CHALLENGES OF AERO-ACOUSTIC MEASUREMENTS IN WIND TUNNEL: IDENTIFICATION AND ELIMINATION OF "PARASITE" NOISE

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Keywords: *Airframe, Aero-acoustic, wind tunnel*

Abstract

The paper presents challenges encountered during aero-acoustic test measurements in identifying and eliminating parasite noise applied to aircraft model and to wind tunnel set-up in order to obtain high quality data. Such challenges are rarely reported according to the authors knowledge. The objective of the aero-acoustic wind tunnel test activity is to quantify the best way possible noise levels and directivity of several design of airframe configuration at different flight parameters. Wind tunnel is an open jet type and is limited in size and consequently aircraft model must be scaled down to 5-20% according to relative sizes of aircraft and wind tunnel. In general, the main interest is to measure radiated noise to the far-field. Recently, more and more surface pressure fluctuations are also of interest mainly for benchmarking of predictive capabilities (LAGOON [1], BANC [2]). Noise "as measured" must be corrected due to the convection effect and diffraction through the shear layer of open jet configuration.

1 Introduction

The dominant sources of airframe noise are known to be associated to the high-lift devices and to the landing gears of the aircraft. Of course this is a broad statement, having more details such as which parts contribute the most is required, however it assumes that no interaction took place between parts. The main expectations of the noise measurements are to observe mainly broadband noise. This is the fundamental assumption made during a wind tunnel test. However, several parasite noises are observed. The difficulty as reported in [3] is to really understand if the measurement corresponds to real noise or to artifact from scaled model, lack of fidelity, manufacturing tolerance, simplification and/or wind tunnel set-up, etc... During the test, judgment must be made to interpret the result in an efficient manner, as wind tunnel financially operates with occupation time, as well as in an effective manner to gather correctly the required data, for quality purpose. In general, they can be qualified as "parasite" only if their locations and generations can be identified. Their locations could be identified during the test relying of data acquisition using microphones array and beamforming techniques. Again for efficient, classic beamforming techniques allows to perform fast turnover (about 1-2 mins after data acquisition) in mapping source locations during test execution.

The paper is organized into 2 parts: first wind tunnel set up will be briefly discussed and its low noise features will be reviewed. Some parasite noises are identified and techniques to eliminate them will be explained. Thirdly, the aircraft model is prone to create tonal noise due to Reynolds number effect, moreover some unexpected tonal noise was hardly identified and they are due to specific simplification of scaled model. They could be eliminated during the wind tunnel test, but not all of them. Most of the data presented in this paper are from an aero-acoustic test performed at DNW-LFF wind tunnel, with an aircraft model scaled to about 7-8%. The arrangement of the aircraft in the open jet section of DNW-LFF with the instrumentation is depicted in Fig. 1, showing fly over microphones, microphones array and sideline microphones. All data presented in this paper are "as measured" during the test, i.e. no correction are applied. Finally, aerodynamic aspect of the different "cures" will be also provided and discussed.

2 Wind tunnel set-up

Over several years of operation, improvement of the open jet wind tunnel DNW-LFF have been implemented in order to reduce "parasite" noise, which is normally called the background noise of the wind tunnel. In [4], extensive details are provided describing all the enhancements for reducing background noise. For the support of the model, DNW-LFF has developed and implemented a new acoustic sting fairing as well as acoustic treatment around the dorsal sting.

2.1 Acoustic sting fairing

Since 2012 DNW-LFF has a new acoustic fairing for the sting mechanism. The objective of this fairing is the reduction of airframe noise caused by the mechanical installations in the alpha and beta joints in the head of the sting. However, such a fairing increases the volume of the sting head significantly. From the middle of the eighties until begin of 2012 DNW-LFF used an acoustic fairing which is a larger volume compared to the new fairing, as depicted in Fig. 1.

Fig. 1 "Old" fairing using in DNW before 2012

In the open jet test section, the blockage effect is not the dominant effect because the open jet can partly compensate the blockage by widening of the jet core. But in combination with an installed tail the deformation of the flow line close to the tail and the acoustic sting fairing can become significant. The external shape of the new acoustic sting fairing is given in Fig. 2. The new fairing has been optimized to reduce the aerodynamic interference between the fairing and the tail area to a minimum. acoustic sting fairing. Noise data has been acquired with vertical tail configuration and with and without the acoustic sting fairing.

