Sonic Boom Alleviation for Next-Generation Supersonic Transport

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Abstract— ***A next-generation supersonic transport (SST) which is expected to be realized in near future has a strong impact on social capability through a high speed transportation and shall activate the industries as well as international cultural exchange. For accomplishment of the next-generation SST, the critical issues of technologies maturity, market viability and environmental acceptability should be overcome. Alleviation of sonic boom is one of the most critical issues as the environmental compatibility of the SST, therefore, sonic boom propagation analysis for boom acceptability assessment and low-boom / low-drag configuration design are presented in the present paper.***

Index Terms— ***Sonic boom, Supersonic airplane***

1. INTRODUCTION

A FORECAST of air traffic demand by JADC (Japan Aircraft Development Corporation) indicates that the RPK (Revenue Passenger Kilometer) in the world in 2026 will be 10,579 trillion which is approximately 2.5 times of the 2006's [1]. In order to satisfy this future passenger demand, many kinds of air traffic including high-speed and/or large amount of transportation are needed.

A supersonic transport (SST) is effective and important for high-speed transportation. Although the "Concorde" was firstly operated commercially in 1976, it was retired on 2003 due to deficiency of cost and environmental acceptability. However, development of the next-generation SST has been required for satisfaction of the above passenger demand on the basis of technology innovation through the lessons-learned with the "Concorde". If there is an SST which connects North America, Europe and Asia of dense population in 5 or 6 hours, it brings more benefit to the society [2].

In Japan, SJAC (The Society of Japanese Aerospace Companies, Inc.) and JAXA (Japan Aerospace Exploration Agency) have continued a feasibility study of the next-generation SST [2], [3] (Fig. 1).

It is recognized that the next-generation SST should be realized by overcoming the critical issues of technologies accomplishment, market viability and environmental compatibility. In this paper, sonic boom alleviation is focused as one of the critical environmental issues.

Figure 1: Image of the next-generation supersonic transport [3]

2. SONIC BOOM RESEARCH AND DEVELOPMENT

A sonic boom is caused by the sudden pressure increase on the ground which is due to the shock waves by an airplane in supersonic flight. The shock waves generated by airplane accumulate into the so-called "N-wave" in the far-field during the propagation. The over-pressure of N-wave gives severe influence on the human beings and animals on the ground, therefore its reduction should be required.

Two approaches to sonic boom issues are considered: (1) Boom acceptability assessment with wave propagation study, and (2) Design of optimized airplane configuration with low-boom and low-drag character. Since the sonic boom regulation shall be defined by ICAO in future, it is necessary to accumulate the data and propose to international community [4].

2.1 Sonic Boom Propagation Analysis

The typical analysis code of sonic boom is the Thomas waveform parameter method [5]. In order to apply the wave propagation methods to estimate the pressure distribution on the ground for the actual airplane configuration, it is necessary to obtain the accurate near-field pressure data either by a wind tunnel test or by a computational fluid dynamics (CFD).

The waveform parameter method is based on the principle that pressure wave is constituted by the appropriate numbers of wave element and represented by the following set of equations as

$$\frac{dm_i}{dt} = c_1 m_i^2 + c_2 m_i \qquad (1)$$

$$\frac{d\Delta p_i}{dt} = \frac{1}{2} c_1 \Delta p_i \left(m_i + m_{i-1} \right) + c_2 \Delta p_i \qquad (2)$$

Manuscript received February 4, 2007.

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$$\frac{d\lambda_i}{dt} = -\tfrac{1}{2}c_1\left(\Delta p_i + \Delta p_{i-1}\right) - c_2 m_i \lambda_i \qquad (3)$$

where

$$c_1 = \frac{\gamma+1}{2\gamma}\frac{a_0}{p_0 c_n} \qquad (4)$$

$$c_2 = \tfrac{1}{2}\left(\frac{1}{p_0}\frac{d\rho_0}{dt} + \frac{3}{a_0}\frac{da_0}{dt} - \frac{2}{c_n}\frac{dc_n}{dt} - \frac{1}{A}\frac{dA}{dt}\right) \qquad (5)$$

and m_i is pressure gradient at the i-th region of wave, Δp_i is pressure difference over shock wave between the i-th and the (i-1)-th wave element and λ_i is time duration of the i-th wave element(= ΔT).The properties p,ρ,t,a,A,c_n,γ are pressure, density, time, sound velocity, wave ray area, wave surface speed at normal direction and specific heat of air. Suffix 0 denotes the properties at surround of wave surface.

