December 11

Project 6

2010

Ben Kowalewski

Personal Computer Chassis
Air Cooling CFD Analysis and Design

Contents

Figures:

Preface

This report's focus is on computer aided engineering techniques that significant work and effort were devoted unto in order to both learn and utilize them for the tools of the study. Three Dimensional Flow analyses can become overwhelmingly complex even when utilizing a state of the art commercial software package. Computation times are significantly longer than most of the FEA done in class and for prior projects, so to learn the software and utilize it properly in this study took a great amount of time using trial and error. Please understand that this took away from putting effort into generating a detailed model with accurate specifications for manufacturing, mechanical retention details, materials, etc. I already have significant experience in the detailed design of products and equipment such that I spent nearly all of my time on this project learning and utilizing a new engineering tool: Advanced Simulation in NX – Fluid and Thermal Coupling CFD Analysis. I have obtained an extraordinary new skill with all this practice and studying of CFD applications, and I'm very happy with the outcome of this report.

Thank you for your understanding:

Ben Kowalewski

1 Introduction

The personal computer is an absolutely astounding device. Over the past three decades starting in the late 1970's, personal computers have gone from average sales of 48 thousand units per year, to over 250 million machines per year in the present day.(1) With such an extensively growing and rapidly developing market, competition has increased and designs have required more and more creativity, ingenuity, efficiency, and innovation.

The personal computer is primarily thought of as an electronics device. While the electronics of the personal computer do represent the system that the end user is most interested in, it is essential to have a sound mechanical framework to keep the electronics functioning properly for the longest lifespan possible. The circuit boards and electronic components of a personal computer must be contained properly away from external mechanical and other electrical interference.

In addition to simple containment and mechanical retention, the modern personal computer generates substantive amounts of waste heat produced primarily by the power hungry processor chips and integrated circuits. It is essential to keep these circuits cool enough so as to not damage them, and to mitigate performance losses caused by overheating. In order to remove this waste heat from the system, typical hardware comes with heat sinks built onto the most susceptible components allowing for more surface area for convective dissipation.

For desktop style computer chassis, the waste heat from the internal components could still be problematic if there is lack of ambient airflow and ventilation in the case. Methods of disposing the waste heat include optimizing the system layout, placing fans in the chassis walls to focus airflow around critical components, and sometimes placing fans directly over the heat sink of a component. Other means of disposing waste heat include liquid cooling, heat pipes, and submersion cooling.

Most computer chassis and internal components are purchased from stock with fans that provide the necessary airflow to keep the system cool. Very rarely and typically only in the custom computer mod community do consumers opt for liquid cooling or other exotic cooling methods, as they are far more expensive and difficult to install.

2 Design Objectives

A successful **computer chassis (or computer case)** accounts for these primary elements and deals with them in the most efficient way to allow for more extreme electronics performance:

- Mechanical Retention of Standard Electronic Components
- Containment and Protection of Electronics
- Easy External Access to Peripherals of the System (such as disk drives and connector interfaces)
- Easy/Simple Assembly and Disassembly
- Minimize Size and Weight without restricting Selection of System Components
- **Maximize Cooling Efficiency**
- Design for Durability and Portability

We will be focusing in on optimizing the **Cooling Efficiency** design goal, as it is a somewhat controversial topic and detailed technical analysis on the problem is scarce. To accomplish this goal, we will study the effects of various air cooling methods by varying fan configurations and orientations and performing a computational fluid dynamics and coupled thermal analysis on a model of the design alternatives.

2.1 Design Information

Computer chassis cooling is a problem most well associated with high performance computing, which is commonly applied in simulation computing, servers, 3D media rendering, and in gaming PC's.

Today's cutting edge computer hardware can cumulatively consume over a kilowatt of power, all of which is likely converted into heat within the chassis. Here are some average thermal envelope specifications for some middle-of-the-road computer hardware you might find in performance geared desktop computers(2):

- **Central Processing Unit:** Phenom II X4 955 Black Edition – 125 Watts, ($140 USD)
- **Graphic Processing Unit/Card:** GeForce GTX 460 – 160 Watts (~$190 USD)
- **Memory:** ~11 Watts Per Stick (non-specific, DDR3 RAM)
- **Hard Drive:** ~11 Watts Per Drive (non-specific SATA HDD)

The possible combinations of hardware you could include in a desktop computer build are massive and the specifications are always changing, but that is not entirely critical to this study. We will simply use the above listed power consumption / thermal envelopes as heat sources.

Fan placement is typically designed such that airflow is directed in through the front, sides, and top of the case – over the critical components such as the motherboard, the graphics card(s), and the disk drives – then out through the back of the case. Other methods include applying constant inward airflow from all fans to generate pressure within the case that forces air out through perforated ventilation panels around the case walls. The primary objective of this project is to determine the optimum method of air-cooling the case, and what types of fan layouts will optimize the case temperature and overall cooling performance. Factors in this design optimization include:

- Number of fans used?
- What size fan would work best?
- What is the optimum placement location for the fans?
- Front, side, top, bottom, or back?
- Should the fan blow air in or out?

Figure 1 - Computer Chassis Air Cooling

2.2 Design Survey and Selection

There are many different layouts and orientations that make a computer chassis more appealing to a certain market or user base. Generally, different layouts and form factors have different external sizing to make the chassis smaller or more ergonomic. If we reduce the design scope to standard personal-computer components and upright tower case designs, there are three major design contenders:

Figure 2: Full Tower Case Design

The full tower case design is the largest of the three design variants. The full tower usually has six to ten externally accessible drive bays, and a handful of internally accessed HDD bays. This tower usually stands at a minimum of 22 inches in height, and is intended to be placed on the floor.

Figure 3: Medium Tower Case Design

The medium tower case design typically stands about 18 inches in height, and has between two and four externally accessed drive bays.

Figure 4: Micro Tower Case Design

The micro tower case design is usually only 14 to 16 inches in height, and typically only has one or two externally accessible drive bays. This case design is sometimes placed horizontally on a desktop and the computer monitor is often placed on top of it.

The most common chassis manifold style is the mid (medium) tower, which is capable of housing nearly any of the cutting edge internal components needed by any user seeking optimal performance for cost. This case sizing is typically found housing a handful of 80 millimeter case fans, and/or several 120 millimeter case fans. Older cases of this size typically only had a single fan situated at the back of the case pumping warm air outward. It is also possible to use a single, very large side panel case fan to blow cool air into the case.

Figure 5: Example Medium Tower Chassis with 1 Back Fan and 1 Side Fan (120mm size)

The case shown in Figure 5 is Apevia's X-Telstar Jr. It comes stock with a 120 mm fan in the back and a 120 mm fan to blow cool air in on the side. They also have a mount location for a 120 mm fan to be place on the bottom inside of the front face of the case. The power supply unit (PSU) is mounted against the inside of the top face of the case against the back wall.

We will study the mid-tower chassis type in this report because of its broad appeal and conservative design. A mid tower chassis can be used for mass production business oriented computers, or for home computers, or for high performance gaming computers.

3 Model

3.1 3D Envelope Sizing:

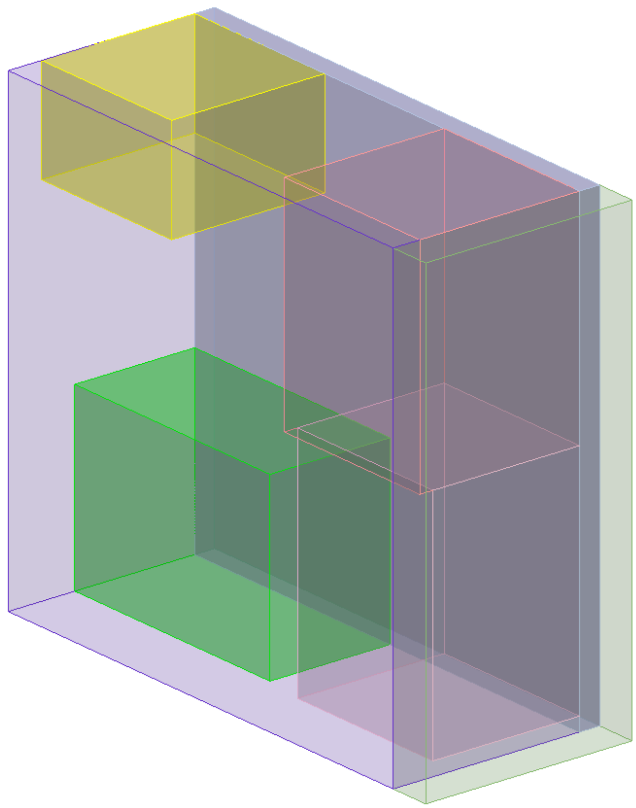
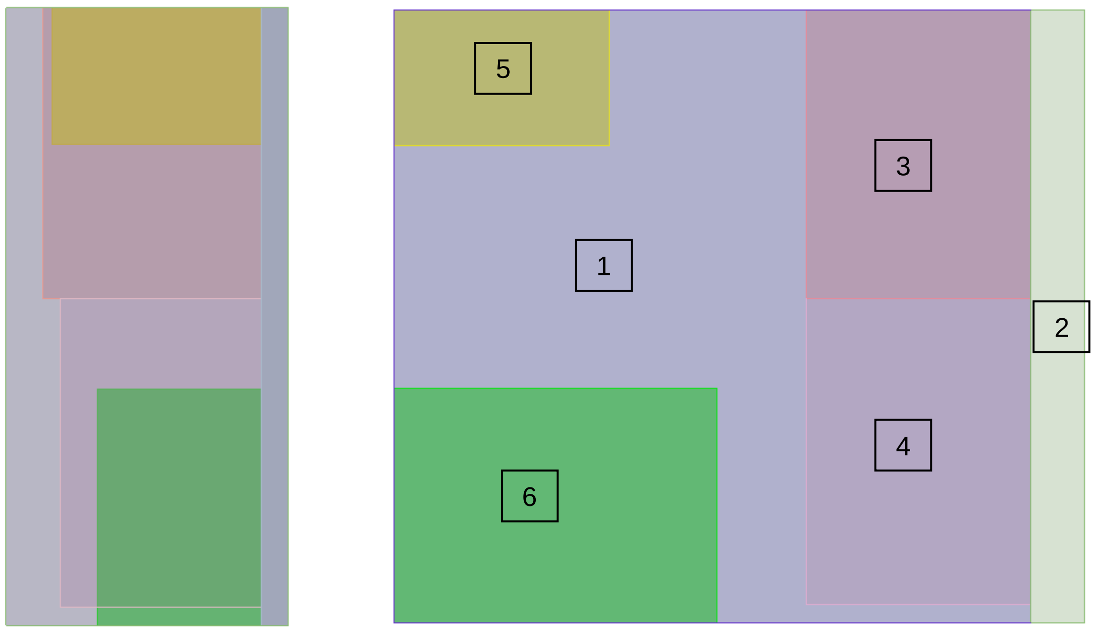


Figure 6: Envelope Trimetric View

A generic layout of a medium tower chassis includes a front panel cover, a structural chassis (commonly made of aluminum or steel), a place to mount the motherboard with room for the CPU cooler and all peripheral cards, as well as a location to mount the PSU. Most cases have the motherboard mounted near the right wall (as observed from the front of the case) on a sheet of metal that spans the case cross section longitudinally. This mount wall also provides space for cables between it and the external case cover.

The PSU can be mounted near the top of the case, or near the bottom, and is typically mounted against the back wall and the mount wall. With the PSU mounted near the top of the case, the motherboard is normally shifted down to allow the peripheral cards to be placed near the bottom of the case. With the PSU mounted at the bottom of the case, the peripheral cards are located above the PSU.

The inside of the front cover is where the disk drives are stored; hard drives, CD/DVD ROM drives, floppy drives, and other accessories can then be accessed through the front panel of the case cover.



1. Aluminum/Steel Case Shell Envelope
2. Plastic Case Cover Envelope
3. Large Peripheral Bays Envelope (5x Bays)
4. HDD and Small Bays Envelope (5x Bays)
5. Power Supply Unit Envelope
6. Expansion Cards Envelope (7x Slots)

This envelope will best represent the primary design layout of the mid tower case under scrutiny in this study.

3.2 Analysis Geometry

The final model used for analysis will be simplified to represent the geometry critical to the chassis airflow and cooling systems. Computation times for complex fluid meshes can be extraordinarily long, so it is important to choose your fluid geometry to be fairly simple at first, and if desired – refine and add details later.

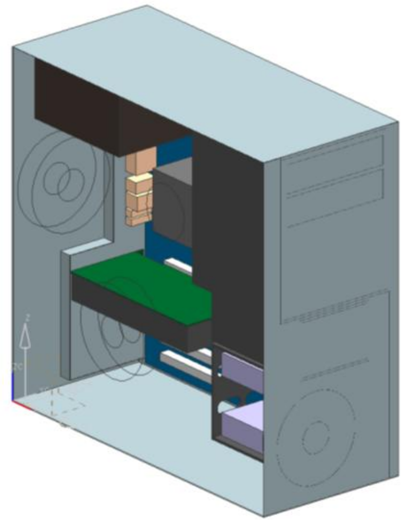


Figure 7 - Computer Model Geometry

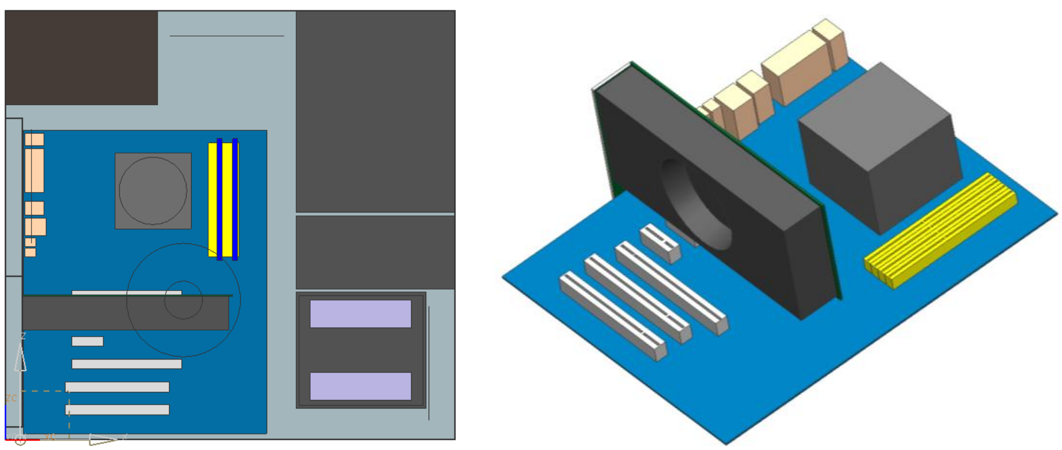


Figure 8 - Side view of Geometry (left), System and GFX boards (right)

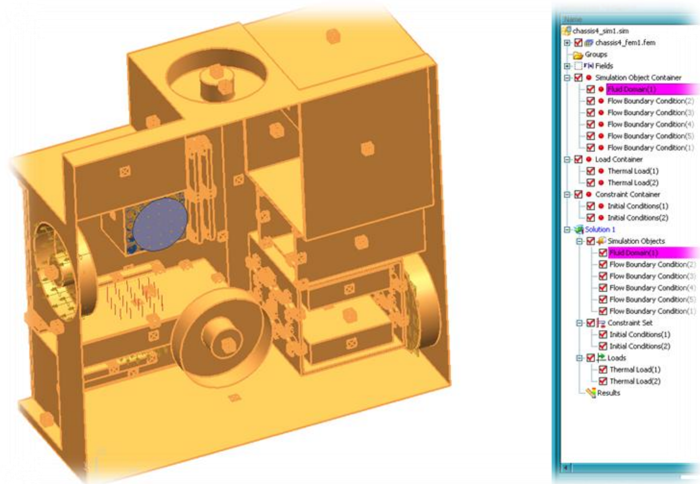
The system is modeled such that air passages in the chassis walls can be easily added, removed, modified, customized, and optimized through the analysis process. To avoid overly complicated meshing and extremely long computation times, the model geometry is somewhat simplified down. Also note that it will be possible to add/remove system components easily to see what the effects of different configurations may have on the efficiency of heat removal.

3.3 Solution Design Variations

To narrow the scope of the limitless possibilities for air flow cooling, I have chosen to study the following five possible fan configurations as the potential final design contenders:

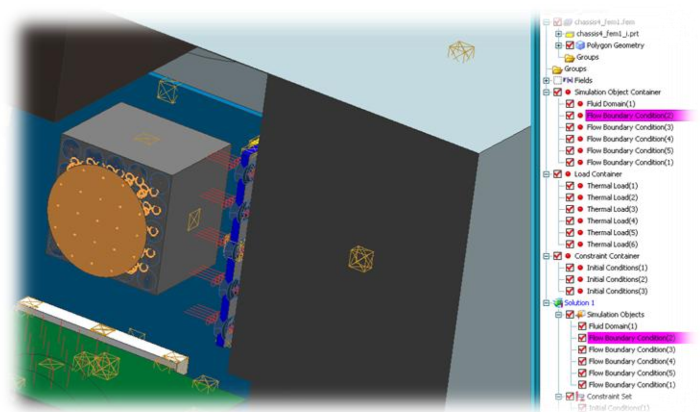
1) A single exhaust fan in the back of the case, with the front fan location acting as a vent.
2) Same as design option 1, but add the side case fan pushing air in.
3) Same as design option 2, but instead of a front vent, there will be a fan there pushing air in.
4) Same as design option 3, but add the top case fan pushing air out.
5) Same as design option 4, but the top case fan flow direction is reversed.

3.4 Boundary Conditions and Domains



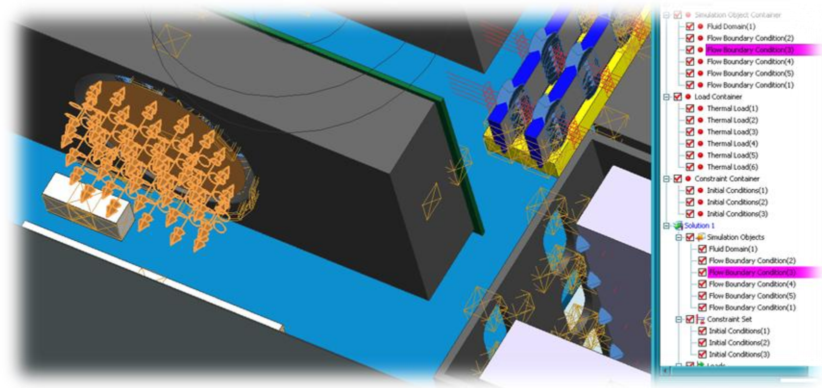
The Fluid Domain is a single solid body that is later divided up into finite elements for the fluid analysis. This solid body represents all of the air that exists within the computer case walls.

