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AERODYNAMIC OPTIMIZATION OF MULTI-ELEMENT AIRFOILS BY GENETIC ALGORITHMS

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Abstract. Multi-element airfoils design determines the performance of the high-lift devices for civial aviation aircrafts to a large degree. To optimize the multi-element airfoil design, the paper presents an effective method. One advanced、time efficient optimization method for multi-elment airfoils is developed by combining OULER with boundary layer correction(MSES) and the genetic algorithms(GA). Given objects and constraints, the gap, overlap and deflection can be optimized. Detailed research is done on one takeoff configuration . The CFD analysis show that the optimization is successful in improving the performance. This method has been used to design takeoff/landing configurations. Most results are validated by windtunnel tests.

1. NOMENCLATURE

M — free stream Mach number
Re — Reynolds number
α （alpha） — attack angle
o/l — overlap
gap — the slot gap width
δ_S — the slat deflection angle
δ_f — the flap deflection angle
C_l — sectional lift coefficient
C_d —sectional drag coefficient
C_m —sectional moment coefficient

2. INTRODUCTION

For the complexity of multi-element airfoil aerodynamic simulation, it's hard to get the explicit expressions and analyse the sensitivity. While traditional optimization methods need sensitivity information, so it's not very fit for multi-element airfoil aerodynamic simulation. On the other hand, flow simulation may fail for some reason, traditional optimization may lead the search to be failed. Compared with traditional methods, GA is more effective.
To do this work, time efficient and high precision CFD method should be coupled with GA method. After testing kinds of 2D methods for multi-element airfoil, we decide to use MSES(developed by Professor Drela)[1,2], for it is one of the most successful viscous/inviscid interaction methods for multi-element airfoil and its streamline grid generation is fast.
By coupling GA with MSES, we successfully optimize the slat/flap position of a three-element airfoil on given constraints.

3. THE NECESSITY TO OPTIMIZE MULTI-ELEMENT AIRFOIL

Efficient high-lift system can provide adequate low speed performance in terms of take-off and landing lengths, approach speed, climb rate, etc. The high-lift device aerodynamic design must be aimed at finding an acceptable compromise between the maximum lift coefficient in landing configuration, lift capability and L/D efficiency at take-off and the needs for re-take-off configuration by multi-disciplinary optimization[6]. For civil aircraft, because of the small sweepback and quite big aspect ratio, the design of 2D multi-element aerofoil is very important in high-lift system design[4,5]. The performance of two-dimensional multi-element airfoil differs from three-dimensional high-lift system, but fine 2D design is the base of the success of high-lift system design for transport aircraft, which can shorten the periods of three-dimensional design and analysis. Because 2D multi-element airfoil optimization is more feasible, we concentrate on developing efficient and global optimum methods for multi-element airfoils.

4. THE ADVANTAGES OF GENETIC ALGORITHMS

The evolution computing approach-Genetic algorithms(GA) perform quite well now in engineering for solving complex optimization problems. It is highly parallel, random and adaptive searching. It characterizes on parallel computing and global information usage, so it is robust and can image the big zone of the searching place by testing just a few structure. Compared with traditional optimization methods, GA mainly shows following advantages[3]:
1) it uses some codings of the parameters but not directly uses the parameters.
2) it begins the search from point colony but not one point.
3) it needs no derivatives and other assistant information but just uses the adaptive information.
4) it makes use of the probability displace rules.
Using MSES to simulate the aerodynamic characters, transform the response(lift coefficient,drag coefficient or lift to drag coefficient) to the "adaptive" tolerance of the design, GA is feasible to carry on the multi-element airfoil optimization.

5. THE OPTIMIZATION DESIGN PROCESS

After setting optimization object(maximum lift or minimum drag,etc), we first Initialize the group, then use CFD to get out the adaptive information of any unit in the group.Then we can compute the next generation by GA.

Following such steps:

Initialize the group P (0) ， t = 0； t stands for the evolution generation;

Calculate all the units' adaptive tolerence in P (0)；

while (not satisfying the rules to be ended) Do

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choose probability "pi" in P (t);

get out the optimum unit in generations by now and the optimum unit in the t generation;

Fo r (k = 0； k < N ； k = k + 2) ， N can be divided by 2 exactly。

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by the way of roulette and according to pi to choose two father units in P (t)

r = random [0， 1]；

if (r F pr)， " insert the two father units in P (t + 1) without changing then carry on variation operation. pr stands for the copy probability".

