Shape Optimization of Hamilton-Sundstrand's 4507419 Fan Duct Using Sculptor & Fluent

Report

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This report describes the steps and results of a shape optimization project for the Hamilton-Sundstrand (HS) 4507419 Fan Duct. The resulting shape optimization with Sculptor coupled with the Fluent CFD solver found a shape that reduced the pressure drop by almost 7% over the Baseline case.

The CAD geometry of the model provided by HS was read into ICEM-CFD, healed, and meshed for the Fluent CFD solver. A hemispherical plenum was added to simulate ambient air entering the system. Figure 1 shows the geometry of the system including the plenum. The full model of the system was meshed so that the flow entering the duct inlet would be representative of the actual flow rather than just entering a flow velocity profile at the duct inlet. The Arbitrary Shape Deformation (ASD) volume of control points, created in Sculptor, is shown encapsulating the duct region of interest for this project.

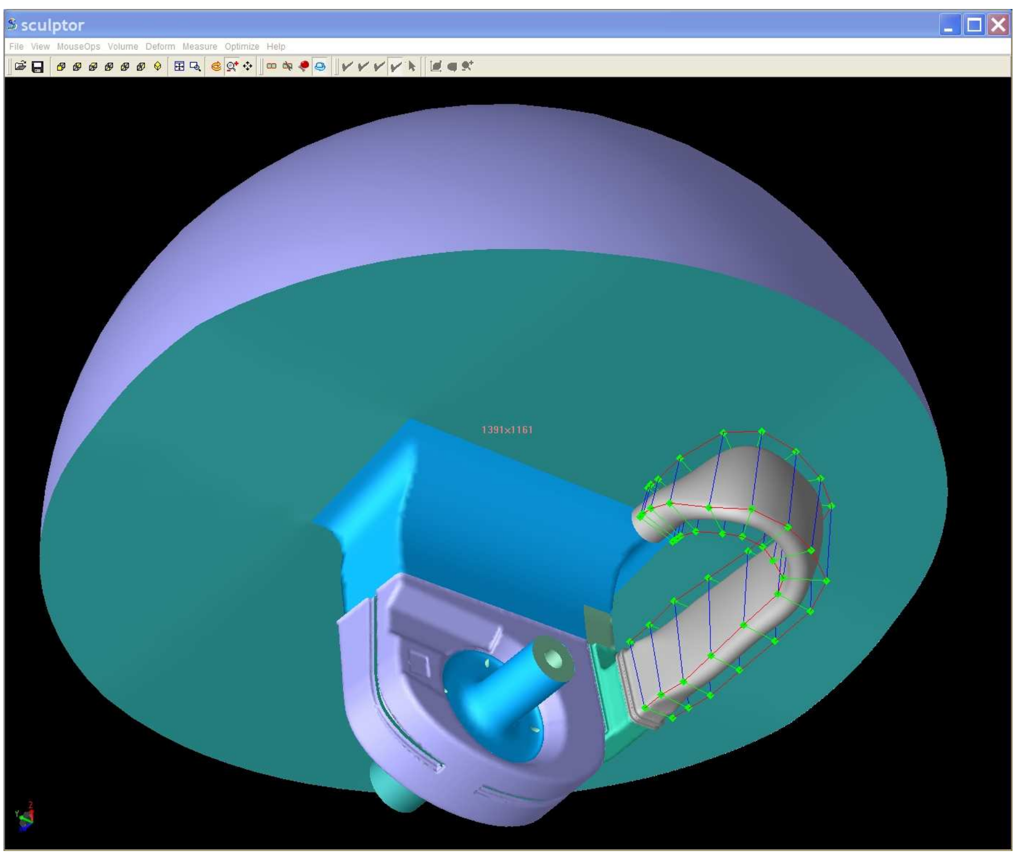

Figure 1. The Fluent model of the HS Fan Duct as displayed in Sculptor.

Figure 2 shows a close up view of the model, the plenum is invisible, and the surface cells are visible. The mesh created has just over 760,000 cells. Tetrahedral cells were used throughout the model except on the inside surface of the duct walls where a layer of prism cells were defined to refine the model at the location of interest. The duct was given proportionally more cells than the rest of the model.

