Center for Global Design and Manufacturing

UNIVERSITY OF Cincinnati

Computational Methods of Additive Manufacturing – Spring 2020

Support Structure Generation on a STL Geometry

Prof. Sam Anand

Background

Support structures are essential features of an AM build part to ensure **good quality** build of an overhang features

Support structures are also viewed as good **heat conducting medium** for overhang features that are prone to higher amount of **distortion**, because, overhang features do not have a part geometry below it to conduct heat towards the **substrate/base support**

All Overhang Features do not require Support

Only features making an angle of more than 45° with the horizontal axis require supports

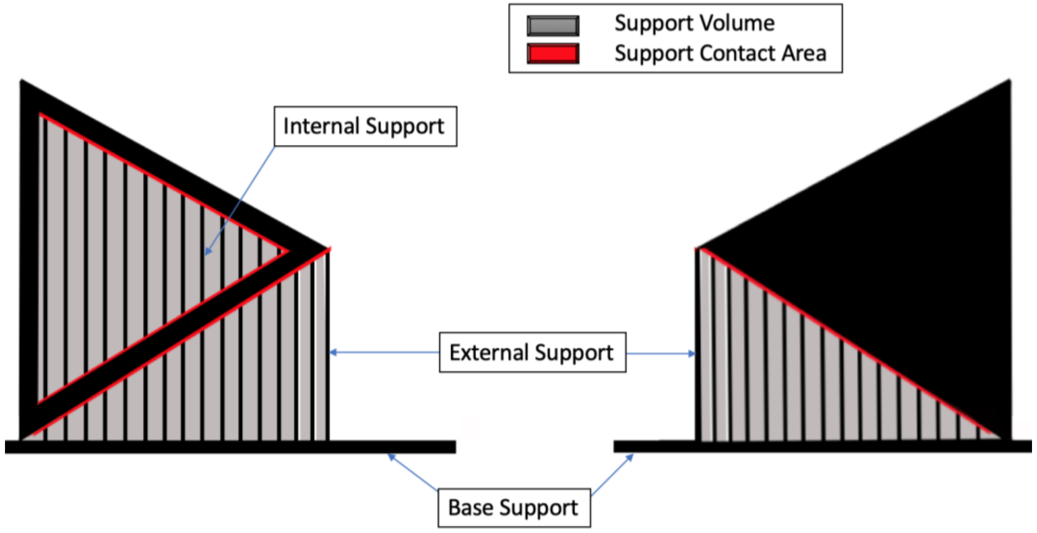
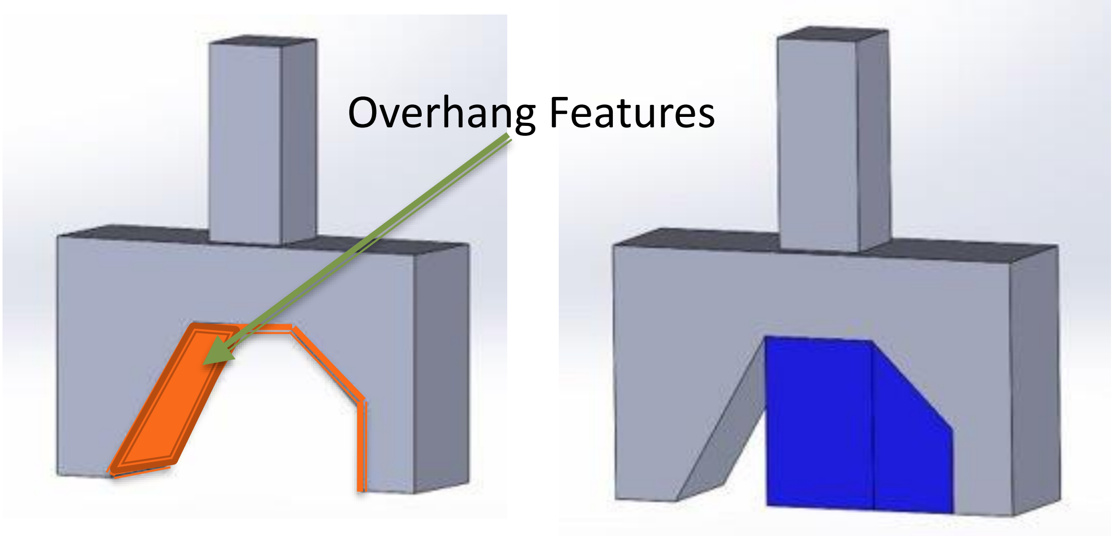
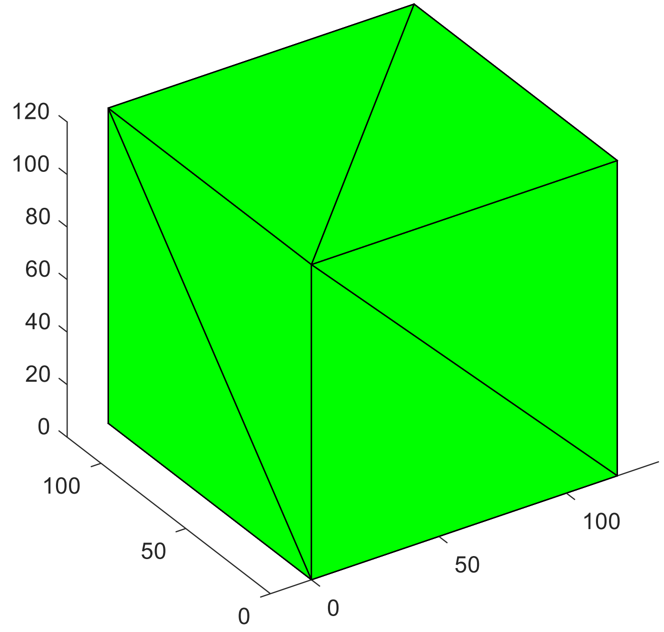