Kubota et al have continued the propagation analysis with use of Thomas waveform parameter method since 1990 [4]. Yamada calculated the far-field boom signature under the condition of Mach 2, angle of attack of 0 degree, airplane length of 66.7 m, flight altitude of 18.9 km with steady flight in no-wind, standard atmosphere [4].

As a flat-top type sonic boom signature is moderate to the response of human beings rather than the sharp N-shaped type [6], the trapezoidal (flat-top type) pressure distribution is applied at the near-field. It is found that, even for the flat top-type near-field pressure distribution, it is reduced to N-type far-field signature when its peak pressure is high (Fig.2). It means that the peak pressure at the near-field should be suppressed in lower level even if the wave form is non N-type.

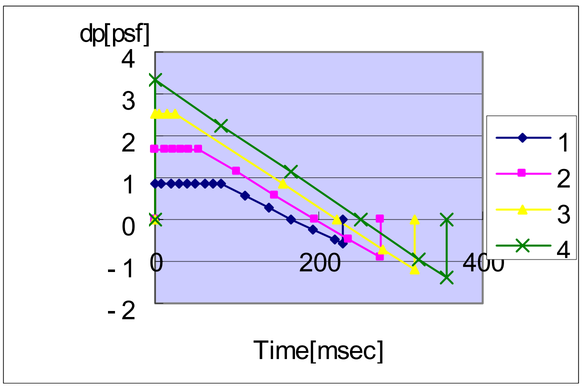


Fig. 2 Sonic boom signature calculated by Thomas waveforrm parameter method [4]

2.2 Low-boom / Low-drag Configuration Design

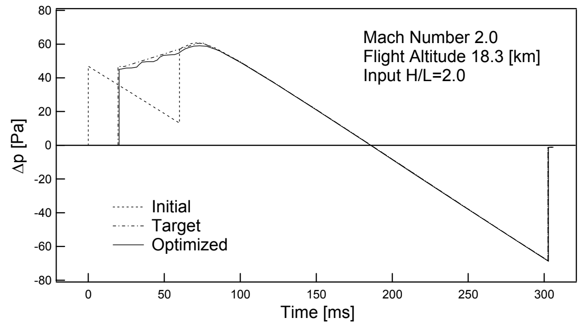
2.2.1 Optimization by Inverse Method

Makino, Kubota et al proposed the inverse method for the targeted ramp-type sonic boom signature with use of both of optimization theory and Thomas waveform parameter method and obtained the optimized fuselage configuration to generate the desired near-field pressure distribution. It is found that the change of fuselage shape can bring the desired boom signature [7].

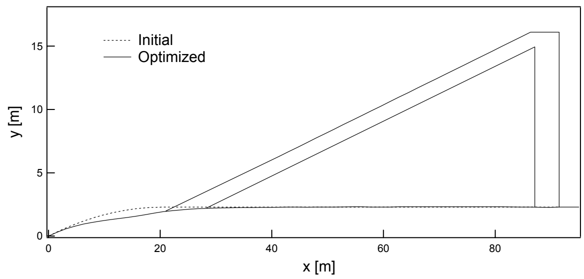
Makino et al also discussed the effects of non-axisymmetrical fuselage design for low-boom and low-drag for the application to a scaled supersonic experimental airplane program, NEXST with jet engine nacelle by JAXA [8].

2.2.2 Airplane Configuration with Oblique Wing

It is known that the oblique wing airplane can reduce the aerodynamic drag in supersonic flight. This shape also has a possibility to alleviate sonic boom. It is shown that the boom intensity can be reduced rather than the arrow wing of the same wing area by the wind tunnel experiment [9].



(a) Ground sonic boom signature



(b) Optimized fuselage configuration

Fig. 3 Optimized airplane configuration for sonic boom reduction [7]

3. Conclusion

The founding for sonic boom alleviation as one of the important environmental issues for accomplishment of the next-generation SST were presented on the standpoint of boom acceptability assessment with wave propagation study and design of optimized airplane configuration with low-boom and low-drag characteristics.

Those studies will surely contribute to realization of the next-generation SST. JAXA is starting a 5-years project of “Quiet Supersonic Airplane Technologies” in 2007 for sonic boom reduction to one half of the present.

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