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PARTICLE SWARM OPTIMIZATION OF TURBOJET ENGINE THRUST

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Abstract. *This manuscript approaches the application of particle swarm optimization to turbojet engine thrust. Thrust is the force produced by the turbine, dependent on certain parameters. Particle Swarm Optimization (PSO) is a meta-heuristic based on swarm intelligence. This paper studies the performance of Particle Swarm Optimization algorithm on engine thrust function, comparing results obtained from optimization against previous data from literature, discussing the algorithm performance*

Keywords: *turbojet, thrust, particle swarm, metaheuristic*

1. INTRODUCTION

The computational methods of optimization aims to find the optimal solution of some problems that is manually difficult to represent. The optimization algorithm Particle Swarm (PSO), created by James Kennedy and Russell Eberhart is a stochastic search method similar to the evolutionary methods, however, the inspiration for manipulation of information did not come from genetic phenomena , but of the dynamics of particles. For this work, we aims to improve the operation of a turbojet engine, studying the parameters that directly act on the thrust function of this motor, so that it is defined in order to apply the PSO algorithm for an optimization attempt.

The rest of the work is organized as follows: Section 2 presents the theoretical foundations that explain the operation of the turbojet engine in question. Section 3 reviews concepts and characteristics of the PSO algorithm. Section 4 presents the proposal of the paper and describes the experimental configuration for the evaluation of the proposal. Section 5 presents and disables the results obtained in the experiments. Finally, Section 6 presents the final considerations about work and future work.

2. TURBOJET ENGINE

A turbojet engine is the simplest type of jet engine used for various purposes. Ideally independently in the late 1930s engineers Frank Whittle of the United Kingdom and Hans Von Ohain of Germany.

This type of engine is mainly used in aircraft propulsion. Basically this engine has 5 stages:

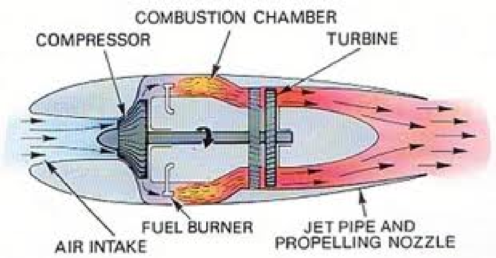

Figure 1. Turbojet engine stages

2.1 Inlet stage

First, the air enters the turbine, going directly to the compressor.

2.2 Compression stage

At this stage, afte the air inlet, it arrives at the high pressure compressor, which contains vanes that rotate at a very high speed, adding energy to the air flow through them as it compresses thereby increasing its pressure and temperature, which increases the burning efficiency at the next stage.

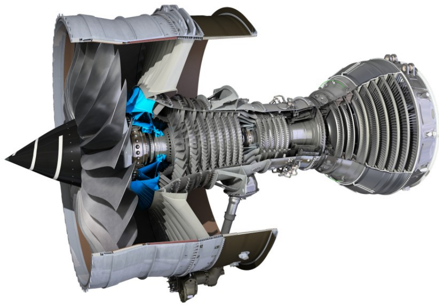

Figure 2. Compressor

After leaving the compressor section, the compressed air flows into the combustion chamber.

2.3 Combustion stage

Upon reaching the combustion stage, the air is mixed with the fuel and then burned. The combustion gases expand towards the turbine with an extremely high temperature.

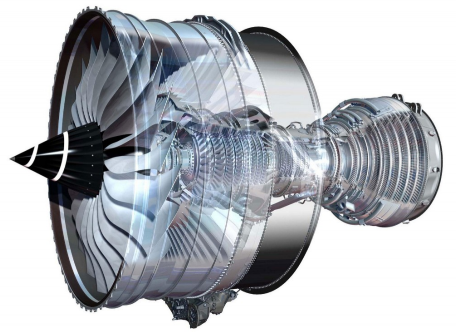

Figure 3. Turbine

2.4 Explosion stage

The gases from the combustion chamber are directed to a high and low pressure turbine. The engine turbines have the purpose of capturing the kinetic energy of the expanding gases exiting the combustion chamber and transforming it into mechanical energy. After passing through the turbine, the air again expands, cools, and exits through the impeller, generating momentum for the displacement of the body.