Figure 9: Fluid Domain



The CPU fan pushes air into the CPU heat sink, causing a pressure rise and forcing air out through the fins. This simplified version simply pushes air toward a flat surface which is later given a heat flux of the CPU power consumption.

Figure 10: CPU Fan



The GPU fan pushes air into the GPU heat sink. Later, we will specify a fluid boundary allowing flow to leave the chassis out through the GPU ports in the back of the chassis.

Figure 11: GPU Fan

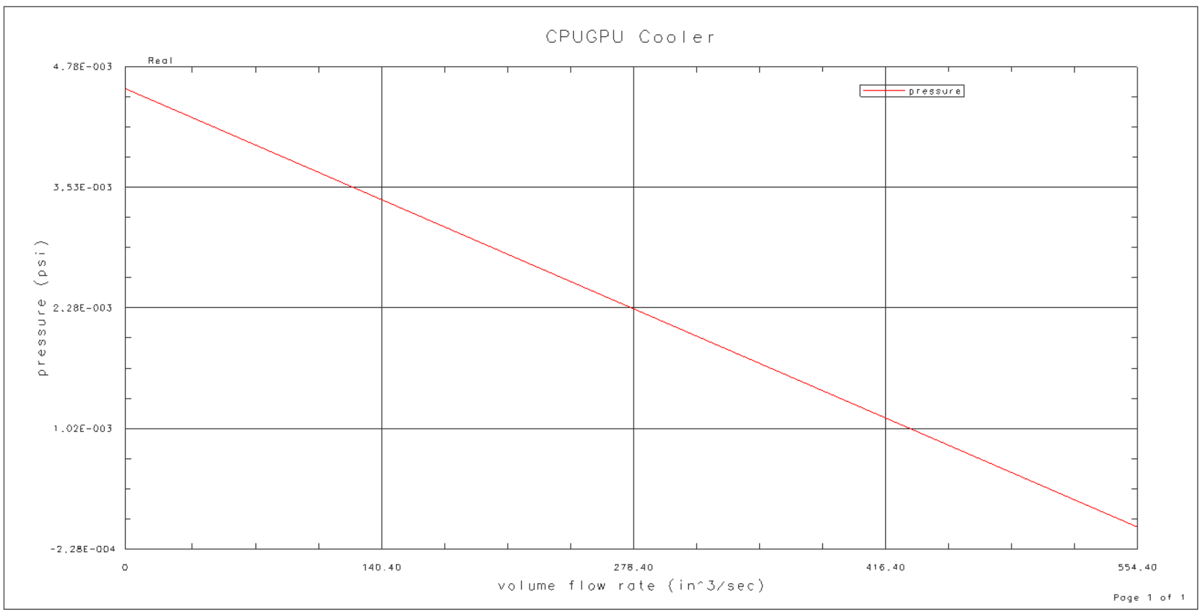
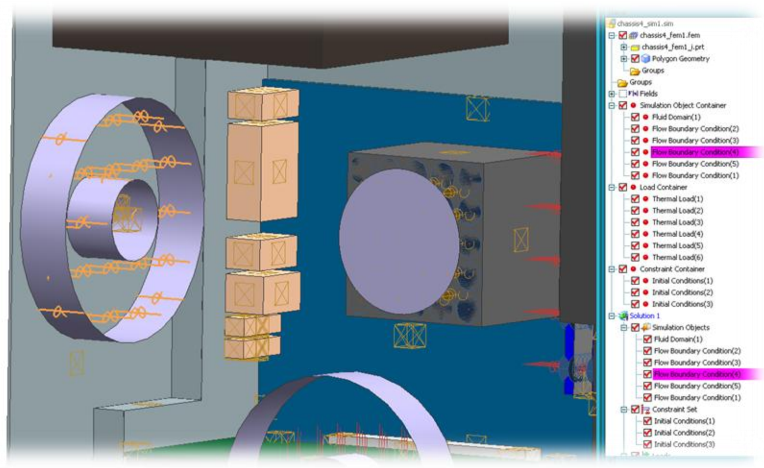


Figure 12: CPU/GPU Fan Pressure vs. Flow Rate Relations

CPU Fan Specifications:

- 2.67 Fan Blade Diameter
- 554.4 cis Free Air Flow
- 3.2 mmH2O (.00455 psi) Static Pressure

The same fan curve has been selected to model the CPU and the GPU cooling fans. It is modeled after a Cooler Master standard style CPU cooling unit fan. (3)



A 120 mm case fan; typically expels hot air out the back of the case.

Figure 13: Back Case Fan

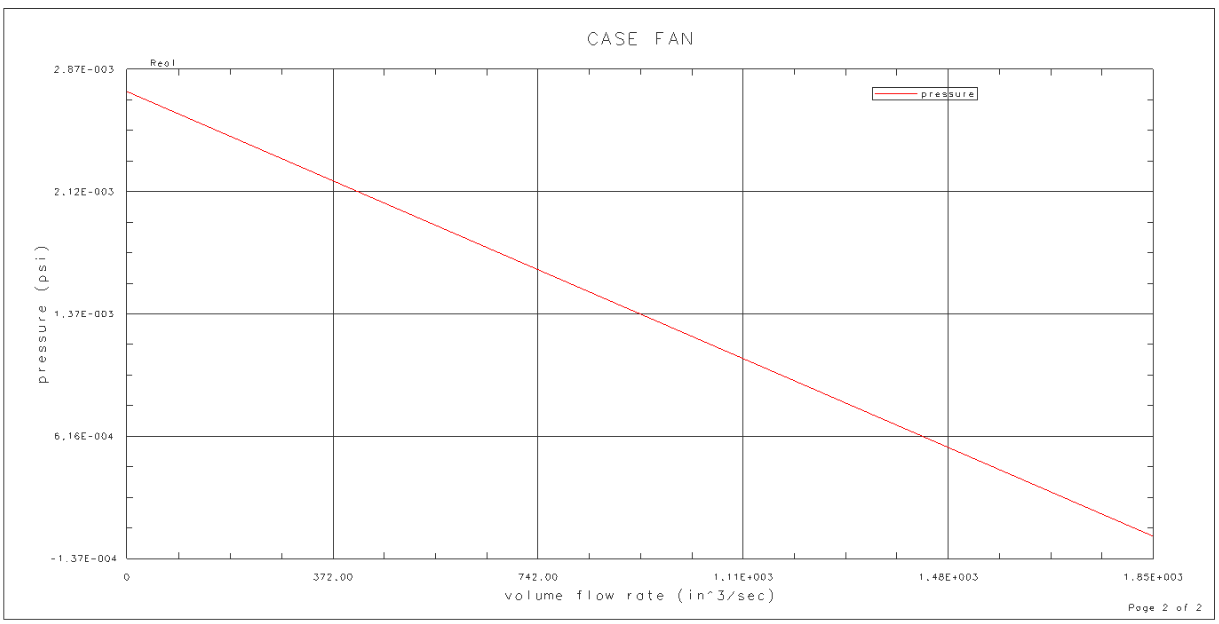
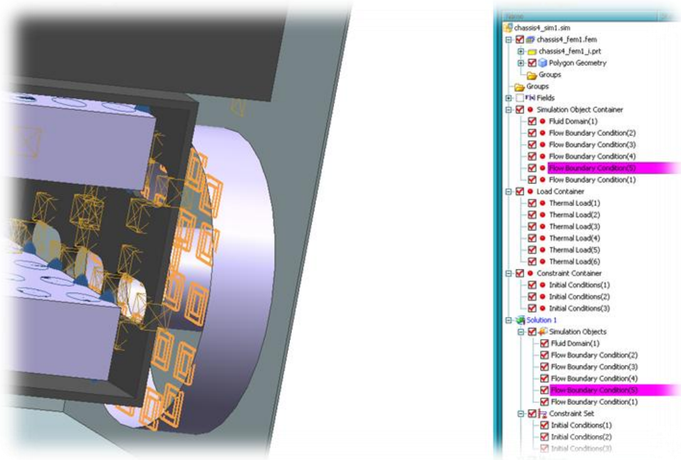


Figure 14: Case Fan Pressure vs. Flow Rate Relations

Case Fan Specifications:

- 4.5 Inch Blade Diameter
- 1.5 Inch Hub Diameter
- Approximated 25 Degrees of Velocity Swirl at Fan Inlets
- 64.3 Cubic Feet per Minute Free Air Flow (1851.84 cis)
- 1.925 mmH2O Static Pressure (.002738 psi)

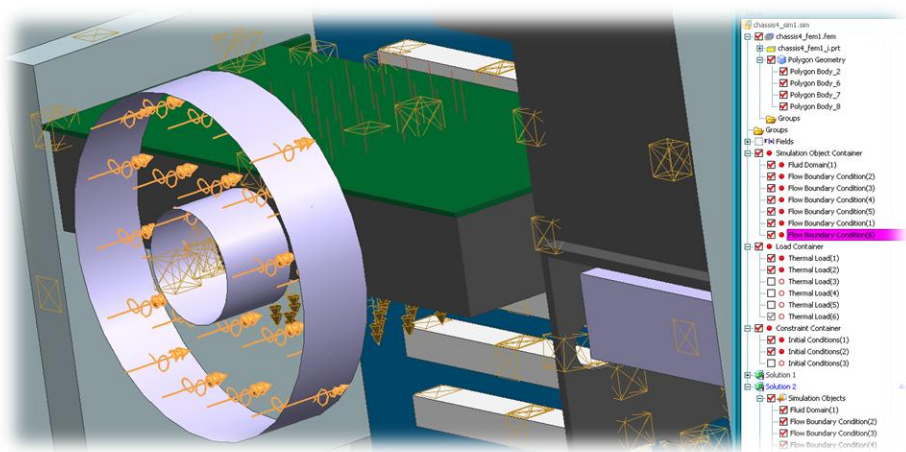
This fan is modeled after a GELID Wing 12 case fan.



A 120 mm case fan; typically blows cool air in to enhance the front intake flow rate.

Figure 15: Front Case Fan

The front case fan typically draws air through porting from the front of the chassis manifold and blows it into the case. In the absence of a fan, this porting still provides the primary influx of airflow for the back chassis fan blowing the air out of the case. Typically this airflow is restricted by the vent styling, or the chassis front cover. For this reason, a fluid boundary was created with an available flow area of 50%, resulting in a head loss coefficient of 3.999. This head loss can be equated to flow through a thin perforated plate, where 50% of the plate area is open to flow, and 50% of the plate area remains un-perforated.



A 120 mm case fan; typically blows cool air in.

Figure 16: Sidewall Case Fan

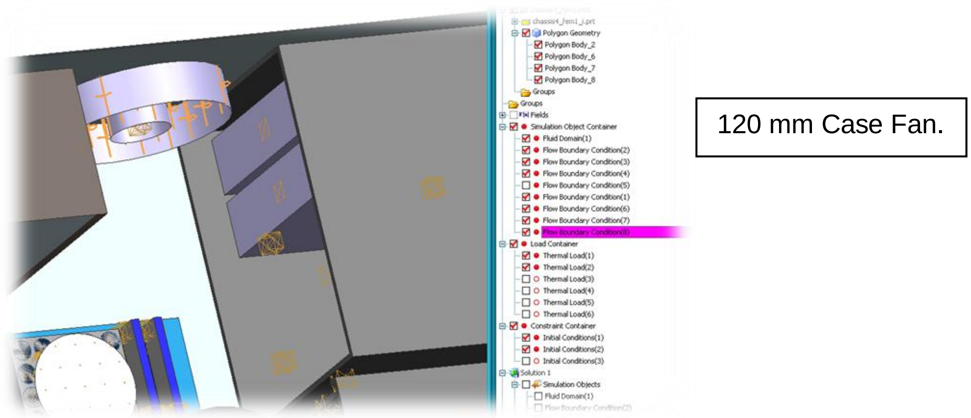


Figure 17: Top Case Fan

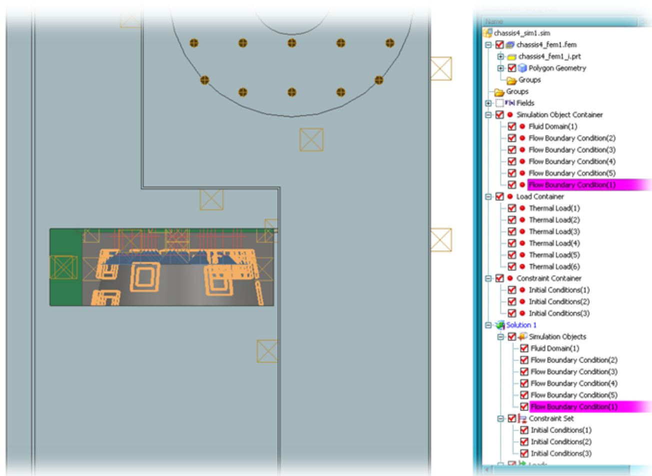
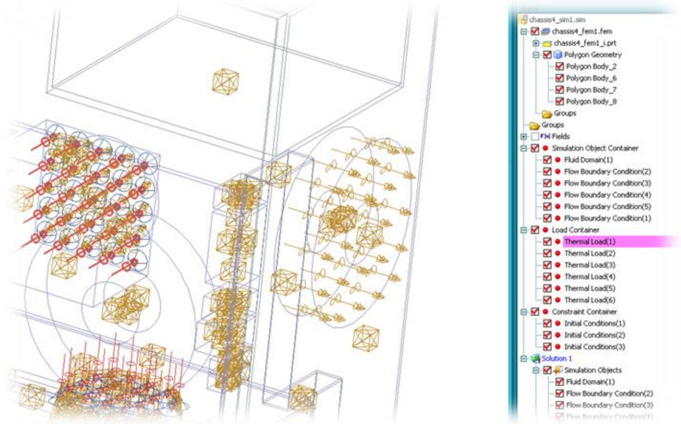


Figure 18: GPU Heat Sink Ventilation

The standard cooling method for most high-performance graphics processors is a two-slot wide ventilated heat sink. The GPU fan blows air up into the heat sink, increasing the heat sink air pressure and forcing air out the vents in the back of the case. To model this, a fluid boundary was created that allows flow either in or out the walls adjacent to the GPU fan, with an available flow area of 40%, resulting in a head loss coefficient of 8.232. This head loss can be equated to flow through a thin perforated plate, where 40% of the plate area is open to flow, and 60% of the plate area remains un-perforated.

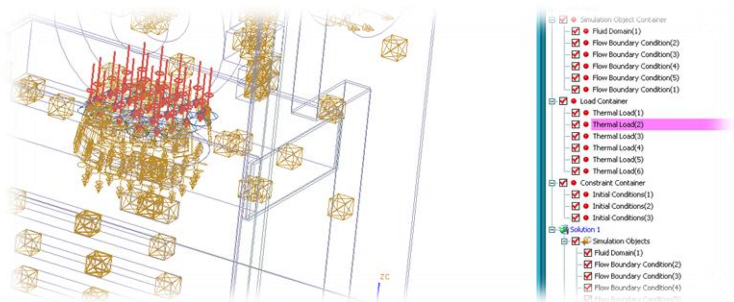
The ambient conditions for this simulation include an absolute pressure value of 14.6997 psi, external fluid temperature of 68 F, and a vertically downward gravitational acceleration of 386.22 in/s^2.

3.5 Heat Sources and Loads



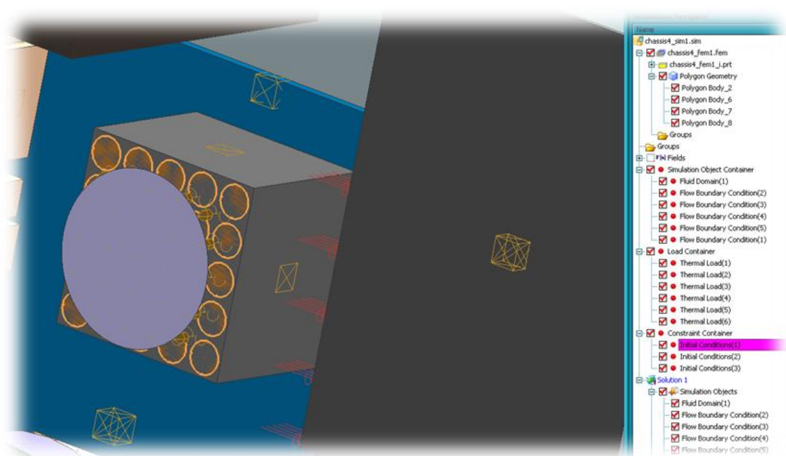
The heat generated by the CPU is modeled as a flux inward of thermal power into the fluid body. The flux value is 125 Watts (0.1185 Btu/s).

Figure 19: Heat Flux from CPU



The heat generated by the GPU is modeled as a flux inward of thermal power into the fluid body. The flux value is 160 Watts (0.15165 Btu/s).

Figure 20: Heat Flux from GPU



An initial guess of the fluid temperature at the thermal flux surface of the CPU was made at 90 F.

Figure 21: Initial Guess - CPU Heat Source Temperature

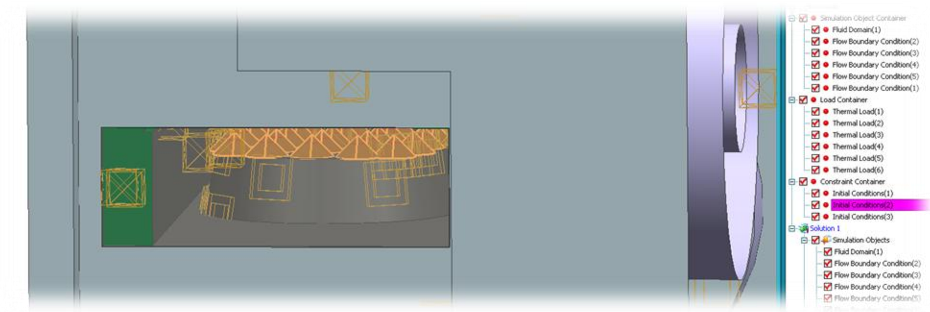


Figure 22: Initial Guess - GPU Heat Source Temperature

An initial guess of the fluid temperature at the thermal flux surface of the GPU was made at 65 F.

