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Project Description

For my Final Project, I decided to manufacture a topographical map of the Grand Canyon. The initial phase of selecting a project idea was challenging as I wanted something both meaningful and creatively engaging. I had brainstormed various ideas like jewelry pieces, a clock, a car outline, and more, but I wasn't fully utilizing the creative freedom the project offered.

Eventually, I hit upon the idea of creating a CAD model of a real-world landscape. I spent hours searching Google Earth for landscapes that were not only visually captivating but also suitable for CNC milling. Initially, I explored terrains in the area where my parents grew up in Mexico, but I realized that the elevation differences didn't provide the pronounced look I was seeking without exaggerating the vertical scaling.

After hours of research and exploration, I decided on the Grand Canyon for several reasons. First, it held personal significance since I have family in Arizona. Second, the Grand Canyon offered the kind of dramatic and intricate topography that would make for an engaging project. However, accurately modeling the Grand Canyon independently in CAD software like SolidWorks or NX was extremely challenging.

To overcome this hurdle, I found a website called Terrain2STL, which allowed me to select an area on a map and convert it into an STL file. While this was a good start, I realized working with STL files in my NX or SolidWorks would be a struggle. I continued my search and discovered a website created by the Iowa State University Geological Department, which had a much better resolution of 10 meters compared to Terrain2STL's 90 meters. Furthermore, this website offered the option to save the file as a .obj format, which was much more manageable in SolidWorks and NX.

In summary, I opted to create a portion of the Grand Canyon for my project due to its significance and the complexity it offered. This choice allowed me to work with a striking and intricate landscape that challenged my computer-aided manufacturing skills while holding personal meaning.

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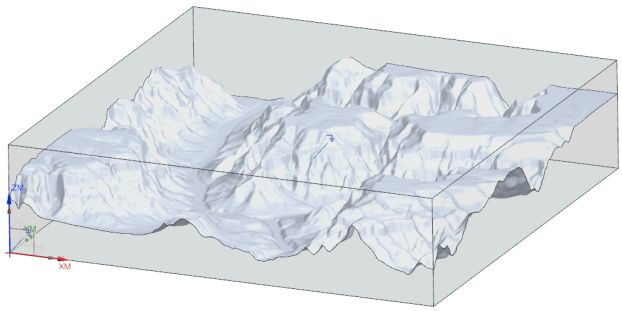
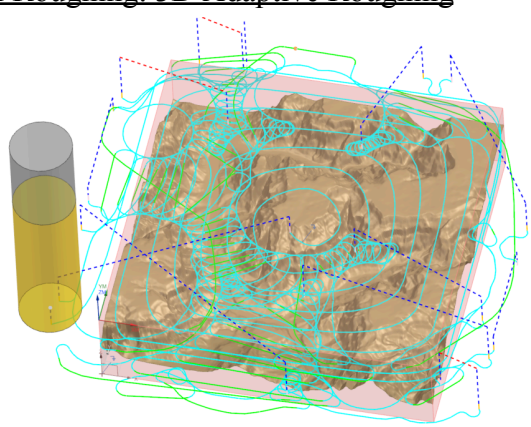
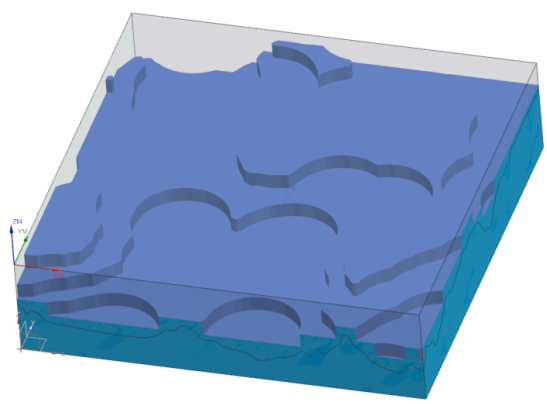
Program Manufacturing Operations



As can be seen in the figure above, I began by importing a 4in by 4in surface model of a portion of the Grand Canyon. Since my CAD part was relatively planar and didn't fluctuate extreme amounts in the Z-direction, I made my blank 1 inch tall so that the amount of material that would be machined on the top would not be excessive.

