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Evaluation of Dimensional and Aerodynamic Parameters for an Aircraft Radio Controlled through Genetic Algorithms and Design of Experiments

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Abstract This paper presents a study of aircraft configuration TKV2012 that is more optimized as possible in all aspects of stage length, questions and restrictions established by the SAE Competition BRAZIL AeroDesign 2012. The analytical method for estimation of the aircraft aerodynamic coefficients was performed using the linear approximation to the theory of Multhopp. Design of Experiments (DOE) was used integrated into the genetic algorithm through the interface ModeFRONTIER®, version 4.3, the company Esteco®. We used the algorithm and Planning SOBOL MOGA II, with about 28 input variables, given the requirements: project report (containing plants and forecast payload), oral presentation, maximum loaded weight, high structural efficiency, "accuracy" Prediction Weight Loaded (Accuracy Project) and bonuses. The primary outcome variable was the total score, since the goal was to maximize their. The results allowed to identify and optimize the dimensional parameters of the aircraft, as well as signaling the main factors that influence the total score, helping to define the configuration of the aircraft 2012.

Keywords Genetic Algorithm, Design of Experiments, Optimization

1. Introduction

The geometric characteristics of an aircraft, such as area, spread and shape in plan are parameters that considerably influence on its flight efficiency, landing and liftoff. The development of an aeronautical project, since its conception, detailed project and construction represents a huge challenge to the draftsman due to the intense complexity of the aerodynamic factors and dimension parameters, integrated to a huge multidisciplinary character. One of the ways of developing and determining safe dimensions to an aircraft project consists on the use of numerical techniques, such as the Design of Experiments (DOE) and the Multhopp method, allied to the optimization tools. Among the optimization methods are highlighted the genetic algorithms, mainly for not requiring the calculation of derivatives, such as required by the deterministic methods.

Every year, on October, takes place in the airport of São Jose dos Campos (SP), one more national edition of the SAE AeroDesign competition. To join this competition,each team must "project, document, construct and fly a radio airplane controlled to raise the biggest payload that is possible, according to specific rules of SAE Brazil AeroDesign regulation.The questions and rules of the competition are changed every year, keeping the challenge and avoiding the reuse of the aircrafts. The SAE BRAZIL AeroDesign competition is composed of three distinct characteristics: Regular, Advanced and Micro, with specific requirements applicable to each grade.

The evaluations and classification of the teams are done in two steps: Project Competition and Flight Competition, in which the projects are comparatively evaluated by aeronautics industry engineers, based on the conception and performance of the projects[1].

On the aircraft project, it became frequent on the last decade the multi-disciplinary optimization (MDO), the use of optimization methods to solve project problems incorporating various disciplines – aerodynamic, structural analysis, propulsion, control theory and economic engineering. Among these optimization methods, is highlighted the genetic algorithms linked to statistical tools, that aimingto minimize the liftoff burden and maximize the charge bulk. Giunta[2] for instance, used the classic statistical methods and the Bayesian inference linked to the approach of Kriging to define a polynomial model approached, and through these classic convex optimization methods, minimize the liftoff burden of a supersonic aircraft.

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Obayashi[3] applied a multiobjective genetic algorithm to the drawing of a planar shape of a wing, focusing on minimizing the dragging and maximizing the available bulk to fuel storage. The same period was also marked for the development of unmanned aircrafts (VANT), with both military and civilian purposes. So, it is natural to have applied the MDO to his projects, as attest the works of Batill et al.[4], Gundlach[5]; Neufeld and Chung[6] and Lee et al.[7].

2. Literature Review

2.1. Design of Experiments

Experiments are done by researchers in virtually all the investigation areas, usually to discover something about a certain process or system. Literally, an experiment is a test. More formally, an experiment is defined as a test or a series of tests in which the international changes are done to the input factors of a process or system in a way that the reasons to the changes in the output can be observed and identified. In general, the experiments are used to study the performance of processes and systems. It is possible to see the process normally with a combination of machines, methods, people and other resources that transform some input (in general a material) into an output that has one or more observable answers[8]. The process, or system, can be represented by the model shown on Figure 1.