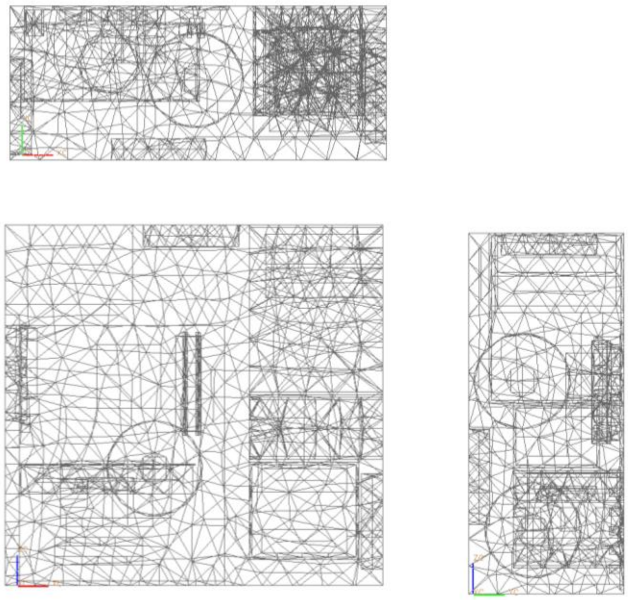


Figure 23: Fluid Mesh

NX Fluid Mesh Refinement Scale: 0.08

Number of Nodes: 15076

Fluid: Air

3.6 Model Simplifications

- Both the CPU and GPU heat generation is modeled as the power consumption rating of the integrated circuit, simplified to a heat flux boundary condition. In reality, the power consumption does not stay at its maximum rated value unless the computer is hammering out graphics rendering and computations. In addition, no conduction modeling is used – which contributes a significant amount to heat dissipation through the chassis walls. This will result in above average temperature results.
- The case geometry has not been modeled for convection or conduction, but rather all of the influx of heat energy must pass out through an opening in the fluid boundaries.
- Case ventilation has been restricted to targeted areas. In reality, the case ventilates through spaces around the seams and mates of the chassis walls.
- Fans are modeled with a linear pressure vs. flow rate relationship. In reality, this curve can be nonlinear, although this should not have a significant impact on the conclusions drawn from this study.
- All case fans are given the same properties. Ideally, it may be beneficial to use a stronger case fan in one location and a weaker case fan in another location. Same goes for the CPU/GPU fans.
- It is being assumed that the power generated by the hard drives, disk drives, RAM, and other IC's is all being dissipated solely through conduction.

