Passenger Spaceplanes and Airplanes that Have Variable Configuration for Sonic Boom Reduction

Constantin SANDU*,[1], Dan BRASOVEANU[2], Valentin SILIVESTRU[1], Bogdan FILIPESCU[3], Radu Constantin SANDU[4]

*Corresponding author
[1]COMOTI – Romanian Research & Development Institute for Gas Turbines, 220 D Iuliu Maniu Ave., 061126, sector 6, Bucharest, Romania, constantin.sandu@comoti.ro*
[2]Systems Engineering Group Inc. (SEG), MD, USA,
[3]Teletrans, Craiova, Romania,
[4]S.C. Structural Management Solutions S.R.L., Bucharest, Romania

DOI: 10.13111/2066-8201.2018.10.2.9

Received: 21 November 2017/ Accepted: 22 January 2018/ Published: June 2018

***Aerospace Europe CEAS 2017 Conference**,*
16th-20th October 2017, Palace of the Parliament, Bucharest, Romania
Technical session & Workshop Aeroacoustics

Abstract: *In the last time, the interest for passenger space plane, supersonic passenger aircraft and supersonic business jets is increasing. For reducing sonic boom effects at ground level, some companies proposed airplanes having fuselage with small traversal section or having curved fuselage. This paper presents a new practical method for exciting vibrations in the leading edge of wing, tail and airplane's nose surfaces in order to scatter the shock wave and to reduce the sonic boom impact at ground level. The leading edges of wing, tail and airplane nose are covered with thin elastic fairings made of carbon fiber composite material which are separated through small gaps by the adjacent surfaces of wing, tail and nose. When the aircraft flies over populated areas, compressed air bleed from the engine compressors excites the vibration of carbon fiber fairings. The air is released through calibrated nozzles and directly impinges on the fairing surface generating their vibration. Thus, the shock waves are scattered and the impact of sonic boom on ground is much reduced.*

Key Words: *sonic boom mitigation, shock wave scattering, boomless aircraft, European business jet*

NOMENCLATURE

L, length of supersonic aircraft, m
M, Mach number, dimensionless
p, pressure, Pa
D', the footprint of 'N' shock wave at ground level without vibration of nose's cone and wing's L.E. surfaces, m
D'', the footprint of 'N' shock wave at ground level with vibration of nose's cone and wing's L.E. surfaces, m
H, flight altitude, m

1. INTRODUCTION

Nowadays, the main aircraft companies are doing efforts to develop spaceplanes, supersonic passenger aircraft and supersonic business jets. An important problem generated by supersonic aircraft is the effect of sonic boom at the ground level. This problem blocked a long time development of supersonic civil aircraft. For reducing sonic boom effects at ground level, Lockheed proposed airplanes having fuselage with small traversal section or having curved fuselage and other designers proposed a biplane type aircraft. Obviously, the curved fuselage strongly perturbs the air stream flowing around the airplane. As a result, more power is required for flight. At the same time, the curved fuselage increases the manufacturing costs of aircraft. In the case of aircraft having small cross section fuselage, obviously the space for passengers is greatly reduced. So, it is very clear that other kind of solutions should be tried for reduction of sonic boom impact on ground. The next points of this paper present such a solution. This solution mainly consists in scattering of shock wave.

2. REVIEW OF SOME SOLUTIONS PROPOSED BY NOW FOR SONIC BOOM MITIGATION

Aerion Corporation (USA) develops a supersonic business jet called Aerion AS2 (fig.1). Program cost 4 billion USD. [1] Simultaneously, Supersonic Aerospace International (SAI) is developing a boomless commercial supersonic business jet (fig. 2), JAXA (Japan) develops a supersonic business jet as presented in fig. 3 and Dassult a business jet as presented in fig. 4. [2]

Figure 1: Aerion AS2 concept

Figure 2: SAI concept

Figure 3: JAXA concept

Figure 4: Dassault concept

As one can see, there are mainly two design directions chosen by designers:

A-Making the aircraft very long and thin
B-Shaping of aircraft nose and fuselage

Figure 5: Thin and long aircraft – Lockheed Martin early concept

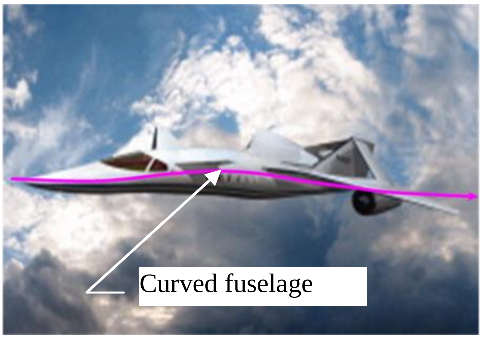

Figure 6: Curved fuselage – Lockheed Martin early concept

In fact, these tendencies were initially launched through Lockheed's and NASA research efforts (fig. 5, 6) [3]. The A & B design directions have some drawbacks which are presented below. In the case A (classic technology, fig. 5), the main drawback is that the aircraft tends to be very long, the transversal area very small and taking off/ landing length correspondingly increases.

