

“INVESTIGATION OF RAPID PROTOTYPING AS AN EFFECTIVE TOOL FOR MANUFACTURING OF INTRICATE GEOMETRIES OF AUTOMOTIVE COMPONENTS”

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ABSTRACT: Tooling is one of the slowest and most expensive step in the manufacturing process, because of the extremely high quality required. To meet these requirements, moulds are traditionally made by CNC-machining, electro-discharge machining or conventional technologies.

The term Rapid Prototyping (RP) refers to a group of technologies that can automatically construct physical model from Computer Aided Design data. Rapid Prototyping allows them to be made quicker and less expensively. The Rapid Prototyping techniques involves basic five step process like, Create a 3D CAD model of the required design, Convert the CAD model to STL format, Slice the STL file, Construct the model Layer by Layer and finally Clean and finish the model. Rapid Prototyping is widely used in fabrication of intricate parts of automotive, aerospace, medical and consumer products industries. Also especially moulds are made from RP model from Rapid Tooling.

In this paper a case study of manufacturing of engine head is taken. In contrast to production of models by machining, based on the removal of material until the required form is achieved, RP model is made by adding material layer by layer until the whole part will be completed.

1. INTRODUCTION

Rapid prototyping is the automatic construction of physical objects using solid freeform fabrication. It fabricates the parts layer-by-layer. It involves adding raw & support material successively, in layers, to create a solid of a predefined shape. These parts are used in the various stages of a product development cycle. Wholers conducted a survey, and found that around 23.4% of RP parts are used as visual aids, whereas 27.5% of them are used as master patterns and for direct tooling. Industries use 15.6% of them for fit and assembly tests, 16.1% for functional tests and the rest for quoting, proposal, ergonomic, evaluation.

The following flowchart shows the flow of a typical RP process. The first step is to validate the 3D CAD model of a part, i.e. to ensure it is a solid. The valid model is then oriented with respect to the building chamber, by considering the build-time and the surface quality. A few models may either be merged into a one-build assembly.. Based on the process requirement, support material may be added to the model, if necessary. It is then sliced with a set of horizontal planes. Each horizontal plane yields a planar slice contour, which is crosshatched to determine the laser trajectories to control the sintering or solidification process. By scanning one layer over another, the part grows incrementally to its final shape. Thus, the main steps for the process planning include orientation support structure generation if necessary, slicing and selection of the process parameters.

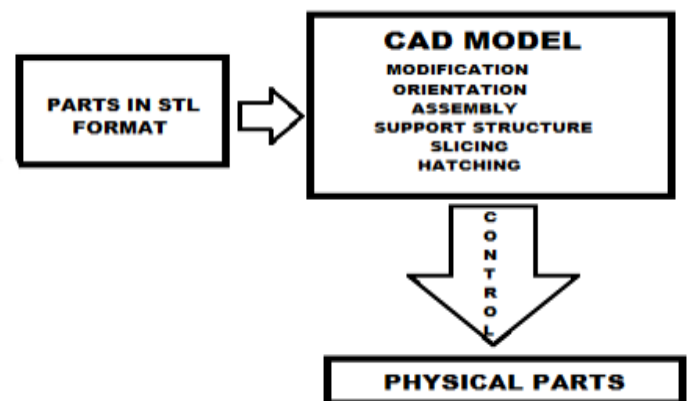


Figure1: RP Process Flow Chart

Process planning is performed to select the process parameters and to generate the control instruction to fabricate a intricate machine part. There is a need to automate the complete process because of very time-consuming process planning & part and quality requirements, which is indeed [2,3]. This can be achieved by linking the designer understands and decision making with the physical process planning is also one of the fundamental mottos of RP, which are

- To build arbitrarily intricate 3D shapes;
- To use a generic fabrication machine which does not require part-specific tooling?
- To generate a process plan automatically, based on a CAD model;

- To diminish human intervention.

This paper describes the fabrication of machine cooling head which is a intricate automotive component. The complete process which we have manufactured by using Fused deposition method (FDM)

2. COOLOING HEAD DESCRIPTION

In an internal combustion engine, the cooling head (often informally abbreviated to just head) sits above the cylinders on top of the cylinder block. It closes in the top of the cylinder, forming the combustion chamber. This joint is sealed by a head gasket. In most engines, the head also provides space for the passages that feed air and fuel to the cylinder, and that allow the exhaust to escape. The head can also be a place to mount the valves, spark plugs, and fuel injectors.