Fig. 2 "New" fairing, configuration without vertical tail showing dorsal (left) and sting

Fig. 3 Sting without fairing, configuration with vertical tail

Fig. 4 shows the 1/3 octave band spectrum with and without the acoustic fairing. The sting without fairing increases the noise dramatically by more about 5 dB at low frequency (< 200Hz) and slight increase for the rest of the frequencies range. Meaning that the noise of the sting is louder that one of the loudest aircraft configuration (high lift device deployed to approach configuration without landing gear), which is very undesirable. The fairing equipped with a "soft material around it" provides a good noise control, however the impact of flow blockage could not be quanitified.

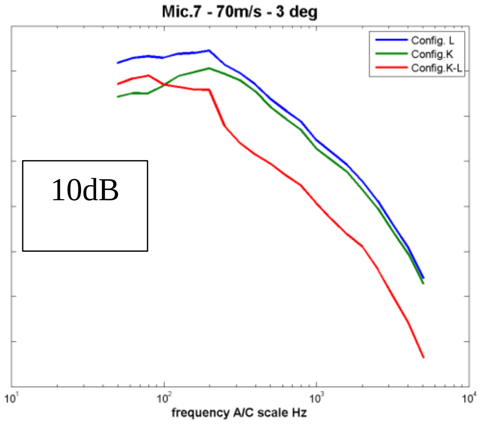

Fig. 4 1/3 octave band spectrum at overhead microphone location with fairing (config. L) and without fairing (Config. K), Red line shows noise levels of the sting (through difference)

2.2 Dorsal sting support

An "acoustic" treatment around the dorsal sting (as shown in Fig. 2) was installed in order to eliminate the noise source coming from it. Data shown that there was no obvious difference between with and without the "soft" material around the sting (Not shown in this paper). Therefore, it was decided to position the aircraft model below the flow, but by keeping the dorsal sting in the flow, as shown in Fig. 6. Such configuration allows to obtain an estimate of the "parasite" noise from the dorsal sting, assuming the main noise source is distributed along the sting from vortex shedding, and assuming that the extra noise source from the junction between the sting and fuselage is secondary.

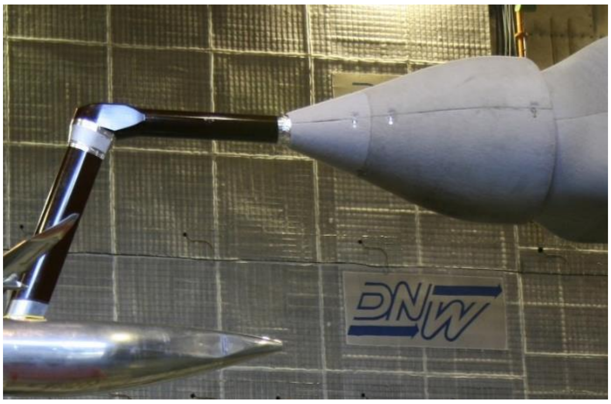

Fig. 5 Same as figure 3 but without the acoustic treatment around the dorsal sting.

Fig. 6 Aircraft model position below the shear layer of the open jet, and dorsal sting exposed to the flow, configuration A3

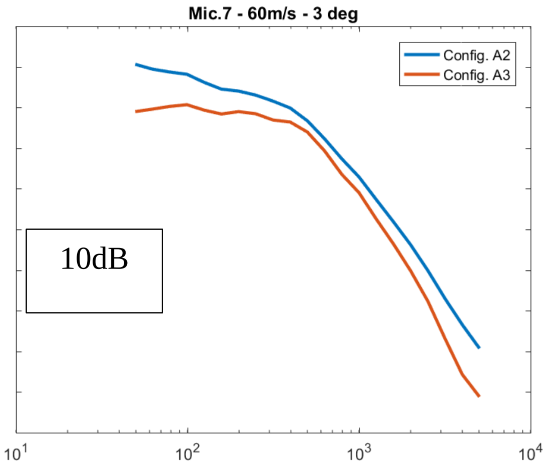

Fig. 7 1/3 octave band spectrum at overhead microphone location with high lift devices (config. D) and with model below the open jet flow (Config. A3)