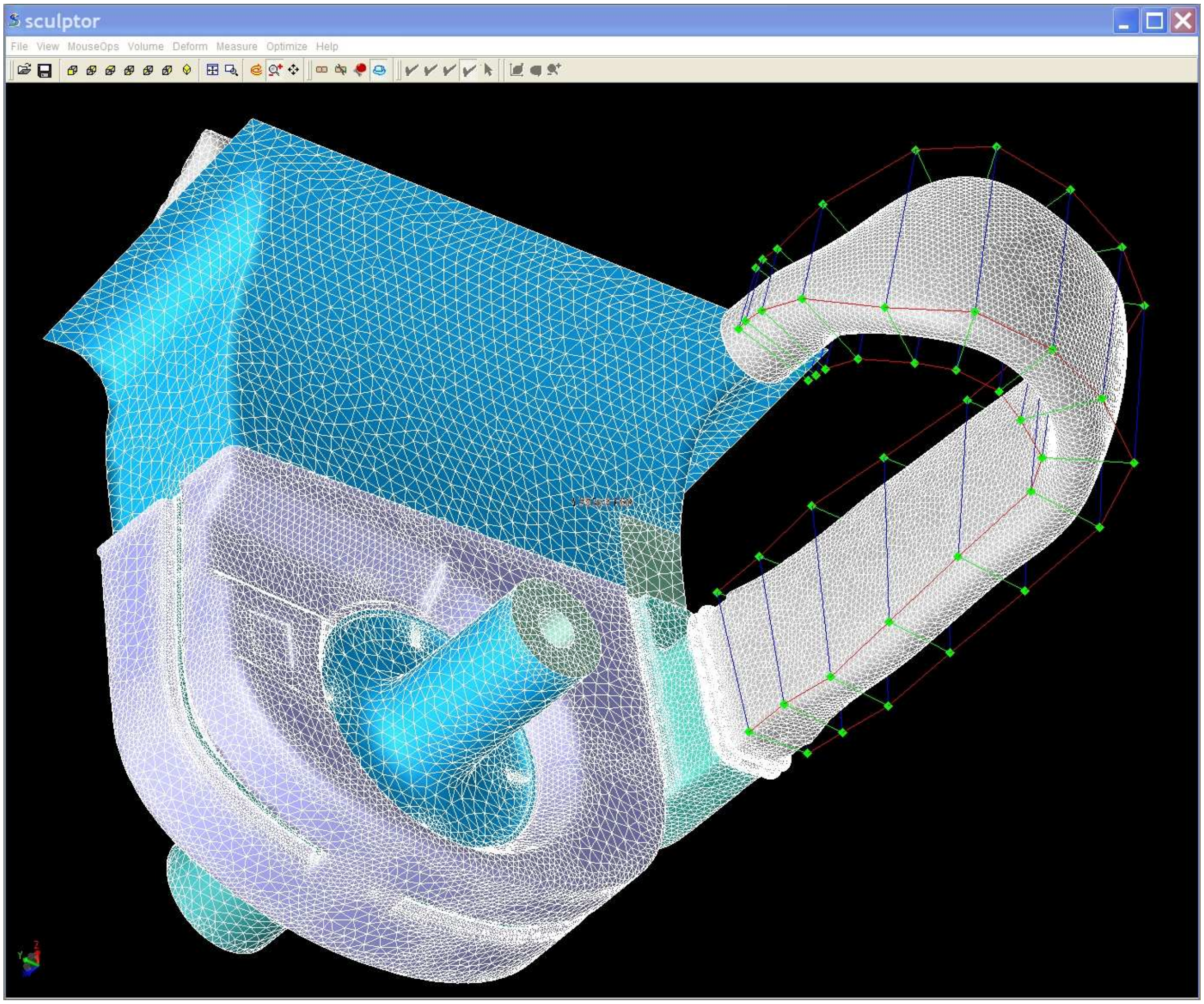

Figure 2. Close up view of model with surface cells visibility and ASD volume around the duct.

