Exploitation and enhancement of design flow dedicated to additive manufacturing for an industrial demonstrator

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A few words about GD Tech

Definition of the industrial case / objectives of the redesign

Design cycle dedicated to Additive Manufacturing:

- Topology Optimization
- DfAM
- Process Simulation

Conclusion
FROM DESIGN

TO MANUFACTURING
Engineering Service company

Founded in 1991

Locations

- Belgium: Liège area
- France: Paris area and Pau

More than 200 employees

- Bachelors, engineers, PhDs
Working on AM related issues since 2015

In the frame of Research Projects:

- **FASAMA** *
  Redesign of Aero-structures for AM production
- **AnyShape 4.0**
  Better understanding of AM processes from a numerical point of view
- **HAWC**
  Hybrid manufacturing for large size structures

* Acknowledgments to SkyWin and the Walloon Government of Belgium
Object of this presentation:
Design cycle dedicated to the production of a T-Piece manufactured via SLM

- Part of the wing leading edge de-icing system
- Pressured hot air bled from engines circulating in piccolo tubes
- Air distributed into piccolo tubes via a T-Piece
Main goals to achieve:

- Reduce weight
- T-Piece and assembly plate in one single part
- Improve fluid performances: Reduce recirculation – make flow « smoother »
Additive Manufacturing Global Design Cycle

1. Choice of the parts for AM
2. Topology Optimization
3. DfAM
4. Structure Validation
5. Process Simulation
6. Printing

DfAM (Design for Additive Manufacturing)
Need a business case for the part to be additively manufactured:

- Large increase in performance and cannot be produced without AM
- Have several parts grouped into one, integrating functions
- Sensible from production time and cost point of view
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Fluid Topology Optimization

Mechanical Topology Optimization
Optimization of the fluid flow

- Fluid topology optimization
- Objective function: pressure drop
- Optimization variables: porosity
- Boundary Conditions:
  - Inlet velocity
  - Outlet pressure = 0 Pa (incompressible fluid)
Principles of the optimization of the fluid flow

- Variable = porosity =>
  - If porosity = 1 : no material => fluid goes through
  - If porosity = 0 : full material : fluid is blocked

- No optimization loop : optimization changes the domain during the fluid problem solving iterations
  => cost of optimization = adding ~20% iterations to the classical problem solving
Optimization of the assembly plate

- Mechanical Topology Optimization of the plate
- Objective function: Compliance
- Constraints: mass, stresses
- Optimization domain: thick original plate
- Boundary conditions:
  - Screws
  - Piccolo tubes
- Loads:
  - Pressure in the pipes
  - Jamming load
- Specification on stresses is considered as a post processing on the filtered model (after removal of the below threshold densities)
Optimization of the assembly plate

- SIMP Law used coupled with Heaviside filtering
  => almost no intermediate density (only one layer around the structure)

- Minimum member size filter used to avoid hollow closed cavities inside the plate
Optimization of the assembly plate

- Results:

  Vmax plate = 85%

<table>
<thead>
<tr>
<th></th>
<th>85%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>0.570</td>
<td>0.482</td>
</tr>
<tr>
<td>Max stress (MPa)</td>
<td>355</td>
<td>355</td>
</tr>
</tbody>
</table>

- Stresses computed on filtered model

- It is possible to create a part much lighter than the specs (85%)
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What to do with the Topology Optimization results?

1) Smooth the STL and print it: NO

- AM induces design constraints that were not available in Topology Optimization commercial packages
- Using AM constraints in Topology Optimization induces an a priori choice of the printing direction
  - We want the structure to be functionally optimal and then we see how to print it.
  - If it is not possible, we can always relaunch Topology Opti with a different non-optimizable domain that includes features that will help printability
What to do with the Topology Optimization results?

1) Smooth the STL and print it: NO

- Solving overhang issues by adding fillets is more efficient than using a structure with no overhang at all (no embossing possible without clever filleting)
- Expecting Topo algorithm to achieve that induces mesh sizes that make the problem size very large with little gain
What to do with the Topology Optimization results?

2) Convert/Rebuild a CAD file using the STL file: OK but...
   - Very few really efficient tools available
   - “Dead” geometry is the output (STEP file)
     - Annoying for small design changes afterwards
     - “Plug and Pray” that it won’t need major changes.
   - Design changes still needed for printability reasons
=> STEP format will not help!
What to do with the Topology Optimization results?

3) Build a CAD file from scratch strongly inspired by the STL file: yes

- More work

But:

- Easy integration of the manufacturing constraints
- Easy definition of “hard support”
- Parameterized model => easy modifications later
- Integration into an assembly in the native format
Final design:

- Large embossment-like material removal in the plate
- Each hole comes with a large-radius fillet on the downskin faces
- Mass gain was more important than required
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Stress level and pressure drop must be checked:

Material: Ta6V
Rm = 895 MPa
Stress level and pressure drop must be checked:

Total pressure loss gain : 45%

Pressure loss gain better than expected: real fluid model including walls law and smooth surfaces was used, compared to the more simple model for topology optimization
Larger than acceptable tolerance
First design of the part was not the one presented above.

Printing was not successful but no simulation software was available at the time.

A posteriori simulation “predicted” the issues faced

For further iterations, simulation was used and no more failed printing job occurred

A loop between DfAM, validation and process simulation is clearly needed to reduce the risk of printing failures
Final solution:
- Upside down => Fillets need to be adapted
- Need for an easily changeable CAD model
- Two parts printed as one
Max displacement cut in half (1.7 mm -> 0.9 mm)

Gain in productivity (one job = 2 parts)
What is the best supporting strategy based on thermal topology optimization?

- **Objective function**: thermal compliance
- **Constraints**: Mass/volume

- **Boundary conditions and loads**:
  - Base plate at given temperature
  - Thermal contact between part and supports
  - Part undergoing uniform heat flux
What is the best supporting strategy based on thermal topology optimization?

What about loads?

- Not ideal as defined today
- Need hotspot detection from process simulation
- Need « easy » transfer of data to topology optimization
- Physical meaning of « hotspot »?
  - Heat flux? Temperature? Temperature rate?
  - Time dependent or steady state?
  - Based on macro layers?
Conclusions
A design cycle dedicated to Additive Manufacturing was presented:

- Mechanical & Fluid Topology Optimization gave the directions to follow for a new design that was 45% more efficient, pressure drop wise, and 50% lighter.

- A CAD model was built, inspired by the Topology Optimization results and including the constraints of DfAM. This design was validated from a fluid and mechanical point of view.

- Process simulation helped to adapt the design to make a tricky printing job a success.

- A loop including DfAM, validation and simulation process was necessary to come up with a final printable design.
- Assessment of assembled parts (bolted, riveted, welded)
- Optimization
- Non-linear analysis, incl. crash
- Fracture mechanics
- Composites
- Fan Blade Out
- Flexible Mechanisms
- Rotor dynamic assessment
- Dynamic resp., random vibrations
- Non-linear vibration identification and analysis
- Additive manufacturing
- Manufacturing process simulation
- Fluid-structure interaction
- Multi physics (piezo, MEMS, thermal, optics, ...)

- CFD assessment (+ link to structure)
- Combustion assessment
- Thermal analysis
- Optimization