Chapter 5
Supersonic Wing Design Optimization Based on Evolutionary Algorithm

5.1 Introduction

Commercial aviation has grown remarkably with the development of the world economy during the last half-century. The growth in air traffic is supposed to continue well into the 21st century with increased demands for more efficient aircrafts such as supersonic transport (SST).

Concorde [1] is the only supersonic airliner currently available for passenger service. Although Concorde is a great achievement from the technological point of view, it doesn't succeed in business very well. The most important limiting factor in the commercial success is its high operating cost. In addition, Concorde has some environmental concerns such as sonic boom, air pollution, and noise at takeoff and landing. Therefore, considerable improvements are required for the next generation SST. Several research projects have been performed worldwide [2-7].

In this chapter, an EA will be applied to an aerodynamic wing shape design for a supersonic transport. The purpose of this study is to examine the feasibility of the EA-based optimization in supersonic wing design optimizations. Structured-coding-based crossover operator developed in Chap.3 will be used.

This chapter is organized as follows. Section 5.2 shows formulation of the present design problem. Section 5.3 describes the detail of the present EA. The design results are shown in Section 5.4.

5.2 Formulation of Optimization Problem

In this study, a supersonic wing shape is optimized at the supersonic cruise design point. The cruising Mach number is set to 2.3. The objective of the present design problem is to maximize the lift-to-drag ratio *L/D* at a required lift coefficient C_L maintaining substantial wing thickness. The optimization problem is defined as follows: the objective function to be maximized is *L/D* at $C_L = 0.1$ with the constraint thickness to chord *t/c* ? 0.35. The aerodynamic performance is evaluated by using the CFD code described in Sec. 4.4.

In the present optimization, the geometric angle of attack at wing root a_{root} is changed so that C_L becomes 0.1 based on the lift coefficient varying linearly:

$$(a_{root})_{CL=0.1} = \left(\frac{(C_L)_{SPECIFIED} - (C_L)_{a=a1}}{(C_L)_{a=a2} - (C_L)_{a=a1}} \right) (a_2 - a_1) + a_1 \qquad (5.1)$$

where a_1 and a_2 are set to 3 and 5 degrees, respectively. This approach requires two extra flow evaluations.

Planform is assumed to be a double-delta wing similar to the NAL scaled supersonic experimental airplane (Fig. 5.1). Wing profiles of design candidates are generated by the extended Joukowski transformation. These extended Joukowski parameters and the twist angle will be given at eight span sections, of which spanwise locations are also treated as design variables except for the wing root and tip locations. Wing geometry is then interpolated in spanwise direction by using the second-order Spline interpolation. Parameter ranges of the design space are shown in Table 5.1.

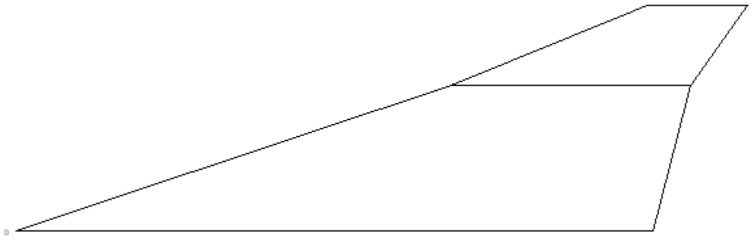

Fig. 5.1 Wing planform

Table 5.1 Parameter ranges of the design space

parameters	x_c	y_c	x_t	y_t	Δ	twist angle
upper-bounds	0.00	0.10	1.050	0.05	0.8	10 deg.
lower-bounds	-0.10	0.00	1.000	-0.05	0.0	-5 deg.

5.3 Optimization Using EA

The present EA uses non-overlapping system coupled with the elitist strategy. The best and the second best individuals in each generation are preserved. The parental selection consists of the SUS and the ranking method using Michalewicz's nonlinear function. Offsprings are produced applying one-point crossover based on the structured coding and evolutionary direction operator at a ratio of 7 to 3. Mutation takes place at a probability of 10% and then adds a random disturbance to the corresponding gene in the amount up to ± 10% of each parameter range shown in Table 5.1. The population size is kept at 64 and the maximum number of generations is set to 50. The initial population is generated randomly over the entire design space. The adaptive search range strategy described in Chap. 2 was not used because this study was conducted before the development of the real-coded ARGAs.

The constraint of minimum thickness is satisfied by using abortion strategy. When a child violating the constraint is produced from a pair of parents through crossover and mutation, reproduction of the child is canceled and then another pair of parents is selected until a satisfactory design candidate is reproduced.

Sixty-four PEs of NWT are used to parallelize the evaluation using the master-slave concept. In the present case, each CFD evaluation takes about 1 h of CPU time (for three Euler evaluations) on a single PE.

