

Wolf Scheuermann / Navigation

TCAS / TCAD Logic

- ✓ Protected Volume of Airspace
- ✓ Demonstration of Properties and Limits

Why about Protected Volume?

- ✓ To show how this Protected Volume of airspace is generated by the software algorithms.
- ✓ To enhance the knowledge about its properties and its behavior.
- ✓ To demonstrate its limits.

TCAS / TCAD

✓ Traffic Alert & Collision Avoidance System (TCAS):

- *Traffic Alert (TA)*
- *Resolution Advisory (RA)*
vertical manoeuvres only

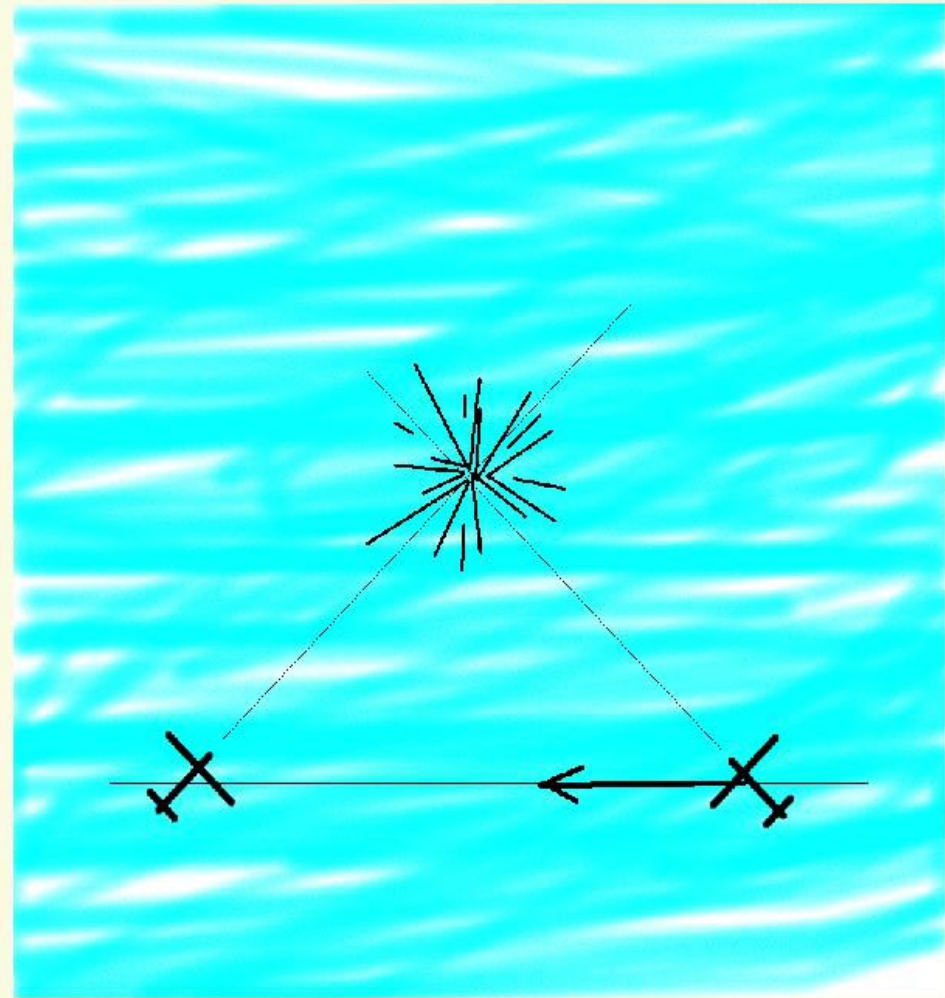
✓ Traffic Collision Alerting Device (TCAD):