The ASD volume was created with a parametric 15x2x2 set of control points. Each plane of control points along the length of the duct was strategically placed to provide enough degrees of freedom (i.e. design variables) for the full length of the duct. The selected control points were grouped together to define individual design variables.

Figure 3 shows two views of the pressure contour plot on the duct for the baseline Fluent solution. The red arrow on the right points to a location of negative pressure with a likely reverse flow situation in the neck-down region just before the straight circular section of the outlet.

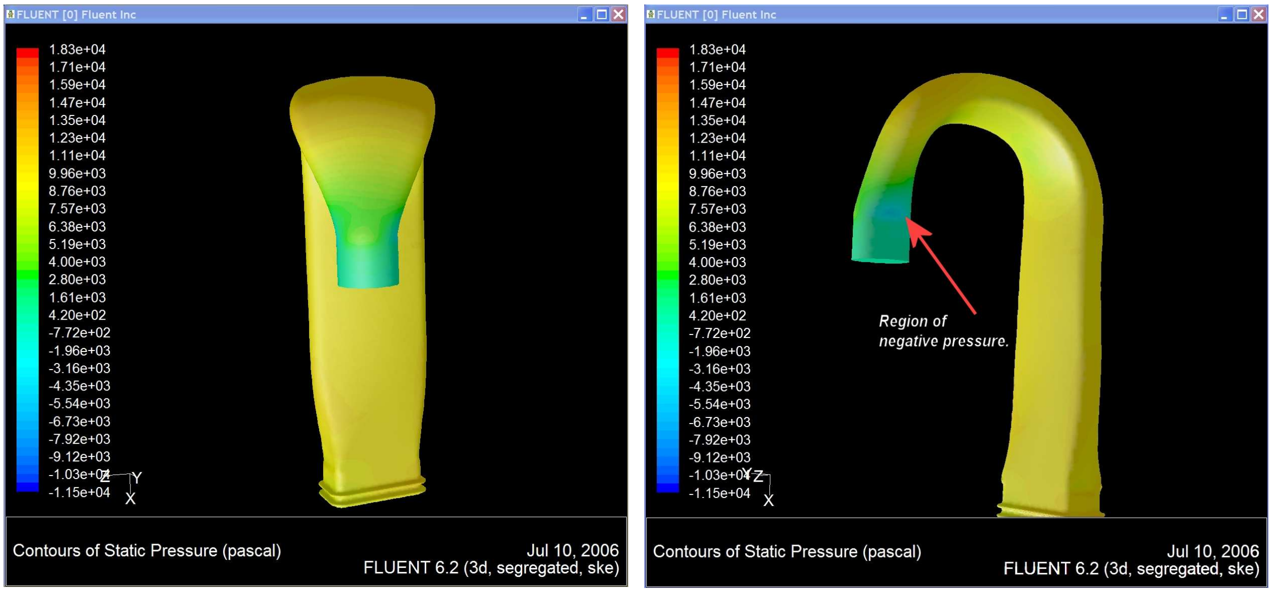

Figure 3. Two views of the pressure contours on the surface of the duct. The red arrow is pointing to the area of negative pressure near the outlet.

Figure 4 shows a front view of the duct's "neck-down" region near the outlet where most of the pressure losses are located.   A sensitivity analysis revealed that the pressure drop was not very sensitive to shape change along the straight section of the duct, thus the shape optimization problem focused on the 180° bend and the neck-down region just before the outlet. The green arrows here show the shape change variables for the transverse direction around the 180° bend.

