Experimental Investigations on the Possibility to Apply the Corrugated Sheet Metal Used in the Past with Junkers Aircraft to Reduce Noise for Future European Aircraft. Other Noise Reduction Experiments for Future European Aircraft

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Abstract: *This paper shows that corrugated skin used in the past with Junkers aircraft to increase the fuselage and wing rigidity can lead to noise reduction for future European aircraft. If the pressure side of wing which is placed above the engine is corrugated, the jet noise reflected by wing will be scattered. This way, the diffuse acoustic field has a lower intensity at ground level and correspondingly, a lower impact on community. Similarly, it is shown that if the underside of fuselage is corrugated, the noise emitted by the nose landing-gear and main landing-gear is also scattered. The existence of this effect is demonstrated by some recent measurements done inside auto-tunnels covered inside with corrugated sheet metal which indicated a reduction of maximum noise level by up to 30%. Some experiments done by the authors at low scale on an Airbus A380 wing model (scale 1:375) showed that the jet-noise reflected by the corrugated skin of wing is reduced by 4 dB in the near field. Reintroducing corrugated skin in the manufacturing process of modern aircraft is beneficial because, on the one hand, it reduces the jet and the landing-gear noise discomfort and, on the other hand, it permits manufacturing stronger frames for passenger aircraft/airliners.*

***Key Words**: aeroacoustics, psychoacoustics, noise reduction, annoyance*

1. INTRODUCTION

Lately, communities have begun to be greatly affected by aircraft noise especially the communities living near airports. Most of the airports are located in the immediate vicinity of the cities and some of them are located even inside the cities, because in time cities have expanded to the airports and eventually incorporated them. It is known that in the middle of the 20th century, Junkers created an aircraft with corrugated skin over wing and fuselage. In future, this solution could be partially used in special areas of the wing and fuselage in order to reduce noise through scattering, both could be applied on classic aircraft and BLI or Electric/BLI aircraft. Several possibilities of using the Junkers solution in manufacturing of future European aircraft are discussed in this paper. The chapters of this paper are:

- **Aircraft noise from a psychoacoustics point of view,** where some important aspects of human hearing in relation with aircraft noise are briefly explained;
- **Underlying of productive research directions for reduction of annoyance produced by aircraft;**
- **Junkers 52 design solution**, where main features of its exception design are presented;
- **The case of present aircraft**, where it is shown that the existent aircraft have the drawback of a strong reflection of noise by wing and fuselage;
- **Applying Junkers 52 solution in future aircraft designs**, where it is shown that the future aircraft should have corrugations on the pressure side of wing (over engines) and on the lower surface of fuselage;
- **The experimental facts**, where experiments or real facts are presented for sustaining the idea of reusing the Junkers corrugated skin in future aircraft designs;
- **The case of Boundary Layer Ingestion**, where using of corrugated fuselage for scattering of fan noise is presented;
- **Discussion on the re-using of Junkers solution in future European aircraft,** where it is shown that reusing this design leads to important advantages.

2. AIRCRAFT NOISE FROM A PSYCHOACOUSTICS POINT OF VIEW

Aircraft noise is a broadband ranging from several tens of Hz to 16000 Hz. For understanding why the aircraft broadband noise is the main problem for communities living in the immediate proximity of the airport or at a short distance from the airport, it is important to summarize some information about Psychoacoustics. Psychoacoustics is a branch of physics specialized in studying the connection between the physical characteristics of sound and the listeners' perception [1].

This science was developed through multiple experiments involving listeners as test subjects and deals with the following characteristics:

a) - hearing thresholds;
b) - localization of sound;
c) - hearing adaption at sound loudness;
d) - frequency selectivity;
e) - timbre and loudness;
f) - analysis of auditory;
g) - influence of noise to health;
h) - masking of sound.

a- Hearing thresholds refer to the fact that sounds are heard better or worse depending on their frequencies.

b- Localization of sounds refers to pinpointing the direction from which the sound is emitted due to the binaural hearing.

c- Hearing adaptation at sound loudness refers to the characteristics of the ear to adapt to sound loudness, i.e. to vary its sensitivity if the sound is too loud or to weak.

d- Frequency selectivity refers to the capacity of the ear to distinguish between various frequencies.

e- Timbre is a feature which indicates how a sound was produced (the instrument) and the loudness indicates how strong is that sound.
f- Analysis of auditory refers to the capacity of the auditory in perceiving a sound.
g- Noise's influence on health refers to the damage done on the human ear and to the mental state of the individual by exposing it to loud noises for long time.
h- Masking deals with the capacity of a sound to mask another sound.
These aspects are important for finding the efficient directions in order to reduce the aircraft noise impact on population. The efficient research directions are presented in chapter 3.

