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A Framework for Rapid Additive Design & Manufacturing: Subtraction before Addition

Abstract

Although the impetus for weight reduction in aerospace compelled engineers to look deeply into topology optimization methods to generate bionic-designs that were elegant and optimised for performance, the recent advances in 3D Printing methodologies are enabling Naval and Marine industries to benefit immensely from the same quick re-design and rapid manufacturing of components. The benefits come from both, direct 3D printing of metal and plastics, and more interestingly, from hybrid techniques wherein 3D Printed sand moulds and patterns can help rapidly make gravity and investment castings.

Both direct as well as the hybrid process, require early manufacturing feasibility assessment of the topologically optimised design. With direct metal printing for example, optimal orientation of the part on the print bed, subsequent generation of the support structure, numerical evaluation of the print process, as well as an assessment of the distortion and the corresponding compensation are all important. Using the indirect method, determining if the part is being gravity or investment casted necessitates an early evaluation of defects such as to avoid performance failures. Partitioning of the dies or patterns and their 3D Printing needs require proper set up.

This presentation will highlight a collaborative simulation driven design framework that captures the entire process from ideation to 3D Printing for Additive Manufacturing. Included are compelling examples with an intention of informing and motivating the Naval engineering community to embrace what is possible. Although some of the methods presented may not be suited for deployment in a moving vessel, the potential impact of rapid manufacturing in both original manufacturing and maintenance/repair for generating replacement of parts, is compelling enough to understand all of them.

Introduction to Topology Optimisation and Constraints

Topology optimisation is the numerical computation method that maximises the performance of a design space by selectively subtracting the material under a given set of loads and constraints. If the design space is a rectangle which is simply supported at two ends and is uniformly loaded, the resulting topological shape is a standard bridge structure as shown in Figure 1.

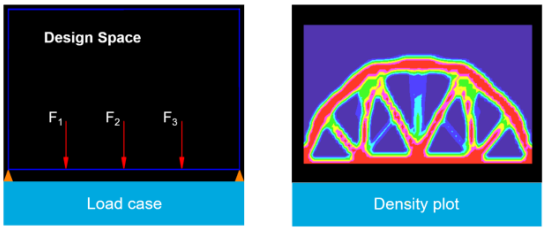

Figure 1: Design space, Load, and Constraints on the left and the resulting topology on right.

There are generally two types of constraints that are used in topology optimisation. One is related to the constraints involved with the performance attributes, and the other is related to the

manufacturing methods; both of which drive the shape of the topology. This paper is focused on the manufacturing constraints. The more Manufacturing constraints we add, there is additional penalty on performance and mass. There are many types of manufacturing constraints that can be used based on the type of downstream process to select and they type of shape that is desired. Unconstrained designs with least amount of manufacturing constraints have the tendency to achieve the best performance goals, catering well to a growing appetite for additive manufacturing as illustrated in Figure 2.

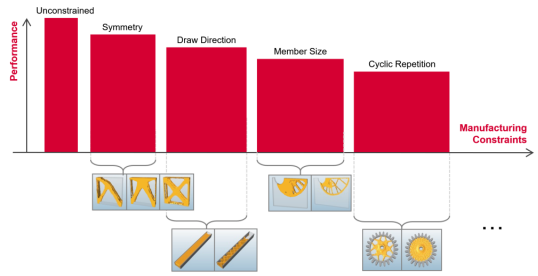

Figure 2: Performance and Manufacturing constraints

Topology Optimisation design process

Identification of the performance loads and boundary conditions is paramount before embarking on an optimisation problem. A generic process flow in Altair Inspire is illustrated in Figure. 3.

An example of a wheel upright showing free form optimisation (with no manufacturing constraints) is shown in Figure 4 to illustrate a practical example in real life. In this case the a free form optimisation was done, considering the downstream manufacturing process to be either direct metal 3D Printing or investment casting. The flexibility for the investment casting is that there is no need to impose casting constraints as the pattern can have under-cuts when 3D Printing. However, the feasibility for investment casting the wheel upright had to be evaluated using Altair Click2Cast (which is renamed to Inspire Cast now and is integrated into Altair Inspire). The 3D printed pattern and the actual cast part are shown in Figure 5.