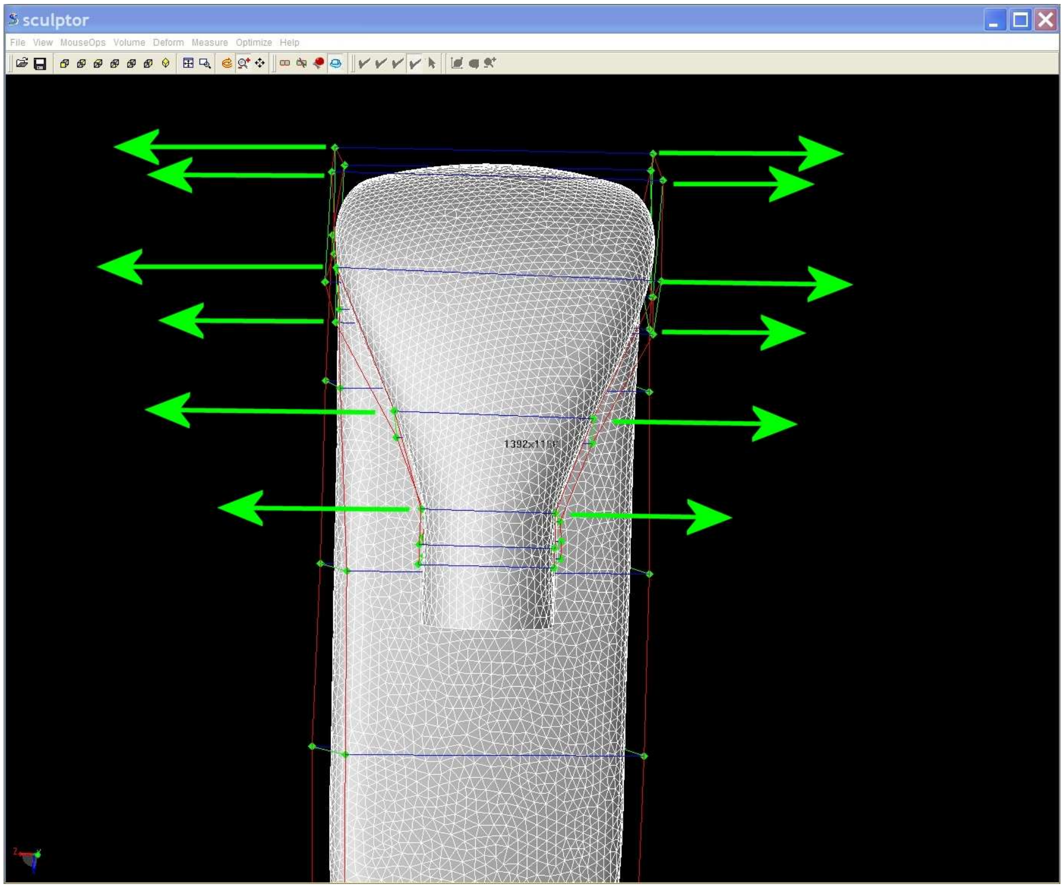

Figure 4. The green arrows show which control points were allowed to move in the transverse direction.

A side view of the duct is shown in Figure 5 with green arrows indicating the shape change variables in the outward radial direction on the 180° bend and the neck-down region. Note: only the outer control points are allowed to move in this case, keeping the inside surface of the bend undeformed.

