# A 2D Algorithm for SoftWalls

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## 1 Introduction

This document gives an outline of a general 2D softwalls approach.

## 2 Control with Bias

Suppose the aircraft is travelling at a constant speed $s$. Let $\theta$ denote the aircraft's heading angle, and let $\dot{\theta_p}$ be the pilot's control input, i.e. the desired rate of change in heading angle. With speed $s$ the aircraft has a minimum-safe turning radius $r_{min}$. The paths an aircraft travels as it banks right or left with radius $r_{min}$ are in figure 1.

Now suppose we wish to prevent the aircraft from entering a no-fly zone. As the aircraft approaches the no-fly zone boundary, one of the minimum-turning-radius paths from figure 1 will interesect with the boundary. As long as the other path has not yet interestected the boundary, the aircraft can still avoid crossing the boundary by moving along this path. At the instant the second path intersects the boundary, forcing the aircraft to fly along the second path will prevent the aircraft from crossing the boundary. This situation is depicted in figure 2.

We can think of this algorithm as applying a bias to the pilot's desired rate of change in heading. Let the actual rate of change in aircraft heading angle be $\dot{\theta}$, and let $\theta_s$, be the control signal generated by the SoftWalls algorithm. Given the pilot's desired rate of change in heading, $\dot{\theta_p}$, we calculate $\dot{\theta}$ from

$$\dot{\theta} = limit_{[-s/r_{min}, s/r_{min}]}(\dot{\theta_p} - \dot{\theta_s}), \tag{1}$$

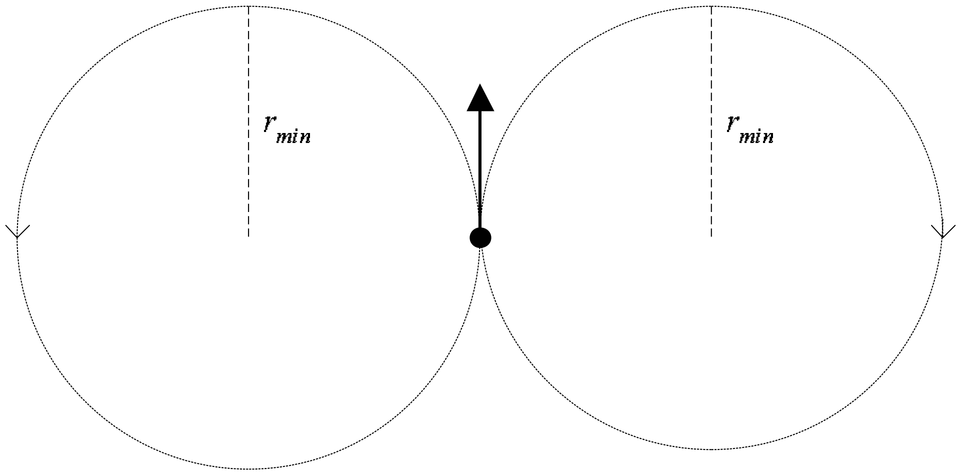


Figure 1: The dot represents the aircraft, which is moving along the center path. The circle paths representent turns at the minimum turning radius.

where

$$limit_{[a,b]}(u) = \begin{cases} b & \text{if } u > b, \\ a & \text{if } u < a, \\ u & \text{otherwise.} \end{cases}$$

By limiting $\dot{\theta}$ to the range $[-s/r_{min}, s/r_{min}]$, we ensure that no safe turn is made.