A first experiment for testing of design case B was done by Northrop Grumman which modified the nose shape of F-5E aircraft.

In figure 7 it can be observed that shaping of the aircraft nose prevented coalescing of the shock wave all the way to the ground. [4]

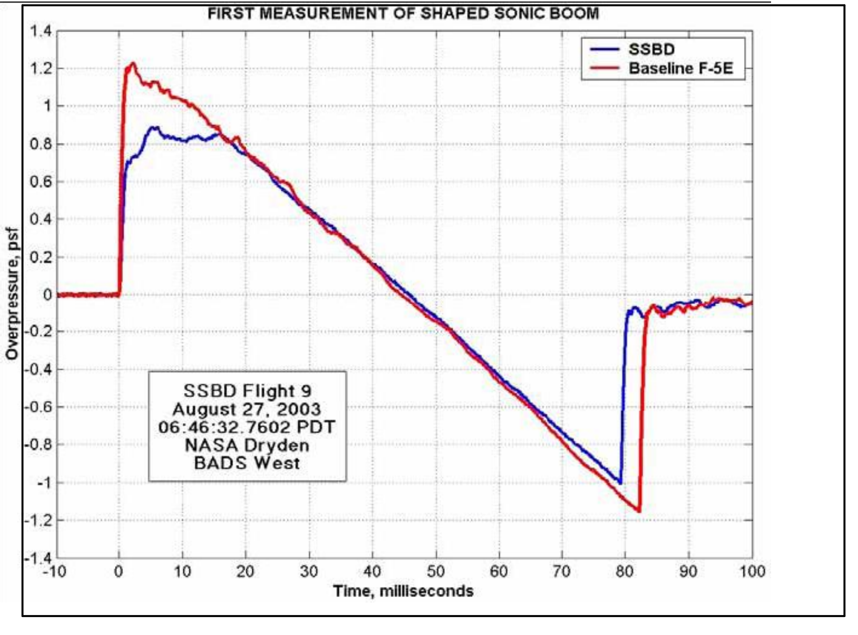

Figure 7: First measurement of shaped sonic boom of F-5E aircraft modified by Northrop Grumman (blue: shock wave after shaping)

Nevertheless, shaping of aircraft nose & fuselage (fig. 6) has the drawback that increases the propulsion power due to the strong deviation of airstream and manufacturing costs because the structure of aircraft is more complicated.

3. IMPORTANT FEATURES OF SHOCK-WAVE WHICH CAN BE USED FOR DESIGNING OF NEW TYPES OF SUPERSONIC AIRCRAFT

In a previous paper the authors mentioned two important features of the shock wave which can be used for reduction of sonic boom effects at ground level: [3]

1-the shock wave is a steady state effect

2-the semi-angle β of shock wave depends not linearly by the semi-angle α of aircraft nose or leading edge of wing.

The first feature is explained by the fact that the aircraft is flying usually with a constant speed. The fixed shape of aircraft nose, wings and tail leads to accumulation of sound waves in the front of aircraft leading to formation of the shock wave in the proximity of M=1. The shock waves of nose, wings and tail coalescence on their way to the ground forming a 'N' shaped pressure wave at ground level (high pressure followed by low pressure) (fig. 8). For example, when aircraft is flying with M≈1.1 at H≈10000m, the pressure step at ground level is $\Delta p \approx 5 kgf/m^2$ [5] and the impact area length D' of shock wave at ground level is about two times the length of aircraft, L.

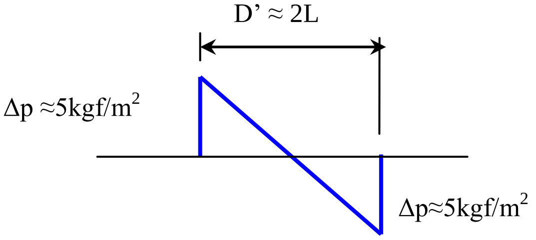

Figure 8: The N shape of sonic boom at ground level

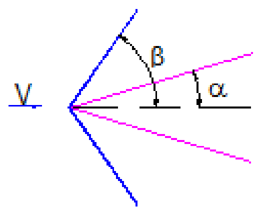

Figure 9: The case of a conical nose of aircraft

The second feature of the shock wave is explained by the equation which correlates the semi-angle α of an aircraft surface (nose cone, wing leading edge angle) relatively to the air stream direction (flight direction) by the position of the shock wave given by the semi-angle β relatively to the air stream direction (fig. 9).

