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Comparative Study of Conventional and Generative Design Process

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Abstract: This study is a comparison of generative design and traditional design process. A generative design process is an iterative design process that uses Artificial Intelligence to generate a range of design solutions that meet the design constraints. In contrast to the conventional design process, which starts with the engineers' expertise, generative design starts with design parameters and employs AI to develop models. The cooperation of generative plans in the production and assembling departments is preferred by significant businesses nowadays. Therefore, our focus will be on generative design's simpler levels to illustrate how boundary conditions and attributes can be changed to show off contemporary applications. Because of the ease of adjustments, stronger resilience, and fewer defects that occur, generative design has shown to be a big improvement in the machine-producing side of the business. However, the creation and design of models are hampered by the additional complexity of structures. The analysis and generative design of a 4-Stroke engine piston are the subjects of this research. The suggested approach is verified using research that closely mimics a prototype used in practice. The examination's goal is to analyze and describe a comparison of two design processes and establish the advantages and disadvantages of each process and let the end user decide which process will be suitable for their applications.
Keywords: Generative Design, Artificial Intelligence, Conventional Design, Piston.

I. INTRODUCTION

Along with technology, the engineer's function has changed. Understanding how to use digital tools to address design difficulties has become a crucial skill for engineers working in all industries as design has developed to rely more largely on computer software. Engineers would conceptualize and test versions before generative design utilizing physical drawing and modeling. Engineers can now provide high-level performance criteria and broad design frameworks using generative design tools, leaving the specifics to the programmed. When characterizing novel materials or simulating difficult-to-define problems and solution spaces, the task of determining these characteristics might be very difficult. Engineers won't need to produce their own design solutions, which is a significant change from conventional design methods. Instead, via the use of generative design, they define and improve the context in which design ideas might be successful. Engineers can concentrate on creativity and complex problem-solving by using generative design, which delegates "thinking" to computers. As compared to Conventional design. Conventional engineering design often involves continual examination and modification of an original concept until a good design emerges. At each stage, the design's attributes are assessed and compared to the established requirements. The traditional design process is divided into four parts. The first stage is to characterize the issue, make specific observations, and then reframe it. The second stage is to decide on a design concept that will guide the notion. The next stage is to broaden the concept. The final stage is to put the idea into action. This research paper primarily focuses on the comparison of the design approach by implementing them on the design of a piston and analyzing the outcomes and differences between Conventional(traditional) design & generative design.

II. LITERATURE REVIEW

Various research papers were referred to on the subject. The first research that was referred to was investigating the design technique and factors to consider while constructing a piston. Solid works software is used to design the piston, and Finite Element Analysis (FEA) is used to do static analysis. the analysis of stress and damage resulting from pressure application was referred [1]. With the help of the rocker arm and brake pedal as examples, this study compared TO, and GD. and additional comparative research was conducted. Both TO and GD tools can effectively implement the results, when compared in terms of mechanical performance. this process makes components lighter and stronger. [2]. Similarly, a review was conducted on the research wherein structural and thermal analysis was conducted on five different materials used in Pulsar 220 cm3 motorcycle's four stroke, single cylinder engine. Operating gas pressure, temperature, and the material characteristics of the piston are the parameters used for the simulation. The appropriate material is chosen based on the results of structural and thermal analyses performed was Al-sic graphite, A7075, A6082, A4032, and AL-ghy 1250. [3]. In order to identify the crucial region and increased stress on a component, this research provided optimization strategies employing finite element analysis (FEM). Optimizing the structural model of a piston using computer-aided design, ProENGINEER/CREO software, reduced the stress concentration on the piston head, skirt, and sleeve and the computer-aided simulation software is used to do the FEM analysis. [4]. The analysis and generative design of a 4-Stroke engine piston are the subjects of this research. A freshly developed design grid for the current cylinder of the F20C 4-stroke 4-cylinder engine that forms the basis of the Honda S2000 is examined in detail and dissected. The goal was to research piston designs that maintain a similar volume yield in the cylinder while being lighter and more effective. By the time all was said and done, the piston's weight was decreased by over 23%.[5] This study looks at ways to make connecting rods lighter and less expensive during the design and development stages. Rod analysis was carried out at two stages. First, loads operating on the rod were analyzed. Next, a finite element study was performed to determine if the general deflection (GD) could bear both comparative and tensile stresses. [6].

