8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Aerodynamic Design of Supersonic Biplane Wing with Complicated Interference Using Inverse Problem Method

***Daigo Maruyama[1], Kisa Matsushima[2], Kazuhiro Kusunose[3] and Kazuhiro Nakahashi[4]**

[1] Tohoku University
6-6-01, Aramaki-Aza-Aoba, Aoba-ward, Sendai, 980-8579, JAPAN
daigo@ad.mech.tohoku.ac.jp

[2] Tohoku University
6-6-01, Aramaki-Aza-Aoba, Aoba-ward, Sendai, 980-8579, JAPAN
kisam@ad.mech.tohoku.ac.jp

[3] Technical Research and Development Institute, Ministry of Defense, Tokyo, 190-8533, JAPAN
kusunose@cs.trdi.mod.go.jp

[4] Tohoku University
6-6-01, Aramaki-Aza-Aoba, Aoba-ward, Sendai, 980-8579, JAPAN
naka@ad.mech.tohoku.ac.jp

Key Words: *CFD, Aerodynamic Design, Inverse Problem Method, Supersonic, Biplane.*

ABSTRACT

There is a concept of Busemann biplane [1] which has possibility of realizing low-boom and low-drag supersonic flight. The theory is to interfere with shock waves and expansion waves between two wings. It was established by *Adolf Busemann* in 1935. However, much progress for practical use did not conducted. The concorde, which was the only supersonic transport (SST), finished service in 2003. It is required to propose a new generation SST. In this paper, verification of an inverse problem method [2] based on the theory of oblique shock wave to supersonic biplane wings and its application for practical designs to obtain high *Lift to Drag (L/D)* at sufficient lift conditions.
The design method determines 2-D airfoil geometry with the help of the local oblique shock relation; that is, $C_p = c_1\theta + c_2\theta^2$, where $c_1 = \frac{2}{\sqrt{M_\infty{}^2 - 1}}$, $c_2 = \frac{\left(M_\infty{}^2 - 2\right)^2 + \gamma M_\infty{}^4}{2\left(M_\infty{}^2 - 1\right)^2}$
θ represents the local flow deflection angle. c_1 and c_2 are the Busemann coefficients. In the sense of airfoil geometry, θ implies ($\frac{df(x)}{dx} - \alpha$), where f(x) represents an airfoil contour curve. The inverse design system uses the small perturbation form [2] of the second order equation to relate pressure to local flow deflection angles. On designs of some 2-D monoplanes, it was confirmed that arbitrary monoplanes converged on target ones within several repetitions of the design cycle. Here, it was examined whether a 3-D tapered biplane wing converged on target geometries by setting up a known C_p distribution as target ones at some span stations. In case of 3-D designs, there are Mach cone effects around wing tips and wing symmetry sections. As shown in Fig. 1, the wing, the upper element of which is a flat plate and the lower one of which is the wing of a Busemann biplane, was set to an initial wing configuration. The result C_p distributions at 10 span stations from the wing root (represented as *y/b*=0, *b* means semi-span length) to the 90% span station (*y/b*=90%) of the upper wing of the Busemann biplane were given as target C_p distributions. The wing tip configuration on

each iteration is defined by using a similarity of its 90% wing configuration. As a flow solver, TAS-code [3] was used and the Euler equations are solved. About 0.55million points' mesh was used on each iteration.

Figure 2 and Table 1 show obtained C_p distributions and geometries and absolute RMS (root mean square) errors after 14th iteration. It has been confirmed that the simple inverse problem method is capable of performing the aerodynamic design of the 3-D biplane wing shape where airfoil geometries are changed along the span direction and two airfoil elements interfere with each other. C_L (lift coefficient) and C_D (drag coefficient), which are one of the most important factors, of the designed wing were successfully converged on those of the original Busemann biplane wing. Obtained C_L and C_D are 0.000 and 0.00310 respectively. They agree well with those of the target wing (C_L=0.000, C_D=0.00310). High L/D wings will be presented by applying the inverse problem method to Busemann biplane wing.

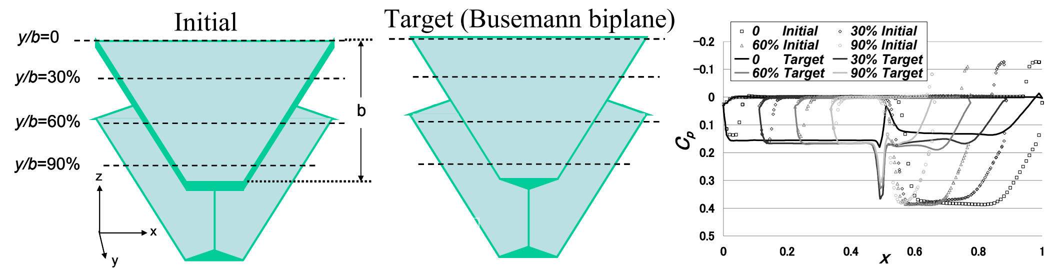

Fig. 1 Simple diagrams of initial configuration and C_p distributions, tapered Busemann biplane and its C_p distributions as target ones (Only 0, 30%, 60%, 90% of y/b are shown.).

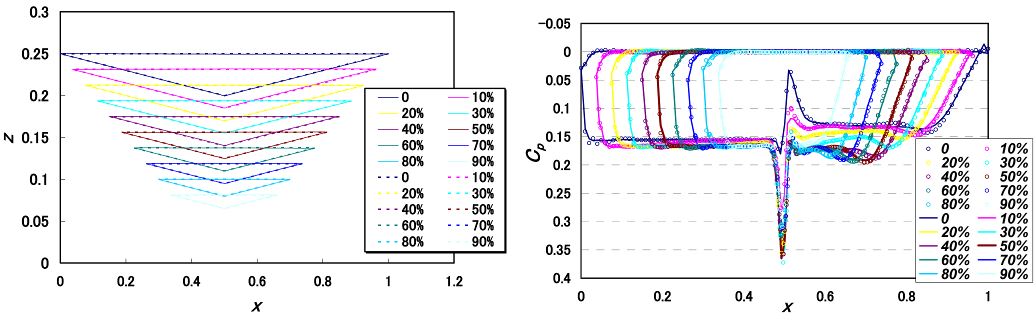

Fig. 2 C_p distributions and geometries at some sections of designed wings after 14th iteration (Real lines and broken ones show obtained and target, respectively.).

Table 1 Absolute RMS errors between the realized and target C_p distributions at each section.

(y/b)	0	10%	20%	30%	40%	50%	60%	70%	80%	90%
RMS($*10^{-4}$)	1.35	1.74	1.41	1.79	1.41	1.90	1.54	1.51	2.14	1.82

REFERENCES

[1] Kusunose K. et al., "A fundamental study for the Development of Boomless Supersonic Transport Aircraft," AIAA paper, AIAA-2006-0654.

[2] Matsushima K. et al., "Numerical Modeling for Supersonic Flow Analysis and Inverse Design," Lectures and Workshop International -Recent Advances in Multidisciplinary Technology and Modeling-, SS05-2.1, May, 2007, Tokyo, Japan.

[3] Nakahashi K. et al, "Some Challenge of Realistic Flow Simulations by Unstructured Grid CFD," International Journal for Numerical Methods in Fluids, Vol.43, 2003, pp.769-783.