A REVIEW OF THE GENERATIVE DESIGN METHOD

A GENERATÍV TERVEZÉS MÓDSZERÉNEK ÁTTEKINTÉSE

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ÖSSZEFOGLALÁS
Ez a tanulmány áttekintést nyújt a generatív tervezési módszerről (GDM); a tanulmány célja, hogy bemutassa, mi a GDM, és hogyan működik ez a tervezési módszer A szemléltetés egy példán keresztül történik, amely a sugárhajtóművekben használt két GE konzol hagyományos és GDM módon történő tervezését mutatja be, majd összehasonlítja a terveket a tömeg, a maximális deformáció és a maximális feszültség három paraméterével. a tanulmány általános lesz, nem egy adott típusú GE konzolra vonatkozóan, és a tanulmányban használt anyag az alumínium AISI10Mg.

1. INTRODUCTION
The modern CAD system is based on interactive computer graphics (ICG); the CAD is used to accelerate the design process, used in the design process such as initial design, modification, development, optimization, and analysis [1] the CAD will drive by a designer from the first to the last step, the generative design method is a modern technique used to explore new designs by using software algorithms; there are many automated explorations method used in the late stage of the design process, the GDM can be used in the early stage of the design process from conceptual design to detailed design this the main difference between GDM and other optimization methods [2].
The Generative design method is used because it has many features such as reducing weight, decreasing development time, and increasing creativity and efficiency [3], [4].
The GDM working depends on software algorithms because the results will differ from one software support GD to another; each design will have properties such as a factor of safety, mass, productibility, and maximum stress [5].
The GDM has components that should be followed to apply the method, these components it is like stages or steps [2]–[5]:
1- **The software** supports the generative design, such as Autodesk fusion 360.
2- **CAD system** to create the generated base form (initial generative model design).
3- **Boundary conditions:** Main dimensions, forces, manufacturing method, material, a factor of safety, and any other boundary condition created by the designer.
4- The design after the previous stage is called **Genotype**, which provides design space.
Space design: this area is created by the designer; this area is a base form of generated design with all boundary conditions applied to it; the software will use his algorithms to explore all possible designs created in this area.
5- **Generate the design** to explore new designs.
6- **Filters**, the software will create all possible designs in the design space. Some of these designs may not fit with the boundary conditions applied by the designer, so we need filters to give the designs that work with the boundary conditions.
Solution space: the results of all possible designs can be created in the space design; the solution space will be all design that works with the boundary conditions or not because we need filters to keep only the designs that work with boundary conditions.
7- The results call **phenotype**, which provides hundreds or thousands of designs that need to sort it by the minimum mass, maximum stiffness, a factor of safety, or any other property we need to reach the design goal.
Traditional way or the usual way to design, the traditional way included several steps to design all these steps driven by the designer [6], the CAD system is used here to accelerate the design process without thinking instead of a designer like the GDM.
In the GDM the requirements and manufacturing method come before starting the design process, and the GDM provides a wide set of alternatives of design which all of these are manufacturable and refine the requirements and goals of design, the GDM use all possible strategies to design to

provide all possible designs in the space design unlike the traditional way of design which in the final provide a design may not refine the requirements or goals or not manufacturable, in the traditional design way can use topology optimization which remove the unnecessary material in the design [7]
The GE bracket is an airplane engine bracket component. During engine maintenance, it serves to sustain the weight of the cowling. It must not crack or distort when the engine is running. The engine is always running. It doesn't actively participate in the engine's operation. Only seldom is the bracket utilized. Any aircraft component's weight has an impact on fuel consumption and pollution levels [8].
Aluminium alloy, in general, is widely used in aerospace because it has good mechanical properties, is lightweight, and strong, there are several types of aluminium each type has different mechanical properties and yield strength, the Aluminium AISI10Mg is recommended to use for complex geometry and aerospace, also the Aluminium AISI10Mg can be used in additive manufacturing [9], [10]

2. METHOD(EXAMPLE)

That the design method will be introduced by an example, the example will contain three designs of GE brackets used in jet engines, by using the traditional design method and GDM, GE brackets must support the weight of the engine during handling without breaking or warping., one of the designs will be in the traditional way of design the others with the GDM.
All designs will be created with the same dimensions and boundary conditions, all the information will be provided in the example.
After the design is done by two methods, will compare them to see the effect of the GDM in the design, the example aims to see how much the GDM can reduce the weight of the design and compare the maximum displacement and maximum von mises stresses.
The first boundary condition for both is material, the material used is Aluminium AISI10Mg (mechanical and strength properties shown in table 1).

