U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Cold Spray Path Optimization for Additive Manufacturing and Structural Repair

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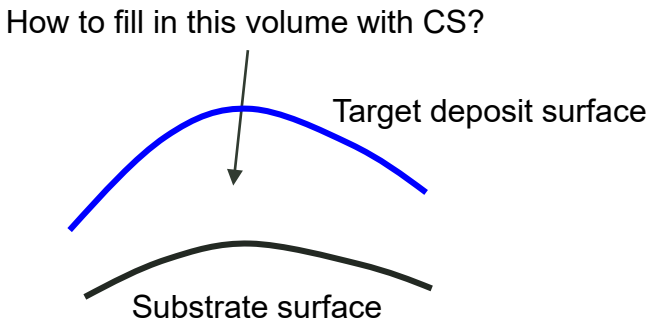
FCDD-RLW-MD

WHAT IS PATH OPTIMIZATION?

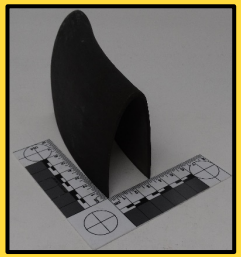
Definition: the process of determining the robotic motion to fill a desired volume with CS while optimizing…

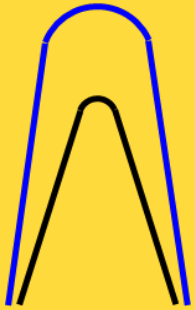
- Efficiency of spray process
- Geometric error of deposit shape
- Structural integrity of resulting part



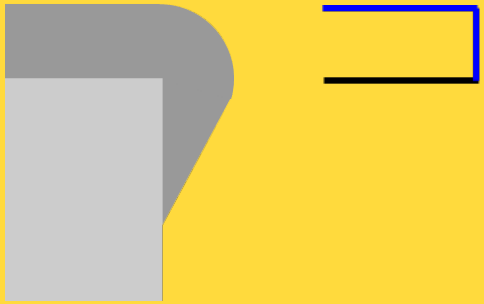
Applications:

Additive Manufacturing

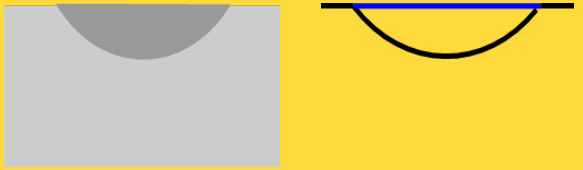




Edge Restoration



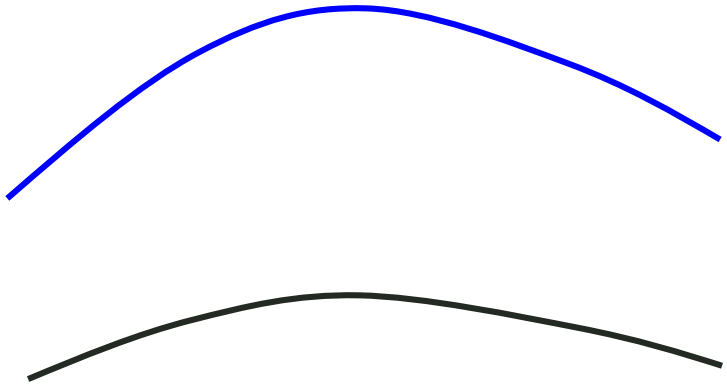
Spiral In-fill



Key Variables:
line spacing, velocity, layer thickness, spray angle, plume width, standoff

PATH GENERATION ALGORITHM

Step 1. Input initial and target surface.

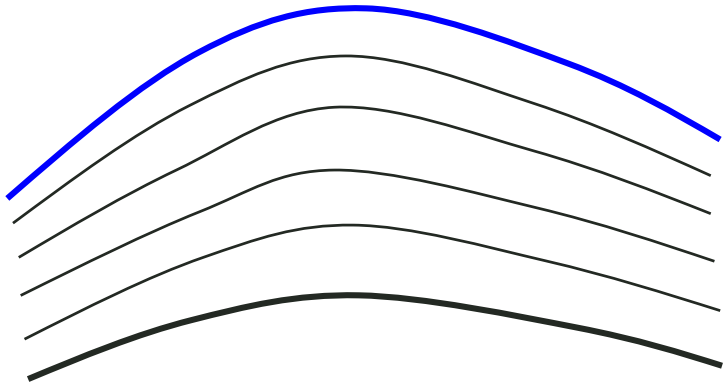


Key

- Mold (Initial) Surface
- Target Deposit Surface
- Predicted Deposit Surface
- Intermediate Layer Surface
- Nozzle Orientation with length weighted by time spent over area (inverse velocity)

PATH GENERATION ALGORITHM

Step 1. Input initial and target surface.
Generate intermediate layers



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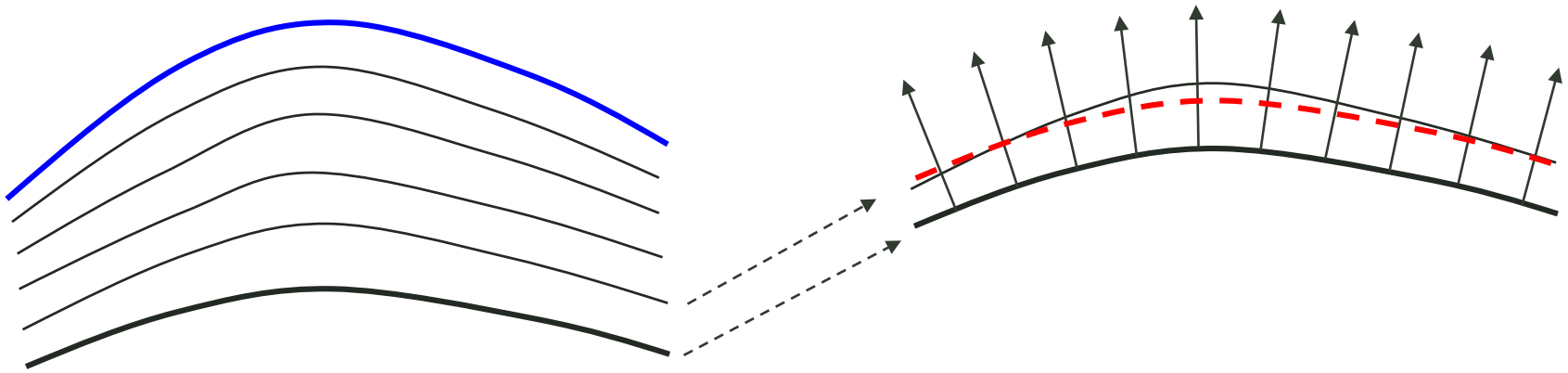
PATH GENERATION ALGORITHM

Step 1. Input initial and target surface. Generate intermediate layers

Step 2. On each layer, generate simple path ‘covering’ the area



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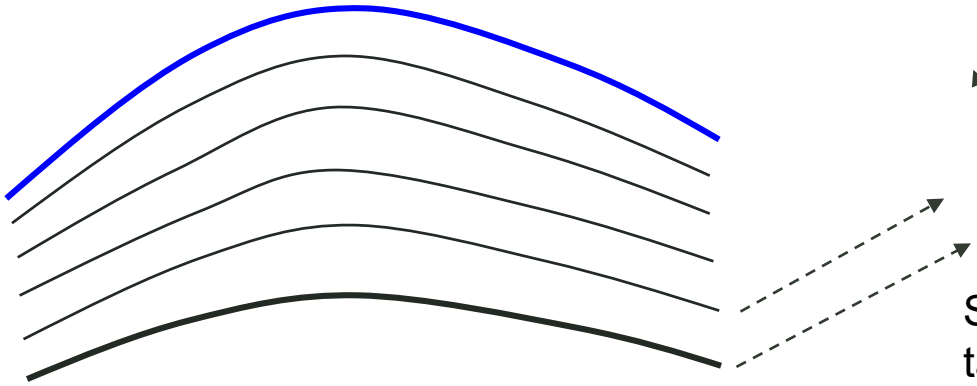

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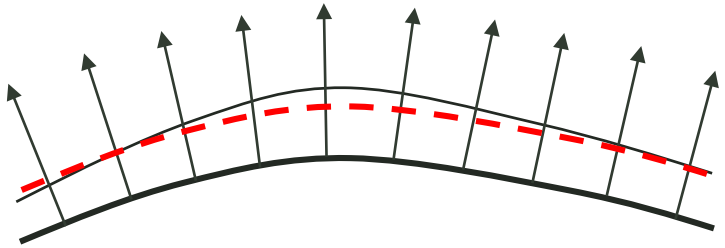
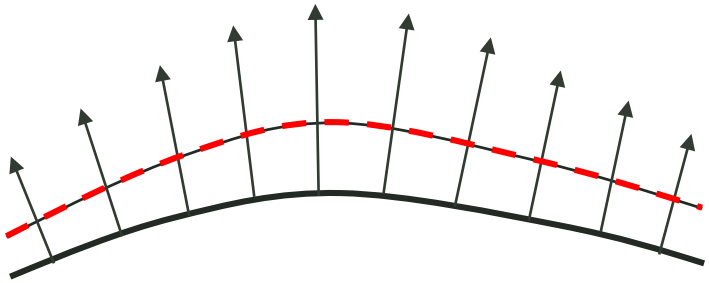


Step 3. Correct path velocity to match targeted layer surface using gradient descent optimization



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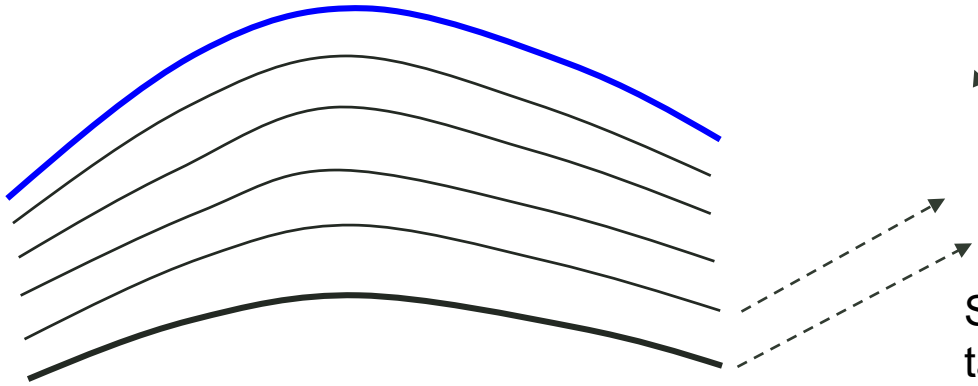

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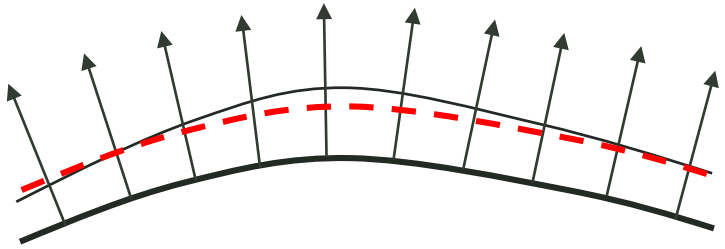

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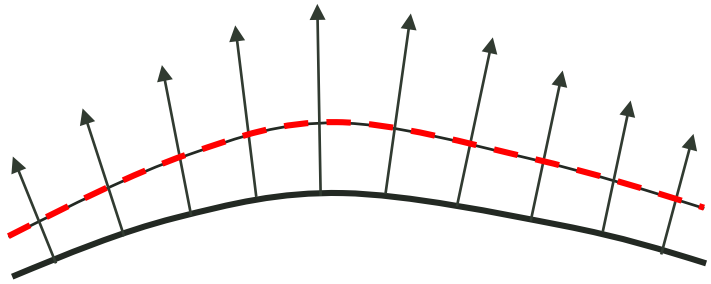

Step 4. Combine the optimized path from each layer into a single path and export to robotic program

Key

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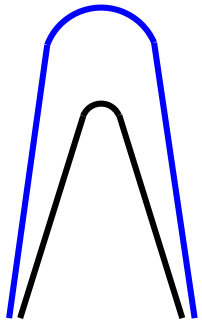
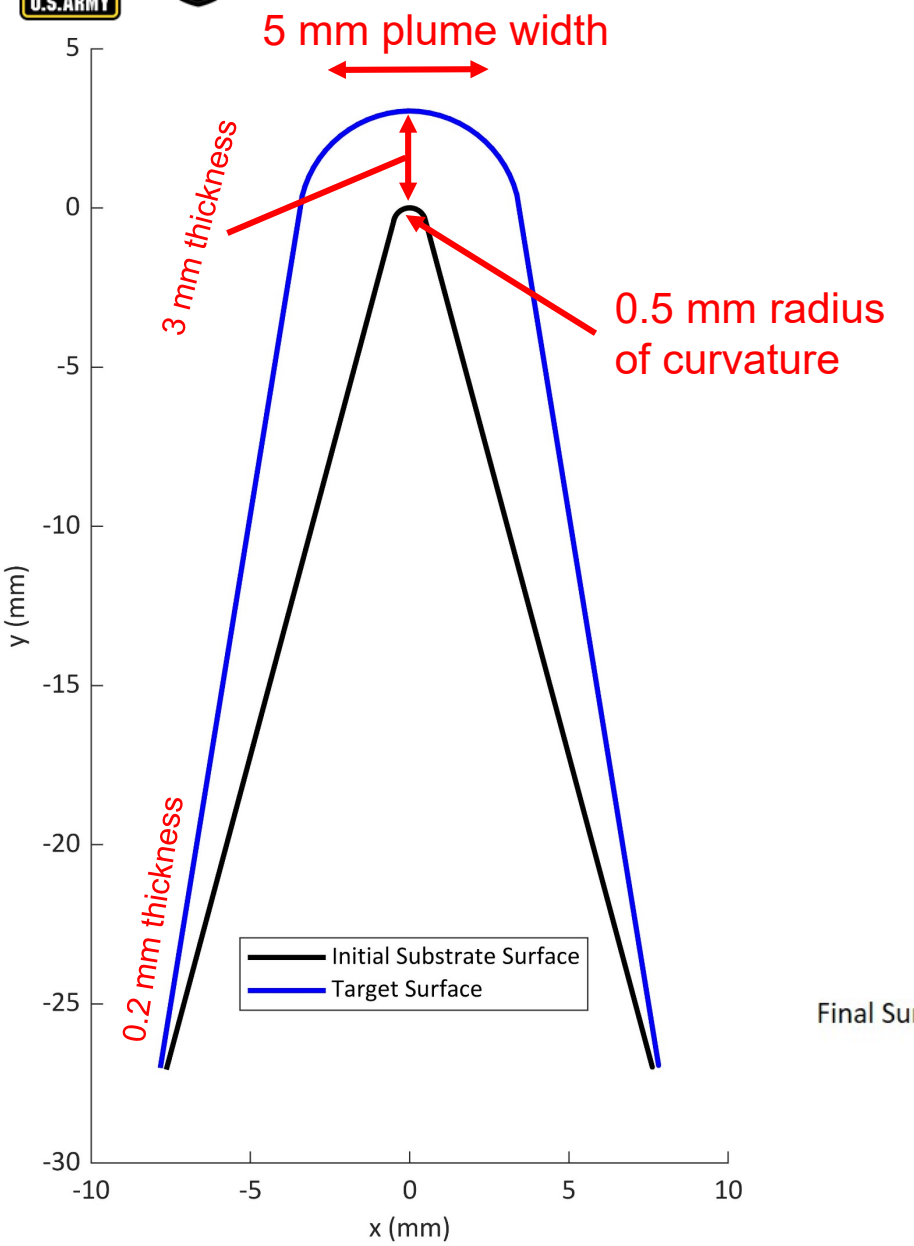
High-Curvature Experiment