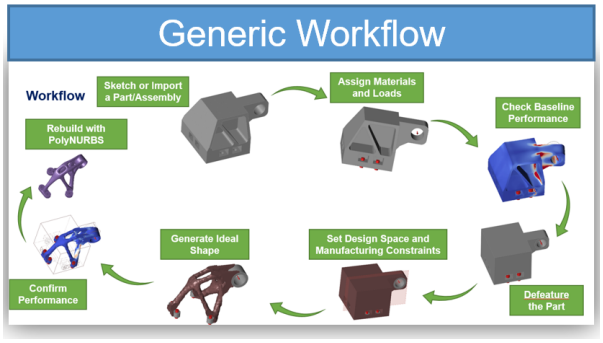

Figure 3: the design process for optimised design for robotic gripper arm

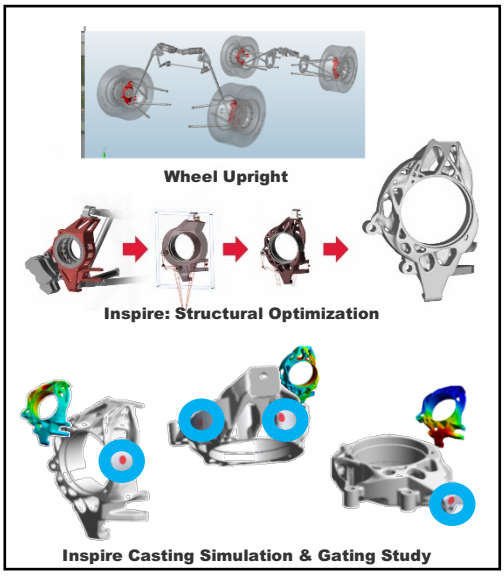

Figure 4: Free form Topology for a wheel upright for casting & subsequent casting feasibility using Altair Inspire

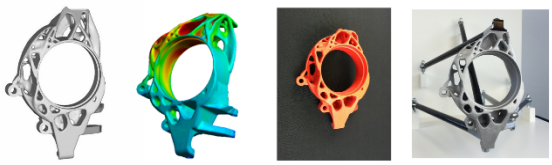

Figure 5: Concept to Actual Investment Casting from 3D printed pattern

Understanding & using Manufacturing Constraints

Altair Inspire provides the widest variety of Manufacturing constraints to drive the shape of topology that needs to be created, based on the downstream production process. One such consideration is controlling the specification of a maximum member size of structural members. As an example a plat with hole constrained in the center is subject to a force on the right corner. As we reduce the value of the maximum member size specified in the topology optimisation is decreased, the structures starts generating thinner members as shown in Figure 4 from left to right. If the part is made by metal casting then the members in the structure are too thin then they can cause turbulence and weld defects during the flow, and conversely, if the structural members are too big, it can cause a big pocket of porosity. Inspire allows you to control how thin and thick these sizes are and see how they affect the design. In Figure 4, the maximum member size is reduced from the left to the right & Figure 6 shows the influence on the porosity.

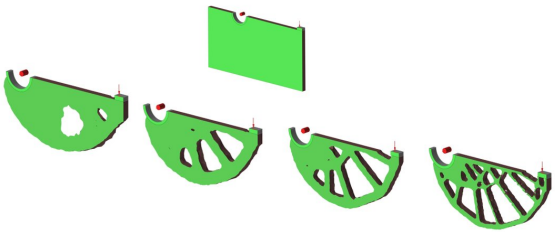

Figure 4. Influence of Minimum and Maximum member size.

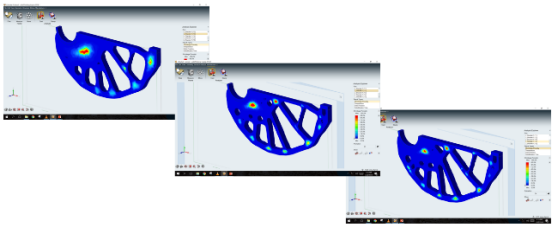

Figure 5. Casting Porosity analysis in Inspire Cast shown for the various member sizes

