WP) 4 has succeeded in producing and testing on a flight simulator an instrument for presenting noise information: the Pilot Acoustic Indicator (PAI).

2. THE PILOT ACOUSTIC INDICATOR

The PAI is an instrument conceived to present information on the current and expected noise emission levels to rotorcraft pilots.

In order to be able to estimate in real-time helicopter noise in manoeuvring flight, a "quasi-steady acoustics" approach is applied, which is commonly used, for instance, in noise optimization tools: the instantaneous acoustic emission is given as a noise Sound Pressure Level Hemisphere (SPLH) centred at the helicopter (H/C), extracted from a database of steady-state predictions.

The PAI has been designed to operate either in *emitted noise* or in *ground noise* mode. The former refers to noise indexes evaluated locally, on the surface of the H/C-centred SPLH, regardless of current height above ground. The latter presents noise indexes evaluated by radiating the H/C noise to the Ideal Flat Ground (IFG) situated at the distance provided by the current height above ground, using a simplified radiation model that neglects both attenuation and all the effects of atmospheric phenomena (e.g. wind, fog, wind shear, etc.).

A detailed description of the PAI is given in Refs. 3 and 4. In the following, a brief synthesis is offered, before dealing with the PAI demonstrator.

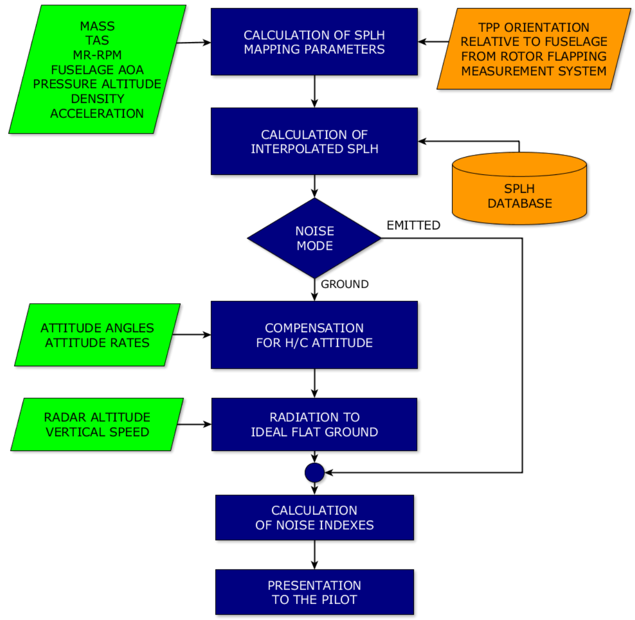

Figure 1: Flow chart of the noise estimation computational procedure.

2.1. Noise estimation computational procedure

The starting point of the noise estimation algorithm is the database of SPLHs produced by MANOEUVRES WP1 [2] for a number of steady-state trimmed conditions. Such database has been mapped using three parameters: thrust coefficient C_T, advance ratio μ and Tip Path Plane Angle Of Attack (TPP-AOA) α_{TPP}.

From the database, an interpolated SPLH can be calculated for the actual values of the three mapping parameters estimated from the current flight condition.

Figure 1 shows the high-level flow chart of the developed noise estimation computational procedure:

- *Calculation of SPLH mapping parameters*. This step deals with the calculation of the current values of the set of parameters (C_T, μ and α_{TPP}) used to map the SPLHs.
- *Calculation of interpolated SPLH*. This step is dedicated to the calculation of the SPLH associated with the current flight condition of the helicopter starting from the SPLHs available in the database.
- *Compensation of helicopter attitude*. In this step, which is skipped in case of *emitted mode*, the SPLH which is fixed with the helicopter fuselage axes is rotated to a normal position (i.e. with z axis perpendicular to IFG), compensating for rotorcraft pitch and bank angles.
- *Radiation to IFG*. In this step the normal orientated SPLH is radiated to the IFG using the simplified radiation model explained in Ref. 3, which is particularly efficient for real-time applications.
- *Noise indexes calculation*. Once the values of intensities have been calculated, it is straightforward to produce noise indexes simply taking the maximum value in dBA of the obtained intensities within the applicable domain.
- *Presentation to the pilot*. This step takes noise indexes and presents them to the pilot, as it is shown in the next section.