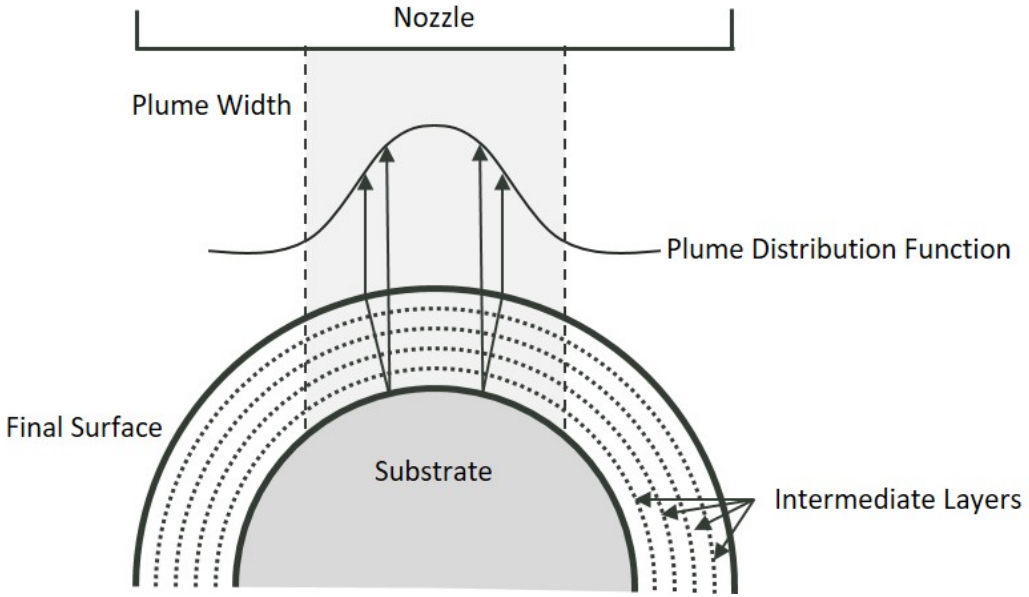


HIGH CURVATURE COUPON DESIGN



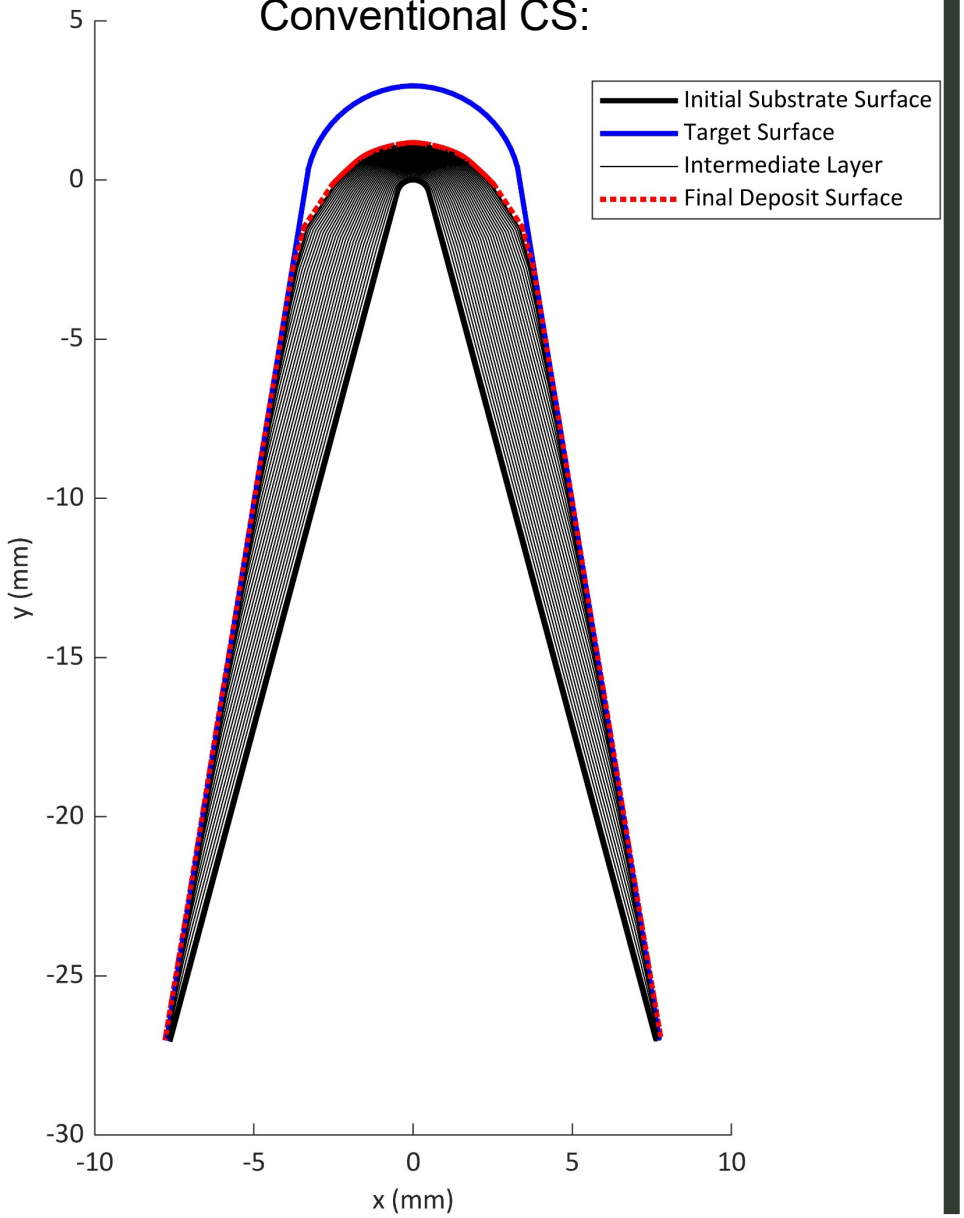
Technical Challenges:

- Plume width much wider than radius of curvature
- Deposit surface area changes significantly
- Steep thickness gradient

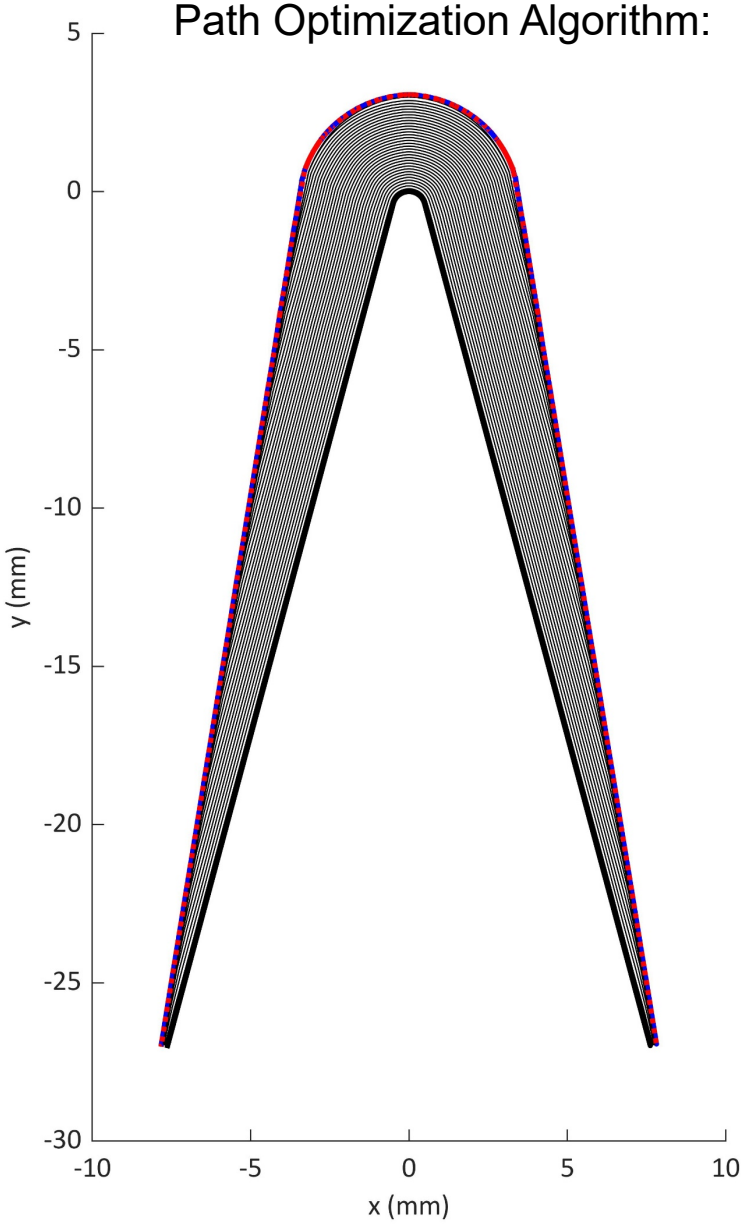


PATH OPTIMIZATION FOR HIGH CURVATURE

Conventional CS:



Path Optimization Algorithm:



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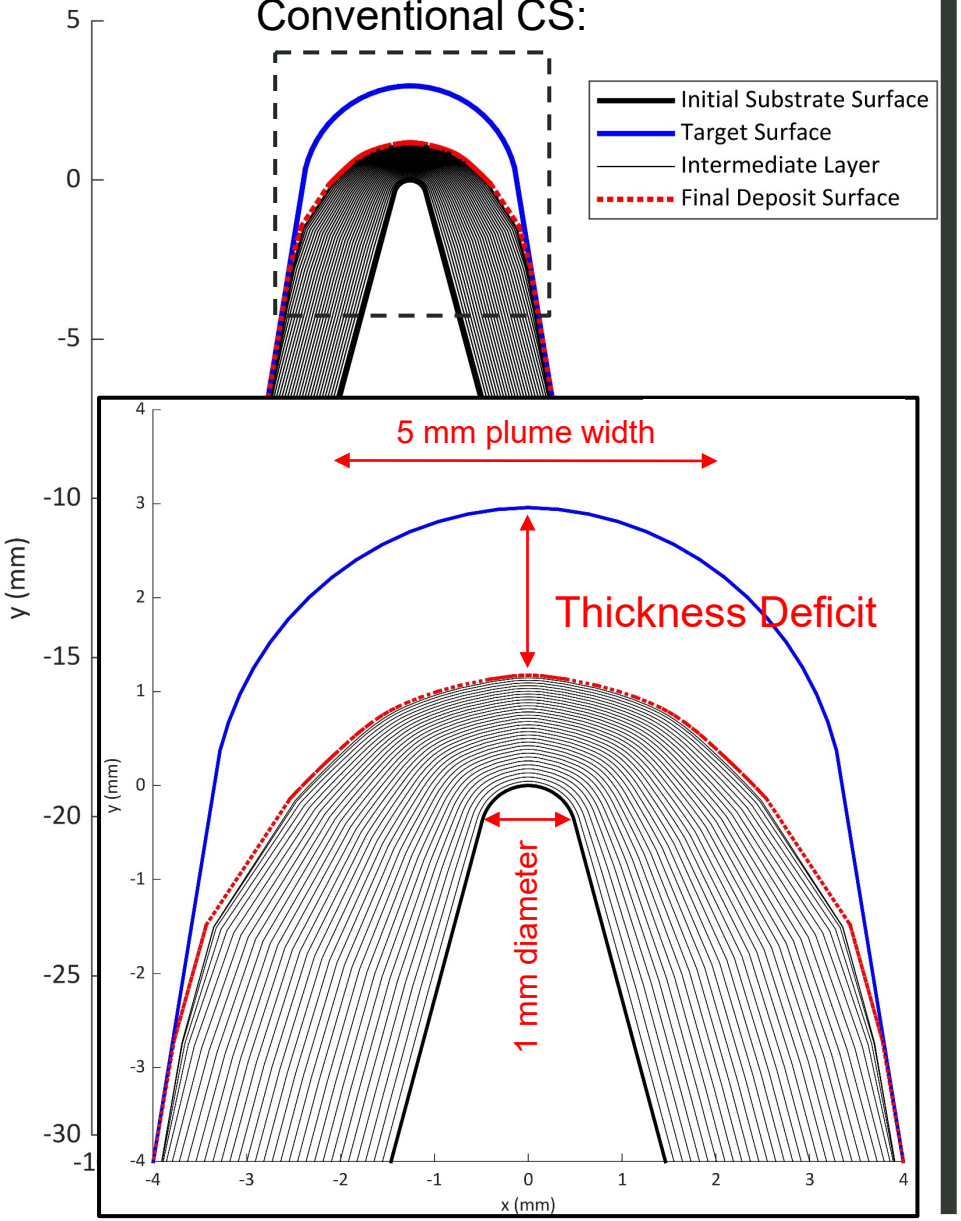
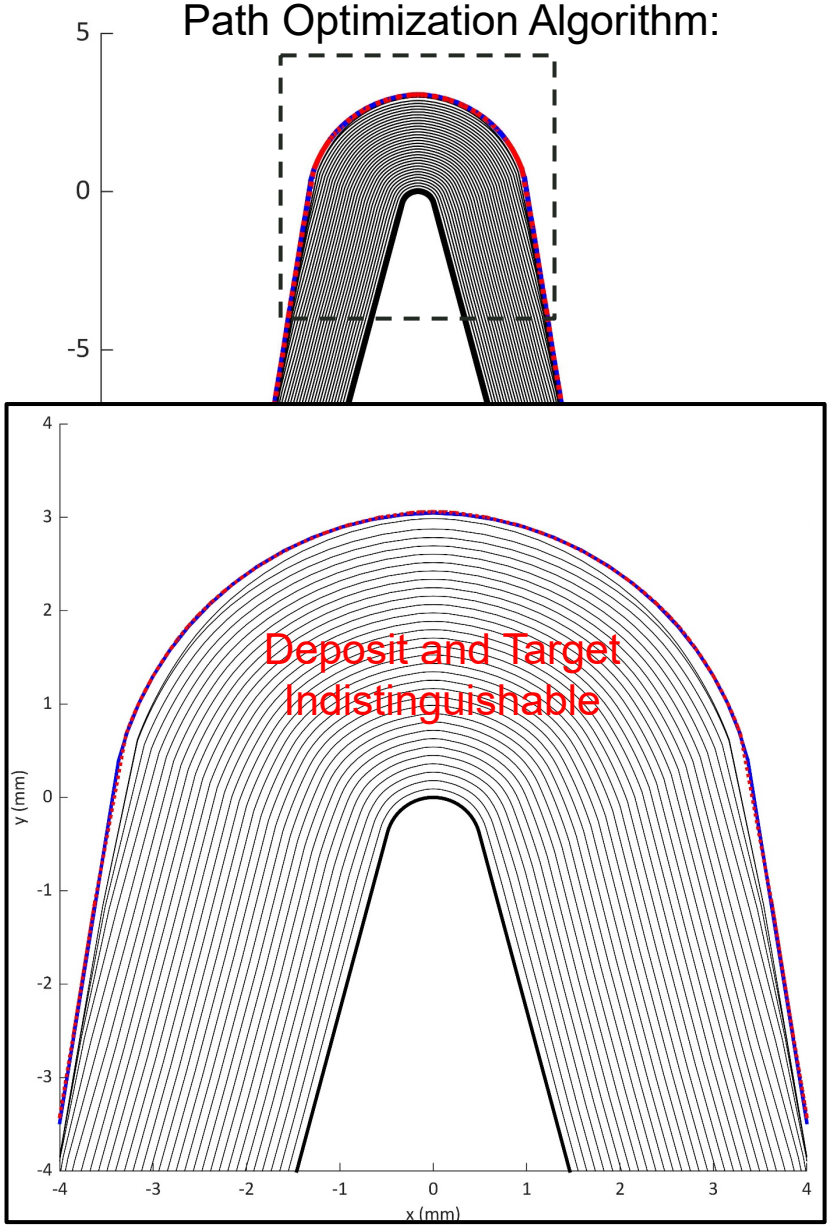


Path Optimization Algorithm:



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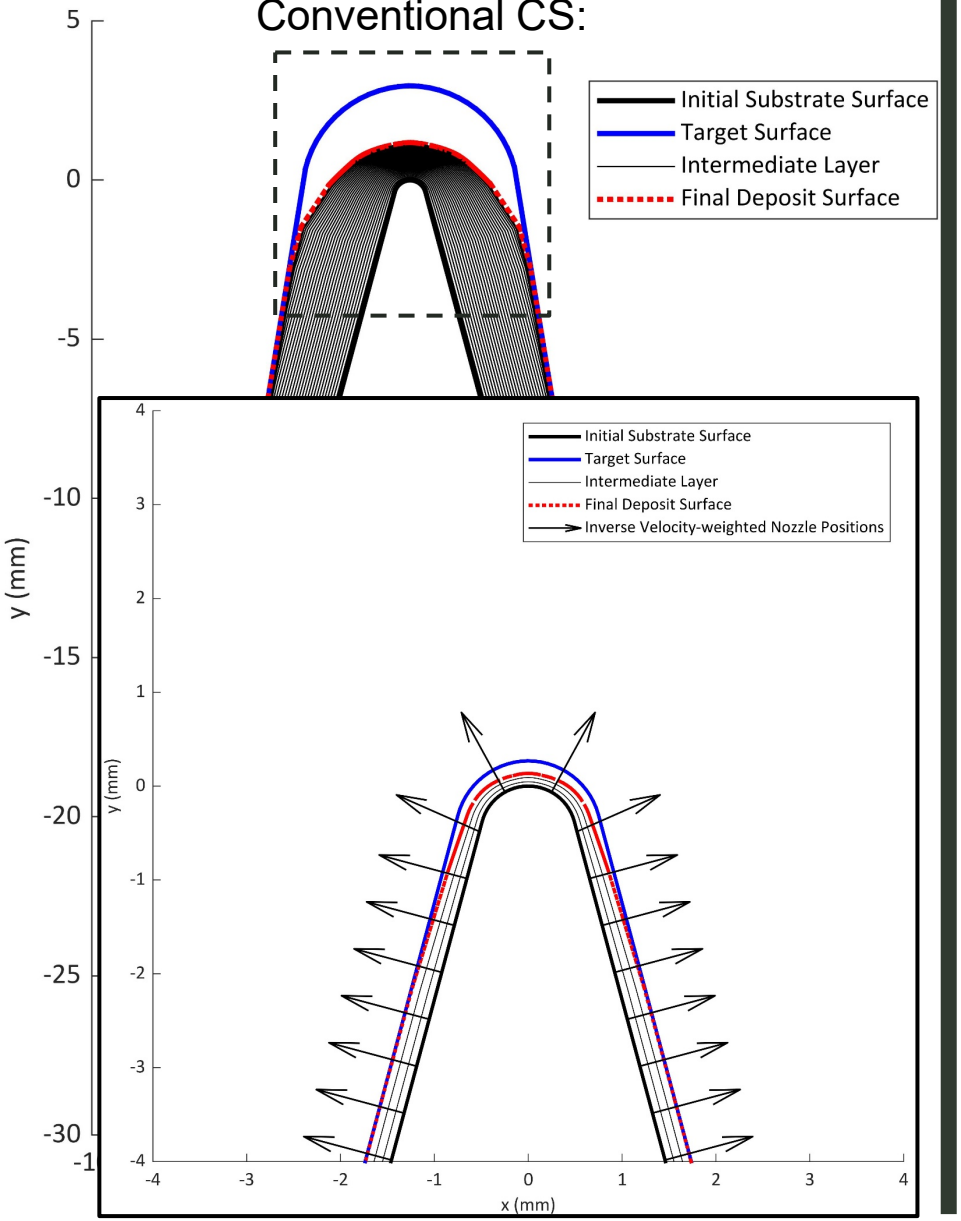