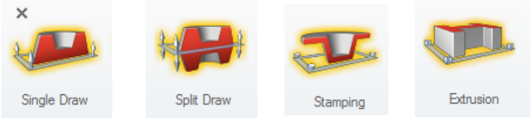

Figure 6. Casting, Stamping and Extrusion Manufacturing Constraints

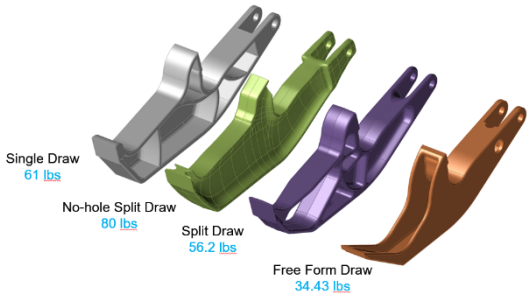

Figure 7. Comparing the shapes generated with multiple manufacturing constraints

Another example is shown here comparing the resulting topologies for various manufacturing constraints and the weight of the resulting designs in Figure. 7. If the downstream process is metal casting, then the subsequent solidification snapshot is shown in Figure 8. The examples will be further discussed during the presentation.

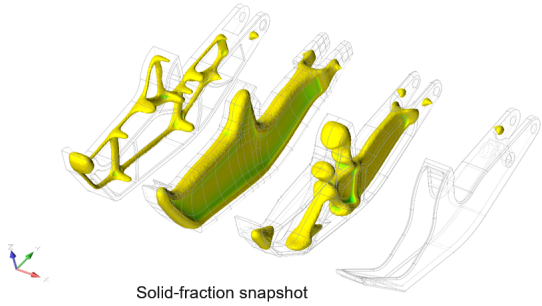

Figure 8. Solidification (Solid fraction) comparison for the various designs using Inspire Cast

Another design problem inherent in Additive Manufacturing is the amount of wasted support material in 3D printing. To minimise this, we specify an angle threshold, typically 45 degrees, for metal printing. This specified overhang angle is the angle at which the Additive Manufacturing process requires no support material. The topology that is then created form Altair Inspire will meet the desired manufacturing constraint as show in Figure 5. The user needs to specify the print direction upfront and can chose a level of penalty as shown in Figure 6. They can also

be run with no-penalty adhering to generating structures that require absolutely no support / or minimal support, generating the tear drop holes.

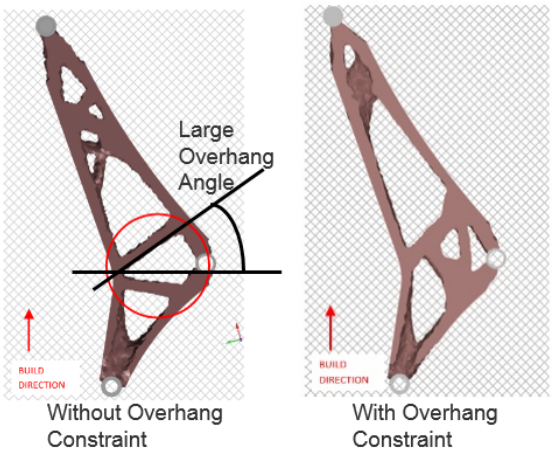

Figure 5. Overhang Angle

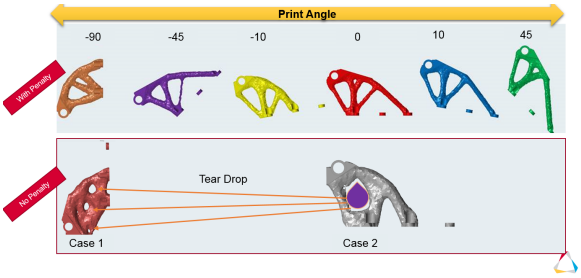

Figure 6. Influence of Printer direction and overhang constraints

CASE 1 – 90 DEGREE

CASE 2: 0 DEGREE PRINT DIRECTION (Z- DIRECTION)

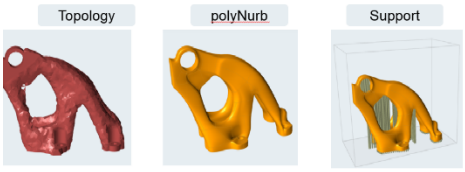

Figure 7. Comparison of designs arising from 0 and 90 degree print directions under same loading

Two of these cases with no-penalty with 90 and 0 degree print direction (to vertical) were selected to compare the designs and called Case 1 and Case 2.

