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Siemens Digital Industries Software

Reducing aircraft noise

Using Innovative tools to develop quieter aircraft without compromising performance

Executive summary

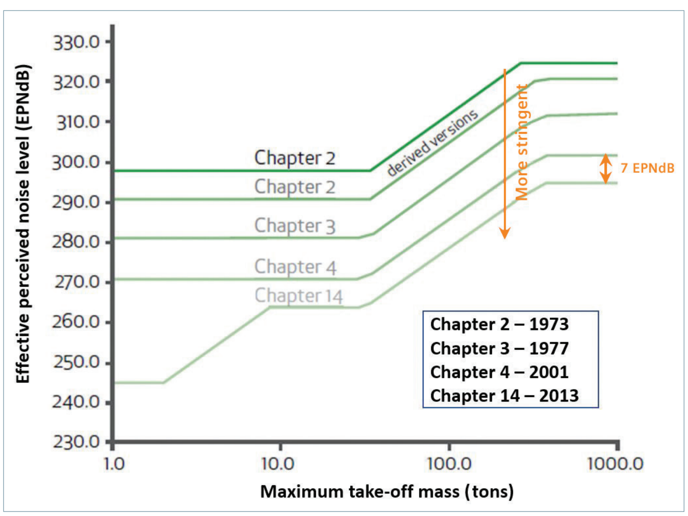
Aircraft manufacturers are facing stricter regulations for aircraft emissions, including environmental noise, and increased pressure to improve cabin acoustic comfort. Vertical take-off and landing (VTOL) vehicles, currently being developed to enable urban air mobility (UAM), must also be optimized to minimize noise pollution in densely populated areas. This challenges engineering teams to efficiently troubleshoot noise issues and develop quieter aircraft design without compromising weight and performance objectives. Simcenter™ software and hardware offer a complete solution for detailed acoustic testing and sound engineering. The solution features a number of technological advancements that help engineers perform acoustic measurements more efficiently for both exterior and interior noise.

Contents

Abstract

How fascinating is it to board an aircraft, take off like a bird and arrive at destination shortly thereafter! Air transportation has radically changed the way people travel and this will not change anytime soon. Air traffic is expected to continue its growth with double the number of deliveries projected over the next 20 years. But this also raises some concerns. With more aircraft flying close to populated areas, the environmental impact becomes even more problematic. Beyond CO_2 emissions and the greenhouse effect, the concern is noise pollution caused by such aircraft. Regulation is becoming more stringent to ensure the latest available noise reduction technology is incorporated into aircraft design to reduce the environmental impact. For instance, the Advisory Council for Aviation Research and Innovation in Europe has set an ambitious goal of reducing aircraft noise from 2000 to 2050 by 65 percent.[1] A recent amendment to the Annex 16 document from the International Civil Aviation Organization (ICAO) also increases the stringency of seven decibels in effective perceived noise level (EPNdB) relative to the previous aircraft noise limit levels.[2] This new, more stringent standard will be the mainstay ICAO standard for subsonic jet and propeller-driven airplane noise for the coming years and is applicable to new airplane types submitted for certification. Such stringent regulations for take-off, flyover and landing noise are forcing manufacturers to limit noise emission from the engine and airframe.

Similar to the automotive industry, electric propulsion could provide many new possibilities for more efficient, flexible and greener air transportation. New concepts, such as VTOL vehicles based on all-electrical or hybrid propulsion, are being studied to enable urban air mobility.[3] However, next to the many technological challenges associated with such innovative concepts, important regulatory barriers still need to be overcome to make flight in urban areas come true. One area of special attention is the environmental noise impact. Although electric motors are typically less noisy than traditional combustion engines, aiming to fly above densely populated urban areas sets challenging acoustic-signature requirements. Experts expect the targeted noise profile of such vehicles to be about 65 decibels (dB) A-weighted at 300 feet, which registers at one-fourth the noise emitted by the smallest four-seat helicopter currently on the market. Such programs will only be viable if environmental noise requirements are met so it is crucial that developers of such VTOL vehicles include noise mitigation as one of the primary objectives.



