DIGITAL DESIGN OPTIMIZATION TO ENHANCE PERFORMANCE THROUGH ADDITIVE MANUFACTURING

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Abstract: Manufacturing Industries and investors are always seeking to improve techniqueto lower the cost, energy and expand their capabilities. Design optimization is oneway to improve the performance of the part & lower the cost of manufacturing. Contrary to established Traditional (Subtractive Manufacturing (SM) and Formative Manufacturing) techniques, whereby material is either removed via machining, drilling or grinding techniques or casted into molds, AM has a higherlevel of design freedom. The ability to fabricate complex parts in one machine and job, has businesses determined to establish AM as a certified end-user product manufacturing technique. The drive behind the rapid advancement of AM technologies is due to the research focus on developing low cost machines, increased material variability, and the complexity advantage to cater to a wide range of applications. The design freedom offered by AM has its advantages and disadvantages from an industry perspective. The ability to produce complex geometries, difficult to achieve utilizing material removal methods, make it unnecessary for AM to follow the traditional design for manufacturing and assembly. Instead, AM falls under its own manufacturing design regulations, design for additive manufacturing (DFAM). However, standardization and establishment of DFAM principles is still progressing.

1. INTRODUCTION

Traditionally, when design a part for CNC milling, one need to consider mill's make and model, capabilities and work volume. These considerations are machine driven while high tolerance features, tool changes, and setups are all partdriven. Beyond machine-versus part-driven considerations, there are details like spindlespeed, materials, and tool type that further impact the manufacturing process withCNC milling. If one has a complex part, it's easier to make on a more complex machine, but those machines are more expensive. Design for CNC milling requires upfront consideration of every operation required to produce a part, as well as the associated tool needed to perform that operation.

Additive Manufacturing (AM) technologies are increasingly adopted as an alternative to traditional manufacturing methods as the process offers significantadvantages. AM enables the creation of highly complex components and realizeslightweight strategies while increasing components' performance. To fully tap into the lightweight, high-performance potential of AM, one must consider many factors, including the degree of design freedom or the design of the component based on its intended use. Design optimization, a systematic process to achieve the 'best' design relative to a set of constraints and criteria, can be applied to create new advanced structural geometries and to optimize components' strength,reliability, efficiency as well as utilization. Additive manufacturing operates by adding layers of material together to make an object. Traditional manufacturing methods, by contrast, are subtractive in nature. Subtractive manufacturing involves removing parts of a block of materialin order to create the desired shape. Cutting wood into useful shapes, for instance,is a very simple example of a subtractive process.

The basic physical difference in how objects are made with additive manufacturing also produces some major functional differences. The most important of these functional differences is that additive manufacturing can be used to create complex geometries that would be difficult or impossible to achieve with traditional manufacturing methods. These complex geometries are often stronger and lighter than their traditionally manufactured counterparts. Strongly related to its ability to create complex geometries more easily than other manufacturing methods is the fact that additive manufacturing eliminates the additional costs normally associated with creating more complex objects with traditional methods, a highly complex part typically costs much more to make than a very simple one. But in additive manufacturing the process is identical regardless of the complexity of a part. Here, below are few examples of optimized design.

Fig. 1: Traditional design (conventional Manufacturing) & Optimized design (Additive Manufacturing)

