OPTIMIZATION OF A CENTRIFUGAL COMPRESSOR IMPELLER UTILIZING GENETIC ALGORITHM COUPLED WITH ARTIFICIAL NEURAL NETWORKS

Başar Burak Özkahya
R&D Department
TUSAŞ Engine Industries
26003, Eskişehir, Turkey
basarburak.ozkahya@tei.com.tr

Onur Tunçer*
Department of Aeronautical Engineering,
Istanbul Technical University, Maslak,
34469, Istanbul, Turkey
tuncero@itu.edu.tr

Abstract

Impeller geometry optimization is performed using genetic algorithms coupled with artificial neural networks. Impeller geometry is parameterized using Bezier splines. Hub and shroud profiles are generated first using Bezier curves. Thereafter blade cross-sections, which are parametrically generated by defining camberline, thickness distribution and meridional profile, are lofted along the quasi-diagonal direction. Steady state RANS CFD simulations are performed for a family of parameters that are picked according to design of experiments rule. These CFD results are used to train the ANN. Genetic algorithm uses the output of the ANN in order to optimize the input parameters that define the centrifugal compressor impeller. Optimized impeller outperforms the baseline by 5% in terms of isentropic efficiency at the operating point.

Introduction

Unmanned aerial vehicles have established an important place in the defense and aviation industries. Small-scale engines are used in UAV's due to their dimensions such as the one shown in Figure 1. These engines typically have lower thrust ratings and smaller dimensions with respect to their full-scale counterparts. Even though there is no difference between small and full-scale gas turbines in terms of working principles, some assumptions do differ due to scales becoming smaller. This in turn brings the need for a whole new design approach. First of all, the fluid mechanical behavior is different between small and full-scale engines. Additionally, there is considerable heat transfer between the components of a small-scale engine and this introduces a design challenge. Lastly, since manufacturing and bedding tolerances are larger in comparison to engine dimensions, these can lead to performance degradation.

Figure 1. UAV Fitted with TJ-90 Engine

* Corresponding author

In small-scale gas turbine engines centrifugal compressors are preferred over axial ones due to their comparative advantages in applications with low air flow rate requirements. This is because, axial compressor losses staggeringly increase as their dimensions get smaller and smaller. One can understand how big of an investment it is to develop centrifugal compressors regarding the surge of interest on small-scale jet engines due to UAV's.

This study is aimed at the re-design and improvement of the centrifugal compressor of an existing UAV engine (TEI TJ-90 as shown in Figure 2) with a suitable state-of-the-art design technique, whose methodology is outlined in the following sections, such that it can respond specifically to tactical military requirements. The UAV onto which the engine is mounted is used as surveillance or as target drone. Two most important performance parameters for the turbine engine are specific thrust and specific fuel consumption. Compressor design clearly affects these parameters the most as a result of sensitivity analysis performed on cycle analysis results. Therefore compressor optimization is necessary for the improvement of engine performance.

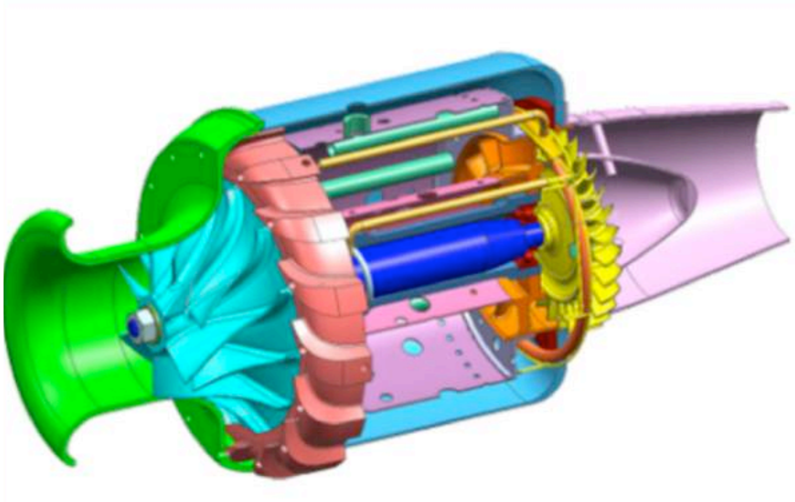

Figure 2. Cut Away View of the TJ-90 Engine

Nowadays, obtaining a state of art design for any kind of turbo machinery is clearly an issue of optimization and efficient methodology, since the difference between a decent and unacceptable design is determined by very small changes to the design. It can be very a though or demanding task to fulfill the performance criteria such as range, efficiency with trial and error. Consequently, automatization of the design process saves significant amount of time and effort alongside ensuring a certain level of confidence.

