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White Paper:
Generative Design for Internal Fluid Flow

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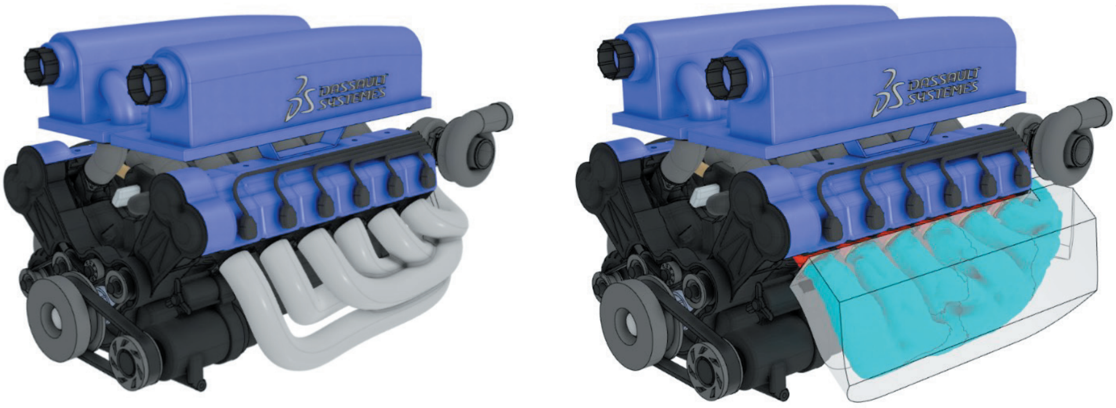
OPTIMIZE INTERNAL FLUID FLOW AND MASS WITH ONE PLATFORM.



Internal flow optimization of an exhaust manifold. (Picture courtesy of Dassault Systèmes.)

With generative design, the computer can finally become an active ally in the design of a product that can be considered the first true computer aided design. Note the emphasis on "aided."

"Rather than asking if this shape meets the requirements, we are asking which shape best meets the requirements," said Keith Meintjes of CIMdata in a 2017 blog post.

Looking critically at what has passed for computer aided design, we realize that its middle name is a bit of a misnomer. CAD replaced our drafting tables; but like drafting tables, CAD only helped with the documentation of a design. The real design—the transformation of an idea into a shape—has already occurred in our heads. The drafting board helped the designer to lay out the design on paper; CAD helped to define the design more neatly, more precisely and in three dimensions. Either way, little design, if any, was taking place on either medium.

Into the present day, design continues as a mental exercise, perhaps helped by sketching on the side using whatever is handy—a cocktail napkin, a tablecloth (why restaurants don't take reservations for groups of engineers), the walls (why the modern offices have erasable wall surfaces or whiteboards), or if the engineer is unabashedly cool, an iPad or its equivalent.

ENTER GENERATIVE DESIGN

Until now, generative design has primarily been demonstrated for structural optimization where a part is optimized, usually for light weight, while subject to loads and restraints based on the limits of the strength of its material. Centuries of study, testing and forensic examination, as well as a generation of simulation, has left engineers with a good intuition of the mechanical behavior of parts. An experienced mechanical engineer has a solid chance of determining a passable structural part by considering how forces pass through it, maximizing material along those paths and minimizing material elsewhere.

An intuitive grasp of fluid flow, however, is further behind, and faulty fluid flow is something we continue to propagate. We excuse ourselves because fluid flow is invisible, dynamic. We can't see it, so how can we correct it? Examples abound. A cargo container is dragged down the highway behind a truck. The underside of a car is a clutter of cavities and corners, pipes and brackets. A bus is as aerodynamic as a tool shed. The air ducts in our homes and offices turn corners, as do the water pipes. If we could see the buffeting, the drag and the streamlines that break up into turbulent flow, surely we would not let that happen.

Without aerodynamic scrutiny, fluid flow is subject only to other, admittedly practical considerations of commonly available stock material or manufacturing operations. Containers are rectangular to accommodate efficient stacking and packing of their contents. The corrugated sheet metal used for shipping containers is necessary for strength but plays havoc on the airstream. Fluid flow separates and recirculates, resulting in turbulence, eddies, vortices and pressure drop.