Progression of the ICAO noise standards for airplanes (source: International Civil Aviation Organization).

Aircraft programs for urban air mobility can only succeed if community noise impact is limited (image courtesy of Airbus).

Airline companies also have to deal with passengers' elevated expectations for cabin comfort. In addition to a means of transportation, passengers are seeking an enjoyable flight experience that calls for a pleasant and quiet cabin environment. This is putting aircraft manufacturers under pressure to find ways to reduce the interior noise level in the cabin and improve its sound quality. This is even more important as competition is getting fiercer in the aviation market. Improved cabin comfort is a way for aircraft manufacturers to differentiate themselves from competitors.

There is increased pressure on aircraft manufacturers to innovate and reach these ambitious acoustic goals. However, noise reduction and sound engineering are continuous challenges in the aircraft design process for both exterior and interior acoustics. Acoustic requirements are frequently in conflict with requirements for lighter and more eco-friendly aircraft. The development of new materials and composite structures provides significant weight reduction. On the other hand, this weight reduction typically has a negative impact on the acoustic performance of the aircraft. Finding the balance between those conflicting requirements is a day-to-day challenge for acoustic engineers. The need to stay within budget and on schedule adds to the challenge. The most efficient way for engineering teams to address these challenges is to consider aircraft acoustic performance earlier in the program and get deeper engineering insight into noise issues. Controlling interior noise levels requires a system-level treatment technique that addresses both airborne acoustic energy and structure-borne vibration energy. Successful engineering relies on choosing the right materials or acoustic treatments and having a deep understanding of how they work, how to test them for feeding models, how and where to install them and how to test final performance improvement. Engineering teams have a clear need for tools and solutions to measure, analyze and get insight into noise generation mechanisms and validate quiet designs.

Simcenter software and hardware, which are part of Xcelerator, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, offer a complete solution for accurate acoustic testing and sound engineering. Simcenter software and hardware contain a number of technological advancements that help engineers perform acoustic measurements more efficiently for both exterior and interior aircraft noise. This includes solutions for assessing the acoustic performance of improved designs, getting detailed insights into noise generation mechanisms or quickly troubleshooting noise issues. Simcenter testing solutions allow you to validate predictions from simulation models early in the program cycle and support efficient aircraft design with a digital thread approach. In this paper, we explain how such solutions help you design quieter aircraft that facilitate noise certification and improve cabin comfort.

A continuous challenge for engineering teams

Test teams need to handle a number of measurement tasks to verify aircraft performance or troubleshoot design issues. These tests typically happen late in the program once the physical components, systems or fully integrated aircraft are available. There is time pressure to perform these measurements quickly and get deep insight into noise issues. Simcenter testing solutions offer a complete suite of software and hardware for acoustics testing and analysis, including straightforward acoustic analysis, material and component testing, sound power and fly-by noise testing, sound source localization, vibro-acoustic engineering, sound quality analysis and validation of simulation models. In the next sections we will highlight how each solution is scalable to project requirements and offers task-specific advantages in terms of return-on-investment (ROI).

Are target noise objectives being met?

For acoustic engineering teams involved in aircraft development, it is crucial to ensure the final design meets target noise objectives. Noise limits are typically defined by certification authorities and must be met to commercialize the aircraft. For instance, this applies to aircraft flyover noise certification measurements, static noise tests for aircraft engines and noise certification for installed auxiliary power units and associated aircraft systems during ground operations. Such noise certification requires detailed measurement procedures, as described in the ICAO environmental technical manual.[4] Critical elements of the procedure are the measurement system and processing software, which should ensure proper data quality and full traceability of the results. The measurement setup typically includes several microphones on the ground several hundred meters from the aircraft and positioned at a specific location with respect to the aircraft trajectory. Measurements are performed for various maneuvers, including take-off and approach and microphone data should be accurately synchronized with the aircraft position. Each microphone is connected to a data acquisition system, which enables the user to record the noise data while the aircraft is flying over it. Given the large distance separating the microphones and the need for synchronizing the recorded data with the aircraft position, performing such measurements can be a challenge. Simcenter software and hardware enable you to be fully compliant with international standards, and provides the capability for time synchronization, customization and integration, making it well suited for such critical measurements.