2.5 Exhaust stage

After passing through the turbine, the air expands again, cools, and exits through the impeller, generating momentum for the displacement of the body.

3. PARTICLE SWARM OPTIMIZATION

To understand this method, we must keep in mind the concept of Swarm Intelligence, this term designates artificial intelligence systems where the collective behaviors of each individual of the population determine the patterns of solution.

The particle swarm optimization algorithm is a type of swarm intelligence inspired by bird behavior. The search for food and the interaction between birds along the flight are modeled as an optimization mechanism. The area that birds fly over is equivalent to the search space of a function, since finding the food corresponds to finding the optimal solution of the function in question. The method is modeled from birds, which make use of their experience and the flock's experience to find the best region of the corresponding search space.

Figure 4. Turbofan engine exit

In the case, the overflown area is equivalent to the search space and finding the place with food corresponds to finding the optimal solution. The algorithm is modeled by birds (henceforth called particles) that make use of their experience and the experience of the flock itself to find the best region of the search space.

Each particle represents a solution in the search space and its position is generated by an equation that, at each iteration, takes into account its best position already found, together with the best position already found by the swarm, thus changing the velocity of the particle in search for better results. The operation is described in the pseudocode in Figure 5.

```
begin
    t = 0;
    initialize particles P(t);
    evaluate particles P(t);
    while (termination conditions are
    unsatisfied)
    begin
        t = t + 1;
        update weights
        select pBest for each particle
        select gBest from P(t-1);
        calculate particle velocity
        P(t);
        update particle position P(t)
        evaluate particles P(t);
    end
end
```

Figure 5. PSO pseudocode

The PSO algorithm was initially introduced for the purpose of optimizing non-linear functions. This method is based on the social behavior of species of birds and clusters of fish. Unlike the genetic algorithms, in the PSO each particle evolves through the cooperation with the other particles and the own history of solutions, representing birds flight. Each particle represents a potential solution to a given problem and is evaluated by a fitness function or called an objective function.

For an objective function in a mono-objective optimization approach, this function is defined by $f : S \rightarrow \Re$ where S is a n-dimensional search space. Each particle is treated as a point in an n-dimensional search space and the i-th particle is defined by the n -components of the search space, $\vec{X}_i(t) = \{x_{i,1}(t), x_{i,2}(t), ..., x_{i,n}(t)\}$, the velocity of each particle is defined by n-components, $\vec{V}_i(t) = \{v_{i,1}(t), v_{i,2}(t), ..., v_{i,n}(t)\}$, and each particle has a variable that holds the best position it has possessed up to the current instant, called $p\vec{Best}_i(t) = \{pBest_{i,1}(t), pBest_{i,2}(t), ..., pBest_{i,n}(t)\}$. In addition, considering the entire swarm of particles, there exists the variable that represents the concept of cooperation between individuals, called $g\vec{Best}(t) = \{gBest_1(t), gBest_2(t), ..., gBest_n(t)\}$ **?**.

At each iteration the position and velocity components of each particle are updated according to equations1 e 2.

