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Sam146 Fan Efficiency Optimization by IOSO

ABSTRACT

Modern computer technologies allow conducting rather complex mathematical calculations in a relatively short period of time. Thus, it has become possible to employ optimization methods in the design of various parts of aircraft engines, even when calculations require large computational resources (structural, thermal, and gasdynamics calculations).

In this prospect we present a real-life problem. The goal of the optimization problem was to increase the efficiency of the fan rotor in the designated point of its characteristics, accounting for the splitting of the flow into core and bypass ducts. The specific feature of this problem was the necessity to satisfy the strength constraints (multidisciplinary approach). To solve this problem, a 3-D CFD code and multilevel algorithm of IOSO technology was used. The search for the optimum was carried out in the multi-objective statement (the compromise between the efficiency levels for core and bypass contours was searched). **The optimization research resulted in the increase of the fan rotor efficiency by more than 1.5%.**

OPTIMIZATION OF THE FAN GAS-DYNAMIC CHARACTERISTICS

Problem statement

In this problem an optimization of the gas-dynamic characteristics of the fan impeller with a high bypass ratio was performed. The main features of this problem were as follows:

- High level of efficiency of the initial project (prototype) and the presence of fairly strict constraints for the air flow and pressure ratio.
- The necessity to search for possibilities of the increase in efficiency of the fan impeller for both external and internal contours.

The formal problem statement is: to find a set of Pareto-optimal solutions, satisfying:

$$\eta_I^*,\ \eta_{II}^* \rightarrow max;\quad \pi_I^* \geq \pi_{Ipre}^*,\ \pi_{II}^* \geq \pi_{IIpre}^*;$$

$$G_{max-} \leq G_{max} \leq G_{max+},\ G_{ef-} \leq G_{ef} \leq G_{ef+},$$

where: η_I^*, η_{II}^* - are the isentropic efficiencies of fan impeller for internal and external contours respectively;

π_I^*, π_{II}^* - are the pressure ratios for internal and external contours respectively; G_{max} - is the maximum airflow through the fan impeller; G_{max-}, G_{max+} - are the minimum and maximum acceptable values of the airflow through the impeller; G_{ef} - is the airflow through the impeller at the point of maximum efficiency; G_{ef-}, G_{ef+} - are the minimum and maximum acceptable values of the airflow through the impeller at the point of maximum efficiency; the '*pre*' index means a set value of the parameter being considered, corresponding to initial configuration of the impeller. Figure 1 shows graphical illustration of the problem statement.

When developing a parameterization scheme, we pursued two main goals:

- Manufacturability of the fan blade. According to this, a solution was searched within the class of symmetrical profiles by varying the position of the centerline of the profile.
- Minor alteration in the strength characteristics of the blade. According to this requirement, thickness of the profile was kept constant.

Figure 2 shows the accepted scheme of the impeller parameterization. It can be seen that the variation of the position of the profile's centerline was done in 5 control points on each of 6 sections along the radius. **As a result, the number of variables was 30.** The blade face was generated by Bezier curves.

When solving optimization problems with 3D CFD codes it is important that a reasonable analysis grid is chosen. Preliminary research showed that the calculation of the flow in the fan impeller with sufficient accuracy is possible with the grid of 1.536.000 knots. The average time for the calculation of one design of the geometry takes about 9 hours on a P-IV 3.0 Ghz computer.