Simcenter SCADAS hardware acquisition frames with integrated signal conditioning for analog sensors can be conveniently distributed, either around the aircraft for ramp noise measurement, or on the ground for flyover noise measurement with distant microphones. This setup allows you to place the front-ends close to the sensors, thus reducing the cable length. The front-ends are connected via a simple fiber optic that ensures perfect synchronization with other frames or aircraft tracking systems. With extra low noise floor and 150 dB dynamic range, measurement accuracy is a given. Simcenter Testlab™ software for data acquisition and processing helps test teams to perform measurements more efficiently. Real-time acquisition and monitoring combined with advanced digital signal processing capabilities, such as real-time octave filtering, allows you to deliver accurate results quickly and with confidence. The system, already approved by certification authorities, provides full data traceability and report generation capabilities to support noise certification.

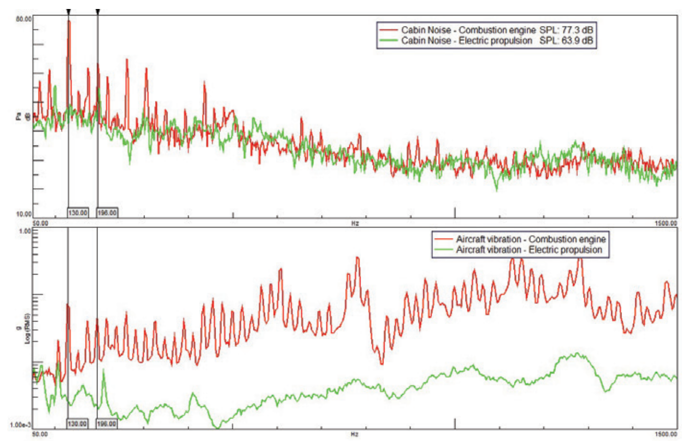
Flyover noise reduction with electric propulsion	Δ LAMax
Low altitude (50 feet)	6.7 dB(A)
High altitude (1,000 feet)	14.5 dB(A)

Impact of electric propulsion estimated with a flyover noise measurement setup.

Overall noise from an aircraft measured during flyover is expressed in effective perceived noise level or A-weighted maximum sound level (LAMax) depending on the aircraft type. Such noise metrics are obtained by processing the raw time signals from the microphones, applying third-octave filtering and corrections for environmental conditions. Flyover noise level is a good indicator of the overall aircraft noise, including sources from the engine and aero acoustic sources from the airframe. It can be helpful to understand how innovative technologies such as electric propulsion can impact aircraft environmental noise. Highlighted here as an example is a comparison of the acoustic performance of two variants of the same aerobatic aircraft, one equipped with a conventional piston engine and the other with an electric motor based on flyover noise measurements.[5] Calculating overall aircraft noise level using Simcenter Testlab shows reductions of up to 14.5 dB, which confirms the great potential of electric propulsion for greener and quieter aircraft.

Streamlining operational measurements

Passenger comfort is a key differentiator for any aircraft manufacturer. Cabins are continuously being improved to provide the most comfortable and enjoyable flights for both passengers and crews. Next to the thermal aspects, providing a quiet and pleasant acoustic environment in the cabin or cockpit is essential to reach such an objective. But reducing interior noise can be a difficult task. Multiple sources contribute to cabin noise, including the engine but also turbulent boundary layer excitation or environmental control system and auxiliary sources. The way these sources radiate in the cabin will vary depending if they follow an airborne or structure-borne path. Acoustic teams also have to deal with conflicting requirements and balance the efficiency of noise control measures with the detrimental effects of extra weight. In-flight measurements can be useful to troubleshoot noise issues or assess the efficiency of noise control measures. But such operational measurements should be carefully planned and efficiently executed since flight testing typically involves high costs. It is important to use flexible measurement techniques that allow you to capture the relevant phenomena and get rapid insights into cabin acoustics. For instance, being able to use microphones to record the sound in the aircraft interior together with vibration sensors instrumented on the aircraft structure helps troubleshooting noise issues more rapidly as noise radiation is often linked with vibration issues.