<u>Initial Roughing: 3D Adaptive Roughing</u>





Tool Type	Tool Diameter	Feeds & Speeds	Stepover	Depth of Cut
End Mill	0.75in	16.30 ipm, 2037 rpm	33% Tool	0.15in

I chose to use 3D Adaptive Roughing rather than a regular cavity mill because I believe that it efficiently removes large volumes of material well with an adaptive cut pattern that makes sure it doesn't go above the stepover listed. This was a roughing pass that left 0.04in of stock.

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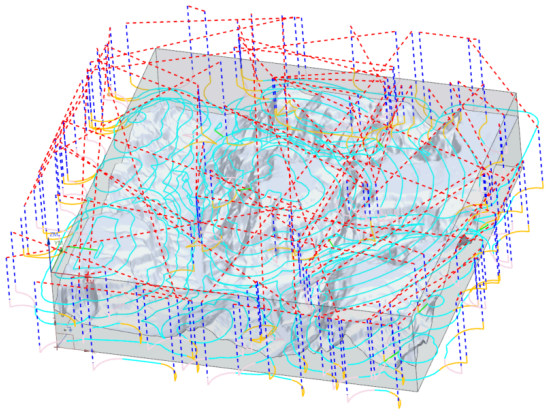
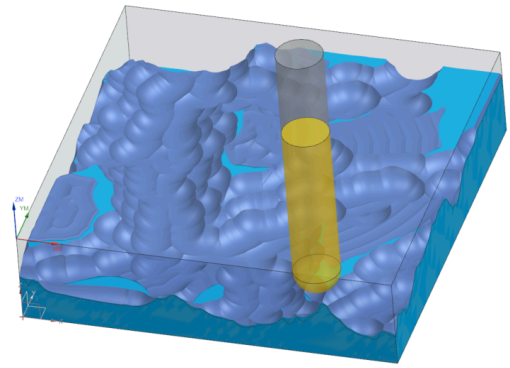
Initial Semi-Finish: Cavity Mill

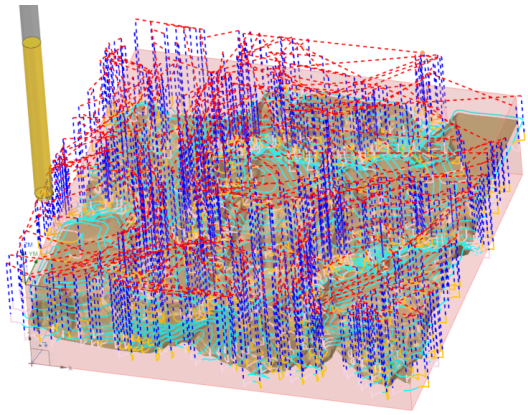


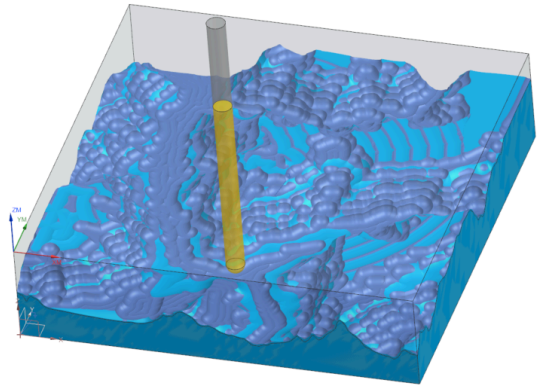


Tool Type	Tool Diameter	Feeds & Speeds	Stepover	Depth of Cut
Ball Mill	0.50in	15.89 ipm, 3056 rpm	33% Flat	0.15in

As I already did a roughing operation, I wanted to prepare for a future area mill. This led me to choose to do a semi-finish pass with a ½” ball mill to remove a lot of the material that was left at a more efficient rate than using a much smaller tool. However, I did not use a ¾” mill again because I also wanted a tool that would fit into tighter areas, and that is my reasoning as to why I thought a ½” ball mill would be the optimal choice. I chose cavity mill this time because these operations work well with cutting a contoured shape, especially those that resemble cavities and do not have boundary conditions. The semi-finish pass left 0.01in of stock. I also considered adding another intermediary step of semi-finishing with a tool size between this ½” ball mill and the final 3/16” ball mill, but after adding it, it only added an extra 30 min without adding much benefit to the overall program, so I removed it.

