HELICOPTER NOISE REDUCTION TECHNOLOGY ADVANCEMENTS

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The CAEP continually monitors research and development in aircraft noise reduction technology to complement the Standard-setting process. As part of this effort, Working Group 1 of CAEP conducted a status review of the noise technology advancements of helicopters. The review included examining both noise reduction technologies and the costs associated with those technologies, which were treated in a qualitative manner by showing interdependencies and possible detrimental side effects. The Year 2000 was selected as the baseline for this study to highlight the developments since the last helicopter noise assessment report conducted in CAEP/5.

The results of the helicopter status review will be published as an ICAO report in 2016. The report includes an overview of international noise technology programmes and research initiatives, including the major research initiatives conducted in the United States, European Union, and Japan since 2000. The state-of-the-art in helicopter design is examined by reviewing the key noise reduction technologies of several modern helicopters. The status of advanced noise reduction technologies currently being tested in research programmes is reviewed. Finally, the constraints and challenges to design these low-noise helicopters are considered. This article summarizes selected topics from the report.

State-of-the-Art in Helicopter Design

To facilitate an evaluation of the status of helicopter noise reduction technology, a number of recently certificated helicopters were selected as state-of-the-art helicopter designs along with one earlier model deemed representative of a state-of-the-art design. The helicopter models selected were considered to adequately represent the best practices in helicopter design over a wide weight range from 700 to 8600 kg. For the purposes of this selection process, state-of-the-art was defined in the broader sense of aircraft level design, but the selected designs typically incorporate the latest helicopter noise reduction technologies and exhibit very good to the best individual and cumulative margins to the Chapter 8 / Chapter 11 noise limits in Annex 16, Volume 1.

Based on a review of both historic and the state-of-the-art helicopter designs, some key design parameters that affect helicopter external noise levels were categorized into three ratings of Low, Moderate, and High values. Table 1 lists the values that were identified as defining each category.

These parameters provide an insight into identifying low noise helicopter designs. An acoustically optimized helicopter design would ideally incorporate low rotor tip speeds, a low to moderate cruise speed, and a high climb rate.
The dominant acoustic sources of a helicopter include the main and tail rotors and, to a lesser extent, the engine exhaust. Rotor noise control can be accomplished in principal by incorporating the following design measures:

- Reductions in rotor rotational speed
- Increasing the number of rotor blades
- Advanced 3-D rotor blade design (radius, chord, twist, planform, airfoil selection and distribution along radius, anhedral/dihedral tip, and tip shape)
- Active rotor technologies (active flaps, active twist, or higher harmonic control)

Parameter	Low Category	Moderate Category	High Category
Main rotor tip speed	< 215 m/s	215 - 230 m/s	> 230 m/s
Tail rotor tip speed	< 200 m/s	200 - 215 m/s	> 215 m/s
Take-off climb rate	< 1200 ft/min	1200 - 1800 ft/min	> 1800 ft/min
Maximum cruise speed	< 130 kt	130 - 150 kt	> 150 kt

Table 1. Key Helicopter Design Parameters Determining Helicopter Noise Levels

Helicopter Design Process

It is important to note that a proper selection of noise reduction technologies is needed to successfully field a low noise helicopter within the multiple design requirements of a modern helicopter. For example, rotor design features intended to reduce a noise source that is dominant in one flight regime can inadvertently trigger increased noise levels in another flight regime. Similarly, a balanced acoustic design is also required to achieve the lowest noise achievable. For example, a large reduction in tail rotor speed can ultimately result in little to no acoustic benefits if the main rotor speed is set to a high value for performance, handling qualities, or safety reasons.

Decreasing rotational speed, whether by design or operationally, is the main lever for reducing the noise level of a rotor. While historically helicopters have typically operated at one fixed rotor speed, a change in rotor speed can now be implemented automatically in certain regions of the flight envelope to reduce noise using new digital aircraft flight control systems and electronic engine controls. The effect on noise levels is obvious in all certification flight conditions but the method has adverse implications on most other engineering discipline involved in the main rotor design and the full aircraft design.