3. THE EFFICIENT RESEARCH DIRECTIONS FOR REDUCTION OF ANNOYANCE PRODUCED BY THE AIRCRAFT NOISE

A first efficient direction to reduce the noise impact on the community is related to the following characteristic: a)-the hearing thresholds. The importance of this characteristic is shown in fig.1 [1] where the absolute thresholds for hearing are given as a function of frequency. The minimum threshold is at 3500Hz for binaural hearing and at 1500Hz for monaural hearing.
This graph leads to the conclusion that the efforts for annoyance reduction should be done in this range, i.e. in the range of high frequencies (1500Hz…3500Hz) or better in the extended range 400Hz…6000Hz where the hearing thresholds are still low.

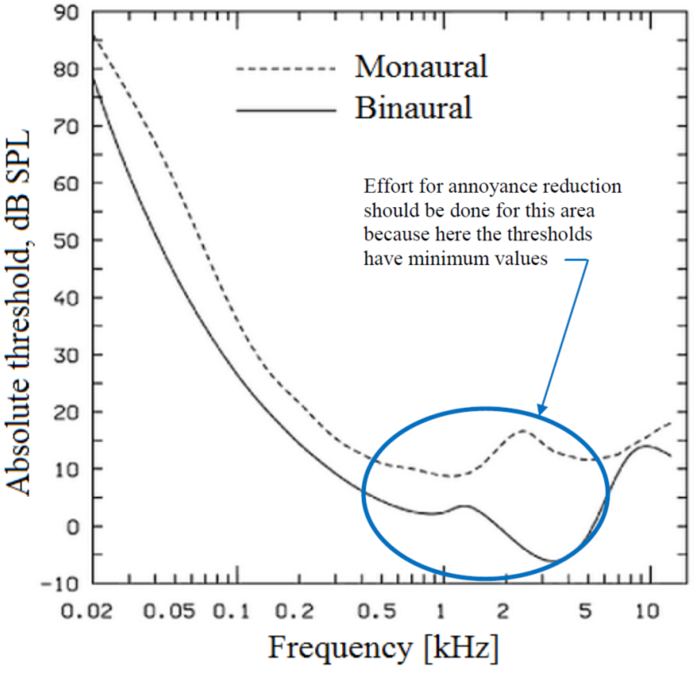

Fig. 1 - Measurements of absolute thresholds for binaural (both-ears) and monaural (one-ear) [1]

Another efficient direction to reduce the noise impact on the community is related to characteristic h)-masking of sound (fig. 2): Low volume sound cannot be heard in the presence of a loud sound. If the loud sound has the same frequency, the loudness of masker signal has a minimal value.
Without insisting in this paper on solutions related by this direction we only mention here that it can be successfully applied for reduction of annoyance through installing sound

machines or loudspeakers in areas where communities are affected by aircraft noise, especially in cities [2].