Final Semi-Finish: Cavity Mill

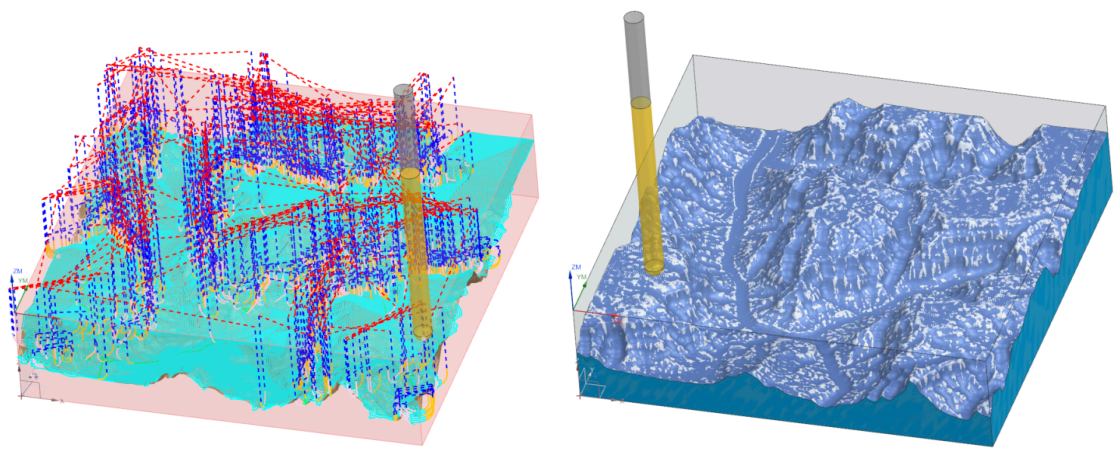




Tool Type	Tool Diameter	Feeds & Speeds	Stepover	Depth of Cut
Ball Mill	0.1875in	9.78 ipm, 8149 rpm	33% Flat	0.0625in

Next, I chose to do a second semi-finish pass, this time with my final smallest tool size that'll be used to also perform the area mill. I did a cavity mill operation because they work well with preparing a part for an area mill, as it optimizes for time without taking away from the final product as it's a semi-finish with a stock of 0.01in. With the tool being a 3/16" ball mill, it was able to cut and prepare the areas that were much tighter and smaller to get to without leading to a much longer time requirement that a ⅛" or 1/16" ball mill would result in.

<u>Finishing: Area Mill</u>



Tool Type	Tool Diameter	Feeds & Speeds	Stepover	Depth of Cut
Ball Mill	0.1875in	9.78 ipm, 8149 rpm	0.0005 Scallop	10% Tool

Finally, I chose to area mill with a finishing pass as this operation is ideal for leaving the best surface finish that could be achieved with the tools I have chosen so far. A 3/16" ball mill was used because it works well with a prior cavity mill with the same tool, and as stated earlier, the ⅛" and 1/16" ball mills required an unreasonable amount of time, and the benefit of them being able to reach smaller crevices did not outweigh the time requirement on top of the risk of breaking such a small tool, as well as having to risk completely restarting (which was a lesson I learned earlier). I also chose to have a maximum scallop of 0.0005, which may seem very small, but in my opinion, was well worth the small amount of time it added compared to a larger stepover.

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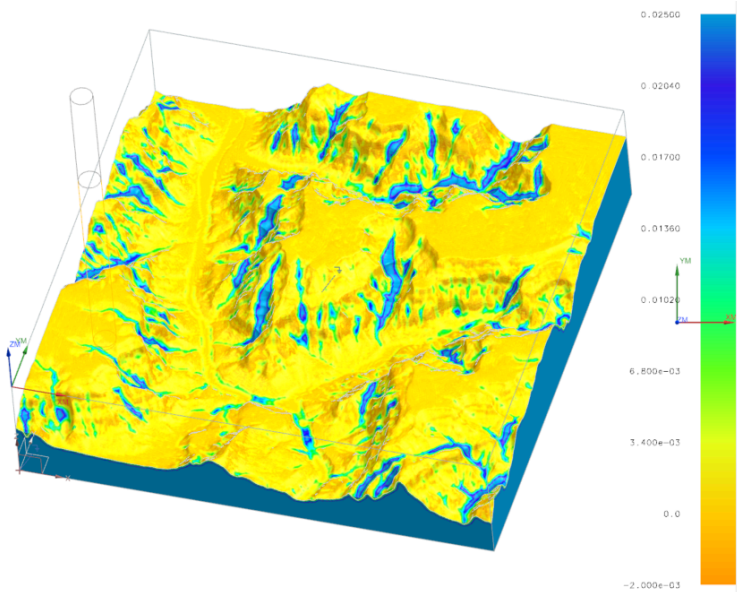

