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Optimization of an Annular Combustion Chamber for Micro Turbo Jet System

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Abstract. This Annular combustion Chamber is designed for micro turbo jet engine. Combustion chamber is positioned in between compressor and turbine of turbojet. Combustion chamber is designed to increase enthalpy without significant pressure loss. Existing combustion chamber is designed by conventional method of trial and error. To further increase its performance then a optimization is needed. The geometry of the combustion chamber is optimized to maximized efficiency, minimized Pattern Factor, minimized pressure loss and lower temperature on the combustion wall. Varying Parameter is chosen based on Sensitivity Analysis with Spearman Correlation method to choose influential changes on geometry. After sampling process with Latin Hypercube Sampling (LHS) method and followed by interpolation with Kriging method, the combustion chamber then optimized using Multi Objective Genetic-Algorithm (MOGA). Performance of the combustion chamber then evaluated by numerical simulation. The combustion chamber will be chosen if it fulfilled pressure loss and temperature on wall criteria. Final design give better performance with a little increase in efficiency and good Pattern Factor.

1. Introduction

The combustion chamber is part of a turbo jet that converts chemical energy into enthalpy. A good combustion chamber can burn the right amount of fuel. The correct combustion of fuel will provide enough power so that the motor can operate in accordance with the design. The aero propulsion laboratory has made several turbojet prototypes with various applications. The results of the combustion chamber [1, 2] are used in one combustion chamber test and have a fairly close result between the design and experimental results. When the combustion chamber is added with a compressor and turbine the combustion chamber becomes less stable and easily dies. By using the ECU to facilitate controlling the engine, it increases stability and have better reliability. Another problem arises when the engine operates on a large air discharge the engine easily dies when the throttle is too quickly lowered.

The fire detaches from the swirler and dies if the throttle lowered too fast. To solve this problem, a new annular-shaped combustion chamber is designed. Reverse annular combustion chambers generally have better stability. The air coming in from the front immediately hit the fuel nozzle, so that at high or low speeds the fire would be maintained and not too shifted out. Longer streamlined lines also provide a better pattern factor, see Fig. 1.

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Figure 1. Rendered annular reverse combustion chamber

Many considerations in the design of the combustion chamber make the optimum design that difficult to achieve. The design method that has been used was trial and error method [3], so that the design direction is based on the analysis of phenomena in several parts of the combustion chamber. In the real case, the modification in one section will change the entire combustion phenomenon so that limited analysis often not produce an optimum design. To facilitate the design process and reduce design time, writer used MOGA method which is paired with the kriging method. MOGA is used by utilizing genetic algorithms to find the desired optimum point.

2. Optimization of Combustion Chamber

The optimization process of combustion chamber performance is based on the flow chart as shown on Fig. 2 below.



Figure 2. Optimization flow chart

Optimization is done using MOGA. Some geometry variables are varied and evaluated for performance using numerical methods. To make the optimization process efficient, sensitivity analysis is carried out. Sensitivity analysis is done to find the relationship between the influence of input variations (geometry variables) on the performance of combustion chamber. For inputs that are not too influential, they will be eliminated from the optimization input. The optimization process that uses genetic algorithms will evaluate many points (individuals) in the design space to get the best optimum

point. Evaluation of the performance of the combustion chamber with a numerical method takes quite a long time, therefore, in doing optimization, the kriging method is used to predict the performance of the entire design space. The kriging method will interpolate the sampling results using Latin Hypercube Sampling as many as 300 samples, see Fig. 3.



Figure 3. Annular reverse combustion chamber notation

2.1. Sensitivity Analysis

Sensitivity analysis in this study uses the Spearman correlation method. The Spearman correlation method will measure the monotonic relationship between two variables measured by an ordinal scale. The spearman coefficient(ρ) has a value of -1 to +1. The magnitude of the spearman correlation value indicates the magnitude of the input effect on the output value. The input geometry variable will be eliminated when the average spearman correlation value is less than 0.1. The Spearman correlation value is obtained by the equation below and Table 1.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

No	Variable	Efficiency	Pattern Factor	Pressure Loss	Tmax Wall	Average Correlation
А	Casing Diameter	0.300	0.466	-0.594	0.564	0.481
В	Annulus-Casing Spacing	-0.227	0.392	-0.395	0.084	0.274
С	4 th Hole Diameter	0.189	0.353	-0.153	0.333	0.257
D	Liner Length	-0.238	0.325	-0.322	0.123	0.252
Е	Annulus Diameter	-0.032	-0.288	-0.34	-0.213	0.218
F	Atomizer Position	0.056	0.154	0.02	-0.254	0.121
G	2 nd Hole Diameter	0.081	0.108	-0.134	0.054	0.094
Н	1 st Hole Diameter	-0.054	0.103	-0.032	-0.09	0.07
Ι	3 rd Hole Diameter	0.149	0.040	0.022	0.051	0.065
J	4 th Hole Spacing	0.053	0.026	-0.032	-0.021	0.033
Κ	2 nd Hole Spacing	0.011	0.061	-0.0008	-0.047	0.03

Table 1. Spearman correlation result

2.2. MOGA

Multiple Objective Genetic Algorithm (MOGA) is a type of NSGA II method (non-dominated sorted genetic algorithm II) to find the optimum point based on the desired target where more than one desired objective. Because the desired target is 2 objectives, a fitness function is needed to provide the desired objective-weighting, as presented on Table 2.