In a flathead or side valve engine, the mechanical parts of the valve train are all contained within the block, and the head is essentially a metal plate bolted to the top of the block; this simplification avoids the use of moving parts in the head and eases manufacture and repair, and accounts for the flathead engine's early success in production automobiles and continued success in small engines, such as lawnmowers. This design, however, requires the incoming air to flow through a convoluted path, which limits the ability of the engine to perform at higher revolutions per minute (rpm), leading to the adoption of the overhead valve (OHV) head design, and the subsequent overhead camshaft (OHC) design.

Internally, the cooling head has passages called ports or tracts for the fuel/air mixture to travel to the inlet valves from the intake manifold, for exhaust gases to travel from the exhaust valves to the exhaust manifold. In a water-cooled engine, the cooling head also contains integral ducts and passages for the engines' coolant - usually a mixture of water and antifreeze - to facilitate the transfer of excess heat away from the head, and therefore the engine in general.

In the overhead valve (OHV) design, the cooling head contains the poppet valves and the spark plugs, along with tracts or 'ports' for the inlet and exhaust gases. The operation of the valves is initiated by the engine's camshaft, which is sited within the cylinder block, and its moment of operation is transmitted to the valves pushrods, and then rocker arms mounted on a rocker shaft - the rocker arms and shaft also being located within the cylinder head.

In the OHC design, the cooling head contains the valves, spark plugs and inlet/exhaust tracts just like the OHV engine, but the camshaft is now also contained within the cylinder head. The camshaft may be seated centrally between each offset row of inlet and exhaust valves, and still also utilizing rocker arms (but without any pushrods), or the camshaft may be seated directly above the valves eliminating the rocker arms and utilizing 'bucket' tapets.

The number of cylinder heads in an engine is a function of the engine configuration. Almost all inline (straight) engines today use a single cooling head that serves all the cylinders. A 'V' engine has two cylinder heads, one for each cylinder bank of the 'V'. For a few compact 'narrow angle' V engines, such as the Volkswagen VR6, the angle between the cylinder banks is so narrow that it uses a single head spanning the two banks. A flat engine (basically a V engine, where the angle between the cylinder banks is now 180°) has two heads. Most radial engines have one head for each cylinder, although this is usually of the monobloc form wherein the head is made as an integral part of the cylinder. This is also common for motorcycles, and such head/cylinder components are referred-to as barrels.

Some engines, particularly medium- and large-capacity diesel engines built for industrial, marine, power generation, and heavy traction purposes (large trucks, locomotives, heavy equipment etc.) have individual cylinder heads for each cylinder. This reduces repair costs as a single failed head on a single cylinder can be changed instead of a larger, much more expensive unit fitting all the cylinders. Such a design also allows engine manufacturers to easily produce a 'family' of engines of different layouts and/or cylinder numbers without requiring new cooling head designs.

The design of the cooling head is key to the performance and efficiency of the internal combustion engine, as the shape of the combustion chamber, inlet passages and ports (and to a lesser extent the exhaust) determines a major portion of the volumetric efficiency and compression ratio of the engine.

3. DESIGNING AND MANUFACTURING OF COOLING HEAD

- A CAD model of cooling head is constructed and then converted to STL (standard triangular language) format.
- The STL is given to RP device (FDM Machine) as a input which created sliced layers of the cooling head. The resolution of future model directly depends on quantity of the layers, since all layers must have identical thickness.
- Thus the fabrication of physical cooling head model is created, by the additive layer thickness, and the process is repeated until completion of the model.
- Finally the model and any support material are removed; the surface of the model is then finished and cleaned. Thus RP model which is prepared is then utilized for formation of mould and pattern was being prepared.