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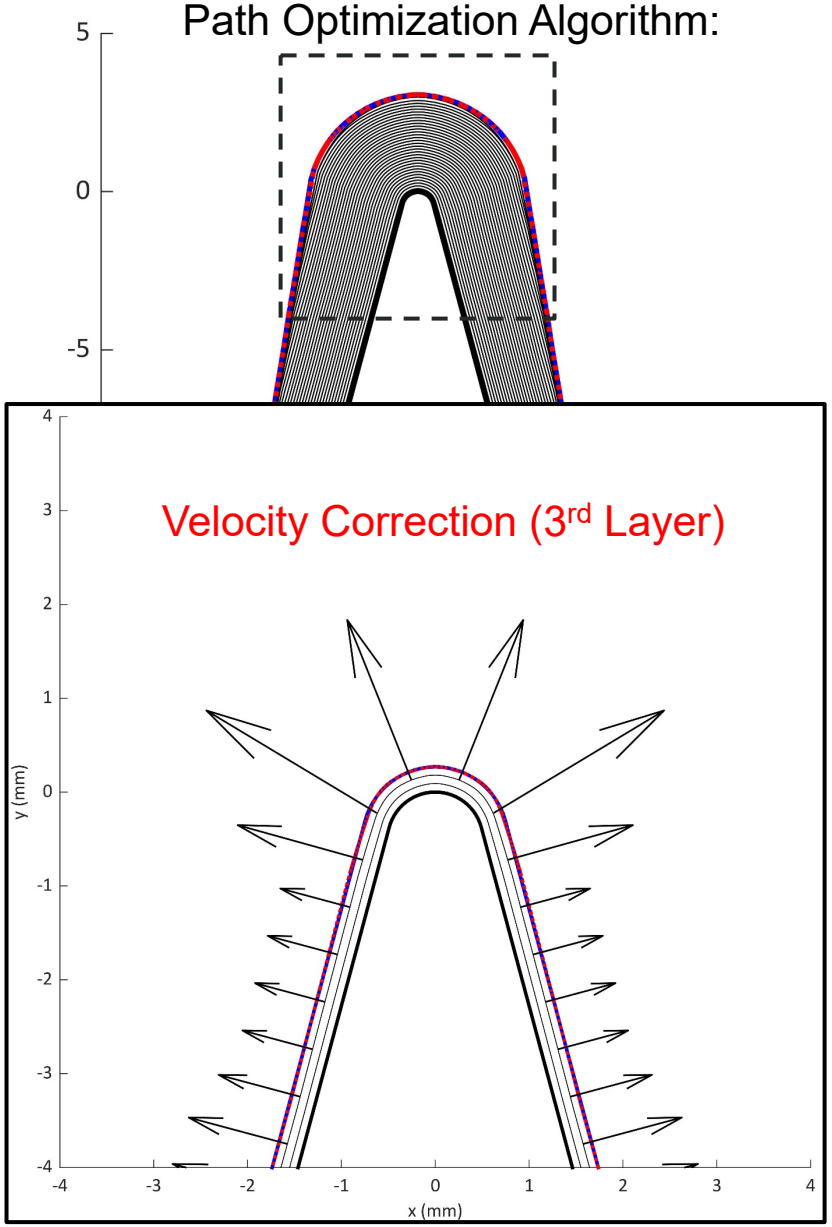
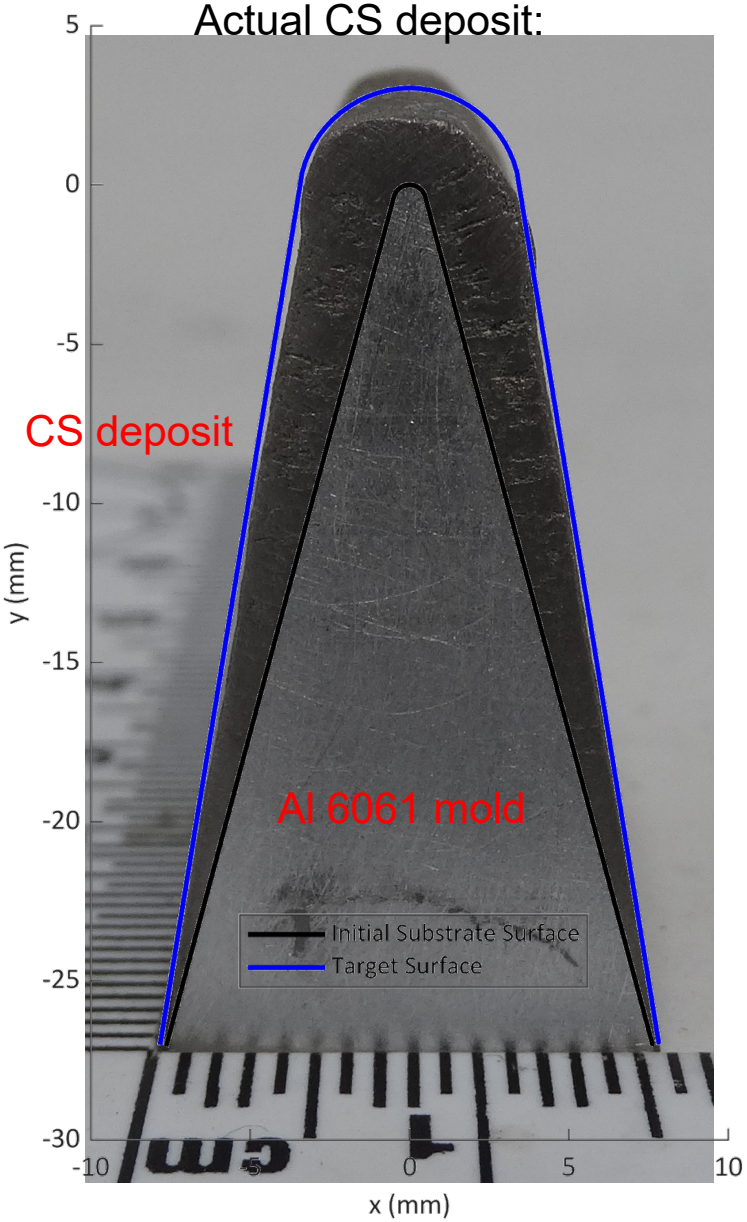
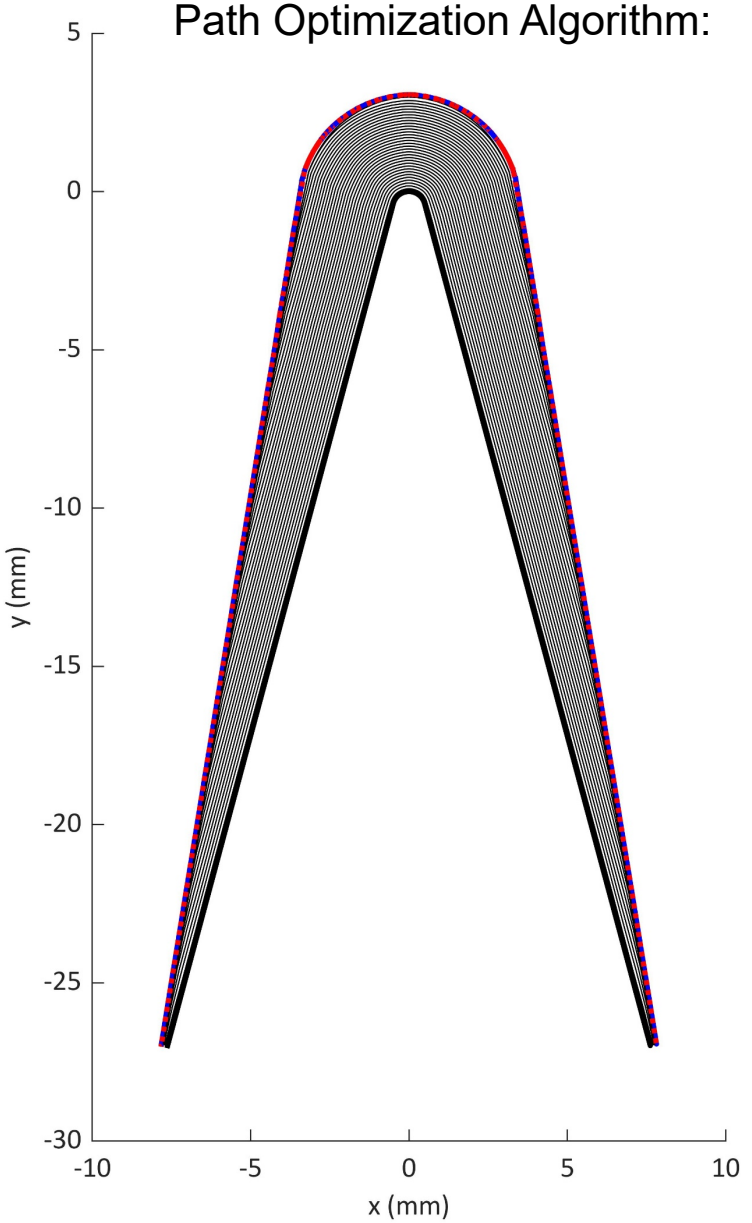


PATH OPTIMIZATION FOR HIGH CURVATURE

Actual CS deposit:



Path Optimization Algorithm:



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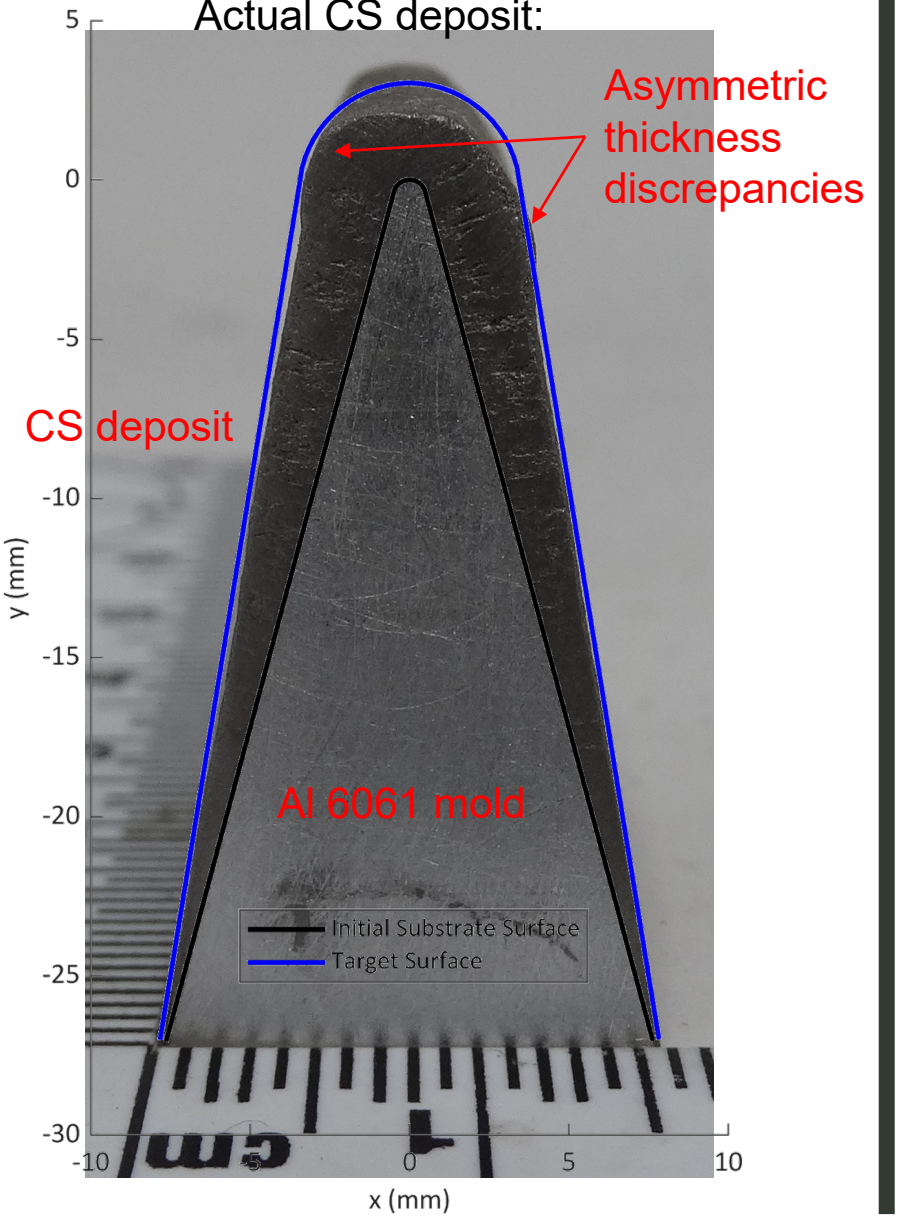

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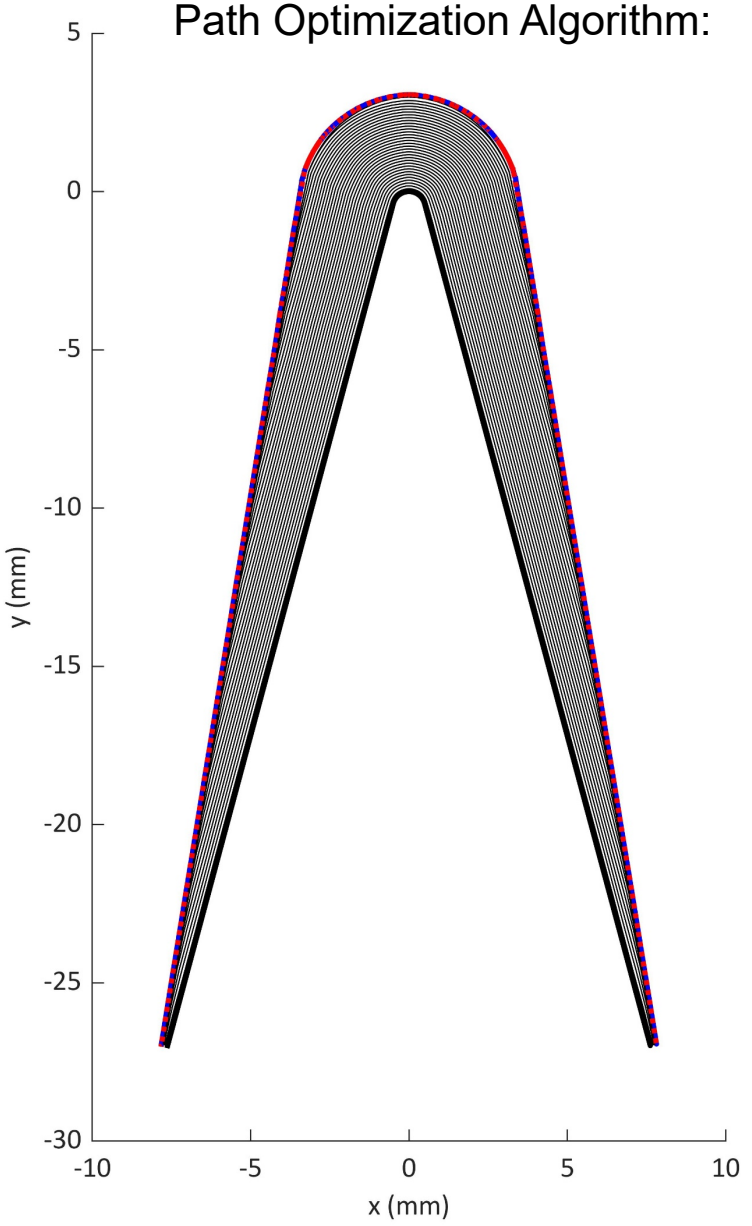