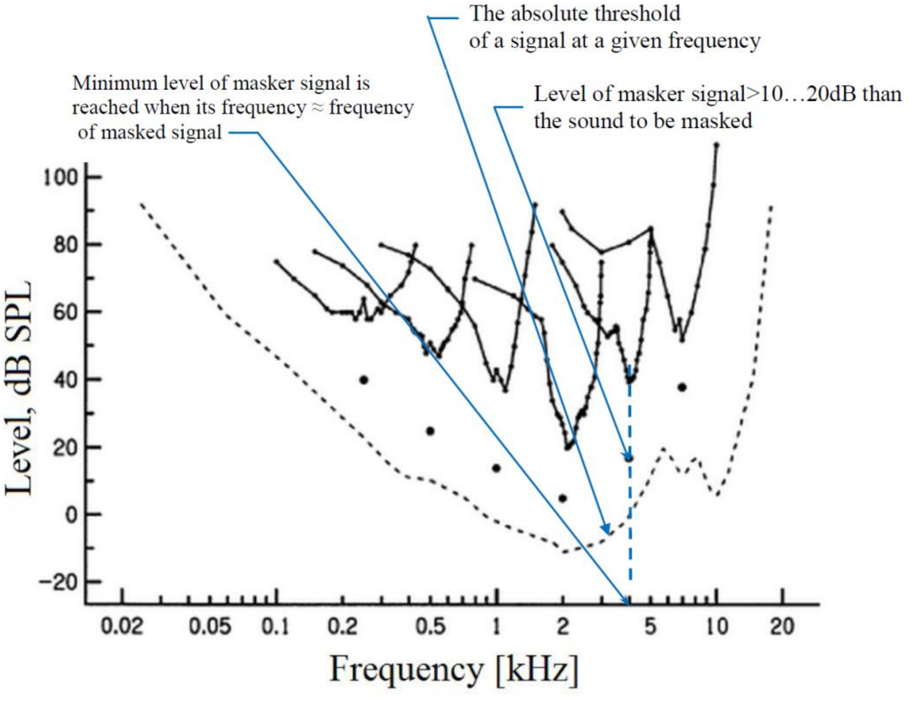

Fig. 2 - Measurements of psychophysical tuning curves showing the level of masker signal which is needed to successfully mask a signal of a given frequency [1]

4. JUNKERS 52 DESIGN SOLUTION

Junkers 52 (JU52) was the most successful model of Junkers aircraft factory. This aircraft was built at Junkers works in Dessau, its first flight taking place in 1936. Almost 5000 airplanes were built serving for decades in 30 airlines and 25 countries all over the world. Now, this aircraft is still used for recreational flights [3]. Some characteristics of this aircraft are given below:

Length: 18.90 m
Height: 6.10 m
Wingspan: 29.25 m
Minimum take-off distance: 500 m
Minimum landing distance: 350 m
Empty weight: 4000 kg
Max takeoff weight: 7000 kg
Capacity: 1820 kg of cargo
Maximum range: 825 km
Take-off speed: 120 km/h
Cruising speed: 190 km/h
Maximum speed: 250 km/h
Engines: Three nine-cylinder Pratt & Whitney radial engines, PW 1340 S1 H1G Wasp
Crew members: 4
Passengers: 16

The specific feature of this aircraft is the use of the corrugated skin which increases its rigidity (fig.3, 4), [3].

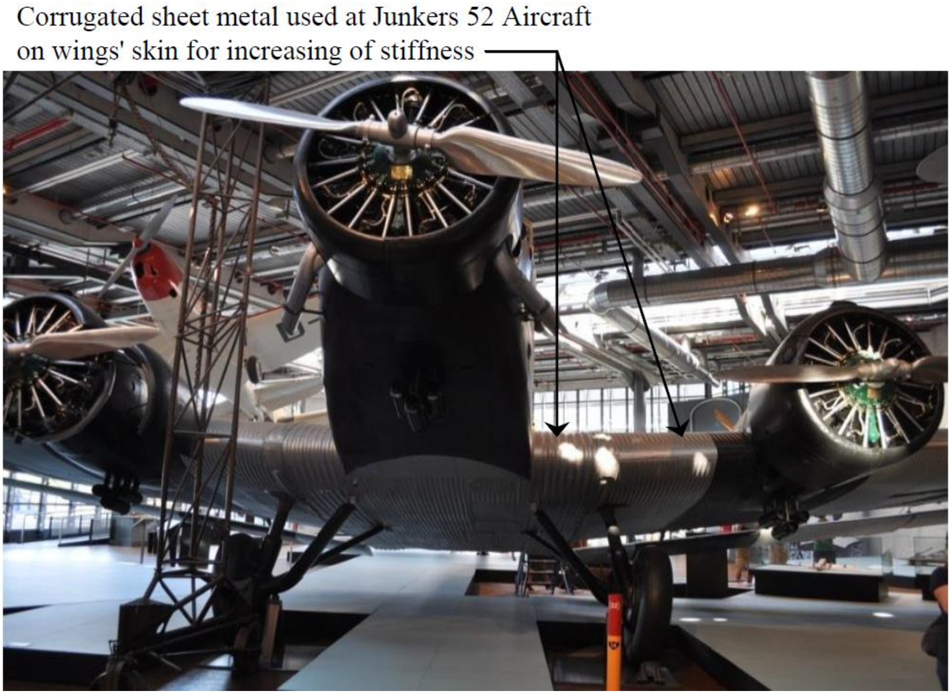

Fig. 3 - Junkers 52 aircraft-front view [3]