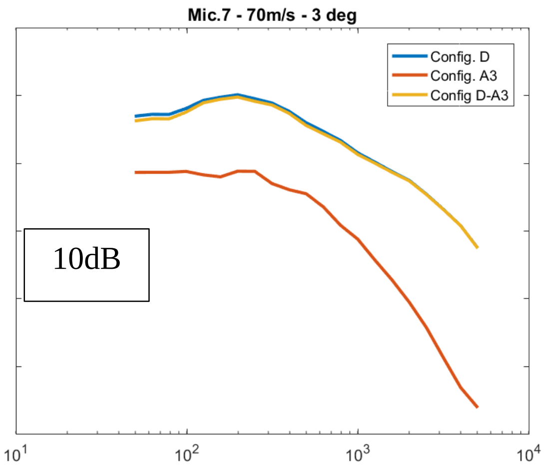

Fig. 8 1/3 octave band spectrum at overhead microphone location with high lift devices (config. D) and with model below the open jet flow (Config. A3), Yellow line shows noise levels of the dorsal sting (through difference)

The results depicted in Fig. 7, show that the dorsal sting and the background noise (configuration A2) is about 2-5 dB above the clean configuration (A3) of the aircraft. Comparing noise level of typical configuration with high lift devices (configuration D) and with configuration A3, depicted in Fig. 8, shows that the background noise is about 10dB below and the difference shows a small impact at low frequency by about 1 dB or less. This validates that the data over the whole spectrum of interest is valid and it is not contaminated by the background noise level.

3 Aircraft Model Set-up

For a standard aerodynamic performance test there are normally some areas on the model which have to be treated with roughness elements to trip the boundary layer from laminar to turbulent state. Typical areas are the nose of the fuselage, the inner and outer leading edge of the through flow nacelles and often also the leading edge of the wing section. Normally flow transition is fixed using carborundum transition strips. For aerodynamic and mainly for aero-acoustic reasons all mechanical cavities in the surface of the fuselage and the wing of the model should be filled with model forming material and covered with high-speed tape (aluminum tape). For a standard aerodynamic performance test, there are normally no aerodynamic reasons to install roughness strips for transition tripping on the leading edge of the winglets or the upper and lower leading edge of the slat or on the tail elements. However, for aero-acoustic reasons it is often necessary to trip these slat areas to prevent tonal noise caused by local laminar flow at the slat. Therefore, it is necessary to perform test first without any tripping and then after analyzing the data with few Mach number and angle of attack cases, the proper treatment can be selected.

3.1 Winglet

The application of carborundum or zig-zag tape on the winglets and the leading edge of the wing (which is the undeployed slat) is decided by the observation of the first acoustic measurements with clean configuration labelled A. The tonal peaks between 2 and 6.3 kHz are caused by laminar flow at the winglet leading edge as shown in Fig. 9. The source mapping using conventional beamforming clearly shows a red spot at the left winglet. For preventing those tones, zig-zag strips of 0.4 mm thickness are applied on the upper and lower side of the leading edge of the winglets, as shown in Fig. 10.

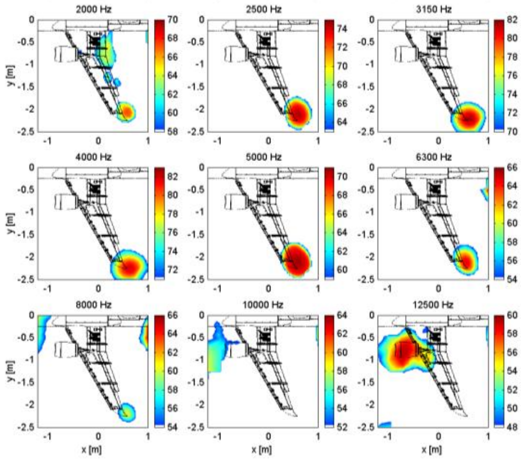

Fig. 9 Power integration and noise source localization at 50m/s for clean configuration A