2. METHODOLOGY

2.1 Block Diagram:

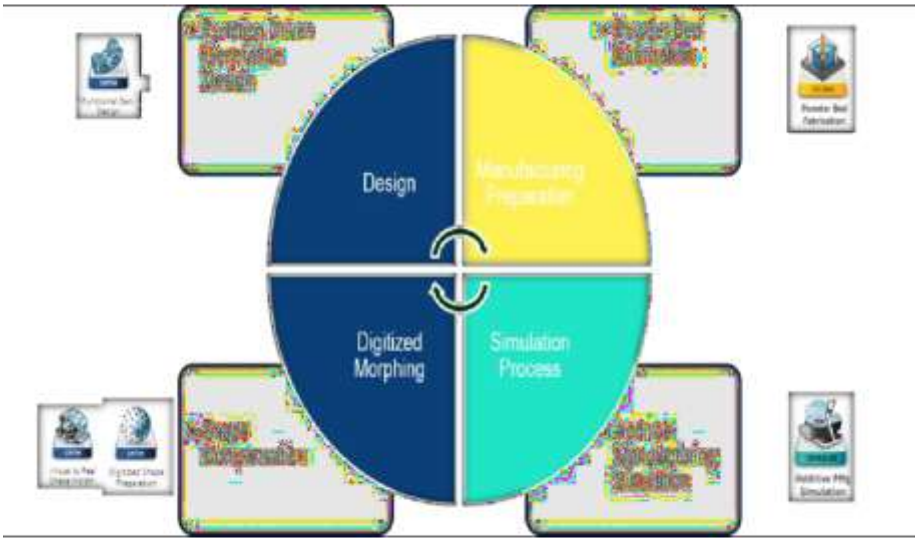


Fig 3.1. Block Diagram

3.2 Workflow Steps:

- **Design Phase:**
  Start with CAD modeling, considering AM-specific constraints (e.g., overhangs, support structures). Optimize the component's geometry for weight reduction,performance, and manufacturability.

- **Manufacturing Phase:**
  Use AM machines (e.g., selective laser sintering, digital lightprocessing) to build the component layer by layer. Monitor the process in real time using sensors and IoT.

- **Post-Processing Phase:**
  Apply finishing techniques (e.g., centrifugal finishing) to improvesurface quality.
  Evaluate the final part's performance and cost.

3.3 Mid Sem Update details:

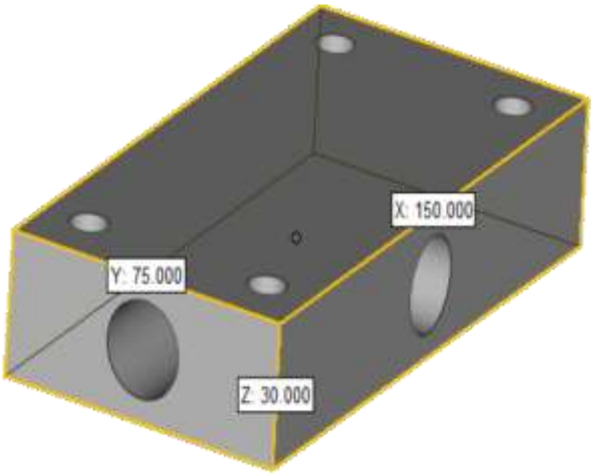


Fig 3.3 Conventional Design of Hydraulic Manifold

The basic modification in the flow path have been done. The flow paths are optimized to rhombus in shape. The intend of modifying the circular path to rhombus is to manufacture the part without support in AM. Only circular shape has been changed to rhombus without changing the connection points. The basicstudy of support analysis is carried out. The modification in shape is done based on one of the DFAM principal. The circular shape (<6mm) is required support to print in AM.