2.2. PAI Human Machine Interface (HMI)

The PAI has been conceived as secondary flight navigation instrument of practical and straightforward use. It provides the pilot with the estimated noise emission index, plus additional information. This may allow him/her to react adequately in order to fly low-noise procedures effectively, with minimum impact on his/her workload. Two different indicators have been designed: *Global Indicator* and *Directional Indicator*.

The *Global Indicator* (Figure 2) is based on a linear scale composed by two segments. The first represents admissible noise values, while the second one represents noise values exceeding a given threshold. At the side of the linear scale, a triangle-shaped pointer shows the current noise index value.

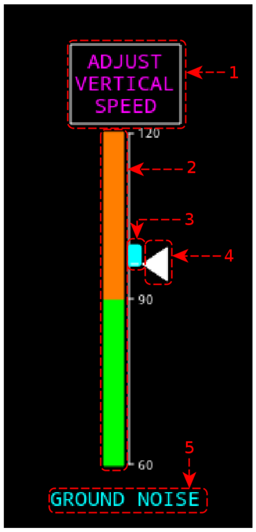

Figure 2: PAI Global Indicator.

Additionally, this indicator provides noise trend information in terms of a cyan bar that, starting from the current index value, shows the expected noise index value at the end of the prediction window if no corrective action is taken by the pilot.

Figure 2 shows the *Global Indicator* elements:

1. *Corrective Action Advice Box*.
2. *Linear Scale*.
3. *Trend Bar*.
4. *Current Noise Index*.
5. *Operational Mode Label*.

The *Directional Indicator* (Figure 3) is based on a radial scale composed by five areas: four sectors of an annulus plus a central circle. The thickness of each area is directly proportional to the current noise emission index relevant to that region. Information is shown only when the noise emission index is above the currently selected threshold. In *emitted noise* mode the indicated regions correspond to four lateral sectors and the lower spherical segment of the SPLH.

In *ground noise* mode the circular sectors display the noise index in each of the $90°$ sectors drawn around the ground-projected helicopter current position, while the central circle shows the noise emission index evaluated at the ground-projected helicopter current position.

Figure 3: PAI Directional Indicator.

The Directional Indicator does not provide any trend information.

Figure 3 shows the *Directional Indicator* elements:

1. *Front Sector*.
2. *Right Sector*.
3. *Back Sector* .
4. *Left Sector*.
5. *Lower Sector*.
6. *Helicopter Symbol*.
7. *Outer Circle*.
8. *Inner Circle*.
9. *Operational Mode Label*.

3. PAI DEMONSTRATOR INTEGRATION WITHIN THE HELICOPTER MANUFACTURER SIMULATOR

As it has been shown in Ref. 3, a suitable combination of PAI demonstrator hardware and software has been developed with the aim of integrating it in AWARE, Leonardo Helicopters flight simulator developed and run by the companys Helicopter System Design department.

3.1. Hardware Integration

As agreed with the helicopter manufacturer, the hardware for running the PAI demonstrator was a dedicated workstation, specifically set up according to consortium requirements and integrated within the AWARE simulation environment.

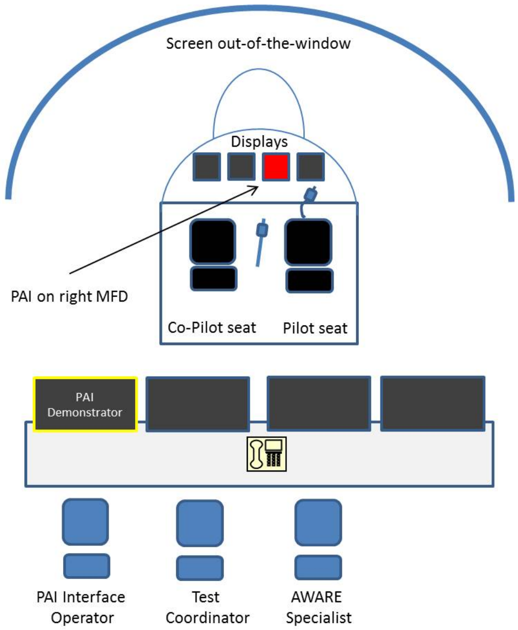

Figure 4: PAI Demonstrator workstation integrated in AWARE simulator hardware.