Taking into consideration the aforementioned issues, a design methodology for the centrifugal compressors is developed and tested. Within the scope of this study, impeller of an existing micro turbojet engine centrifugal compressor is used as baseline for optimization. Only the impeller part of the compressor will be the concern for this paper, however the same methodology can be applied to any part of a centrifugal compressor, given the adequate amount of time. Results are compared against the baseline to demonstrate the power of the methodology over a trial and error design.

Optimization Baseline

The centrifugal compressor whose design shall be improved is used in a turbojet engine with 430 N of thrust. This existing compressor of the TJ-90 engine has a compression ratio of 1:4 with a measured polytropic efficiency of 0.73. Measurements are performed at the test rig shown in Figure 3.

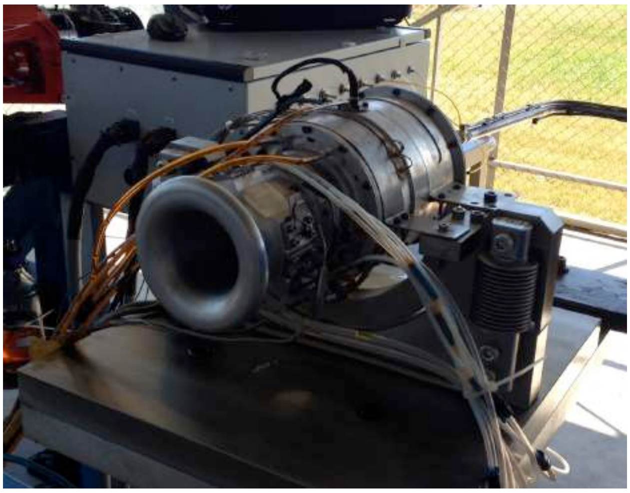

Figure 3. Engine Test Rig

Target for the optimization is 5% increase in terms of polytropic efficiency, at the design point, without any change to pressure ratio and mass flow rate. Additionally, any operating range decrement shall not occur. Optimized impeller shall to replace the baseline and shall work with the same baseline diffuser, meaning any increase in the performance parameters due to the changes only in impeller. Optimized design will be compared to compressor, whose map is provided in Figure 4. Note that the key challenge with the baseline design is that due to high RPM typical of engines of this size the tip Mach number of the impeller is supersonic. This brings significant aerodynamic challenges in terms of the optimization task at hand.

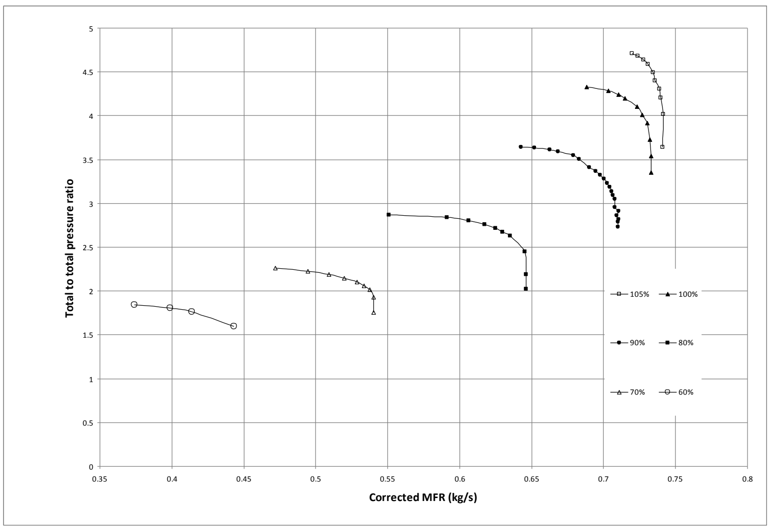

Figure 4. Baseline Compressor Performance Map

Methodology

Geometry parameterization is the first step and it si performed using mainly Bezier curves. Few other geometrical parameters are also be utilized. The range of these parameters is determined mostly by manufacturing reasons or for other obvious practical purposes.