4 Airflow and Cooling Analysis Results

4.1 Solution 1: Back Case Fan On, Front Ventilation

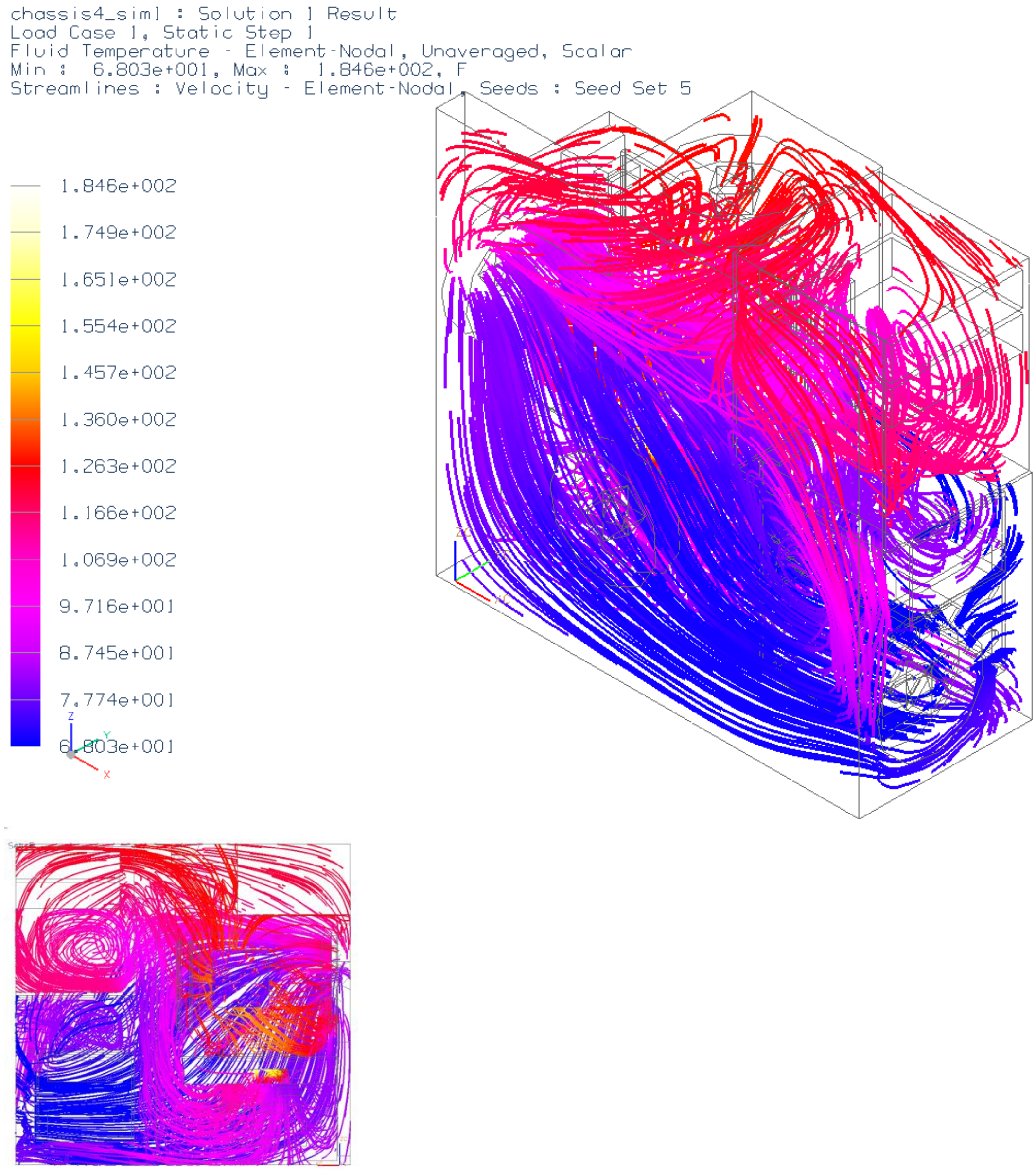


Figure 24: Solution 1 - Case Temperature

Solution time to solve: 18m 18s

Maximum Temperature: 184.563 F

Minimum Temperature: 68.026 F

Average Air Temperature: 94.628 F

Standard Deviation: 20.764 F

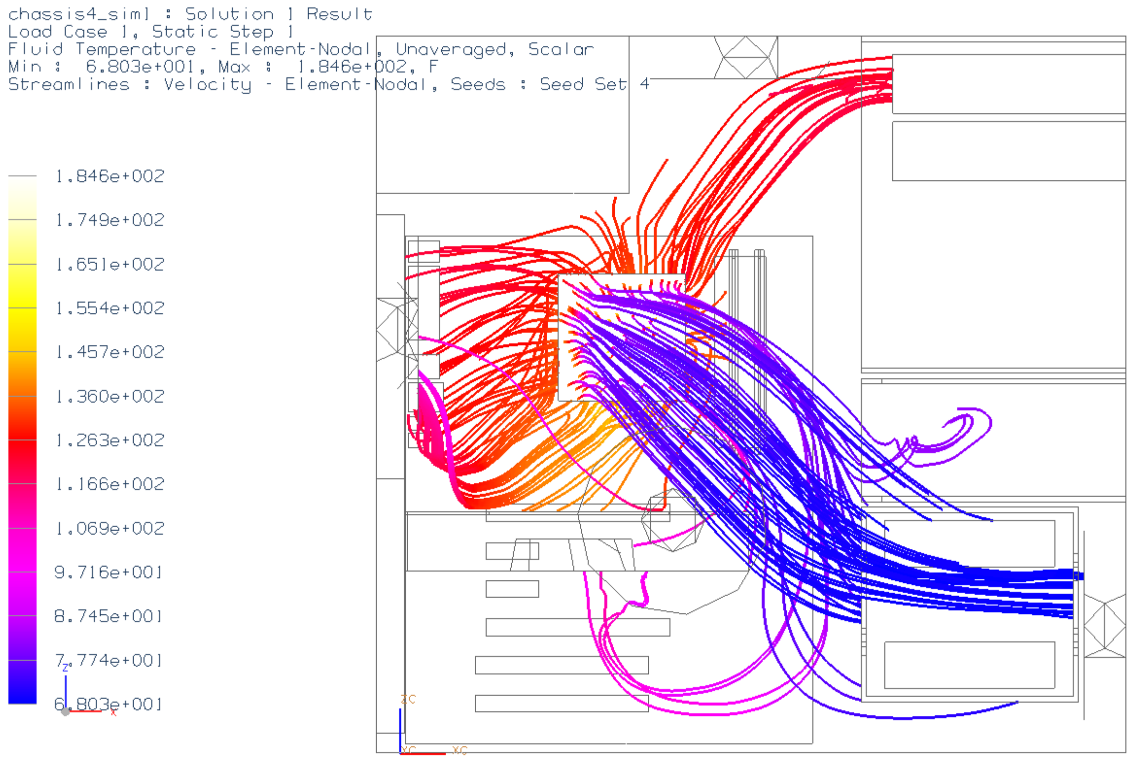


Figure 25: Solution 1 - CPU Cooling

Average Relative Pressure on CPU Sink: 7.380e-4 PSI

Average Velocity on CPU Sink: 3.606e1 in/s

Average CPU Temperature: 120.4 F

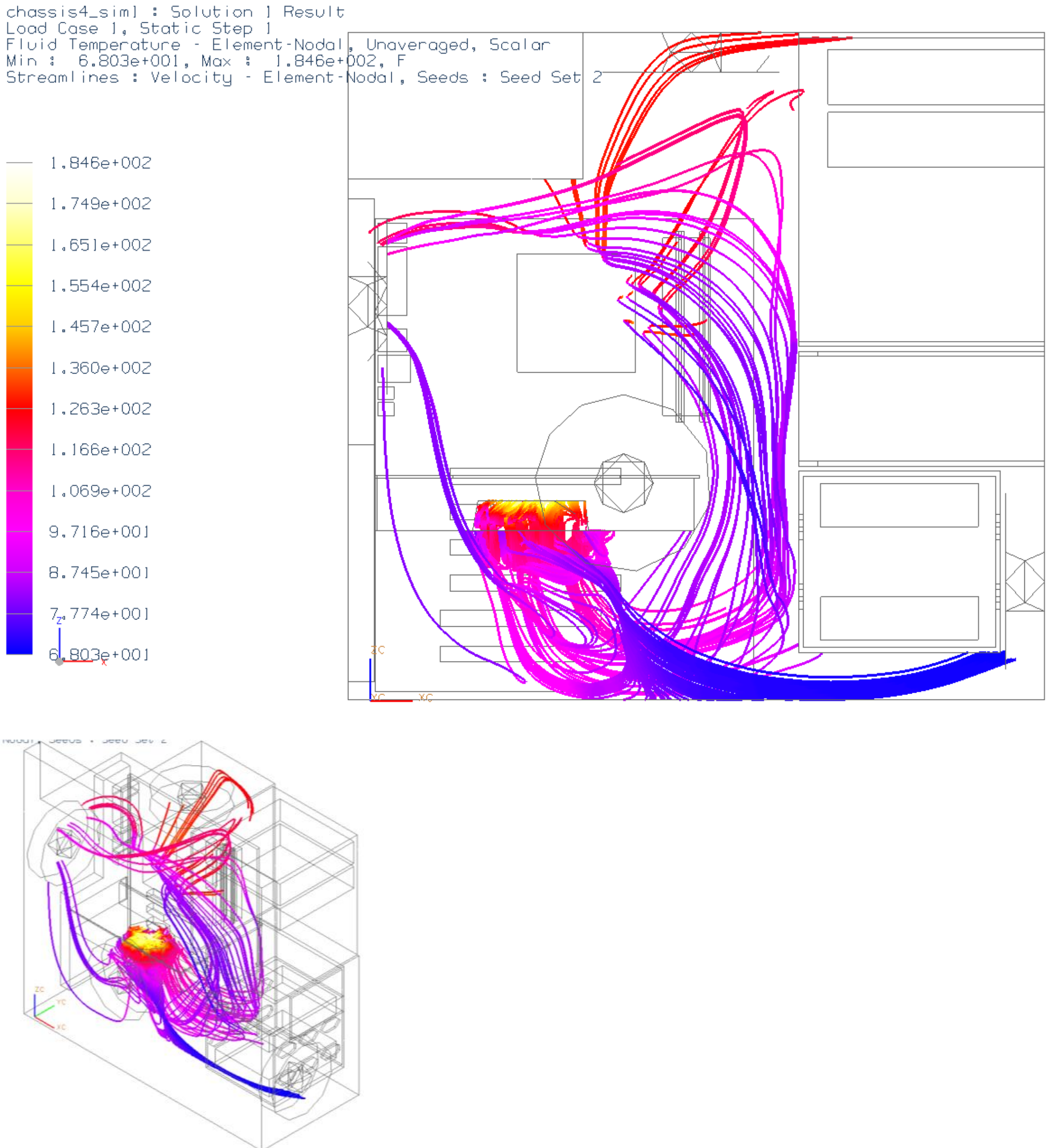


Figure 26: Solution 1 - GPU Cooling

Average Relative Pressure on GPU Sink: 5.463e-4 PSI

Average GPU Sink Temperature: 110.6 F

Mass Flux Through GPU: 2.287e-3 lbm/s-in^2

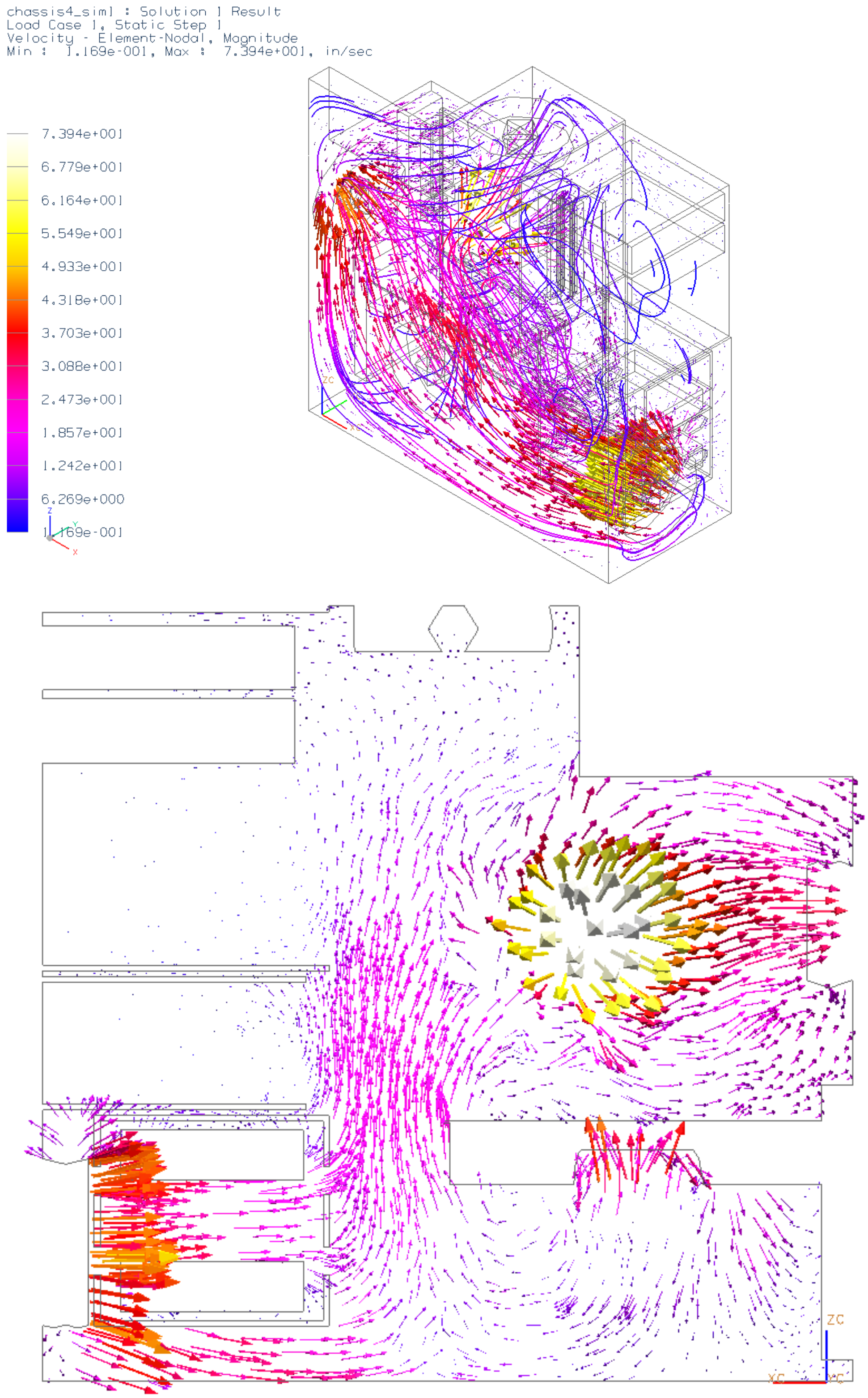


Figure 27: Solution 1 - Flow Velocity

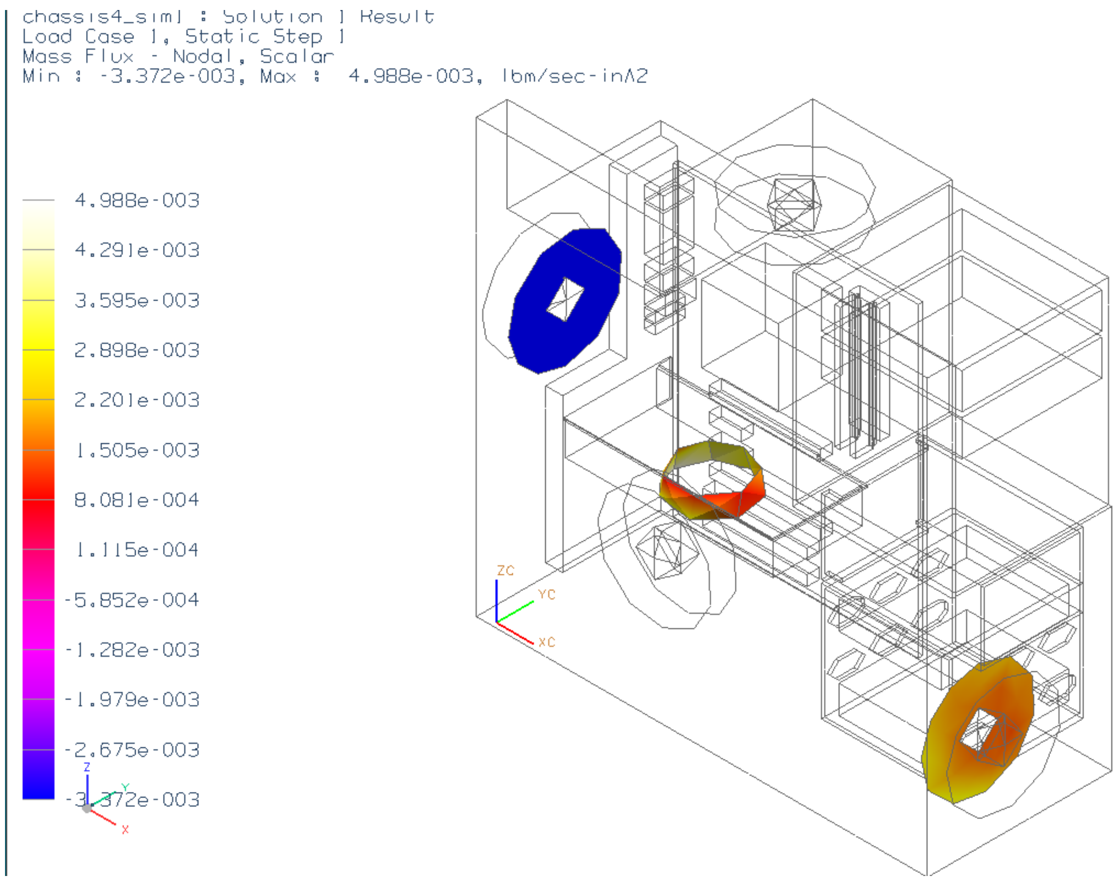
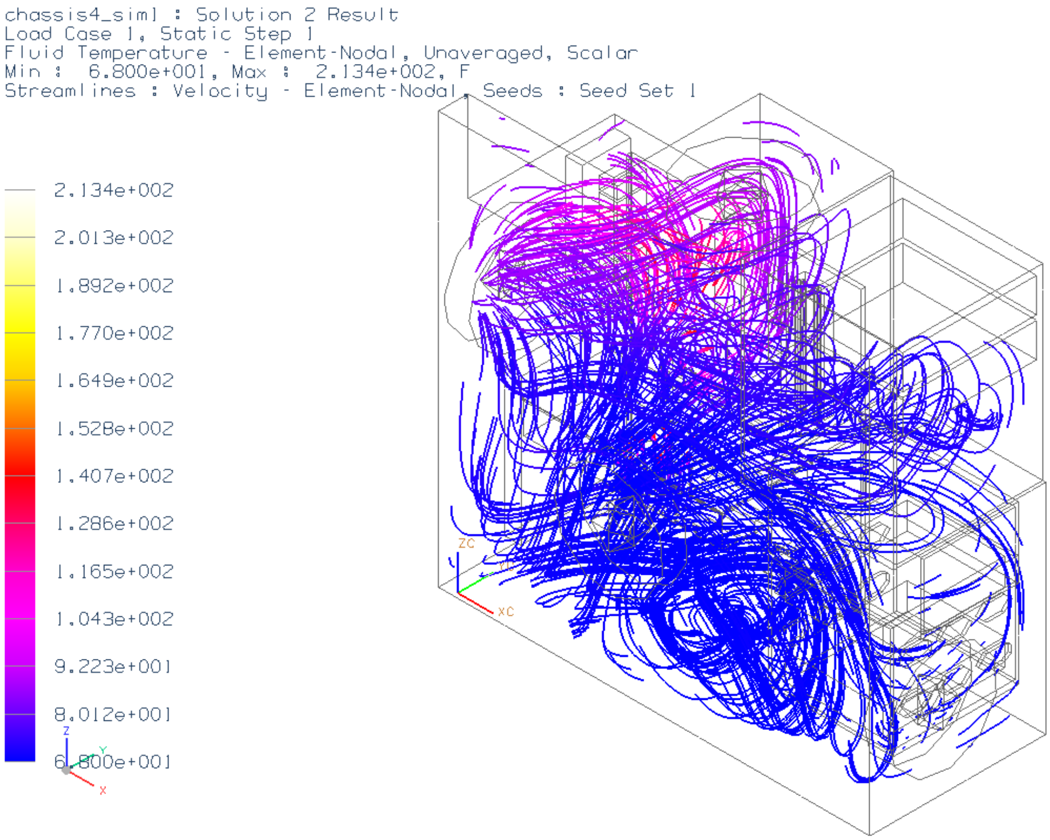