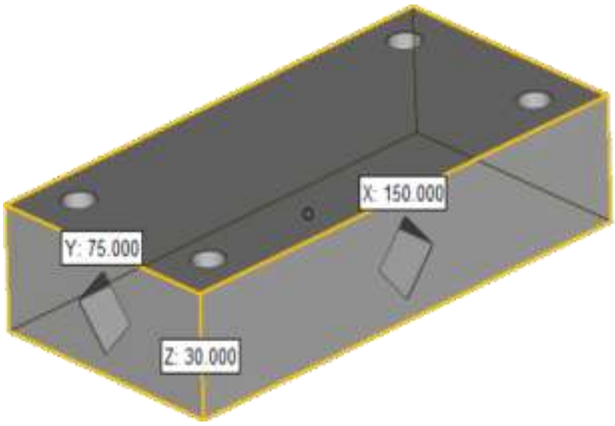


Fig. Modified flow path shape of Hydraulic Manifold

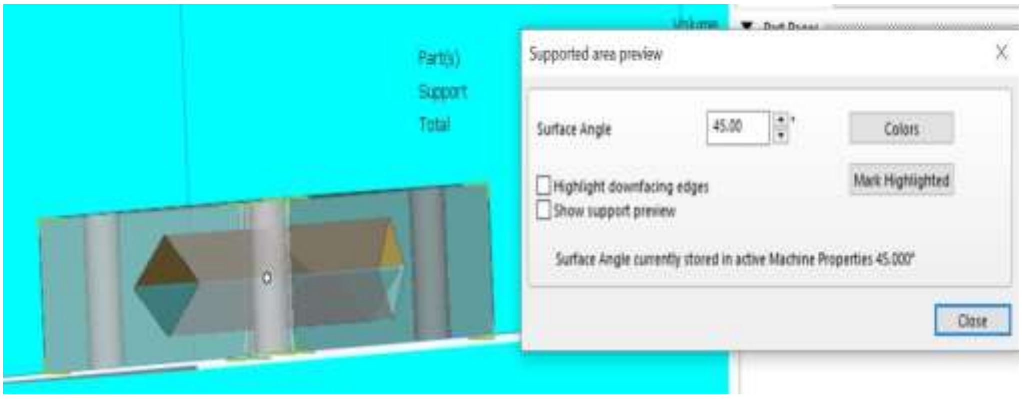


Fig Support Analysis in flow path

The support analysis shows that there is no support is coming inside the flow path. The support angle is specified as 45˚. This is another principle of DFAM that surfaces >45˚ can be printed (manufactured) without support in AM.

3. ANALYSIS

3.1 Structural Analysis:

Structural analysis is done using Ansys for both the designs (conventional& AM). The analysis was done by applying a load of 20KN and for SS316L material. The analysis shows that the optimized design is having enhanced mechanical properties than the conventional design.

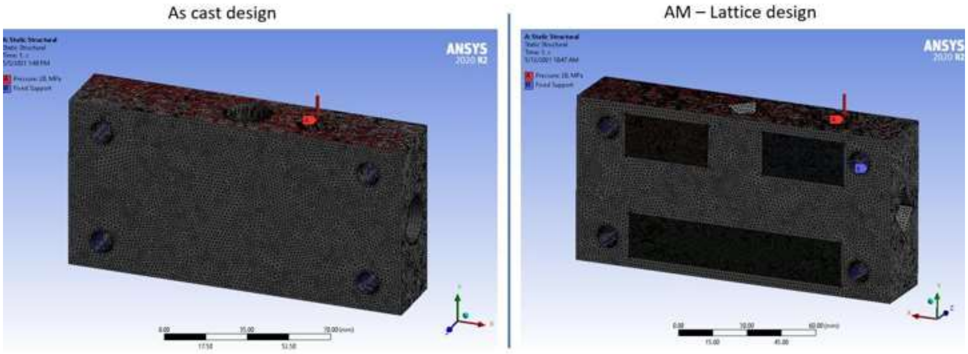


Fig. Load applied on both the designs

A load of 20 KN was applied on the top of the design as shown in the fig.

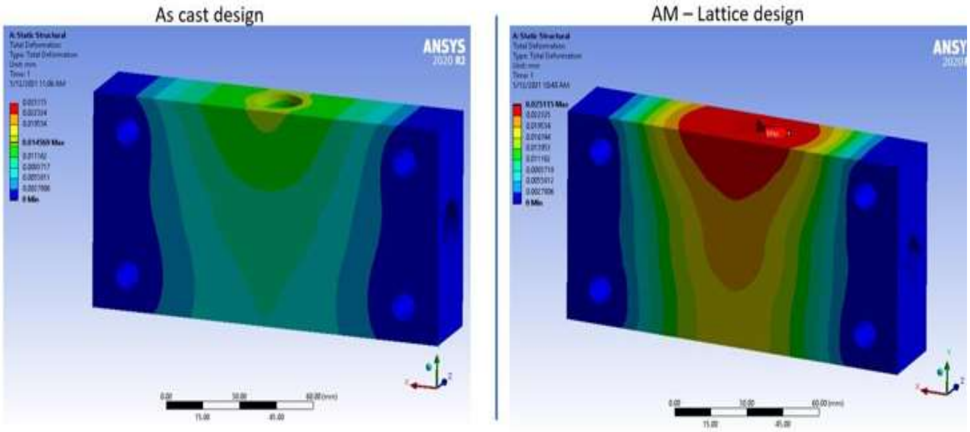


Fig. Deflection analysis using Ansys

AM lattice design shows max. deflection of 0.025 mm while conventionaldesign shows 0.014 mm deflection. This is expected considering reduced stiffness in Lattice based design.

