Experimental investigation of the influence of boundary layer ingestion on turbo-fan noise generation

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Introduction

The effects of boundary layer ingestion (BLI) on the acoustics of a turbofan were experimentally investigated under realistic conditions in the DLR project AGATA3S in spring 2022. The main objectives of the project were to assess the relevance and increase the understanding of the physical mechanisms behind the effects, to validate and extend prediction and design procedures, and to capture the relationships between the aircraft's external aerodynamics and the effects caused at the fan. The effects of BLI on the aerodynamics, aeroelasticity and structural mechanics of the fan were examined in the multidisciplinary measurements as well.

BLI test cases derived from CFD of aircraft with UHBR engines

Realistic test cases were derived for an engine embedded in the rear of an A320-like commercial aircraft concept. As depicted in Figure 1 inhomogeneous flow distributions in the engine inlet were calculated by means of CFD simulations for varying engine embedding degrees and for different flight conditions [1]. These were transferred as realistic specifications for experimental investigations to the turbofan model. The aircraft was powered by an ultra-high bypass ratio (UHBR) engine. The engine was positioned as far aft as possible to take advantage of the natural contraction of the rear of the fuselage, to allow a smooth transition from the fuselage into the engine inlet and to ensure that the maximum boundary layer thickness of the fuselage was sucked in.

Fan test rig and inflow distortion device

The fan stage consisted of the counter-rotating turbofan model CRISPmulti (Counter Rotating Integrated ShroudedPropfan). As a link to the aircraft modelling a performance model of a suitable turbofan engine was created, which largely corresponds to a classic unmixed 2-shaft turbofan. The fan can be seen in Figure 2 and was manufactured as a demonstrator for a new lightweight manufacturing technology made of carbon fibre composite material (CFRP) [2]. Rotor 1 consists of 10 blades and rotor 2 of 12 blades. The rotor diameter is 1 m with a hub ratio in the interstage area of 0.32. For the design point with an axial inflow Mach number of 0.69, a pressure ratio of 1.3 results with a mass flow of 159 kg/s. The pressure ratio corresponds to a bypass flow. The pressure ratio corresponds to a bypass ratio of approx. 16. The CRISPmulti-Fan was operated and measured for the first time on the DLR's multistage 2-shaft axial compressor test rig (M2VP).

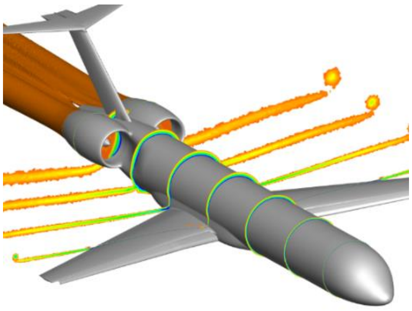

Fig. 1 CFD of aircraft with aft embedded engines to derive representative BLI test cases.

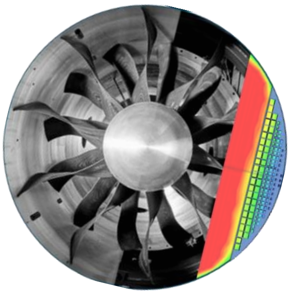

Fig. 2 BLI test cases were applied to CRISPmulti fan with optimized distortion fence.

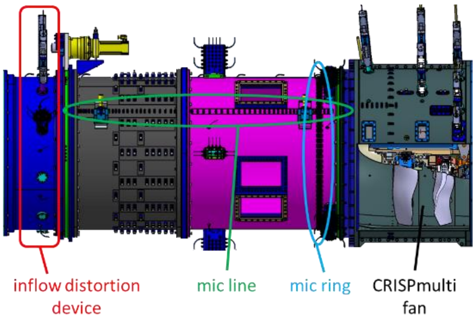

Fig. 3 Acoustic measurements were carried out at M2VP test bed under realistic engine conditions.

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The experimental technique for generating BLI-representative inflow disturbances was carefully optimised through combined experimental and numerical studies [3]. A very important requirement was to assess the current blade loads of the rotors as well as those generated in long-term operation in advance in order to ensure safe rig operation. The design of the finally selected distortion fence is shown schematically and together with the generated inflow disturbance in Figure 2. The impact on the fan was measured with extensive instrumentation and measurement techniques in various planes upstream, between and downstream of the CRISPmulti rotors, including total pressure rakes, hot-wire anemometry, particle image velocimetry, image pattern correlation technique and microphone arrays in linear and annular arrangements, see also Figure 3.