EXTERNAL FLUID FLOW

In the world of fluid flow, external airflow is the poster child of computational fluid dynamics (CFD) programs. Our walls are adorned with multicolored streamlines over F1 racing cars and our bookshelves with pictures of an airfoil's angle of attack.

Still, external fluid flow simulation and testing is reserved for the most glamourous and expensive products—our airplanes, rockets and bullet trains. They are the ones most often depicted with visualized flow in CFD programs or in wind tunnels using smoke trails and fluttering ribbons on surfaces. Lesser products that could benefit from flow testing or simulation cannot afford it. A wind tunnel can cost tens of millions of dollars to build and hundreds of dollars an hour to rent.

CFD, thought to be a savior of fluid flow and a less expensive and more practical alternative to wind tunnels, remains in the realm of expert practitioners and is still not mainstream in terms of availability or ease of use for the typical product engineer.

INTERNAL FLUID FLOW

Less glamourous than external fluid flow but far more common is internal fluid flow, such as the flow inside vehicle and aircraft cabins, gas and liquid manifolds, automatic transmissions, exhaust systems, heat exchangers, gas turbines, rocket engineers, air ducts, pipes, dishwashers, pumps and compressors. But because it is inside—even more hidden from view—internal fluid flow is even less likely to be considered.

WHO CAN USE GENERATIVE DESIGN FOR FLUIDS?

Generative design for fluids, when integrated with other design and manufacturing applications in a product development platform, is intended for use by product engineers. It does not require and is not limited to skilled analysts and specialists as are stand-alone optimization or CFD applications. Therefore, when used up front and early in a design context, an integrated generative design application is in position to prevent flow problems before they are baked into a design.

Generative design for fluids early in the design phase allows for more design exploration for all professions that currently would apply CFD simulation, such as those in the transportation industry (powertrain engineers and jet propulsion engineers, for example), AEC (HVAC designers), manufacturing (injection mold designers) and in the piping and process industry.

UP FRONT DESIGN

The traditional linear approach to the product development cycle has simulation follow design. If simulation rejects the design, the design is modified. If a product passes simulation, it gets manufactured.

Allowing generative design to operate in the design phase is asking “what if?” over and over again, as in “what if we shape a part this way?” If that doesn’t improve the part, it will try another way, with an incremental change. Generative design will do so rapidly and without pause, over and over again, stopping only when performance criteria is met, and then only to try a different tack to reach an alternate solution. It will find as many solutions as you will give it time for. You will be left with many solutions—all meeting the design and performance goals you set. You can flip through them like a picture book and select one that pleases you the most, knowing all of them will work and that one or more could be far superior to its traditionally designed forebearer.

The modern age of engineering is called the Fourth Industrial Revolution by the World Economic Forum and Industry 4.0 by others. It includes generative design (the focus of this study) and 3D printing, which together form the dream of the fluid flow specialist and the design engineer.