Figure 28: Solution 1 - Mass Flux

4.2 Solution 2: Back Case Fan On, Side Fan On, Front Ventilation



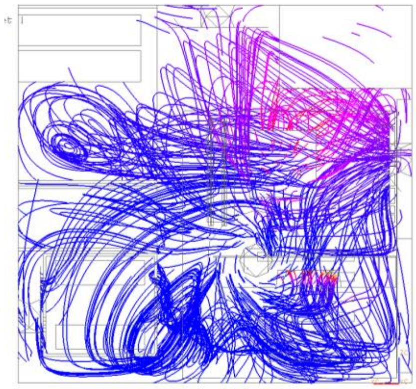


Figure 29: Solution 2 - Case Temperature

Solution time to solve: 18m 29s

Maximum Temperature: 213.394 F

Minimum Temperature: 68.000 F

Average Air Temperature: 74.297 F

Standard Deviation: 9.5673 F

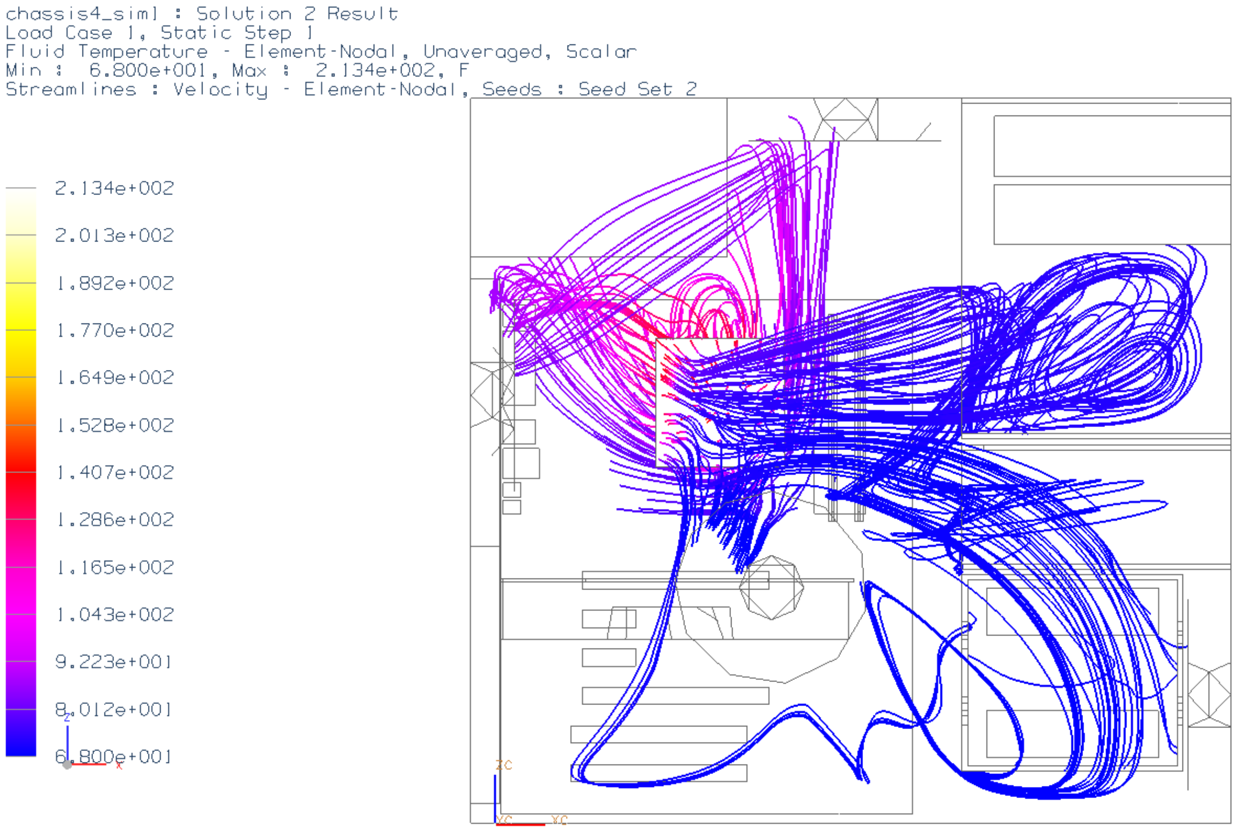


Figure 30: Solution 2 - CPU Cooling

Average Relative Pressure on CPU Sink: 2.694e-4 PSI

Average Velocity on CPU Sink: 4.452e1 in/s

Average CPU Temperature: 100.7 F

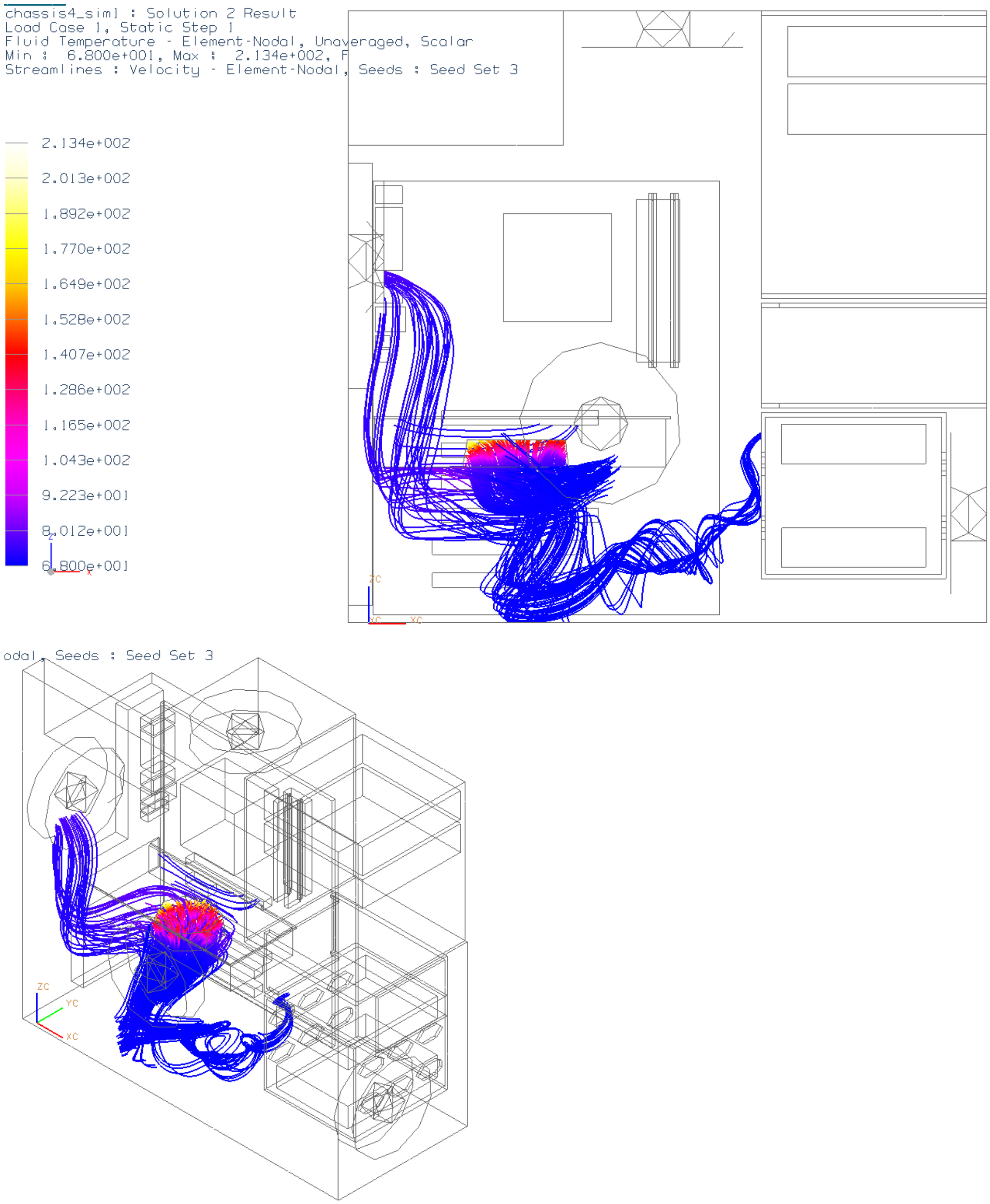


Figure 31: Solution 2 - GPU Cooling

Average Relative Pressure on GPU Sink: 7.460e-4 PSI

Average Temperature of GPU Sink: 119.7 F

Mass Flux Through GPU: -1.119e-3 lbm/s-in^2

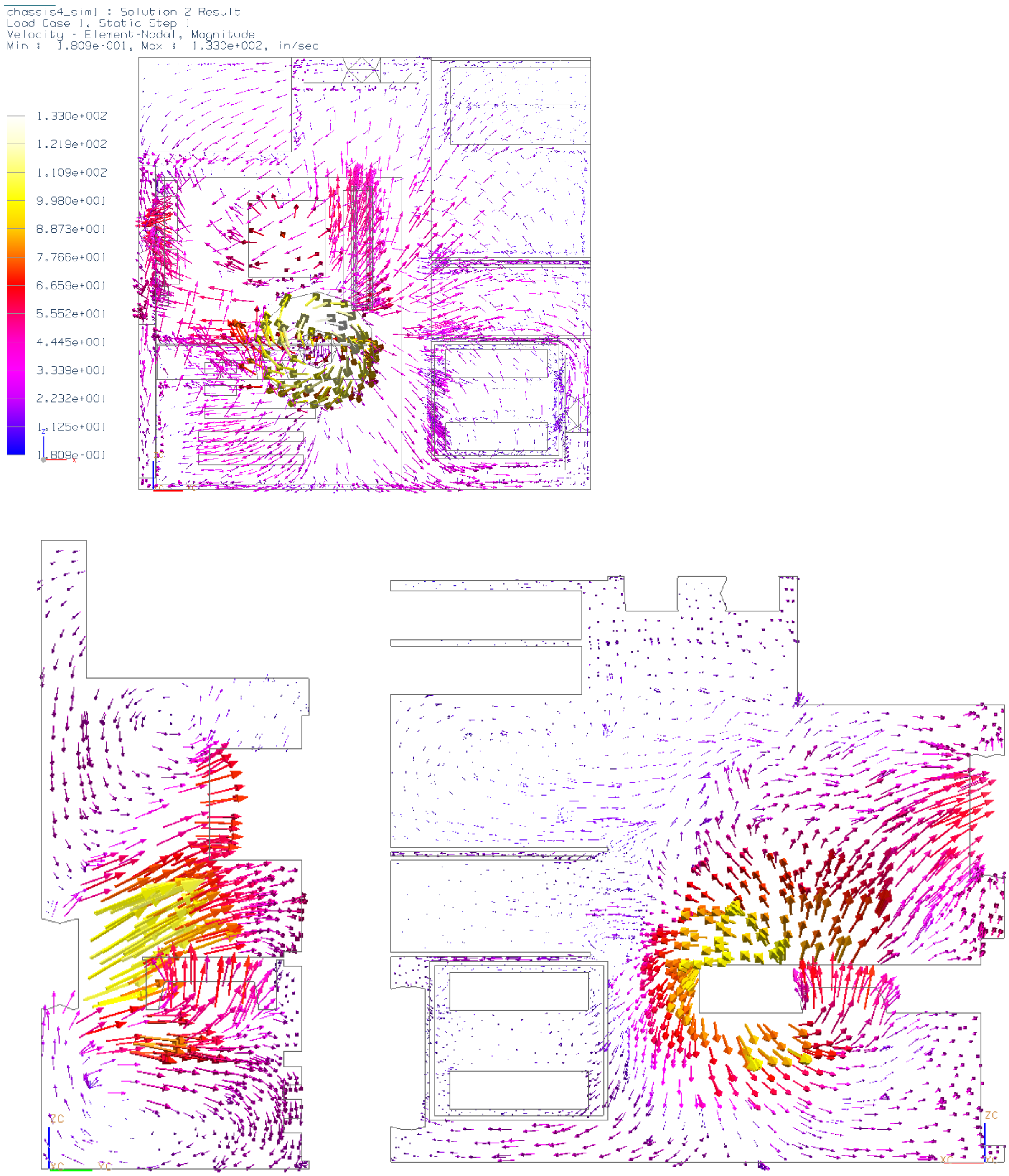


Figure 32: Solution 2 - Flow Velocity

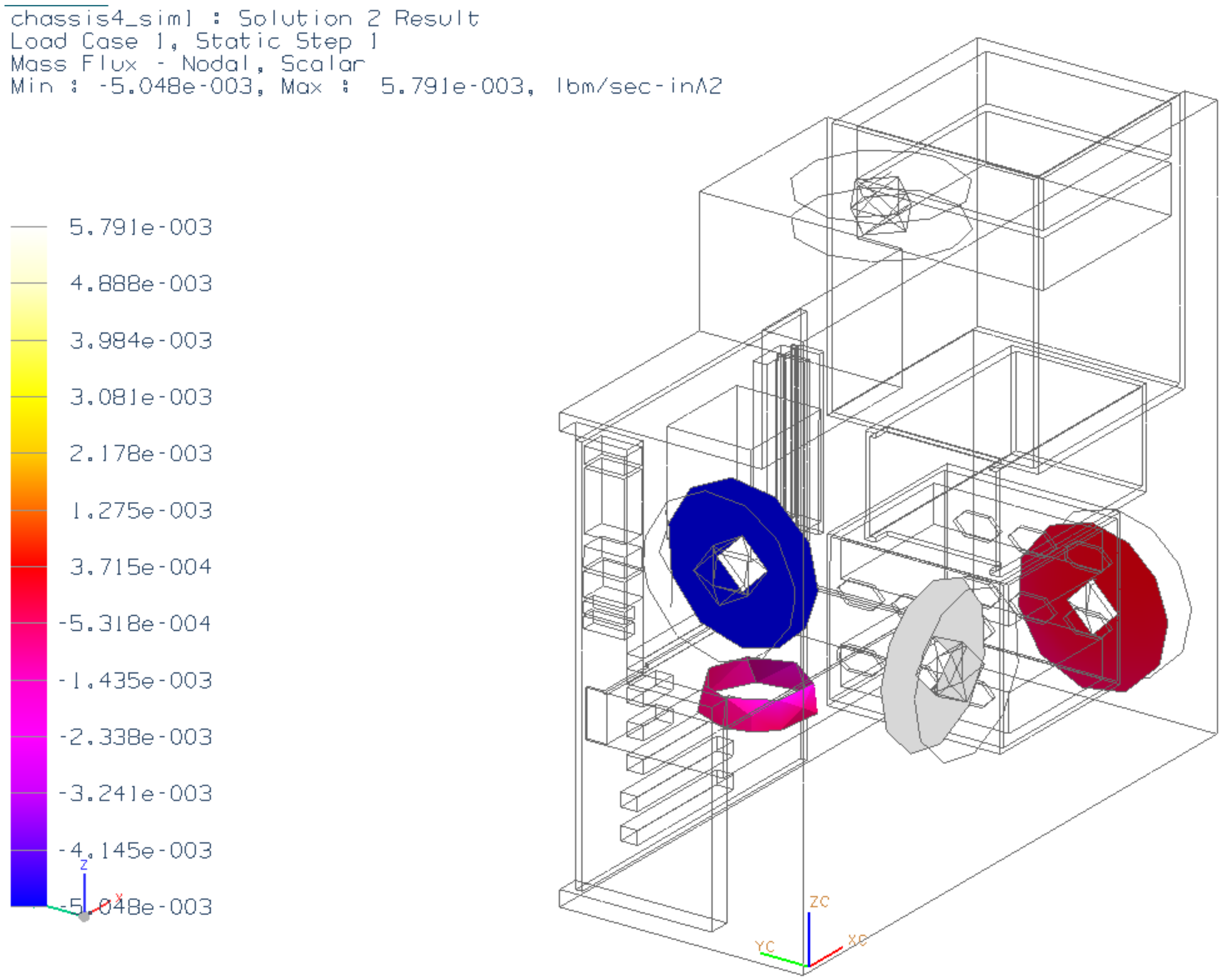


Figure 33: Solution 2 – Mass Flux

4.3 Solution 3: Back Fan On, Side Fan On, Front Fan On

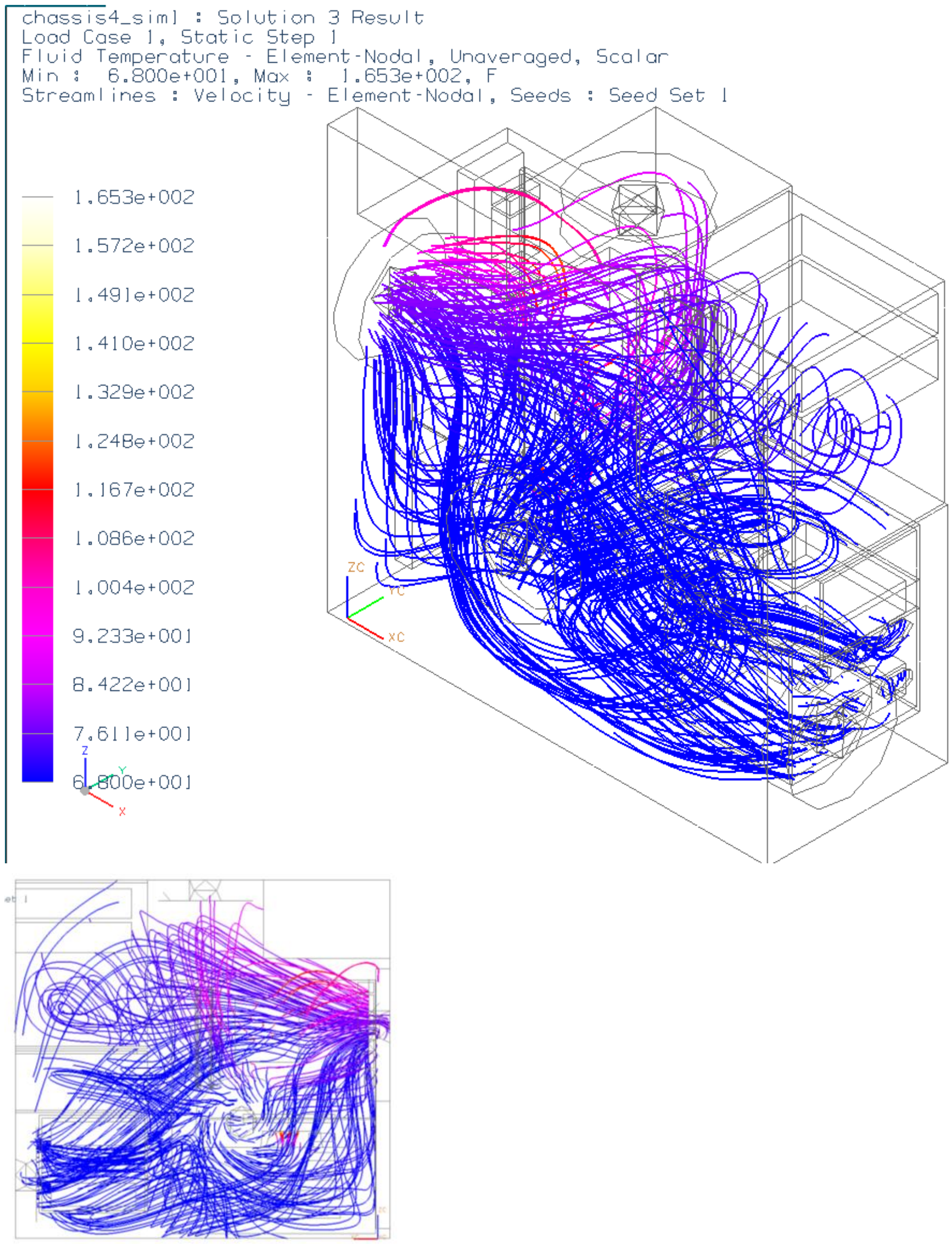


Figure 34: Solution 3 - Case Temperature

Solution time to solve: 18m 19s

Maximum Temperature: 165.323 F

Minimum Temperature: 68.000 F

Average Air Temperature: 73.002 F

Standard Deviation: 8.771 F

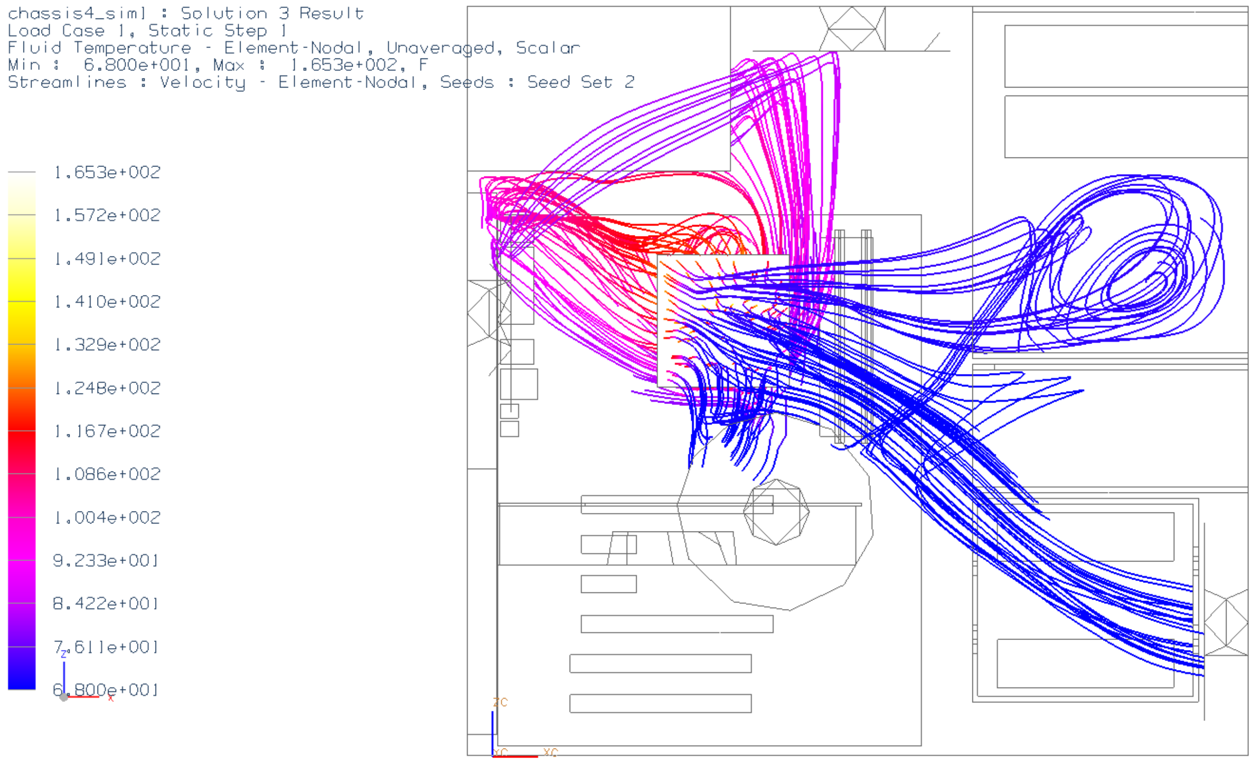


Figure 35: Solution 3 - CPU Cooling

Average Relative Pressure on CPU Sink: 6.445e-4 PSI

Average Velocity on CPU Sink: 4.169e1 in/s

Average CPU Temperature: 98.85 F

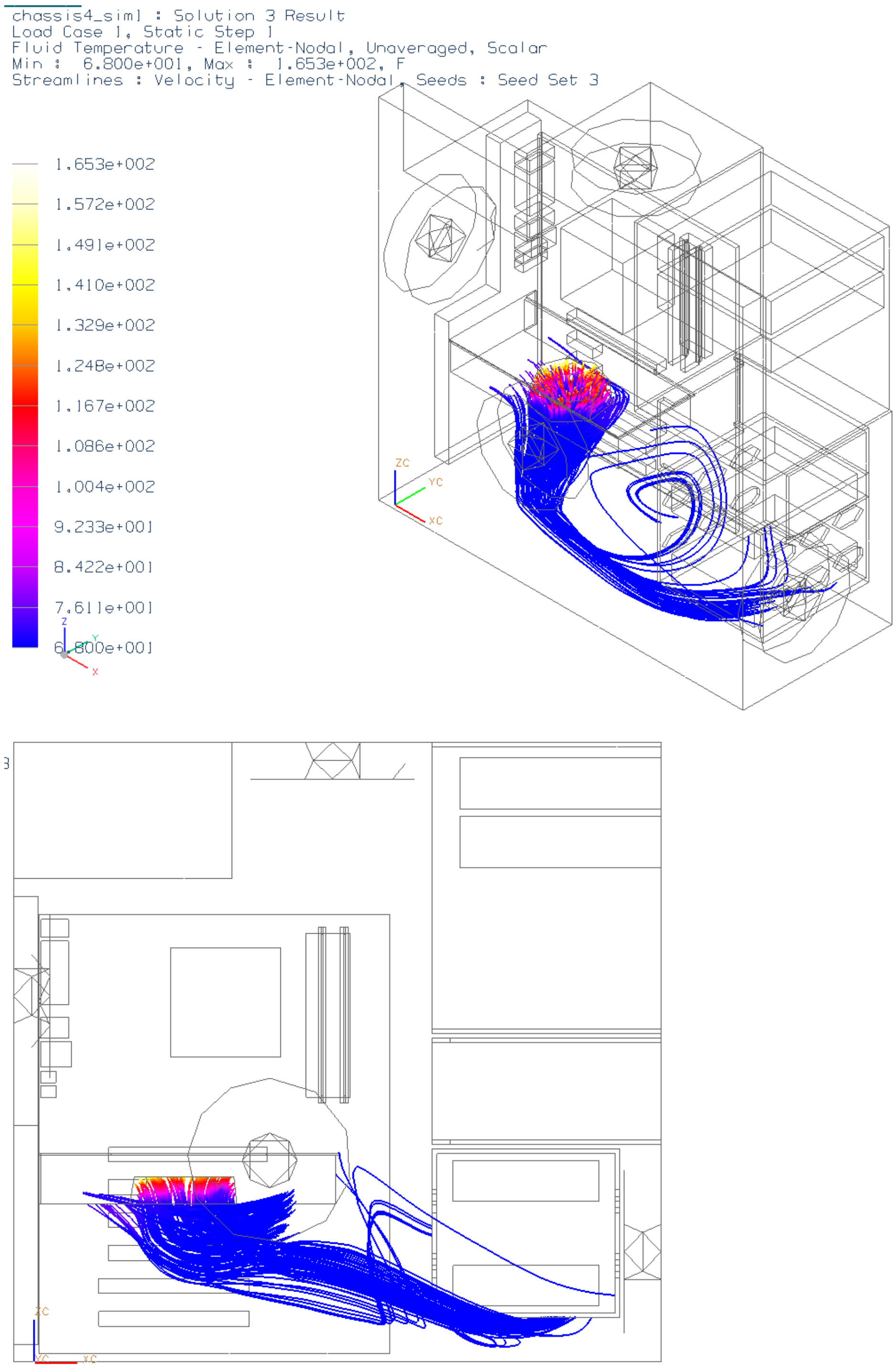


Figure 36: Solution 3 - GPU Cooling

Average Relative Pressure on GPU Sink: 1.017e-3 PSI