Assuming $\dot{\theta}_p$ is limited to $[-\dot{\theta}_M, \dot{\theta}_M]$, which corresponds to the limits of the flight yoke, we can choose $\dot{\theta}_s = \dot{\theta}_M + s/r_{min}$ to force the aircraft to turn right at the maximum turning radius, irrespective of pilot input. This works because this value of $\dot{\theta}_s$ makes $\dot{\theta}$ in equation 1 equal to $s/r_{min}$ for any $\dot{\theta}_p \in [-\dot{\theta}_M, \dot{\theta}_M]$. Similarly $\dot{\theta}_s = -\dot{\theta}_M - s/r_{min}$ will force the aircraft to turn left. If the right path is the second path to interesect the boundary, the control signal $\dot{\theta}_s = \dot{\theta}_M + s/r_{min}$ will steer the aircraft right, and if the left path is the second to interestect the boundrary, the control signal $\dot{\theta}_s = -\dot{\theta}_M - s/r_{min}$ will steer the aircraft left. By applying the appropriate $\theta_s$ to the input, the SoftWalls algorithm (the path/boundary-interestection algorithm) can garauntee the plane to never crosses the boundary. This is a step bias, because the bias is either present or absent.

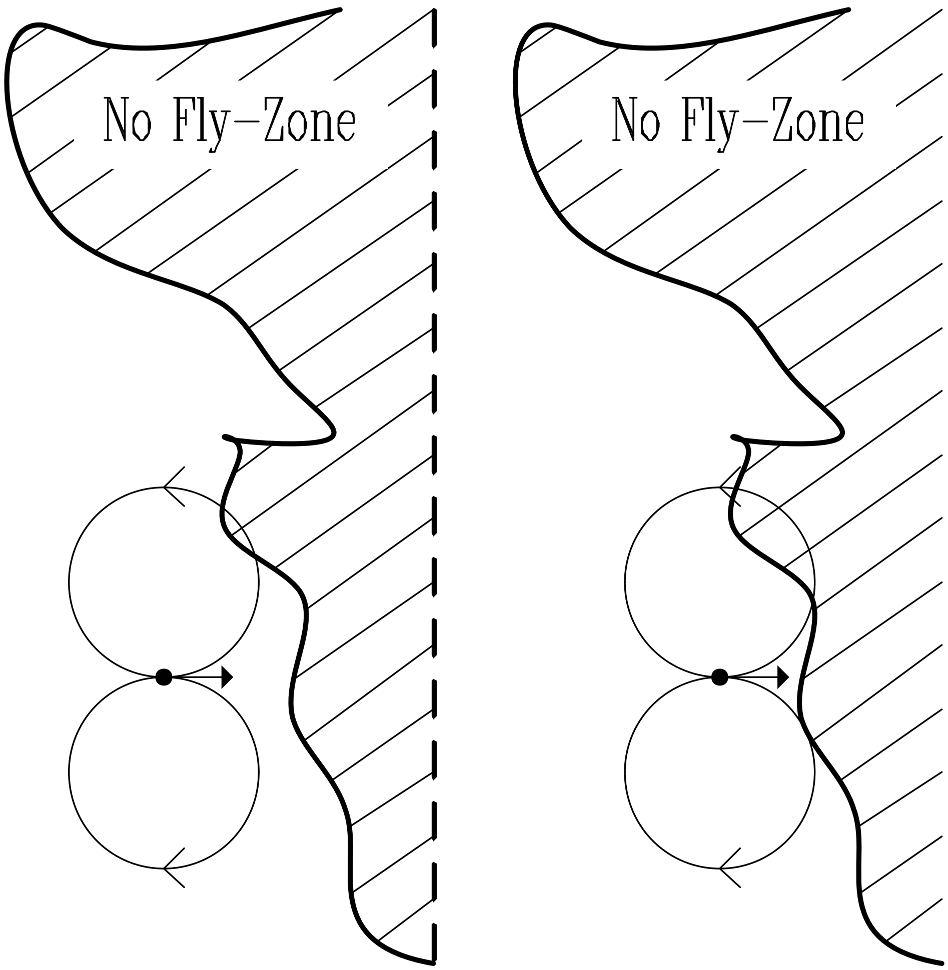


Figure 2: On the left picture, the aircraft still has one free path. On the right picture, the aircraft must move right at the minimum turning radius to avoid crossing the boundary.