Else "insert the two son units in P (t + 1) then carry on hybridizing and variation operation"；

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Randomly substitute the two currently units by the optimum unit by now and the optimum unit in the t generation;

Calculate all units' adaptive tolerence in P (t + 1)；

t = t + 1。

}

6. THE OPTIMUM RESULTS

Before this optimization, the three-element airfoil (for take-off) has been designed by gradient-based optimization and wind tunnel tests. Then we try the new GA optimization, the numerical value analysis by means of Euler's equation with boundary-layer (MSES). We define the slot parameters as shown in figure 1. CFD results show that GA method can improve the aerodynamic performance effectively. After the optimization, we have also done limited wind tunnel tests to validate the CFD results. The tests were carried out in NPU's NF-3 2D wind tunnel.

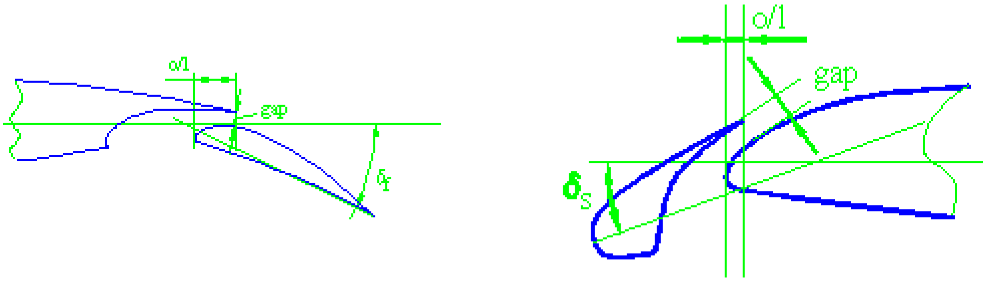

Figure 1. the slot parameter definition of slat and flap

1) Case1:Minimum drag optimization

The optimization goal is the minimum drag at attack angle of 10 degree(v=50m/s). With the deflection angle of slat constant and keeping the flap position, there are 2 variable parameters: the gap increment of slat: ΔGap:-0.5%C～1%C; the overlap increment of slat: Δo/l:-3%C—0.5%C(C is the basic airfoil chord length). The contrast of optimized and the original location is shown in fig.2 (T1:the original; TY11: the optimized),and the contrast of the results is shown in table 1.The CFD simulation gives the same trend with the test: the drag is decreased. So GA ‘s advantage in the global research can really work in such optimization.

Configuration T1： δ_S＝16.82°，$(O/L)_S$= 3.41%C， gap_S=0.93%C；δ_f =15.83°，$(O/L)_f$ = 6.79%C，gap_f =1.425%C；

Optimized configuration TY11：δ_S＝16.82°，$(O/L)_S$=0.957%C，gap_S=0.758%C；δ_f =15.83°，$(O/L)_f$ = 6.79%C，gap_f =1.425%C.

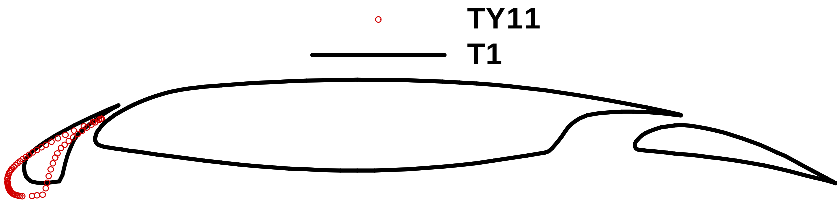

Figure 2.The contrast of optimized and the original position of slat

	c_l （CFD）	c_d （CFD）	c_d （test）	c_m （CFD）	Δc_d (TY11-T1)/c_d (T1)	
Original(T1)	2.5945	.0238	.0249	-.3332	-5.4%（CFD）	-4.0%（test）
Optimized(TY11)	2.6171	.0225	.0239	-.3121		

Table 1 optimization for minimum drag（$\alpha = 10^{\circ}$， v=50m/s）

Case2:maximum lift to drag ratio optimization

The optimization goal is the maximum lift to drag ratio at angle of attack 10 degree(v=35m/s). The original three-element airfoil is still T1, with the deflection angles of slat and flap constant, there are 4 variable parameters: the gap increment of slat: ΔGap:-0.7%C～0.5%C， the overlap increment of slat: Δo/l :-3%C—0.5%C. the gap increment of flap is ΔGap:-0.5%C～0.5%C，the overlap increment of flap is Δo/l：-3%C～1%C。The contrast of optimized and the original location is shown in fig.3 (T1:the original, TY12: the optimized),and the contrast of the results is shown in table 2.We can see that lift to drag ratio is improved after the optimization, and at the same time the pitching moment is improved too.