Illustration of Support Structures



Read an STL file in MATLAB

- Read STL file generated from NX using "**stlread**" function in Matlab. (for using this function you have to download 'stlread.m' from https://www.mathworks.com/matlabcentral/fileexchange/22409-stl-file-reader and place it in the folder to which you write your code)
- We will get the Faces, Vertices & Normals information of STL triangles from this function
- Part can be plotted from STL file using **plot3** with all the vertices information of the faces
- Instead of **plot3** , **patch** can be used to visualize part as solid.




```
>> [F,V,N] = stlread('cube.stl');
>> figure(1);axis equal;
>> patch('Faces',F,'Vertices',V,'FaceColor','green')
```

F	12x3 double
N	12x3 double
V	36x3 double

Eric Johnson (2020). STL File Reader (https://www.mathworks.com/matlabcentral/fileexchange/22409-stl-file-reader), MATLAB Central File Exchange. Retrieved March 23, 2020.

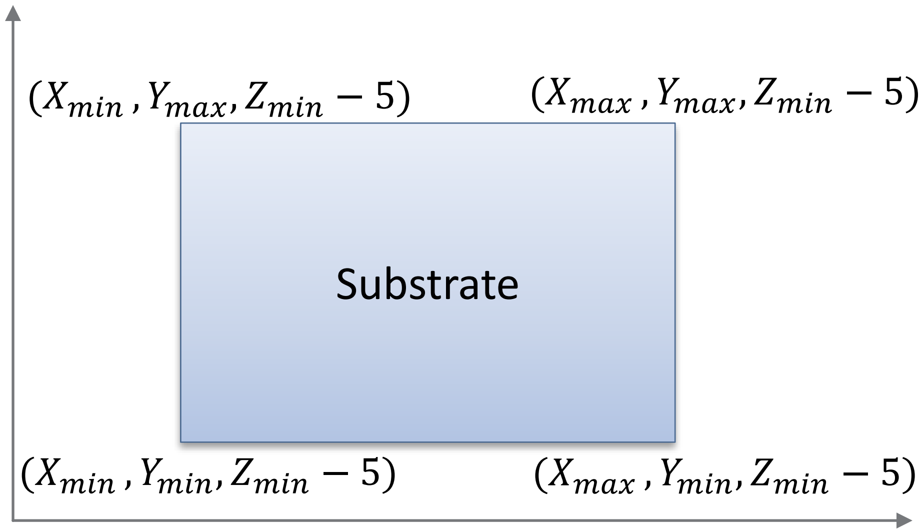
Support Generation Method

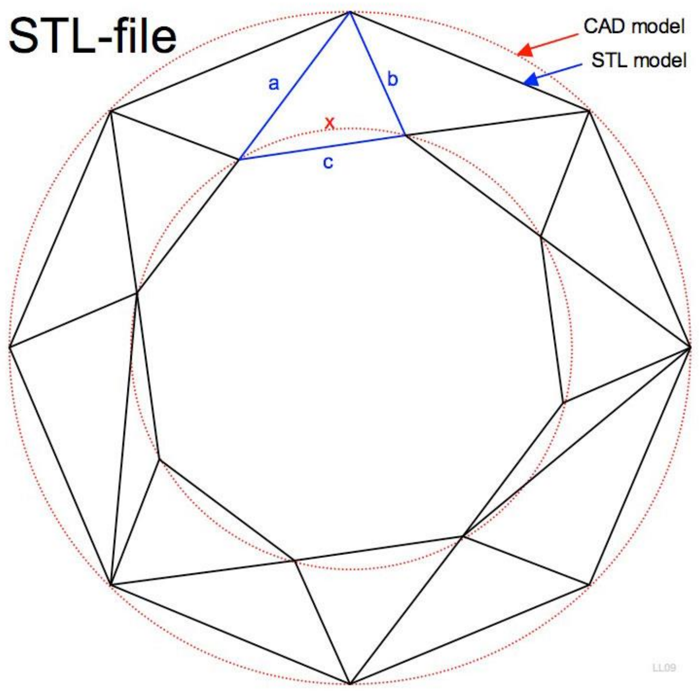
Support Generation Method for part geometry represented in STL file format

Step 1: Creation of Substrate / Base plate

Substrate or base plate is the platform on which the part is built External supports are built to meet the substrate and internal supports are built to meet the part – as shown in previous slide

For a given build orientation, find the maximum and minimum X – coordinate and Y – coordinate, and the minimum Z - coordinate





STL file format is represented by triangular facets with information on vertices, faces, and face normal

Support Generation Method

Support Generation Method for part geometry represented in STL file format

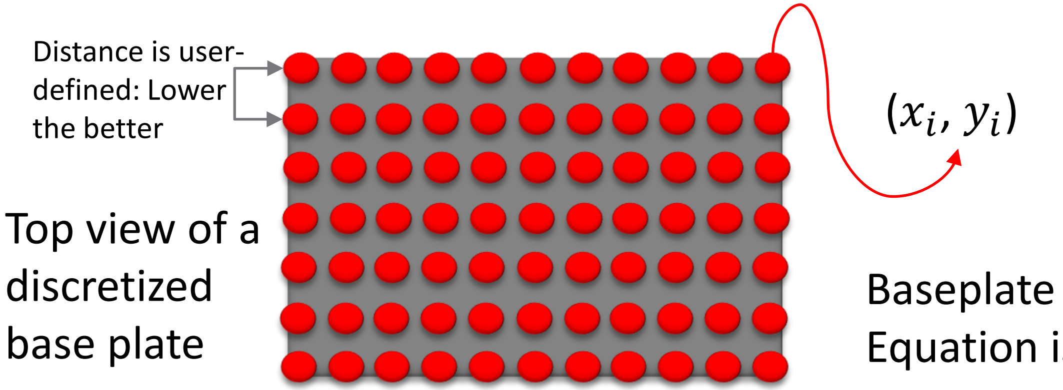
Step 2: Shoot rays from the baseplate plane in +Z direction