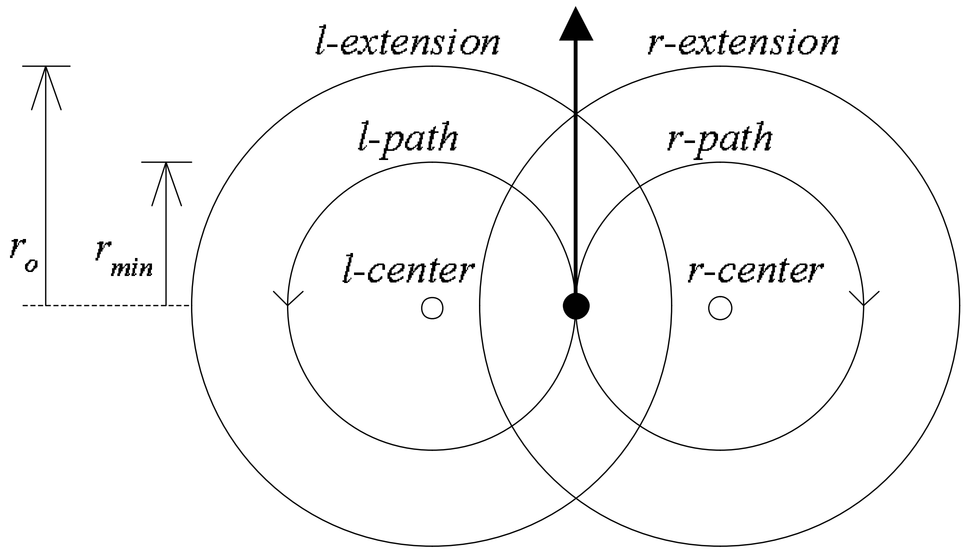


Figure 3: The black dot represents the aircraft, and the dark arrow represents its current path. The r-path represents a right turn at the minimum turning radius and the l-path represents a left turn at teh minimum turning radius.

## 3 Smooth Bias

The method in the previous section takes all control away from the pilot when the bias is applied, and returns all control when the bias is turned off. This can be dangerous because a pilot may not be ready to take the aircraft over again when the bias is turned off. We would like to increase and decrease the bias smoothly to prevent this situation.

To apply a smooth bias, we first draw a circle of radius $r_o$ around each path of radius $r_{min}$ in figure 1, as in figure 3. We choose $r_{min} < r_o < 2r_{min}$, so that the larger circles do not encircle the centers of the opposing circles. We call the circular path that a plane would take to go right at the minimum turning radius the *r-path* and the center of this circle the *r-circle*. We call the circle of radius $r_o$ centered at r-center the *r-extension*, because it will be used to extend the region of SoftWalls bias for smooth control. Similarly the *l-path* is the circular path that a plane would take to go left at the minimum turning radius, which is centered at the *l-center* and surrounded by the *l-extension*.

When none of the two extension circles intersect the no-fly-zone boundary, the SoftWalls bias is zero. At any instant, we are interested in two points on the boundary. The one closest to r-center has distance $d_r$ from r-center, and the one closest to l-center has distance $d_l$. When one of the extension circles, say l-extension, crosses the boundary, the bias remains zeros until the second circle, r-extension, intersects the boundary. At that point the bias increases linearly as $d_r$ decreases up to the point where the r-path intersects the boundary, and the maximum bias is applied:

$$\dot{\theta}_s = \frac{d_r - r_{min}}{r_o - r_{min}}(\dot{\theta_M} + s/r_{min})$$

When the l-extension leaves the no-fly zone, we should decrease the bias linearly as $d_l$ increases, until there is zero bias applied:

$$\dot{\theta}_s = \max\{(\frac{d_r - r_{min}}{r_o - r_{min}} + \frac{r_o - d_l}{r_o - r_{min}})(\dot{\theta_M} + s/r_{min}), 0\}$$

Then at the point where the resistant pilot's aricraft is parallel to the wall at distance $2r_{min}$, zero bias is applied, and an escape path is available.