In-flight operational measurements are easily performed with Simcenter testing solutions.

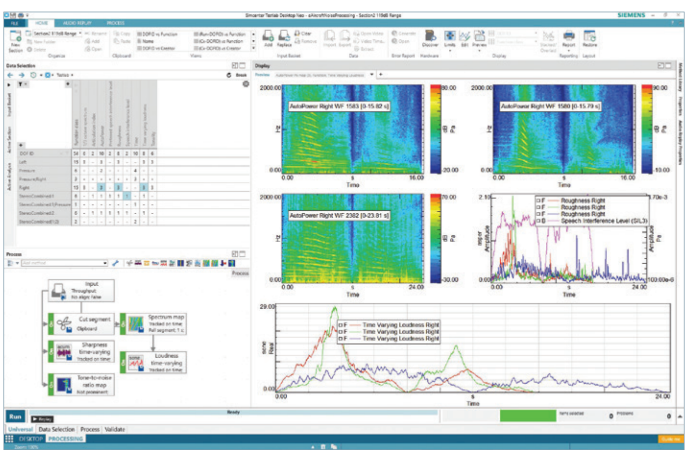
Simcenter SCADAS data acquisition systems are well suited for lab and field measurements.

Simcenter SCADAS data acquisition systems are used to efficiently replace tape and other cumbersome data-recording solutions that are used to acquire operational noise or vibration data. The range includes handheld systems for quick headset measurements or general-purpose in-flight measurements as well as high-channel-count configurations for operational acoustic and vibration measurements. These solutions allow the user to easily synchronize with other events thanks to the standard Inter-range instrumentation group (IRIG-B) interface or a Global Positioning System (GPS) time synchronization. Multiple measurement scenarios are supported to best accommodate the schedule of the flight test teams. Data can be directly measured, monitored and processed online on a connected computer during the flight. Alternatively, a complete standalone mode can be used to record data for the entire flight on a solid-state CompactFlash card and be downloaded later for further analysis. Built-in signal conditioning eliminates the need for additional equipment and ensures the highest possible data quality for various types of microphones or vibration sensors (including accelerometers and strain gages). The Simcenter SCADAS measurement systems are extremely compact and fit in limited space. Simcenter SCADAS XS is a pocket-size handheld device that is well suited to measure noise levels inside tiny cockpits and verify they are not excessive. Simcenter SCADAS Mobile hardware systems are well suited for higher channel-count measurements involving a wide range of sensors. The Simcenter SCADAS measurement system is designed to meet airworthiness constraints and is used for a broad range of operational measurements aboard civil or military aircraft. Measured data is analyzed using the rich postprocessing capabilities of Simcenter Testlab software.[6]

In-flight measurements aboard an electrically propelled aircraft are illustrated here and compared with the same aircraft equipped with a traditional combustion engine. Cabin noise level is clearly seen to be reduced and less tonal thanks to the electric propulsion. Vibration level measured using accelerometers on the aircraft structure reveals that some of the low-frequency tones heard in the cabin are propagating dominantly via a structure-borne path. This indicates that locally changing the structural design or applying vibration treatments such as damping patches would help reduce the acoustic contribution of these tones. On the other hand, variation of vibration levels at higher frequencies don't correlate with cabin noise level, which proves that acoustic radiation is mostly airborne in this case. Acoustic insulation would be an efficient noise control measure to improve cabin comfort in such a frequency range.