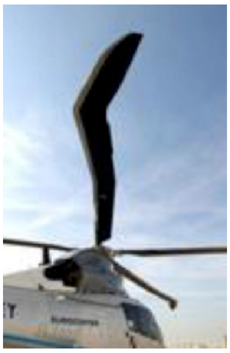

Figure 1. Prototype 3D blade profile tailoring.

One adverse effect of decreasing the rotor speed is that it also reduces the kinetic energy stored in the rotor. In case of engine failure this energy is essential to a safe autorotation landing. If the rotational speed is designed to be decreased, the inertia of the rotor may have to be increased by adding additional blade mass, which adversely affects aircraft payload. The aircraft certification cost is also significantly increased due to the additional flight test time required. Furthermore helicopters are generally limited by gearbox torque at low altitudes. A reduction of rotational speed thus means less power available for the rotor and therefore deteriorated helicopter performance. Increasing the gearbox torque limits on an in-production design would mean a major redesign of the complete transmission system resulting in additional weight and increased manufacturing cost, which in most cases has been shown to not be economically reasonable. For future designs, advanced gearbox technologies that will enable higher torques at a lighter weight have been tested in the laboratory environment.

Another aspect to be considered is the functionality of passive vibration reduction devices used to ensure an acceptable ride

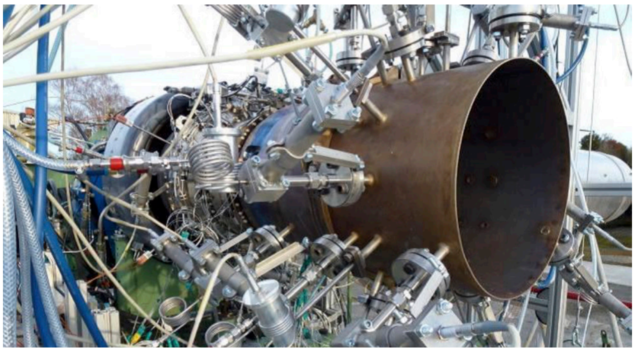

Figure 2. Turboshaft engine exhaust noise identification test

quality. Most vibration reduction devices are effective at only one rotor speed. When designing for multiple rotor speeds, the implementation of an active vibration control (AVC) system capable of multi-frequency response may be required. AVC systems can be effective but do introduce added weight, complexity and cost challenges. However, helicopter AVC is a new technology that is now being implemented on some large helicopters.

Other rotor design parameters influence the noise to a lesser extent and are oftentimes only effective to mitigate certain phenomenon appearing only in a specific flight condition. In particular, a rotor blade tip shape designed to minimize noise in one flight regime can adversely impact noise levels and aerodynamic performance in other flight regimes. It is now just becoming possible for computational fluid dynamics (CFD) modeling to capture the physics of a rotating rotor in edge-wise flight so that the rotor noise can be predicted and used to make design decisions. Nevertheless, these advanced CFD methods are still too costly to be intensively used for rotor design or optimization. The capability to manufacture advanced blade designs in a production environment must also be considered. An affordable rotor blade design that universally reduces noise emissions can be elusive.

Status of Noise Reduction Technologies

The evaluation of the state-of-the-art helicopter models confirms that available mature noise reduction technologies are being implemented in both new designs and in many new derivative models. These technologies include unequal blade spacing on ducted fans and open tail rotors, new rotor designs and blade planforms, and reduced or even automatically-controlled rotor speeds.

The helicopters included in this study equipped with low-noise tail rotor designs operating at moderate or low blade tip speeds verify the importance of anti-torque related noise in achieving cumulative margins of more than 12 EPNdB below the ICAO noise certification limits. The smaller twin-engine helicopters with alternative anti-torque concepts such as ducted fan or ducted thrust designs achieved even more impressive cumulative margins of more than 17 EPNdB. On one derived version, the replacement of a high tip speed open tail rotor by an acoustically-shielded ducted fan

Figure 3. Full-scale rotor blade active flap test

on a helicopter already containing a quiet main rotor provided a cumulative noise benefit of 5 EPNdB for an otherwise acoustically identical configuration. However, the use of a ducted fan system has been limited to date to light to intermediate helicopters weighing less than 6000 kg due to an unfavorable scaling of system weight, efficiency and acoustic benefits.