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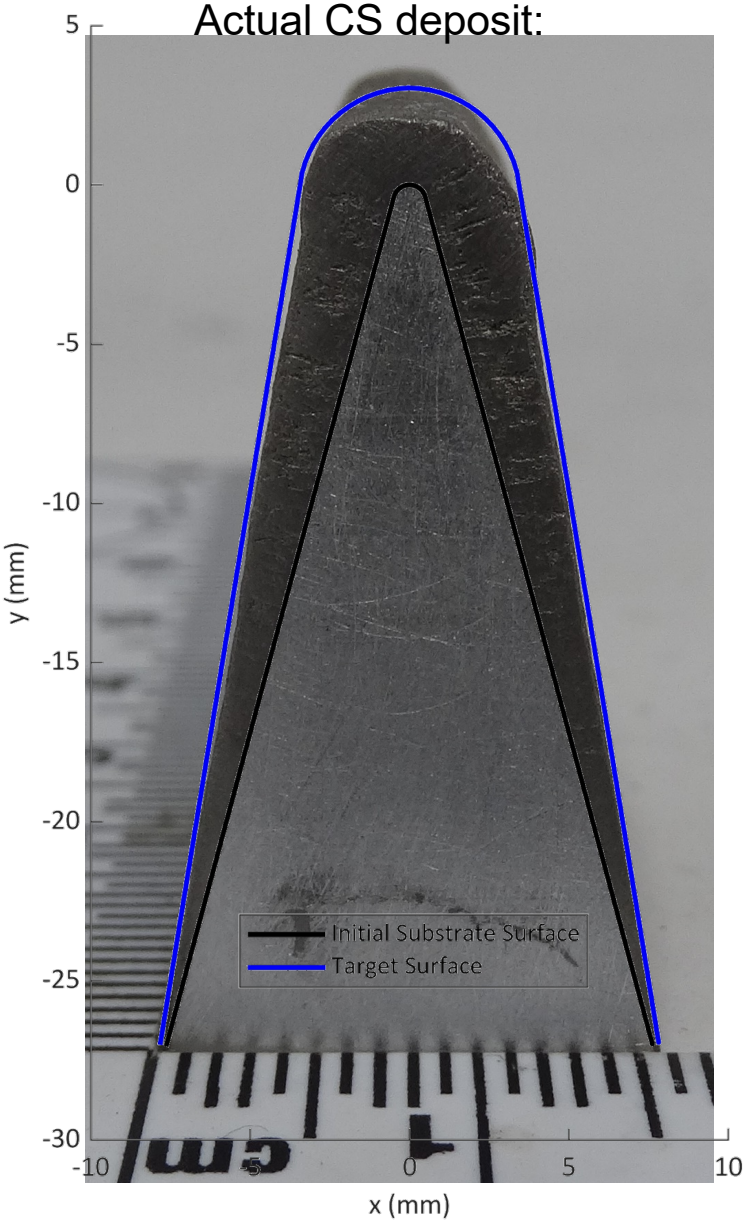
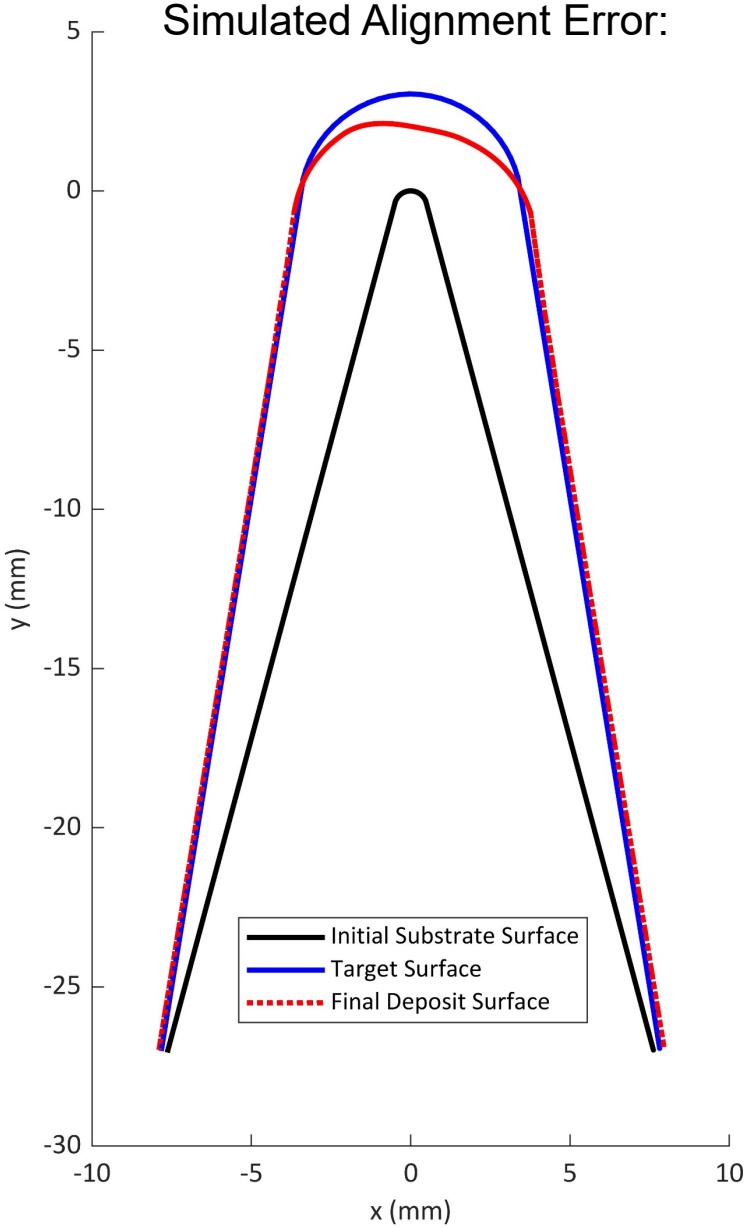


Simulated Alignment Error:



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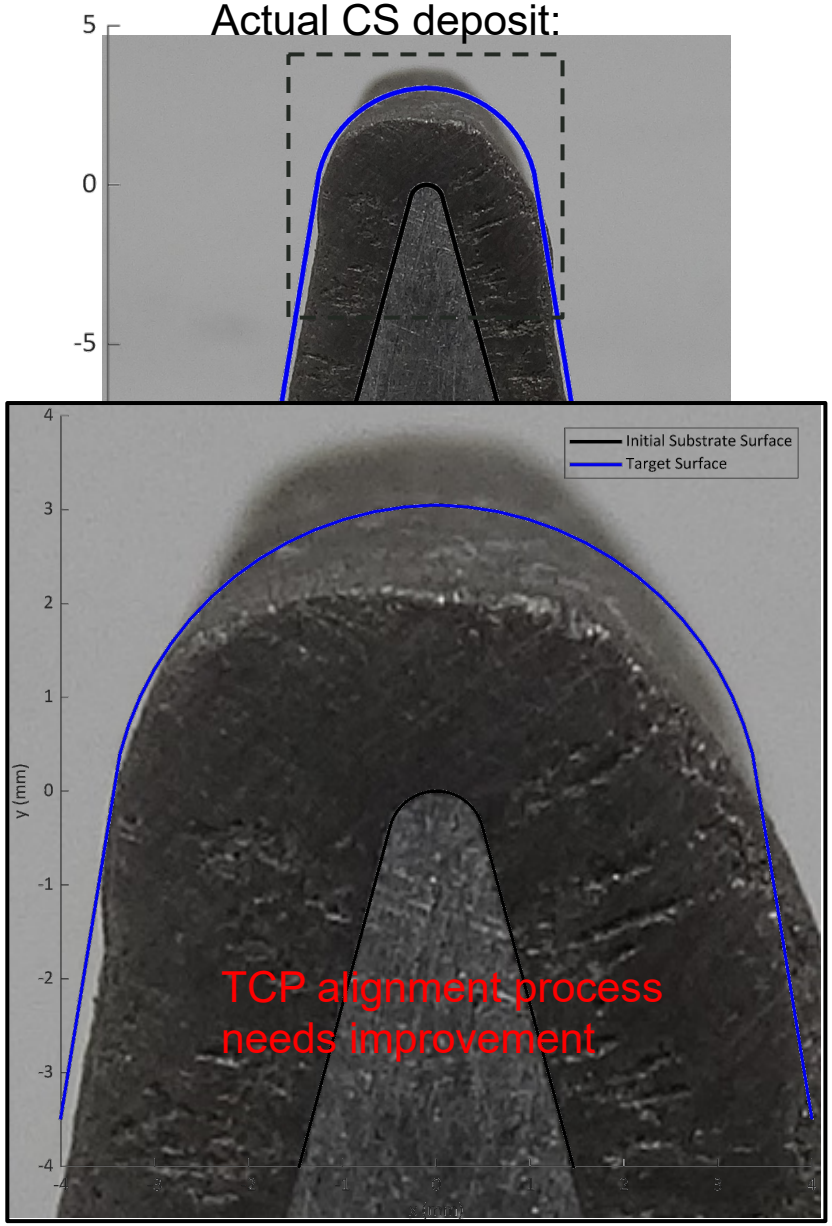

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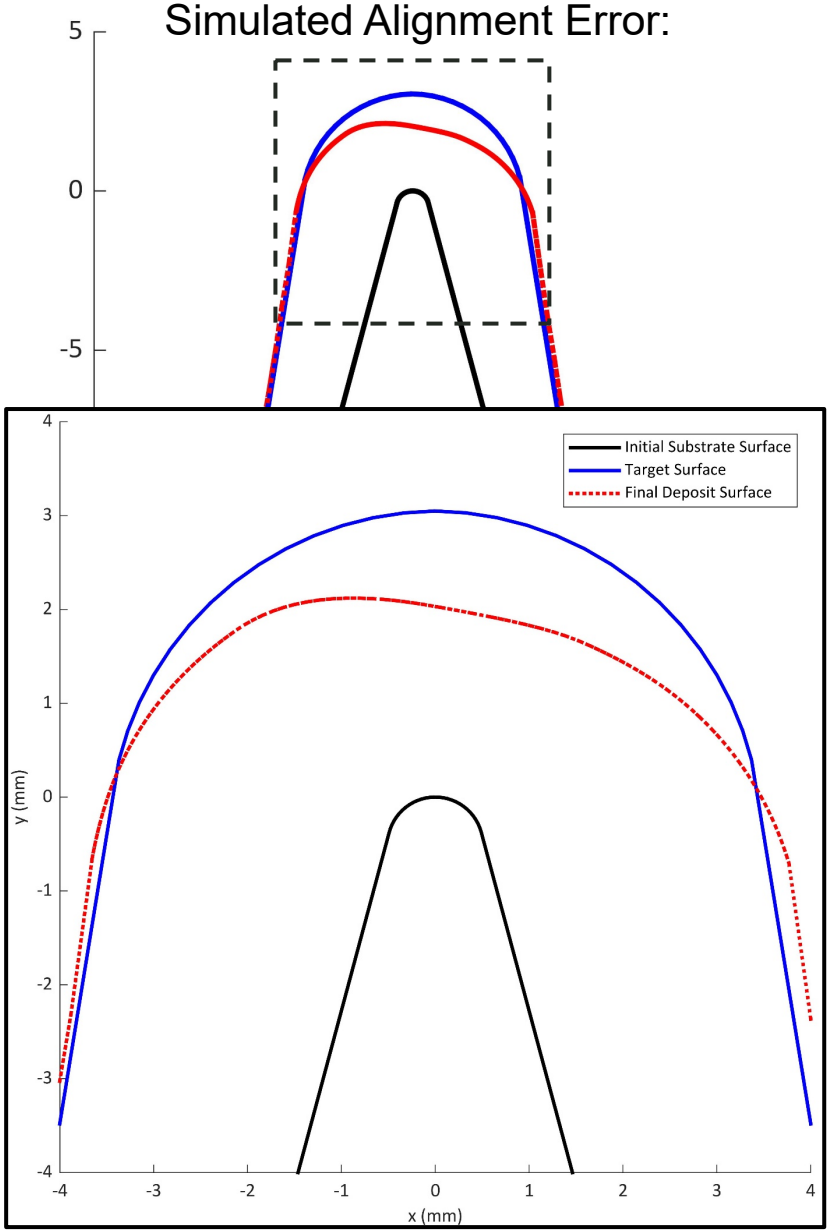
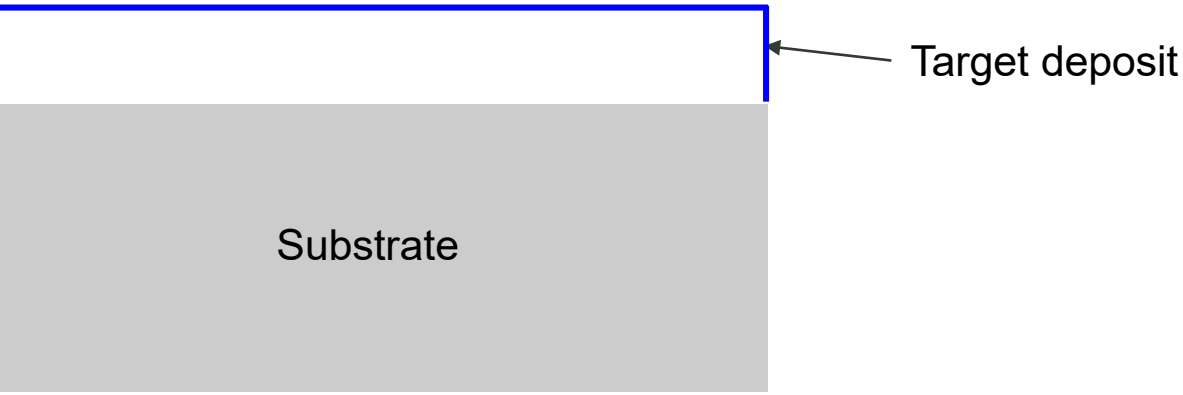


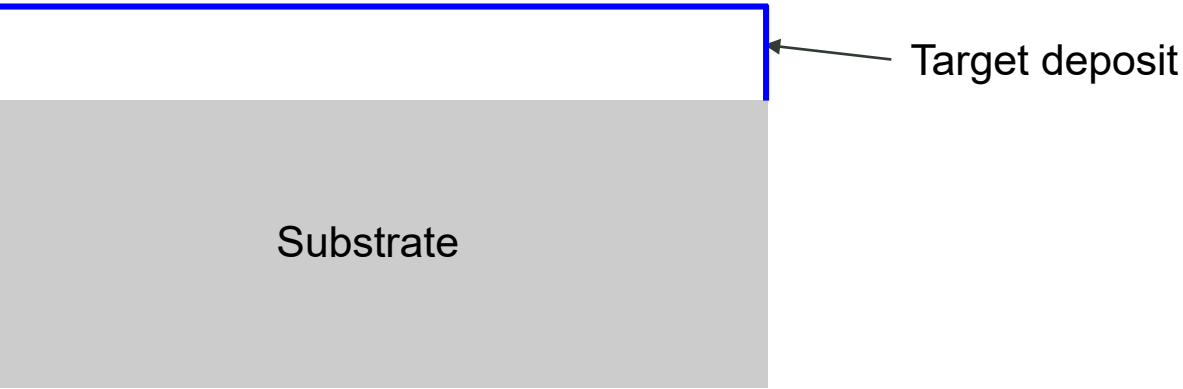
Structural Repair: Edge Restoration

EDGE RESTORATION PROBLEM DEFINITION

Conventional CS Edge Restoration



Optimized Edge Restoration



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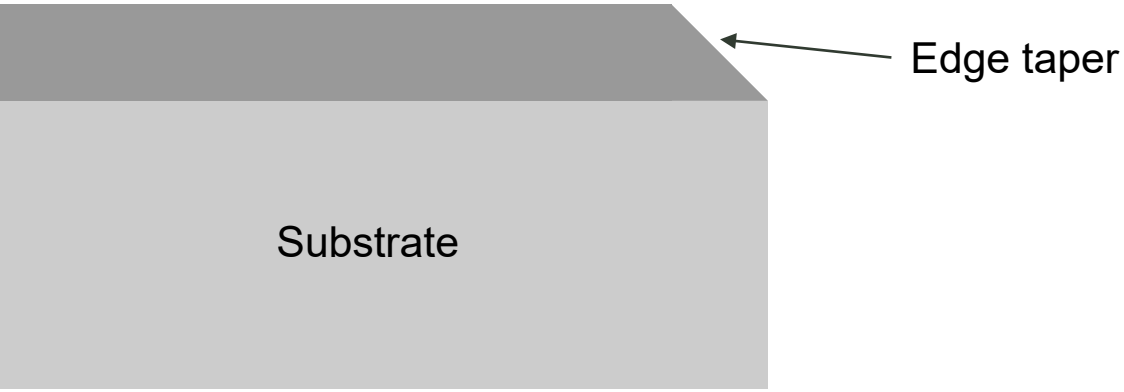