Above, I present the analyzed version of the final operation. As can be seen, with my choice of tool and operations, I was not able to fully reach every point in the terrain, but the tools did pretty well. Outside of the tight crevices, the rest of the machined part is very accurate to the design and well worth the total time of 3 hours and 58 min.

CNC Manufacturing Summary

To begin, I used a horizontal bandsaw to remove 2 inches from the 4in by 4in aluminum square stock. I then made sure to clean up the edges using the belt sander next to the horizontal bandsaw. Next, I set my stock piece up in the CNC milling machine on top of parallels, with the cleaner side facing down, as this side would be the base and the rougher side on top would get machined. I then uploaded my post-processed g-code into the CNC mill, making sure to save it to the memory so that I could remove my USB.

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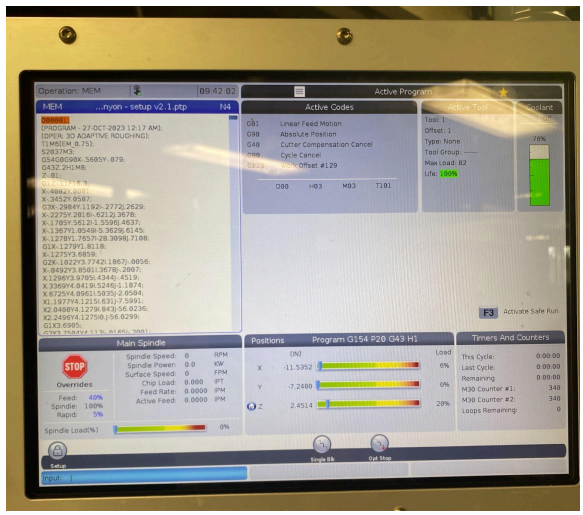
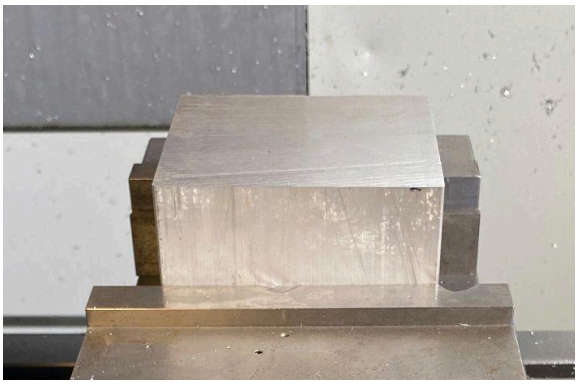
Next, I set up all the tools I needed into the correctly mounted locations and then zeroed the X and Y of my part using the edgefinder. After this, I used a dial indicator to set the Z zero for each tool, as they all have different lengths. Finally, I was ready to begin my program and started with a 40% feed rate, 5% rapid, and made sure I had Single Block and Op Stop turned on.



During the CNC manufacturing process of my part, I encountered several challenges and issues, and I took various measures to address them:

1. Prolonged Machining Time: The machining time for my part was quite long, which led to concerns about efficiency and potential tool wear. To mitigate this, I reduced the risk of tool breakage by giving the last tool breaks during the operation and made sure the coolants were aimed correctly, which helped maintain tool integrity.



2. Tool and Vise Clearance: As the part wasn't very tall, there was a risk of the cutting tool hitting the vise during machining. To address this, I extended the stock material length to provide additional clearance, ensuring that the tool wouldn't come into contact with the vise.