Active rotor concepts attempt to reduce some inherently contradictive design tradeoffs between flight conditions by allowing an adaptation to the flight condition. Active flaps on rotor blades and individual blade control concepts have progressed to flight test demonstration, and active twist rotor blades have progressed to wind tunnel demonstration. However, the reduction of external noise by active means while maintaining acceptable cabin vibration levels remains a challenging task and system integration, productionization and airworthiness certification all remain significant challenges. The integration of an active rotor technology adds complexity to the design and considerably increases both acquisition costs and direct operating costs. Active rotor systems investigated in research programs to date are not yet reliable enough for product integration.

Noise abatement flight procedures have especially proven to offer noticeable potential to reduce helicopter noise impacts on the ground in specific situations. The implementation of noise optimized procedures is facilitated by comprehensive guidance material published by helicopter manufacturers and promoted by helicopter pilot organizations. New automated approach procedures have been flight test demonstrated and hold even greater promise to reduce the associated pilot workload and encourage regular use.

To address turboshaft engine noise, the testing of inlet and exhaust liners has progressed to the flight test demonstration phase. There has been no activity yet to address core noise. For piston engines, the use of upturned exhausts and new muffler designs has proven effective and both are used in production. Piston engine exhaust resonators have also progressed to the flight test demonstration phase.

Design Tradeoffs and Constraints

Unlike most fixed-wing aircraft, helicopters are designed for multi-purpose usage. The wide range of mission objectives leads to the challenging fact that the typical rotorcraft design requires not one but rather a number of design points for a multitude of missions. Designs therefore have to be evaluated to cover a large flight envelope and a wide range of weather conditions. The respective trade-offs in the design depend heavily on the class (size) of helicopter and the anticipated mission priorities envisaged for this type of helicopter.

Safety or economic considerations for certain helicopter missions obviously can require somewhat different trade-offs leading to certification noise levels closer to the applicable limits in Chapter 8 or Chapter 11 of Annex 16, Volume 1. Though the helicopters examined in the study incorporate most of the latest noise reduction features in terms of rotor blade design, the dimensioning of rotor tip speed and blade loading was typically optimized rather towards a performance to weight ratio needed to have a marketable aircraft.

Low noise design capabilities are inherently impacted by technological feasibility and economical reasonableness issues which often correlate with weight class. For example, some low noise anti-torque technologies are technologically feasible for very small helicopters but may not be economically reasonable to implement in a given design. As gross weight increases to the light-medium weight class, these anti-torque designs become more economically reasonable. As gross weight further increases, however, the technological feasibility disappears with unfavorable scaling of system weight and performance. Hence these anti-torque technologies have yet to be incorporated into medium to heavy weight helicopter designs. However, technologies such as automated rotor speed control, advanced 3D rotor blade designs and active rotor control increasingly become both technologically feasible and economically reasonable with increasing gross weight.

Conclusions and Perspectives

The data presented in the report highlights that significant progress in the reduction of helicopter source noise has been achieved in the last 15 years for both new type designs and some derived versions. Considerable funding has been dedicated to low noise helicopter research particularly in the United States, the European Union, and Japan. The activities focused on the exploration of active and passive rotor technologies, the improvement of numerical acoustic prediction capabilities, the development and operational verification of noise abatement procedures and, to a smaller extent, engine noise reduction concepts.