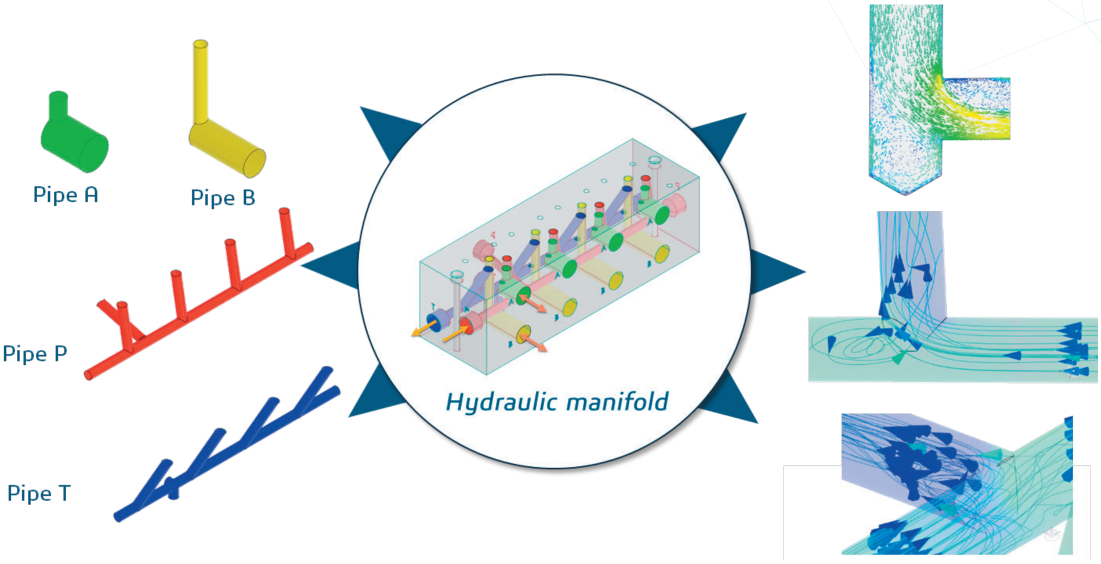
Where the design engineer may have dismissed curvy fluid paths as impossible to manufacture, along come 3D printers who say, “We can do that.” Indeed, a curvy shape can be made just as easily with 3D printing as can a shape with sharp corners or bends. The marriage of these two technologies—generative design for imagining the optimum shape and 3D printing for manufacturing it—should open up a brave new world for improving fluid flow, promoting fluid flow simulation to its proper place at the initial phase of product development—the place in which 80 percent of total product cost is determined—rather than being relegated to last place, backwardly driven by methods of manufacture convenient to the machinist.

ALL TOOLS IN ONE TOOLBOX

At its onset, those daring to venture into the world of generative design had to find topology optimization applications, many of them spun off from university research. These applications may have been written for specialized purposes, be it structural, fluid flow or general-purpose optimization, those that found rates of change of one parameter over incremental change in another, plotting the derivative of an interpolated curve and setting it equal to zero to find minima/maxima – there being optimums.

Such offshoots of academic work are not known for their approachability or ease of use, often lacking a friendly face (UI) or a positive disposition. Even as these programs matured and adapted, becoming more usable to the general engineer—some of them even acquiring a following that described them as “best of breed”—they were still different enough from the design applications, with their own nomenclature, commands and UI. Also, moving geometry between generative design applications, CAD and CAM involved translation, which can and often does come with errors and losses in model fidelity, as optimized shapes can be uneven, faceted and organic—anything but the smooth and straight geometry that conventional design and manufacturing applications are most comfortable with.