III. METHODOLOGY

A. Conventional Design Process

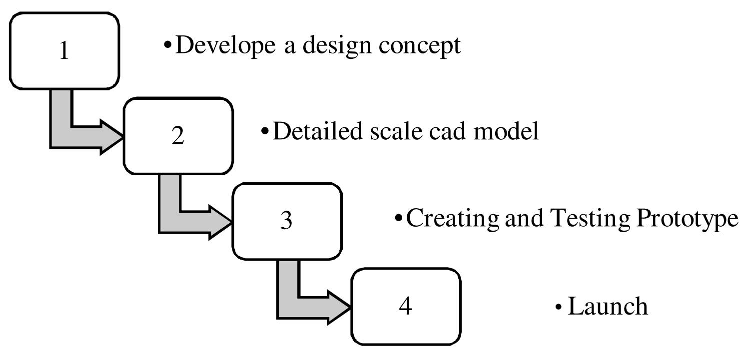

Figure 1. Conventional Design Process

1) Develop a Design Concept

Creating a design concept is the first stage in the CAD modeling process. The client's preferences must be known by the designer. After that, the designer will create a design concept and submit it for the client's approval. The designer will then use the program of his choosing to produce a rough draught of the design.

2) Make a Detailed Scale CAD Model

You should have a clear understanding of the final model's visual appearance before beginning a 3D product design. A talented designer may produce both aesthetically pleasing and ergonomically sound products. A model that can be simply produced by a 3D printer can be created with the help of good 3D CAD modeling services.

3) Creating and Testing Prototype

One of the essential steps in the product design process is prototyping. You might develop a physical prototype or an integrated system, depending on the product. Both can be used to test your theories and determine whether your solution can actually address the issue it was designed to address. It is essential to test your prototype on actual people and solicit their input on how to make it better. You could keep making changes to your prototype until you accomplish your initial objectives. The prototype will give you more insight into how your product will appear, feel, and work, as well as whether it will be able to meet the original requirements.

4) Launch

After that, the brand-new product design is exhibited in a very striking manner. In order to attract people and persuade them to purchase the goods, it must be promoted effectively. A positive first impression of the company and its brand should be created through the product's presentation.

B. Generative Design Process

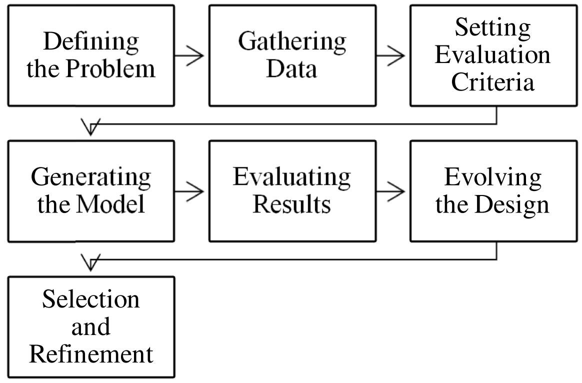

Figure 2. Generative Design Process

1) Defining the Problem

Defining the problem is the first stage in generative design. Thus, the decision regarding the structure to be built must be made by the designer and their client. They should decide on the fundamental terms and requirements for the design as well as what to exclude. They must also decide what qualifies as a suitable design in addition to that. In addition, they also state the features they want to emphasize or minimize. This phase's main objective is to aid in the understanding and definition of the project. You would want to pose questions and obtain answers while breaking the project down into smaller, easier parts.