Shaping the right sound quality

Keeping overall aircraft noise level under control is important but designing an improved aircraft acoustic signature might require going one step further. Sounds can generate a variety of feelings of annoyance for a listener. For instance, a fluctuating tonal sound is typically more annoying than a steady broadband sound even though both might have the same energy level. Shaping a sound so the human ear likes it is the domain of sound quality engineering and can be useful for engineering teams working on aircraft noise. Sound quality metrics allow you to process the recorded noise and provide quantified indicators on various aspects of annoying or pleasing sounds. Such metrics consider how the human ear perceives certain characteristics of sound such as fluctuation in time, spectral content or interaction between multiple sources. Sound quality can help improve exterior aircraft noise – certainly in the context of new urban air mobility where the impact on the community is critical – and design improved cabin comfort to respond to the higher expectations of passengers.



Detailed sound quality engineering performed using Simcenter Testlab software.

The process of sound quality engineering involves the recording of different sounds, which is done using a binaural recording device, such as Simcenter SCADAS XS hardware and the binaural headset. Detailed sound quality engineering can then be efficiently performed using Simcenter Testlab. Equalized and calibrated playback allows you to listen to recorded sounds as if the listener were sitting in the plane during flight or on the ground during flyover. Interactive filtering enables subjective evaluation of original and modified sound. Objective evaluation is possible thanks to a wide range of sound quality metrics, such as time-varying loudness, speech interference level (SIL), articulation index, fluctuation strength, tonality, etc. Sound quality analysis is an interesting technique for engineering teams to address aircraft noise from a human perception standpoint and complement traditional measurement techniques based on sound level and spectrum analysis.

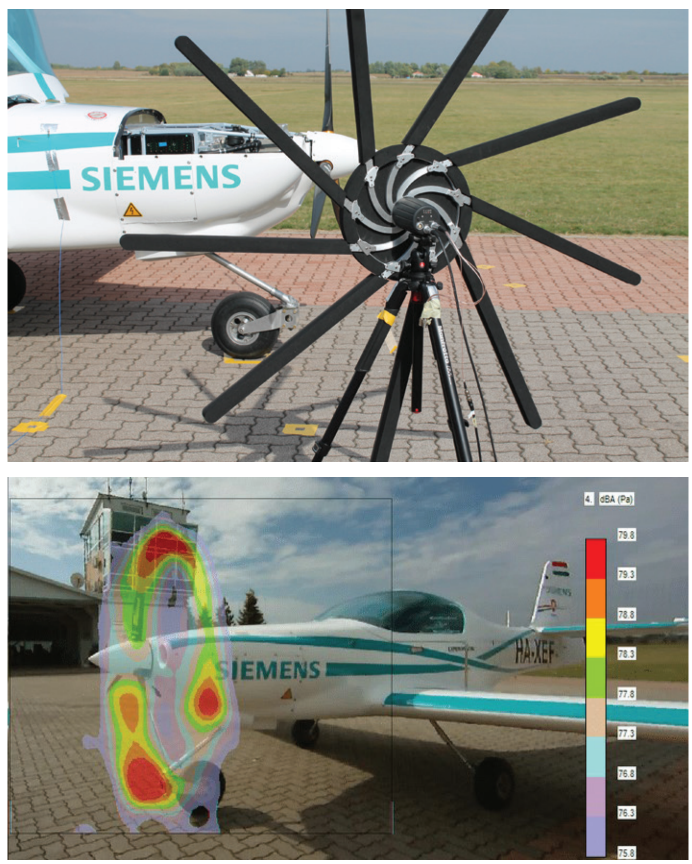
Where is the sound coming from?

Aircraft noise results from the contribution of multiple complex sources. Getting a good understanding of noise generation mechanisms and the relative contribution of each source is crucial to develop noise control measures that significantly improve aircraft acoustic performance. Ranking the contributing sources can also be useful for calibrating and validating numerical models. However, for both exterior and interior noise, precisely identifying the location and amplitude of a sound source is a challenge and can be quite time-consuming. Sources can be different in nature: low or high frequency, tonal or broadband, airborne or structure-borne, steady or impulsive, and they may only appear during certain flight conditions. Engineering teams need measurement techniques that can deal with such complexity. Moreover, measurement techniques should be quick and easy to set up so test teams can deliver results as quickly as possible because flight testing is expensive!