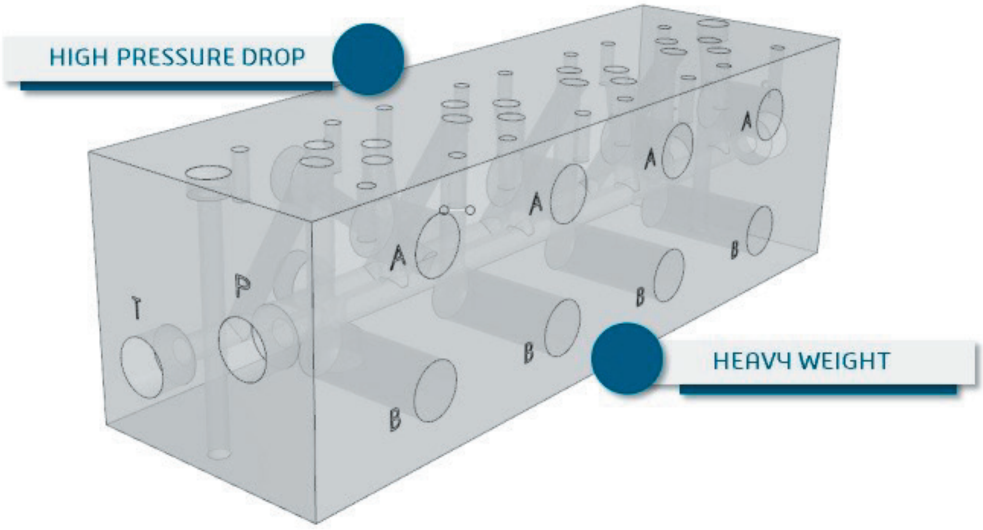
FLUID FLOW GENERATIVE DESIGN IN PRACTICE: A HYDRAULIC MANIFOLD



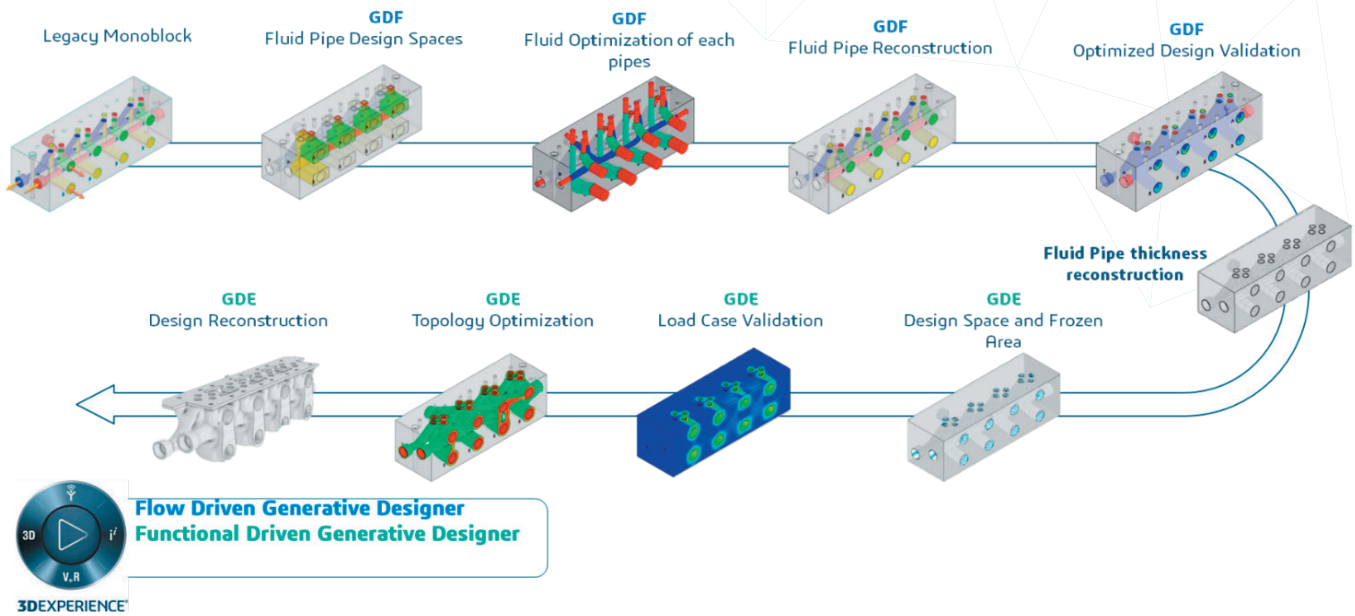
Hydraulic manifold showing internal fluid paths and valves. (Picture courtesy of Dassault Systèmes.)

Take the design of a hydraulic manifold, which is basically a block of material with internal flow paths and valves on each end. They are made of metal in order to withstand high pressures and the easiest material to start with is a rectangular block cut to the right length.

The easiest fluid paths to make are holes drilled from one face that meet with holes drilled from another face. The holes can be off different size to create different hydraulic forces and mass flows at the output port. Drilling holes, by its nature, produces straight holes. When holes intersect at right angles, as they would when the outlet port is on an adjacent face of a rectangular block, the pressure drop is severe. The pressure drop occurs to a lesser extent when the holes abruptly change diameter. In both cases, smooth, linear flow gives way to recirculation, eddies and turbulence—all energy-robbing components of pressure drop.



Hydraulic manifold legacy design has a high pressure drop from inlet to outlet and a mass of 8.3 Kg. (Picture courtesy of Dassault Systèmes.)



Optimization process for conventionally designed hydraulic manifold. (Picture courtesy of Dassault Systèmes.)

Fluid manifolds designed as above are created with regard to convenient methods of manufacture—and without regard to optimum fluid flow. In effect, the manufacturing has designed the part, a reversal of the ideal design-manufacture workflow.