Figure 2: Cooling Head

4. DATA FLOW OF THE BASIC RP PROCESS DURING MANUFACTURING OF COMPONENTS

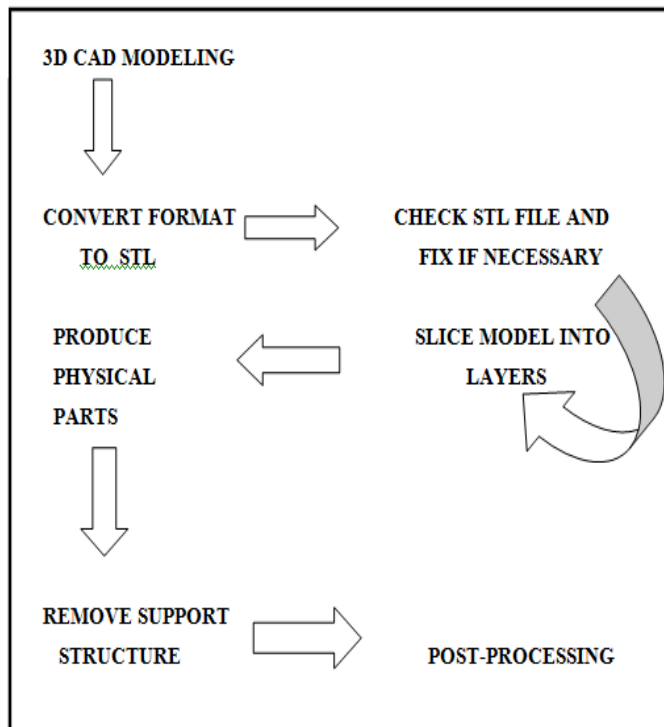


Figure 3: The data flow of the basic RP process

Most current CAD packages can export a CAD file in STL file format, and good STL files will assure a speedy quote turnaround, and good quality RP models. The STL format is an ASCII or binary file used in the RP process. It is

a list of triangular surfaces that describe a computer-generated solid model. The binary files are smaller when compared to ASCII files. The facets define the surface of a 3D object. As such, each facet is part of the boundary between the interior and the exterior of the object. The orientation of the facets (which way is “out” and which way is “in”) is specified redundantly in two ways that must be consistent. First, the direction of the normal is outward. Second, the vertices are listed in counterclockwise order when looking at the object from the outside (right-hand rule).

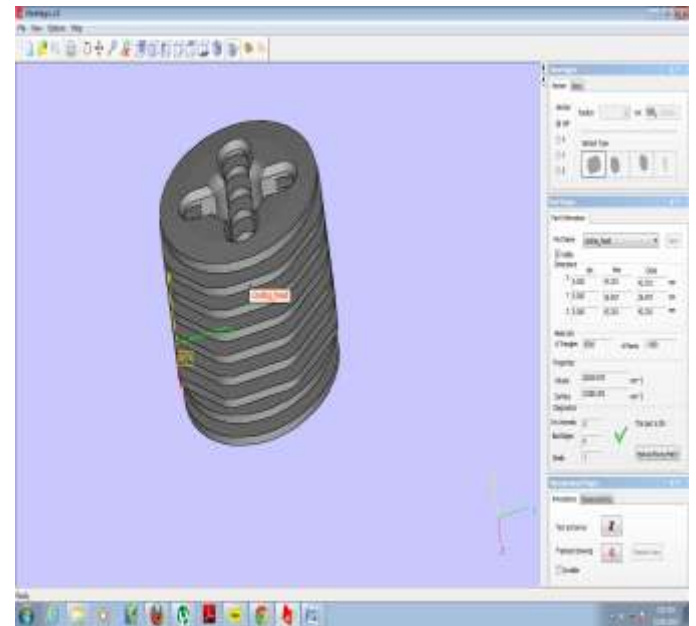


Figure 4: Designing of Cooling Head

5. MODEL BUILDING

Once the STL file is sliced and transferred into an RP machine it will be converted into the build process which is fully automated. The support material is being removed from the build material by increasing the temperature of the solution to melt the support material but not the build material that has a higher melting temperature. The method of support material removal can vary from process to process. For example, some processes will require support breakaway or grinding operation to remove the support material.

5.1 FDM Technique

FDM FEATURES

- Competitive with other RP technologies
- Strong and durable model
- ABS plastic (with color choices) and Elastomer material choices, Water proof, paintable .

- Maximum size- 10" x 10" x 16"

Rapid prototype models can be used as design evolution, manufacturing tools (assemblies, test fixtures, visual aids), sales tools (internal and external), estimating tools (prototype parts included in drawings) and master patterns for composite molds.