2) Gathering Data

It's now time to begin collecting data after finishing the defining phase. Requirements and limitations for the project are the main emphasis of this stage. Depending on the style and location of the structure, they can differ significantly. You might need to be aware of the space's characteristics when designing an exhibition hall, for instance. Boundaries, as well as the places where restrooms, entrances, and exits are located, are among them. The desired column placements, as well as the overall size and form, are other possible input factors. Design restrictions come next on the list. Client requests might be one of these, while pre-existing boundaries might be the reason for another. During this stage, the project is further defined, and the information needed for the initial iterations is provided.

3) Setting Evaluation Criteria

With the customer, the designer would decide on the project's objectives or evaluation standards in the third phase. Additionally, the customer would need to specify their expectations for the design as well as set objectives and evaluation standards. It's crucial to specify the requirements as precisely as possible. The design and solution may get more complicated as a result. However, modern computers are capable of handling that, and GD software gives better and more relevant results with more input parameters.GD software program might not be able to provide any practical answers for poorly specified targets. Results could be worthless and are probably random. And doing so would just cause the project to be delayed.

4) Generating the Model

It's time to create the model after outlining the project objectives and evaluation standards. It would be a good idea to document every design phase because it will make creating models much simpler. You must enter the design limitations and other crucial project details for the GD programme to function. For instance, the type, amount, and price. The designer should also think about how the design aspects relate to one another. The design's interaction with the environment is another factor to consider. It is time to enter any relative limitations if there are any. After that, you can run the software to generate a variety of design options.

5) Evaluating the Results

The software evaluates and ranks all of the design options it generated in this step using the pre-established metrics. The best answers are then chosen from each category, and these serve as the foundation for the following set. It gains knowledge and enhances the general caliber of each set in this way.

The criteria established in earlier steps directly affects how well the outcomes turn out. So, if the GD programme was given measurements that were not well specified, the quality of the designs as a whole would be off. Because of this, it's unlikely that much progress will be made during this evaluation phase. And it's likely that you won't receive the best design.

6) Evolving the Design

The software chooses the best design options and bases new designs on them in the sixth step of generative design. This phase's function is to eliminate suboptimal solutions and identify the top ones in each category. To improve your chances of getting the greatest final result, you might need to adjust the search metrics during this stage. Iterations are the technical term for the several design generations that make up a GD process. Some projects may require up to 100 iterations. And having tens or even hundreds of designs per iteration is not uncommon.

7) Selection and Refinement

The process of selection and refining is the last step in generative design. In this section, you can examine the software's top design suggestions. Then, you would choose from a limited selection of designs, ideally ones that do well across all categories. A select few carefully chosen designs are the subject of the refinement phase. Before deciding on the best option with the client's input or agreement, the designer manually enhances them to satisfy all the criteria.

To compare the two design processes, we implemented the conventional design process and Generative design process on design on piston for a 250-cc engine with 24Nm @7500 rpm and 30Hp @9000 rpm.

C. Material Selection

1) AlSi10Mg aluminum parts are perfect for applications that call for a balance between high thermal performance and lightweight.
2) It may be used for parts with complicated geometry and thin walls. Since it has good strength, hardness, and dynamic qualities, it is also utilized for parts that must withstand heavy loads
3) AlSi10Mg is very processing-friendly and distinguished by both a strong electrical conductivity and an excellent resilience to corrosive environments.
4) It may be utilized for highly stressed components due to its ability to achieve high strengths while preserving dynamic load capacity.

Properties	**Values**
Yield Strength	251 MPa
Elastic Modulus	76600 MPa
Tangent Modulus	5000 MPa
Poisson's coefficient	0.33
Bulk Modulus	$7.5098*10^4$ MPa
Shear Modulus	$2.8797*10^4$ MPa

Table 1. Material Properties of AlSi10Mg

- *Piston:* Engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. The modeling of the piston was carried out using two different processes: first conventional design and other generative design.

D. Calculations

Engine Type	Single Cylinder, 4- Stroke, 4V DOHC Engine
No. Of Cylinder	1
Cooling system	Liquid Cooling
Displacement	248.76
Max Power	30 hp @9000 rpm
Max Torque	24 Nm @ 7500 rpm
Bore	72 mm
Stroke	61.1 mm
Compression Ratio	12.5 : 1

Table 2. Engine Specification

E. Conventional Design

The conventional design process was followed in design the piston. First, a design concept was created. Illustrating the design parameters and requirements. Then a detailed sketch was created using Fusion 360 as shown in Fig. 3. With all the specified dimensions.