Acoustic arrays can be efficiently used to address these challenges. They are made of multiple microphones arranged in a specific spatial pattern that all record the sound at the same time. The principle of the array technique is quite simple but powerful; it considers the relative delay of the sound waves reaching each microphone to localize the noise sources. The great advantage of such method is it captures the entire sound field at once and only requires a few seconds of measurement to provide the source map. Siemens Digital Industries Software has designed a number of cutting-edge solutions to increase overall testing productivity for both in-flight and on the ground sound source localization. Those solutions have been developed in collaboration with MicrodB and Airbus and allow for a significant saving of time and resources.[7] Dedicated arrays have been designed for optimal source localization and quantification in interior or exterior sound fields. State-of-the-art processing methods have also been implemented to produce results that are accurate and easy to interpret. The complete process has been optimized to minimize setup, measurement and analysis time.

The Simcenter Sound Camera Digital Array is a modular, high-quality digital microphone array for sound source localization. The system has been designed to be a versatile solution, with arms that can be added or removed. Adjusting the size of the array and the number of microphones allows you to handle a variety of testing situations. Reference sensors such as additional microphones or accelerometers can be used for coherence analysis and to get deeper insights into airborne or structure-borne sources. For instance, this array can be conveniently used to analyze engine or propeller noise sources as illustrated here.

Sound source localization can also be performed on the flying aircraft. In this case, a large number of microphones are placed on the ground and constitute a customized acoustic array spanning up to 20 or more meters. Using such large-size array allows you to



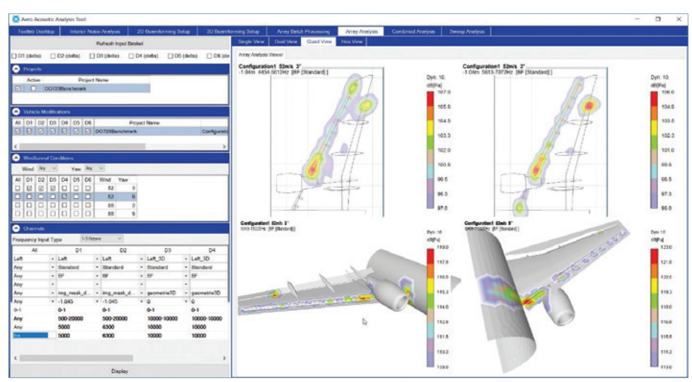
Using the Simcenter Sound Camera for exterior sound source localization.

capture sources contributing to all aircraft noise, including engines and airframe sources. Microphones are connected to Simcenter SCADAS acquisition frames that can be distributed in the field to minimize cable length. Simcenter Testlab is used for source localization, as well as sound power estimation and source ranking. The beamforming technique is enhanced with deconvolution techniques that provide better spatial resolution.

Interior sound source localization for cockpit or cabin noise and acoustic leak detection is efficiently performed using the Simcenter 3D Acoustic Camera. This rigid spherical acoustic array drastically speeds up aircraft acoustic testing compared to traditional scanning methods. It allows for one-shot sound source localization, enabling you to perform measurements in a few seconds that provide acoustic maps, back calculated and projected on a 3D view of the cabin or equipment. This yields on-the-spot accurate and comparable results. To improve the localization maps, microphones are inserted in a full rigid sphere. This allows the user to increase the spatial resolution in comparison to an open sphere design as it better separates direct incident waves coming from one side of the array from scattered waves coming from the other side.[8] As such, it allows you to capture sources from all directions and provides a detailed 360-degree view of the sources in the aircraft interior. This technique can be employed not only for source localization, but also for quantification and ranking. A full acoustic view of radiating sound is obtained in a short time, even from transient sounds (for example, from the sound of electronics or landing gear retracting). The combination of a solid surface array with additional microphones on extension arms also allows the user to cover a broad frequency range for interior measurements. Such technique quickly reveals the full sound field of the aircraft interior in various ground and flight conditions and offers excellent spatial resolution to clearly separate sound sources.