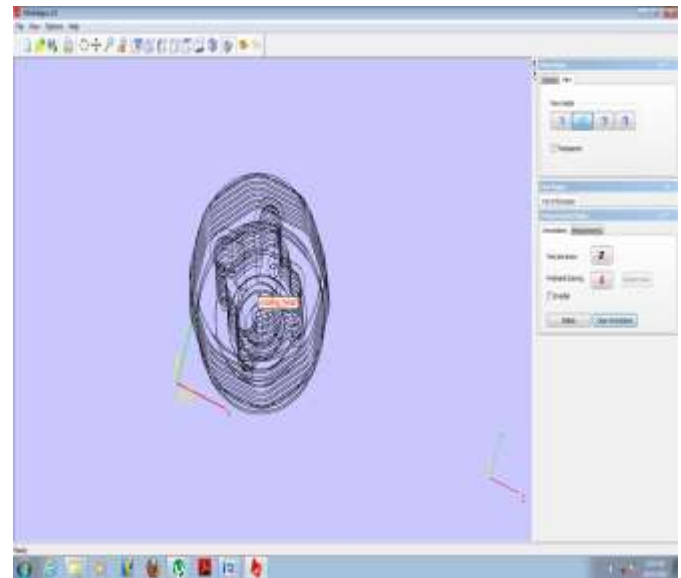


Figure 5: Fused Deposition modelling (Machine)

5.2 SLICING THE STL FILE

The generation of a series of closely spaced 2D cross-sections of a 3D object is known as slicing. Generally, the user can specify the Z-thickness of the slice. Typical thickness is 0.006 in. This is always an approximate process. The main error associated with this is the staircase error because the surface finish in the Z-direction will not be

good. After the STL part is properly oriented and positioned, the user then slices the part into layers. Figure 45 shows the sliced file for the first orientation of the cone. After the part is sliced, it automatically generates the support structure, as most RP software does. For the first orientation of the cone, five layers of support material were generated under the base of the cone. Five layers is the machine default in order to allow the part not only to hold tight to the plastic sheet in the FDM machine, but also to allow the part to be easily separated from the plastic sheet after the build is complete. Figure 46 shows the same cone rotated 180° so that it is sitting on its point. If the user wanted to build the cone in the inverted orientation, for whatever reason, the software provides the user with the ability to designate other support alternatives. One example would be to encapsulate the part in support material to hold it in place. The downside to this selection is the build time. Since there is support material being deposited on every layer of the build, this will be the longest build time compared to the build with the cone sitting on its base. After the orientation and the support decision have been made, the user then determines the tool path that the machine will use to build each layer. The tool path allows a great variety of options to the user depending on finished part strength, build time, or weight and surface finish. One of the biggest variables is the orientation of the tool path. The software allows the