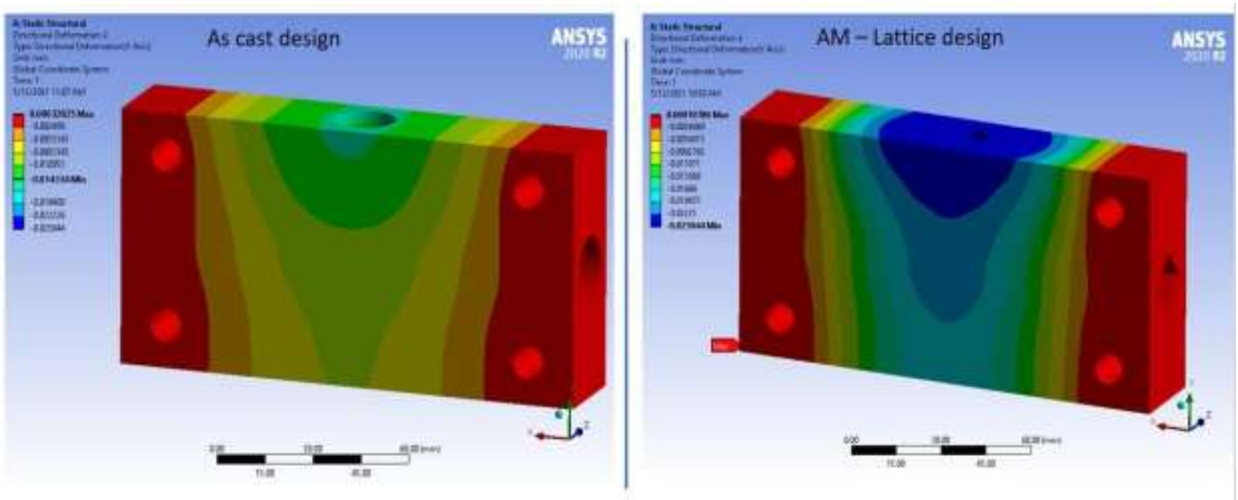


Fig. Directional deformation analysis

Both the designs show total deformation driven by vertical “Y” deformation. Thisis observed that both the design has similar deformation in the vertical ‘Y’ direction.

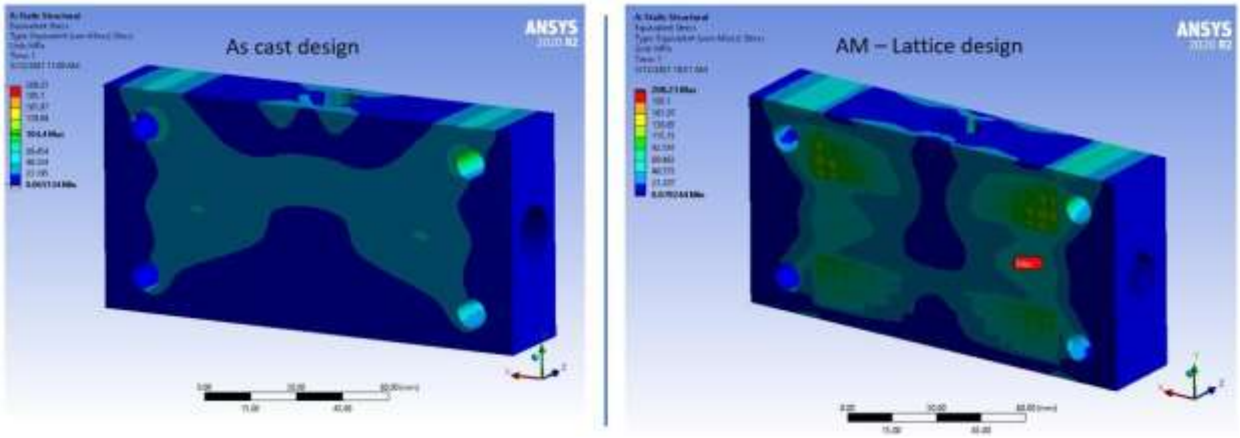


Fig. Equivalent max. stress under pressure load

Maximum stresses in both the models are local and compressive in nature. AM design with lattice shows relatively high stress induces in the lattice region with max equivalent stress of 140 MPa. Conventional design shows max. equivalent stress of 86 MPa at the bolt hole region. The induced stresses can be lowered bythe heat treatment of the AM printed part. The normal annealing cycle would helpto get it reduced to the normal. This will also help to improve the density and strength of the part printed in AM.