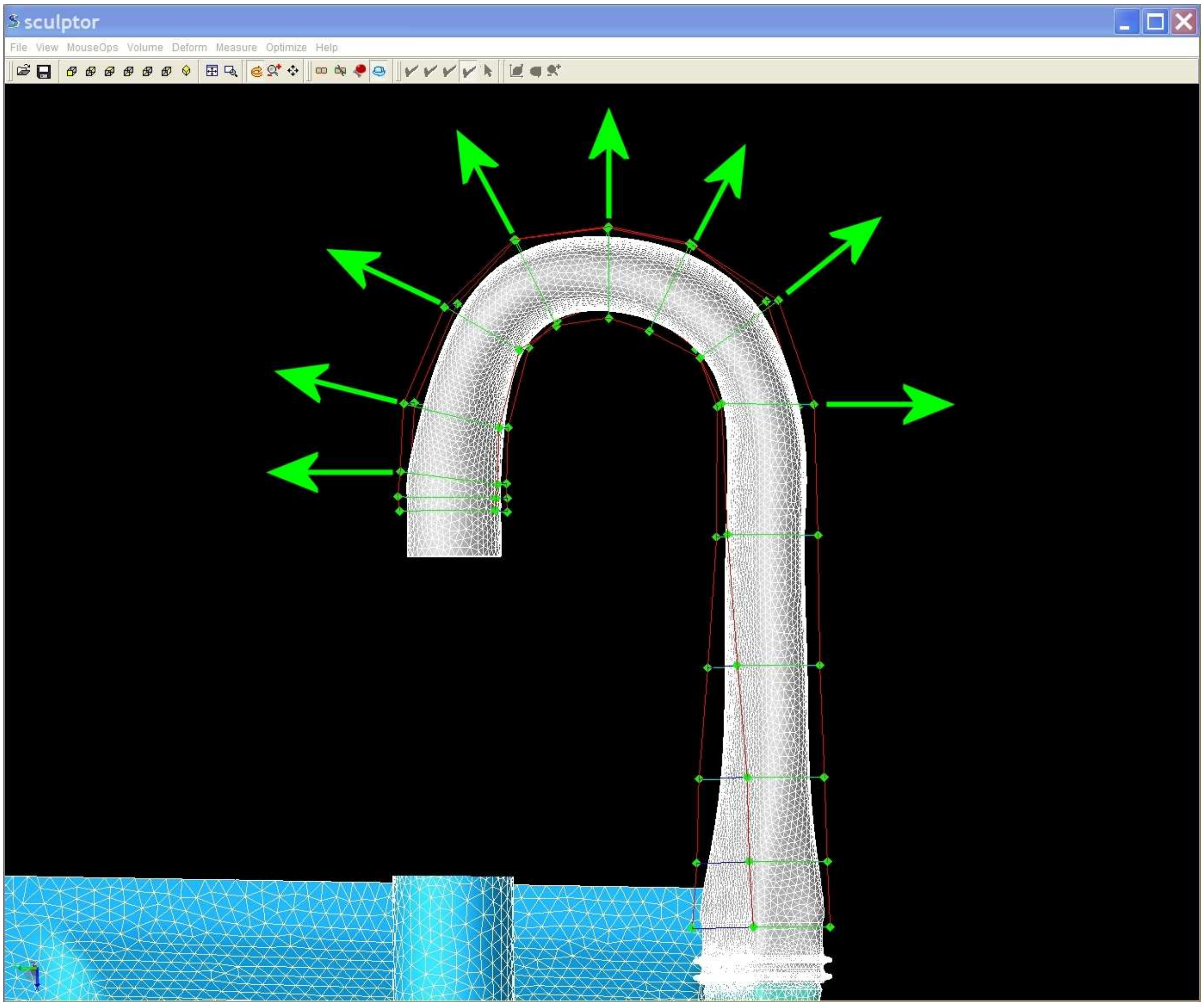

Figure 5. The green arrows here show which control points are allowed to move to deform the outer wall of the bend.

Figure 6 shows two views of the pressure contour plot on the duct for the optimized shape. Notice that there is no longer a concentrated blue region near the outlet indicating the removal of the negative pressure zone. The fluid flow around the bend was improved to reduce separated flow, recirculation, or negative pressure by changing the shape of the duct with subtle deformations in just the right amount in the correct locations with ***Sculptor***.