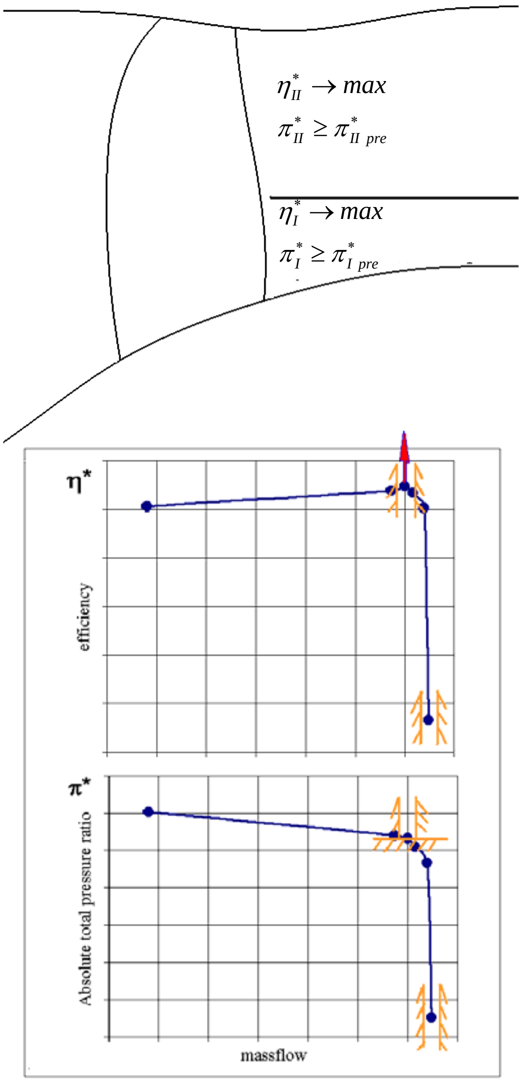

Fig. 1: Optimization problem statement

To reduce the amount of time for the optimization, it was decided to use a multilevel IOSO technology optimization algorithm. At the same time, at the initial stage the optimization calculations were done with a "course" grid (430.000 knots, average computing time is 3 hours). The optimization criteria included not only the efficiency for the first and second contours ($\eta_{I}^{*}, \eta_{II}^{*} \to max$) but also the corresponding number of pressure ratios ($\pi_{I}^{*}, \pi_{II}^{*} \to max$). After the preliminary stage, 50 variants of the geometry uniformly distributed in the objectives space of criteria were picked up; calculations with a "refined" grid were carried out; then the optimization process continued.

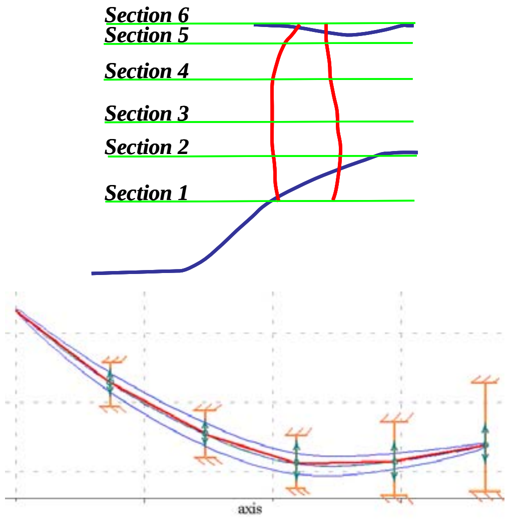

Fig. 2: Fan blade parameterization

Main results

At the preliminary stage of the optimization, 29 iterations of the IOSO parallel optimization algorithm were performed with the use of a "course" computational grid (30 calculations for each iteration) ; and then 5 more iterations with the use of a "refined" grid. It is important to note that at the initial stage of the optimization there were many cases when for the given values of variables it was impossible to perform calculation of optimization criteria and constraints (the models cashed). Figure 3 shows how the ratio of successful and unsuccessful calculations changes as the optimization problem progressed. It can be seen that during the solution process the stability region of the model is being outlined and the number of crashed calculations is being decreased.

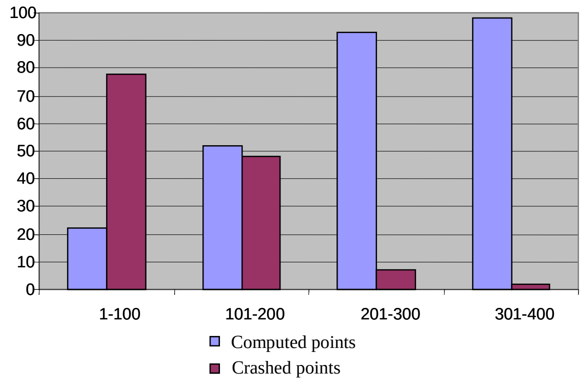

Fig. 3: Dynamics of the 3D-CFD module stability while solving the task

The results of the calculations which use a "refined" grid and meet the constraints are shown in Figure 4.