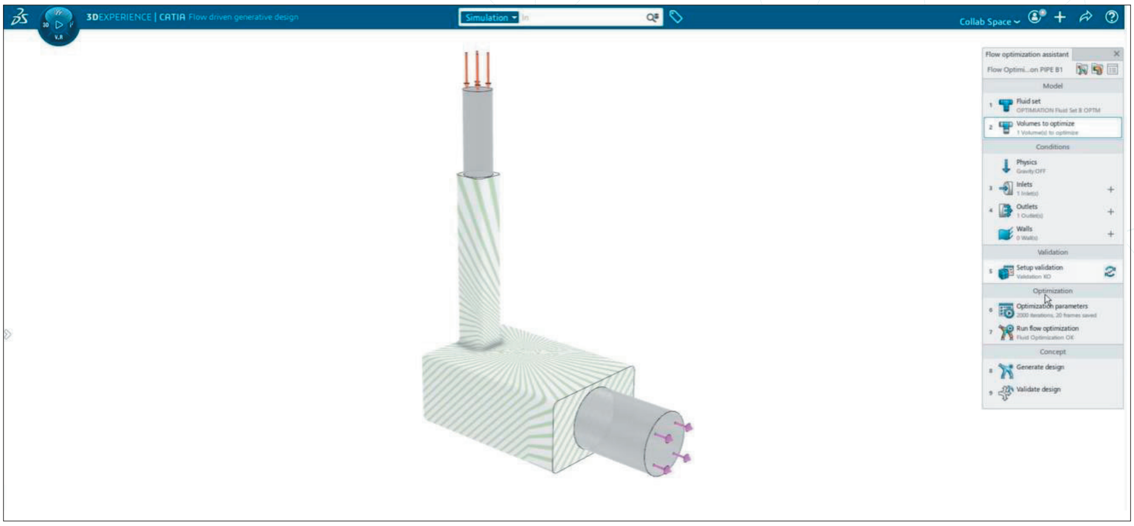
Let's use the hydraulic manifold as an example of how to improve the fluid paths—and then use generative design to optimize material used.

We start with the CAD geometry of the conventionally designed hydraulic manifold. This CAD geometry must be imported into the generative design tool. If you are using the 3DEXPERIENCE platform, the CAD geometry is available directly without translation.

We select the geometry we want to preserve from the CAD model; in this example, this would be the inlet and outlet diameters. That geometry is marked as frozen. Next, the design space, or design envelope, is determined. This is the volume that the generative design has to work within. It can be selected from the CAD geometry, but in this case, the design space is constructed as an expanded volume around the existing flow path, giving the fluid more room to flow.

However, we are careful not to interfere with other flow paths and stay within the exterior, rectangular volume of the manifold exterior.

The parameters associated with the flow on each area are entered as velocity and direction, which establishes the boundary conditions.



A simplified flow path with one inlet port, the design space from which an optimized flow path will be extracted, and an outlet port. The design space was constructed to avoid fluid paths that run through the manifold in a transverse direction. (Picture courtesy of Dassault Systèmes.)