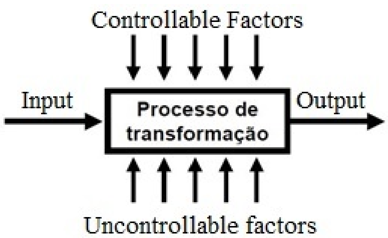

Figure 1. General Model of a process or system. Source: Montgomery, 2005

The Design of Experiments is composed of a group of statistical techniques that provide an organized method to planning, execute and analyze experiments, used to determine which is the great combination of variables to obtain the desired answer[9]. The DOE was created around 1920 by Sir Ronald A. Fisher, a British cientist that studied and proposed a more systematic approach to maximize the knowledge acquired from the experimental data. Its main goal was to determine the great sunlight, water, amount of fertilizers and soil underlying to the necessary condition to produce the best harvest[10]. Before his studies, the traditional approach was to test a factor in a time, during the experimental phase, the first factor is moved while the other factors were maintained constantly, then, the next factor is examined and so on[11].

The original use of DOE, planned by Fisher, refers to methods used to obtain the most relevant and significant information from a database of experiments, that do the shortest number of experiences. The proposed method by Fisher to the execution of experiences eliminated the redundant observations and reduced the number of tests to provide information about the important interactions between the variables[11]. The DOE approach became essential to determine and examine the behavior of the objective function and identify the most significant factors.

2.2. Genetic Algorithms (GA)

Genetic algorithms are constituted of computational models developed through the natural selection principles developed by the naturalist Charles Darwin, in which beings that have characteristics that allow larger adaptability and compatibility with the environment that they live, have their surviving and reproducing probability increased, allowing a larger spreading of their genes to their descendants.

The GAs are implemented as a computer simulation, in which a population of sample representations of solutions is selected in search of optimal approaches. The evolution is generally started from a set of solutions randomly created, being held by generations. Each generation, the adaptation of each solution in population is evaluated. Some individuals are selected to the next generation and recombined or suffer mutation to create a new population. Then the new population is used as an entrance to the next iteration of the algorithm[12].

Genetic algorithms differ from the traditional optimization ones in basically four aspects:

- based on an encoding of all the possible solutions;
- the results are presented as a population of solutions rather than as a single solution;
- require no knowledge derived from the problem, only an evaluation of the results;
- use probabilistic transitions and not deterministic rules.

2.2.1. Objective Function

The objective function is the object of the optimization. Can be an optimization problem, a test set to identify the fittest individuals, or even a "Black Box", where only the input format is known. The genetic algorithms don't need the behavior knowledge of the objective function, only requiring to have it available to be applied on the individuals and compare results.

2.2.2. Individual

The individual merely is a carrier of its genetic code. The genetic code is a representation of the space in search of the problem to be solved, in general, in the form of bit sequences. Problems with multiples inputs can match the inputs in an only one sequence of bits or work with more than one "chromosome", each one representing one of the inputs. The genetic code must be a rearrangement able to represent all the set of possible values in the search space, must be of finite size.

2.2.3. Selection

The selection is also another key part of the algorithm. In general, the algorithm of selection is used by "roulette", where the individuals are ordered according to the objective-function and are assigned decreasing probabilities of being chosen. The choice is made randomly according to its probabilities, allowing the parents selection the most well adapted, without leaving the diversity of the less adapted behind. Other ways of selection can be applied depending on the problem to be treated.

2.2.4. Recombination

The recombination is a sexual process, in other words, involves more than one individual, that emulates the phenomenon of "crossover", exchanges the fragments between chromosome pairs. In a simpler way, it is a random process that occurs with fixed probability that must be specified by the user.

2.2.5. Mutation

The mutation process in GAs is equivalent to the random search. Basically, a position in a chromosome is selected and the corresponding gene's value is changed randomly to another possible allele. The process is usually controlled by a fixed parameter that indicates the probability of a gene to suffer mutation.

3. Methods and Materials

The input variables that correspond to the project and punctuation variables were configured. There were restrictions imposed that correspond to the dimensional limits of the aircraft, maximum weight limit of the aircraft and load of 20kg, wingspan between 1000mm and 3500mm, wingspan and elevator ropes and rudder limitation, wing elongation between 4 and 6 and stretching weighted between 0.5 and 0.9. The generated wings are reto-trapeizoidal, for the better recovery area and smaller tailing-edge. The tapering is between 1 and 0.5, to increase the estolconditions[13]. The bulks of tail used were of 0.024 to vertical empennage and 0.35 to horizontal.

In the software ModeFRONTIER were integrated implemented algorithms in Matlab® environment relative to the Multhopp method to the calculation of lift and drag generated by the wing, and the corresponding equating to the takeoff roll to obtain the maximum verge load in the end of the 50 meters to each configuration. The weight of the components of the aircraft were estimated according to data collected during the construction process by the team during the last three years and the used report grade and oral presentation were considered as close to the previous year. The total punctuation was operationalized by the requirements and restrictions of the competition, according to the 2012 regulation, must be designed such that the dimensional restriction is respected:

$$D = L + H + \sum_{i=1}^{n} B_i,\ 4000 \le D \le 5800 \quad (1)$$

where:

L - maximum length or the maxim dimension found from the foremost to the rearmost point of the aircraft;

H - maximum height or the maximum value found from the sole until the highest point of the aircraft;

n - number of aerodynamic surfaces;

Bi - maximum wingspan (or maximum width) of each aerodynamic surface that generates vertical lift, or has a vertical lift component.

