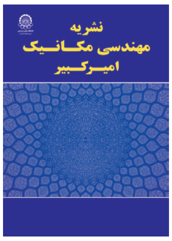

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Optimization of S-Shaped Inlet Diffuser for Improvement of Total Pressure Loss and Flow Uniformity

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ABSTRACT: The intake is a part of the aero engine, which provides air to the compressor uniformly and with a minimum total pressure loss. Today, due to the abundant application of S-shaped inlets, optimization of these diffusers has been considered by many researchers. The uniform distribution of the flow at the inlet of the compressor has a direct effect on engine performance. On the other hand, the flow separation through the duct reduces the pressure recovery and the engine thrust. In this article, an S-duct intake has been optimized to reduce the total pressure loss and flow distortion. The neural network, coupled with the genetic algorithm, is used to optimize the objective functions in the shortest possible time. Two optimization cases have been done. In the first case, new geometries have been generated by changing the centerline coordinate and the cross-sectional area ratios. The first optimization results in an enhancement of 32.5% for the pressure recovery coefficient and a reduction of 35.8% for flow distortion. In the second optimization, the length of the duct has also been decreased. By decreasing the length of the duct, the weight of the aerial vehicle is reduced, and on the other hand, the useful space inside the body is increased. This optimization gave an enhancement of 35.96% for pressure recovery coefficient and a reduction of 39.4% for flow distortion and a 25% reduction in the duct length.

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1- Introduction

Today, the use of an air inlet duct with high efficiency in a vehicle has been taken into consideration. This is important because the uniform distribution of flow at the inlet of the compressor has a direct impact on the engine performance, and the non-uniform flow in the compressor inlet can lead to surge. On the other hand, separation of flow through the duct reduces the pressure recovery and thereby reduces the thrust of the engine. In this paper, an S-shaped duct has been optimized to reduce total pressure loss and reduce flow distortion. For this purpose, a new optimization method (coupling of the genetic algorithm and neural network) is used to achieve the desired targets in the shortest time.

2- Methodology

In this paper, a genetic algorithm coupled with artificial neural networks is used to find the optimum geometry of the S-shaped duct. A Computational Fluid Dynamics (CFD) solver is used to simulate the duct performance.

2- 1- Baseline geometry

The geometry used in this paper has been introduced by Wellborn [3], designed at NASA's Lewis Research Center in 1993. This geometry is shown in Fig. 1.

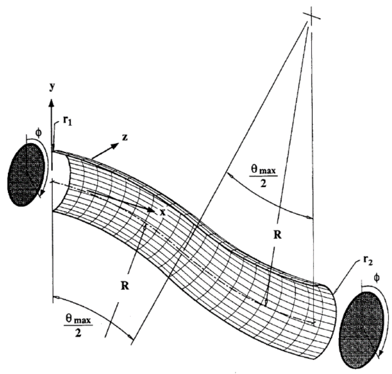

Fig. 1. The geometry of the S-shaped duct of Wellborn [3]

2- 2- The objective functions

Several parameters can evaluate the performance of the S-shaped duct. Among them, total pressure loss and flow distortion are selected as the main parameters.

Total pressure loss: Total pressure loss occurs due to non-ideal flow behavior, and especially flow separation. The pressure recovery coefficient describes this pressure loss is calculated by mass flow average formula from the CFD results. In order to reduce the pressure loss in the duct, the PR coefficient must reach the maximum possible value. As

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the optimization algorithms are designed to minimize target functions, the objective function should be defined as follows:

$$f_1 = 1 - PR = 1 - \frac{P_{out}}{P_{in}} \tag{1}$$

Where P_{out} is the average pressure at the outlet section of the duct (or compressor inlet) and P_{in} is the total pressure at the inlet section of the duct.

Distortion: The second objective function is flow distortion; minimizing this parameter improves the flow uniformity at the compressor face. Eq. (2) is used to calculate the amount of total pressure distortion at a section.

$$f_2 = DC\left(60\right) = \frac{P_f - P_{60}}{q_f} \tag{2}$$

In this Equation, P_f is the average total pressure at the engine face, q_f is the average dynamic head, P_{60} is the average total pressure in the 'worst' 60-degree sector of the section [12].