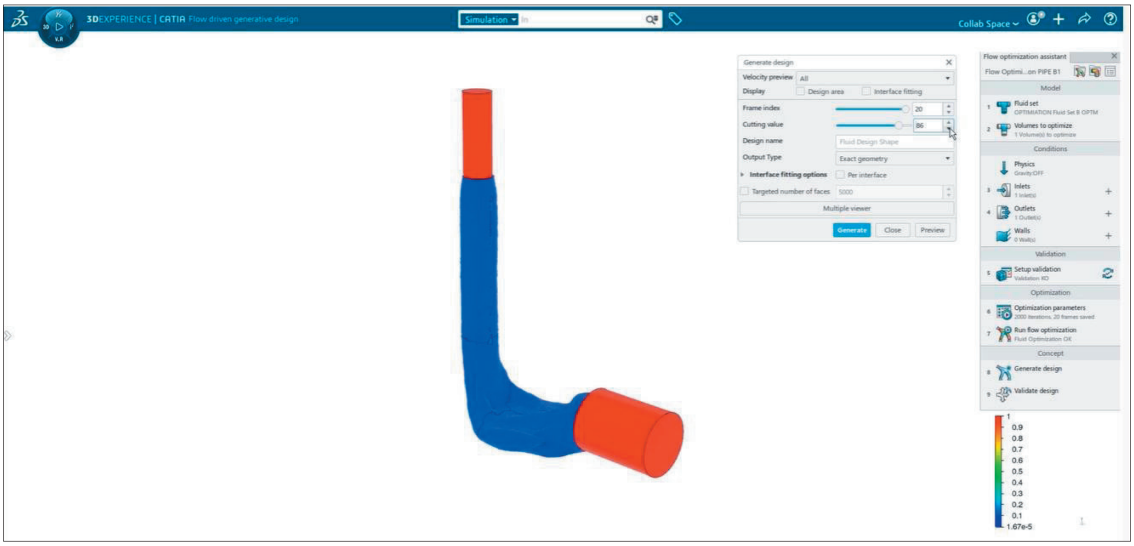
For simplicity, we will show a one flow path with its inlet and outlet ports.

Note CATIA's Flow Optimization Assistant, which appears as a panel on the right of the screen in the illustration above. The engineer needs only to go down the list of choices in the panel to complete the simulation.

"We want to simplify this process and not have it be something you need a PhD in fluid dynamics to use," says Colin Swearingen, Solution Consultant at Dassault Systèmes, who guides us through the example.

The designer is spared from having to create and fine tune the mesh. That task will be done by a CFD program behind the scenes. In this example, we use Tosca Fluid which, in conjunction with a specially developed Abaqus solver using the RANS (Reynold-averaged Navier-Stokes) approach, quickly makes the mesh of the initial flow path volume and runs the flow analysis.

Recirculation can occur around sharp corners and abrupt changes in section areas. However, the normalized flow field, which Tosca can easily determine, selects only the volume without recirculation and results in an improved flow path within the design space.

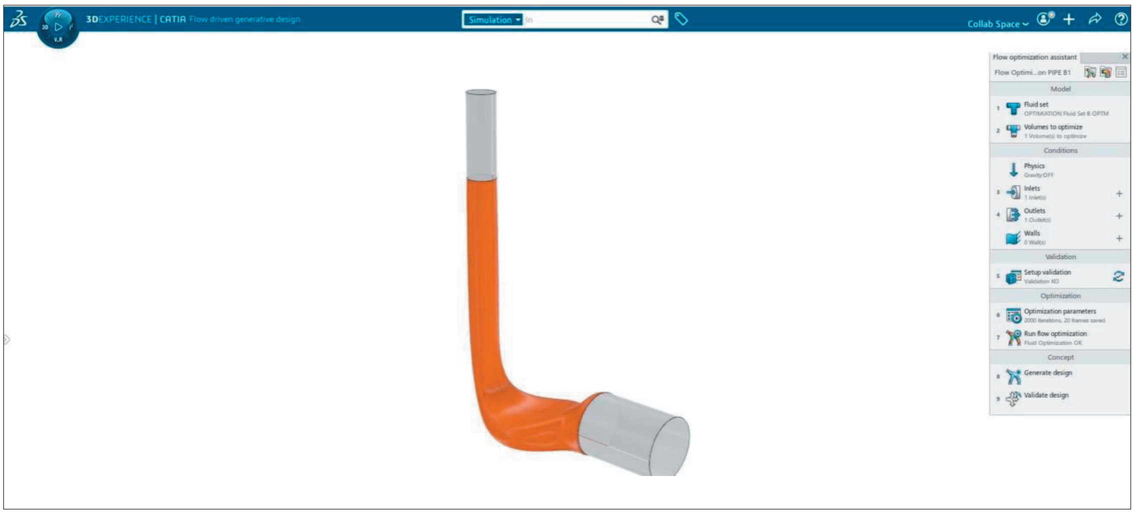


Velocity preview: All
Display: ☐ Design area ☐ Interface fitting
Frame index: 20
Cutting value: 86
Design name: Fluid Design Shape
Output Type: Exact geometry
Interface fitting options: ☐ Per interface
☐ Targeted number of faces: 5000

The flow path volume with normalized flow field selected and turned into geometry. (Picture courtesy of Dassault Systèmes.)