$$v_{i,n}(t+1) = \omega v_{i,n}(t) + c_1 r_1 (pBest_{i,n}(t) - x_{i,n}(t)) + c_2 r_2 (gBest_n - x_{i,n}) \tag{1}$$

$$x_{i,n}(t+1) = x_{i,n}(t) + v_{i,n}(t+1) \tag{2}$$

The equation 1 presents the modified version of the PSO, presented by, where c_1 e c_2 are two positive constants that are weights for social and collective learning, respectively,and r_1 and r_2 re random values between zero and one. This modified version proposes the insertion of the inertial coefficient ω that allows the algorithm to balance the global search and the local search. High values promote global search and smaller values promote local search. This coefficient can be a positive constant or a linear or non-linear function of time. In this work a linearly decreasing function will be used, as can be seen in the equation ref eq: omega, as done in **?**, where ω_{max} e ω_{min} the maximum and minimum values that the inertial coefficient can assume, i_{max} is a constant parameter that limits the point at which the decrements takes the minimum value established for the inertial coefficient and i is the value of the current iteration.

$$\omega = \begin{cases} \omega_{max} - \frac{\omega_{max}-\omega_{min}}{i_{max}} i, & \text{se} \quad i \leq i_{max}, \\ \omega_{min}, & \text{se} \quad i > i_{max}. \end{cases} \tag{3}$$

Based on the objective and characteristics of the PSO metaheuristic, this article uses the algorithm to minimize the error function of a PID controller, using as objective function, in a mono-objective optimization, performance meters as *Integral Squared Error* (ISE).

4. PROBLEM DESCRIPTION

The turbine power of an aviation is directly related to the thrust generated by the engine, this thrust is dependent on several parameters, such as pressure (internal and external to the engine), temperature, mass flow through the turbine, Coefficients of the gases involved and also donate.

Considering the five stages described in the previous section, the calculation of the buoyancy function of the motor in question is made based on the exhaust stage compared to the properties of the environment. The search area of the PSO algorithm is given by the parameter Gamma (isentropic coefficient of combustion gases or coefficient of adiabatic expansion), which is the ratio between thermal capacity at constant pressure and thermal capacity at constant volume.

$$\gamma = \frac{Cp}{Cv} \tag{4}$$

Such coefficient is an intrinsic property to each gas, influencing the magnitude of the thrust.

The thrust function is:

$$F = M * \sqrt{2 * cp_{gas} * Eff * T * (1 - \frac{P_0}{P})^{\frac{gamma-1}{gamma}}} \tag{5}$$

Where F is the thrust function, M is the mass flow through the turbine, Cp and gamma are the heat and combustion cofinders respectively, Eff is the combustion efficiency, T is the turbine temperature, Po and P are the and inside the turbine.

Developing this concept in the PSO algorithm, we use to apply the optimization a population of size 200, in a optimization of a dimension. In addition, according to literature data, we have that one of the smallest Gamma coefficients is that of the C3H8 gas, which is worth 1,130, we assume this as the optimal value for the optimization problem, so we limit it as the minimum value.

5. RESULTS

Applying optimization to the problem at hand, we get the following result.

Table 1. Results

	Gamma	Thrust
Initial value	1.33	9.64e4
Optimal find value	1.116	1.02e5

The table shows that a smaller value for the Gamma coefficient implies higher values of thrust. Observing equation (4) we see that gases with higher thermal capacity at constant volume tend to have lower Gamma values, making the motors more powerful.

The following table shows the convergence time that the PSO algorithm took to arrive at the optimal value of the problem:

Table 2. Convergency time

	Optimal value	Iterations	Convergency time
PSO	1.160	3	0.69 seconds

6. CONCLUSION

The preliminary results for this optimization, as mentioned in the previous section, allow us to conclude that for smaller Gamma values, we obtain higher thrust values. These current results show a performance gain in two orders of magnitude. Theoretically, we conclude that this performance gain is directly related to the fuel burning efficiency. From these figures we can verify the efficiency of the PSO algorithm in the search for optimal solutions in engineering problems, we observed that the PSO with few iterations and quickly converged to a value very close to the optimal result. Considering that the objective of this work was to study the efficiency of the PSO, future work will focus on a more in-depth study of the influence of the Gamma coefficient on motor efficiency, as well as its physical properties, as well as limitations and viability analysis.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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9. RESPONSIBILITY NOTICE

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