Optimized configuration TY12：δ_S＝16.82º，$(O/L)_S$ =0.787%C，gap_S =0.499%C；δ_f =15.83º，$(O/L)_f$ =5.847%C，gap_f =1.087%C

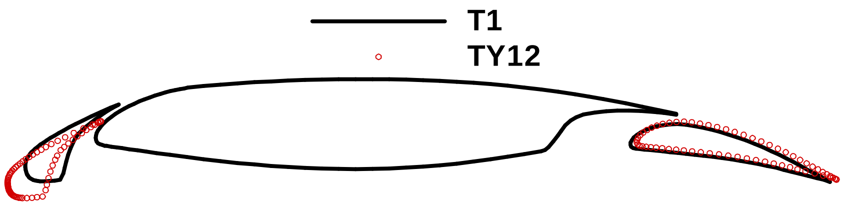

Figure 3. The contrast of optimized and the original position of slat and flap

	c_l （CFD）	c_d （CFD）	c_m （CFD）	$\frac{c_l}{c_d}$ （CFD）	$\frac{c_l}{c_d}$ （TEST）	$\Delta \frac{c_l}{c_d}$(TY12-T1)/ $\frac{c_l}{c_d}$(T1)	
Original(T1)	2.5586	.0259	-.3288	98.77	88.39	7.6% （CFD）	6.9% （TEST）
Optimized(TY12)	2.5967	.0243	-.3102	106.83	94.55		

Table 2 optimization for maximum lift to drag ratio（$\alpha = 10^\circ$， v=35m/s）

We also do the optimization with 6 variable parameters: slat deflection increment: $\Delta\delta_S$ =±3°; flap deflection increment: $\Delta\delta_f$ =±3°; the gap increment of slat: ΔGap=-0.5%C—2%C; the overlap increment of slat: Δo/l =-3%C—1%C; the gap increment of flap: ΔGap =-1.5%C—1%C; the overlap increment of flap: Δo/l =-3.0%C—1%C. But for some reason corresponding wind tunnel test wasn't carried through, so table 3 just gives out the CFD results.

The detailed slat and flap parameters list here:

Before optimization： δ_S ＝ 14.84°， $(O/L)_S$ =4.82%C， $(gap)_S$ =0.88%C； δ_f =15.83°，$(O/L)_f$ = 6.77%C，$(gap)_f$ =1.92%C;

After optimization： δ_S ＝ 15.08°， $(O/L)_S$ =1.98%C， $(gap)_S$ =0.81%C； δ_f =18.50°，$(O/L)_f$ = 7.41%C，$(gap)_f$ =2.59%C。

	c_l	c_d	c_m	c_l/c_d
Before the optimization	2.1221	.02087	-.3642	101.67
After the optimization	2.2918	.01784	-.3861	128.46

Table 3. the contrast of aerodynamic characteristics before and after optimization（M=0.2, $\alpha = 6^{\circ}$）

The improvement of lift-to-drag ratio is obvious. Compared with the original configuration, there is a large increase on working lift coefficient and less moment increase. The genetic Algorithms (GA) optimization makes the modality of upper-surface pressure much satiation and gets good effect on lift increase and drag reduction.

7. SOME PROBLEMS

Although MSES needs streamline grid and can generate grid fast, as the position parameters changed, the predefined grid may not fit; and in the computing process the transition position need to be adjusted manually. If not, the computation may diverge. So this may cause the self-evolution missing the truly optimization for CFD simulation convergence problem.

8. CONCLUSIONS

In order to improve the reliability of multi-element airfoil CFD simulation, while paying no cost of computing, we use coupled viscous/inviscid method(MSES) to simulate the complex flow of multi-element airfoil and get comparatively exact results.

To choose appropriate position for slat and flap of three-element airfoil, GA is used to do the optimization work. For the advantages of this method, we can optimize the position parameters relatively robust by parallel computing, so it’s time efficient and engineering fit.

The paper gives the process of optimizing one three-element airfoil (takeoff).The wind tunnel test has validated the optimization results. The test cases show that CFD and experiments fit well.

9. REFERENCES

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