Conflict Detection: horizontal

$$\underline{v}_{own} = \begin{pmatrix} V_{own} \sin \chi_{own} \\ V_{own} \cos \chi_{own} \end{pmatrix} \qquad \underline{v}_{int} = \begin{pmatrix} V_{int} \sin \chi_{int} \\ V_{int} \cos \chi_{int} \end{pmatrix}$$

$$\underline{v}_{rel} = \underline{v}_{own} - \underline{v}_{int}$$

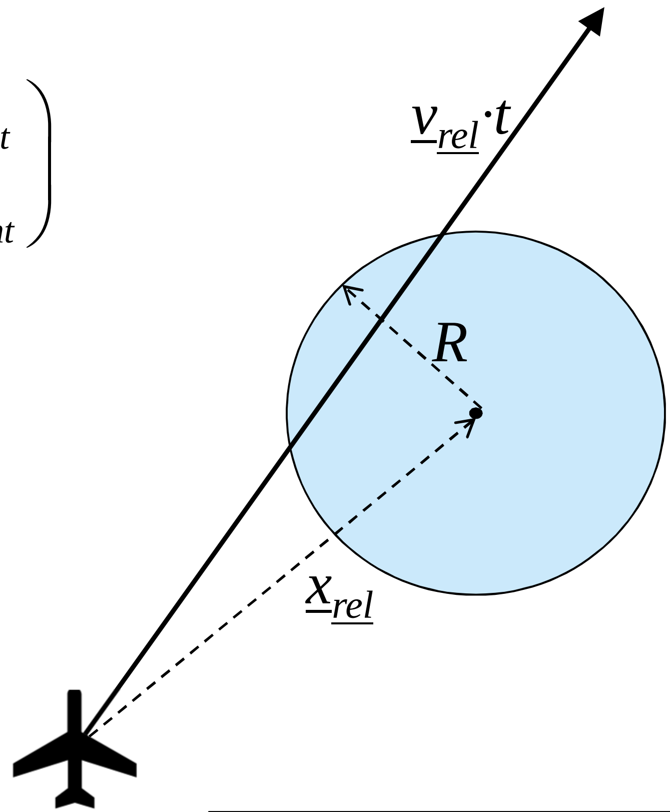
$$\underline{x}_{rel} = \begin{pmatrix} dist \cdot \sin(bearing) \\ dist \cdot \cos(bearing) \end{pmatrix}$$

$$\left| t \cdot \underline{v}_{rel} - \underline{x}_{rel} \right| = R$$

$$(tv_1 - x_1)^2 + (tv_2 - x_2)^2 = R^2$$

$$\underline{v} \cdot \underline{v}\, t^2 - 2t\, \underline{x} \cdot \underline{v} + \underline{x} \cdot \underline{x} - R^2 = 0$$

$$t_1, t_2 \Rightarrow t_{inhor} = \min(t_1, t_2) \qquad t_{outhor} = \max(t_1, t_2)$$

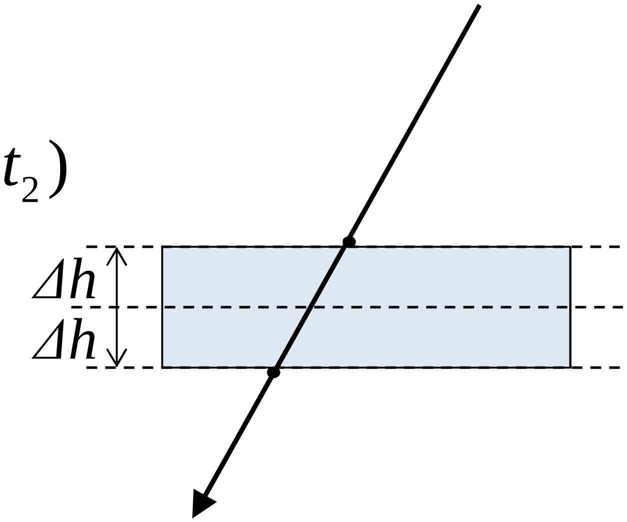


Protected Zone (PZ):
R= 5 nm
½ h = 1000 ft

Conflict Detection: combine with vertical

$$(h_{int} - h_{own}) + t \cdot (VS_{own} - VS_{int}) = \pm \Delta h$$

$$t_1, t_2 \Rightarrow t_{invert} = \min(t_1, t_2) \qquad t_{outvert} = \max(t_1, t_2)$$