Table 1: mechanical and strength properties of Aluminium AISI10Mg.

Material	Young modulus (GPa)	Poisson's ratio	Shear modulus (MPa)	Density (g/cm^3)	Yield strength (MPa)
Alumi-nium AISI10Mg	71	033	26690	2.670	240

The second boundary condition is force, which will apply in the ring part of the GE bracket the force is 5000 N on two axis Y& Z.
The main dimensions will show in the figures in the traditional design and GDM design section.

2.1 Traditional design method:

In the traditional design method, we should follow the simplest way of design to reach the goal, here is the design of the GE bracket designed by the GrabCAD site.
To design in the traditional way there will be steps, ideating about the problem, thinking about how to solve it, sketching the idea, making a prototype, analyzing the solution then asking if the problem solve or not.
These steps were skipped, and the design was taken readily from the GrabCAD site to ensure that it was designed in the traditional way.
Figures 1 & 2 show the design with its main properties.

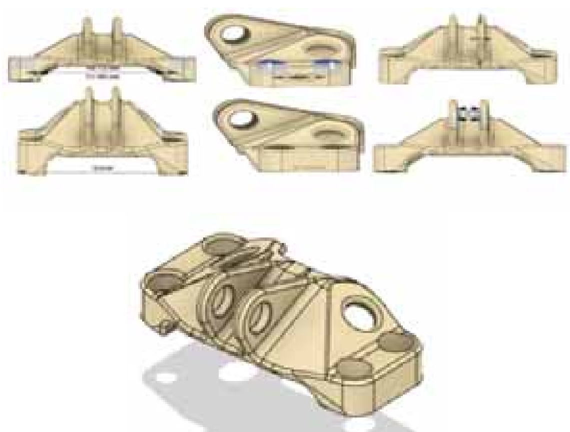

Figure 1.: GE bracket designed in a traditional way. By GrabCAD.

Figure 2. shows the forces applied (blue rows) (5000N in Y and Z axes) in the ring part of the GE bracket.

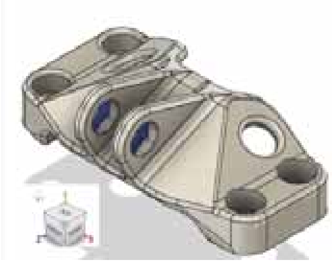

Figure 2.: Forces applied in GE bracket

2.2 Generative design method:
Designing models by GDM should follow the steps mentioned above.
The first step selects CAD and software support generative design, we chose Autodesk Fusion 360 student version for both, then from the library of fusion 360 we took generated base form of the GE bracket, the generated base form (figure 3 & 4) means where the GE bracket will install in the jet engine, in other words, we can say it is a part of the engine from this part should create the right GE bracket.

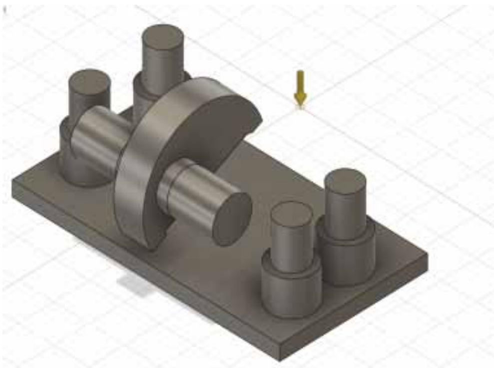

Figure 3.: Generated the base form of the GE bracket

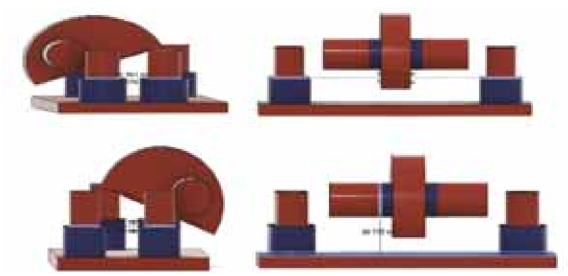

Figure 4.: The main dimension of the generated base form

In Figure 5 we see the starting shape of the GE bracket, that shape is taken from the generated base form just to make it easier to understand how to make the bracket from this form, it is not a step of GDM it is to imagine the bracket from this form.
Figure 5 the starting shape of the GE bracket with the main dimension.