As it can be noticed in Figure 4, the PAI demonstrator computer (box with yellow outline) is connected to the simulator network, and feeds its output directly to the right Multi-Function Display (MFD).

3.2. Software Integration

Figure 5 shows the software architecture adopted for the PAI demonstrator. The whole functionality has been split among four co-operating tasks, communicating via TCP/IP sockets:

- Data Source Task (DST)
- Noise Index Task (NIT)
- Pilot Display Task (PDT)
- PAI Management Task (PMT)

DST takes care to retrieve all necessary data from the flight simulator network (boxes in green background in Figure 1), to calculate values of C_T, μ and α_{TPP} and to feed all information, including the predicted values, to NIT. The latter is in charge to generate the current and predicted interpolated SPLHs, starting from data available in the aeroacoustic database, compensate for helicopter attitude and radiate to IFG – according to the selected operating mode – and pass the set of current and predicted Noise Indexes to the PDT, dedicated to symbols generation and display management. PMT, as the name implies, is in charge of managing the whole process.

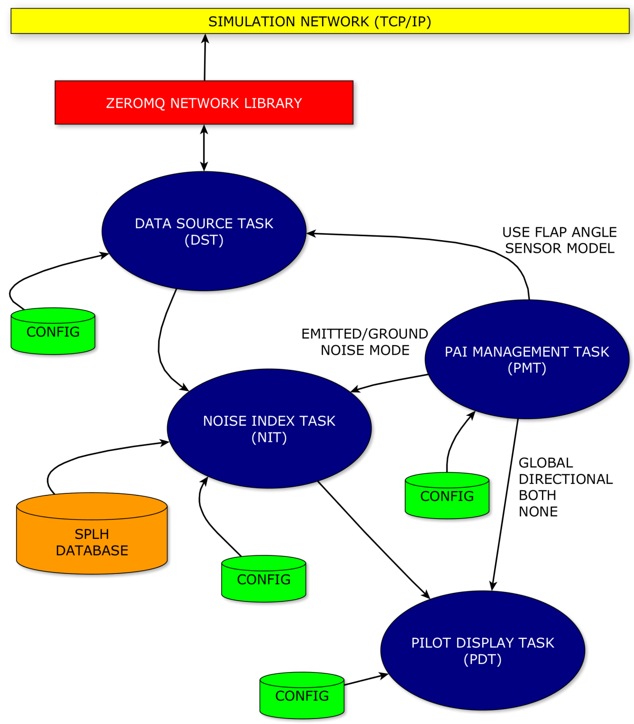

Figure 5: PAI Demonstrator software architecture.

The multi-task approach brings in some minor drawbacks, mainly a slightly higher software configuration control effort, but has been chosen because it provides a number of key advantages, mainly in terms of scalability.

An important feature has been included in the PAI demonstrator software: the capability to dump to file all data evaluated in real time, permitting off-line, post processing time evaluation of the behaviour of the instrument.

The logged parameter list includes:

- H/C state (mass, attitude, velocity, radio altitude, etc.).
- Air data (Calibrated Air Speed (CAS), True Air Speed (TAS), density, pressure altitude, etc.).
- Rotor state (blade angles, rotor angular velocity, etc.).

- Current noise indexes (Global and Directional, both in *emitted mode* and *ground mode*).
- Predicted noise indexes (Global and Directional, both in both in *emitted mode* and *ground mode*).

The PAI Demonstrator code has been integrated and thoroughly tested within the AWARE flight simulation environment, in more than a dozen dedicated sessions that involved the co-operation with the helicopter manufacturer specialists.

4. FINAL DEMONSTRATION PLANNING

The purpose of the PAI final demonstration is:

- To demonstrate the capabilities of the proposed noise instrument in real-time operations.
- To evaluate the impact on the Test Pilot of the presence of the PAI in terms of workload and Situational Awareness (SA).
- To collect the Test Pilot impressions, opinions and suggestions for PAI improvement and future development.

4.1. Planning

The PAI demonstration simulated flight campaign has been planned with the involvement of several helicopter manufacturer specialists, including contributions from Helicopter System Design, Flight Mechanics, Research and Technology and Flight Operations.

