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UNMANNED AIRCRAFT DESIGN WITH MINIMUM ACOUSTIC FOOTPRINT

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Besides meeting the civil noise certification requirements, the acoustic footprint is a key design parameter for large military unmanned aircraft. Surveillance missions for example must be carried out without being acoustically detected on the ground. During the design phase, the final aircraft configuration is frozen after several design loops during which elements affecting the acoustic footprint like engine type and location may change. This paper describes the acoustic footprint design process followed at Airbus Defence and Space from early development to the in-service compliance evidence to the Customer. This paper also addresses the quest for balance between acoustic footprint requirements and the many other design requirements and constraints. At the early stages of the development, the analysis process must be fast enough to be able to follow design changes whilst providing realistic but not necessarily extremely accurate results. It must also be able to incorporate field data coming for example from other platforms. Before configuration freeze, the analysis process must be able to more accurately estimate the design robustness to minor component or configuration changes. At configuration freeze, the analysis process must be able to accurately predict the aircraft footprint for the foreseen mission profiles. Once field data is available, either from flight test or in-service operation, the analysis process must be able to include such data. This paper describes the toolset used at Airbus Defence and Space during this process. Examples of acoustic signature analysis results during the various development stages are shown for a generic unmanned aircraft.

Keywords: unmanned aircraft, acoustic footprint, acoustic signature

1. Introduction

Typical Customers of large unmanned aircraft like the ones shown in Figure 1 are sovereign nations or organisations like NATO. In addition to specific aircraft performance, reliability and maintainability figures, Customers demand, from an Acoustics point of view, a minimum acoustic footprint. In turn, this takes the form of mission requirements and possible certification requirements. The former is generally expressed in the aircraft susceptibility context and it determines the ability to fulfil a certain mission knowing what the aircraft radar, infra-red, optical and acoustic signature are. The latter becomes a major design driver if, for example, the aircraft is required to operate from civil runways. In this case, fulfilment of the EASA and the ICAO Appendix 16 certification requirements may become mandatory. In other words, unmanned medium altitude long endurance aircraft constitute a formidable challenge for the Aero-Acousticians as they combine civil aircraft certification and Acoustic Fatigue aspects with military signature constraints.

Recent history shows that Customers tend to award the contract to a company or to a consortium only after running an evaluation phase where the prime contractor is down-selected. During such period, several competing companies are given the same set of initial requirements and they have to produce deliveries (sometimes even flying aircraft prototypes) which demonstrate that their offer is worth the contract. In this phase the 3P rule applies, where Politics, Price and Performance play different roles with different levels of importance.

This paper describes the acoustic footprint design process followed at Airbus Defence and Space from conceptual design, through preliminary and critical design to the verification, validation and certification phase.

Figure 1: Airbus Defence and Space Talarion (left) and Barracuda unmanned aircraft.

2. Conceptual Design

The main objective of the conceptual design phase is to freeze the overall aircraft configuration (aircraft loft) and select the engine type. To achieve this, a large number of trade-off studies must be carried out in order to make sound technical and commercial decisions which have implications throughout the entire life of the aircraft fleet. For example, the outcome of the trade-off studies has to guide the 'make or buy' policies and in case of the latter, whether the component is COTS (commercial off-the-shelf) or newly developed by a supplier.

At Airbus Defence and Space, low-fidelity in-house tools, based, amongst others, on [1] and [2], are used to estimate the acoustic footprint based on a few input parameters such as blade geometries, Cl and Cd distributions for propeller driven aircraft, or basic jet engine and mixer data for turbofan aircraft, combined with acoustic analogies. Given the large number of cases to analyse, the computational time for each case must be low, of the order of a few minutes. Such low-frequency tools must be able to estimate the near field noise as well as the noise at different heights above ground over a relatively large area. They have to consider, as explained in [3], Doppler shift flight and weather effects. They also have to include ground and atmospheric absorption, spreading losses, coherence, loading versus thickness noise (for propeller aircraft) and fan-mixer-jet noise (for turbofan aircraft). Installation effects must be considered, for example, for pusher configurations. Finally, propeller rotation direction, blade relative angle, blade number, blade geometry, mixer type, outlet geometry etc. must be part of the toolset. In this phase of the aircraft development, aircraft configurations and engine options can change on a daily basis and therefore the Aero-acoustic tools (and engineers) must cope with such environment. Typical deliveries in the conceptual design phase are videos showing the acoustic footprint during a fly-over under certain flight conditions, audios, obtained with auralisation techniques, where the noise during the fly-over is estimated and 'carpet plots' as exemplary shown in Figure 2 This information is crucial for Airbus Defence and Space to be able to offer the best platform to the Customer, and it is also crucial to the Operational Researchers to determine the estimated overall aircraft susceptibility, i.e. the combination of radar, infra-red, optical and acoustic signature.