Using this sketch as the baseline a 3d model was created using the revolve command, which illustrates the detailed 3d cad model of the piston on which the analysis was done. The Fig. 4. Represents the detailed cad model of the piston designed using conventional design process with material specifies from table 1, and specification derived from Table 2. The Fig 5. Represents the section view of the piston on Y-axis.

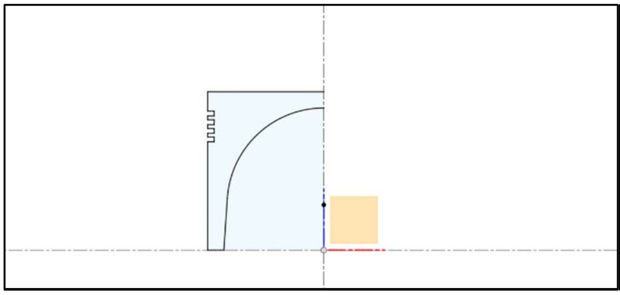

Figure 3. Piston Sketch

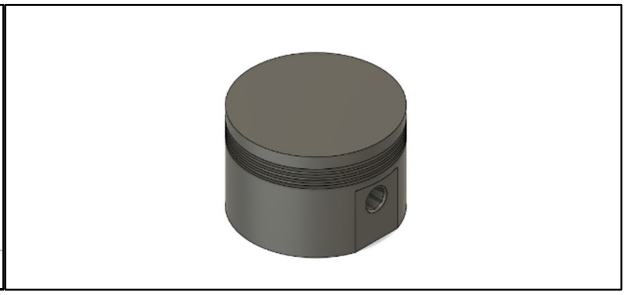

Figure 4. 3d-Isometric View of Piston

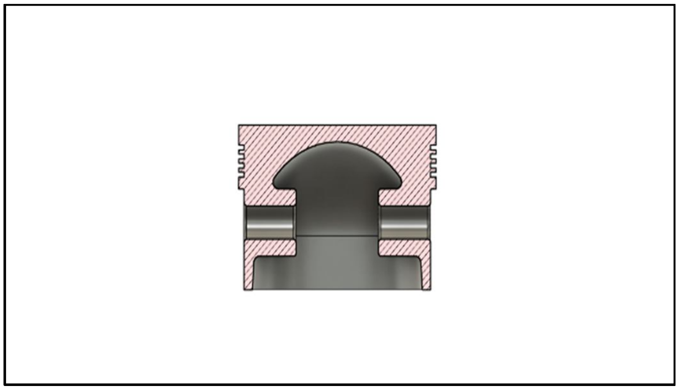

Figure 5. Section View

Next, we performed weight reduction techniques on the original piston by removing material from the areas which was not under the maximum stress and thus reducing the overall weight of the piston, as shown in Fig. 6.

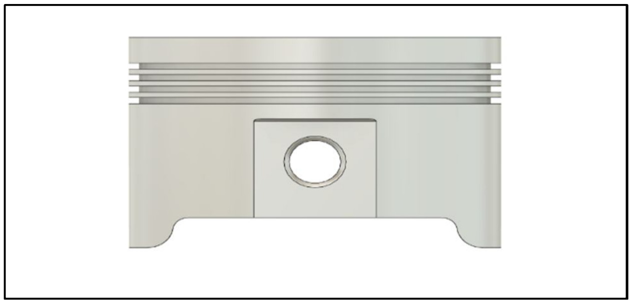

Figure 6. 3d View of Piston

F. Generative Design

Now moving to the generative design process, the piston design is totally opposite to the conventional design process. Using the above calculation data, we could define the problem and set a few parameters. On these parameters the initial sketch is designed below.

