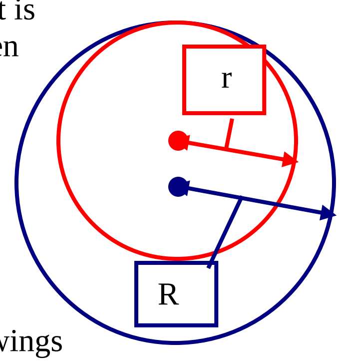
Using Mathematics to allow plasma spray guns to coat parts with complex geometries

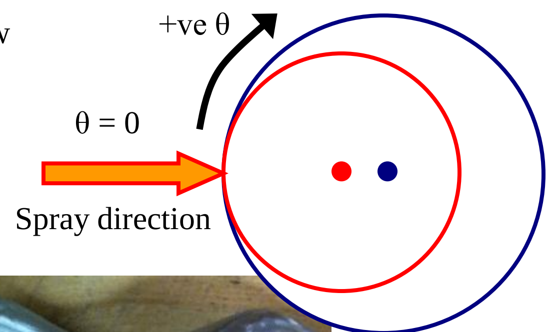
Praxair Surface Technologies sprays metallic and ceramic coatings that enable resistance to wear, high temperatures and corrosion. When these coated parts form components of an aircraft engine, landing gear, gas turbine, oil rig etc. it is essential that the coating is applied uniformly across the whole part, even those with complex geometries.

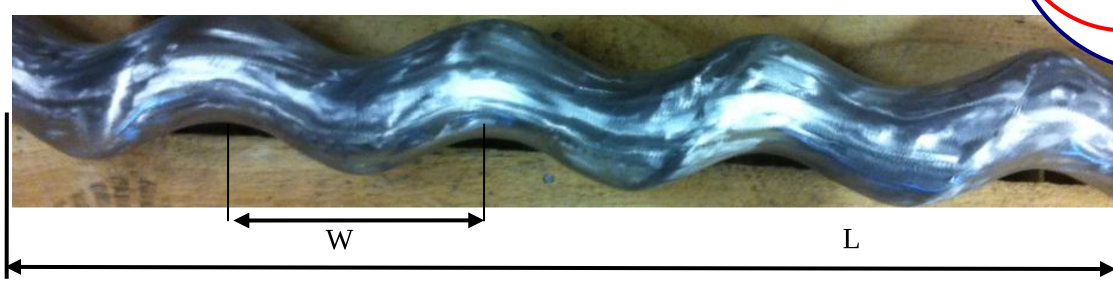


One such part is in the shape of a spiral bar, or corkscrew. The bar is rotated while the spray gun travels along it's length. The intention is to follow the "flight" like cutting a screw. This is then repeated, once the part has been rotated to the next flight path, until the part is completely coated. The speed of the spray gun needs to be calculated so that it is always travelling the right path along the corkscrew.

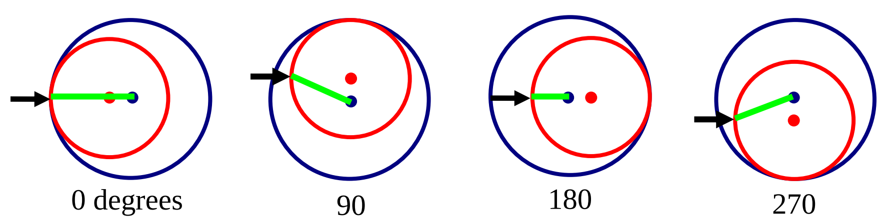
We know the following information about the part from customer drawings and inspecting the part:

R = the radius swept by the furthest width of the corkscrew
r = the radius of the corkscrew in section
L = the length of the part
W = wavelength of the corkscrew
θ = angle of rotation (zero when the corkscrew is closest to the gun head)





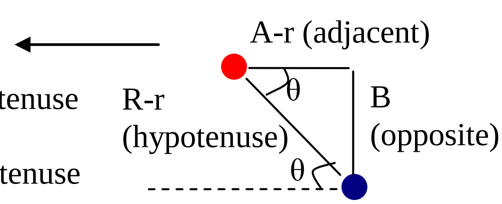
The stripe diameter (green line) is used to calculate the length of the stripe (distance between the centre of the part and the closest point of the corkscrew to the gun). Imagine unravelling a kitchen roll cardboard tube. Black arrows = the spray direction.



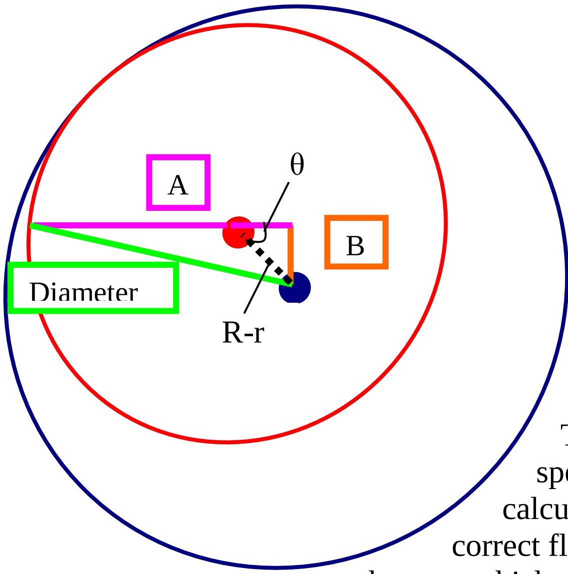
It is important to find the stripe diameter to inform calculations for the traverse speed of the gun. The calculation uses Pythagoras' theorem and is as follows (see diagram on next page):