This is unique to Dassault Systèmes' flow-driven generative design. Only it can "cut" the normalized flow field out from the whole flow field and turn it into actual solid geometry at the click of a button. There is no need for the user to laboriously create a surface mesh, export the STL file into the CAD program and hope to be able to convert it into a solid. Instead, the optimal flow path for the design space is obtained directly, automatically, and quickly from the simulation. In less than a minute, engineers have geometry they can continue to work with.

Another flow analysis based on the new path with normalized flow can be run for validation. The engineer can decide at this point if the new path reduces recirculation enough or if another "cut" at the flow field is needed by evaluating the resulting pressure drop on this individual duct.



Flow optimization assistant

Flow Optimi...on PIPE B1

Model

1 Fluid set
OPTIMIATION Fluid Set B OPTM

2 Volumes to optimize
1 Volume(s) to optimize

Conditions

Physics
Gravity:OFF

3 Inlets
1 Inlet(s)

4 Outlets
1 Outlet(s)

Walls
0 Wall(s)

Validation

5 Setup validation
Validation KO

Optimization

6 Optimization parameters
2000 iterations, 20 frames saved

7 Run flow optimization
Fluid Optimization OK

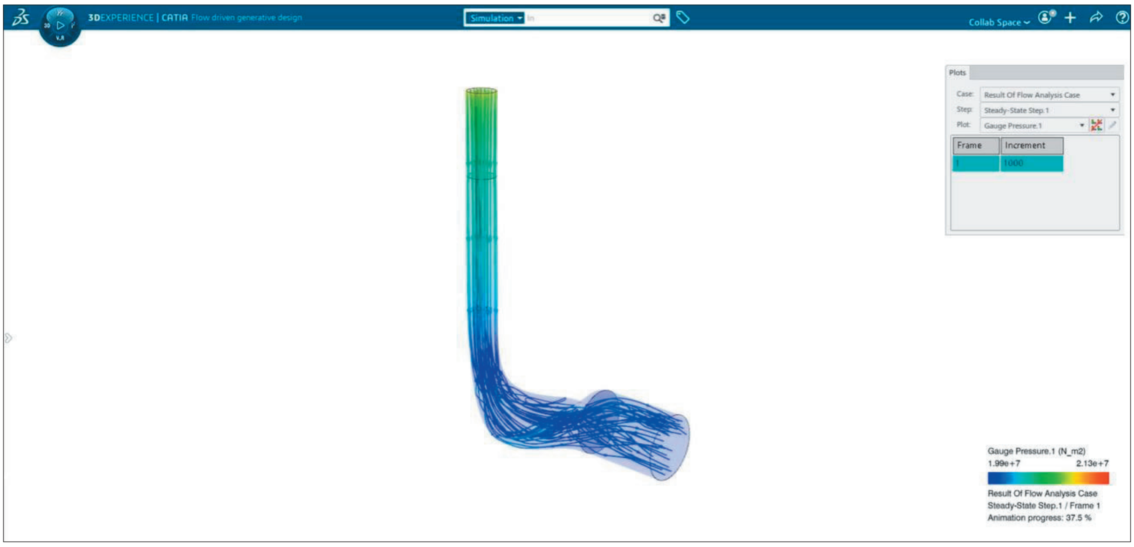
Concept

8 Generate design

9 Validate design

The rough volume of normal flow is automatically morphed into a smooth shape. (Picture courtesy of Dassault Systèmes.)

Then the design engineer, working with geometry tools they are familiar with, can automatically morph the flow path into a smooth shape.



Case: Result Of Flow Analysis Case
Step: Steady-State Step.1
Plot: Gauge Pressure.1

Frame	Increment
1	1000

Result Of Flow Analysis Case
Steady-State Step.1 / Frame 1
Animation progress: 37.5 %

Flow lines show no recirculation in the volume cut out of the flow field. (Picture courtesy of Dassault Systèmes.)