The resulting PAI demonstration selected trajectory was an approach to Milano Malpensa airport Final Approach and Take Off area (FATO) area AG following *FATO APP SOUTH* procedure.

This trajectory had to be flown with three different slope angles: 3, 6 and 9 degrees, with the PAI at first turned off, and then set to *emitted mode* and *ground mode*.

Table 1 recaps all the 9 possible combinations of trajectory planned for PAI demonstration.

Table 1: PAI Demonstration planned trajectories.

	PAI MODE OFF	PAI MODE EMITTED	PAI MODE GROUND
3 deg	Baseline 3	PAI Emitted 3	PAI Ground 3
6 deg	Baseline 6	PAI Emitted 6	PAI Ground 6
9 deg	Baseline 9	PAI Emitted 9	PAI Ground 9

4.2. Procedure details

The purpose of this simulated flight is to define a baseline in terms of pilot workload necessary to fly an Instrument Flight Rules (IFR) procedure in the AWARE simulation environment with the selected helicopter, flying the approaches at the various slope angles, with the PAI set to *OFF*.

Subsequently, the same trajectories are flown with the PAI set to *emitted mode* and *ground mode*, and Test Pilot impressions on the impact of the instrument on workload and SA are evaluated. Finally, Test Pilot remarks, requests and suggestions useful for the potential future development of the instrument are collected.

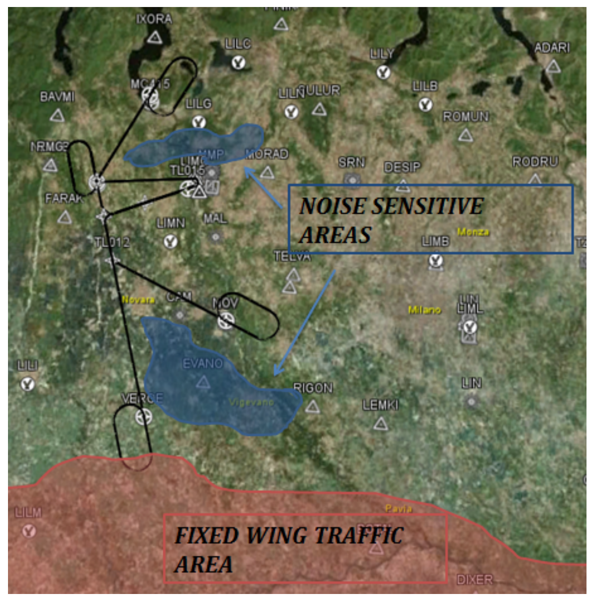

Figure 6: Demonstration procedure map.

4.3. Procedure description

With reference to Figure 6, the detailed description of the procedure is given:

1. A south approach to a Malpensa is carried out following FATO APP SOUTH (from VERCE) procedure.
2. Starting point is located on the VERCE $\Rightarrow$ TL012 vector, located at 3 NM from TL012 (Waypoint 0).
3. Once MAP is reached, flight is continued with a visual approach to FATO AG.
4. The simulation ends at 360 ft over FATO. There is no need to land.

5. Information on lateral and vertical deviation with respect to the pre-loaded path are presented to the pilot
6. PAI set to the applicable mode.

5. AEROACOUSTIC DATABASE EXTENSION

The requirements for the PAI final demonstration were limited to the assessment of the functional features of the instrument and to the evaluation of the impact of the availability of such novel noise monitoring instrument on the pilot.

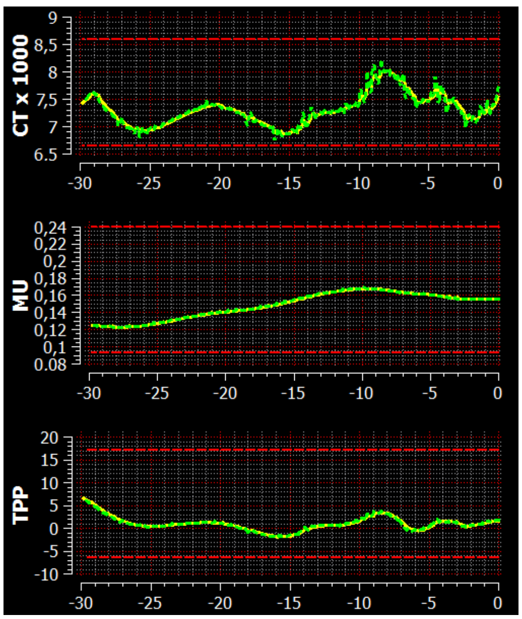

Figure 7: PAI Demonstrator real-time display of C_T, μ and α_{TPP} time history.