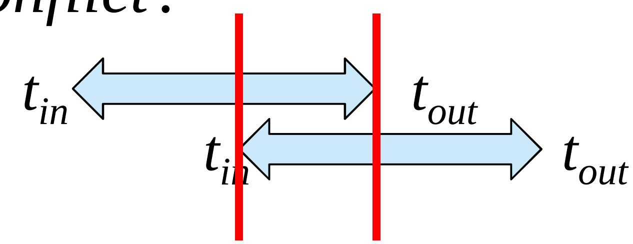
Combine with horizontal times:

$$t_{in} = \max(t_{inhor}, t_{invert})$$

$$t_{out} = \min(t_{outhor}, t_{outvert})$$

Protected Zone (PZ):
R= 5 nm
½ h = 1000 ft

$$t_{in} < t_{out} \quad \wedge \quad t_{out} > 0 \quad \wedge \quad t_{in} < t_{lookahead} \Rightarrow conflict!$$



Typical values:

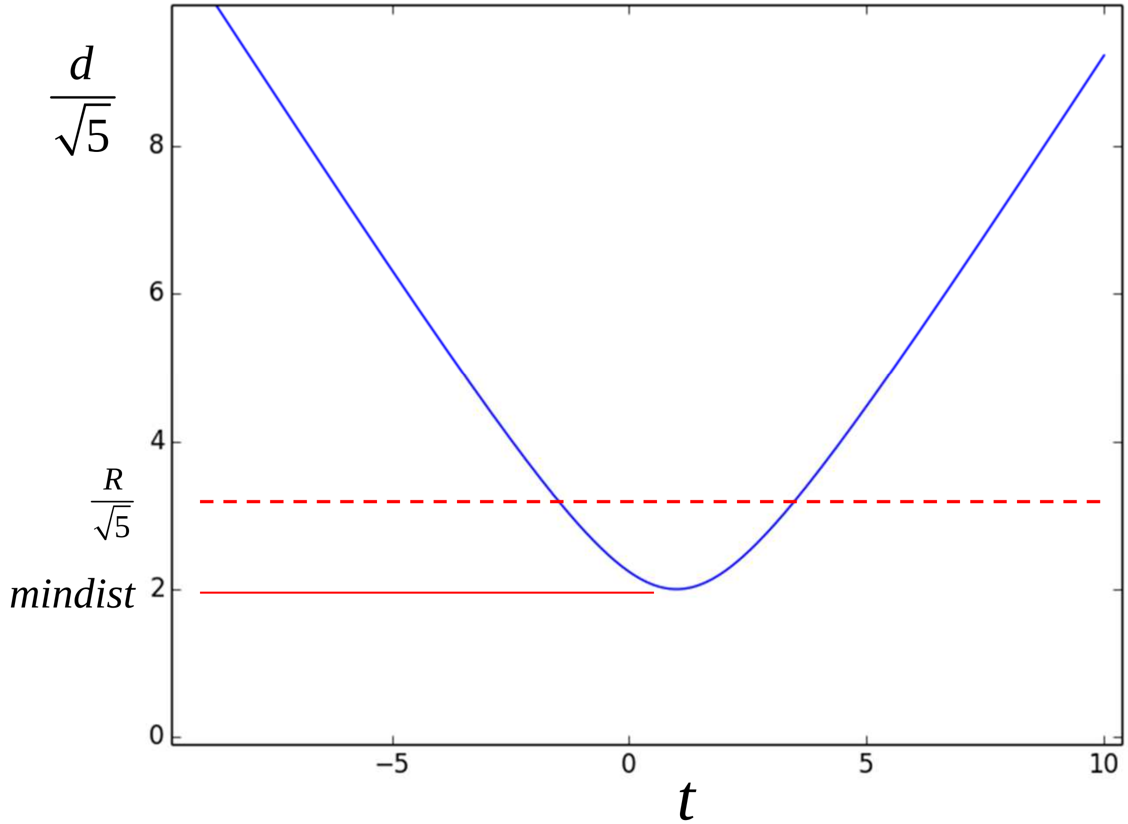
$$R = 5\ nm \quad \Delta h = 1000\ ft \quad t_{lookahead} = 180 - 300\ s$$