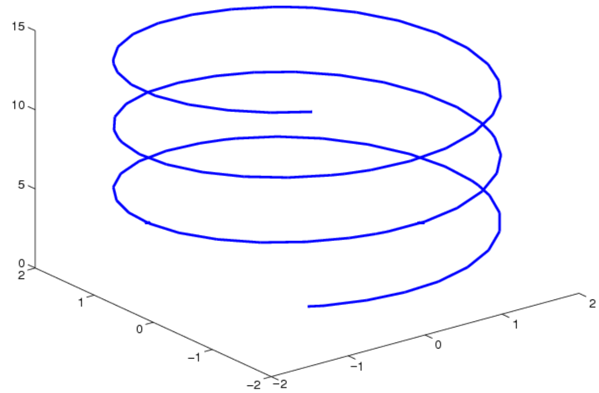
A (horizontal component of the stripe)
= [(cosθ*{R-r})+r]
B (vertical component of the stripe)
= [sinθ*(R-r)]
Stripe diameter = √(A^2 + B^2)

As:
Cosθ = adjacent/hypotenuse
Sinθ = opposite/hypotenuse



Where R-r = the difference in the radii of the 2 circles

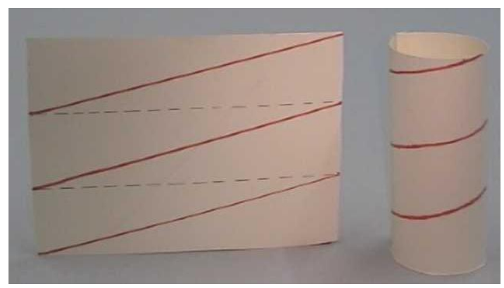


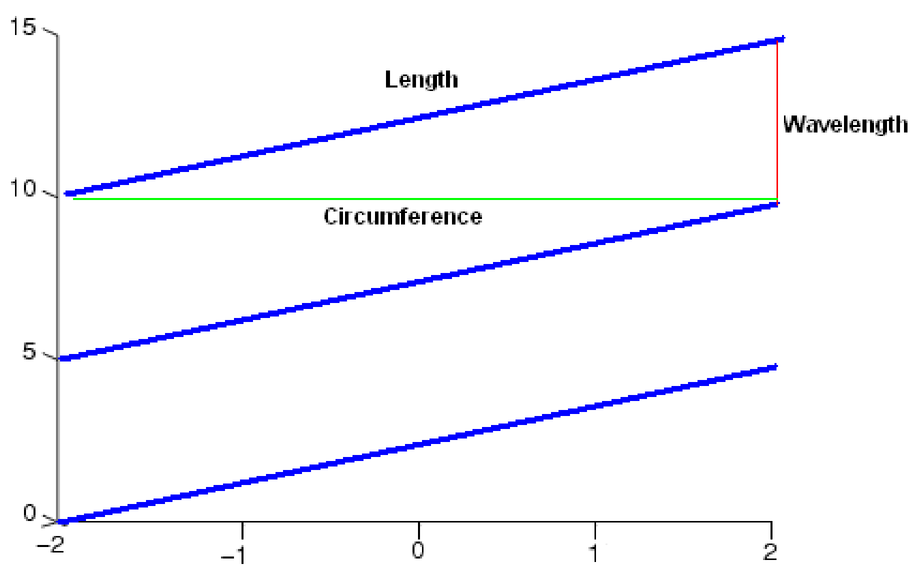


The speed of the torch relative to the part (surface speed) is always set at 381 mm/s. Now we need to calculate the traverse speed of the torch to keep on the correct flight diameter (the speed of the torch travelling along the part, which will be less than the surface speed).

A single flight path drawn out can be expressed as in the graph above right (taken from mathworks.com). We know from the previous calculation that the flight diameter is: $\sqrt{[(\cos\theta*\{R-r\})+r]^2 + [\sin\theta*(R-r)]}$

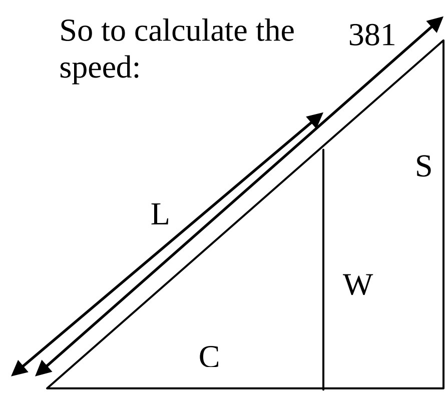
To calculate the speed, we first need some information on the flight diameter/wavelength ratio. The flight path can be drawn on the surface of a cylinder, such as the picture on the right. The result is shown below:





We can see that the chord length can be found using Pythagoras: $L = \sqrt{C^2 + W^2)}$ Where C = circumference and W = wavelength

So to calculate the speed:



Where L = flight length for one twist
S = speed (distance travelled in a second)
As the two triangles have the same angles then we can say they have a ratio of: $W/L = S/381$
Then: $S = W*381/L$
So: $S = W*381/\sqrt{[W^2 + C^2]}$ Where $C = \text{flight diameter}*\pi$