- *Traffic Alert (TA)*

Collision Situation

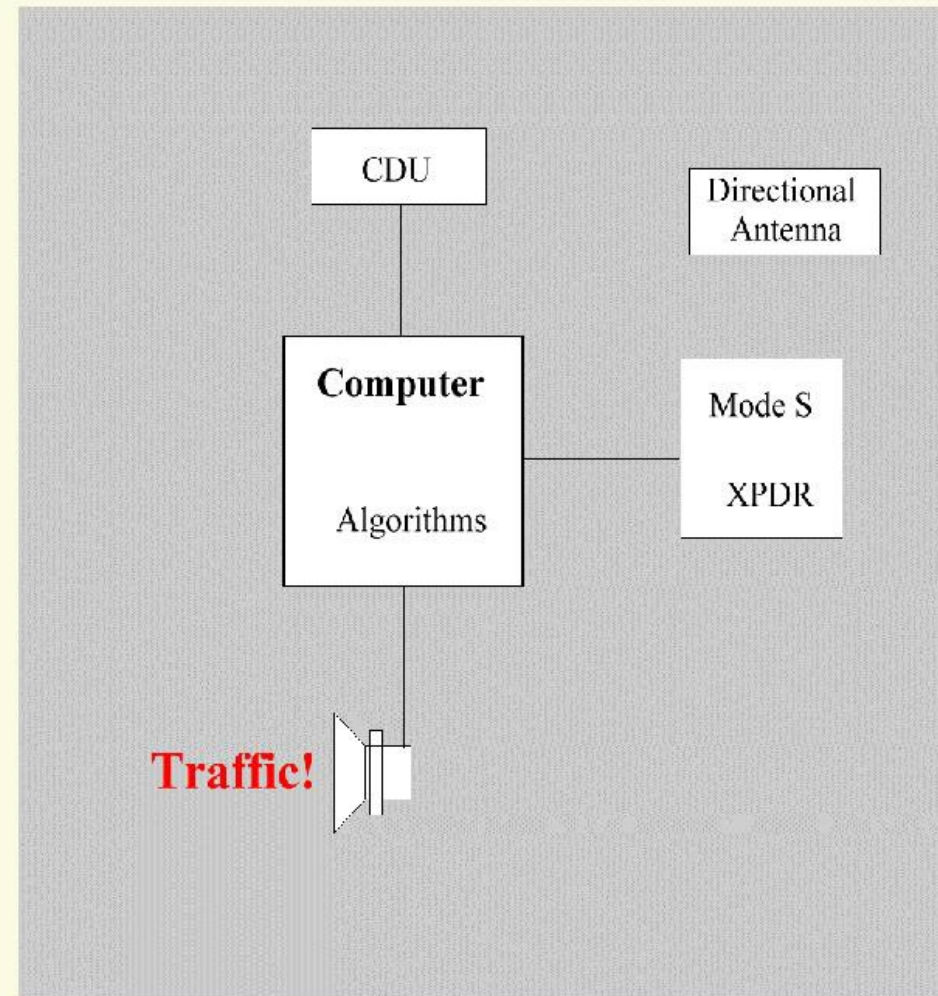
- ✓ Own A/C
- ✓ Intruder
- ✓ Fixed Bearing
- ✓ Range decreasing
- ✓ **COLLISION!**

Collision Plane



TCAS / TCAD *System Components*

- ✓ Computer
- ✓ Software Algorithms
- ✓ Directional Antenna
- ✓ Mode S Transponder
- ✓ Control & Display Unit (CDU)
- ✓ Speaker



Measurements

- ✓ Surveillance Volume: 40 NM
- ✓ Alert Time (TA) at average altitudes: $\tau = 40$ sec
- ✓ Alert Time (RA) at average altitudes: $\tau = 25$ sec

Measured parameters of the intruder:

- ✓ Range (r) & Altitude (Alt) & relative Direction

Calculated parameters of the intruder:

- ✓ Range Rate (r')
- ✓ Altitude difference to own A/C (ΔAlt)