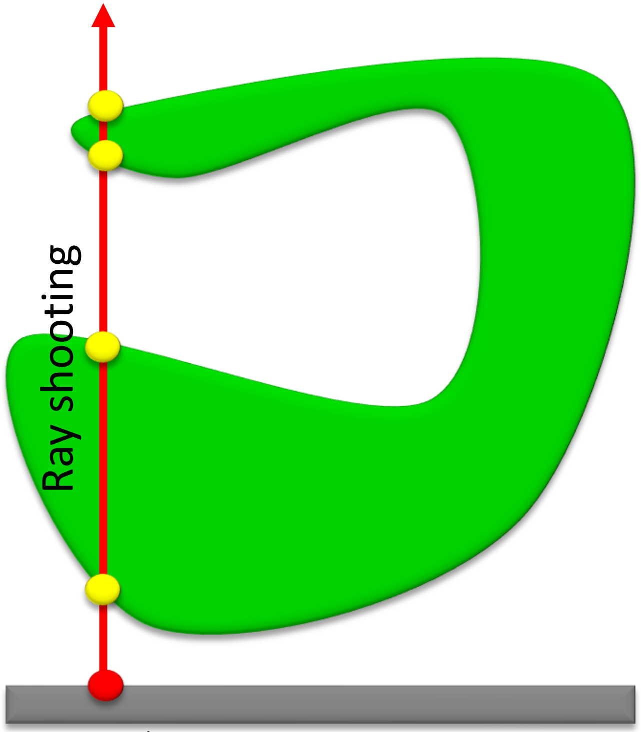
Uniformly discretize the substrate into points with user given distance

Create a ray with a start point created in step 2, the direction of the ray is the build direction, +Z direction. So the function of the ray is:

$$\begin{cases} x = x_i \\ y = y_i \end{cases}$$

(x_i, y_i) is the x and y components of the start point, and i is the index for the points





Support Generation Method

Support Generation Method for part geometry represented in STL file format

Step 3: Calculation of Intersection Points of ray and geometry

Calculate the intersection points between the geometry and the ray created in step 2.

For STL file, it means calculate the intersection between the ray and each triangular facet.

If all the x-coordinates of a facet are greater than or less than the x-coordinate of the baseplate point, then you can disregard that facet or you can find the intersection point (it if exists) for all facets and do an 'inside-outside' test or a sum of triangles test – covered in previous lectures.

$d = \frac{(p_0 - l_0) \cdot n}{l \cdot n}$ ... (A)

p_0 : point on the facet – any one of the facet vertices under consideration
l_0 : point on the ray – base plate point
l : direction of the ray +Z direction
n : normal vector of the facet – given

If $l.n = 0$, then the ray and the facet plane are parallel
Else
Point of intersection is $l_0 + ld$

Support Generation Method

Derivation of Equation A

At point of intersection p, the equations of line and plane should be satisfied.

So,

$(p - p_0).n = 0$ --- (1)

$p = l_0 + ld$ --- (2)

Substituting (2) into (1)

$$((l_0 + ld) - p_0).n = 0$$

$$(l_0 - p_0 + ld).n = 0$$

$$d(l.n) + (l_0 - p_0).n = 0$$

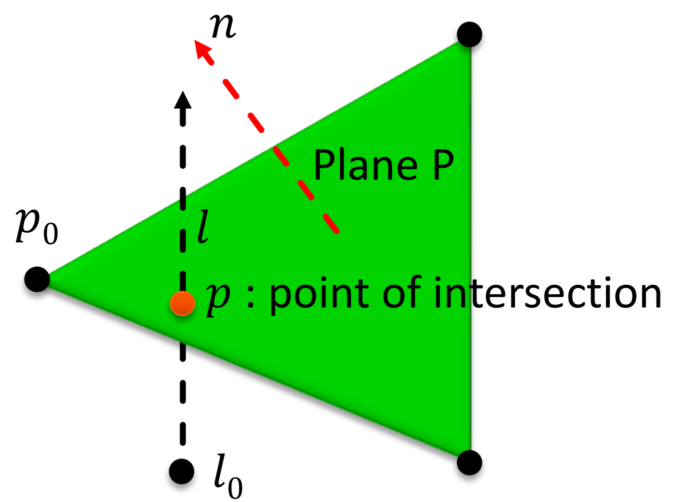
$$d = \frac{(p_0 - l_0) \cdot n}{l \cdot n}$$