Shape Horizontal Distance vs time

$$\underline{d}(t) = \begin{pmatrix} 5 \\ 0 \end{pmatrix} + t \begin{pmatrix} -1 \\ 2 \end{pmatrix}$$

$$\left|\underline{d}(t)\right| = \sqrt{(5-t)^2 + (2t)^2}$$

$$\left|\underline{d}(t)\right| = \sqrt{5} \cdot \sqrt{(t^2 - 2t + 5)}$$



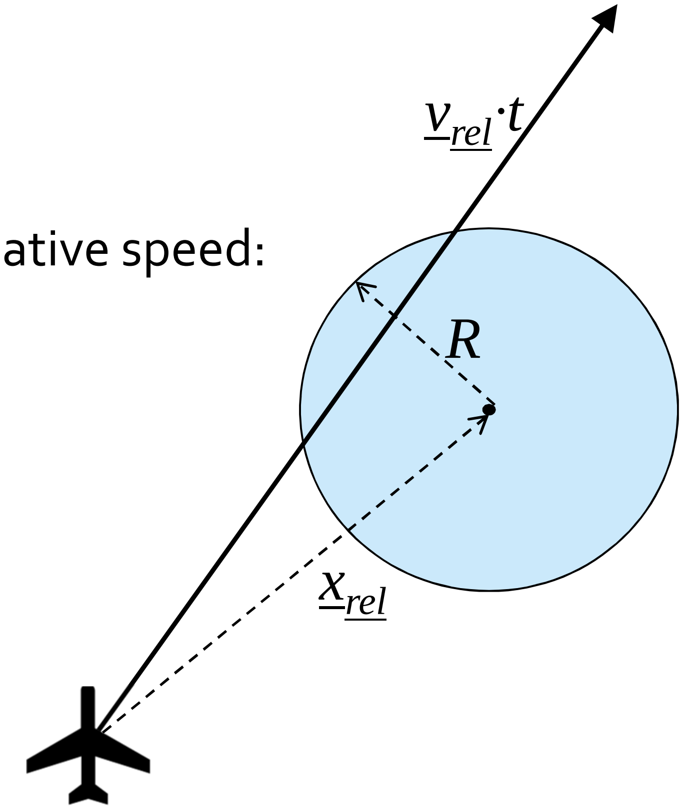
$$f(t) = \sqrt{(t^2 - 2t + 5)}$$

Closest point of approach

- Relative distance vector perpendicular to relative speed:

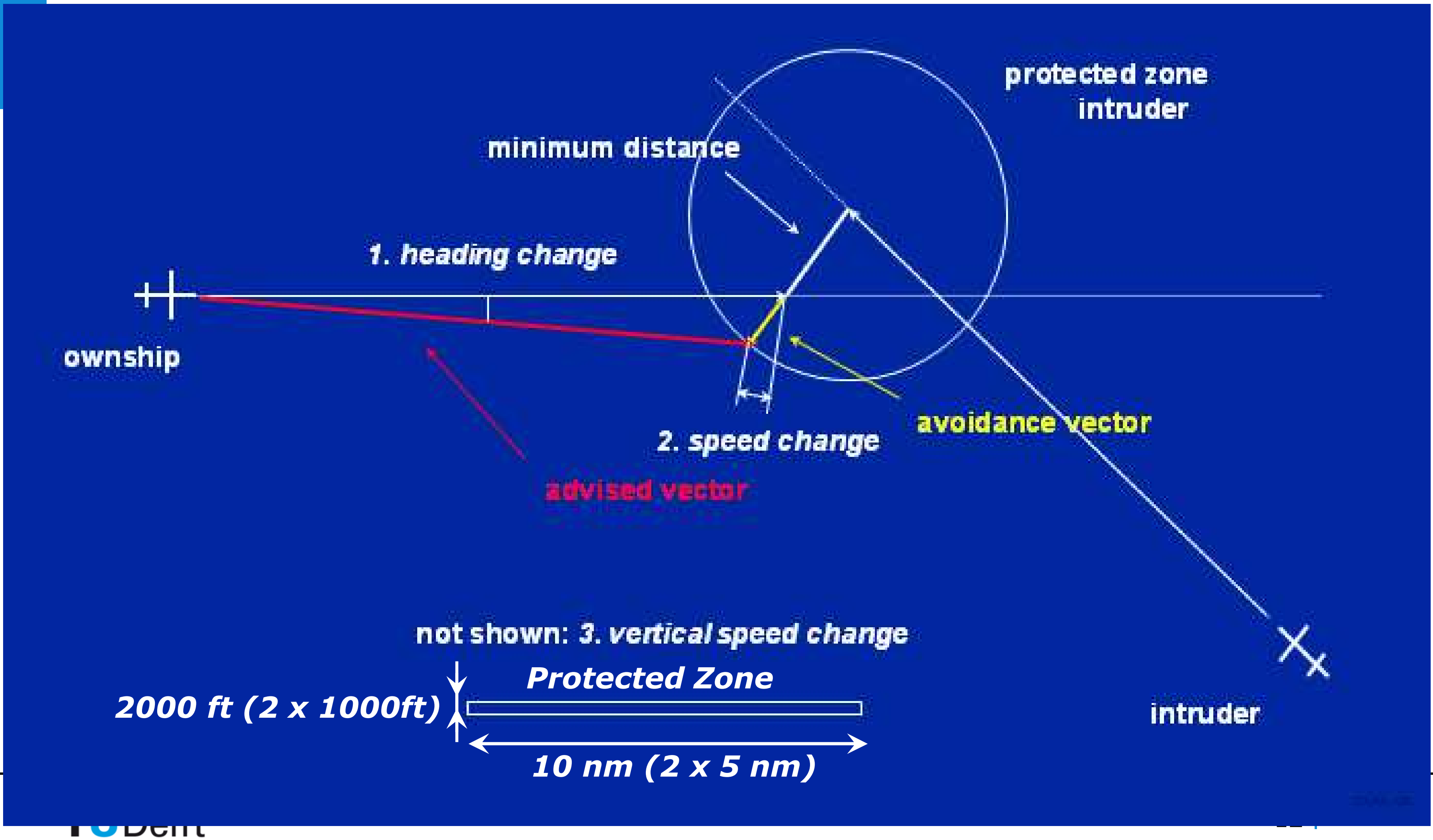
$$\left(t\,\underline{v}_{rel} - \underline{x}_{rel}\right)\cdot \underline{v}_{rel} = 0$$