Aeroacoustics measurements based on acoustic arrays in wind tunnels also provide a detailed understanding of complex aircraft noise sources. Wind tunnel tests help the user to investigate new aircraft concepts, verify performance of innovative designs and validate prediction models. Wind tunnel testing is the ultimate way to validate such models long before the aircraft can fly. However, measuring in such a facility is expensive and must be performed efficiently to get the most out of the limited testing time. Siemens has implemented a number of innovative technologies based on Simcenter SCADAS hardware and Simcenter Testlab software to handle such measurement processes more efficiently. Detailed insights can be obtained thanks to real-time visualization of results during measurements and directly comparing results from several acoustic arrays or multiple runs. Optimal array design combined with state-of-the-art processing algorithms such as deconvolution ensure superior accuracy.[9] The ultrafast processing engine that delivers source maps right after the measurement provides a high level of productivity. Comprehensive management of large data sets and full integration of the measurement system with the wind tunnel controller make the solution extremely reliable.

A spherical array allows rapid sound source localization throughout the aircraft cabin.



Dedicated measurement and analysis solution for productive wind tunnel testing.

Pinpointing the root cause of sound

Aircraft interior noise arises from exterior sources transmitted through a variety of paths into the cabin and from interior noise sources linked to the environmental control system or auxiliary systems. Pinpointing the root causes of the sound and understanding how the energy is transferred from the sources to the receiver in the cabin is essential to derive efficient noise control measures. For instance, one may wonder how the operational vibrations in the main gearbox of a helicopter propagate to the frame and how much noise is radiated in the cabin. With the increased usage of distributed electric propulsion, understanding how the vibration energy from these sources propagates through the aircraft structure and how they interact with each other is also important to achieve improved cabin comfort. Simcenter hardware and software solutions help the user to gain engineering insight into these phenomena by implementing a comprehensive source-transfer-receiver approach. The principle of this technique is to decompose the different transmission paths through the aircraft structure from the sources to the receiver to identify possible issues.

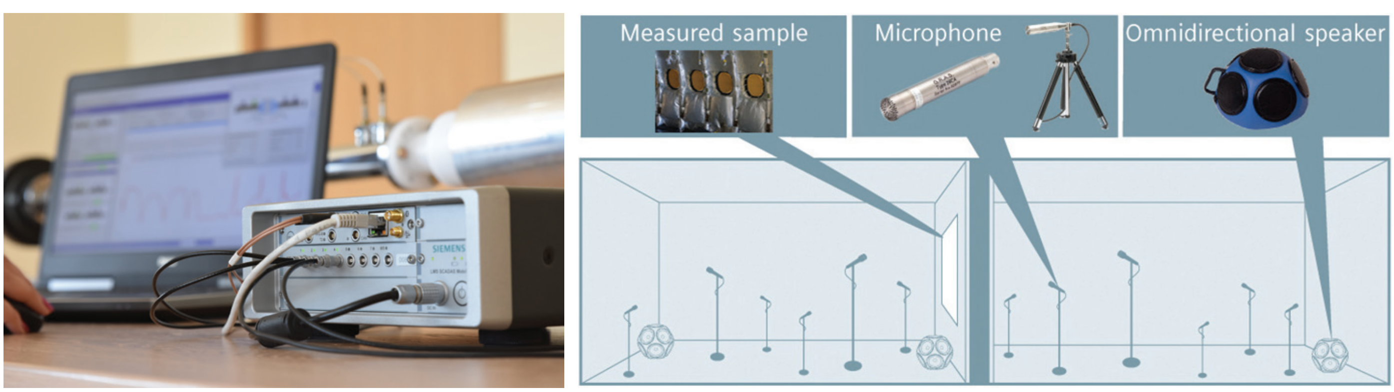
The transfer path analysis technique helps find the root cause of noise and vibration issues (image courtesy of Belgian Defense Forces).