Efficiency	Objective	High priority
Pattern factor	Objective	High priority
Pressure loss ratio	Constraint	less than 0.2
Tmax Wall	Constraint	less than 1300 K

Table 2. MOGA Target and constrain

Workflow from MOGA begins with random generation of initial populations taken from the response surface that generated by kriging interpolation. Furthermore, from the initial population it will produce new generations generated through the process of genetic algorithms in which there is a selection process, cross-section and mutation to produce new individuals. The formation process of this generation will continue until it reach the specified convergence critical limits. Convergence criteria are used in this optimization is the stability percentage convergence and the maximum number of generations. The stability percentage convergence (algorithm convergence) is a percentage which represents the stability of the population, based on its mean and standard deviation [4, 5].

Maximum number of generations is the maximum possible number of generations the algorithm executes. If this number is reached without the optimization having reached convergence, iteration will stop. This also provides an idea of the maximum possible number of function evaluations that are needed for the full cycle, as well as the maximum possible time it may take to run the optimization, as presented in Fig. 4.



Figure 4. Pareto Frontier

3. Results and Discussions

Performance form kriging interpolation produced satisfying result. This could achieve higher efficiency, and lower pattern factor which are desired. However, combustion chamber produced higher pressure loss and higher temperature on the wall. Since it just an idea we have to check it again with CFD analysis not with interpolation but real geometry, highlighted in Table 3 and Fig. 5.

Performance	Base	Optimized	Delta (%)
Efficiency	93.742	98.675	4.933
Pattern factor	0.927	0.59	-36.356
Pressure loss	0.176	0.191	8.991
Tmax Wall	1161.6	1255.15	8.054

 Table 3. Optimized combustion chamber performance



Figure 5. Total temperature contour

The temperature contour from optimization result is more evenly distributed after passing through the liner area and entering the outlet channel, compared to base geometry. In the outlet section, it also have more distributed temperature and the value of the pattern factor is smaller than the base geometry result. From the temperature contour, it can also be seen that the temperature on the combustion chamber wall have smaller area with maximum temperature. Temperature on the outlet wall also lower than the base geometry. This occurs due to changes in some geometry size, including the reduction of the width of the annulus and the position of the atomizer away from the inner liner wall. Where, the inner liner wall is the place of the maximum temperature in combustion chamber.



Figure 6. Velocity contour

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There is some reduction in the area of the annulus that causes the velocity in the annulus area increase. The increase in annulus velocity is followed by an increase in the penetration angle of the liner holes [5, 6]. With increasing penetration angle of the liner holes increase, the intensity of turbulence inside the liner will increase and produce a better mixing quality [6]. The efficiency of combustion will increase by increasing the quality of the mixture so that the optimization results of the reverse annular combustion chamber have an efficiency increase by 2.3%.

Decreasing on pattern factors and increasing on efficiency after being optimized is followed by an increase in pressure loss in this combustion chamber. Pressure loss is generated due to the skin friction on the combustion chamber wall and the separation flow in the combustion chamber. The pressure loss of the annular reverse combustion chamber is quite large, because of the flow pattern that turns 180^o twice, so it will produce the separation flow and a larger skin friction. It increase pressure loss mainly because lesser annulus area, with casing and liner wall getting closer it will increase shear stress. Interaction between wall become more apparent and made higher pressure losses, see Table 4.

Parameters	Base Geometry	Optimized Geometry	Delta (%)
Efficiency (%)	93.58	95.90	2.315
Pattern Factor	0.412	0.181	-56.07
Pressure loss ratio	0.151	0.190	20.52
Tmax on the wall (K)	1302.07	1242.03	-4.611

Table 4. Combustion Chamber performance comparison

4. Conclusions

After analyzing optimized geometry of the combustion chamber, it has better performance. As already mentioned before, there're slight decrease in performance aspect but not overshadowing the increased efficiency and pattern factor. In term of percentage we have 20% higher pressure loss, but in number it is around 0.039 which is still acceptable. The higher efficiency, lower pattern factor, lower temperature on combustion chamber wall and generally increases in performance. It could be achieved a better performance with MOGA to design combustion chamber. For future work writer suggest to optimized engine as a whole turbo jet. Which would increase performance not just each part but overall performance as a whole engine. Maybe there could be some interaction between part that still uncertain, and by doing optimization to whole system it may have better understanding of those interaction.

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