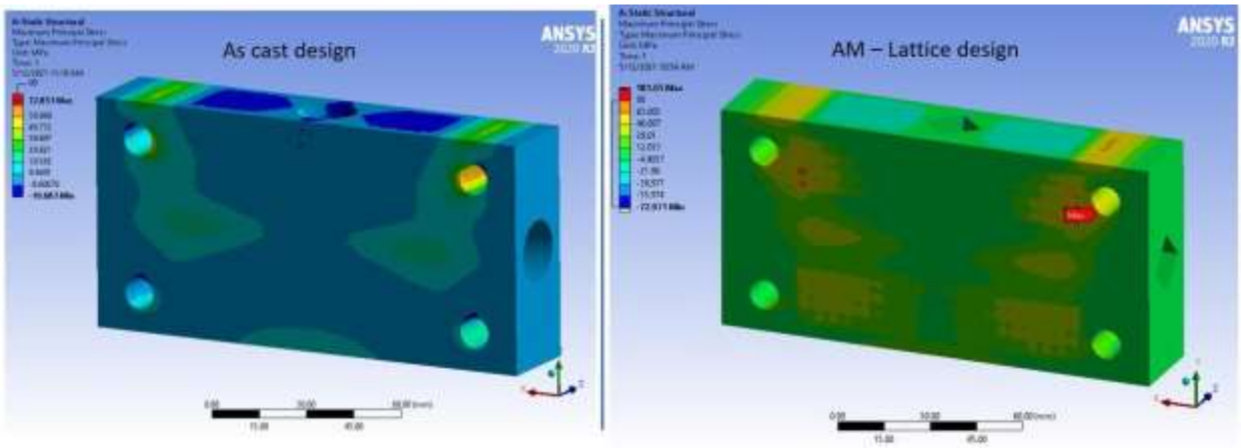


Fig. Principal stress under pressure load

- Both the design shows max. principal stress in range of 70-80 MPa with this loading. Yield limit for the design is 220MPa.
- As a conclusion of the structural analysis, it is observed that the AM design withlattice will have all the mechanical properties in the specified range for conventional manufacturing process (casting/machining). Lattices helped to reduces the weight of ~35% from the conventional design. This will lead to reduce the print time in AM.

3.2 Flow Analysis:

CFD analysis was also performed to check the pressure drop with AM optimizeddesign. The flow analysis is performed using Discovery Live software. Below boundary conditions were used for this simulation. The flow analysis was performed for Hydraulic oil DTE-24.

Table-1: Boundary conditions used for CFD

Boundary Name	Boundary Conditions
Inlet	Velocity inlet (Corresponding to 50 lpm flow rate)
Outlet	Pressure Outlet (1 bar absolute pressure)
Walls	No slip (1000 micro-inch surface roughness considered for walls)

Table-2: Fluid properties used in CFD

Fluid	Density (kg/m^3)	Dynamic viscosity (kg/m.s)
Hydraulics Oil DTE-24	864.2	0.041

By applying these boundary conditions, flow simulation was performed, and weobserved following result for the AM part.

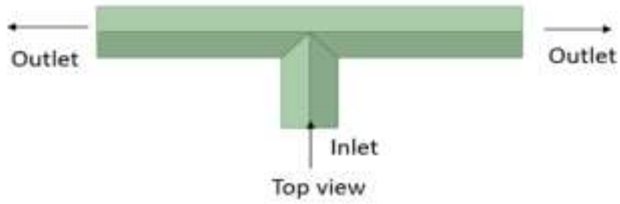
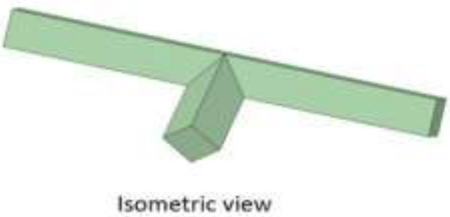