All smooth internal paths shown in hydraulic manifold. (Picture courtesy of Dassault Systèmes.)

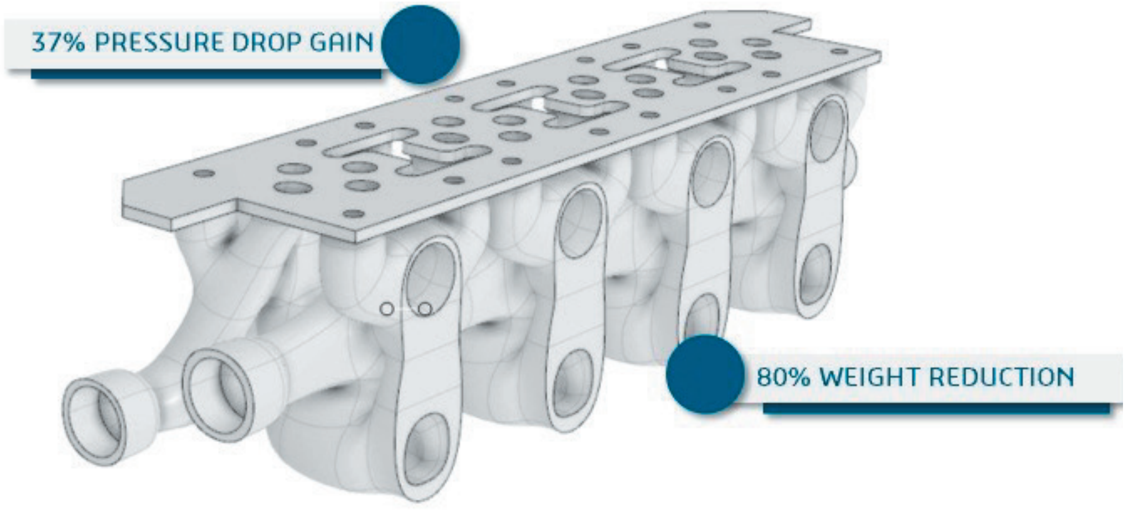
A flow simulation is done to validate the smooth shape.

The individual smooth flow paths are reassembled to make all the flow paths in the hydraulic manifold. At this point the pressure drop is recalculated—and it has dropped significantly. The elimination of recirculation in the flow paths has resulted in a 37 percent average improvement in pressure drop.

Now that the internal volumes are established, we can turn our sights to lightweighting. Using the optimized internal volumes (the new flow paths), we use a structural generative design program to create an exterior that results in the least possible mass of the manifold.

With an integrated platform such as 3DEXPERIENCE, the structural generative design program can work on the geometry left by the flow generative design. There is no loss of data or time in importing and translating models.

The structural generative design process is covered elsewhere and we will not go into its details here, but suffice it to say that big savings in mass (80 percent) were gained from optimizing its shape from a machined block of steel to one that can be 3D printed or cast.



After generative design, a hydraulic manifold has a 37 percent gain in pressure drop and mass that has been reduced to 1.7 Kg. (Picture courtesy of Dassault Systèmes.)

CONCLUSION

We have seen how a design platform with integrated and robust applications for conventional and generative design can be a time and money saver.

While a standalone fluid flow optimization tool may be expected to make great improvements with internal fluid flow by being able to react to unseen recirculation and eliminating it, having to rely on importing and exporting geometry back and forth between CAD and optimization applications runs the risk of data loss and increases the time spent on task, causing project delays. Plus, when the fluid optimization is done, it must be exported into CAD for shape processing, then into simulation for validation. This process is repeated for optimization for lightweighting. In an industrial environment, this involves files moving from one station to another, at each station being attended to by specialists, with friction and losses as it moves about.

The alternative, shown in this study, is a common platform with integrated applications, avoiding data loss and saving considerable time—as much as 10X by Dassault Systèmes' estimate. The 3D model essentially stays intact and in one place as a single product design engineer, not a series of specialists, is able to perform all that is necessary to optimize the design, a task made far easier by having only basic engineering knowledge and with tools that have an interface with so much in common with each other that they come close to blending together as one.

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To learn more about generative design, visit GoEngineer.

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