For this reason, the aeroacoustic database developed within the frame of the MANOEUVRES project was restricted to a subset of the domain that would otherwise be necessary to cover all the combinations of the database mapping parameters (C_T, μ and α_{TPP}) that could possibly be generated within the entire flight envelope of the rotorcraft. Such subset was initially selected to include the range of the mapping parameters expected for the executions of the PAI demonstration simulated flights.

However, initial tests showed that for most of the simulated flight the (C_T, μ and α_{TPP}) values fell out of the available aeroacoustic database domain.

A long series of simulated test flights has been performed by the helicopter manufacturer Flight Mechanics and Flight Simulator specialists, with the objective to fine tune the H/C flight mechanics model in terms of weight and balance in order to have limit as much as possible the *out-of-database* points within the planned demonstration trajectories.

The availability of an addition to the PAI Demonstrator software that has been tailor-developed by the consortium has been crucial in this phase: the possibility to display on the simulator MFD in real time the current values of C_T, μ and α_{TPP} and their evolution during the last 30 seconds of simulated flight (Figure 7).

The excellent work performed on the model by the specialists led to a dramatic reduction in *out-of-database* points, but, in order to have the best possible operation during the Final Demonstration campaign, it has been decided to invest some additional resources in the population of the aeroacoustic DB.

As a result, a number of new SPLHs has been generated, and the combined aeroacoustic database domain is shown in Table 2, where:

- *O* denotes a SPLH present in the original aeroacoustic database;
- *E* denotes a SPLH present in the extended aeroacoustic database.

Table 2: Expanded aeroacoustic database domain.

Speed	Gamma [deg]							
[Kts]	-3	0	3	6	9	12	15	18
40	E	O	O	O	O	O	E	E
50	E	O	O	O	O	O	E	E
60	E	O	O	O	O	O	E	
70	E	O	O	O	O	O		
80	E	O	O	O	O	O		
90	E	O	O	O	O	O		
100	E	O	O	O	O	O		

SPLHs have been evaluated for three values of the helicopter mass: 6,400 kg, 6,800 kg and 7,000 kg.

6. PAI DEMONSTRATION CAMPAIGN

The 18 simulated flights planned for the PAI Demonstration Campaign have been performed on the Leonardo Helicopters AWARE flight simulator in late spring 2016. The following personnel has been involved:

- *Test Pilot*. The task of the Test Pilot is to fly the simulator along the planned procedures and subjectively assess the effects of the presence of the PAI in terms of

  - Impact on workload;
  - Impact on SA.

  Additionally, the Test Pilot will provide at mission debriefing time important feedback on PAI behaviour, presentation style, effectiveness, and the like, that will be crucial for a subsequent evolution of the instrument.

- *GRC5 Leader & MANOEUVRES Topic Manager*, for supervising the tests and guarantee that they are performed according to the project targets.
- *MANOEUVRES WP4 Task Leader*, which, being responsible for the development of the PAI, supervises the correct operation of the PAI Demonstrator simulated instrument and interact with the rest of the simulation crew to collect data for the deliverable.
- *Helicopter Manufacturer Helicopter System Design/Flight Mechanics specialist*, supporting the Test Pilot in the execution of the approach (acting as a Flight Test Engineer) and recording his remarks, notes and feedback.
- *Helicopter Manufacturer Flight Simulator Specialist* present to assure the correct operation of the simulator during the progress of the demonstration and to provide support in case of issues.

7. DEMONSTRATION OUTCOMES AND CONCLUSIONS

The PAI final demonstration flights have been performed flawlessly as planned. Pilot impressions and comments have been collected through a questionnaire filled at each flight debriefing time. The outcomes of the demonstration are presented in the next paragraphs, grouped by the particular aspect they pertain to.