Fig. Optimized flow paths



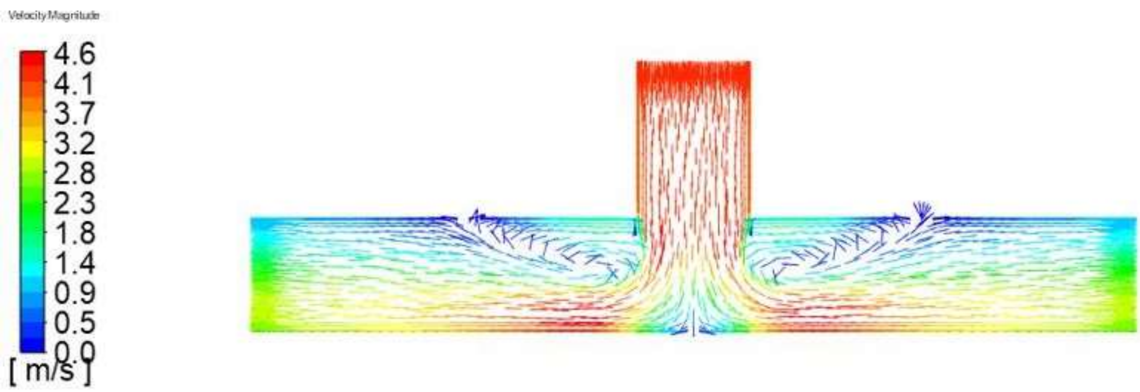


Fig. Flow velocity of fluid in the manifold

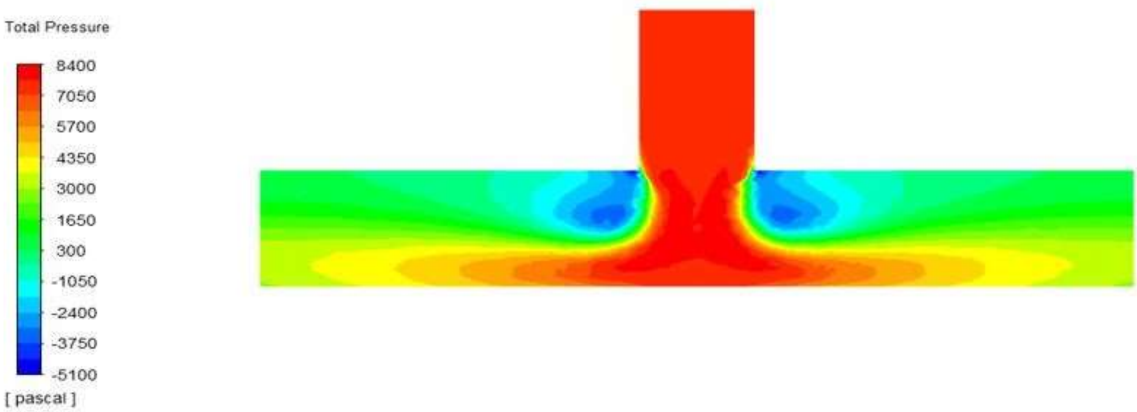


Fig. Pressure drop in the manifold

The analysis shows that there is a pressure drop of 5660 Pa (0.05 bar) in the manifold which is very low. The optimized design is having very good fluid flowand the pressure drop is negligible. In the analysis, the surface roughness was considered very high. The process parameter of the material can be further optimized and hence the surface roughness will also be improved. Thus, the pressure drop in the optimized design will be reduced further.

4. CONCLUSION

Additive manufacturing has almost no barriers in terms of complex design! Considering the principle of Design for Additive Manufacturing. We can say that it has the capability to manufacturing any design with no limitations! We've used some of those DfAM principles and optimized the conventional design to AM design. The weight of the part has been reduced by 30% with additive manufacturing!!! Additive Manufacturing is also capable for low volume series production! Hence, by reducing the weight in the design, the manufacturing cost of the component will also get reduced! As the flow paths are optimized from circular shape to rhombus shape. No support is required to print the flow paths? This is again material saving in terms of support! This will also reduce the post-processing cost after manufacturing!!! Additive Manufacturing is faster than the conventional manufacturing process. The time of manufacturing of these optimized parts will also be faster than the conventional one! Additive Manufacturing do not needs any tool or die. The design can be modified at any time, as required! And the cost of manufacturing of the part will remains almost the same! The simulation result shows that the optimized part has similar or improved properties in some respects. The AM part is having same mechanical properties as the conventional one! The CFD (flow analysis) shows that the optimized design has very minimal pressure drop in fluid flow! Due to the light weight of manifold, efficiency of the entire system will be improved? These DfAM principles can be applied in any hydraulics manifold and the flow paths can be optimized for additive manufacturing!!! Design optimization of flow paths will remove the problem of leakage in the manifold. As the paths would be continuous and there would be any lee plug. As we observed in the CFD analysis, pressure drop is also minimal, this will help to increase the efficiency of the manifold! Thus, there would be huge fuel (cost) saving by using this optimized design of manifold.

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