5.4 Results

Because the wing planform is fixed and the viscous drag primary depends on the planform area, inviscid calculations are used for the present aerodynamic evaluations. The total drag evaluated here consists of the volume wave drag, the lift dependent wave drag, and the induced drag. Among the three drag components, the lift dependent wave drag primary depends on the planform. Therefore, a design that achieves the minimum volume wave drag and the minimum induced drag will ensure the feasibility of the present approach.

The optimization history of the present EA is shown in Fig. 5.2 in terms of C_D. The design has drag coefficient of 77.7 counts and *L/D* of 12.83. Because the evaluation takes about 1 h per generation, the optimum is obtained in 50 h

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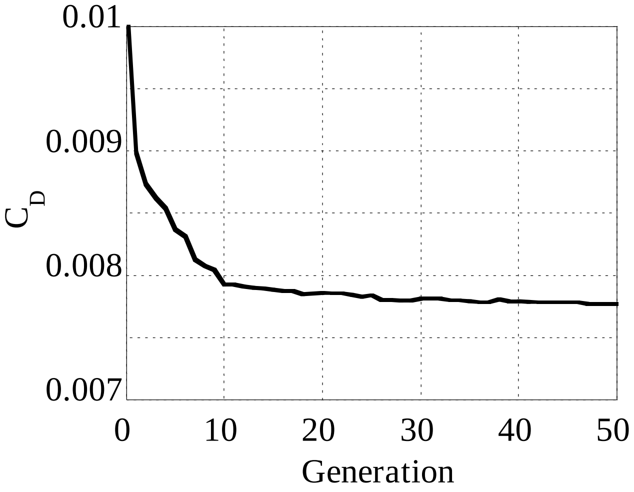

Fig. 5.2 Optimization history

Figure 5.3 compares the spanwise loading distribution of the designed wing with a parabola that is known to give the minimum induced drag when the structural constraint is considered [8]. The parabolic load distribution indicates that the design achieves the minimum induced drag.

The optimized airfoil sections and the corresponding pressure distributions at the 0, 33, and 66% spanwise locations are shown in Fig. 5.4. The designed wing increases the camber toward the wing tip to increase c_l. This helps to yield the parabolic load distribution to achieve the minimum induced drag. On the other hand, the airfoil thickness becomes as thin as possible in the given design space to minimize the volume wave drag, as expected. The plot is not shown here, because the thickness is simply 3.5% to the chord.