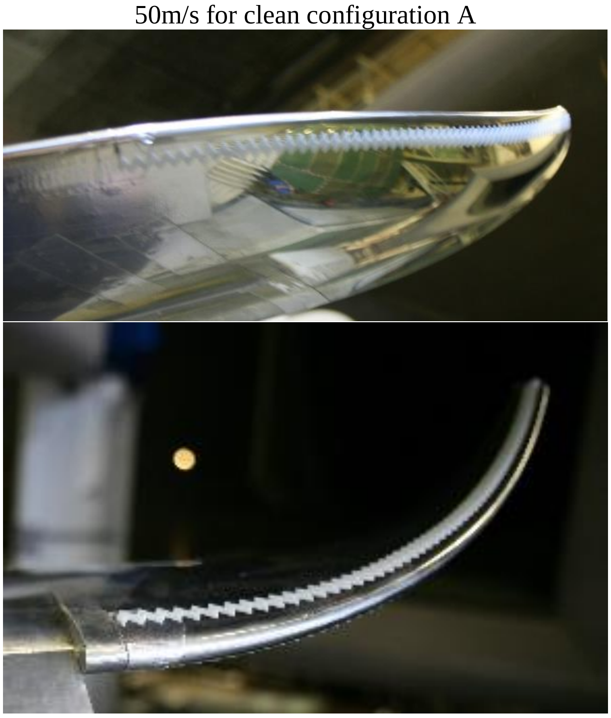

Fig. 10 Zig-zag tape on the upper (top) and lower (bottom) surface of the winglet

Figure 11 demonstrates the effectiveness of the applied zig-zag tape by removing the tonal noise from the model. The difference in 1/3 octave band noise level (integrated power level) between the 2 configurations without and with zig-zag tape is depicted in Figure 12. The tonal noise removal is clearly seen, especially at 4kHz, where the noise source is more distributed along the trailing edge of the flap. However, noise at 5kHz does not change, which could be real noise source from tip vortex.

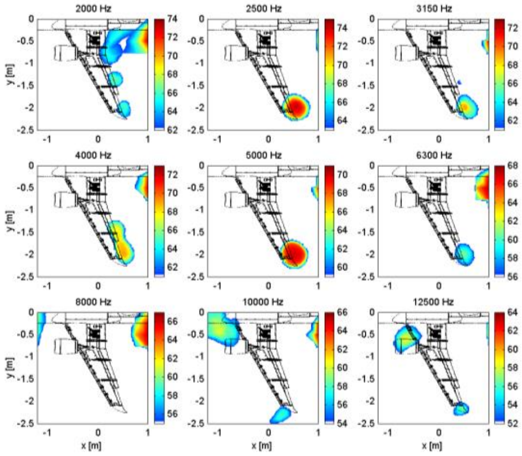

Fig. 11 Noise source localization at 50m/s for configuration A2

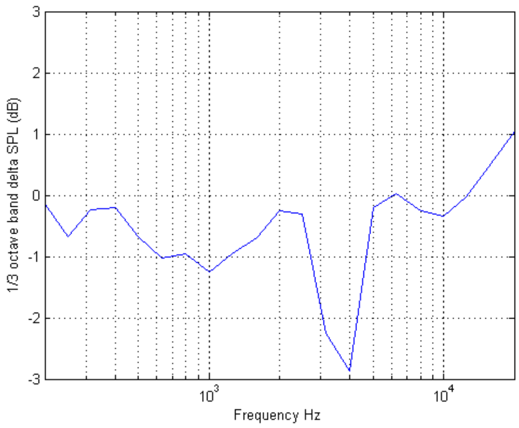

Fig. 12 Difference in power integration between configuration A and A2 (with zig-zag tape) at 50m/s

3.2 Slat

Figure 13 shows online result data from the scanning of only left wing area for the model with high left devices deployed to approach configuration with landing gears deployed. Tonal peaks between 7.5 and 9 kHz are understood to be caused by laminar flow at the slat leading edge area. At the 1/3 octave band of 8 kHz, red spot at the outer slat is visible with high level.