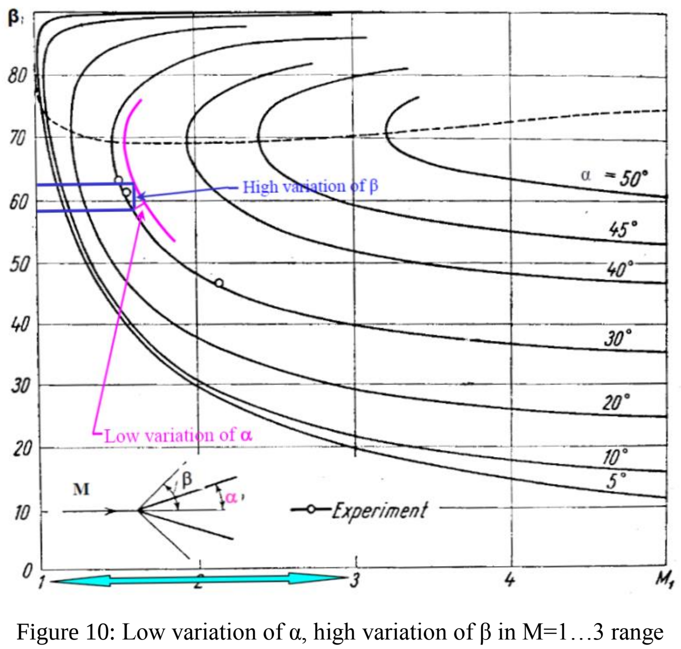

Figure 10: Low variation of α, high variation of β in M=1…3 range

For example, in the case of a cone having the semi-angle α, the second feature is described by the graph from fig. 10 and equation (1). [6]

$$\cot\alpha = \tan\beta\left[\frac{k+1}{2(M^2 sinx^2\beta - 1)} - 1\right] \tag{1}$$

where k=1.4 is the isentropic coefficient for air and M is the Mach number.

In fig. 10, the semi-angle β of shock wave can be found as function of cone semi-angle, α, for a given Mach number M.

It can *e* observed that between M=1...3, the slopes of curves β=f (M) are high for a given value of angle of cone semi-angle, α. This effect is even stronger between M=1…2.

These two features of shock wave can be used for mitigation of sonic boom if an original method is applied.

It is difficult to make the flight of a supersonic aircraft to be non-steady through the variation of speed.

It is easier to change the local geometry of nose and wing's leading edge. This technology is presented in the next point of this paper.

4. THE TECHNOLOGY FOR VIBRATION OF AIRCRAFT NOSE AND WING LEADING EDGE SURFACES

In a previous paper [3], the authors presented a preliminary design solution for scattering of shock wave through vibration of nose's cone surface and wing's leading edge surface. In that solution (fig. 11), the leading edges (L.E.) of wing, horizontal empennage and aircraft nose were covered with thin elastic fairings made of carbon fiber composite material.

When a variable hydraulic pressure is injected in fairing, the angle α has small variation and correspondingly the angle of the shock-wave, β, has small variation, too (fig. 12).

As a result, at ground level, the 'N' footprint of shock wave (D") extends on hundreds of meters instead of two aircraft lengths, in this way impact on community being diminished.

