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

APPLICATION OF PARSEC GEOMETRY REPRESENTATION TO HIGH-FIDELITY AIRCRAFT DESIGN BY CFD

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Key Words: *CFD, Aerodynamic Design, Wing, Parametric Geometry Representation.*

ABSTRACT

Nowadays high performance aircraft designers are interested in high-fidelity design using CFD (computational fluid dynamics). One of the high-fidelity design challenges is Japanese SST (Supersonic Transport) project which has realized an innovative SST with NLF (natural laminar flow) wings in 2005 [1]. The SST is called NEXST-1. Figure 1 shows NEXST-1 and the grid distribution around wing-fuselage model for CFD. The wing design procedure is described in Fig.2. It is iterative and contains Navier-Stokes flow analysis and inverse problem design. To realize high-fidelity design, detailed shape control using many points to define airplane geometry is required. In fact, for NEXST-1 design, 20200 (200x101) control points were used to modify wing surface geometry to attain an NLF wing. The inverse problem can computationally determine geometry of 20200 points in one hour. On the other hand, for a CAD process which integrates designed wings and other elements into an airplane, geometry definition using many points may cause difficulty. In addition the CAD operation is manually conducted, therefore the CAD process usually requires extremely long time. For the NEXST-1 case, it took 3.5 days (see Fig.2).

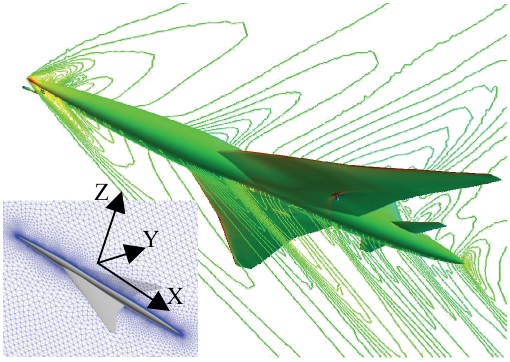

Fig. 1 NEXST-1 Flying at Mach 2.0.

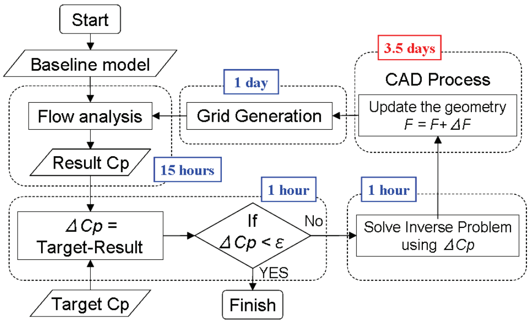

Fig. 2 Iterative Inverse Design Procedure.

In this article, aiming to eliminate the work load in CAD process, the idea of PARSEC [2] geometry representation is applied to wings shape definition. The PARSEC method was devised by Prof. Sobieczky. It represents an airfoil shape as a polynomial function using eleven coefficients [2]. Later, he and his group improved the method and named it as PARSEC13 [3]. Here, the objective is to precisely represent the SST wing, which is the set of grid point coordinate values, by analytical functions. As a result, the wing geometry can be represented by the following polynomial functions (Eqs.(1)-(3)) within 1% l_2-norm error.

The upper and lower wing surfaces are expressed as $Z=f_+(X,Y)$ and $Z=f_-(X,Y)$, respectively. X is chord-wise and Y is span-wise directions. Then f is expressed as the combination of a camber *Zc* and thickness distribution *Zt*.

$$f_{\pm}(X,Y)=Z_c(X,Y)\pm Z_t(X,Y) \qquad (1)$$

$$Z_c(X,Y)=a_0(Y)X^{\frac{1}{2}}+\sum_{n=1}^{6}a_n(Y)X^n \qquad (2) \qquad Z_t(X,Y)=b_0(Y)X^{\frac{1}{2}}+\sum_{n=1}^{5}b_n(Y)X^n+b_6(Y)X^{\frac{3}{4}} \qquad (3)$$