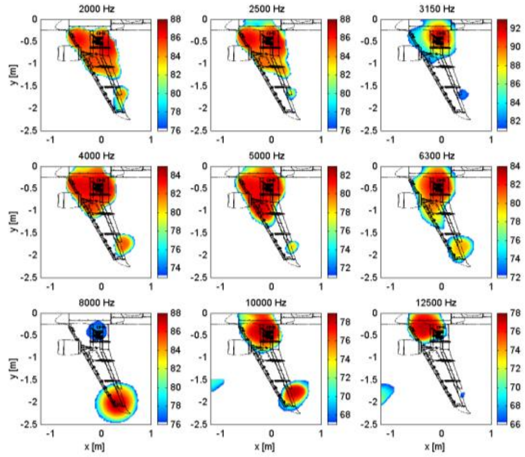

Fig. 13 Noise source localization at 50m/s AOA=6deg for configuration C

Figure 15 demonstrates the effectiveness of the applied zig-zag tape at the leading edge of the slat (See Fig. 14) by removing tones between 7.5 and 9 kHz. Figure 16 depicts the difference in narrowband of the total integrated power, showing that applying zig-zag tape on the slat has very small impact on the remaining spectrum. This result is different compared to previous section, where the zig-zag on the winglet (which is much smaller in area coverage) has a much larger noise impact, however the change was for a clean configuration. Not shown here, but extra tones at 3.4 kHz and 6.8 kHz (harmonic) are not removed thus they are not due to slat and it is discussed in the next section.

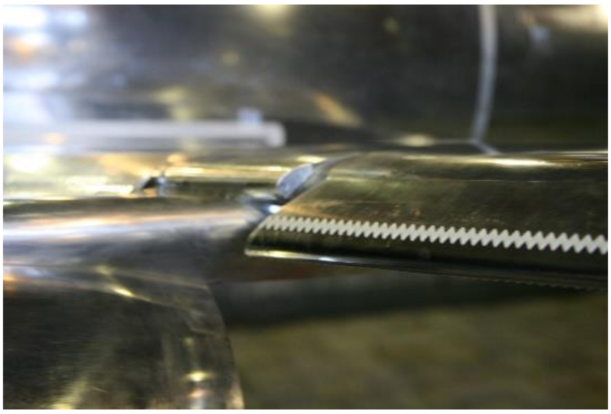

Fig. 14 Zig-zag tape applied on the slat upper and lower (not shown) surface of the slat

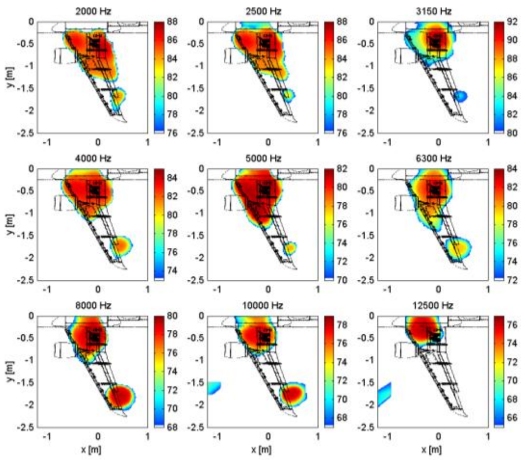

Fig. 15 Noise source localization at 50m/s AOA=6deg for configuration C2

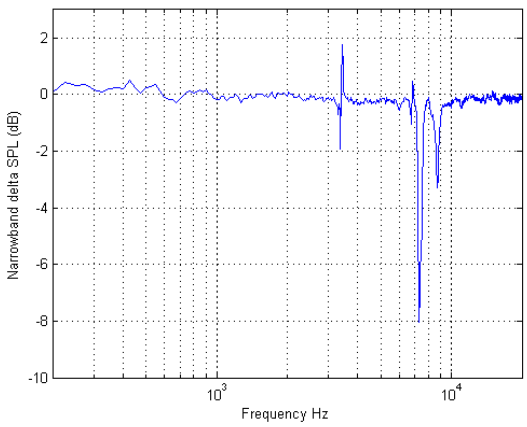

Fig. 16 Difference in power integration between configuration C and C2 (with zig-zag tape) at 50m/s AOA=3deg

3.2 Landing gear wheel

After the elimination of the laminar tones at the slat, tones at 3.4 kHz and at 6.8 kHz (harmonic) indicating that there is still parasite noise source in the model. Fig. 13 and 15 shows result data from the scanning of the left wing area, indicating high noise source level at the main landing gear location (detailed geometry shown in Fig. 17). Interestingly, the appearance of this tonal noise was not observed at AOA=0deg, but appears at AOA=3 and higher, as depicted in Figure 18. This is not well understood, but it also reminds that several sweep at different Mach number and angle of attack are necessary in order to guarantee that acoustic data are “clean” from parasite noise. Figure 15 demonstrates the effectiveness of the applied sealing (Configuration C4) of the holes in the wheels of the main landing gear by use of tape removing the 3.5 kHz base tone and the first higher harmonic at 7 kHz.