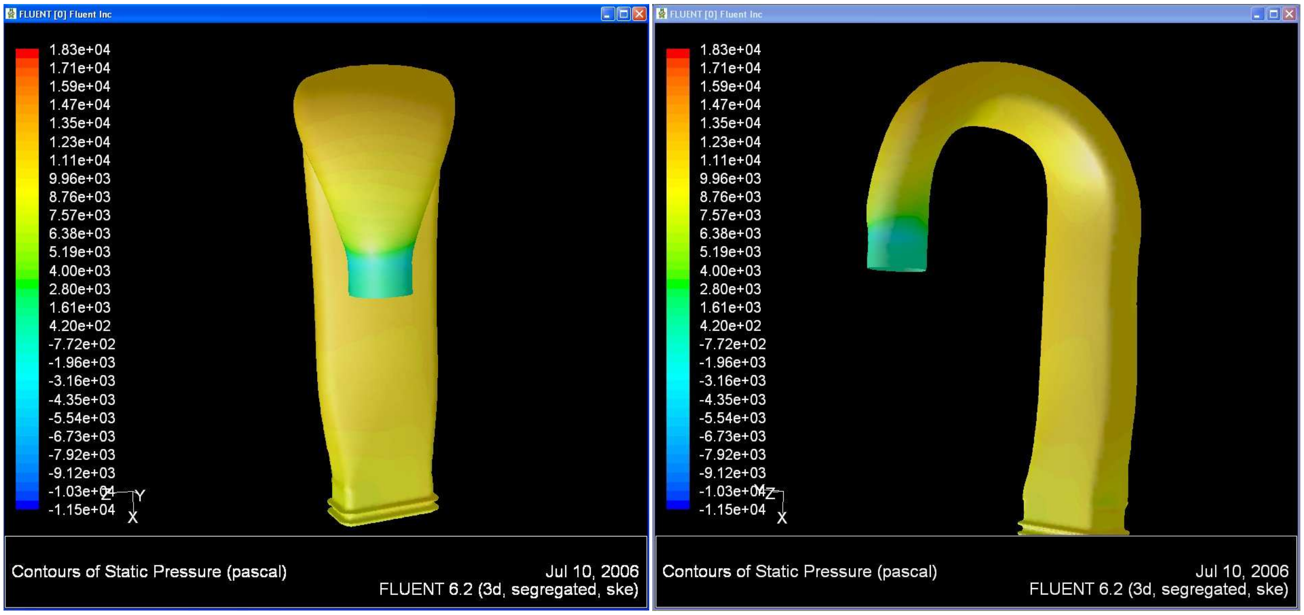

Figure 6. The duct shown in front and side view showing that the dark blue contours of negative pressure are no longer present due to the improved shape optimization.

Figure 7 shows the two front views of the fan duct before deformation (left) and after deformation (right). It is important to note that the deformations are subtle, but indeed they are there, and they produce an improved shape for reduced pressure loss. Most improvement in CFD shape optimization studies are due to subtle, smooth, volumetric shape deformations.