Fig. 4 - Junkers 52 aircraft-side view [3]

5. THE CASE OF PRESENT AIRCRAFT

In the case of present aircraft, the noise emitted by jet and landing gears (LG) is strongly reflected by the pressure side surface of wing and lower surface of fuselage, for this reason having a strong impact on the community (fig. 5, 6& 7).

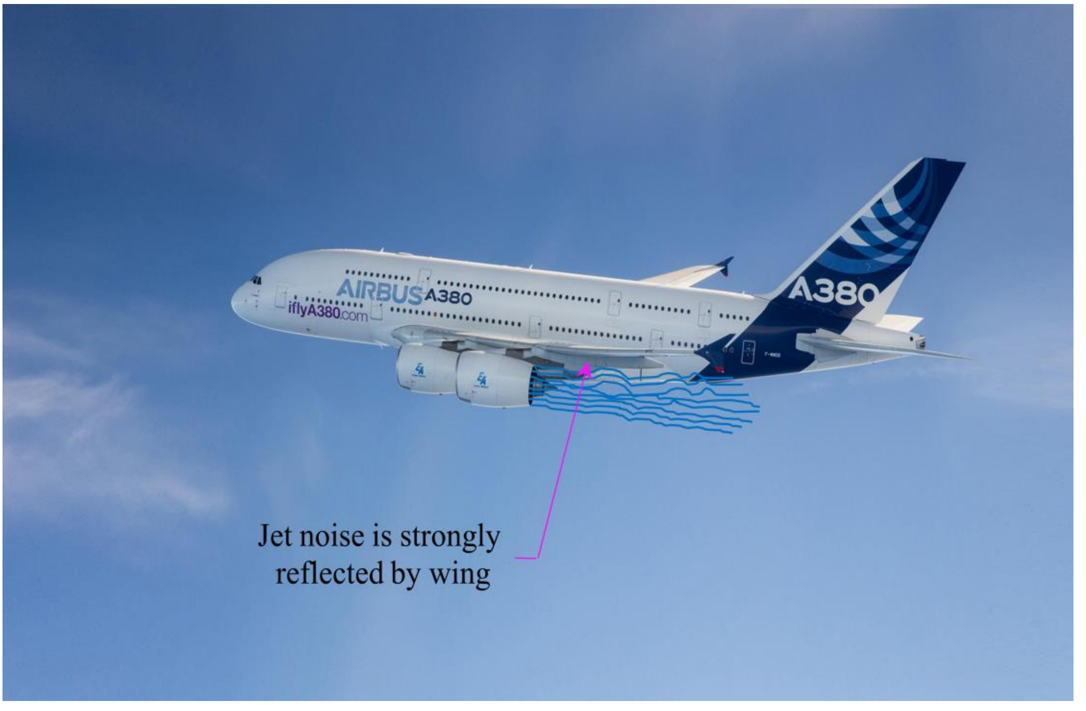

Fig. 5 - Reflection of jet noise by pressure side of wing at present aircraft

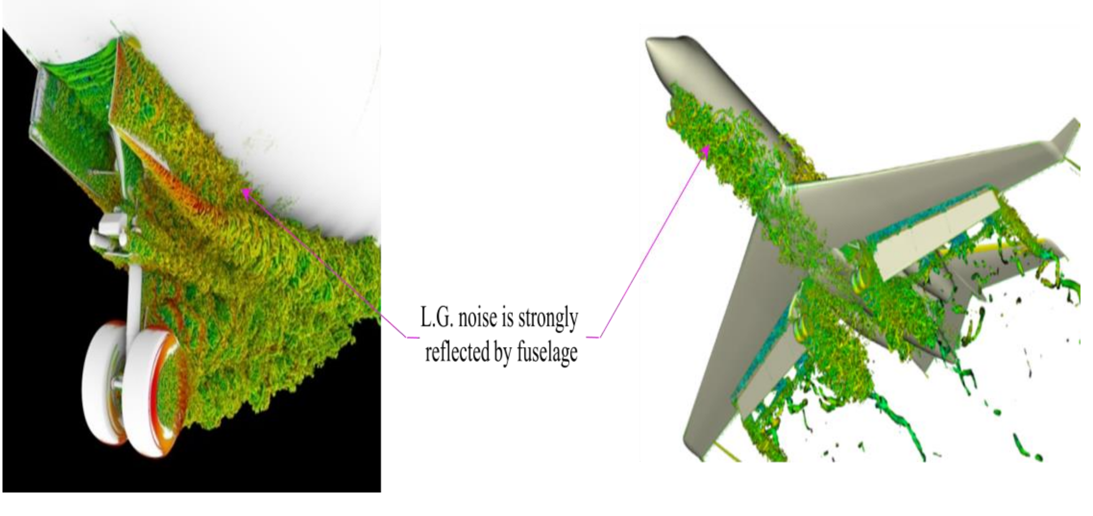

Fig. 6 - Reflection of LG noise by the lower surface of fuselage

In Fig.7 one can see that due to the wing pressure side flatness, the noise emitted by the engine jet propagates on the community along short paths, d. For this reason only a small power of noise is absorbed by the air viscosity and the noise impact at ground level is high.

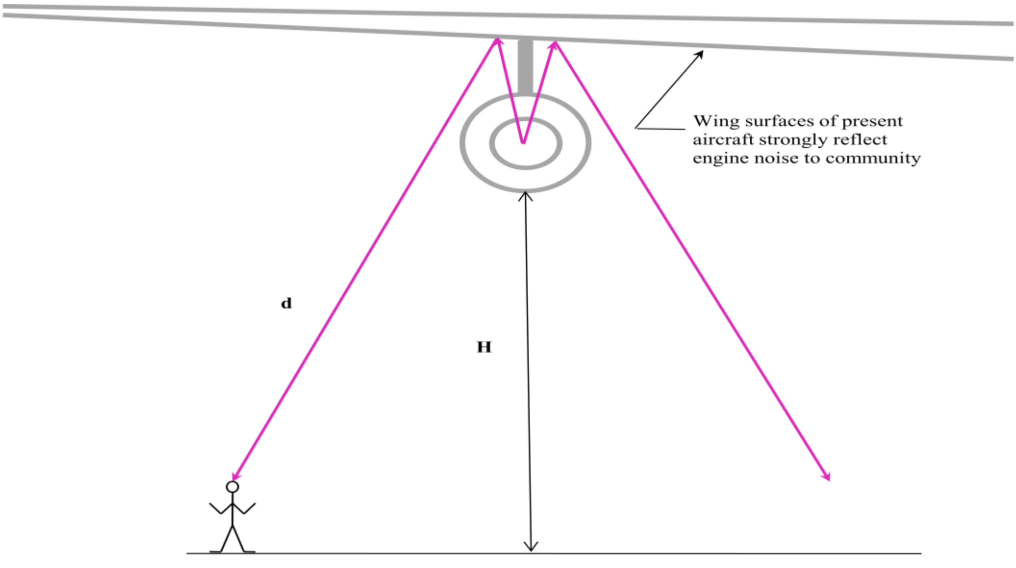

Fig. 7 - At present aircraft jet noise is reflected by wing along short paths, d.

6. APPLYING JUNKERS 52 SOLUTION IN FUTURE AIRCRAFT DESIGNS

Junkers solution can be applied with reasonable costs in future aircraft designs as presented in Fig. 8.

Fig. 8 - Applying of Junkers solution on wings of the future aircraft

Due to corrugations, the noise is scattered at much larger angles than in Fig. 7 and in this way the propagating distance of noise on the community is increased.

As it can be seen, the corrugations are done only in a limited area over engines, i.e. where the intensity of reflected noise has a maximum value.

For scattering of LG noise during flying over, landing or taking off, the lower surface of fuselage can be corrugated, too.

7. EXPERIMENTAL FACTS

The problem of noise scattering produced by corrugations is very complicated from the theoretical point of view [4].