Fig. 17 Details of the wheel showing the holes responsible for the whistle noise at 3.5 kHz

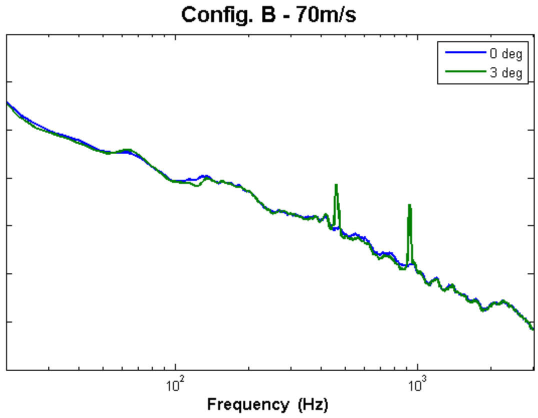

Fig. 18 Max SPL from source localization for configuration with landing gear only at AOA=0 and 3 deg

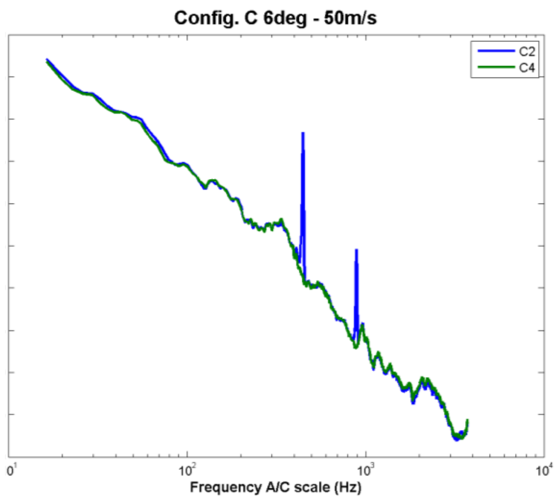

Fig. 19 Integrated power for configuration with (C4) and without (C2) sealing the wheel hole

3.3 Tail

Configuration with vertical tail is now compared with configuration without tail. It is understood that the vertical tail is not a major noise source, thus the whole test campaign was conducted without the vertical tail. Moreover, the vertical tail is located just behind the dorsal sting, thus wake from the dorsal sting will impinge on the vertical tail, creating additional "parasite" noise. From aerodynamic aspect, vertical tail is necessary for the stability of the model. Without the tail, the maximum angle of attack is limited to less than about 10deg due to decrease of roll moment. As mentioned earlier, a new acoustic sting fairing has been implemented in order to mainly reduce the noise from the sting, and to allow to test configuration with tail. SPL at overhead microphone shown in Figure 20 is practically identical between the two configurations with and without vertical.

4 Conclusions

The paper discusses and presents "parasite" encountered during wind tunnel test of typical aircraft model. Wind tunnel and model set-up potentially create unwanted noise that we must treated as they are discovered, requiring constant data analysis during the performance of the wind tunnel test. Moreover, some noise characteristics of the airframe could not be explained and could not be repeated with a subsequent test, few years later, with same model and same wind tunnel, but data show that there are some differences, which will be reported in future article.

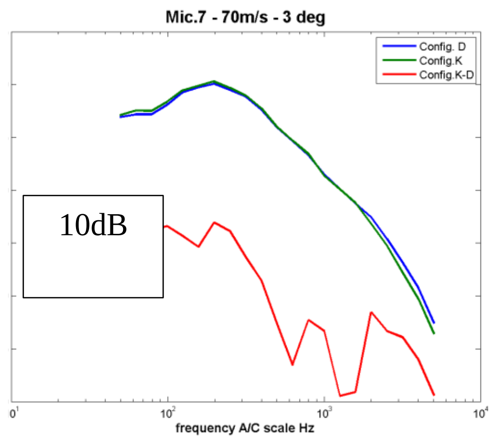

Fig. 20 1/3 octave band SPL for configuration without tail (D) and configuration with tail (K), red line shows the difference between K and D configurations

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