7.1. Usage of PAI in Simulated Flights

Concerning pilot workload, the adopted flight procedures do not require high workload to the pilot. In order to better appreciate the interaction between the Test Pilot and the machine, it has been agreed not to use autopilot upper modes, tolerating a slight increase in the workload required to keep the flight parameters. Workload general evaluation is moderate: for the 6 degrees slope approach is higher than the one for 3 degrees slope, but only marginally. The global evaluation remains moderate (not raised to considerable). Similarly, the workload for 9 degrees slope approach is higher than the one for 3 degrees and 6 degrees slopes, but only marginally. The global evaluation remains moderate (not raised to considerable). The above reported observations and issues are clearly not related with the PAI, but rather with the AWARE flight simulator engine.

With respect to SA, the overall level of information and pilot awareness provided by the simulator displays and out-of-the-window is good. The PAI increases awareness level, but it remains good (not raised to excellent).

7.2. PAI Exploitability

Helicopter pilots generally fly under Visual Flight Rules (VFR). If their rotorcraft is equipped with the required avionic equipment, they can decide to plan their flight under IFR, even if this is neither caused nor required by poor visibility conditions. IFR flights set more constraints in terms of waypoints, upper/lower altitude and speed. Therefore, the PAI system could inform the pilot about the noise generated, but it is expected that only a very limited set of corrective actions will be available.

Operations to/from helipads within densely inhabited urban areas and airports must follow precise procedures (e.g. Cat A), which typically impose very stringent bounds also for Rate of Descent (RoD). Therefore, pilots action is strictly constrained and no corrective manoeuvre can be put in place by him/her. Also in this case, the PAI role could just be informative.

However, when flying over mid populated areas where Air Traffic Control limits are not particularly restrictive, or over scarcely populated areas with no particular restrictions in terms of flight procedures, but with noise limitations (e.g. natural reserves), PAI could assist the pilot in flying a low-noise trajectory/manoeuvre.

7.3. Low-noise guidance desiderata

According to the pilot, it is difficult to provide corrective actions in terms of variations of horizontal and/or vertical speed or of input on collective and/or cyclic control based on the PAI information, because each of the mentioned measures would have an impact on all the others.

It would be more effective to have the real-time ground acoustic footprint displayed on a map, so that the pilot can autonomously act on flight controls to mitigate noise emission and/or concentrate it over non-sensible areas (e.g. far from schools, hospitals, residential areas).

7.4. Future PAI development

Current information conveyed by the PAI are considered useful by the pilot, but with sub-optimal representation. The graphical representation of noise footprint is considered a minimum requirement for a potential future development of the system. Ideally, noise footprint should be superimposed on a map, and display information related to the margin of the current noise intensity perceived on every point of the map compared to the maximum intensity allowed by the local regulations on that point.

The PAI, as it is now, could be used on production H/C for augmenting the pilot SA, and in particular during training activities. Looking at the instantaneous noise emitted and/or radiated to the ground, in fact, pilots can have an immediate feedback on the impact of their actions on flight controls on noise, and can therefore be trained to optimise their manoeuvring techniques for low noise in an effective, efficient and inexpensive way. Additionally, recording the time history of noise generated during the mission, it can be possible to carry out an off-line noise analysis at mission debriefing time.

Finally, it has already been shown that the PAI can be very effectively integrated into a flight simulator. Capitalising the availability of such system, it would be possible to use the simulator to design and optimize low-noise procedures (i.e. defining speed and RoD), specifically customized for different sets of helicopter parameters (i.e. weight and centre of gravity position).

ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

CAS	Calibrated Air Speed
DST	Data Source Task
FATO	Final Approach and Take Off area
GRC5	Green Rotorcraft 5
H/C	helicopter
HMI	Human Machine Interface
IFG	Ideal Flat Ground
IFR	Instrument Flight Rules
MFD	Multi-Function Display
NIT	Noise Index Task
PAI	Pilot Acoustic Indicator
PDT	Pilot Display Task
PMT	PAI Management Task
RoD	Rate of Descent
SA	Situational Awareness
SPLH	Sound Pressure Level Hemisphere
TAS	True Air Speed
TPP-AOA	Tip Path Plane Angle Of Attack
VFR	Visual Flight Rules
WP	Work Package

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