In some practical cases (corrugated auto-tunnels) a 30% noise reduction was measured using sound camera video technique (Fig. 9) [5].

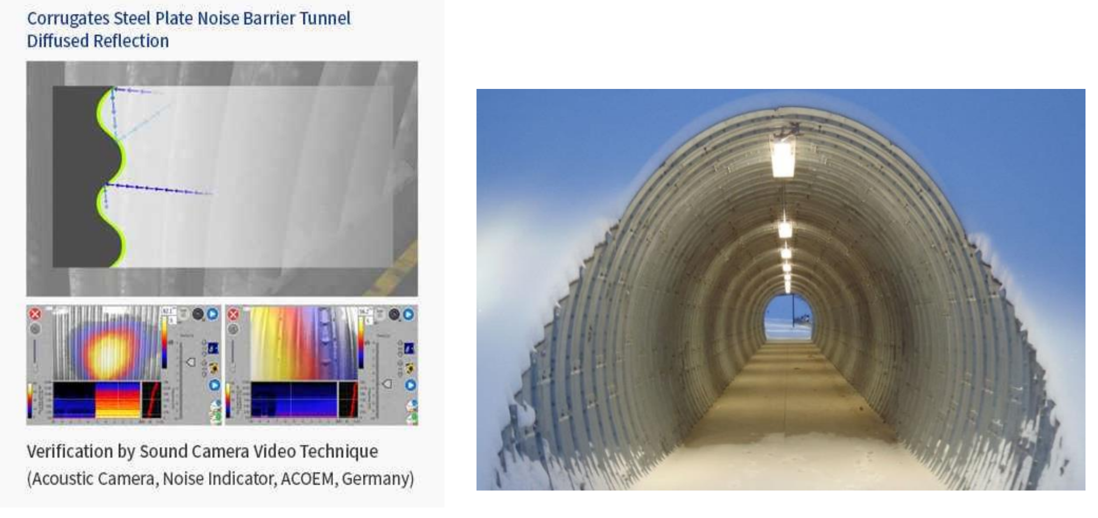

Fig. 9 - Applying of corrugations in auto-tunnels and measurements done with sound camera [5]

Experiments done at very low scale (1:375) on an Airbus A380 wing model done by the company SMCPFA-Bucharest (now SMS-Aerospace-Bucharest) showed a 4 dB noise reduction when a corrugated sheet was applied on the pressure side of wing (Note: the corrugations had a V shape, see Fig.10).

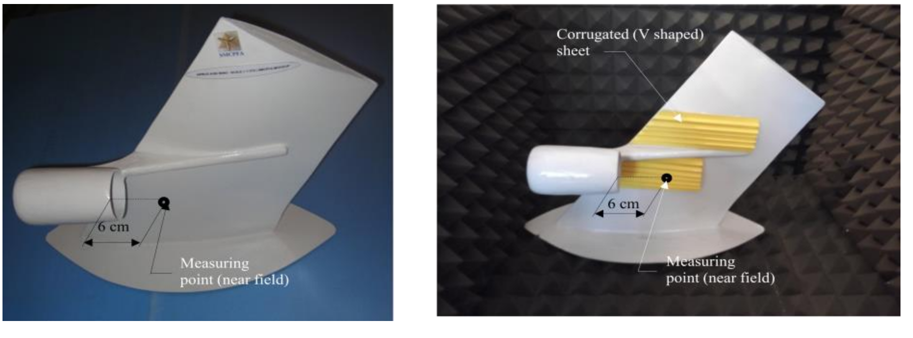

Fig. 10 - Application of V corrugations on pressure side of Airbus wing model (scale 1:375).
(These experiments were done at low scale by SMCPFA-Bucharest (SMS-Aerospace-Bucharest))

During the specified experiment, the noise level measured in near field without applying of V shaped corrugations on pressure side of wing was 82 dB (jet noise + wing reflection). After applying the V shaped corrugations, the noise measured in the same point was 78 dB.
For a better understanding of phenomena, intuitive experiments were done using a concentrated light source (fig.11) and a corrugated reflective surface by the company SMCPFA-Bucharest (now SMS-Aerospace-Bucharest).
The experiments shown that the light is scattered by the corrugated surface and its intensity decreases accordingly.

