DOI: 10.14529/jsfi180317

Optimization of BWB Aircraft Using Parallel Computing

Kirill S. Anisimov[1], ***Andrey A. Savelyev***[1], ***Innocentiy A. Kursakov***[1], ***Alexander V. Lysenkov***[1], ***Prajwal S. Prakasha***[2]

Nacelle shape optimization for Blended Wing Body (BWB) is performed. The optimization procedure is based on numerical calculations of the Reynolds–averaged Navier–Stokes equations. For the Top Level Aircraft Requirements, formulated in AGILE project, the propulsion system was designed. The optimization procedure was divided in two steps. At first step, the isolated nacelle was designed and optimized for cruise regimes. This step is listed in paragraph 3. At second step the nacelles positions over airframe were optimized. To find the optimum solution, surrogate–based Efficient Global Optimization algorithm is used. An automatic structural computational mesh creation is realized for the effective optimization algorithm working. This whole procedure is considered in the context of the third generation multidisciplinary optimization techniques, developed within AGILE project. During the project, new techniques should be implemented for the novel aircraft configurations, chosen as test cases for application of AGILE technologies. It is shown that the optimization technology meets all requirements and is suitable for using in the AGILE project.

Keywords: optimization, CFD, Blended Wing Body, nacelle, power plant.

Introduction

The AGILE EU Project [3] is dedicated to the development of distributed multidisciplinary optimization methodology. The project is based on the key technologies developed over the last 10 years in the DLR: such as, for example, common data format CPACS [6] and RCE environment. The main purpose of AGILE project is to reduce the time of the convergence process in the aircraft optimization by 20%, and for the multidisciplinary optimization in a team of various experts by 40% by the end of 2018. The main objective for TsAGI in the current project is to optimize the external aerodynamics of the power plant. This task is possible within the framework of the project, because the project ideology at each step of the global optimization permits both the disciplinary analysis and the disciplinary optimization. At that, a number of specific requirements are made to the optimization. One of such requirements is the optimization speed, because it is necessary to optimize the external aerodynamics of outer nacelle at each step of global optimization.

1. Task Formulation

In the project beginning, the Top Level Aircraft Requirements were formulated [5]. The initial shape of airframe was also designed (Fig. 1). The requirements for airplane was reformulated to the initial parameter of optimization: cruise Mach Number = 0.8; operation altitude = 10668m (35000ft); operation weight = 300000 kg (it means Cy = 0.5185 for the BWB with mentioned above parameters and wing area equal to 900 m^2).

All the calculations were performed using solver EWT–TsAGI [2] based on the full 3D non–stationary Reynolds equation system closed by Spalart–Allmaras turbulence model. In the present work automatic algorithm [1] for structured computational mesh rebuilding is developed. All operations are made in program Grid_Creator developed in TsAGI (Russia). Free library

[1]Central Aerohydrodynamic Institute, TsAGI, Russian Federation
[2]Institute of System Architectures in Aeronautics, DLR, Hamburg, Germany

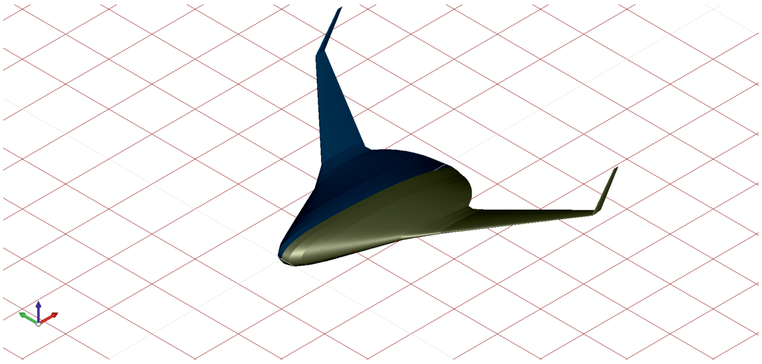

Figure 1. Reference airframe for engine design

cgnslib version 3.1.3 is used in the program Grid_Creator for operation with CGNS format. In addition Grid Creator has a number of additional functions: usage of additional possibility of EWT–TsAGI [2] solvers (families, turbulence model parameters, etc.), setting of irregular flows on the computational region boundary, cluster load optimization. The solver EWT–TsAGI could be efficiently paralyzed up to 500 cores for a task with number of blocks in structured mesh greater than 2000. The optimization efficiency additionally increased by running computations for a number of geometry variants simultaneously. The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University supported by the project RFMEFI62117X0011 [7].

During the optimization, the value of effective thrust losses (1) for isolated nacelle at the cruise regime has been used as an objective function.

$$dP_{eff} = P_{id} - P_{eff}, \tag{1}$$

where P_{id} – the ideal engine trust; $P_{eff} = P - F_x$ – the effective engine trust (thrust–minus–drag); P_{id} – the engine thrust determined with the use of the internal parameters; F_x – projection of the total force of external drag on the engine axis.