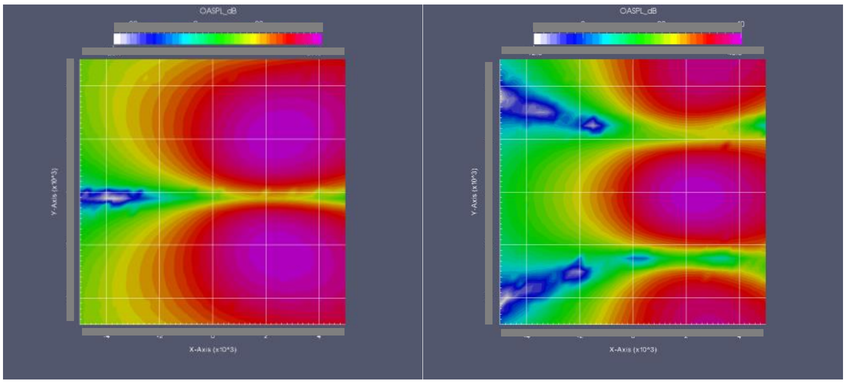

Figure 2: Estimated Acoustics Footprints on the ground of a generic twin propeller aircraft with two different relative blade angles.

3. Preliminary Design

The main objective of the preliminary design phase is to freeze the aircraft configuration and the main systems, determine the preliminary flight control laws and therefore estimate the preliminary aircraft performance. In this phase the low-fidelity methods used during the conceptual design are no longer fit for purpose as the required accuracy is greater than what they can provide. In this phase the installation effects must be better quantified and the main noise sources must be modelled, including those that were not considered in the previous phase. However, as the aircraft development still allows significant changes, during this phase the acoustic tools must be able to react to such changes and therefore they cannot be extremely computationally expensive. At Airbus Defence and Space the strategy is to model noise sources with a sufficient degree of accuracy using CFD or semi-empirical methods (Figure 3, left), then to predict the acoustic radiation in the adjacent small scale domain using finite difference methods, discontinuous Galerkin methods or finite element methods based, amongst others, on [4], then to include large scale installation effects using boundary element methods or Lattice Boltzmann methods and finally determine the acoustic footprint on the ground for a given flight path and condition using ray-tracing and semi-empirical methods (Figure 3, right). Although this process may seem cumbersome, it has the great advantage of being flexible, allowing local changes (due, for example, to design changes) to be assessed in isolation without having to run the complete chain each time. In addition, this step-wise strategy allows trade-off studies to be carried out at component level, an element which becomes of fundamental importance in the next critical design phase.

In parallel to the activities described above, model validation is the second major pillar of the preliminary phase. This includes acoustic wind tunnel test campaigns and other types of ground testing. Together with existing flight test measurements coming from previous developments, the goal is to provide data which can be used to validate the numerical models or they can directly be used (as look-up tables for example) within the semi-empirical routines. Ground testing and model validation are outside the scope of this paper, however their fundamental importance must be emphasised even in a paper on methods and process like this.

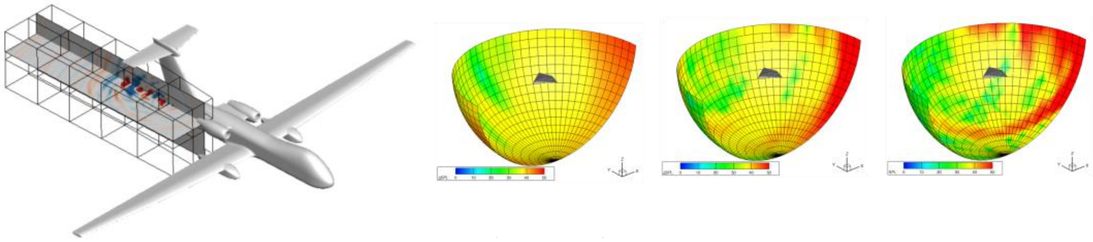

Figure 3: High-fidelity Acoustic near field jet propagation (left) and radiation pattern on a hemi-sphere for different frequencies (right).

4. Critical Design

The critical design phase focusses on the detailed design of components, where accuracy becomes a must and therefore where high-fidelity like Navier-Stokes or Lattice Boltzmann based methods (see [5], [6] and [7]) find their use. The activities which are taken place in this phase from an Acoustics point of view are many. This paper does not want to provide an exhaustive list of such activities, but rather focus on a fundamental aspect, which during the critical design can make or break the programme: the quest for balance. It is trivial to say that an aircraft design is the outcome of a careful balance between many disciplines. It is also trivial to say that the quest for balance must be sought from the conceptual design onwards. What it is in practical terms absolutely not trivial to achieve is such perfect balance throughout the entire aircraft development. In other words, as the critical design is, by definition, the phase where all disciplines come together in every detail of the aircraft, if such balance was somehow skewed in earlier phase, then the critical design is where dire prices are paid. The weapon bay or the landing gear bay design can be taken as a representative example (Figure 4).