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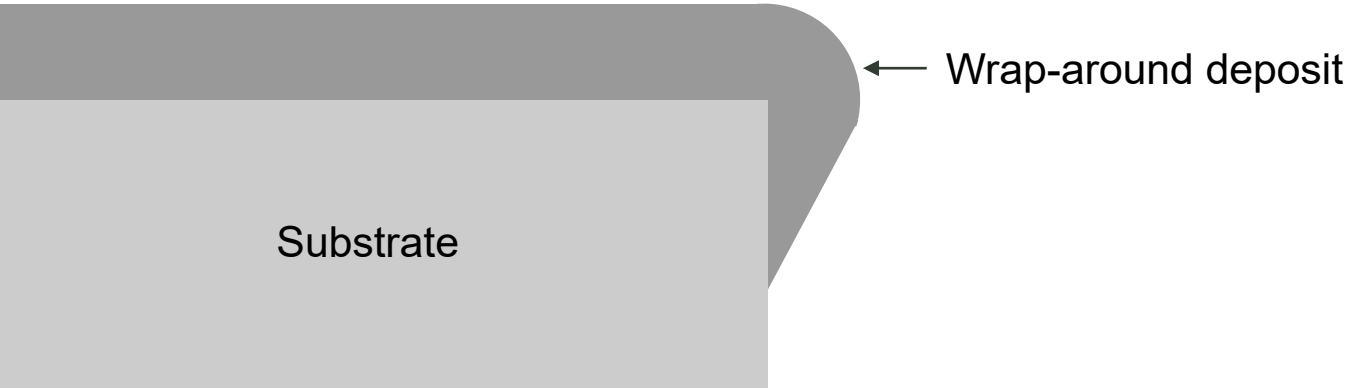

CS deposit

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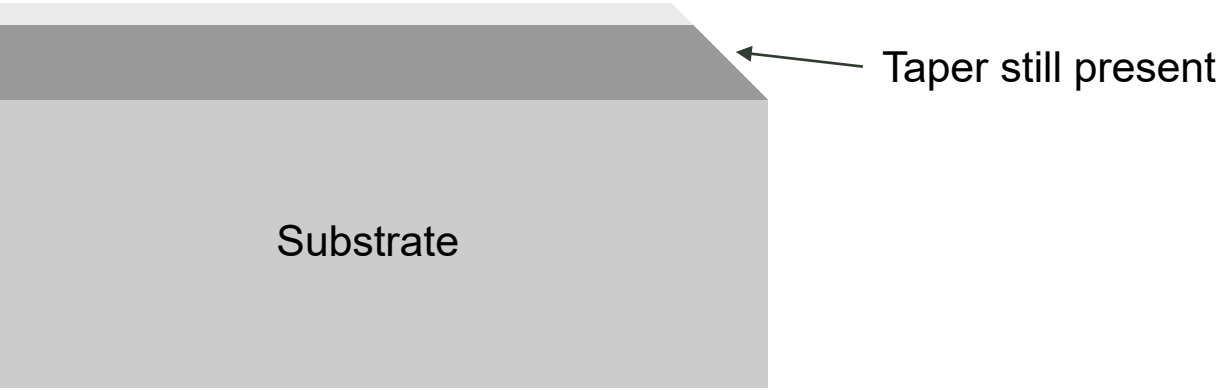

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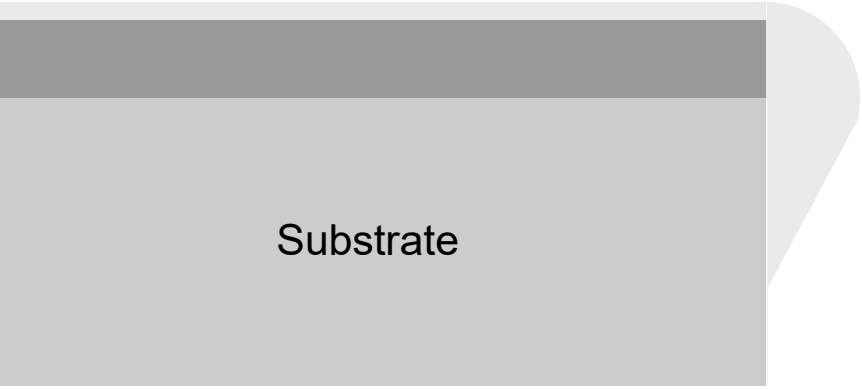
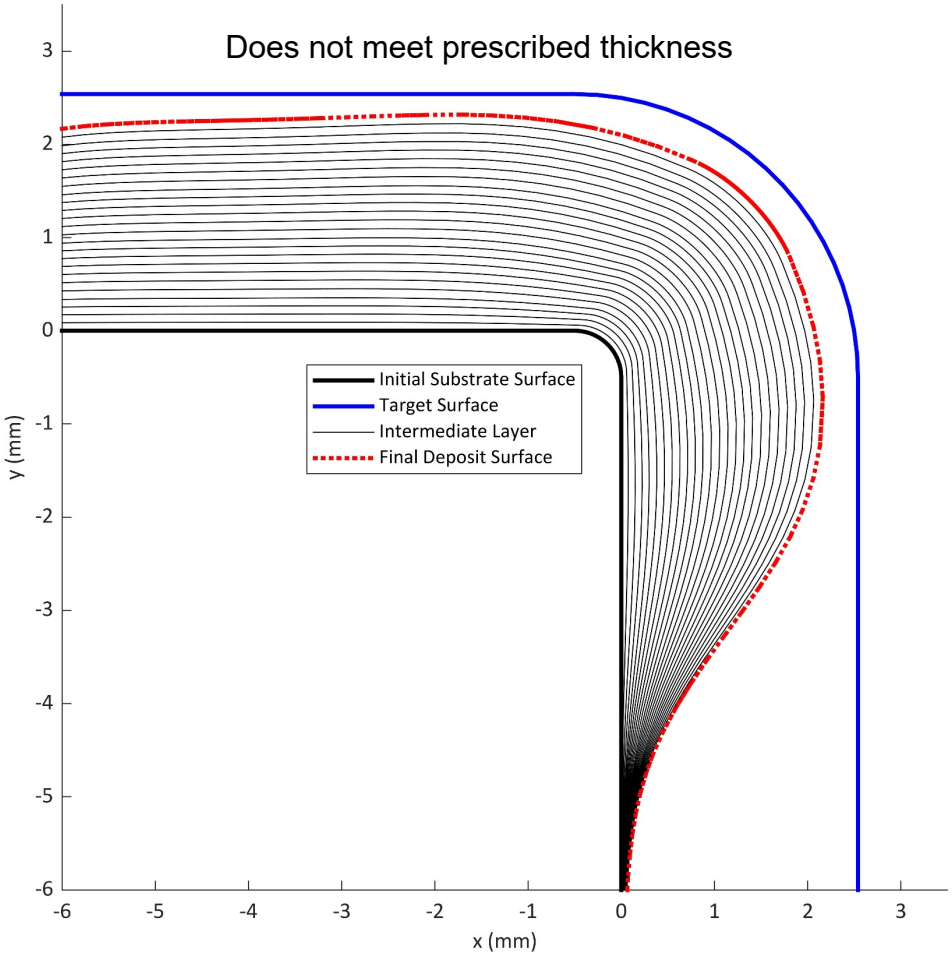


Post-finish

PATH OPTIMIZATION FOR EDGE RESTORATION

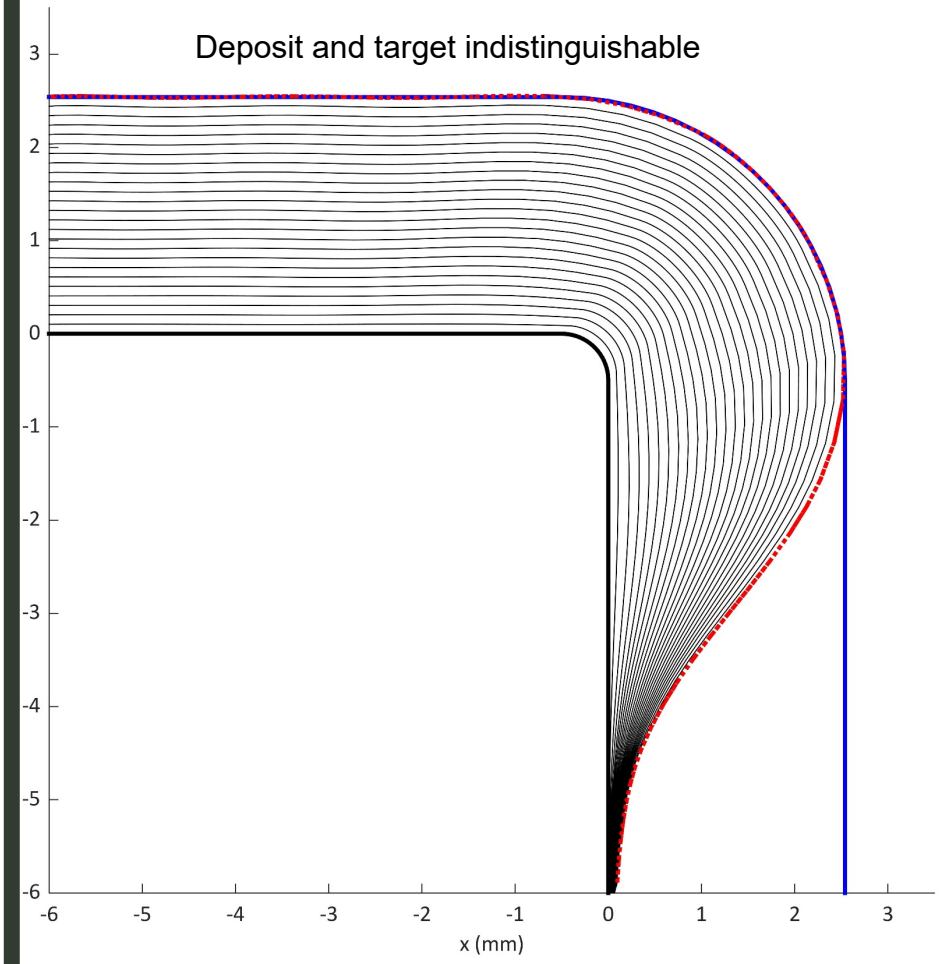
Non-optimized Deposition:

Does not meet prescribed thickness



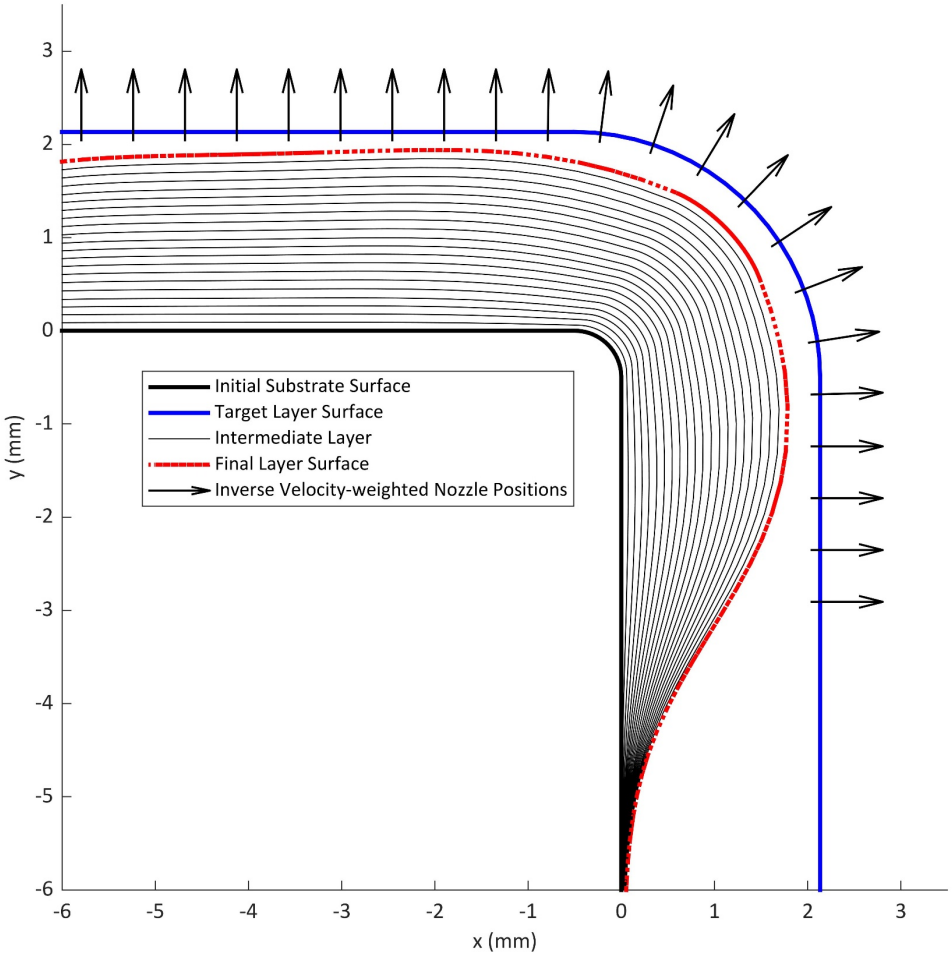
Optimized Deposition:

Deposit and target indistinguishable

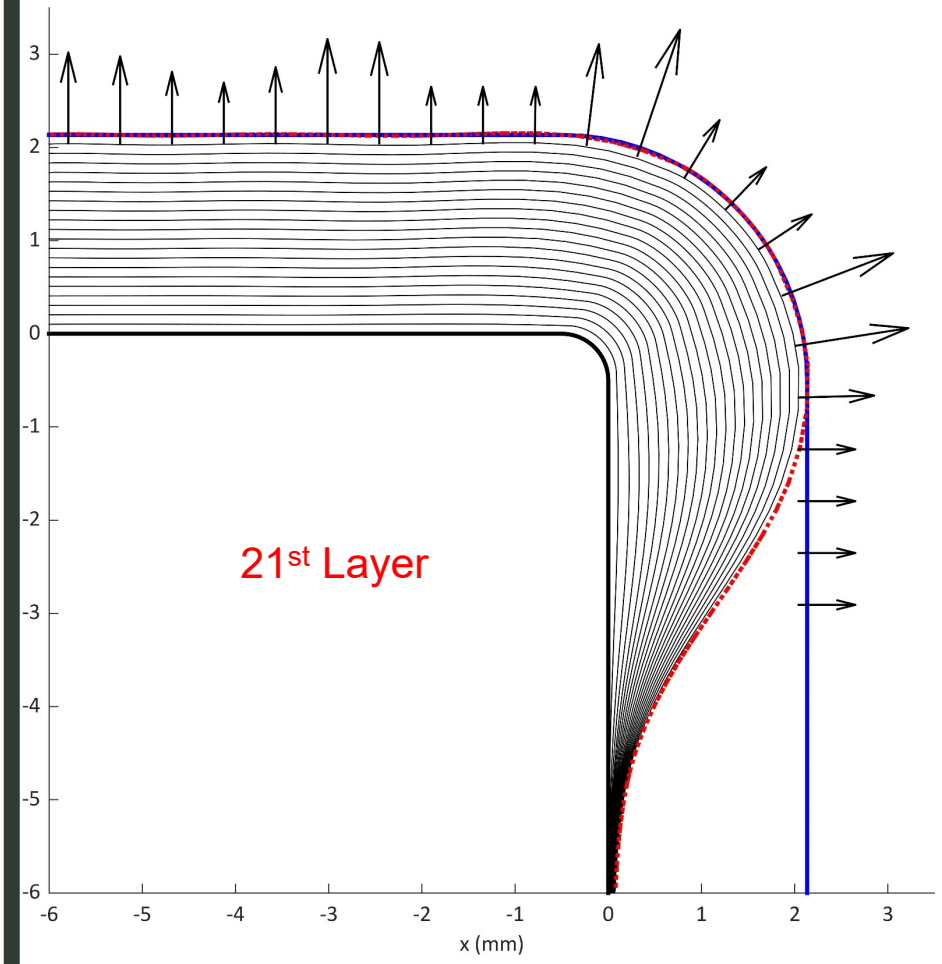


PATH OPTIMIZATION FOR EDGE RESTORATION

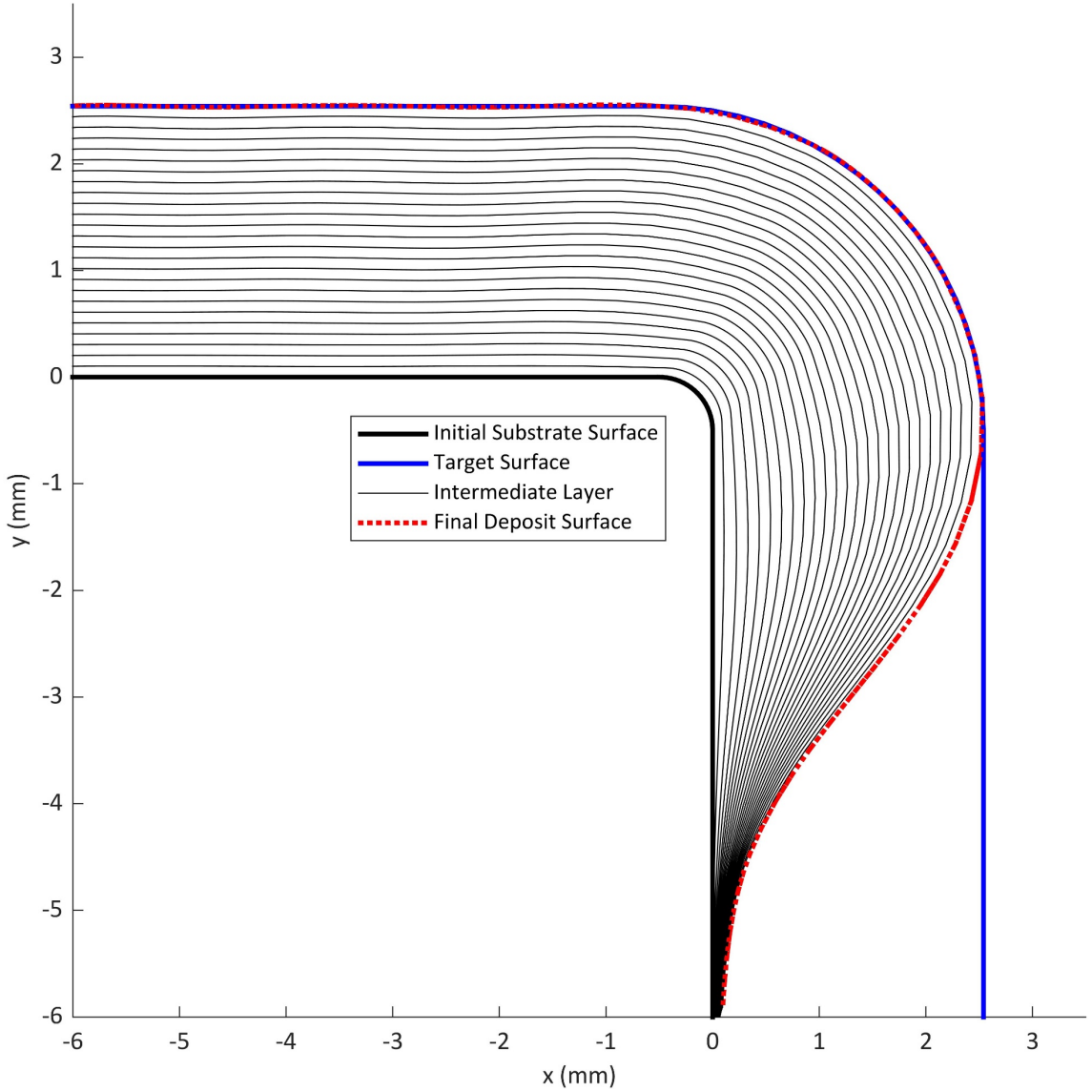
Constant Path Velocity:



Optimized Path Velocity:



FINISHED EDGE RESTORATION



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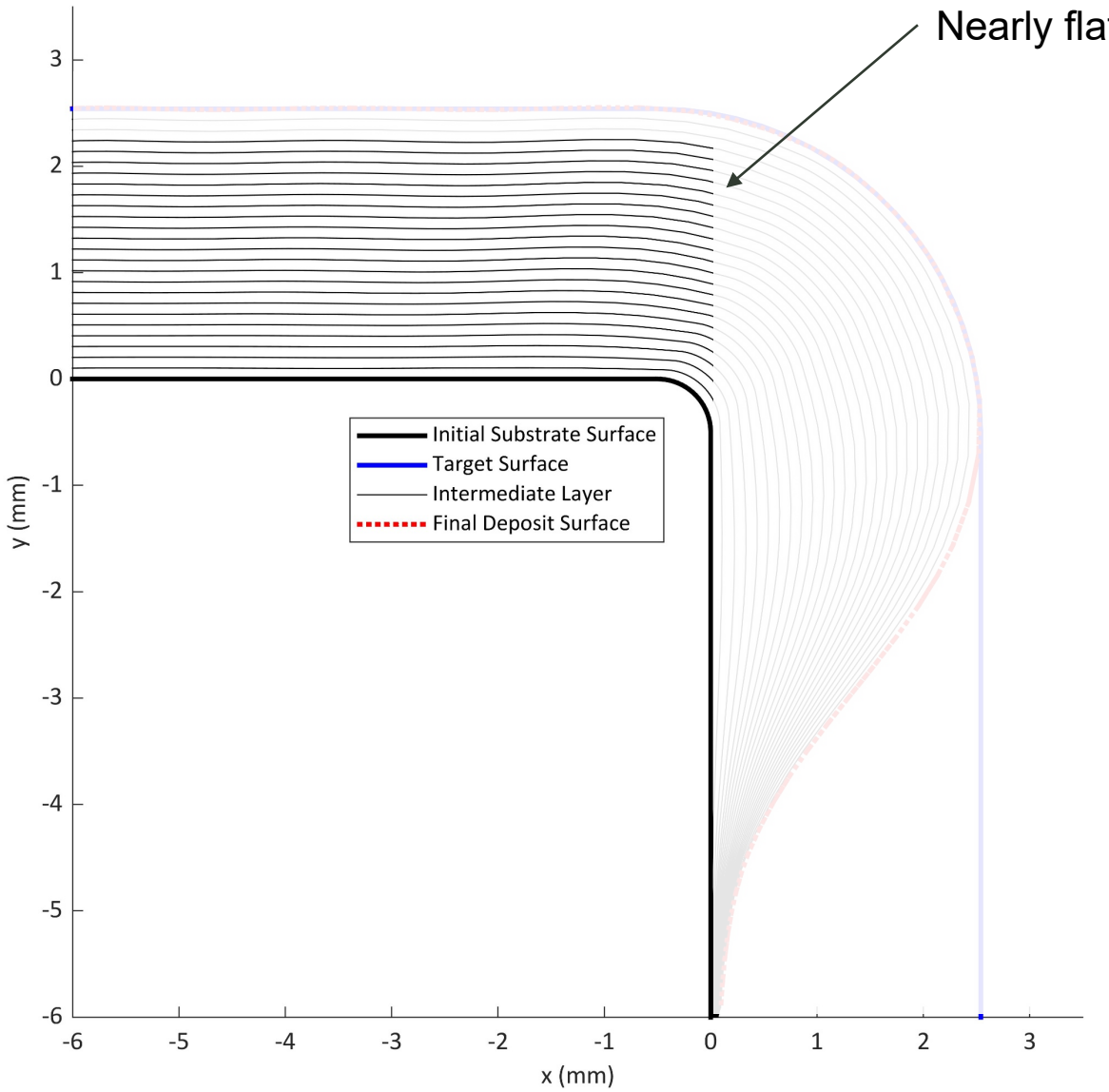
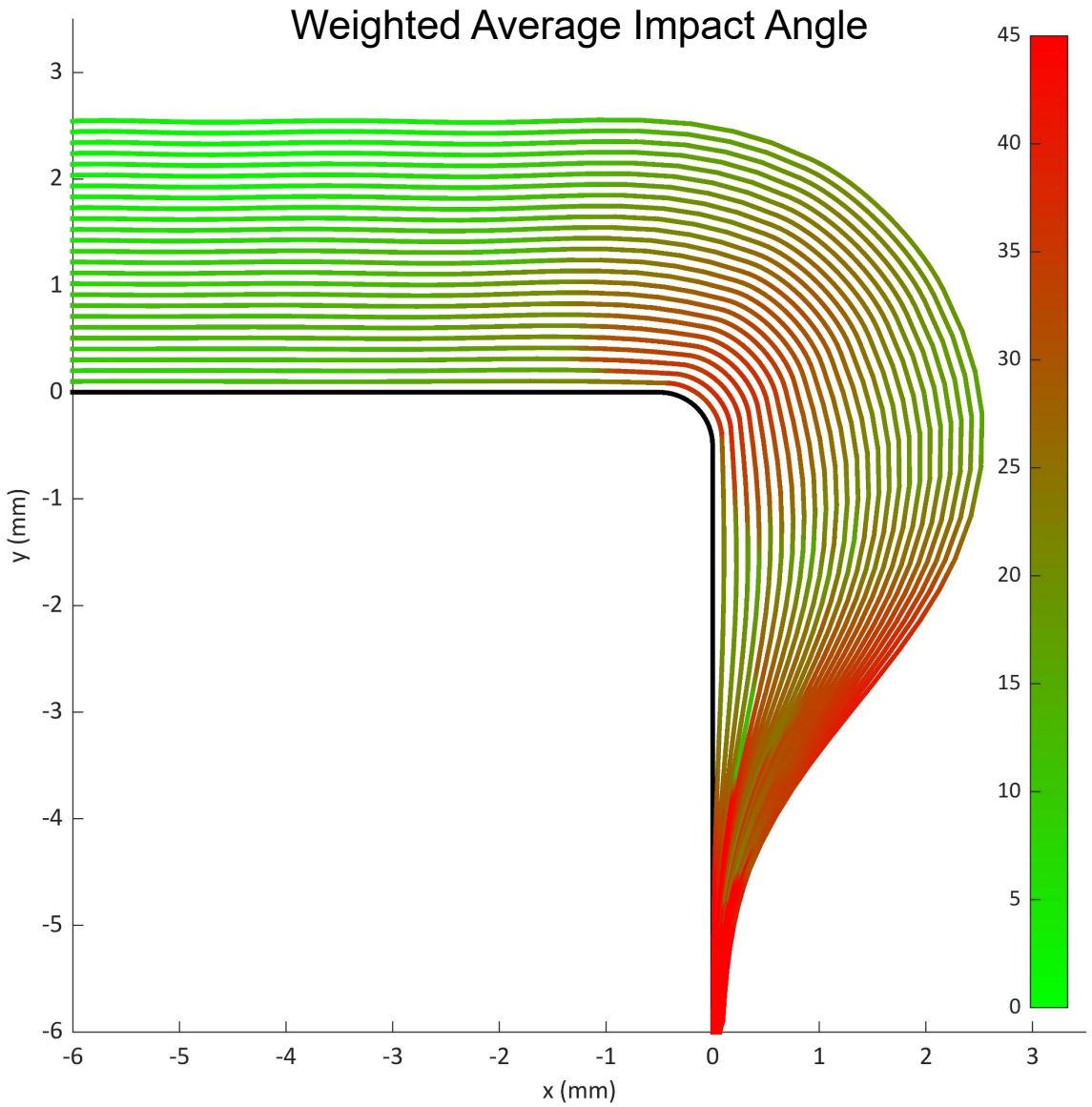


Post-finish

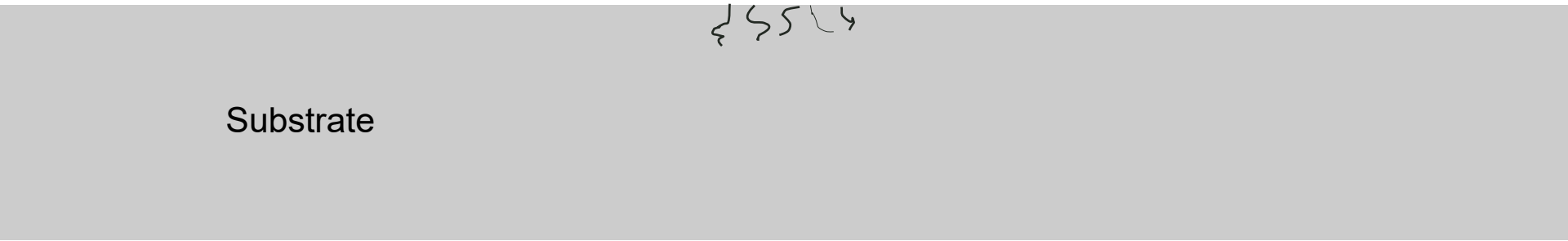
INTERMEDIATE LAYER PROPERTIES



Structural Repair: Spiral In-fill

SPIRAL-INFILL PROBLEM DEFINITION

Conventional CS In-Fill



Optimized In-Fill

SPIRAL-INFILL PROBLEM DEFINITION

Conventional CS In-Fill

Substrate

Optimized In-Fill

Substrate

Blend out with spherical cutting tool

SPIRAL-INFILL PROBLEM DEFINITION

Conventional CS In-Fill

Substrate

Optimized In-Fill

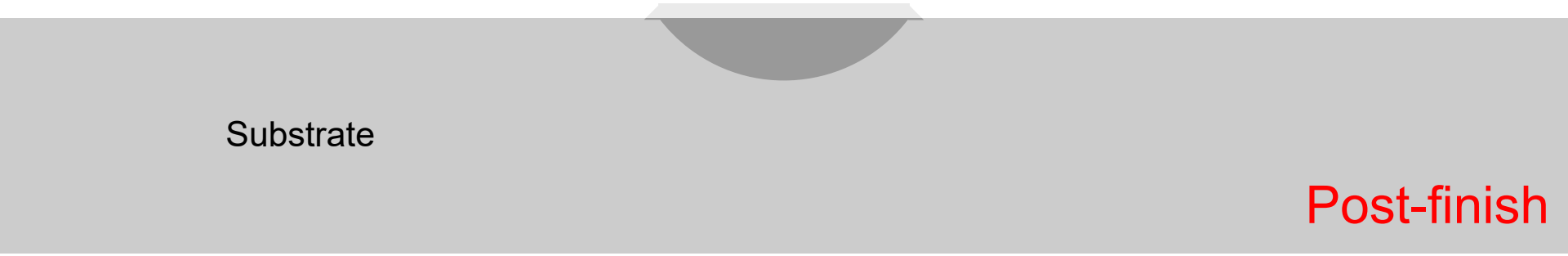
Substrate

Fill-in with CS

SPIRAL-INFILL PROBLEM DEFINITION

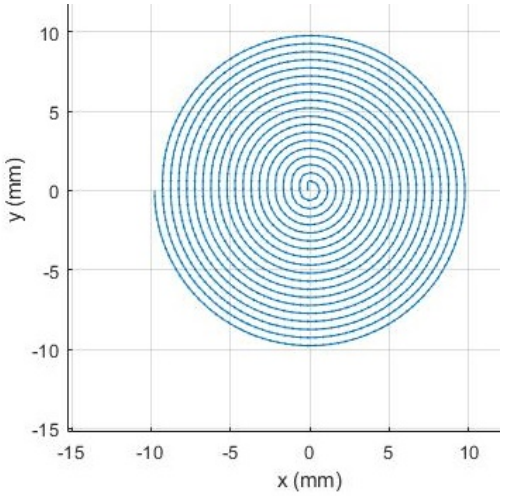
Conventional CS In-Fill

Optimized In-Fill

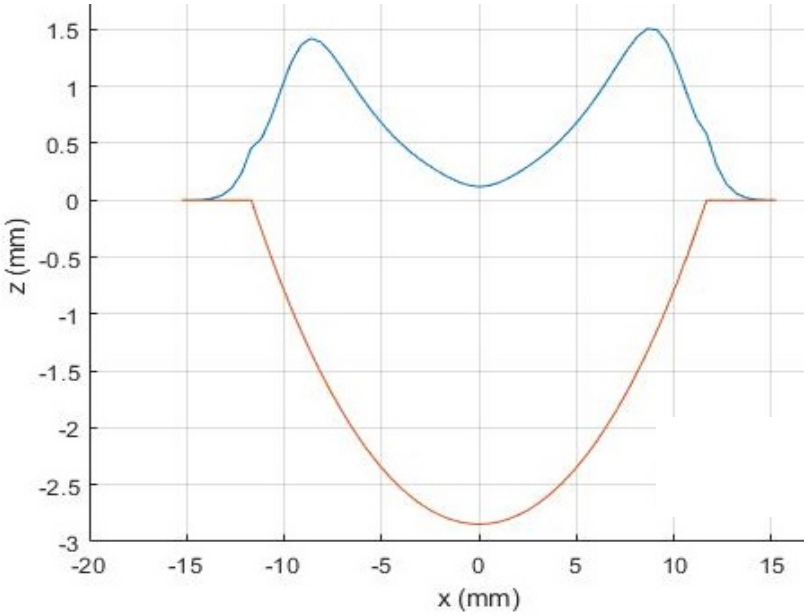


SPIRAL IN-FILL PATH OPTIMIZATION

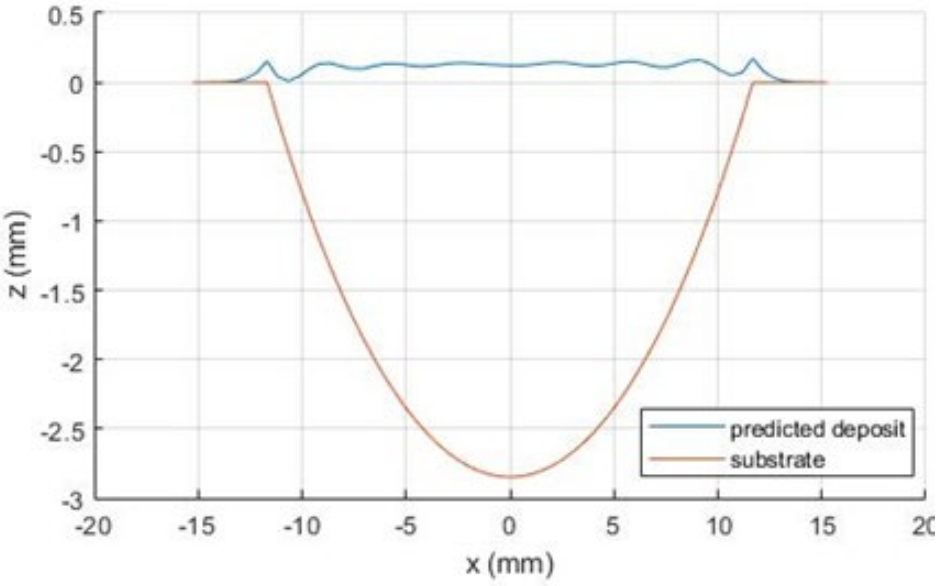
Spiral path (top-down view):