As an optimizer code, SEGOMOE, developed by ONERA [4] is used. SEGOMOE is very efficient for the tasks with expensive problem, in terms of computing resources, with moderate noise pollution (depending on the used calculation method and the grid detalization), and non–zero probability of finding local extremes. It means that it is possibly necessary to use global nongradient–based optimization methods with the purpose to reduce the noise influence and try not to get into local extremum. Initial DOE (Design Of Experiment) points are computed simultaneously, but after DOE points are running one by one.

2. Isolated Nacelle Optimization

Based on the authors experience, which has been obtained in the optimization of nacelle turbofan engine with high bypass ratio, and based on the results of calculations performed in the preliminary design stage, it has been concluded that there is weak interference between the nozzle and the inlet. Therefore, the initial problem of designing the aerodynamic contours of nacelle has been divided into two independent nozzle and inlet design optimization problems.

Nacelle geometry has been divided into two parts at mid–section. At that, mid–section diameter and position are nozzle parameters. For this reason, the nozzle has been designed at the first stage. At the second stage, the inlet has been designed for mid–section diameter and position chosen at the first stage.

After the designing a shape of the axisymmetric inlet, setting of the inlet takes place: the inlet axis rotates around the OZ axis at an angle with respect to the engine axis. The convergence of effective thrust losses received by SEGOMOE is shown in Fig. 2. For this task 30 DOE points for 18 parameters and 2 constraints are used. Gas mass flow rates throw core and fan nozzles are used as constraints. After 90 points, SEGOMOE found the optimal solution with satisfying of constraints. The further calculations (Fig. 2) showed that the discovered solution was optimal. It is a very good result for an optimizer with this kind of task.

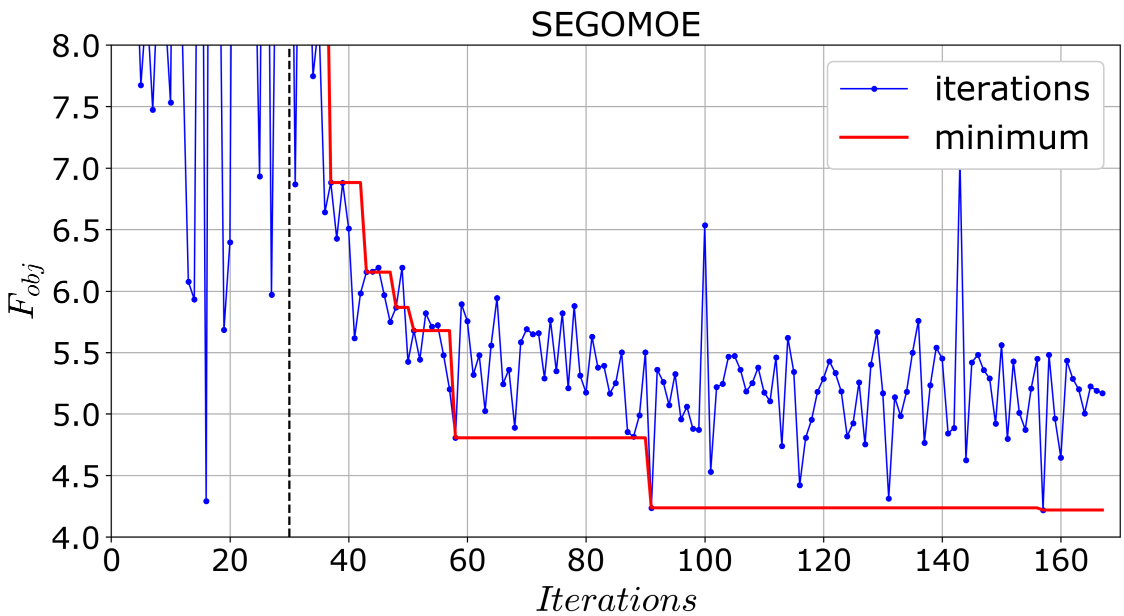

Figure 2. Convergence of effective thrust losses by SEGOMOE

3. Engine/Airframe Integration

The position optimization was proceeded like the isolated nacelle optimization. In this case, the design parameters were: x and z coordinates of central nacelle; x, y and z coordinates of side nacelle; angle of attack of nacelles (the angle was the same for all nacelles); sweep angle for side nacelle; aircraft angle of attack. This parameters are necessary for supplying of constraint. As a constraint the lift force was used for satisfying (equivalent of Cy = 0.5185) of Top Level Aircraft Requirements for Operation Weight. After finishing optimization procedure the optimal parameters were received. The received lift coefficient for overall configuration was Cy = 0.5185. This means satisfying of requirements. The final configuration is presented in Fig. 3.