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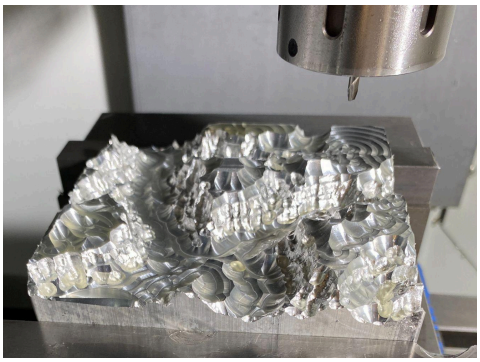
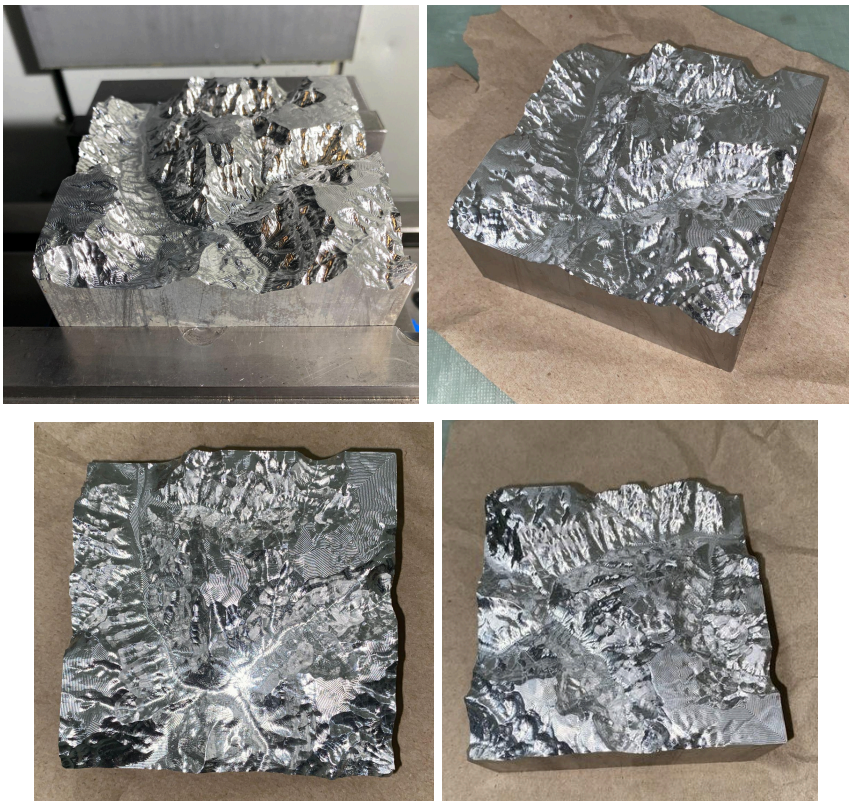


3. Tool Breakage: During my first attempt at CNC manufacturing my project, a 1/8" ball mill broke halfway into the final 4-hour operation (total 6-hour program), which was a significant setback. The exact cause of the breakage wasn't clear, and while coolant spigots' alignment might have been a contributing factor, I also considered factors like depth of cut, surface feet per minute (SFM), and feed rate as potential culprits, even though I followed all the rules regarding each of them. This led me to use a 3/16” ball mill in my second attempt, which ended up working great, as well as making sure that the final area mill had very little stock left to cut.

4. Deformed Collet: A challenge arose when I realized that the collet I had for the 3/16" tool had deformed slightly internally, preventing the tool from being securely held in place. I went to Bob, one of the shop professionals, and his initial solution was to ream the collet's inside to its original diameter, but clamping it vertically proved tricky. Eventually, he pulled out a gauge pin set to use, along with some brute force with a hammer and a 3/16" gauge pin to restore the collet to its proper shape. While not the most elegant solution, it was effective given the circumstances and the fact that it was the only a 3/16” collet we had.

5. Maintenance: I learned that regular maintenance is crucial for CNC milling. Following the advice of the shop professional, Bob Taglia, I used Scotch Brite to scrub the collet chucks to ensure proper tool retention and minimize the risk of slippage or deformation.

Overall, the CNC manufacturing process presented various challenges that required resourcefulness and problem-solving. In the end, it worked out well, as I present the results of my CNC-milled final project below.



Final Results and Reflection

Overall, I learned that a lot of work goes into preparing to machine a very complex part in a CNC mill. I also learned that a lot of time must go into preparing a part within a CNC mill, to make sure nothing goes wrong. If I could revise my project, I would enlarge the designed part so that the details are larger and easier to mill. I would also attempt to use a ⅛” ball mill again, this time in addition to the changes I made that helped ensure a broken tool would not result in my second attempt. In the end, I feel like my final project went well, and am proud of what the hours I spent working on resulted in.