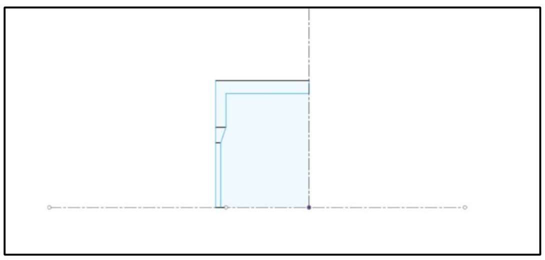

Figure 7. Sketch for Generative Design

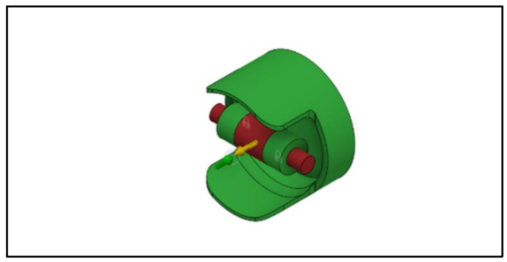

Figure 8. Preserved and Obstacle Geometry

The following image is a definition of the design criteria. The preserved geometry and the obstruction geometry are described in the provided image. One of the geometry kinds in the design space is an obstacle geometry. It is given to bodies to symbolize areas that you wish to keep out of the design. On the canvas, bodies assigned an obstacle geometry are shown in red. They stand for voids where no material is produced during the development of results. Without the obstacle geometry body in your model, you may still produce results. One of the geometry kinds in the design space is a preserved geometry. You give bodies the responsibility of incorporating them into the design's ultimate shape. On the canvas, the bodies given a preserved geometry display in green. They remain unchanged while the outcomes are generated. Your model needs at least one body that is utilized as the preserve geometry in order to get results. The final design includes the preserved geometry, which is considered as a part of design, however the obstacle geometry must be avoided by the generative design method and should not have any additional material added.

Figure 9. 3d-Isometric view

Figure 10. Side view

The provided image is the final design form generative design process, with all the final finishing done.

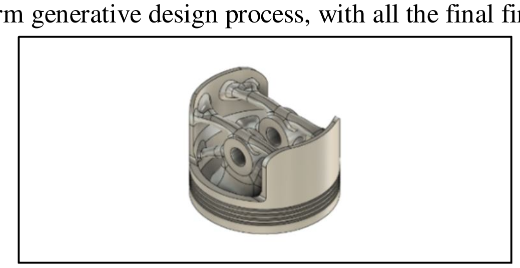

Figure 11. Bottom Isometric view of Piston

The above Figures Fig.9, Fig.10, Fig.11, shows different views of the piston developed using the generative design process. It could be observed that in generative design the minimal material is used, and thus it results in weight and cost saving.

IV. OBSERVATION

A. Displacement

Following figure shows the maximum displacement of the piston head due to forces applied on it, i.e., 0.004701 mm observed at the lower portion of the piston head in Fig. 12A, and 0.007557 mm in Fig. 12B.

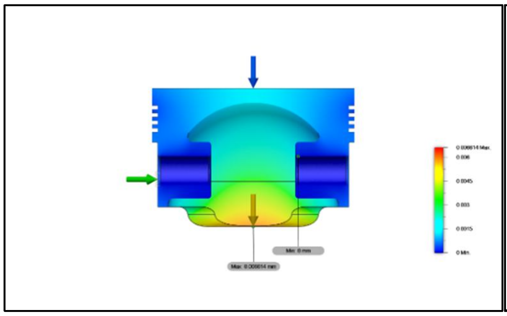

Figure 12A. Displacement in Conventionally Designed Piston

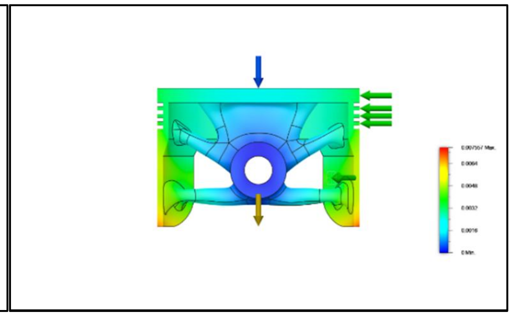

Figure 12B. Displacement in Generative Designed *Piston*

B. Heat Flux

Following figure shows that the maximum and minimum heat flux i.e., 1.997 W/mm2 and 0.008157 W/mm2 respectively in Fig. 13A, and 4.945 W/mm2 and 0.004 W/mm2 respectively in Fig. 13B.