The received data analysis permits to talk about huge negative interference between wing and fuselage. During the optimization, all parameters try to increase the distance between two nacelles, as well as nacelles and the fuselage to reduce the interference. But the constraint and range of variety force them to be together. If we will analyze the thrust of different engines we can find the thrust of central engine equal to $P_c = 75244.52$ and side engine $P_s = 77721.41$. This showed bigger efficiency of side engines because of low interference. This fact points out the conclusion about negative interference.

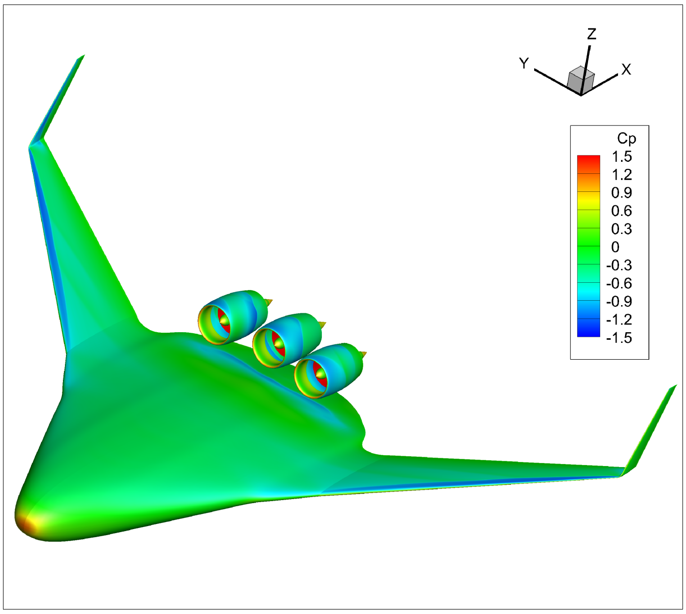

Figure 3. Pressure coefficient distribution over BWB aircraft with three optimal engines

Conclusions

The task aerodynamic design of propulsion system was successfully made for BWB configuration. The airplane with three optimal engines satisfy the Top Level Aircraft Requirements. This configuration is appropriate for further investigation in this area and possible to be used for multidisciplinary optimization of overall aircraft. During further investigation huge attention should be paid to the aerodynamic interference between airframe and fuselage.

Acknowledgments

The research presented in this paper has been performed in the framework of the AGILE project and has received funding from the European Union Horizon 2020 Programme H2020-MG-2014-2015 under grant agreement N 636202. The authors are grateful to the partners of the AGILE consortium for their contribution and feedback.

References

1. Anisimov, K., Savelyev, A., Kursakov, I., Lysenkov, A., Mirzoyan, A., Prakasha, P.: Propulsion System - Airframe Integration and Optimization of Civil Aircraft- AGILE EU Project. ICAS Conference Proceedings, Belo Horizonte, Brazil (Sept 2018)

2. Bosnyakov, S., Kursakov, I., Lysenkov, A., Matyash, S., Mikhailov, S., Vlasenko, V., Quest, J.: Computational tools for supporting the testing of civil aircraft configurations in wind tunnels. Progress in Aerospace Sciences 44(2), 67–120 (2008), DOI: 10.1016/j.paerosci.2007.10.003

3. Ciampa, P.D., Nagel, B.: chap. The AGILE Paradigm: the Next Generation of Collaborative

MDO. AIAA AVIATION Forum, American Institute of Aeronautics and Astronautics (Jun 2017), DOI: 10.2514/6.2017-4137

4. Lefebvre, T., Bartoli, N., Dubreuil, S., Panzeri, M., Lombardi, R., D'Ippolito, R., Della Vecchia, P., Nicolosi, F., Ciampa, P.D.: chap. Methodological Enhancements in MDO Process Investigated in the AGILE European Project. AIAA AVIATION Forum, American Institute of Aeronautics and Astronautics (Jun 2017), DOI: 10.2514/6.2017-4140

5. Prakasha, P., Ciampa, P., Della Vecchia, P., Ciliberti, D., Voskuijl, M., Charbonnier, D., Jungo, A., Fioriti, M., Anisimov, K., Mirzoyan, A.: Multidisciplinary Design Analysis of Blended Wing Body Through Collaborative Design Approach: AGILE EU Project. ICAS Conference Proceedings, Belo Horizonte, Brazil (Sept 2018)

6. Rizzi, A., Zhang, M., Nagel, B., Boehnke, D., Saquet, P.: Towards a unified framework using cpacs for geometry management in aircraft design. In: 50th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition. pp. AIAA 2012–0549–(2012), DOI: 10.2514/6.2012-549

7. Sadovnichy, V., Tikhonravov, A., Voevodin, V., Opanasenko, V.: "Lomonosov": Supercomputing at Moscow State University. In: Contemporary High Performance Computing: From Petascale toward Exascale. pp. 283–307. Chapman & Hall/CRC Computational Science, CRC Press, Boca Raton, United States (2013)