Average Temperature of GPU Sink: 102.6 F

Mass Flux Through GPU: -2.364e-3 lbm/s-in^2

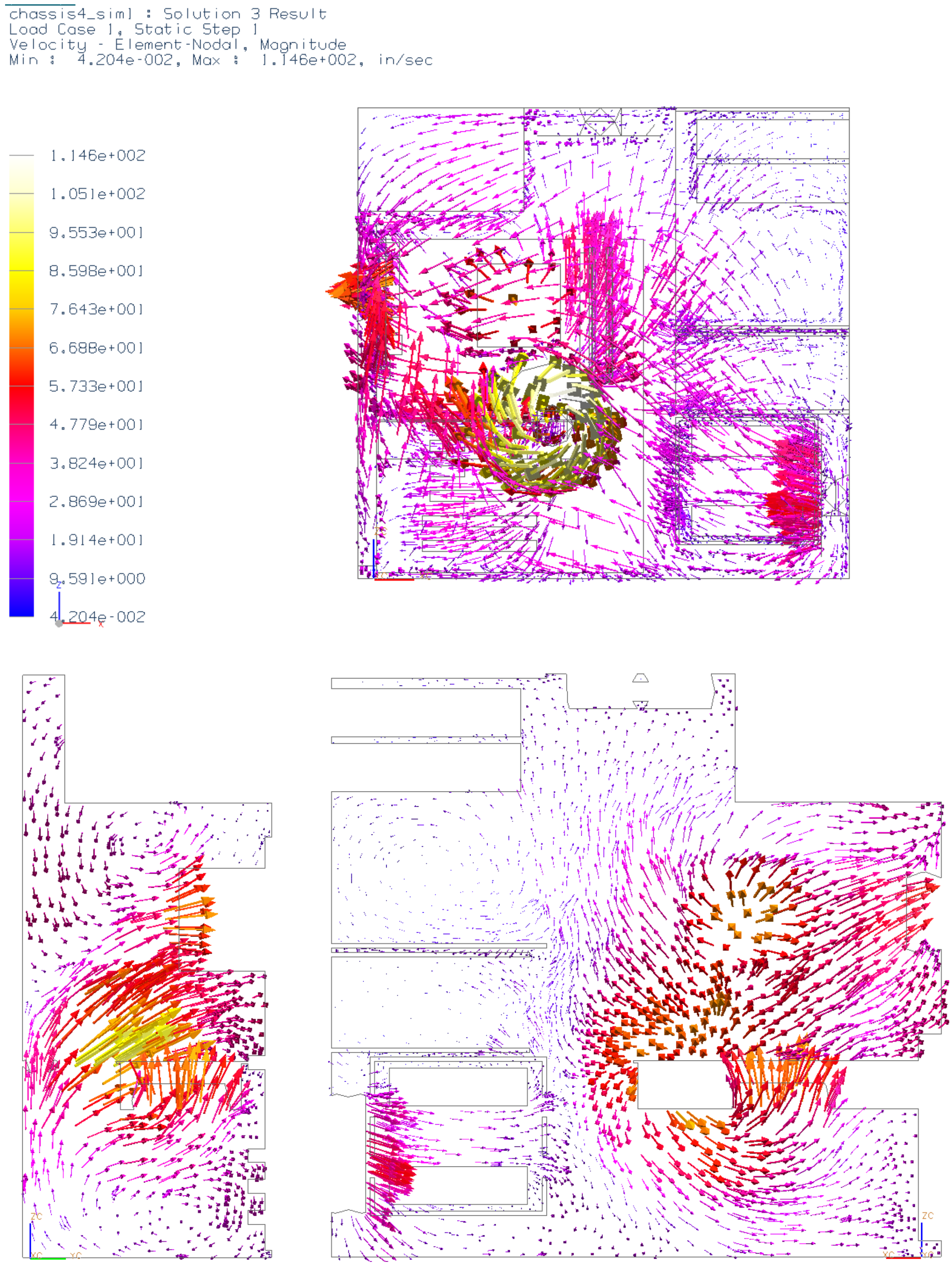


Figure 37: Solution 3 – Flow Velocity

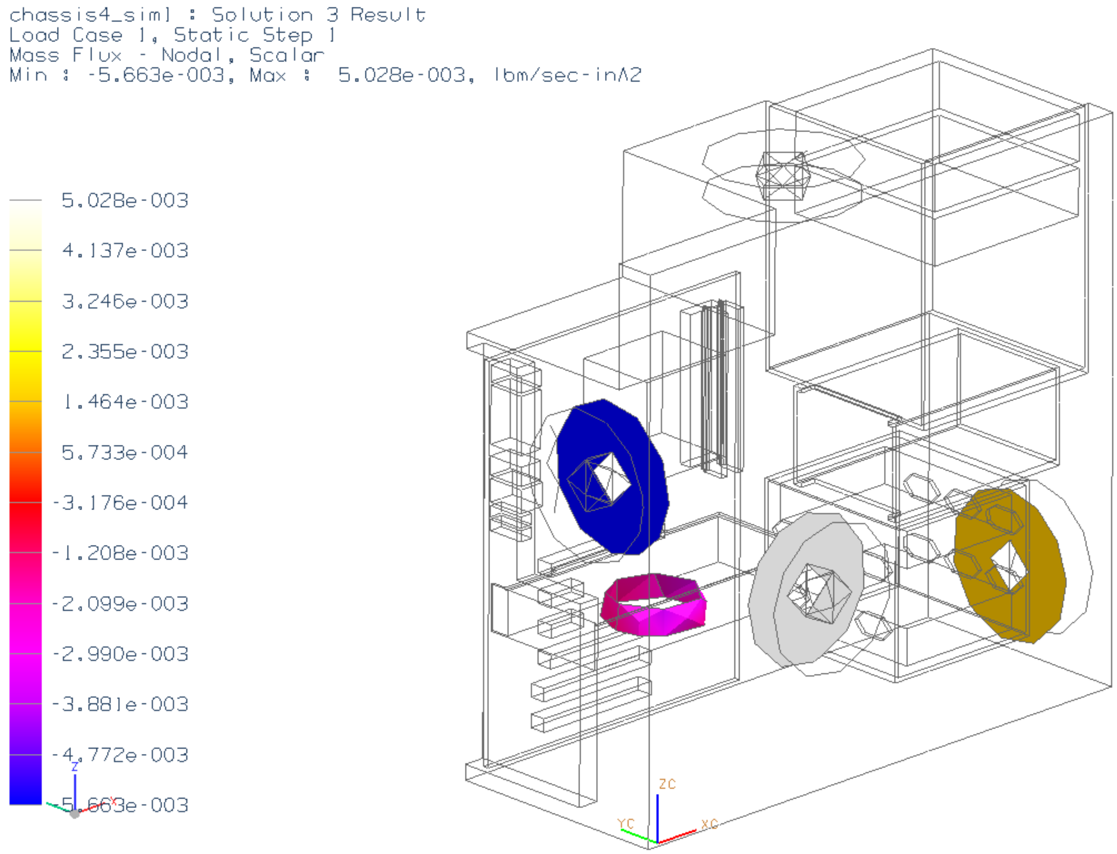


Figure 38: Solution 3 - Mass Flux

4.4 Solution 4: Back Fan, Side Fan, Front Fan, and Top Fan On

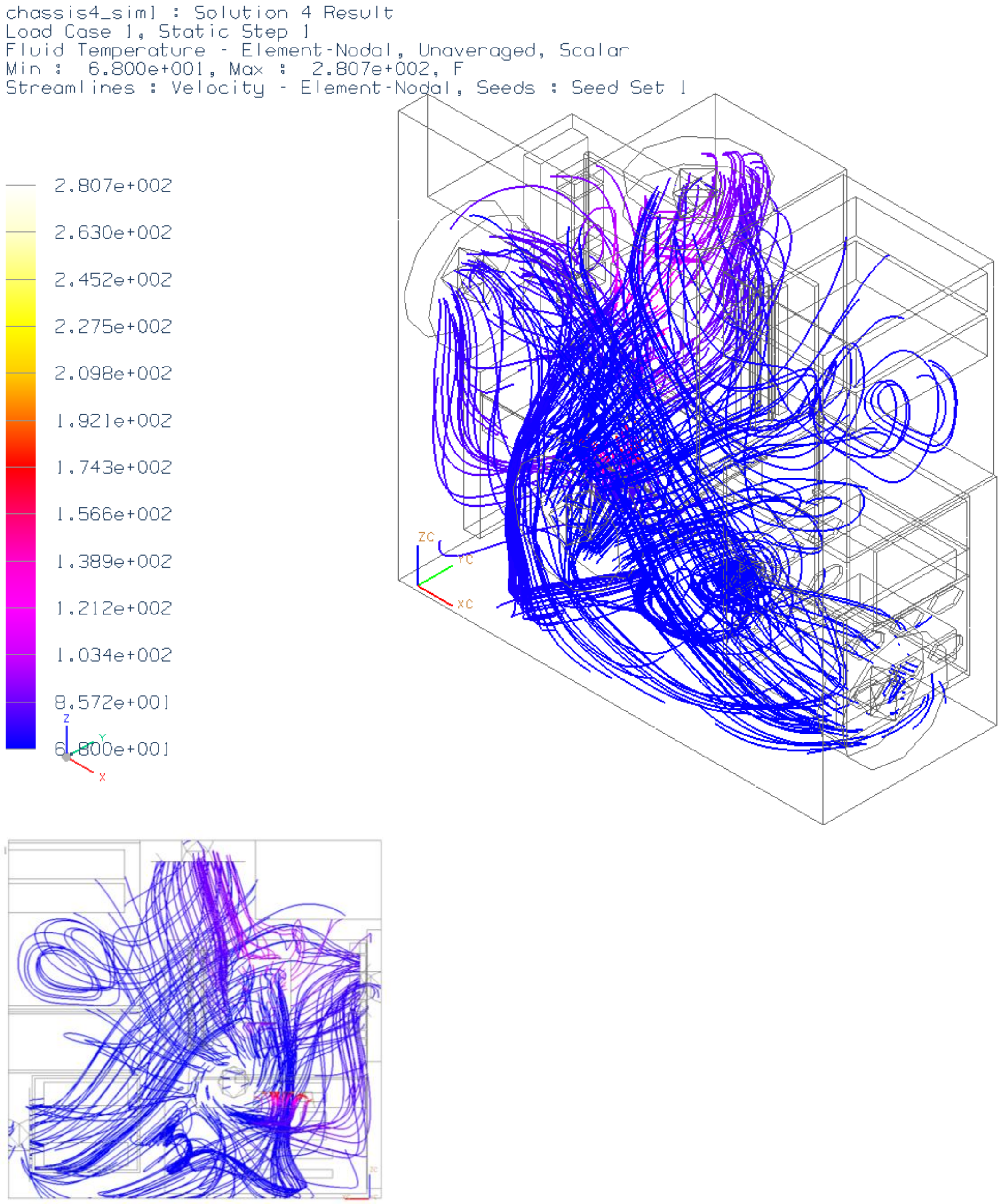


Figure 39: Solution 4 - Case Temperature

Solution time to solve: 18m 40s

Maximum Temperature: 280.687 F

Minimum Temperature: 68.000 F

Average Air Temperature: 73.981 F

Standard Deviation: 9.746 F

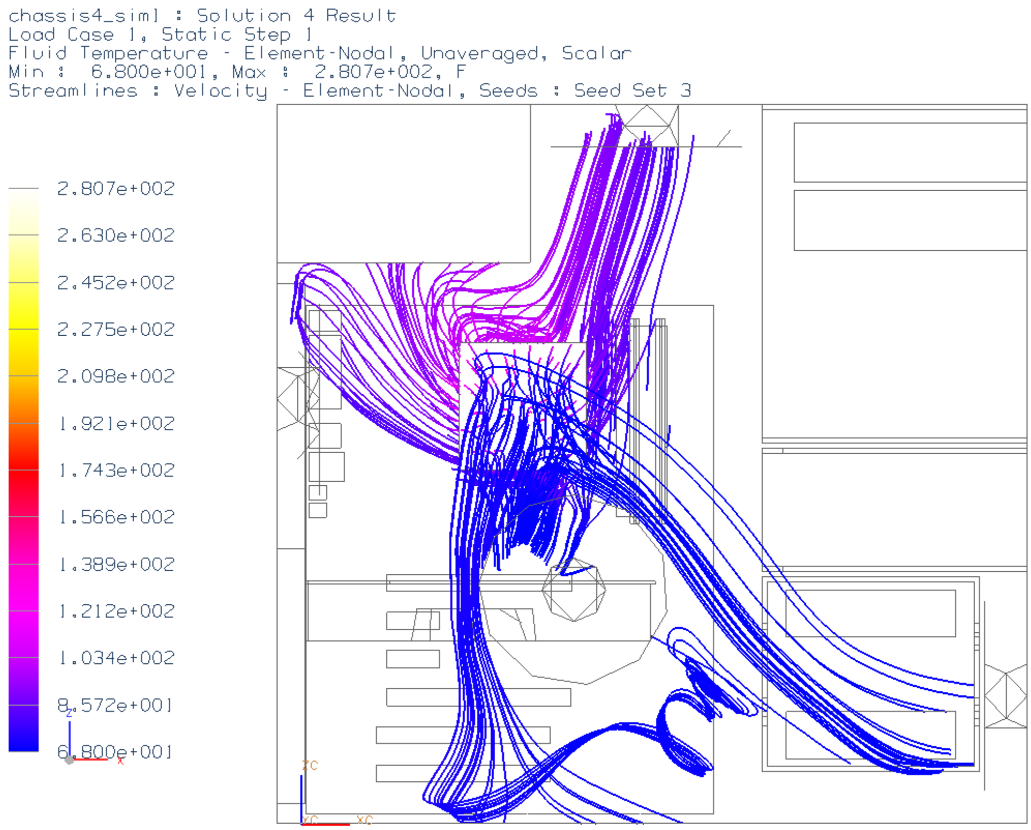


Figure 40: Solution 4 - CPU Cooling

Average Relative Pressure on CPU Sink: 3.516e-4 PSI

Average Velocity on CPU Sink: 4.607e1 in/s

Average CPU Temperature: 95.21 F

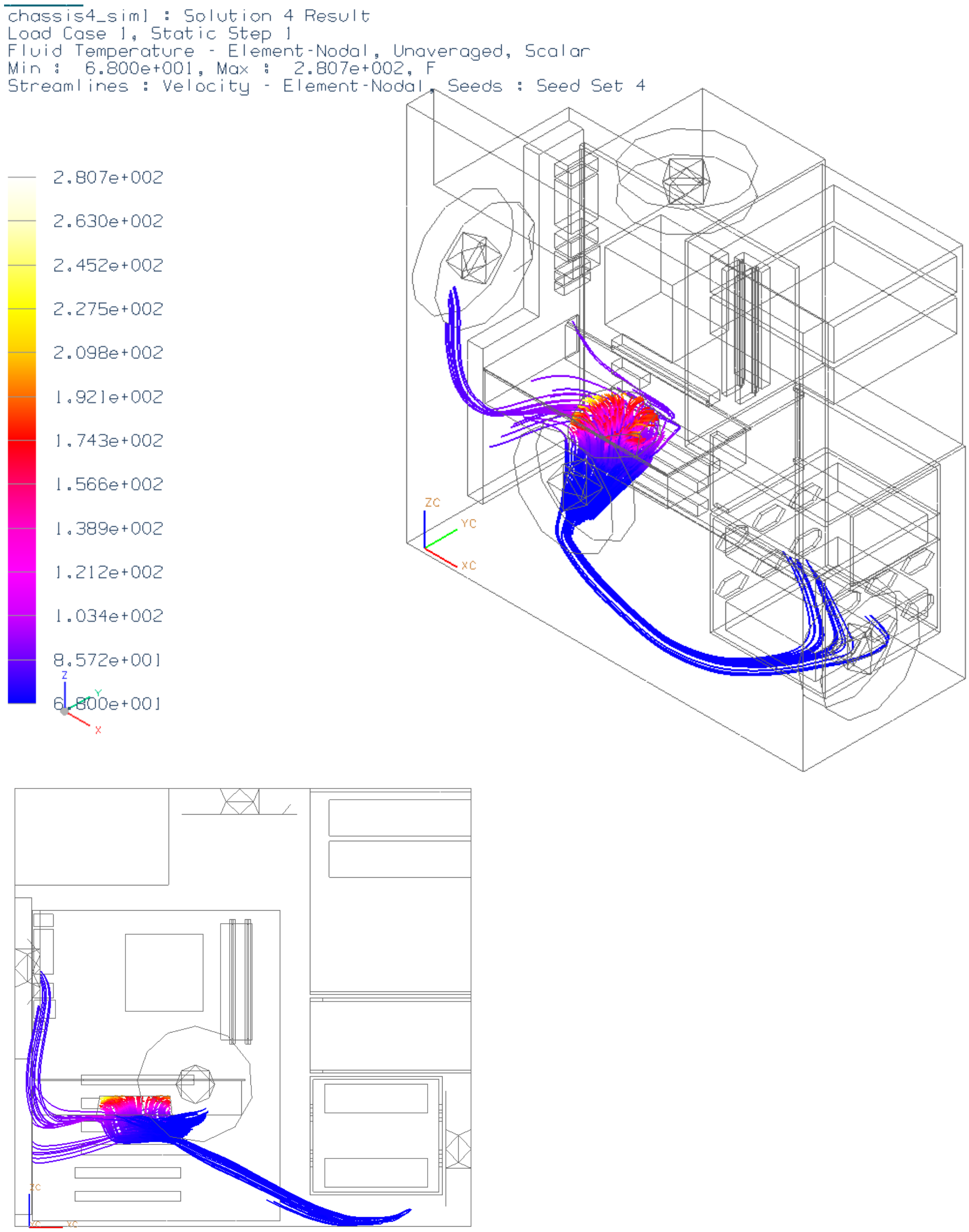


Figure 41: Solution 4 - GPU Cooling

Average Relative Pressure on GPU Sink: 3.950e-4 PSI

Average Temperature of GPU Sink: 146.5 F

Mass Flux Through GPU: 8.020e-7 lbm/s-in^2

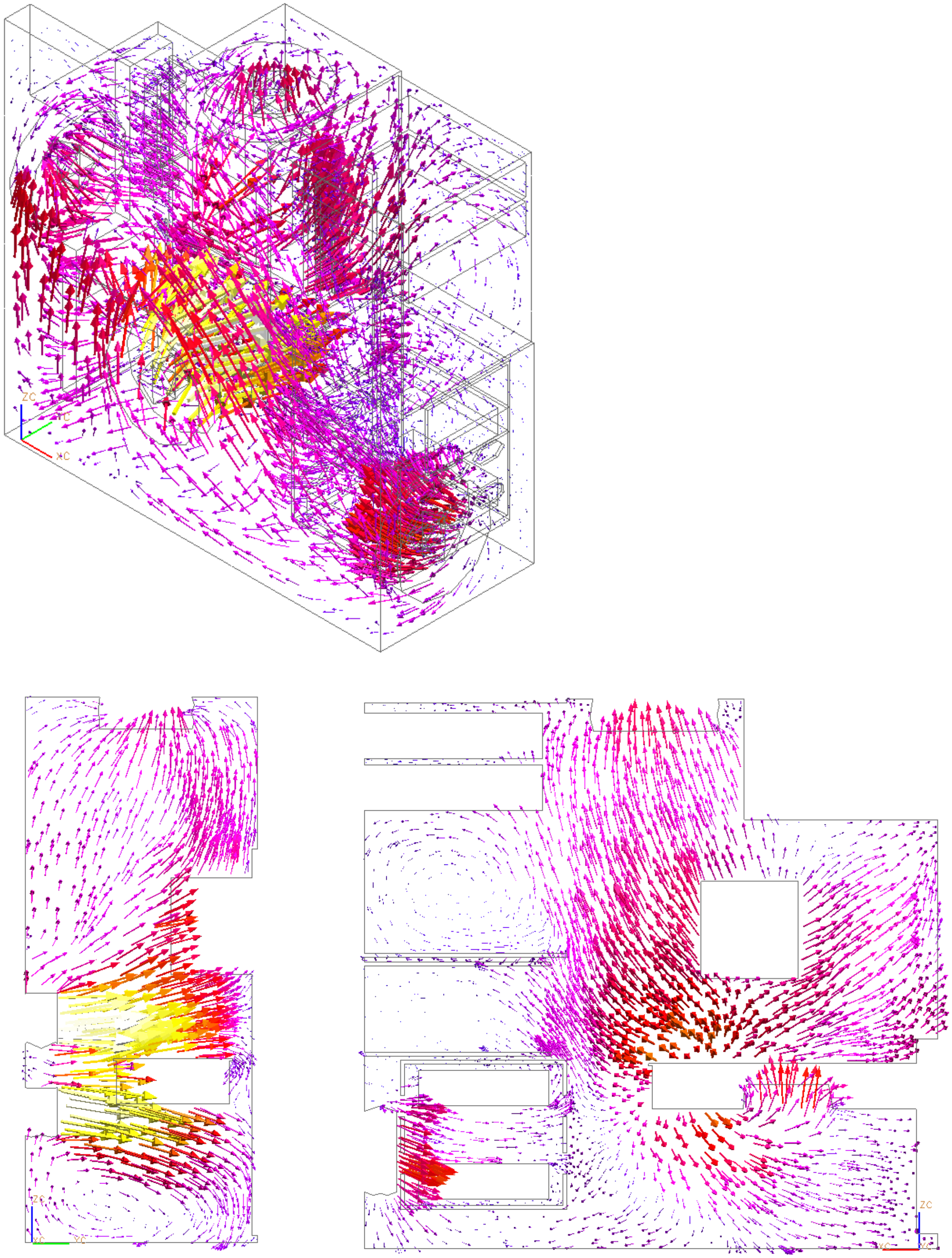


Figure 42: Solution 4 - Flow Velocity

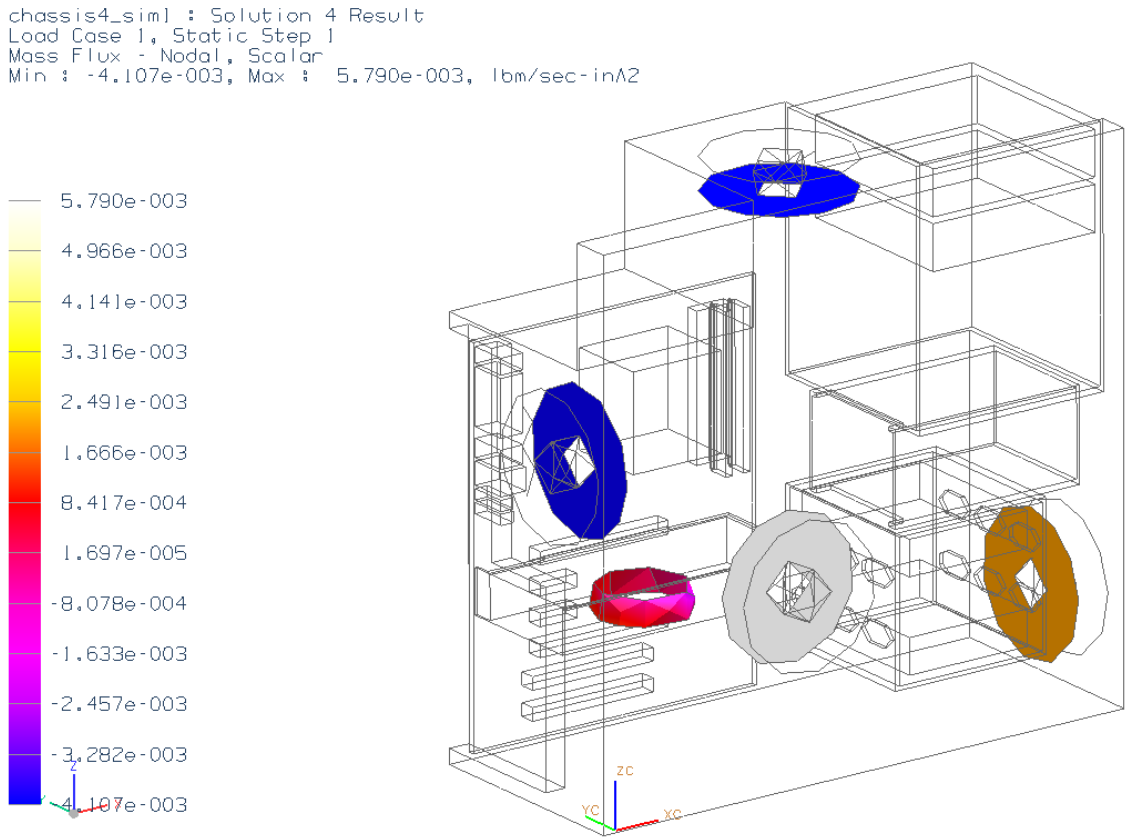


Figure 43: Solution 4 - Mass Flux

4.5 Solution 5: Back Fan, Side Fan, Front Fan, and Top Fan On (Reversed)

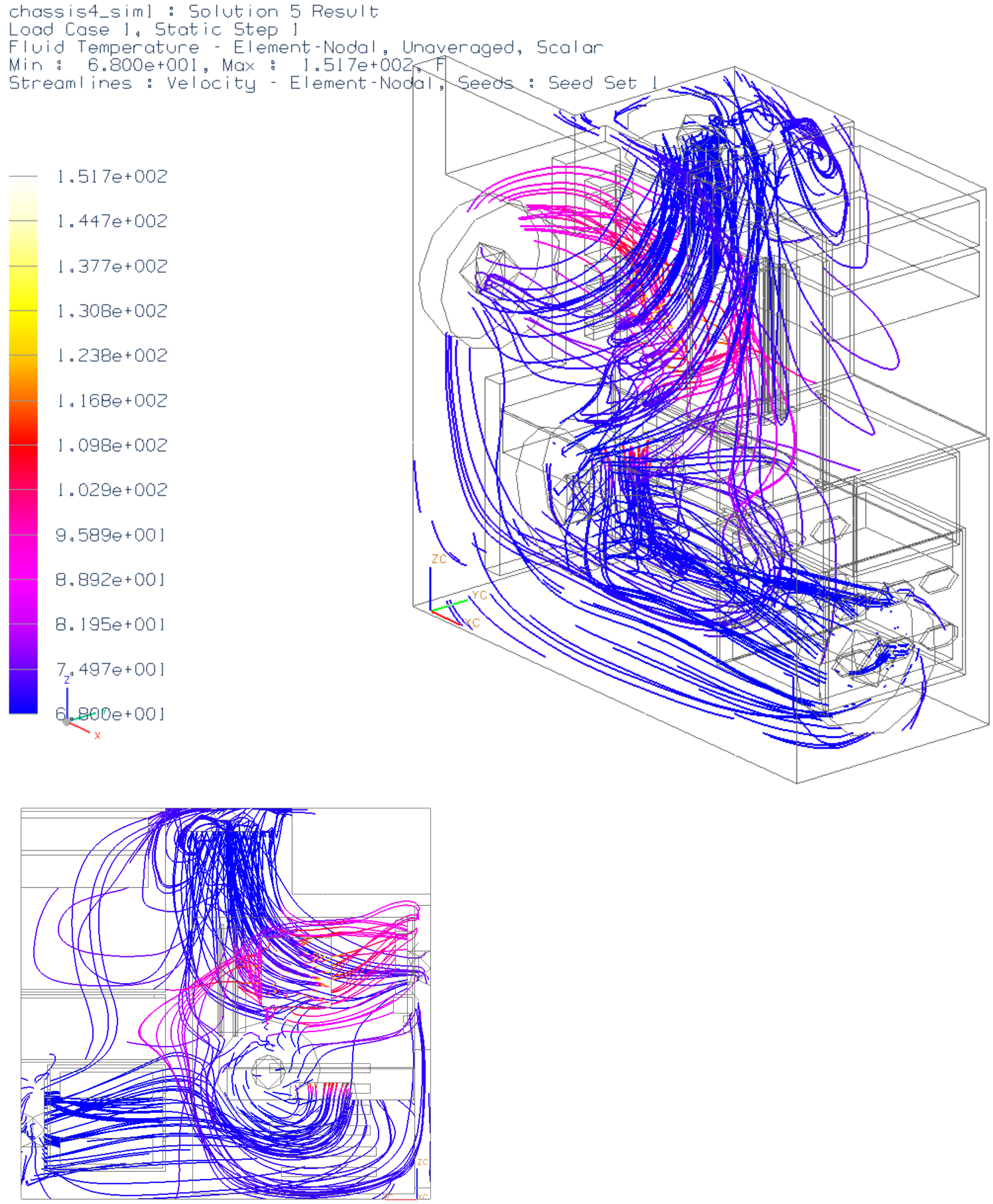


Figure 44: Solution 5 - Case Temperature

Solution time to solve: 18m 44s

Maximum Temperature: 151.673 F

Minimum Temperature: 68.000 F

Average Air Temperature: 75.421 F

Standard Deviation: 7.968 F

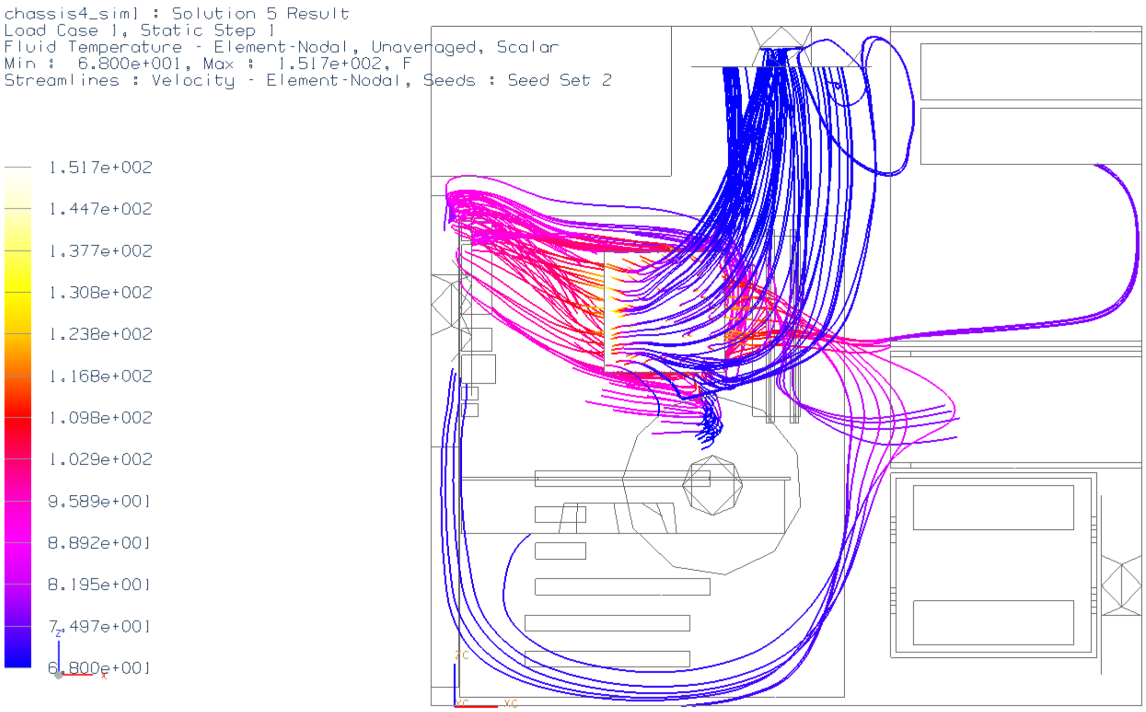


Figure 45: Solution 5 - CPU cooling

Average Relative Pressure on CPU Sink: 1.400e-3 PSI