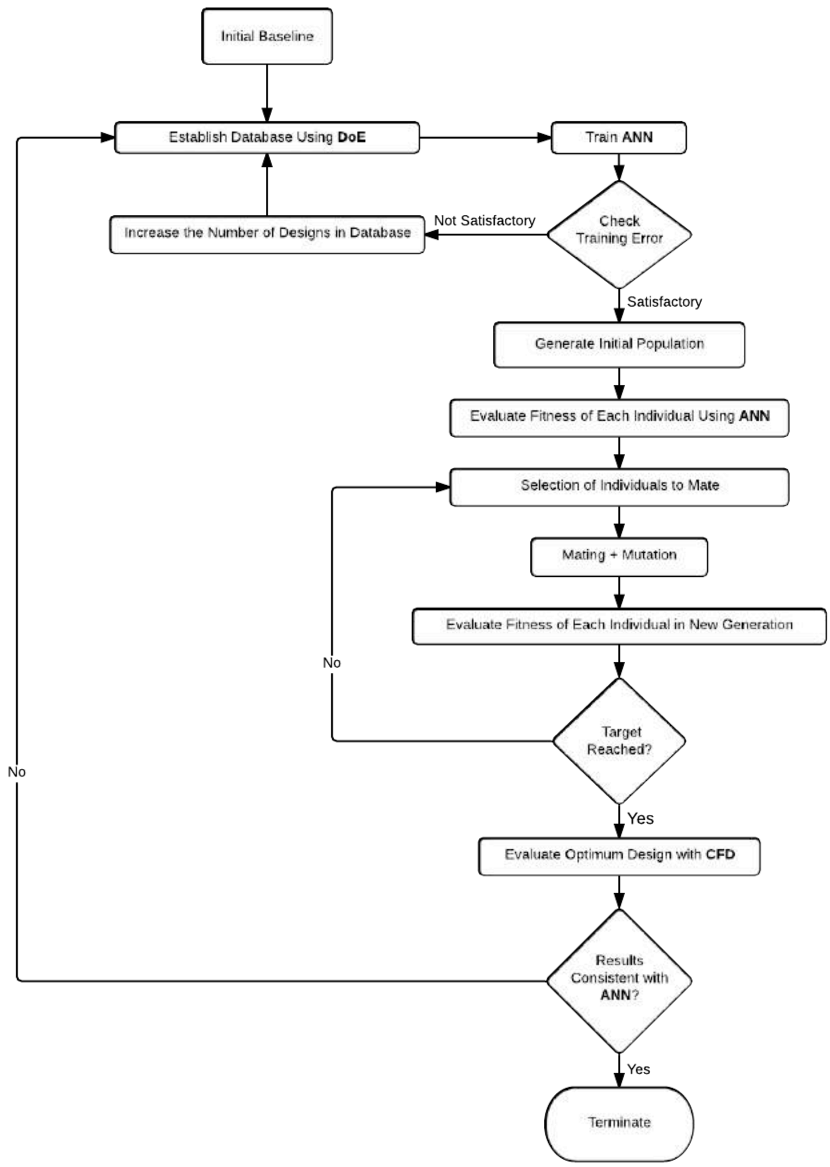

Figure 5. Optimization Flowchart

Computational cost of coupling a CFD code directly to an optimization algorithm is prohibitively large. Therefore a set of CFD simulations were performed, whose parameters are judiciously selected using a design of experiments (DoE) methodology to cover the entire design space. Results of these simulations are then used to train an artificial neural network. Further note that CFD methodology is verified such that its solutions can exactly replicate the baseline performance map which is measured through experimentation in a separate compressor test rig.

So the optimization process includes setting up a database based on CFD results, training an artificial neural network as a fast performance prediction tool and a genetic algorithm code for creating new individuals (designs) until optimization criteria are satisfied. Flowchart of the entire methodology is provided in Figure 5.

Results and Discussion

As a result of optimization experiments show that the polytropic efficiency of the centrifugal compressor is raised to 0.78 at the same operating point. This results validates the optimization methodology.

Note that this design improvement of the compressor positively affects the turbojet engine performance parameters. Baseline engine (with the baseline compressor) has a specific fuel consumption value of 42 (g/kN.s). As a result of this geometry optimization, this value is targeted to drops to 33 (g/kN.s). This in turn corresponds to a significant improvement in the flight endurance and range of the UAV.

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