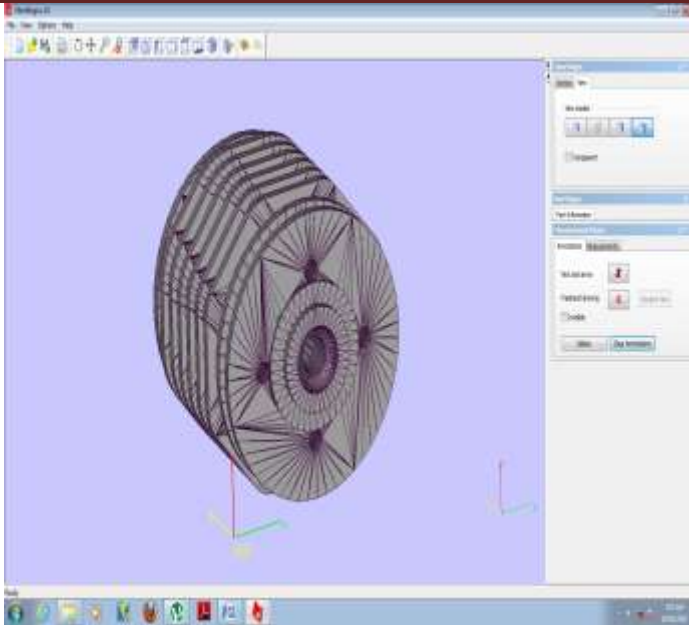


Figure 6: The Cooling Head is sliced into fine layers

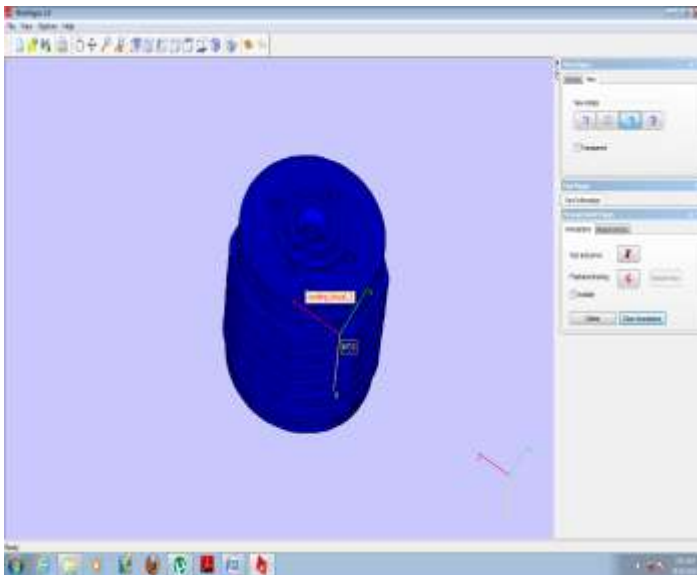


Figure 7: The Cooling Head is rotated 180° so that it is sitting on its point.

The software allows the user to set the orientation in each layer. For a more isotropic part, it automatically sets the layers to a $\pm 45^\circ$ orientation with the exterior boundary curve. This tool path selection can be seen in given figures. It also has the capability to generate a “hollow” part by creating a tool path with larger air gaps in the middle that forms a mesh-like interior. This sparse fill, as it is called, dramatically decreases material used, which in turn increases the build speed of the part.

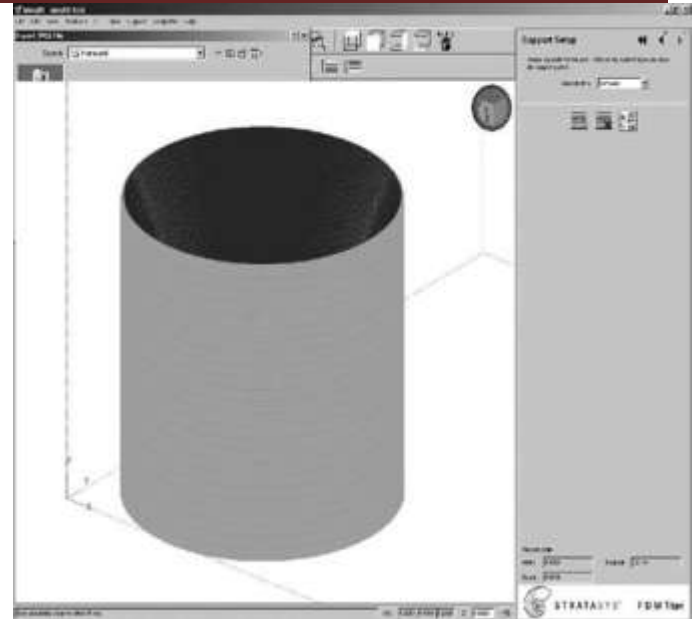


Figure 8: The support material surrounding the part is generated for the inverted Cooling Head