The Bi dimension is the wingspan or "maximum width designed on the plan" of the respective surface i. This measure will be taken between the most external points of each surface, for instance, "winglets", rounded wing tips, "endplates" or any point that is more external from the surface, including mechanisms, servants, "horns", links, etc.[14].

To each validated flight, will be accounted a punctuation that is proportional to the carried charge(P_{CP}) according the expression:

$$P_{CP} = 10 \cdot C_A + 3 \cdot C_B \quad (2)$$

where:

C_A: Charge type A (MDF or HDF plates - Medium/High Density Fiberboard) transported by the aircraft;

C_B: Charge type B (MDF and/or HDF coated, any kind of special MDF or HDF which density excels 1000kg/m³, metals (except lead), timbers, polymers) transported by the aircraft;

The opening of the charge compartment after each valid flight will be timed, and bonus points will be added to the teams that succeed the complete operation (in other words: open the charge compartment and take off all the useful charge and segregate them in the types A and B) in until 90 seconds, obeying the following bonus rule:

$$B_{RC} = 10 \cdot \left[1 - \left(\frac{t}{90} \right)^{0.70} \right],\ if\ t < 90 \quad (3)$$

Additional points in the Regular category will be added based on the Structural Eficiency factor, in other words, useful charge ratio/Empty weight of the aircraft:

$$P_{EE} = \frac{6.5 \cdot 10^7 \cdot e^{EE^{0.65}} \cdot \alpha \cdot CP^{0.25}}{D^{2.0}} \quad (4)$$

being:

B_{RC} - bonus for the time of withdrawal charge;

P_{EE} - points obtained by the Structural Eficiency factor;

CP - total payload (Type A+ Type B) transported by the aircraft (in Kg);

EE - Structural Eficiency;

α - ratio between the final report grade obtained by the team (NR) and maximum possible grade of the project report (NM);

t - time, in seconds, of the withdrawal load;

D - sum of the aircraft dimensions (in millimeters);

With the aim of stimulate the teams to increase the processes of Engineering was inserted a factor called Predictor Factor of Empty Weight:

$$FPV = 1.10 - 15 \cdot \left(\frac{PV_{previewed} - PV_{real}}{PV_{previewed}} \right)^2 \quad (5)$$

where:

$PV_{previewed}$ - previewed empty weight;

PV_{real} - Real empty weight.

On the question of landing, there is the option of three sectors to the acquisition of bonus points, landing in 50 m, 75 m or 100 m, obeying the following rule:

$$B_{PO} = 0.10 \cdot 2^{(4-n)} \cdot EE \cdot CP \quad (6)$$

where n is the number of sectors, varying from 2 to 4.

The flight punctuation (P_{flight}) is calculated by the sum of the payload (P_{CP}) and structural efficiency (P_{EE}) punctuations, multiplied by the factor of empty weight (FPV), such as shown:

$$P_{flight} = FPV \cdot (P_{CP} + P_{EE}) \quad (7)$$

Additional points will be added based on the accuracy of the charge preview to be transported by the aircraft, when compared to the real transported charge during the competition. The resultant punctuation of this "accuracy" is calculated with the weight of the previewed charge and the weight of the real useful charge, expressed in kilogram (kg):

$$P_{AC} = 30 - 830 \cdot \left| \left(\frac{CP_{previwed} - CP_{real}}{CP_{previwed}} \right)^{1.75} \right| \quad (8)$$

Another benefit will be assigned to the teams that get more than one flight with a many charge:

$$B_{CF} = 15 \cdot \left[1 - \left(5 \cdot \frac{(P_{B1} - P_{B2})^2}{P_{B1}} \right) \right] \quad (9)$$

Being:

P_{B1} - total score of the best flight battery;

P_{B2} - total score of the second best flight battery.

The final score (P_T) will be considered by the operationalization of all the requirements and restrictions of the competition, with the best score of each battery added to the relative scores to the report grade and the oral presentation, subtracted from the penalizations assigned during the competition.

$$P_T = B_{RC} + B_{CF} + B_{PO} + P_{AC} + P_{EE} + NR + NO + P_{fligth} - PN \quad (10)$$

The initial population that was considered was of 400 individuals that evolved along 500 interactions, with a mutation probability of 1%. The optimization algorithm MOGA II was used by its good convergence and strength[15]. The objective function was to the maximization of the final score.