New noise reduction techniques necessitate extensive interdisciplinary design evaluations. Consequently integration into new products requires considerable time and expense. While new technologies continue to be explored, mature noise

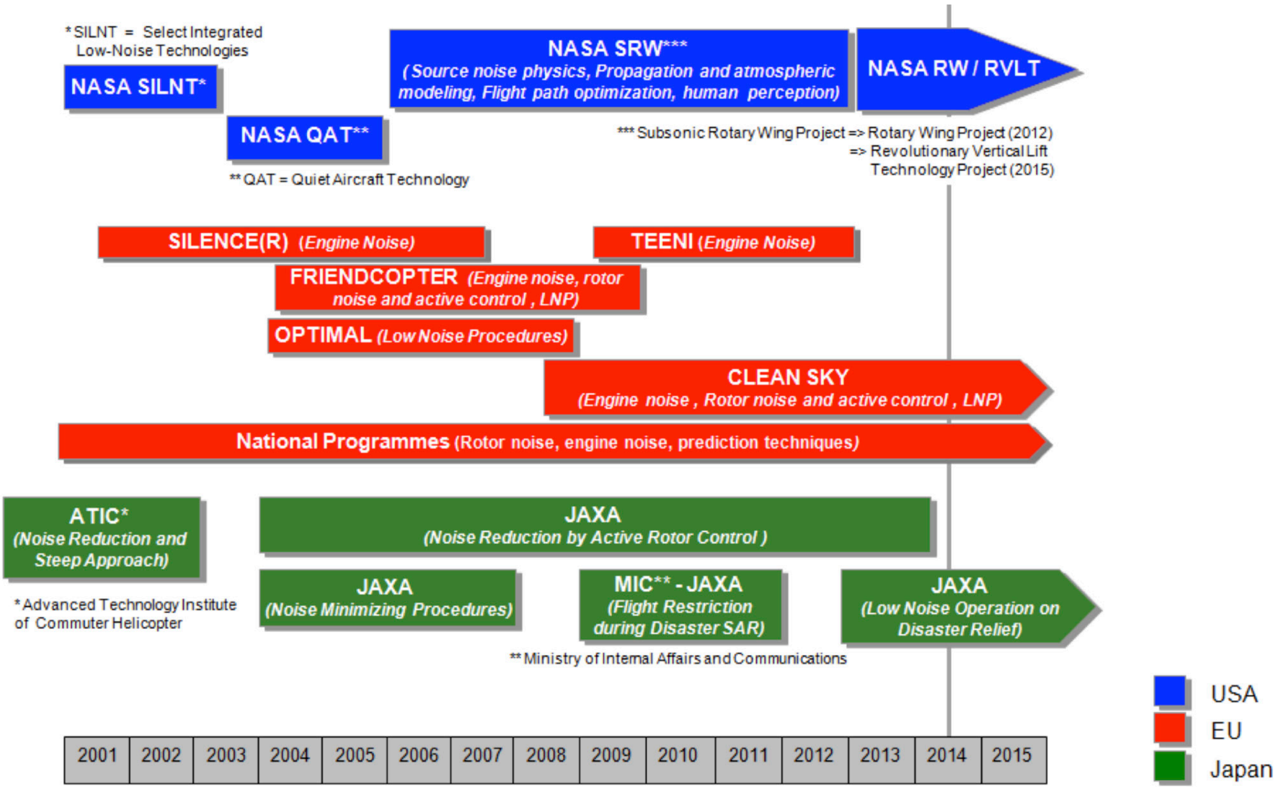

Figure 4. Major Initiatives in Helicopter Noise Research Since 2000.

reduction technologies are being integrated in the designs of all major manufacturers. State-of-the-art helicopter designs achieve cumulative margins of 4 to 17 EPNdB relative to the most stringent maximum permitted noise levels contained in Annex 16, Volume 1.

High margins are achievable for small- and intermediate-sized helicopters partly due to low noise anti-torque concepts and typical mission related design tradeoffs for these weight classes. For certain missions, safety, performance, and economic design tradeoffs may, however, lead to smaller noise certification margins. Special missions that require new hybrid helicopter configurations (for long range and high speed) could face difficulties complying with the applicable noise limits specified for conventional helicopter configurations.