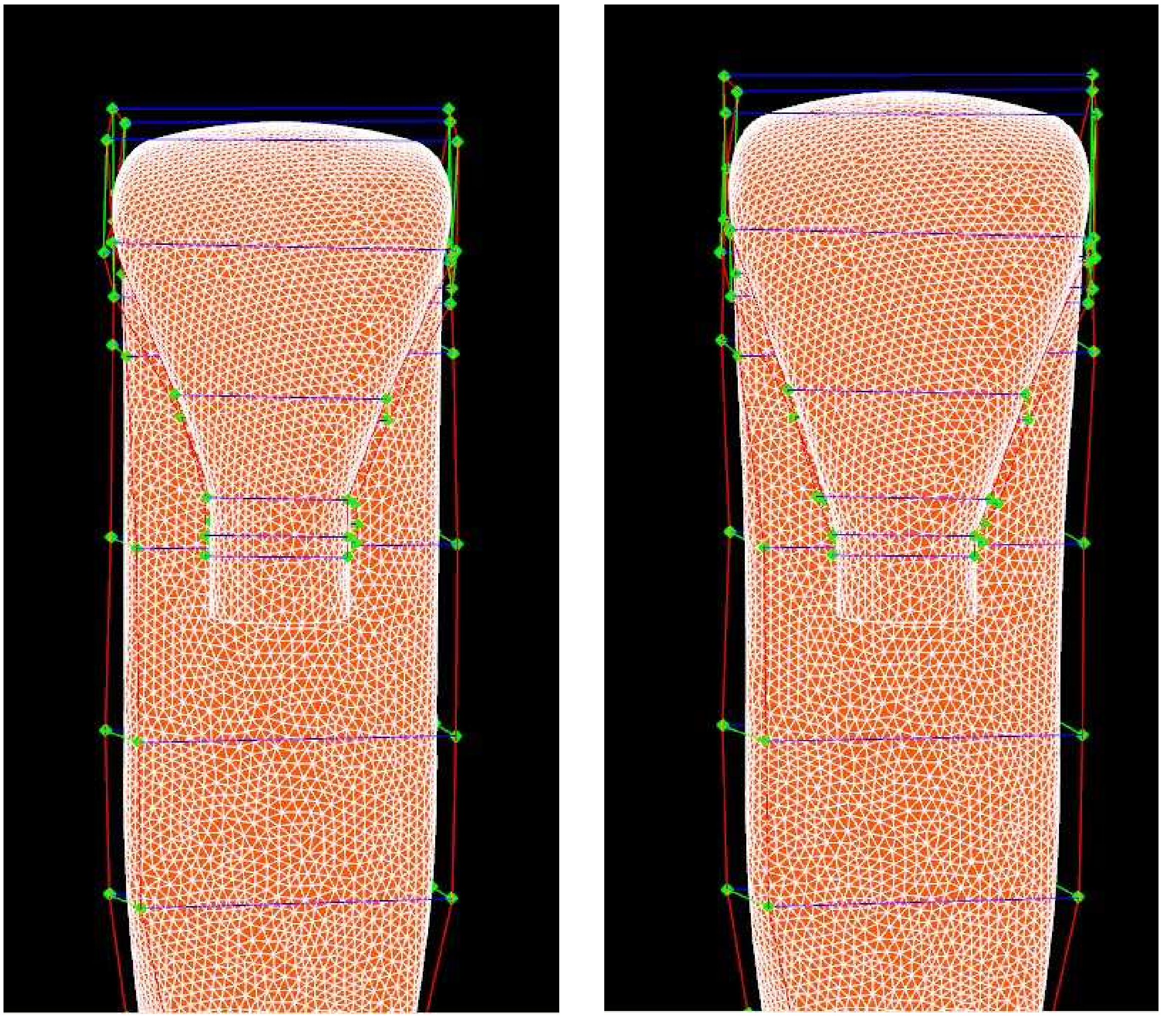

Figure 7. Baseline and Optimized shapes shown here side by side for comparison.

As requested, Table 1 shows a comparison of the total mass averaged pressure and mass flow at several locations in the system, including the fan duct inlet and outlet.

	Baseline: total pressure (Pa) (mass averaged)	Baseline: mass flow (kg/s)		Optimized shape: total pressure (Pa) (mass averaged)	Optimized shape: mass flow (kg/s)
1. Ambient plenum inlet	18,168.0	4.431		18119.9	4.431
2. Fan duct inlet *	13,781.3	0.9925		13,640.9	1.0261
3. Load section outlet	13,288.0	-1.4172		13,202.5	-1.4129
4. Power section outlet	13,041.7	-2.0374		12,921.5	-2.0275
5. Duct interface	13,781.3	4.546		17,443.0	4.546
6. Fan duct outlet	11,866.7	-0.9764		12,199.5	-0.9906

Table 1. A summary of the total pressure (Pa) (mass averaged) and the mass flow rate (kg/s) at six locations for the Baseline case and the Optimized Shape is tabulated here.

Final results: The static pressure drop between the fan duct inlet and outlet for the Baseline was calculated as 9,595.5 Pa. The static pressure drop for the Optimized Duct was calculated as 8930 Pa. This represents nearly a 7% reduction in pressure drop over the Baseline case.

The 7% reduction in pressure drop for the Optimized Duct is an improvement over the Baseline case. However, it should be pointed out that the Baseline case was a good shape to start with. The shape optimization process in Sculptor is designed to find the small subtle shape changes and in essence seeks out the 'hard to find' improvements.

Project Deliverables:

- This report
- A PowerPoint file with the same information.
- Fluent mesh of Baseline model created in ICEM-CFD.
- Fluent case and data files of the Baseline model.
- Fluent case and data files of the model with the optimized duct.
- Sculptor files (.mdf, .vol, .stu, files defining the ASD volume and Design Variables.)