Case 1 is 60.87% Heavier, it has 67.11% more support structure, is overall 139.52% heavier and has 242% more deformation. Case 2 the 0 Degree case is the best in this scenario.

3D Printing for Multiple Purposes

As was mentioned in the introduction, 3D printing can be used for multiple purposes. Direct 3D printing being the most common case. Figure 8 shows several examples of 3D printed parts. 3D printed sand moulds and patterns can also be used to create more efficient casted parts.

Altair Inspire can also be used to create additively manufactured patterns and molds as illustrated in Figure 9; thus providing a very unique and immersive framework for simulation driven design for light weighting.

Figure 8: Examples of 3D printed parts

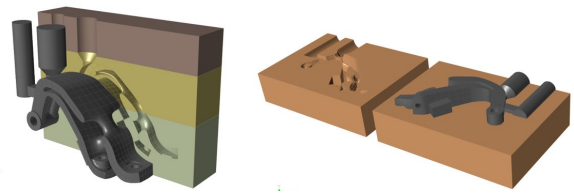

Figure 9. Additive Manufactured sand mould showing cast part

The symmetric plane and the design space and the resulting iterative topology shape and process development is shown Figure 10. The process was refined and a chiller was added to address a solidification porosity in the junction as show in Figure 11.

Figure 10. Optimised design going through casting checks.

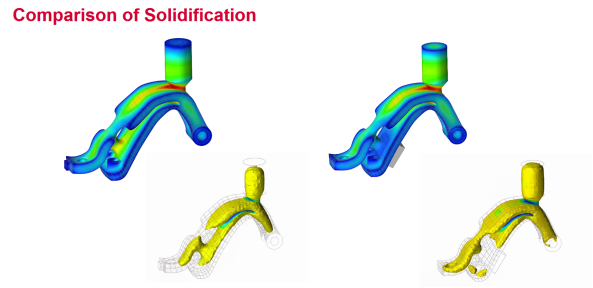

Figure 11. Design on left without Chiller and on the right with the chiller showing solidification

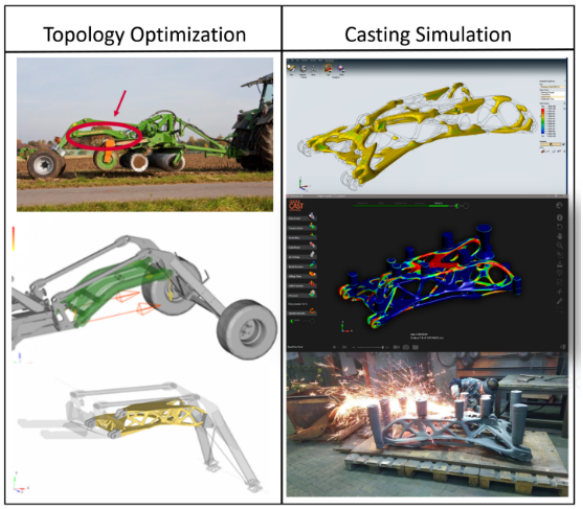

Figure 12. Large casting poured into a 3D Printed Sand Mould generated from Altair Inspire Platform

Conclusion

Thorough understanding of manufacturing constraints that drive designs are essential in generating topological shapes that are easier to manufacture. An immersive environment that facilitates generation of shapes that are cognisant of the manufacturing process is essential. Brute force exploration, without using the right constraints, can be computationally intense, financially expensive, and sub-optimal for both manufacturing and performance.

Evaluation of the manufacturing feasibilities, in combination with efforts for weight reduction with the right optimisation tools, on large structures, for the Navy and Maritime industry in combination with Additive & Hybrid-Additive Manufacturing methods can be certainly useful as illustrated in other industries.

A good understanding of the performance requirements and early involvement in the design phase is lot more efficient than re-designing towards the end of the product design cycle, when changes are more expensive. Using tools like Altair Inspire Platform in the in the concept design phase will ensure that designs can be light-weighted, and be manufactured quickly and efficiently with minimal defects.

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Ravi Kunju – Senior Vice President, Simulation Driven Design, Altair

Raj K. Bishnoi – Technical Account Manager

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