Figure 5.: Starting the shape of the GE bracket with the main dimensions

Figure 6 shows the steps of applied boundary conditions to the base form design.
A - The blue parts are reserved areas that do not change during the GD process.
B - The green parts are reserved areas and the whole body is blue which is the area of generation.
C - Shows the forces applied in the body as a vector in the ring parts, 5000N in the Y & Z axis.

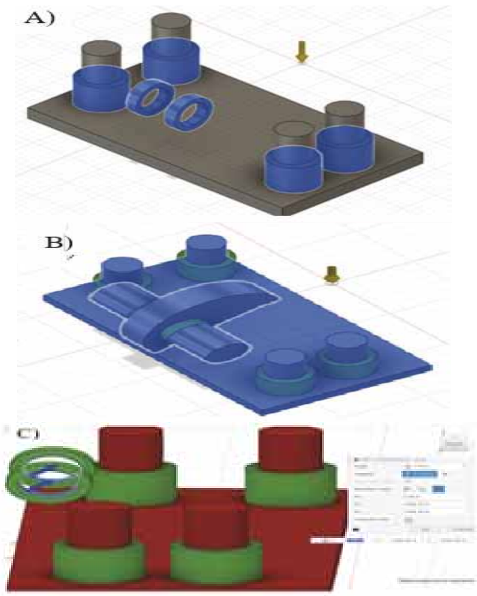

Figure 6.: A- reserved area, B- main dimensions of generation space, C- forces applied

The minimum Factor of the safety (limit) set is 2.36, the limit comes after applying the forces on the traditional design and analysis by using the fusion 360 software to make the generative design with this minimum factor of safety to make a fair comparison between the designs, the federal aviation regulation set a limit of the factor of safety is 1.5 [11], the results of the factor of safety in the traditional way is acceptable with the regulations so we will build the example on it, the software calculates the factor of safety depends of yield strength of the material which mentions in the first figure.

The other boundary condition is the manufacturing method we decided to choose from the software additive manufacturing and unrestricted, the manufacturing method is important because it affects the type of used material and the other properties such as mass.

3. RESULTS

3.1 Traditional design

As we mentioned before the traditional design is already taken from the GrabCAD site, the results of it will come after applying the same boundary conditions to it, applying 5000 N in the Y&Z axes with 4 fixed supports in the bracket.

The mass is 494.253g, the maximum displacement (total) is 0.2299mm, and the maximum von mises stress is 101.7MPa, the next figure shows the distribution of the displacement and stress on the traditional design.

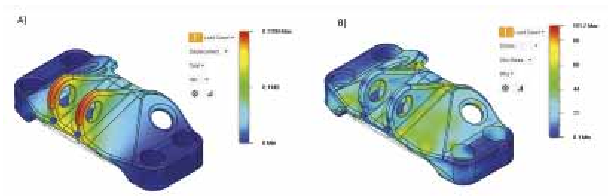

Figure 7.: Traditional design analysis, A) displacement, B) von mises stress.

3.2 Generative design

The generative design method will provide hundreds of designs because the study aims to study the effect of GDM on mass we chose a minimum mass filter to get the results with different manufacturing methods.

The GDM works as we see in figure 8, the software starts from the left to the right, and in every iteration, the software will analyze the new design and check if it is reaching the goals and boundary conditions or not, then will provide to the client the whole designs reached the goals and boundary conditions.

Figure 8.: Progress in GDM

3.2.1 Generated design with additive manufacturing method

We chose among hundreds of designs the lowest mass-generated design (Figure 9) which is manufacturable with the additive manufacturing method.

Figure 9.: Generated design with additive manufacturing

The mass of generated design with additive manufacturing is 287.921g, we exported the design to the simulation section in fusion 360 software to analyze the design, and after that they got a maximum displacement (total) of 0.179mm and maximum von misses stress 101.65 MPa as we see in figure 10 the distribution of displacement and stress on the design.

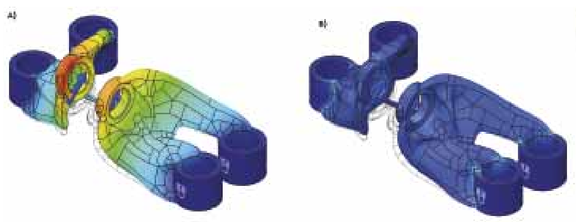

Figure 10.: Generated design with additive manufacturing, A) displacement, B) von mises stress.

3.2.2 Generated design with unrestricted manufacturing method

The same steps done in the generative design with additive manufacturing will do it here but with an unrestricted manufacturing method (figure 11).