3- Results and Discussion

The results of the optimization procedure are described here. In this paper, Wellborn's geometry is studied and optimized. Two different optimization test cases with different conditions are carried out.

3- 1- Optimization by changing the cross-sectional area ratios and the centerline

In this optimization case, the inlet and outlet of the duct are unchanged, and only the area ratio of the duct sections and y-coordinate of the centerline of the duct is changed. The number of simulations performed to find the optimal geometry is 190. In this optimization, the first objective function, i.e., the total pressure loss is decreased by 5.32% and second objective function, namely distortion, is improved by 8.35%. In Fig. 2, the velocity contours are shown on the symmetric plane of the duct in the optimized and the baseline geometry. As it is seen, in the optimal geometry, the flow separation region, after the first bend, is highly eliminated. The reduction of the separation zone has two significant advantages: firstly, the total pressure loss is highly reduced, and secondly, the flow is delivered more uniformly on the duct outlet plane (engine inlet).

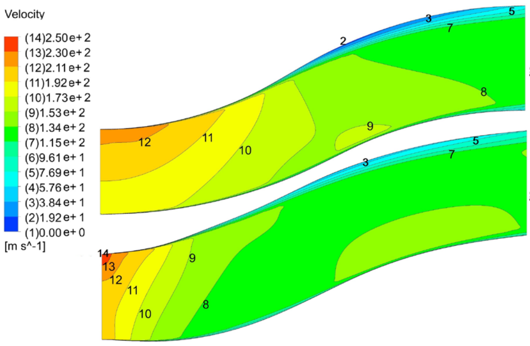

Fig. 1. Comparison of velocity contours on the symmetry plane in baseline geometry and optimal geometry

3- 2- Optimization with shorter length

The second optimization condition is similar to the first one, else, in the second optimization, the length of the duct also decreases. In the S-shaped ducts, with the decrease in the length of the duct, the probability of separation of flow, due to the high rate of diffusion, increases. In this case, the adverse pressure gradient is increased. On the other hand, the reduction of the length of the S-shaped duct is always desirable for the inlet designers, since it has many advantages, including vehicle weight reduction, increment of the useful space inside the vehicle to locate other equipment, reduction of the total pressure loss due to the reduction of friction on the duct walls.

In this optimization case, the length of the duct is reduced by 25%, the total pressure loss is improved by 35.96%, and distortion is improved by 39.44%. Fig. 3 shows the velocity contours in the duct symmetric plane in the optimized and baseline geometries.

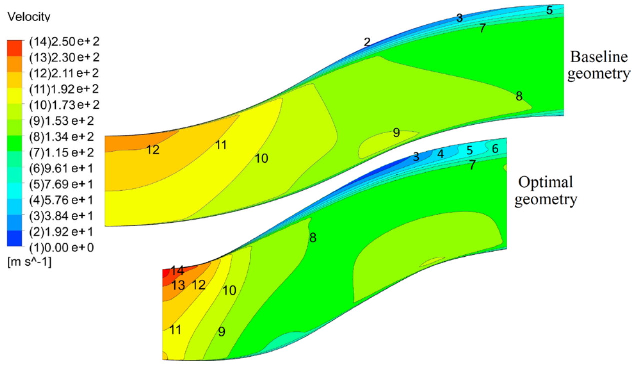

Fig. 2. Comparison of velocity contours on the symmetry plane in baseline geometry and optimal geometry

4- Conclusions

In this study, an optimization procedure was used to improve the S-shaped duct performance. The genetic algorithm was coupled with the neural network in order to reduce the computational time of the optimization procedure. The purpose of this optimization is to reduce total pressure loss and distortion of flow in the duct outlet plane. A review of the researches in this field suggests that researchers have not investigated optimization with this method; therefore, this study presented a new method to optimize S-shaped ducts, which has succeeded in achieving the desired goals, with the lowest computational cost.

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