Non-optimized deposit (side view):



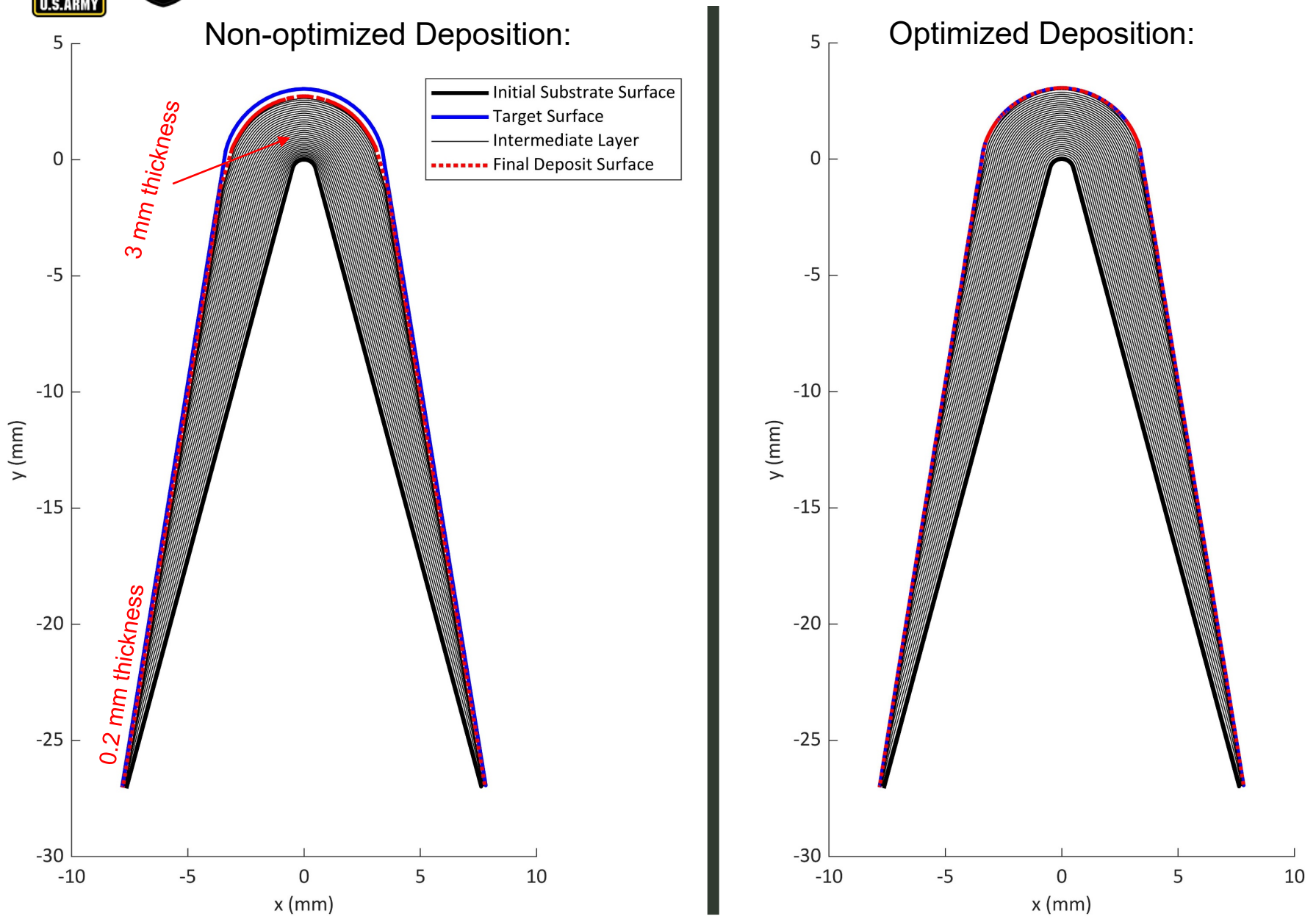
Optimized deposit (side view):



Questions?

Extra Slides

PATH OPTIMIZATION FOR HIGH CURVATURE



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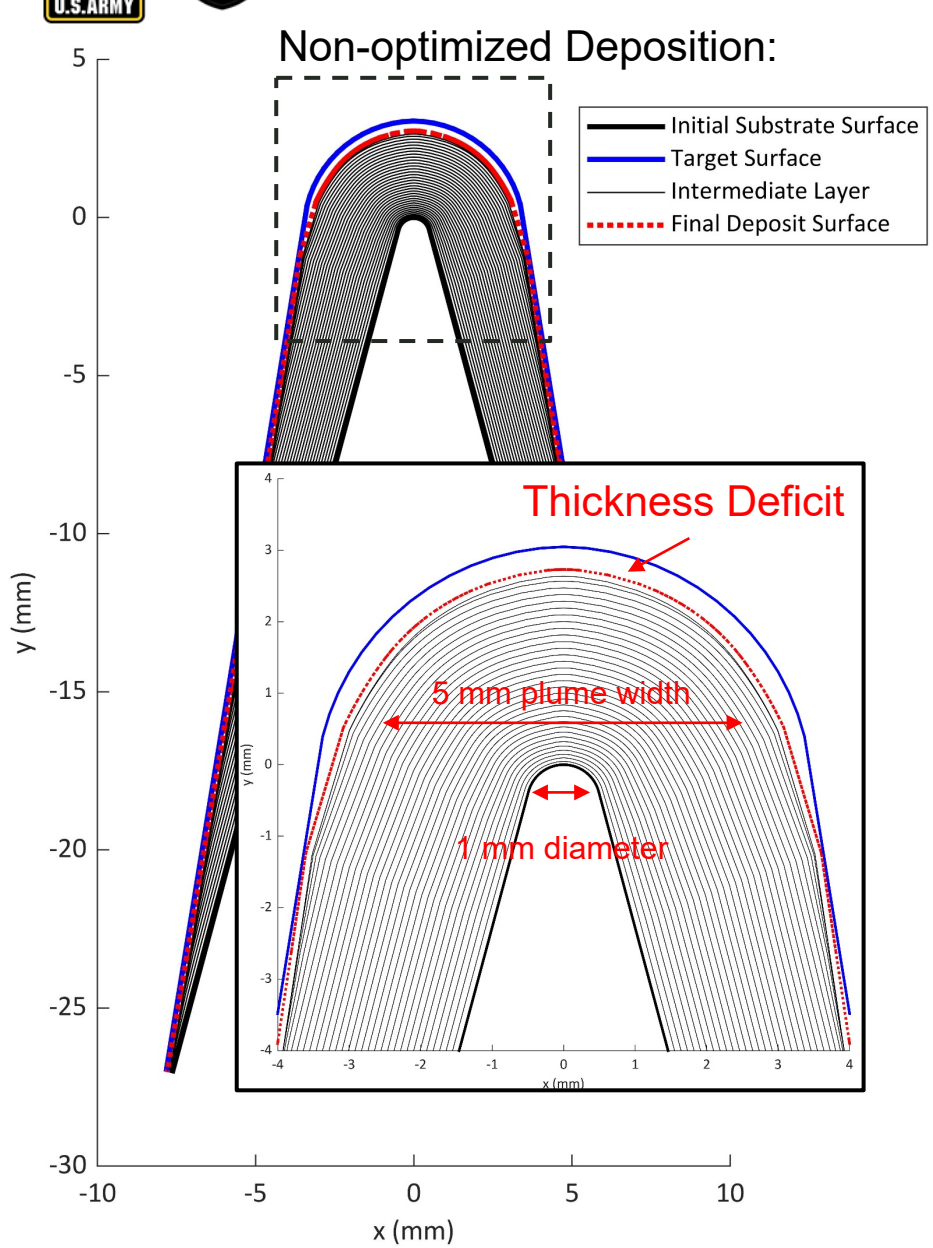
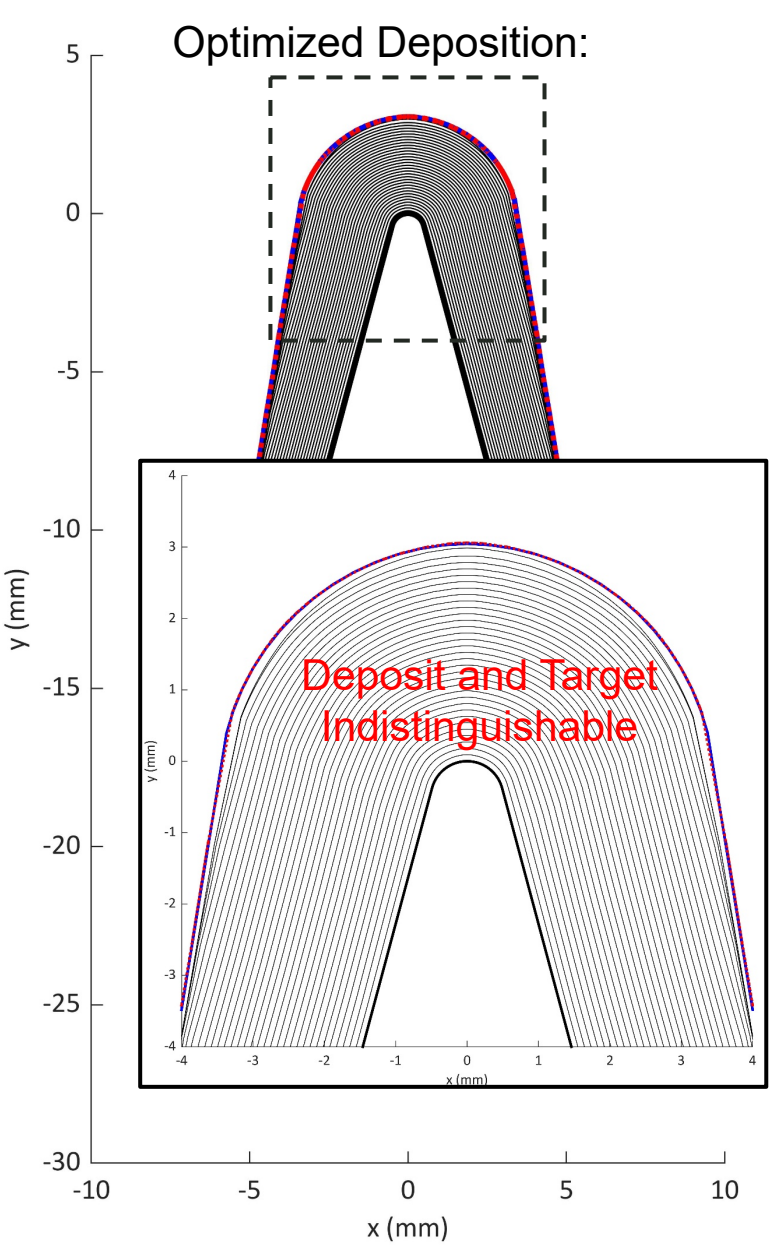
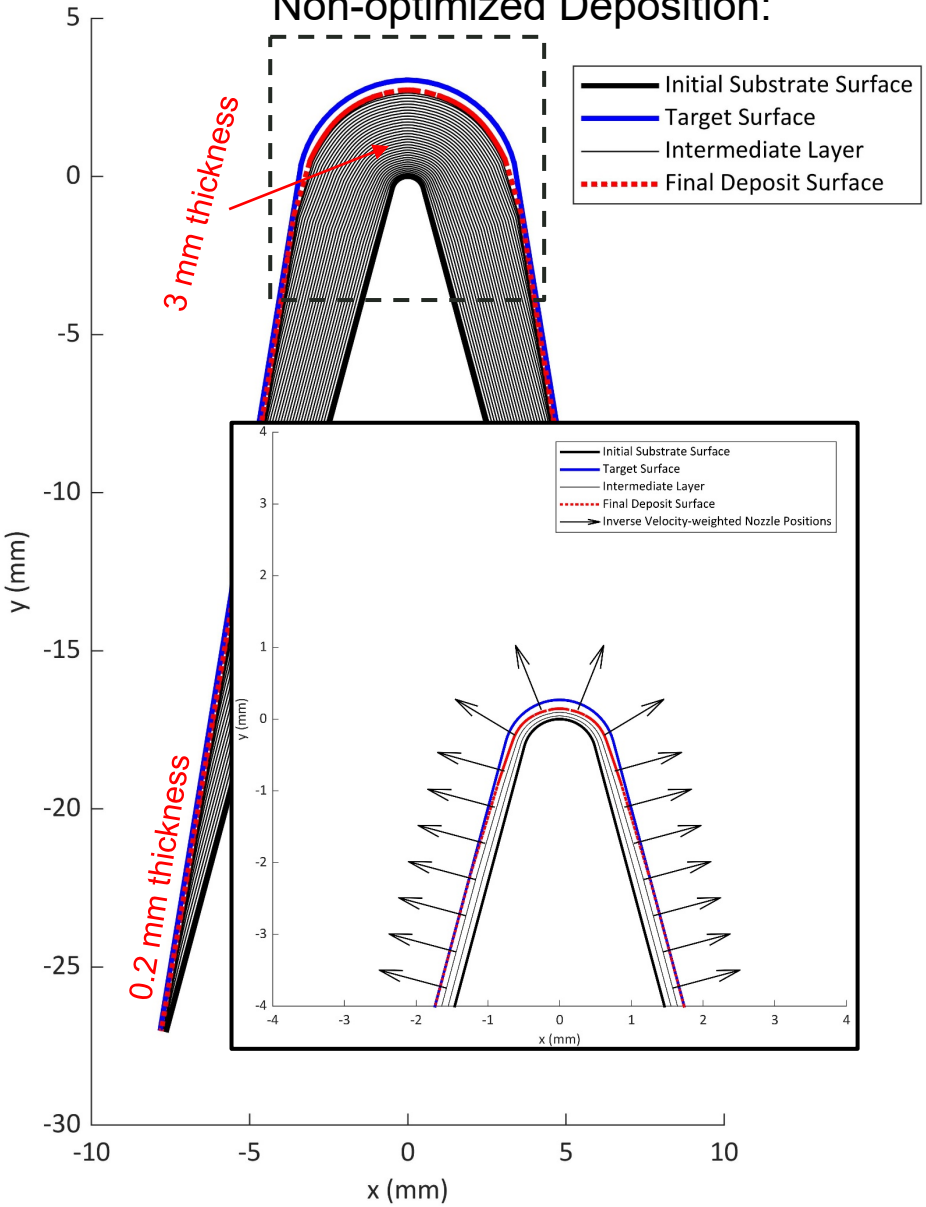


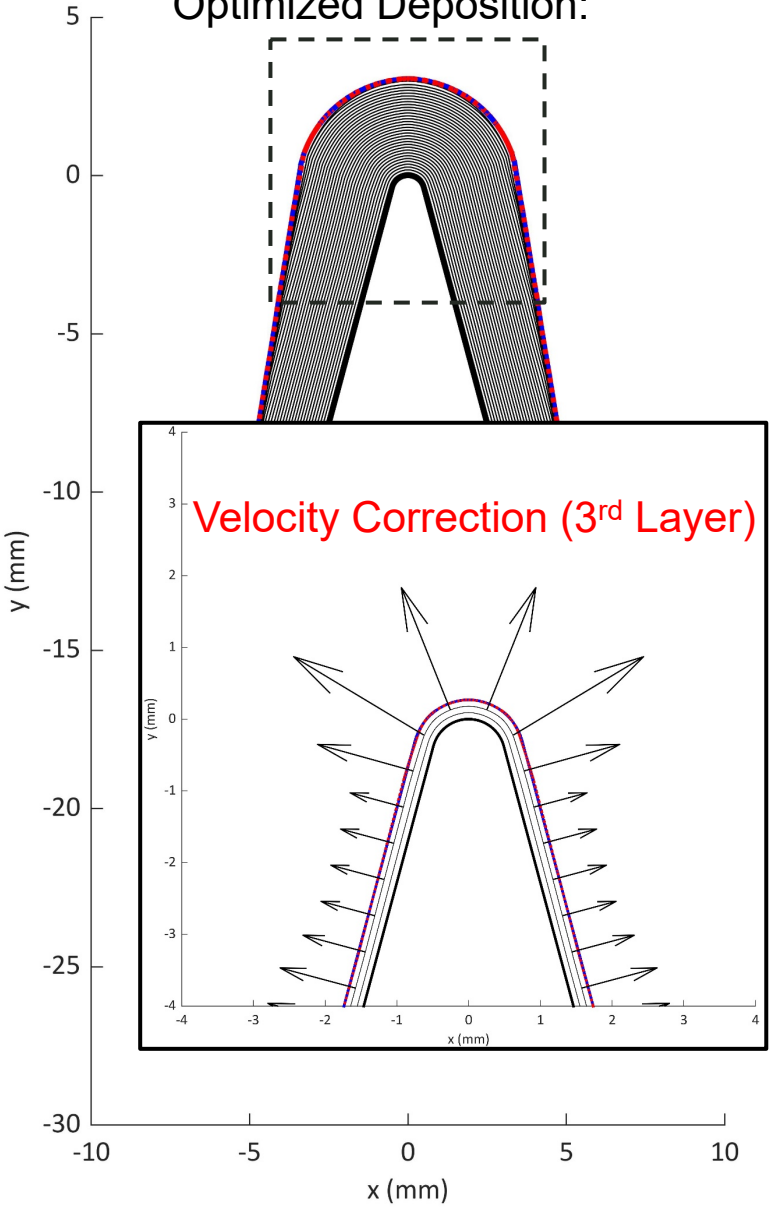


PATH OPTIMIZATION FOR HIGH CURVATURE

Non-optimized Deposition:

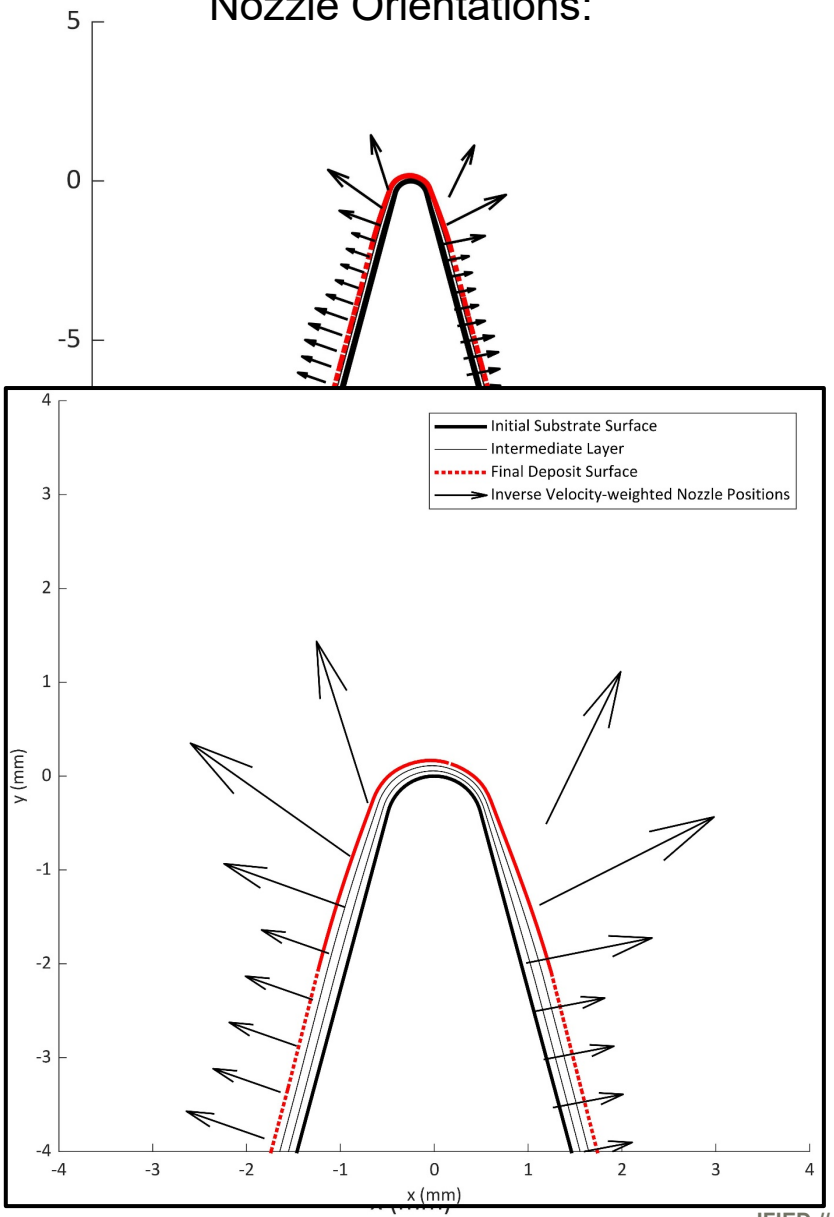


Optimized Deposition:

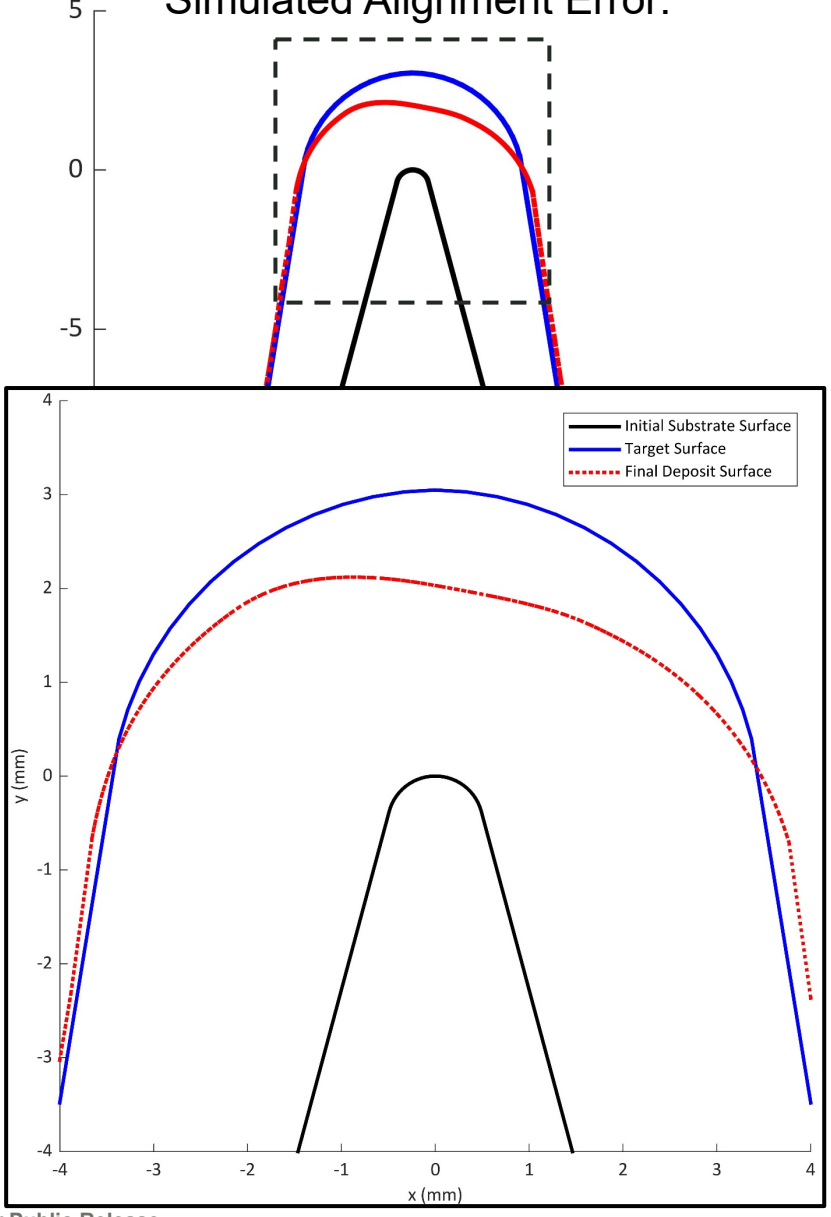


PATH OPTIMIZATION FOR HIGH CURVATURE

Nozzle Orientations:

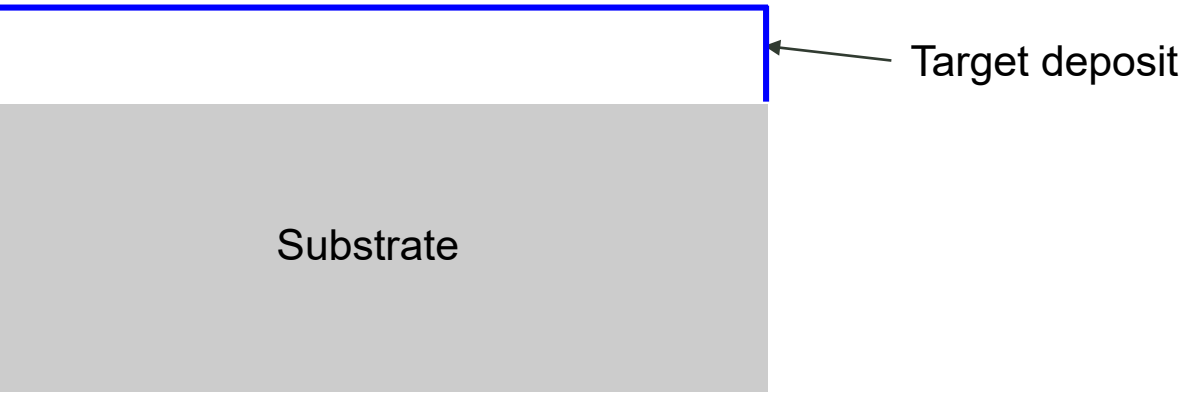


Simulated Alignment Error:

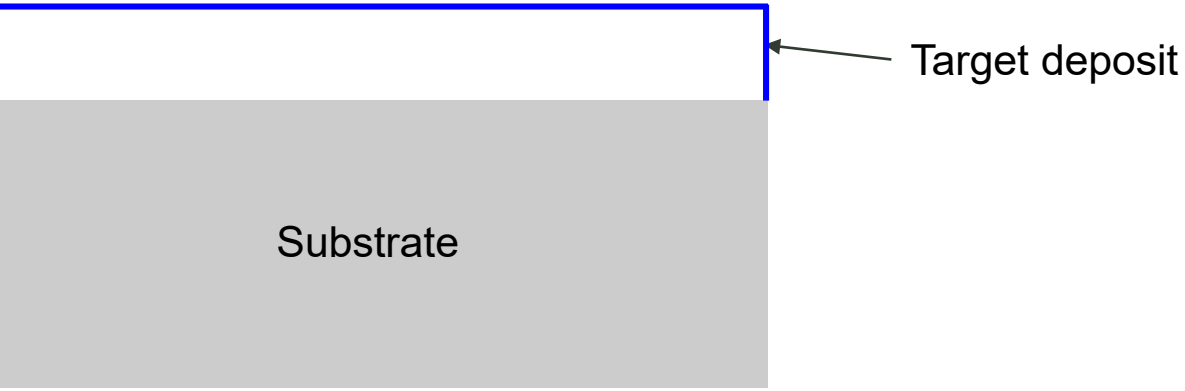


EDGE RESTORATION PROBLEM DEFINITION

Alternative CS Edge Restoration

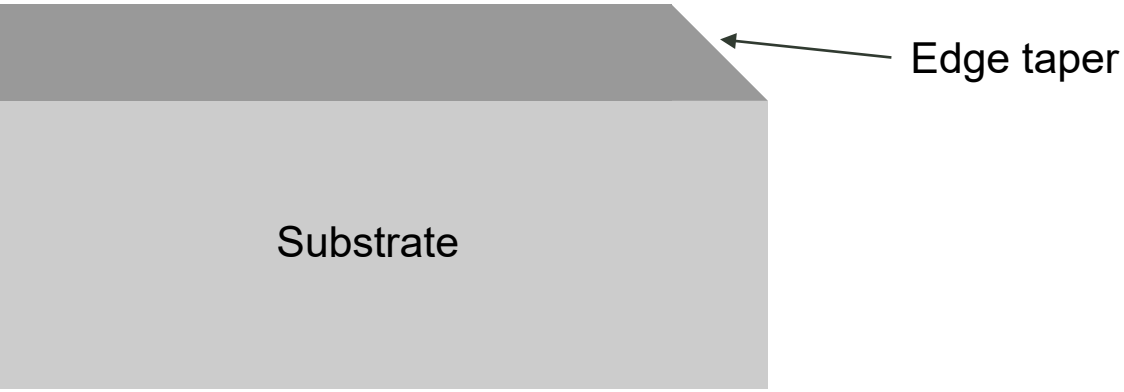


Optimized Edge Restoration



EDGE RESTORATION PROBLEM DEFINITION

Alternative CS Edge Restoration

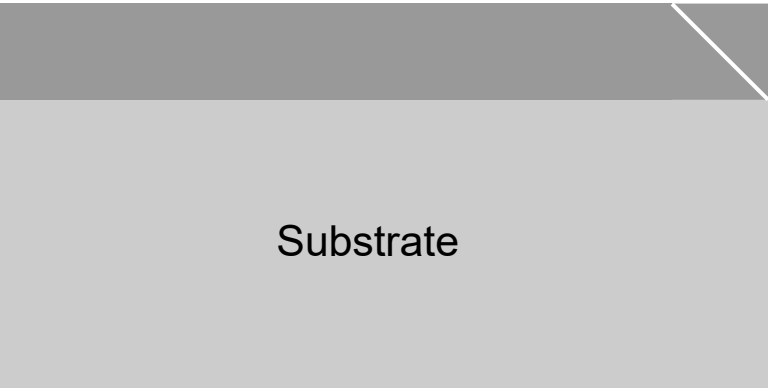


Optimized Edge Restoration

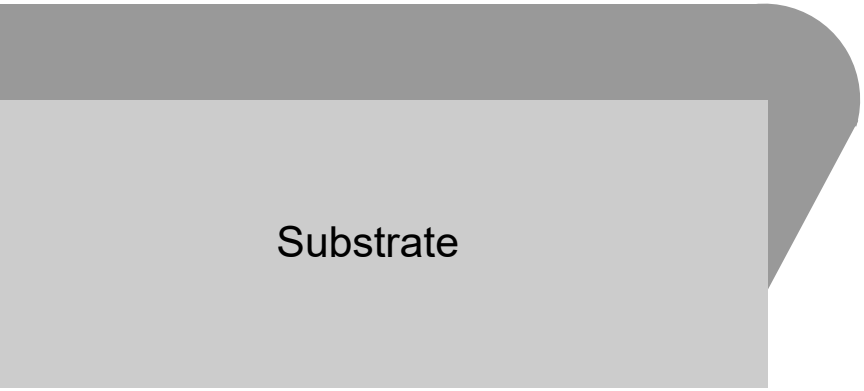
First CS deposit

EDGE RESTORATION PROBLEM DEFINITION

Alternative CS Edge Restoration



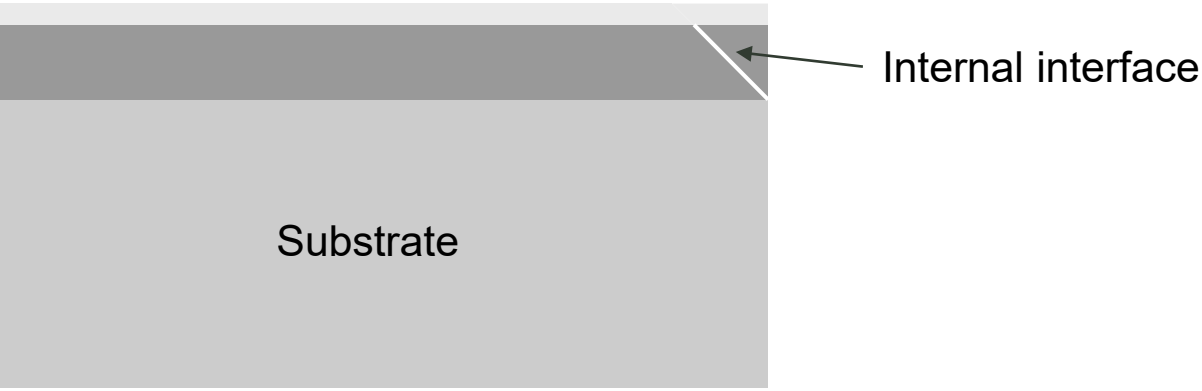
Optimized Edge Restoration



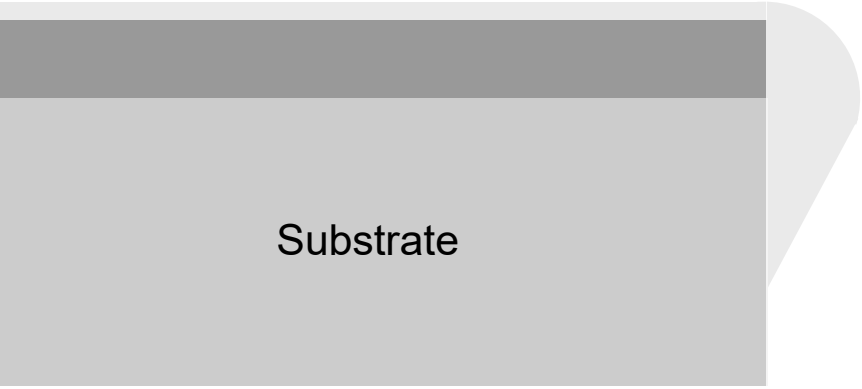
Second CS deposit

EDGE RESTORATION PROBLEM DEFINITION

Alternative CS Edge Restoration



Optimized Edge Restoration



Post-finish