Point of intersection: $p = l_0 + ld$

Plane equation is $(p - p_0).n = 0$

p_0: point on the plane – already given as facet vertices

n: plane normal or facet normal



Line equation is $p = l_0 + ld$

l_0: point on the line

l : unit vector of the direction of the line [0 0 1]

d : scalar parameter that defines the distance between the point l_0 and plane P.

If $l.n = 0$ means $|l||n|cos\alpha = 0$

which means α = 90, i.e., line and plane are parallel

Support Generation Method

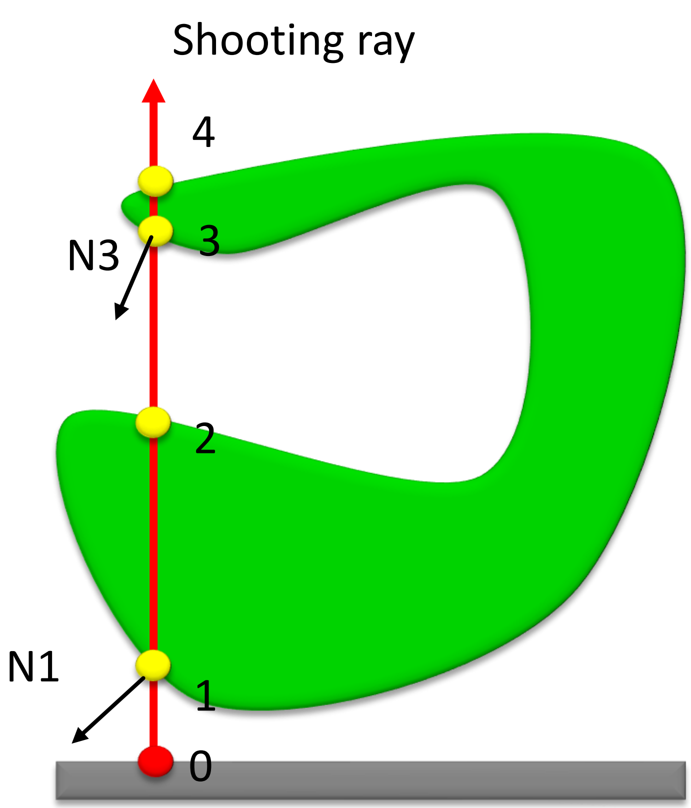
Support Generation Method for part geometry represented in STL file format

Step 4: Finding appropriate points of intersection and calculating angle between ray and outward normal of the facet

Once you get the points of intersection for all the base plate points or you can find support structures for each point of intersection and then move to the next base plate point

1. Sort them by their Z-coordinates
2. You will always have even number of points of intersection. Only consider the odd number ones as they are the points that enter the geometry – points 1 and 3 in the figure for example
3. Find the angle between the ray and the facet normal at those points
4. If the angle is beyond the threshold, that particular point of intersection needs support structures.
5. To plot a support structure (in the form of lines), plot a line from the point (odd number point that satisfies the angle criteria from (4)) to the previous point (even number point below). In this case

   support structures go from point 3 to point 2 and point 1 to point 0 or base plate point.



For coding efficiency, if at one point of intersection to a particular facet exceeds the angle criteria, all points of intersection on that facet can be classified as once that require support structures. YOU DO NOT NEED TO CALCULATE THE ANGLE EVERYTIME BECAUSE THE LINE SEGEMENT HAS ONLY ONE DIRECTION – Z DIRECTION