Figure 11.: Generated design unrestricted manufacturing method

After the analysis of the second generated design (shown in Figure 12), we got 279g, the maximum displacement (total) is 0.181mm and the maximum von misses stress is 101.7MPa, the distribution of the displacement and stress is shown in Figure 12.

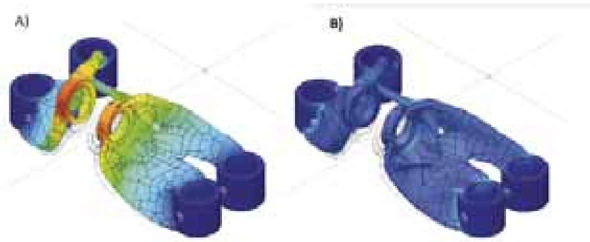

Figure 12.: Generated design unrestricted manufacturing analysis, A) displacement, B) von mises stress

3.3 Comparison of the traditional design to generated design

Table 2: shows the mass, maximum displacement(total), and maximum von misses stress of each design, the mass will provide as a percentage for the generated designs to show the effect of GDM on mass., the minus sign means the design reduces amount from the traditional design.

Figure 13 shows three charts, each chart has a comparison of the three designs with different parameters.

Table 2: Comparison between traditional design and generated designs

Design method	**Mass [g]**	**Maximum displacement (total) [mm]**	**Maximum von mises stress [MPa]**
Traditional method	494.253	0.2299	101.7
Generated with additive manufacturing	-41.7%	0.179	101.6
Generated with an unrestricted manufacturing method	-43.5%	0.181	101.7

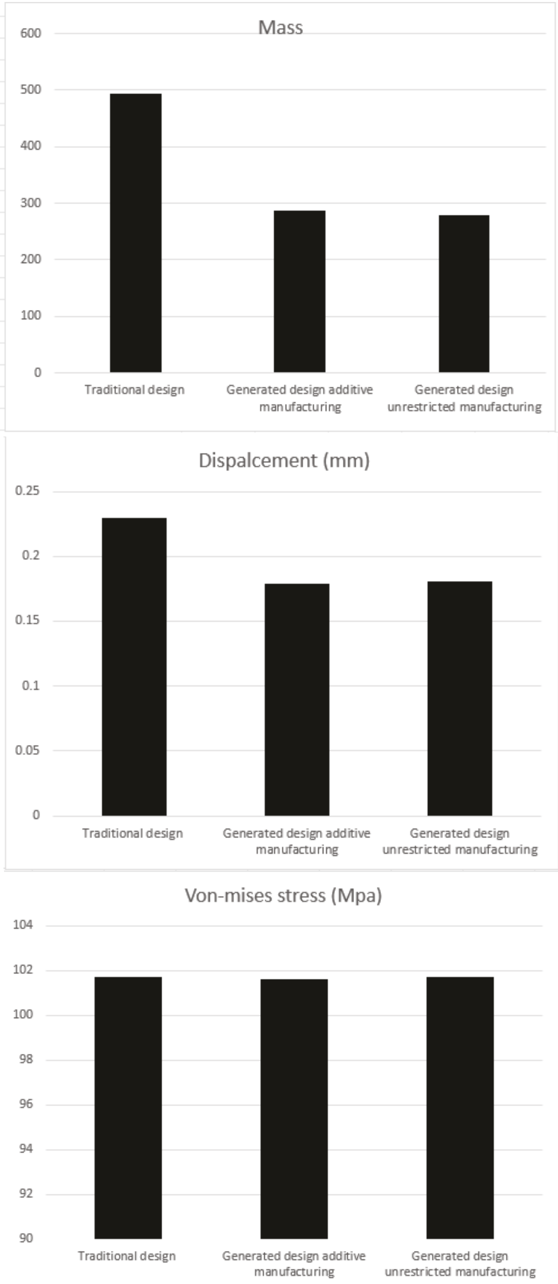

Figure 13.: comparison in mass, displacement, and von mises stress between the designs

4. CONCLUSION

The GDM is a method that uses software algorithms to explore all possibilities that refine the boundary conditions and goals of the design, the results of the GDM in the previous example are more complex than the traditional design method which will affect the production time but in the other hand, the GDM provide a design lighter than the traditional one so they will save on raw materials in general because they are lighter, based on The purpose of the design, if it is commercial or personal use, the designer or producer determines what he will choose, the generated design with the additive manufacturing method lighter than the traditional 41.7%, and the generated design unrestricted manufacturing was also lighter than the traditional around 43.5%, the manufacturing method it is a one the boundary conditions which effect on the mass of results of GDM.

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