Average Velocity on CPU Sink: 3.487e1 in/s

Average CPU Temperature: 102.5 F

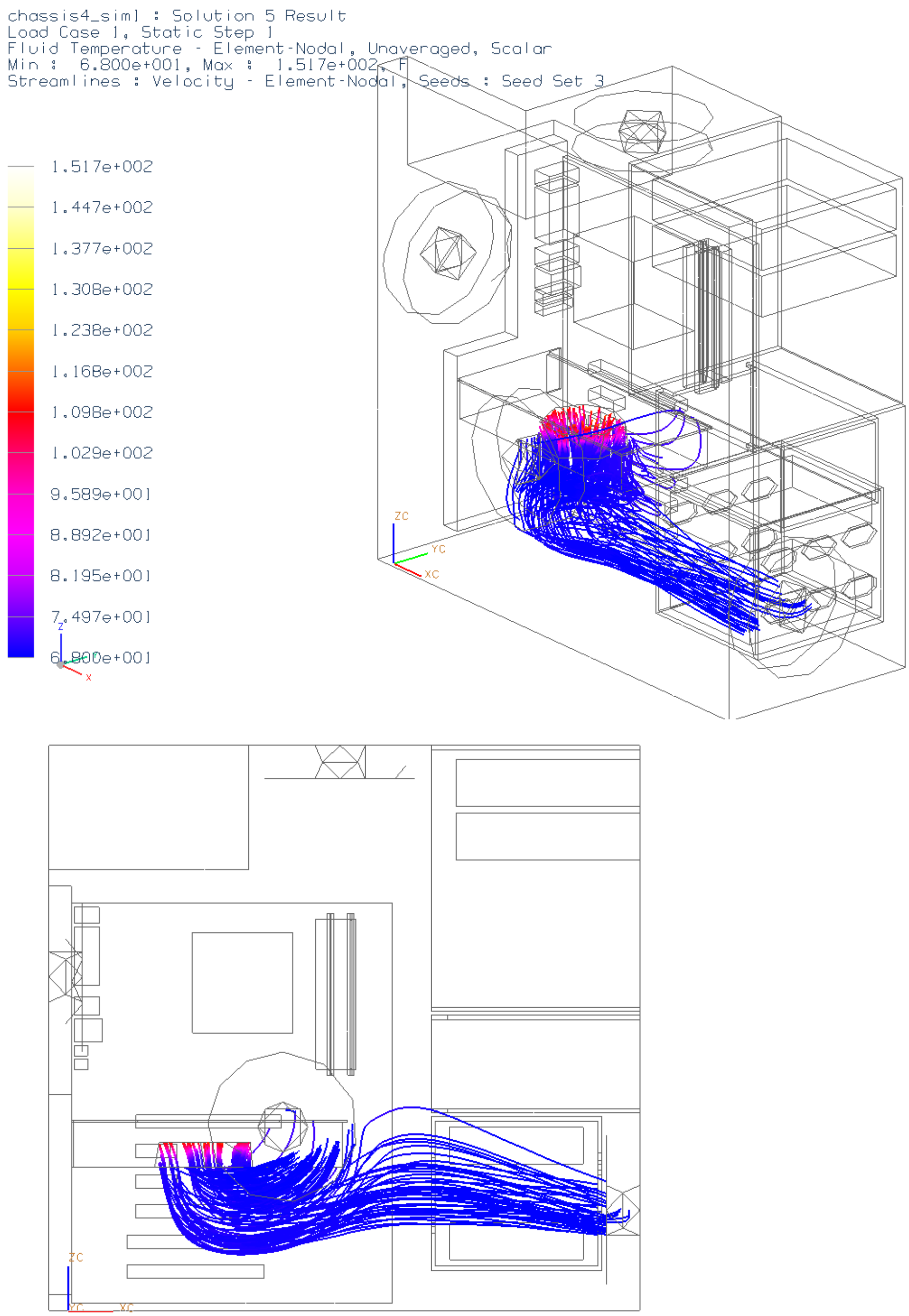


Figure 46: Solution 5 - GPU Cooling

Average Relative Pressure on GPU Sink: 1.234e-3 PSI

Average Temperature of GPU Sink: 83.99 F

Mass Flux Through GPU: -4.932e-3 lbm/s-in^2

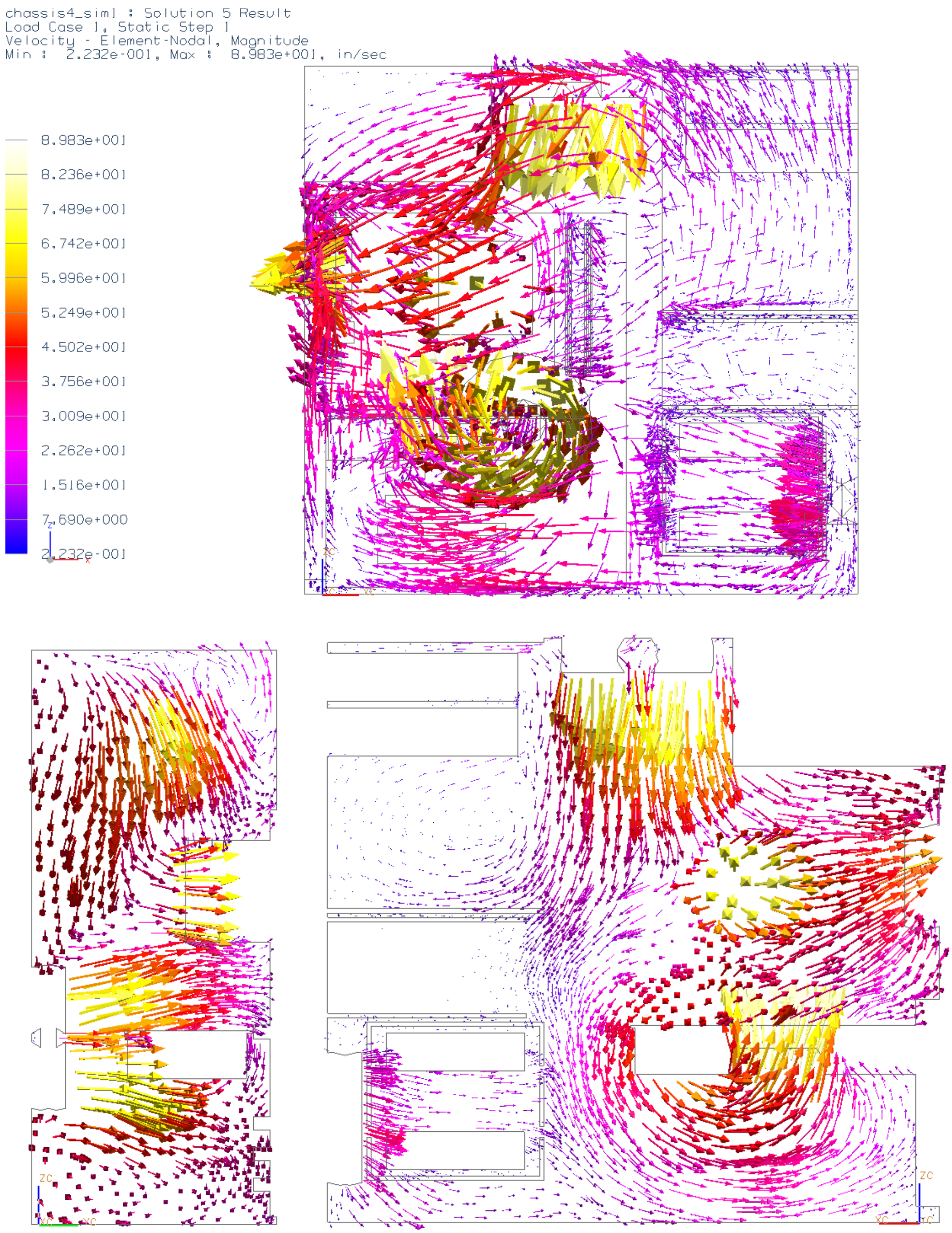


Figure 47: Solution 5 - Flow Velocity

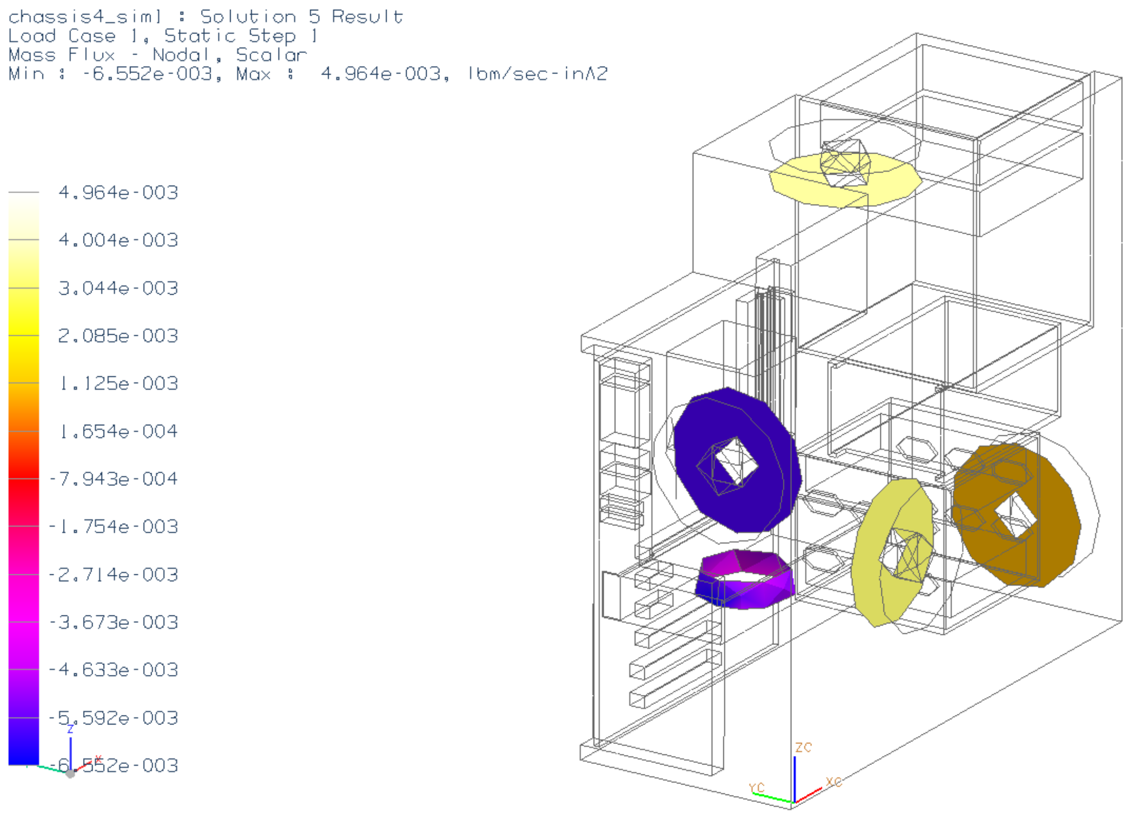


Figure 48: Solution 5 - Mass Flux

5 Final Design Selection

5.1 Design Comparison Matrix

Solution	Max Temp (F)	Ave Temp (F)	CPU Pressure (PSIe-4)	CPU Flow Rate (in/s)	CPU Temp (F)	GPU Pressure (PSIe-4)	GPU Mass Flux (lbm/s-in^2)e-3	GPU Temp (F)
1	184.563	94.628	7.38	36.1	120.4	5.46	2.29	110.60
2	213.394	74.297	2.69	44.5	100.7	7.46	-1.12	119.70
3	165.323	73.002	6.45	41.7	98.85	10.17	-2.36	102.60
4	280.687	73.981	3.52	46.1	95.21	3.95	0.00	146.50
5	151.673	75.421	14.00	34.9	102.5	12.34	-4.93	83.99

My computer chassis at home is very similar to solution 3, with the exception that my system has an additional GPU operating at 43 Celcius (109 F). My CPU temperature is measured at 38 Celcius (100.4 F) and my main GPU is operating at 66 Celcius (150.8 F). The combination of the additional head from the extra GPU, the flow restrictions caused by the extra GPU, as well as the fan speed monitoring of the primary GPU could account for the large difference in temperature between the simulated GPU and my real GPU. A real graphics processor typically has a temperature tolerance of well over 150 F, so generally a fan speed controller will allow for the GPU to heat up by slowing the fan speed.