$$t_{cpa} = \frac{\underline{x}_{rel}\cdot \underline{v}_{rel}}{\underline{v}_{rel}\cdot \underline{v}_{rel}}$$



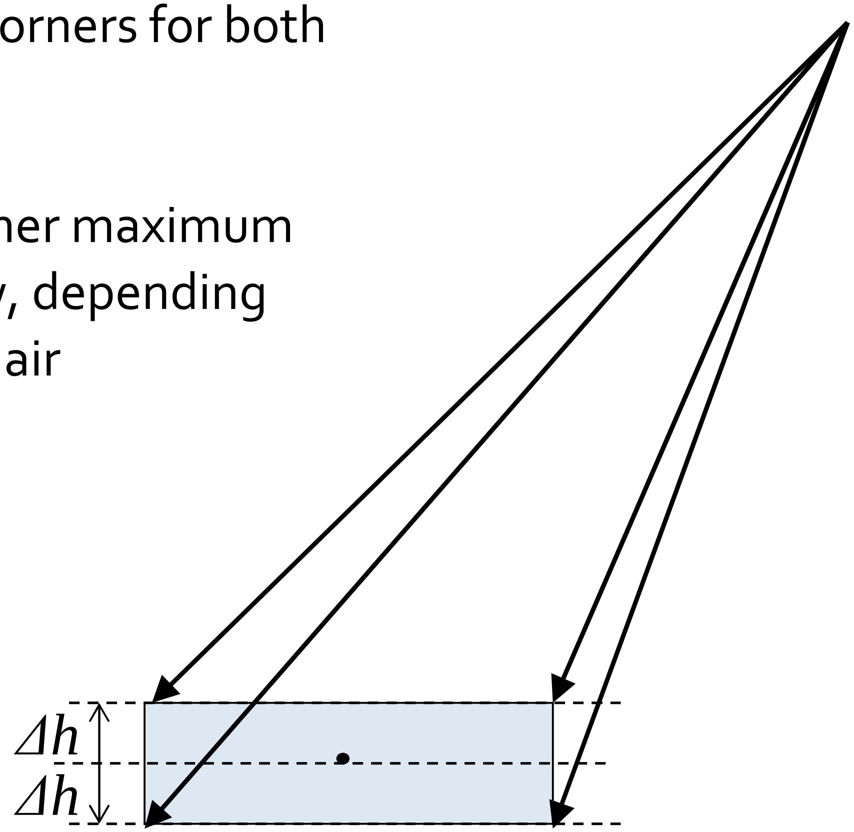
Use t_{cpa} *with absolute speed vectors* $\underline{v}_{own}$ *and* $\underline{v}_{int}$ *to find actual conflict location and geometry*

Conflict Detection & Resolution implicit coordination



Conflict resolution:
How to avoid conflict vertically?

- Calculate vertical speeds for all four corners for both t_{in} as well as for t_{out}
- From these 8 vertical speeds take either maximum or minimum for avoid above or below, depending on conflict geometry and rules of the air



Conflict resolution:
How to avoid conflict horizontally?

- Relative speed should stay out of this cone
- "Velocity Obstacle"