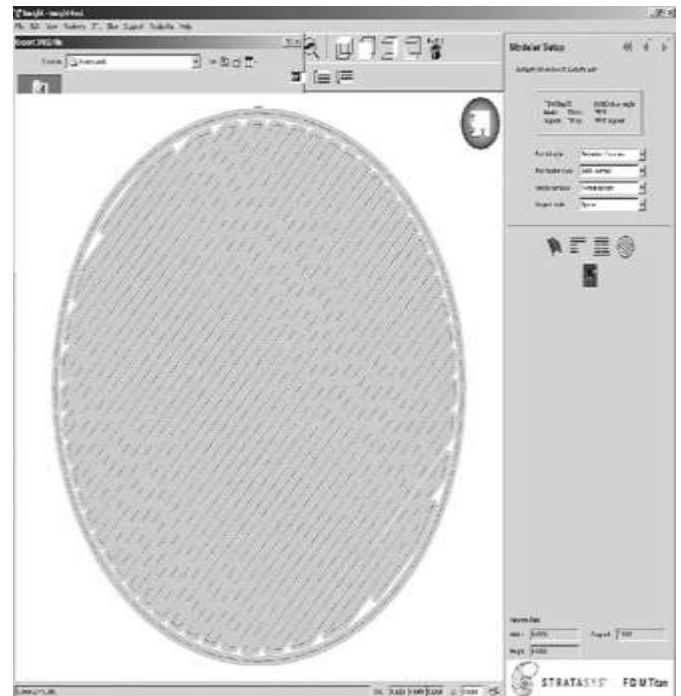


Figure 9: Tool Path Selection

The tool path shown in one layer. The tool path is 45° in a zig-zag pattern. Note that there is a tool path that is along the boundary of the layer to make the outer surface smoother. The above figure shows an airplane example to be sliced with Insight. The upright orientation will produce better surface quality on the wing structures but will result in a longer build time. Figure shows the result of slicing the STL file at the selected layer thickness. The STL file

disappears, but may be redisplayed if necessary. Each layer is a cross-section of the interior and exterior boundary and one can view a single layer, a group of layers, or all layers in any orientation. The FDM machine's tip sizes and slice thicknesses with their respective default tool path widths as well as their minimum and maximum tool path widths. The speed of the drive wheels can control the flow of material creating a range of tool path widths. The default tool path widths may result in unfilled areas as shown in Figure. As this is a printer part that was to be used as a functional prototype, the hole was to be reamed out to a precise size but with the gap, the center would break out, making it unusable. Within Insight, the user can create custom groups of tool path parameters as shown in Figure to achieve the proper fills enabling them to ream the hole and use the part as a functional prototype.

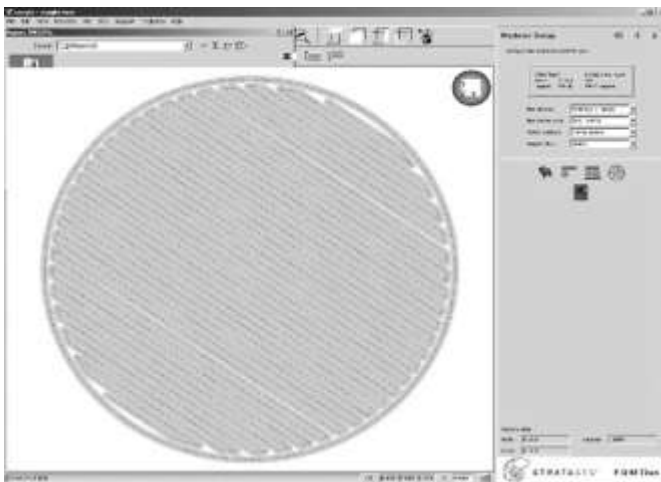


Figure 10: The tool path is also in 458 in a zig-zag pattern but in a different orientation

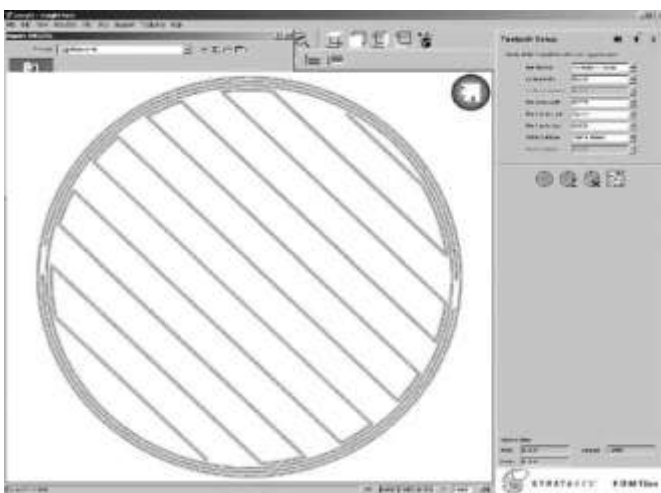


Figure 11: The “sparse fill” generates a hollow part that is created with tool paths with larger air gaps in the middle that forms a mesh-like interior. After the support and tool path are defined, the location and orientation of the model is built is as shown as follows.



6. CONCLUSION

This paper has revealed that the most advanced manufacturing technique i.e rapid prototyping in mechanical engineering has great potential in the Manufacturing of complex intricate parts. The manual method is subjective by nature but this defined advanced methodology allows the designer to intuitively control the final design.

7. REFERENCES

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