Although weapon bays and landing gear bays fulfil very different purposes, their Physics is quite similar. In both cases unsteady aerodynamic pressures are applied on the bay doors or enter the bay cavity generating acoustic phenomena. Such unsteady pressures result in dynamic loads on the component, which in turn become dynamic stresses on the structure. As a result, parts may fail if the residual factors are not sufficient or they may lead to fatigue induced failures. In either case, treatments or design changes must be introduced to avoid ruptures. In conclusion, to ensure that the design is fit for purpose the Aerodynamics, Acoustics, Structural Dynamics, Stresses and Fatigue engineers and their methods must function and interface with each other like clockwork. This is another trivial thing to say, but most certainly not a trivial thing to put in practice.

Figure 4: Similarities between a weapon bay (left) and a landing gear bay (right).

5. Verification, Validation, Certification

Requirement verification, evidence of fitness for purpose and ultimately aircraft certification must be obtained to demonstrate to the Airworthiness Agencies that the aircraft is safe to operate and to the Customer that the aircraft performance meets the contractual technical demands. The 'classical' admissible means of compliance are engineering judgement, analogy, analysis and test. In Acoustics, intended as interior acoustics (for manned aircraft), acoustic fatigue and exterior acoustics test is still the main means of compliance required by the EASA (or MAWA) regulations and the Customer specifications. Although the exterior acoustics certification test procedures are quite established, it is not uncommon to augment the test instrumentation with additional sensors to measure the near and far acoustic fields. Besides the microphones required to gather certification evidence, beamforming techniques are often used to identify the aircraft noise sources. This information is necessary in case the aircraft shows marginal compliance with the requirements or, in general, if immediate or future modifications are planned. Similar techniques are also used during the acoustic footprint measurement campaign, where evidence is gathered to ensure compliance with the Customer susceptibility requirements under different atmospheric and flight conditions, as schematically shown in Figure 5.

Once the certification campaign is completed and the IOC (initial operational capability) is demonstrated, the aircraft can be employed to fulfil its initial missions. Once the FOC (final operational capability) is achieved, the aircraft can be employed to execute any mission it is intended for. During its in-service operations, it is very important to gather field data in order to improve the numerical models and identify best practice for future upgrades of the type or new developments.

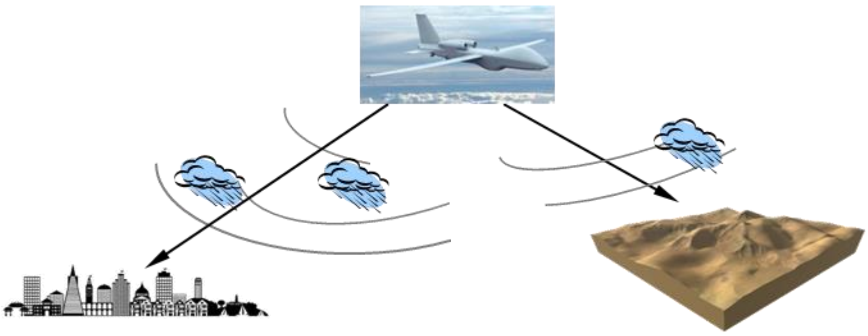

Figure 5: The aircraft acoustic footprint fitness for purpose must be demonstrated under several atmospheric and flight conditions, as well as over urban and rural terrains.

6. Conclusions

Low-fidelity computational aero-acoustic tools are fast enough and accurate enough to fulfil the conceptual design needs, but they are still not accurate enough to be used at later stages of the aircraft development. On the contrary, high-fidelity computational aero-acoustic tools are accurate enough to be able to fulfil the critical design needs, but they are still too computationally expensive to be used at during the early stages of the development. Therefore the Industry demands that computational aero-acoustic methods are developed to cover the middle ground between low and high fidelity tools. Today, Lattice Boltzmann based methods are a reality in the automotive sector and they seem to be very promising for aerospace applications (as shown in [7]), where development times and costs must decrease. Another fundamental need of the aerospace sector is the ability to carry out high-fidelity numerical simulations at aircraft level, including parts which have an acoustic impact. They are not only the classical ones, like landing gear, slats and flaps, but also fairings, doors and antennae. The ability to accurately model the Aero-acoustic effects of centimetre size components as well as (at the same time) 30+ meter aircraft is becoming a reality, thanks to recent developments in the field. These capability improvements are not just 'nice to have', but they are necessary in order to minimise the risk of missing challenging requirements, like for example the imminent Chapter 14 cumulative noise levels, which are coming into effect in late 2017 and 2020.

Virtual certification, where an aircraft is certificated with no or minimum ground or flight testing, is not yet reality. Views on this matter cover a very ample spectrum, ranging from the hyper-skeptical to the hyper-optimistic. The author is a doubting Thomas on this or, being an Acoustician, he does not believe unless he hears it. Surely, recent developments show that the amount of acoustic wind tunnel, ground resonance and flight testing can be tailored to cover conditions where interpolations carried out with validated numerical methods are possible. Also surely, the current numerical methods are improving by the day. However, the day where virtual certification becomes reality is still quite in the future.

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