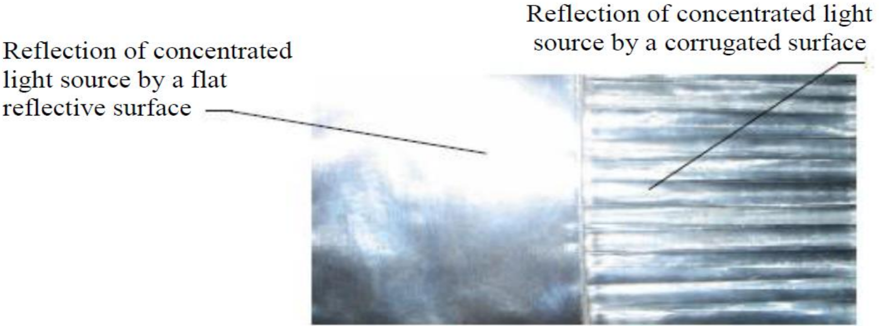

Fig. 11 - Experiments done with a source of light reflected by a flat and a corrugated surface
(These experiments were done at low scale by SMCPFA-Bucharest (now SMS-Aerospace-Bucharest))

Note: It is true that the corrugation could increase in a certain limit the dynamic drag of aircraft due to increasing of the surface area. This problem could be solved as follows: It is known that in some experiments, small fine longitudinal grooves done in the body surface reduced the aerodynamic drag by 10% to 20% (those grooves were aligned with the free air stream [6]). Such grooves could be used to compensate the dynamic drag increasing due to corrugations, i.e. fine longitudinal grooves should be applied on aluminium sheet before its corrugating.

8. THE CASE OF BOUNDARY LAYER INGESTION

The principles of Boundary Layer Ingestion (BLI) are well known. To understand the subsequent proposed solutions, a short presentation of BLI principles is done below (Fig.12) [7].

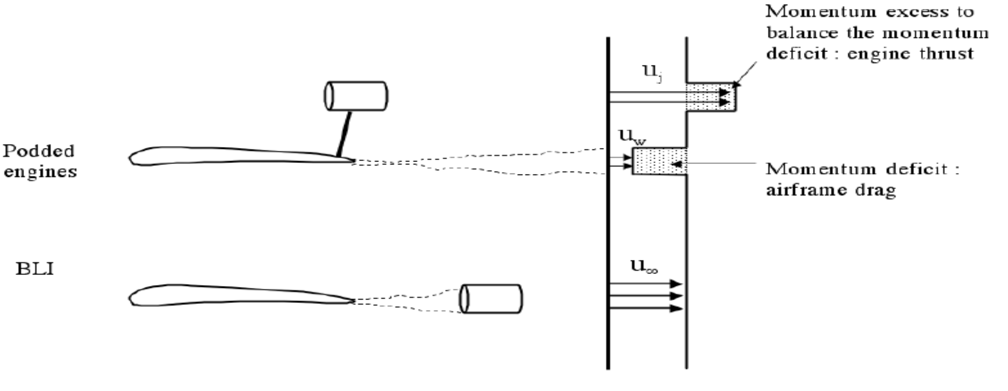

Fig. 12 - Explanation of BLI principles [7]

With present aircraft, the thrust of engines placed under the wings is given by equation (1).

$$F_{engine} = \dot{m}\left(u_j - u_\infty\right) = \dot{m}\left(u_\infty - u_w\right) = D_A \tag{1}$$

where, F_{engine} [N] is the thrust, u_∞ [m/s] is the upstream speed, u_j [m/s] is the engine jet speed, u_w [m/s] is the air speed in wake, m is the engine airflow, D_A is the aerodynamic drag which must be balanced by the engine thrust, F_{engine}.
The necessary power for creating the thrust is given by equation (2)

$$P_{no\ BLI} = \frac{\dot{m}}{2}\left(u_j^2 - u_\infty^2\right) = \frac{F}{2}\left(u_j + u_\infty\right) \tag{2}$$

In the case of BLI, the engine is placed at the tail of the aircraft and it ingests the turbulent wake produced by the fuselage accelerating it at the speed of aircraft, u_∞ (i.e. $u_j=u_\infty$).
In this case the thrust is given by equation (3)

$$F_{engine} = \dot{m}\left(u_j - u_w\right) = \dot{m}\left(u_\infty - u_w\right) = D_A \tag{3}$$