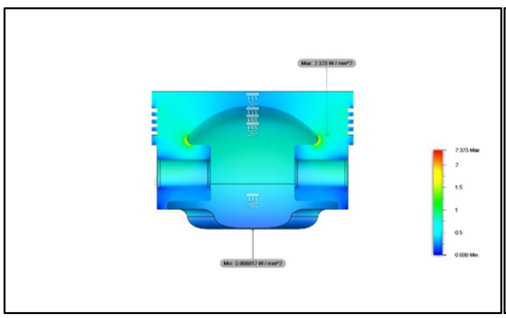

Figure 13A. Heat flow rate in Conventionally Designed Piston

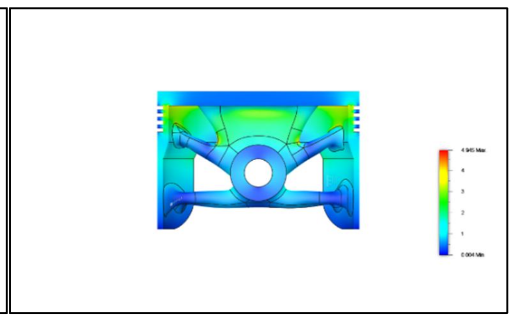

Figure 13B. Heat flow rate in Generative Designed Piston

C. Safety Factor

From the following figure it is observed that the overall safety factor of the design is 15 in both the cases as shown in Fig 14A. & Fig. 14B., hence the design is super safe.

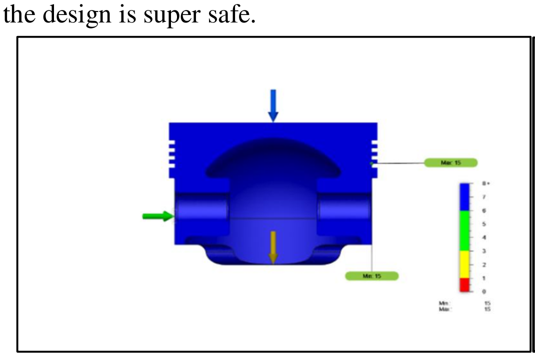

Figure 14A. Safety Factor of Conventionally Designed Piston

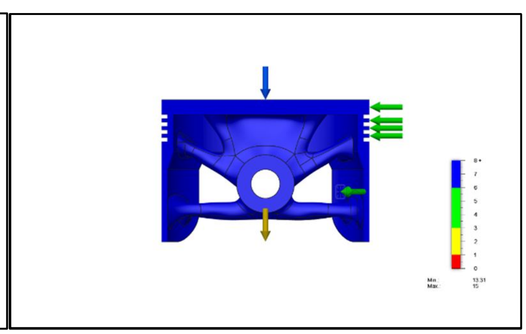

Figure 14B. Safety Factor of Generative Designed Piston

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D. Strain Equivalent

The strain in the model was in the range 0.001E-04 to 3.093E-04 in conventionally designed piston, as shown in Fig. 15A. similarly for piston designed using generative design, the strain was in the range of 0.002E-04 to 4.162E-04 as shown in Fig. 15B.