5.2 Final Selection

One could spend a long time optimizing and reconfiguring to find the best way to use fan based cooling in a computer chassis. There are countless combinations to try, different ventilation constraints, fan types, fan orientations, component orientations; the list goes on. In light of this, using the design constraints I have implied and the studies undertaken, one can make the following observations:

- An outward GPU mass flux (negative) is desirable, in order to reduce the amount of extra heat brought into the case from the GPU.
- Generally, a positive case pressure is desirable; it helps balance airflow and pushes heat out of the case through ventilation or exhaust fans.
- The average temperature is less important than the critical component temperatures.

The accuracy of the solutions in this analysis should be adequate to make a formal design decision based upon the results. **The best design is deemed to be the one who's average CPU/GPU temperatures are the lowest.**

Solution	Average CPU/GPU Temp
1	115.50
2	110.20
3	100.73
4	120.86
5	93.25

The best design configuration is clearly Solution 5.

- Solution 5 has the lowest critical component temperatures, and the most well organized air flow patterns and flow structures.
- Solution 5 also has a low average case temperature and the highest CPU/GPU relative pressures (which results in better convection through the heat sinks).

5.3 Updated CAD Model and Finalized Design

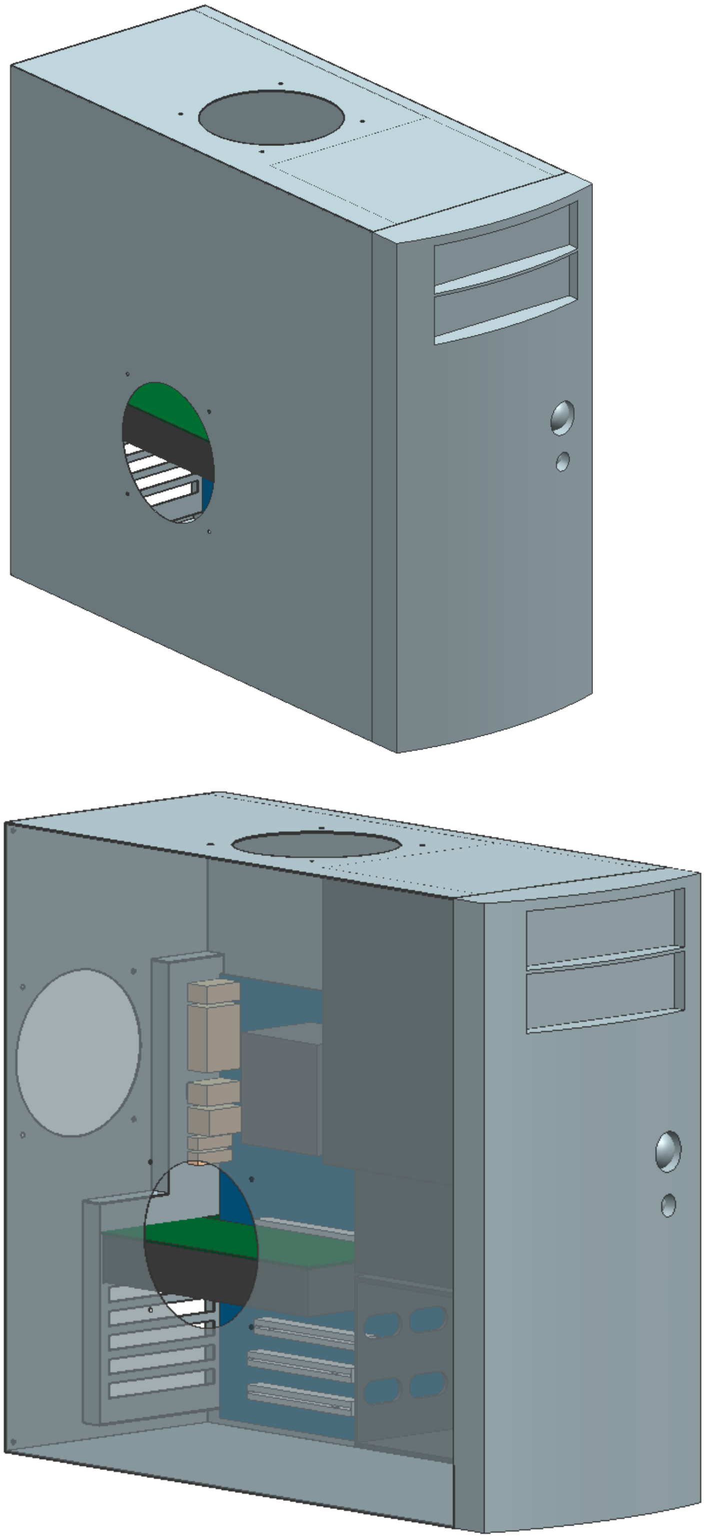


Figure 49: Final Design

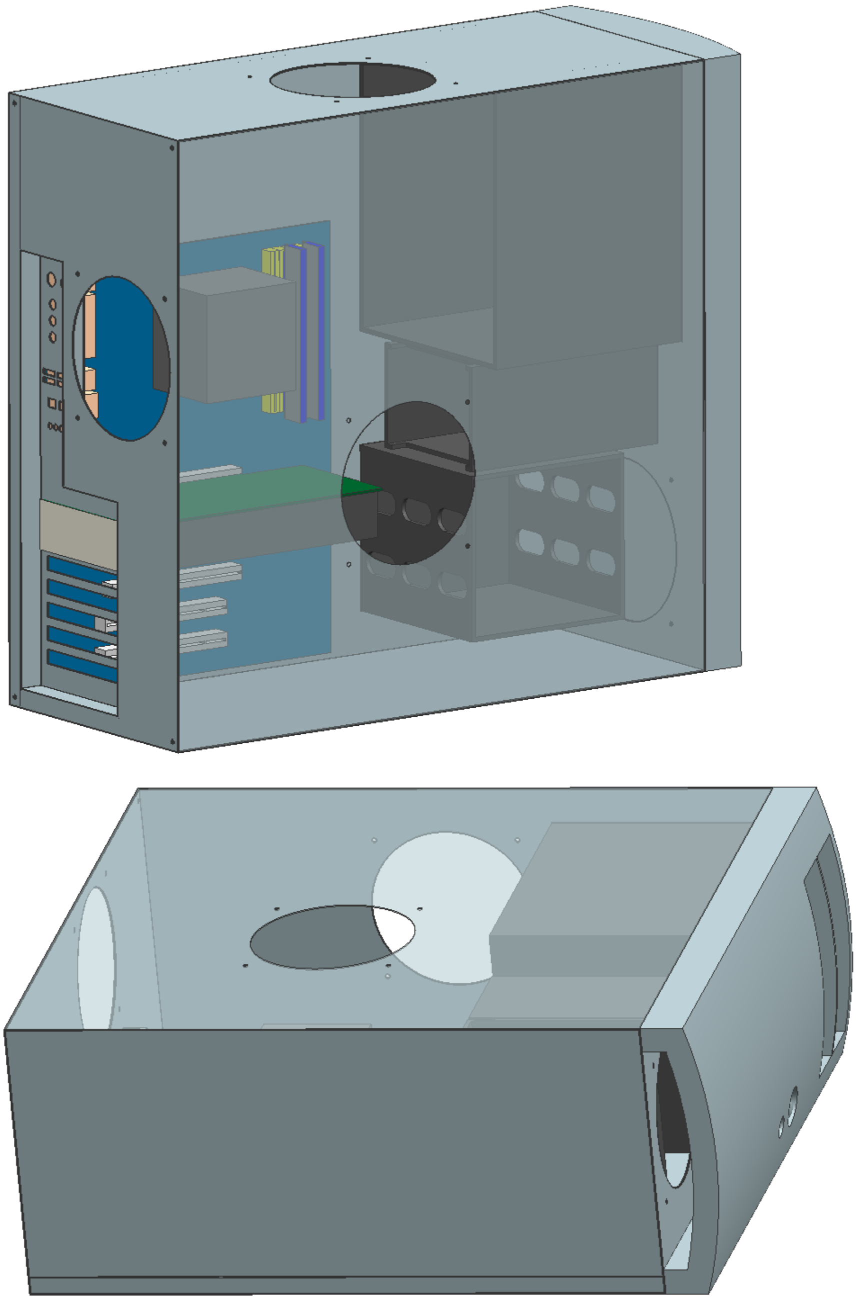


Figure 50: Final Design

As per the analysis, the final design has 120mm fan ports in the appropriate front, back, side, and top chassis walls.

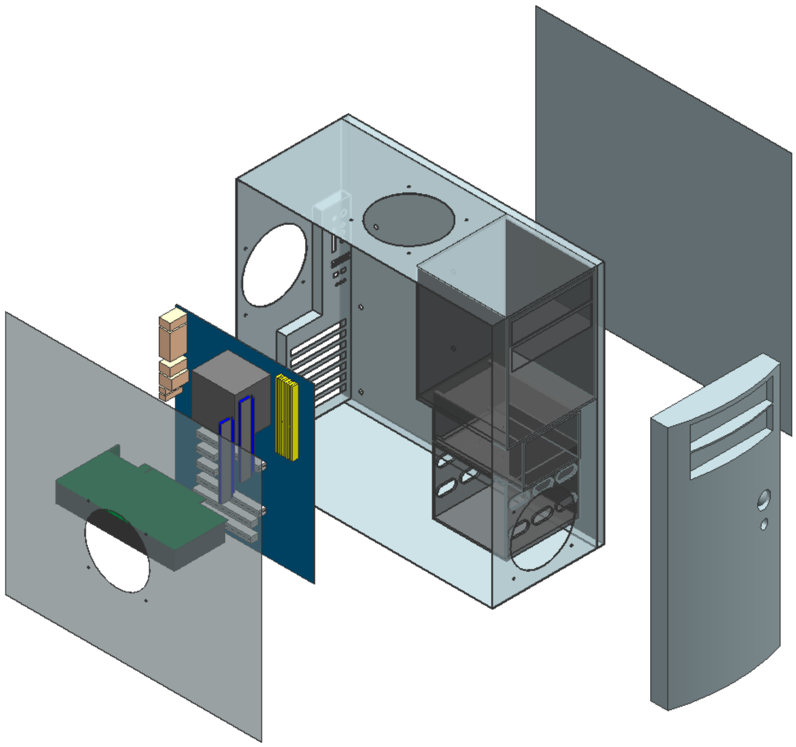
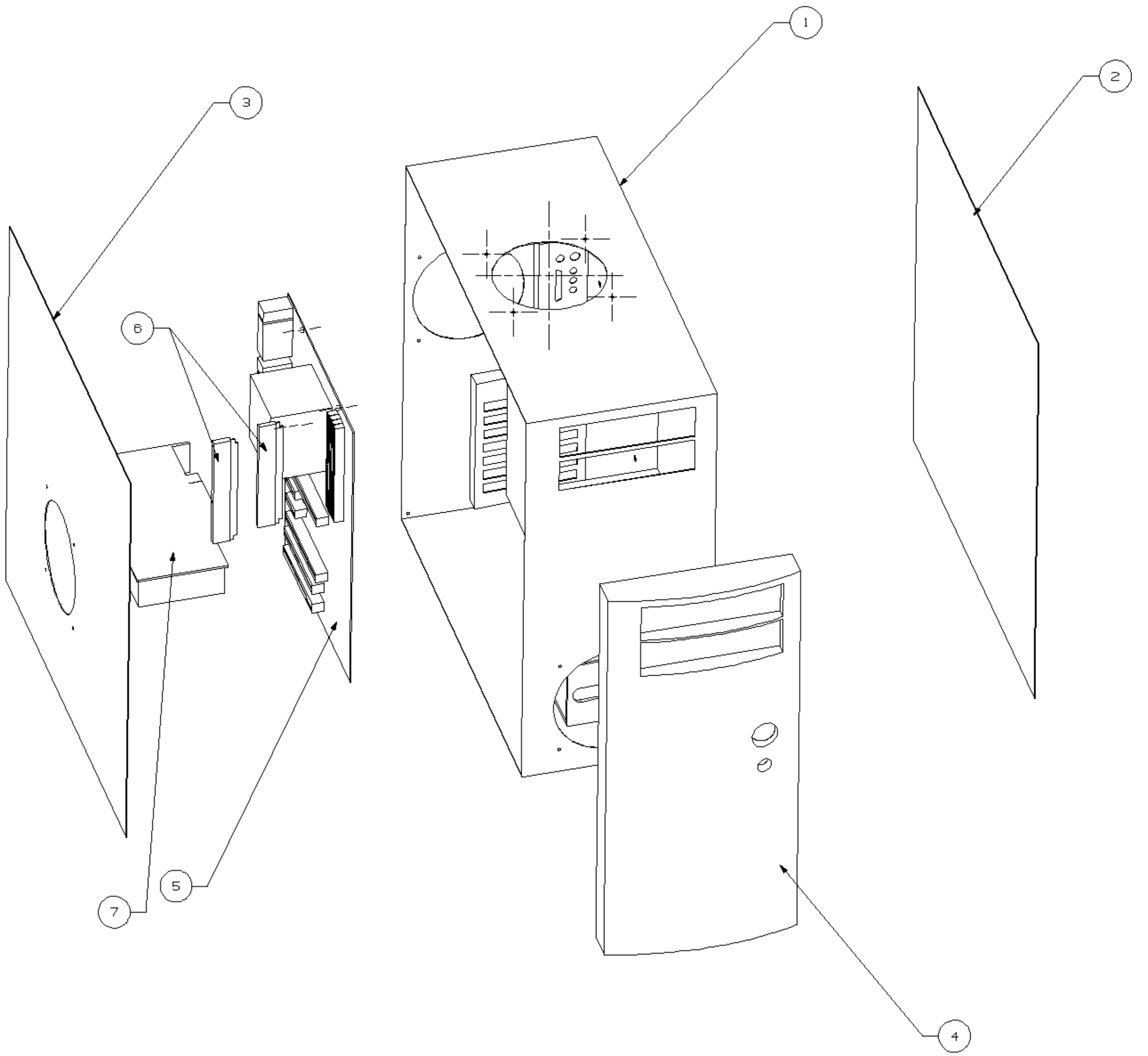


Figure 51: Exploded Case Overview

A fully detailed case design includes the two side panels that seal off the air flow on the left side, and retain cabling and routing on the other side. This case also utilizes a standard type plastic case cover that snaps onto the front of the aluminum chassis.



FIND NO.	PART NAME
1	CHASSIS FRAME
2	RIGHT COVER
3	LEFT COVER
4	FRONT COVER
5	SYSTEM BOARD
6	RAM STICKS
7	GRAPHICS BOARD

Figure 52: Assembly Drawing Exploded with BOM

6 Conclusion

The successful completion of fluid motion analysis led to a great design justification in this study. The difficulties faced were all related to properly setting up boundary conditions and constraints in the coupled fluid motion and thermal analysis setup. The other problem was the length of time that it took to solve the CFD problem using the software. Often I would make a slight tweak to a boundary condition to see how it affects the system, but then re-running the analysis takes between 10 and 20 minutes depending on the mesh refinement level. Course meshes saved time for doing setup and checking of the solution, to see if it makes sense.

If given more time, I would vary the geometry more significantly, add more detailed ventilation areas, perform an optimization sweep of certain fan placements, refine the mesh more, study the solutions more thoroughly and the meanings behind all of the results, and I would add a meshing to the solid case body and model the convection and conduction of the air and the case body.

I have learned a huge amount of information about how to use the NX6 advanced simulation interface. I have also learned quite a bit about fluid flow and CFD. I took a course in CFD programming and now I finally got to use some of the knowledge from that course in a commercial software package, rather than trying to write my own script!

7 Works Cited

1. *Wikipedia.* [Online] 2010. http://en.wikipedia.org/wiki/Personal_computer.

2. *Tom's Hardware.* [Online] 2010. http://www.tomshardware.com/.

3. *Cooler Master.* [Online] 2010. http://www.coolermaster-usa.com/product.php?product_id=2994.