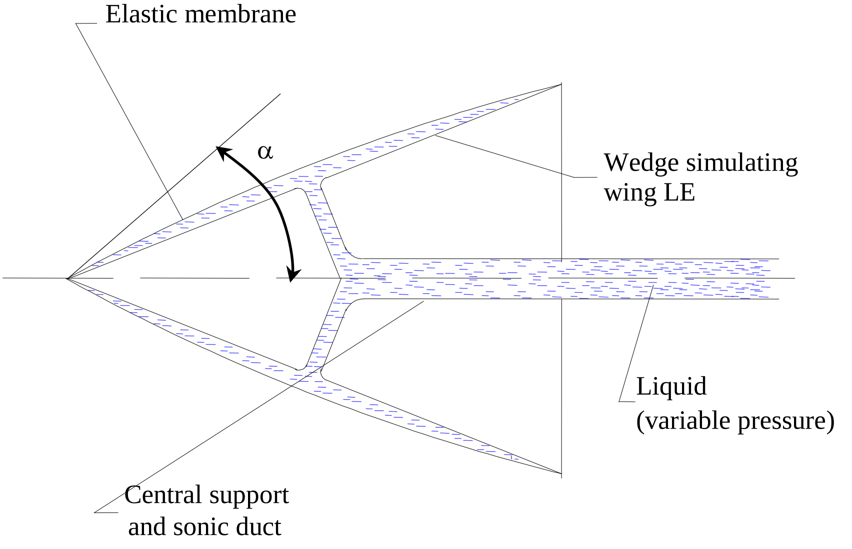

Figure 11: Variation of α at the preliminary design solution

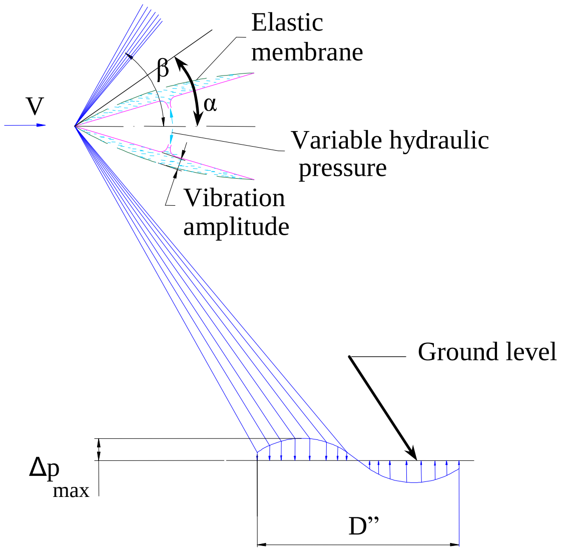

Figure 12: Scattering of shock wave by means of vibration of elastic fairings produced by hydraulic pressure

Obviously, applying of elastic membranes on nose’s cone and wing’s L.E. implies a difficult technology. Instead of that design, a new one can be seen in figures 13 and 14.

Table 1-Variation of β function of variation of α at M=1.6

α	β
10°	51.076°
11°	52.846°
Δα=1°	Δβ=1.77°

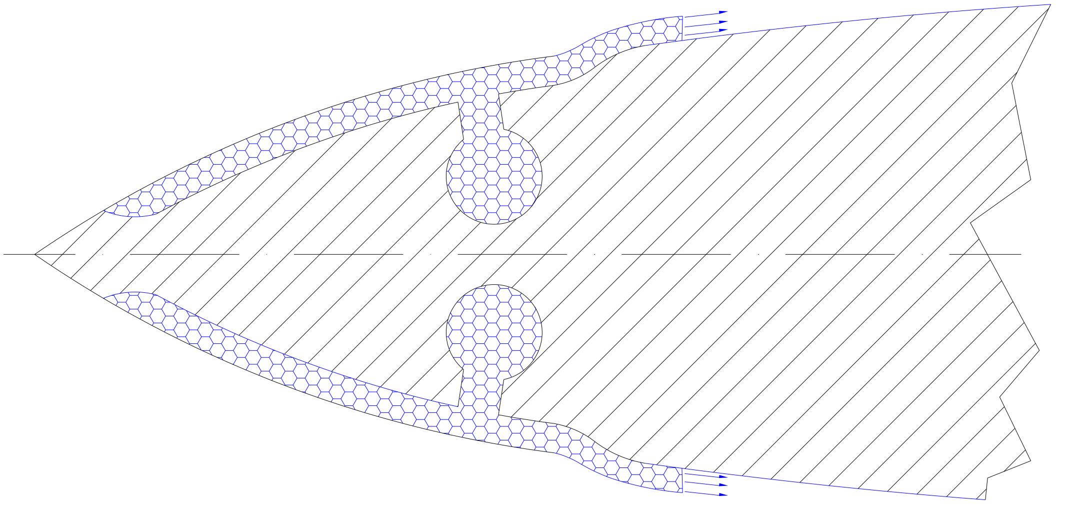

Figure 13: Scattering of shock wave by means of vibration of elastic plates induced by compressed air

This time the membrane is substituted by an elastic fairing made of thin carbon fiber composite fixed by the nose’s cone or by wing’s L.E. When the pressure in the air manifold varies (for example sinusoidal variation with frequency of 10 Hz), local forces appear on elastic fairing determining its vibration. The variation of pressure must be equally to the fundamental vibration frequency of elastic fairing for obtaining of maximum vibration amplitude with a minimum pneumatic power.