Measured BLI impact on fan acoustics

The rotor-rotor configuration allowed an explicit examination of the tonal sound sources caused by BLI-rotor interaction, since in subsonic operation and under homogeneous inflow, each rotor produces no tonal self-noise. Exemplarily, the impact of different disturbance fence heights on the harmonics of the blade passing frequencies (BPF) of rotor 1 are shown in the left diagram of Figure 4 for an operating point with 85% rpm on the working line. It should be noted that the largest disturbance corresponds approximately to a BLI for an engine embedding degree of 15% at Climb operating point. The tones were separated from the rotor incoherent components using cyclostationary analysis. Apparently, tonal components can also be detected in the case without disturbance fence, which indicates non-uniformities in the base flow. However, it is clearly noticeable that by introducing the disturbance, the sound excitation increases significantly, up to 25 dB for the BPF fundamental harmonic.

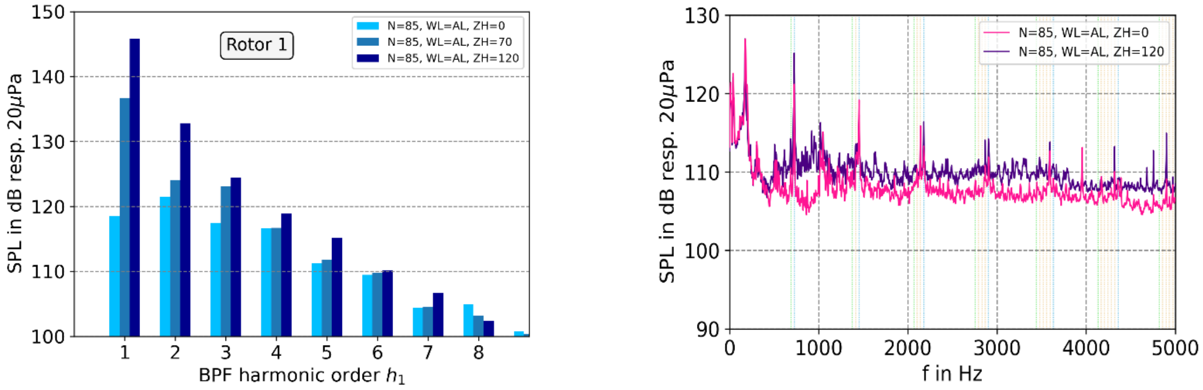

Fig. 4. Influence of inflow distortion fence height (ZH) on fan noise generation at 85% shaft speed on the working line. Level of rotor1 bpf harmonic tones (left diagram) and filtered rotor-incoherent components (right diagram).

The right-hand diagram in Figure 4 shows the influence of the inflow disturbance on the rotor incoherent noise excitation. At the highest disturbance fence height, there are significant level increases, which are predominantly in the range of 2dB to 3dB, depending on the frequency. The broadband sound excitation is largely determined by the intensity and distribution of the turbulence in the inflow, which interacts with the rotors and influences the rotor-rotor interaction. For a more in-depth analysis, hot-wire measurement were executed. Figure 5 shows in the left the profiles of the axial turbulence intensity for different test cases. The radial extent of high turbulence intensities increases with the fence height. The turbulent length scales shown in the right of Figure 5 are small in relation to the chord length of the rotor blades, which is associated with a broadband spectral characteristic [4].

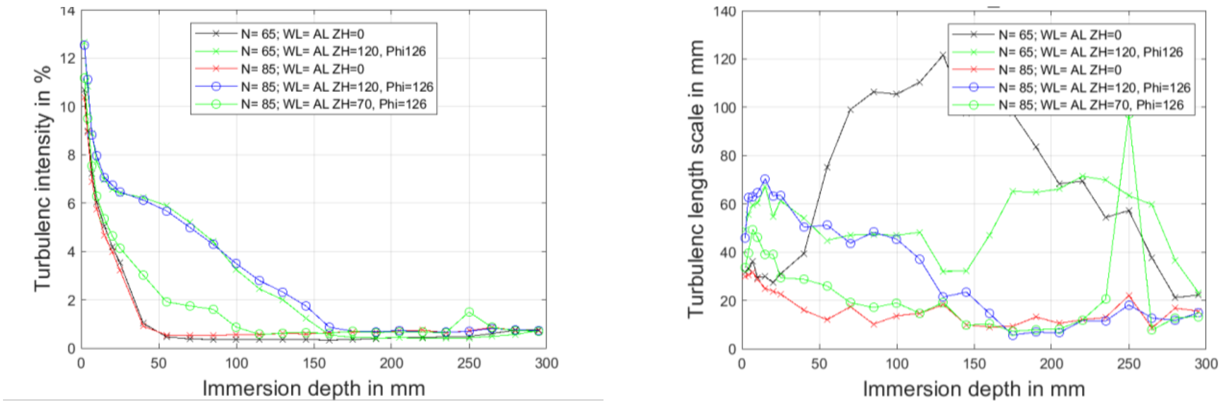

Fig. 5. Result of hot-wire measurements for different disturbance fence heights and operating points. Radial profiles of axial turbulence intensity (left diagram) and of axial turbulence length scale (right diagram).

Outlook

In the workshop presentation, the measurement results are presented on a larger scale and their usefulness as input or reference data for model calculations is outlined.

References

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