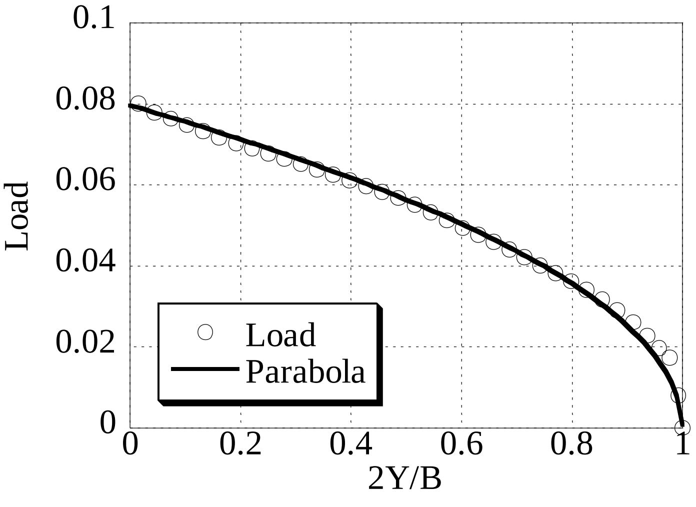

Fig. 5.3 Spanwise load distribution of the designed wing

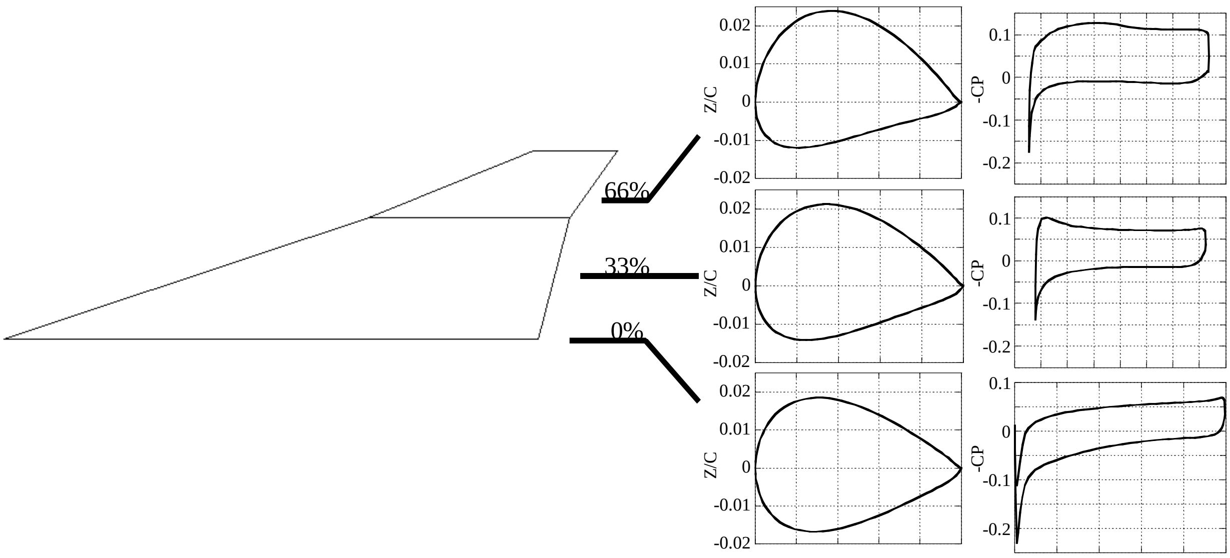

Fig. 5.4 Optimized airfoil sections and the corresponding pressure distributions

Figure 5.5 illustrates the spanwise twist angle distribution and its control points of the designed wing. Geometric angle of attack is set to 5.63 degrees to have C_L of 0.1. Remarkably, three control points are located near the kink at the 60% spanwise location so that the wing twist reduces from 2.5 degrees to 0.5 degree rapidly. The spanwise twist angle distribution varies drastically here while the spanwise load distribution shown in Fig. 5.3 is surprisingly smooth. Resultant pressure contours on the upper surface of the wing is depicted in Fig. 5.6.

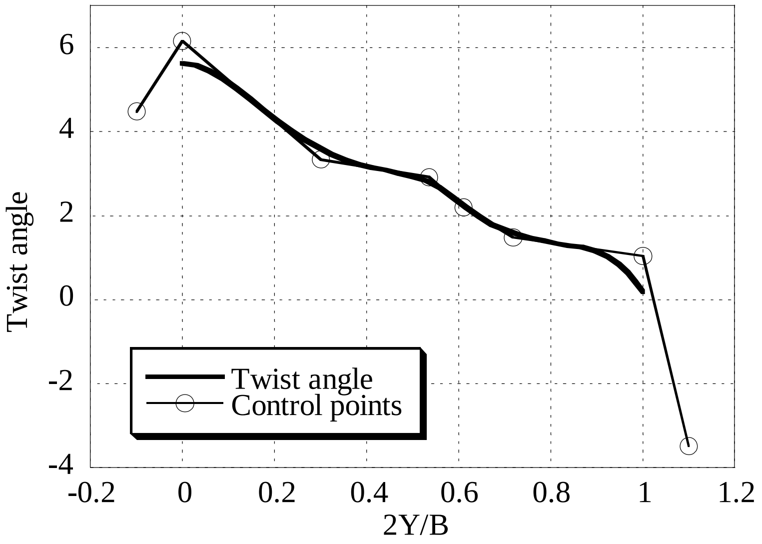

Fig. 5.5 Spanwise twist angle distribution and its control points

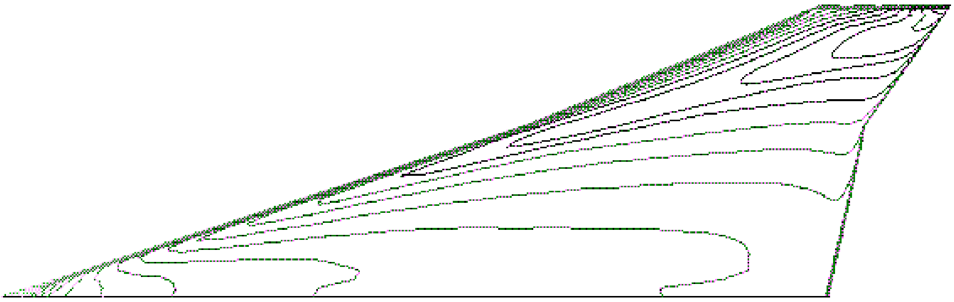

Fig. 5.6 Pressure contours on the upper surface of the wing

5.5 Summary

To ensure feasibility of EAs in supersonic aerodynamic design optimizations, an EA coupled with an Euler code has been applied to a supersonic wing shape design. To overcome enormous computational time necessary for the optimization, aerodynamic evaluations are distributed to the PEs of NWT. Parallelization of EA on NWT is straightforward, and its performance is extremely good in reducing the turnaround time.

The optimum design obtained from the present approach yields both the minimum induced drag and the minimum volume wave drag in the given design space. This indicates the feasibility of the present approach for aerodynamic design of supersonic transport.

In addition, the present study indicates the most important features of supersonic wing design as compared with conventional transonic wing design as follows:

1) Warp geometry based on camber line and twist angle distributions plays a more important role than spanwise thickness distribution. In the present design, the thickness became simply as thin as possible.
2) Because the wing thickness constraint comes from the wing structure, a more practical structural constraint will be required.

References

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