In the case of a conical nose having the semi-angle α=10º moving with speed M=1.6, it was calculated using equation (1) that if the semi-angle α oscillates between 10º and 11º, i.e. with Δα=1º, the semi-angle β of shock wave oscillates between 51.076º and 52.846º, i.e. with Δβ=1.77º (Table 1). [3]

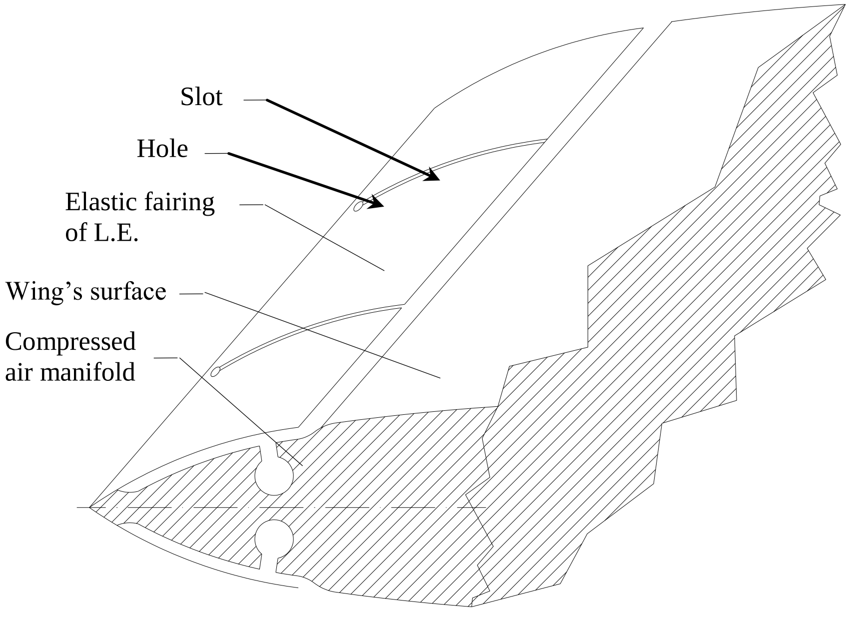

Figure 14: View upwards of a wing L.E. showing elastic fairing design

If the aircraft is 23 m long and is flying at 15000 m with speed M=1.6, the footprint of ‘N’ wave at ground level is about double the length of aircraft i.e. it has about D’=46 m.

For an oscillation with Δα=1º (α=10...11º), the shock wave semi-angle variation is Δβ=1.77º (0.0309rad) and, if the aircraft flies at height H=15 000 m, the shock wave footprint due to scattering at ground level should be:

$$D'' = H \cdot \Delta\beta = 15000 \cdot 0.0309 = 463m \quad (2)$$

i.e. the footprint at ground level is ten times larger than in the case when the surface is not vibrated.

The energy of shock wave is in this way spread on a ground area which is ten times larger than in the case when vibration is not used and obviously impact of shock wave on community is much reduced.

5. CONCLUSIONS

▪The future supersonic business jet could benefit by scattering of shock wave.

▪Mainly, scattering of shock wave is done through vibration of nose’s cone or wing’s L.E.

▪This can be done pneumatically through vibrating of elastic carbon fibre composites surfaces placed on nose’s cone or wing’s L.E.

▪For saving pneumatic power, the frequency of air pulses which pushes the elastic fairing must be equally to the first proper frequency of fairing.
▪The presented solution does not have the drawback of present design solutions: too thin and long fuselage, curved fuselage, high manufacturing price, long taking off and landing distance.

REFERENCES

[1] C. Trautvetter, Aerion SSBJ Now a Trijet with Bigger Cabin, More Range, *Aviation International News*, 20 May 2014.
[2] * * * https://www.flightglobal.com/news/articles/m-as-in-mach-seven-supersonic-business-jet-dreams-412079/
[3] C. Sandu, D. Brasoveanu, *New solution for sonic boom mitigation. Concept and testing methodology. Application at European supersonic business jet*, Proceedings of the 33-rd Caius Iacob Conference-Fluid Mechanics and Technical Applications, September 29-30, 2011, Bucharest, Romania, 2011.
[4] J. M. Morgenstern, A. Arslan, V. Lyman, J. Vadyak, *F-5 Shaped Sonic Boom Demonstrator's Persistence of Boom Shaping Reduction through Turbulence*, AIAA-2005-0012, 43rd AIAA Aerospace Sciences Meeting and Exhibit - Reno, NV, 2005.
[5] E. A. Jr. Haering, J. W. Smolka, J. E. Murray, K. J. Plotkin, *Flight Demonstration of Low Overpressure N-Wave Sonic Booms and Evanescent Waves*, NASA Technical Reports, 2005.
[6] E. Carafoli, *Aerodinamica vitezelor mari*, Editura Academiei Republicii Populare Romane, 1957.