The wing section airfoil shape at the span station Y_0 is $f(X, Y_0)$. To express f as a polynomial function we apply the PARSEC method. For the precise representation of the NEXST-1 wing section, two modifications have been made on the PARSEC method. The first modification is that airfoil geometry (Z) is decomposed to camber (Zc) and thickness (Zt) as shown in Fig.3. Then, PARSEC is applied to Zt. In this application, the second modification is introduced. We add a parameter which indicates one Zt-X relation between the leading edge and the crest. This parameter is special because its X location (X_{add} in Fig.3) is not fixed, but optimized by parametric study during the PARSEC process. The polynomial expression of Zc is obtained by the least square approximation. Therefore, Eqs.(2) and (3) are obtained at each span station. The set of 200 point coordinate values can be almost perfectly represented in a function form which uses 14 parameters for a wing section airfoil. Next, the coefficients of X^n terms, $a_0(Y) - a_6(Y)$ and $b_0(Y) - b_6(Y)$ at each span station are considered. There are 101 sections in a half span wing. Aiming to functionalize the coefficients, their distribution along span-wise direction has been adjusted by using the Bezier curve (Bernstein function). That does not cause noticeable change in a section airfoil shape (see green and pink solid lines in Fig 4). Finally, flow analysis about the SST has been conducted to compare the wing surface pressure (Cp) distributions of original and represented shapes. In Fig. 4, results at 50% half span station are shown. It can be seen that the mathematically represented shape and its Cp distribution correspond very well with originals. It is also found that the function representation smoothen unnecessary roughness. The total computational time for the polynomial representation of the wing is only 150 seconds with a single processor PC of Itanium 1.6GHz.

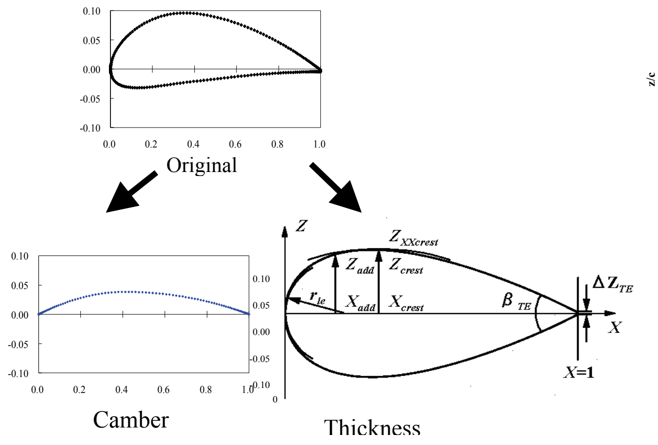

Fig. 3 Modified PARSEC Representation.

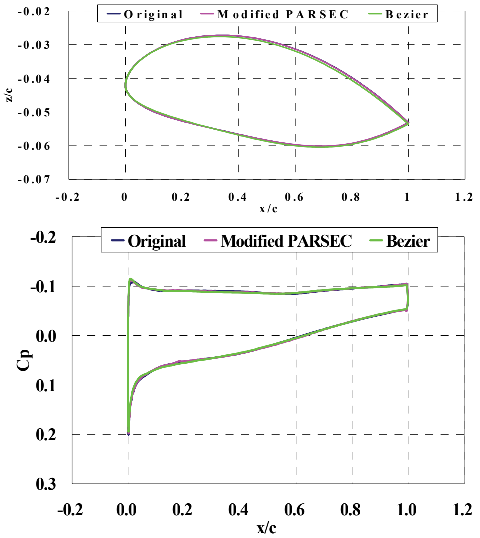

Fig. 4 Comparison regarding geometry and Cp distribution.

The method is not perfect, yet, for the wide range of application. It is being examined and improved for the precise geometry representation of practical wings and other fluid elements. At the conference, the improved version of the method and its results will be shown.

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