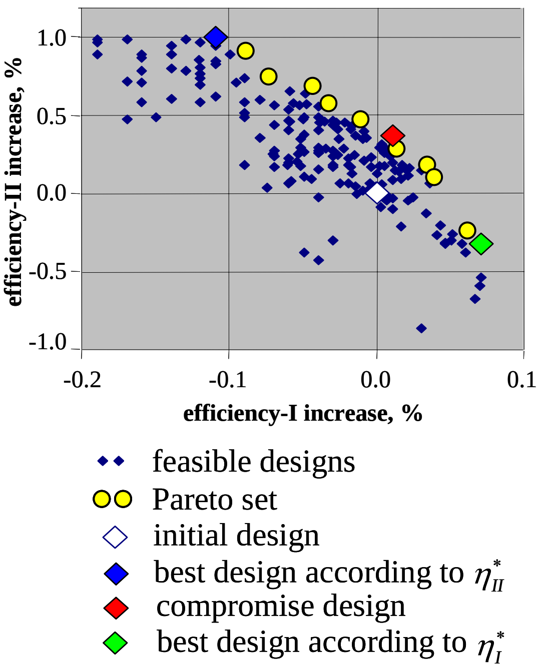

Fig.4: Optimization results

The analysis of the obtained results shows that despite strict limitations that substantially narrow the search area, the problem has a significant area of compromise between optimization criteria. For example a suitable choice of geometry of the impeller made it possible to increase the efficiency on an external contour by about 1% by the decrease in the efficiency of the internal contour by approximately 0.1 %. After the analysis, one of the compromise configuration (providing an increase in the efficiency for both external and internal contours) was chosen. Figure 5 shows a distribution of Mach numbers at the periphery of the impeller for the initial and the chosen optimum configurations. A slight drop of intensity jump and decrease in the flow separation zone for the optimum project is observed.

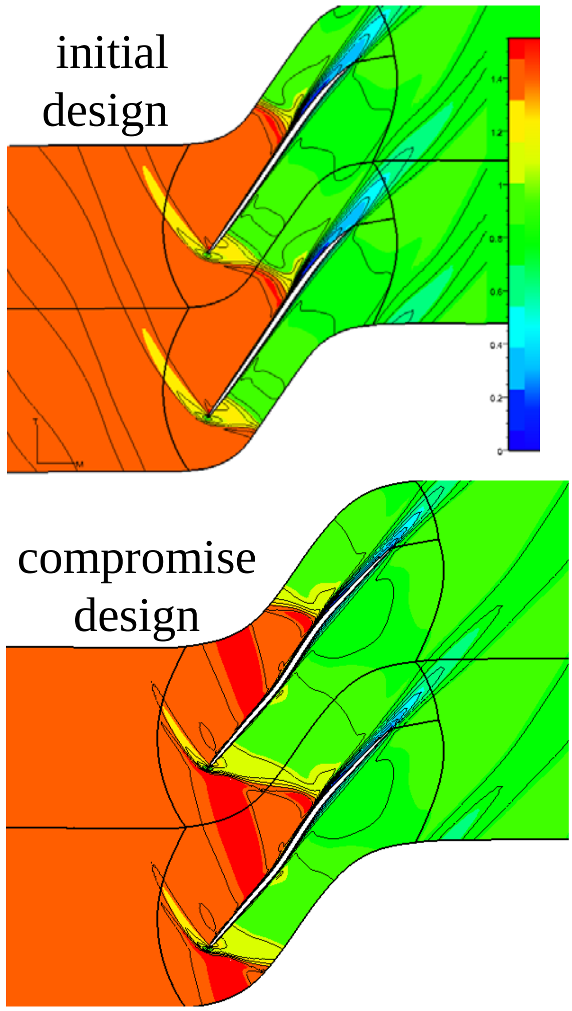

Fig. 5: Comparison of day-time picture for initial and compromise designs

CONCLUSION

The obtained results indicate the possibility of solving extremely complex problems of optimization of the gas-dynamic and strength characteristics of modern fans using 3D methods and IOSO optimization technology. With all this, a substantial decrease in the computational time can be achieved due to the use of parallel multilevel optimization procedures.