In other words, the source-transfer-receiver method decomposes operational data, measured from a target or receiver location, into a sum of individual partial contributions. These partial contributions can be written as operational quantities at the source, multiplied with the transfer function between the source and the target. The procedure to build a conventional transfer path analysis (TPA) model consists of two steps: first, identify operational loads from in-operation tests in-flight or on the ground and then estimate the frequency response functions (FRF) between the load interfaces and target locations. The data is then processed to obtain contribution plots, highlighting possible issues at the source side along the transmission path (like a structural resonance) or due to dynamic interaction between the source and the structure. This systematic vibro-acoustic analysis approach is fully supported by Simcenter testing solutions. Guidance is provided to engineering teams at each step of the process, including vibro-acoustic modal identification, operational data measurement at source and receiver, vibro-acoustic transfer function measurements using calibrated vibration and noise sources (Simcenter Qsources™ hardware) and detailed transfer path analysis. Finding the root cause of noise with such a systematic approach helps engineers make important design decisions, save time and costs and improve the entire development cycle.

Selecting the right materials and components

Once dominant sources and transmission paths have been identified, engineering teams need to design proper noise control treatments. However, attenuating acoustic radiation of sources and vibrating panels in the cabin is a challenging task. The easiest way to reduce the sound transmitted through a panel vibrating at low frequency is to increase its mass. But this is conflicting with the need for more high-performance and lighter aircraft. Increasing usage of composite material in aircraft makes it even more complex as such materials typically have weaker acoustic performance than traditional metallic panels. For optimal passenger comfort, fuselage panels, ceiling and floor panels or separation panels can help to absorb acoustic energy. Damping and absorption material should be well characterized and their vibro-acoustic behavior well understood to reach the largest noise reduction for minimal extra weight. Simcenter Testlab software offers a full spectrum of tools to study and examine the sound behavior of materials and components. In combination with Simcenter SCADAS hardware, it provides accurate results and helps determine how such material would affect the overall sound. The outcome of a successful material test provides a set of extensive, high-quality data that can also be used to greatly enhance further numerical acoustic analysis based on finite element or statistical energy analysis.

For small material samples and components such as environmental control system mufflers, the impedance tube is typically used to obtain material absorption and sound transmission loss properties. For assessing the acoustics of larger items, Simcenter Testlab supports room methods. Absorption characteristics of large material panels is measured in reverberant rooms according to international standards such as International Organization for Standardization (ISO) 354-2003 or ASTM C423. With this method, the absorption properties of the material are calculated by comparing the reverberation in an empty test room with the reverberation in a room where the material sample is being analyzed. On the other hand, sound transmission loss of fuselage panels or doors can be efficiently measured using a two-room method according to the ISO 16283-1 standard. In this case, the measured sample is placed in-between the two rooms and the ratio between the measured incident and transmitted power provides the transmission loss. Array-based techniques for sound source localization can also efficiently complement these traditional methods to obtain more advanced engineering insights.



Determining the acoustic properties of sound treatment materials.

Conclusion

Aircraft manufacturers are under pressure to develop quieter, greener and more comfortable aircraft. Engineering teams have the difficult task of reaching interior and exterior aircraft noise objectives without compromising the overall aircraft weight and performance. Ground and in-flight acoustic measurements are essential to achieve these goals. The Simcenter hardware and software solutions are designed to efficiently support the widest range of acoustic measurements in support of quieter aircraft design. Fully traceable and accurate measurements are performed to verify that target noise objectives meet aircraft certification standards. Operational measurements are executed in a flexible, efficient and reliable way to assess noise levels and be able to shape the right sound quality while minimizing flight testing time. State-of-the-art technologies, including array-based sound source localization and transfer path analysis, are available to provide a deep understanding of the noise generation mechanisms and efficiently design noise control measures. This combined set of capabilities in Simcenter hardware and software testing solutions offer a complete and scalable acoustic engineering solution for aircraft noise. The solution has proven to be extremely efficient in providing essential insight into the development of quieter and more efficient military and commercial aircraft.

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