4. Results

Table 1 shows the great values to the spread (m), root rope (m), tip rope (m), trapezoidal percentage, height (m), area (m²) and length (m) of the wing. After the calculation phase and successive generation, the software presented 15 great aircrafts with high score, based on the optimization of the aerodynamic parameters related to the wing.

Table 1. Wing optimized Values

Dimension	Aircraft		
Spread (m)	0.23	0.23	0.23
Wing area (m^2)	1.33	1.35	1.31
Movement root (m)	0.64	0.64	0.63
Rope edge (m)	0.19	0.19	0.18
% trapezoidal	0.21	0.21	0.20
L (m)	1.63	1.66	1.63
H (m)	0.4	0.4	0.4
Total sum (m)	4.96	5.01	4.94

Figure 2 presents the dispersion graphic to the interaction between each individual's score variables (axis X), total dimension (axis Y) and Wingspread (color of the bubbles) to the generated populations. Is observed that the individuals that highlighted are medium aircrafts having dimensions sum between 4758 mm and 5158 mm with spreads between 2260 mm and 2520 mm.

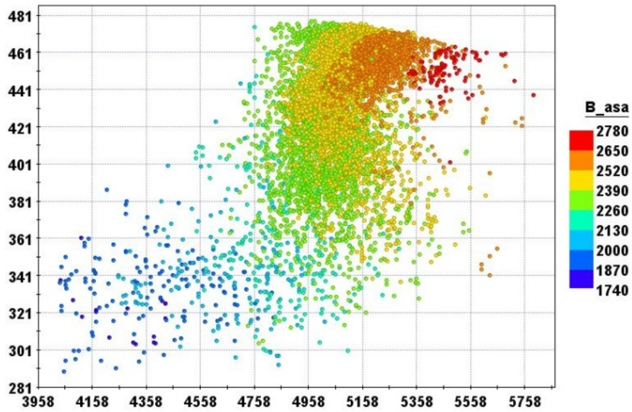

Figure 2. Score X Total dimension X Wingspan (B)

Aircrafts of small wings and dimensions got low score due to the rule 2012 obligate the wooden charge, requiring a large bulk structure, resulting in a big loss of central area of the wing and a reduction of weight to be carried, which reflects to a low structural efficiency and total score.

For the aircrafts with big dimensions, with greater wingspan than 2520 mm, is verified that the score suffers an asymptotic falling with the increased wingspan, in ratio, the wing represent about 30% of the total bulk of the aircraft, the wingspan increasing was significant above this percentage, causing structural efficiency reduction and consequent final score reduction.

Figure 3 shows the analysis of sensibility to the score quests of the rule 2012 to a population of 10000 individuals using the algorithm from the SOBOL experimental planning. Is observed that the report score is the score that mostly influences the final score operationalization of the aircraft with 16.4%. It is noticed that the accuracy quests, oral presentation, empty weight, payload and the landing distance bonus are significant to the total score sum, corresponding to 66% of the entire grade.

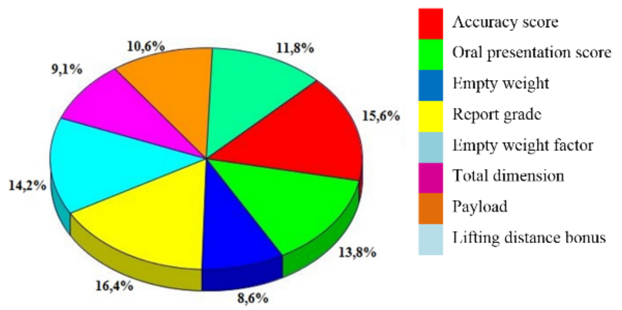

Figure 3. Sensibility of the project variables analysis

5. Conclusions

The global sensibility analysis revealed the significance of the dimension and of the empty weight of the aircraft in ratio of the proportionality of the structural efficiency score, showing that medium and light aircrafts result in a better final score.

The project report grade and payload were the most influent quests on the total score of the competition.

The Best configuration is an aircraft with wingspan of 0.23m, wing area of 1.33m², root rope of 0.64m, tip rope of 0.19m, trapezoidal percentage of 0.21, length of 1.63m and height of 0.4m and to the best score is necessary to channel the enhancement of the structural project, on the weight reduction of the aircraft reconciled to a satisfactory aerodynamic performance.

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