The power consumed in the case of BLI is given by equation (4)

$$P_{BLI} = \frac{\dot{m}}{2}\left(u_j^2 - u_w^2\right) = \frac{\dot{m}}{2}\left(u_\infty^2 - u_w^2\right) = \frac{F}{2}\left(u_w + u_\infty\right) \tag{4}$$

Considering equations (2) and (4), one can see that the necessary power is lower in the case of BLI, obviously because $u_w<u_j$.
In the case of BLI solution created by ONERA (Fig.13), using corrugated fuselage at the fan inlet leads to scattering of the fan noise.

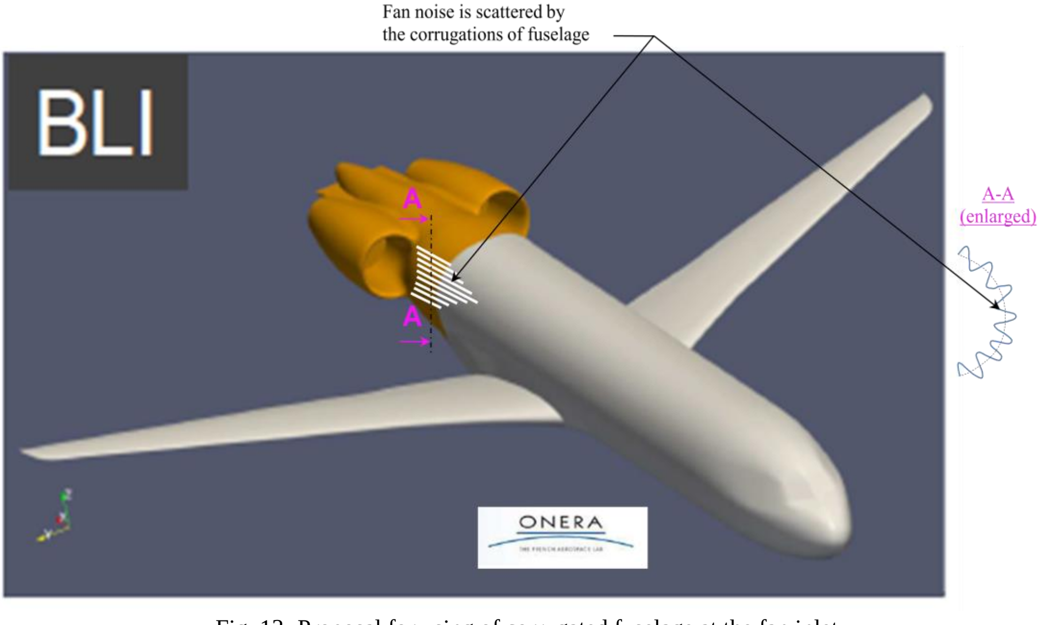

Fig. 13 -Proposal for using of corrugated fuselage at the fan inlet
(BLI solution was created by ONERA)

9. DISCUSSION ON RE-USING JUNKERS SOLUTION IN FUTURE EUROPEAN AIRCRAFT DESIGNS

In future, reusing Junkers solution can lead to:
- Reduction of noise reflected on the community (fan noise, compressor noise, core noise, jet noise and LG noise) due to scattering of noise by corrugated skin of wing and fuselage;
- Reduction of aircraft skin mass because corrugations increase bending strength and thus the thickness of aircraft skin can be reduced.

10. CONCLUSIONS

- Using corrugated skin on wing pressure side, over the engines, leads to scattering the jet noise reflected on the community.
- Measurements done in corrugated auto-tunnels showed a 30% noise reduction due to scattering.
- Experiments done at very low scale using an Airbus A380 wing (scale 1/375) showed that if the wing skin is corrugated the reflected jet-noise decreases by 4 dB (in near field).
- Intuitive experiments done using a concentrated light source showed that light is strongly scattered by a corrugated reflective surface.
- For BLI solution created by ONERA, the fan noise can be scattered if the fuselage skin is corrugated in the front of engines.
- Re-using Junkers solution in future European aircraft designs (mainly on the bottom surfaces of aircraft) is productive for reducing the noise perceived at the ground level and for increasing the aircraft strength.

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