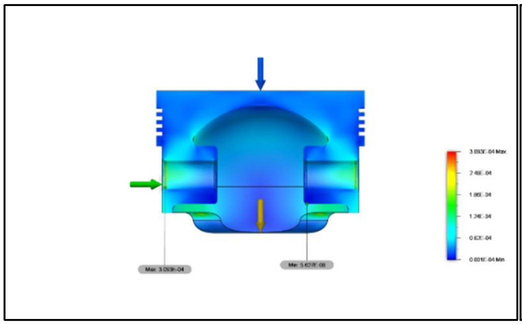

Figure 15A. Strain occurred in Conventionally Designed Piston

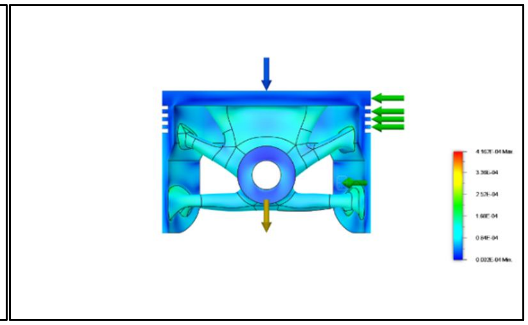

Figure 15B. Strain occurred in Generative Designed Piston

E. Temperature

Following figure shows the maximum temperature applied at the top surface of the piston due to fuel combustion taking place is 500 C. Some of the heat is absorbed by the oil as it acts as a coolant from the under surface of the piston. About 450 W/m^2 K is absorbed by oil and about 300 W/m^2 K heat is transfer to the engine block. The Fig. 16A, Fig. 16B shows the temperature distribution along the piston.

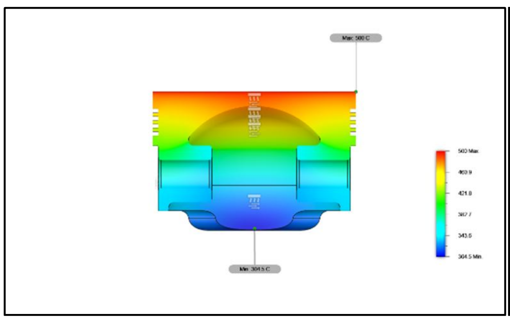

Figure 16A. Temperature distribution in Conventionally Designed Piston

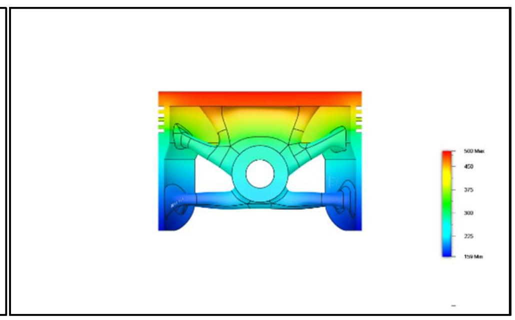

Figure 16B. Temperature distribution in Generative Designed Piston

V. CONCLUSION

In the traditional design process, an initial concept is analyzed and modified until a satisfactory design is produced. At each stage, the design qualities are evaluated and compared to the defined requirement. Generative design, on the other hand, is an iterative design approach that uses a computer to produce a certain number of outputs that adhere to predetermined requirements. Comparing both the results of Conventional and generative model. It is found that heat flux of Conventional design was 1.997W/mm2 and 0.008157W/mm2. and in generative design it was around 4.945W/mm2 and 0.004W/mm2. Talking about Strain in both models in generative design and conventional design is respectively 4.162E-04 to 0.002E-04 and 4.578E-08 to 2.831E-04. Temperature noted in both the Case is same maximum around 500C while we could see a better temperature distribution in piston designed using generative design with minimum t6emperature of 159 degC. Talking about Von mises stress in generative design goes from lower 0.01Mpa to 18.04Mpa & in conventional is Higher 14.2 Mpa and lower is 0.003708Mpa

In this research, a both design approaches were used, where the piston was first created using a conventional design procedure. The use of obstacles and conserved geometry was then used as part of a further generative design approach. Where a certain design element was preserved while cutting down an undesirable component. The piston's weight was successfully reduced by 45% using this design strategy, making it lighter and more effective. Because of this, GD procedures use less raw material than traditional design processes, which reduces costs and improves engine efficiency. It not only reduces costs but also has a significant positive environmental impact. This decreases the need for raw materials, which lowers their price, decreases mining, and lowers the environmental damage caused by mining. Also, further investigation is needed to be conducted in this area and solutions need to be presented how generative design process can be implemented with the conventional design process, and how a hybrid design process will have impact on project management, cost of the project and time required to complete the project.

VI. ACKNOWLEDGEMENT

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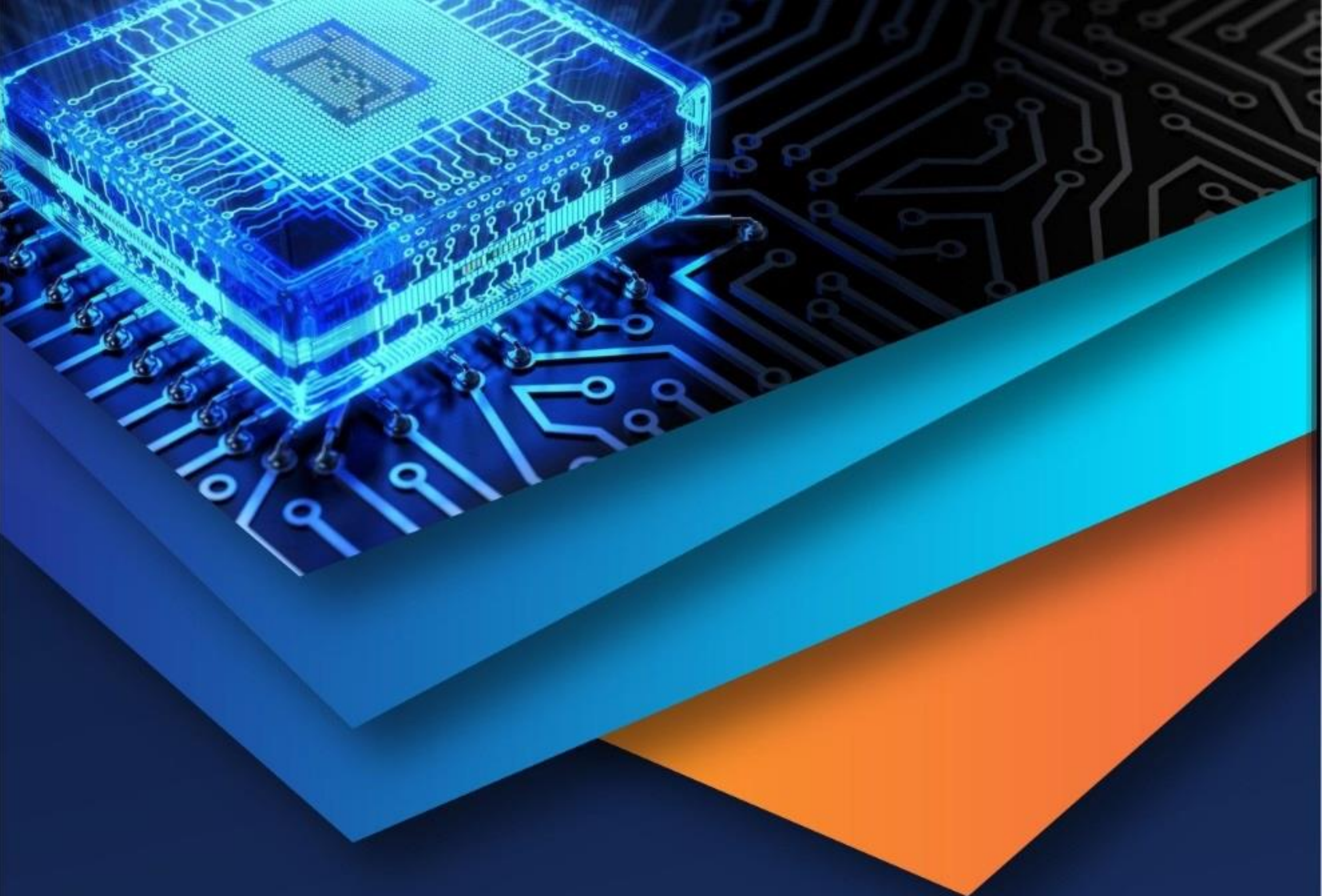

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