Protected Volume

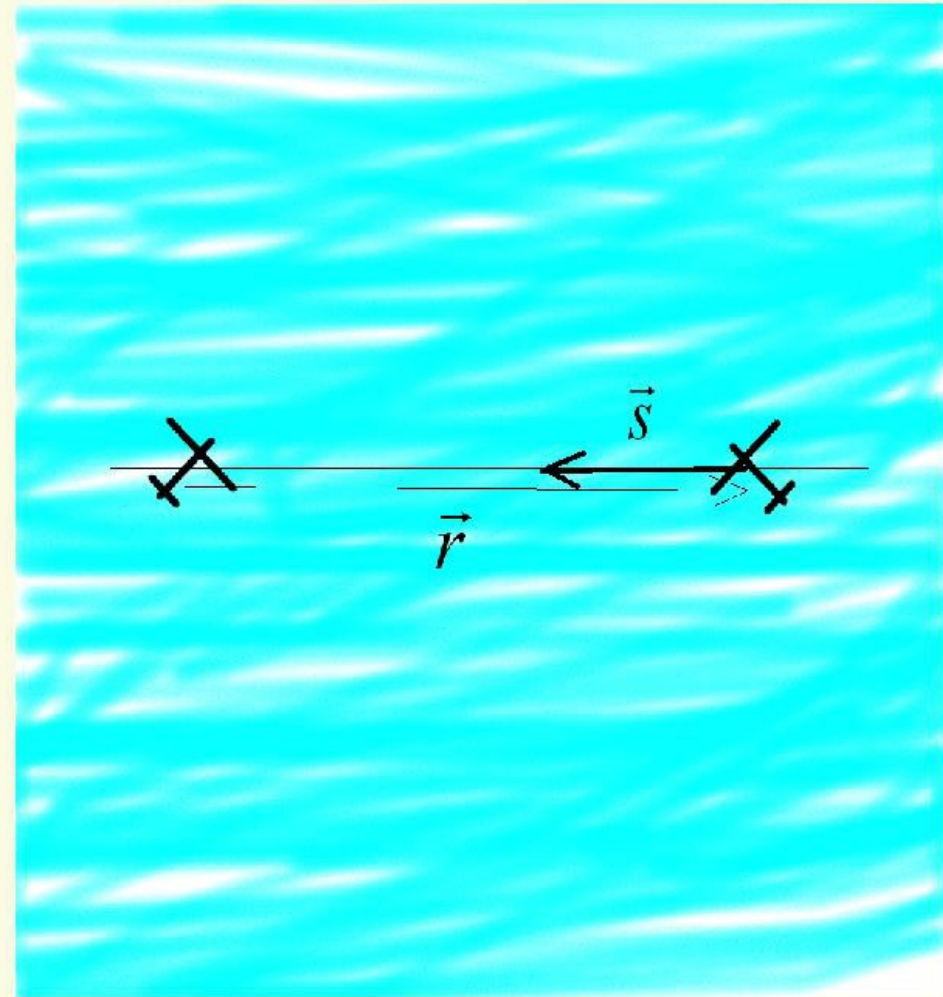
Part 1

Collision Situation

- ✓ Range (r)
- ✓ relative Speed (s)

Alert τ sec before impact:

$$\vec{r} = -\vec{s} \cdot \tau$$



Protected Volume

Part 2

Collision Situation

✓ Here

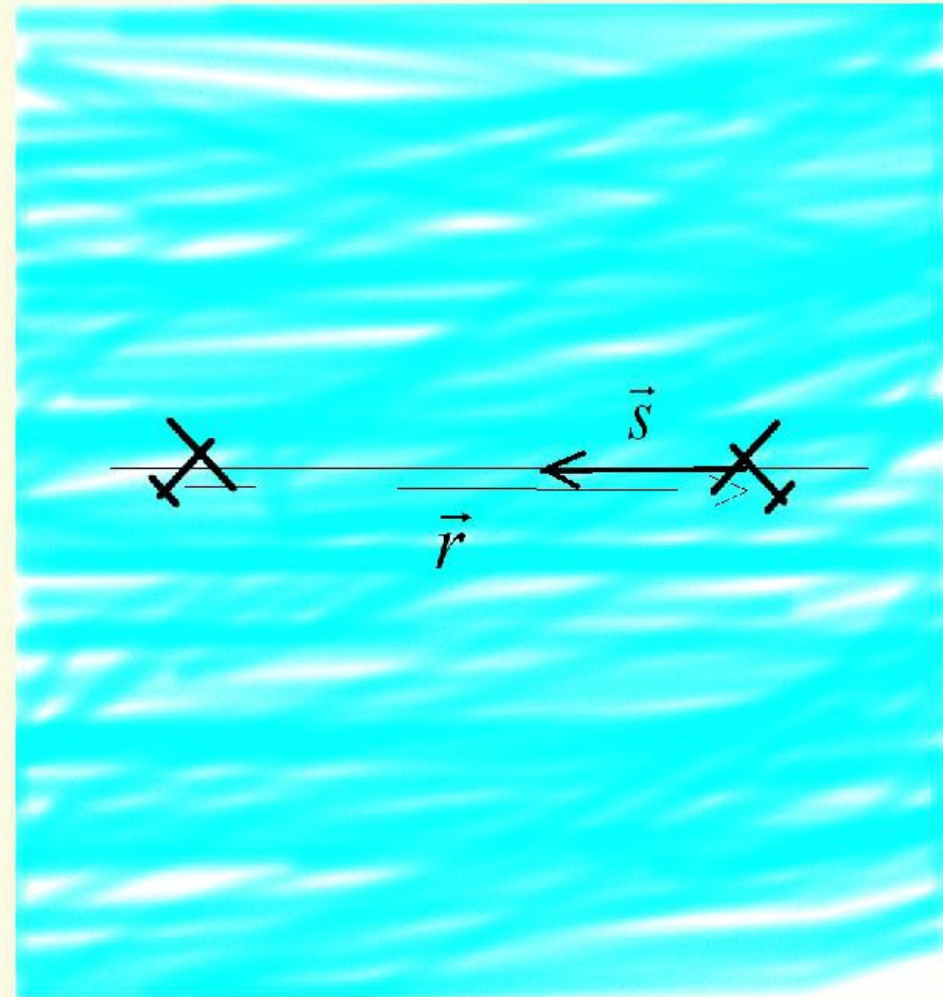
$$\vec{s} = \dot{\vec{r}}$$

✓ Therefore

$$\tau = -\frac{\vec{r}}{\dot{\vec{r}}}$$

(*τ Criterion*)

✓ Range Test



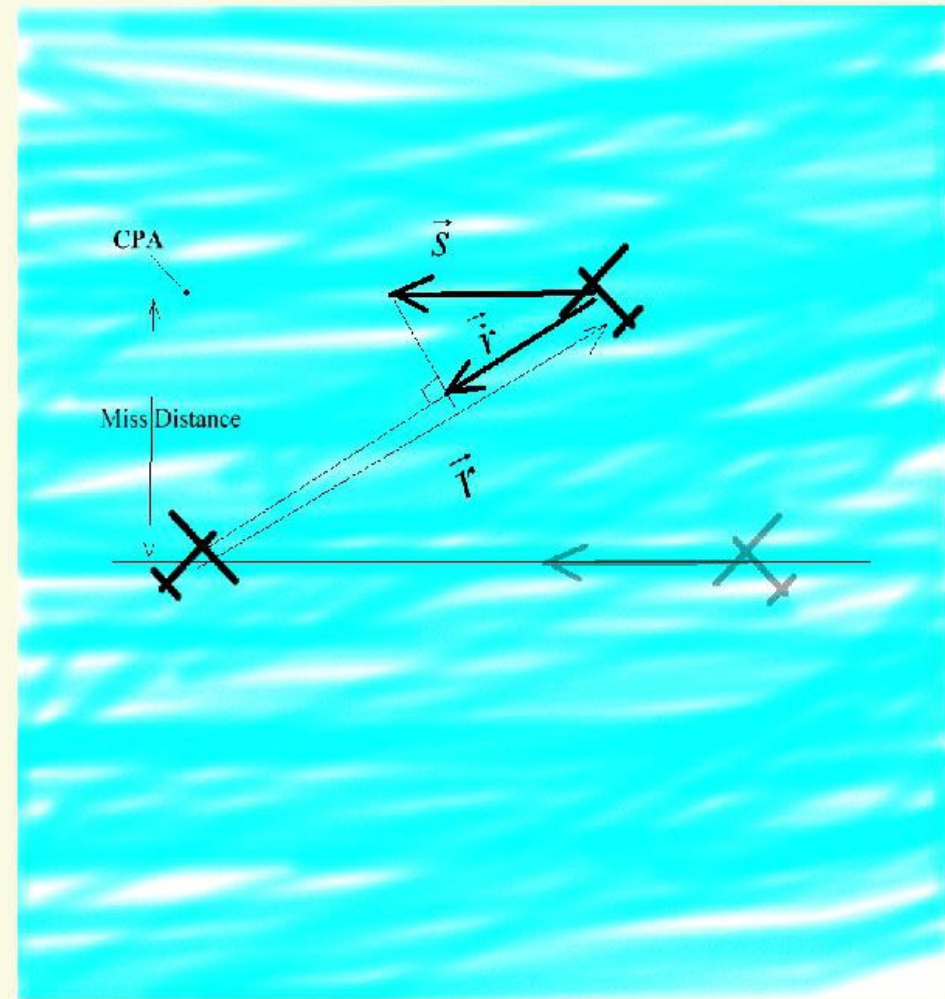
Near Miss

Part 1

- ✓ Same relative speed s
- ✓ Miss distance
- ✓ Closest Point of Approach (CPA)

✓ Here $\vec{s} \neq \dot{\vec{r}}$

✓ How does the τ criterion work here?



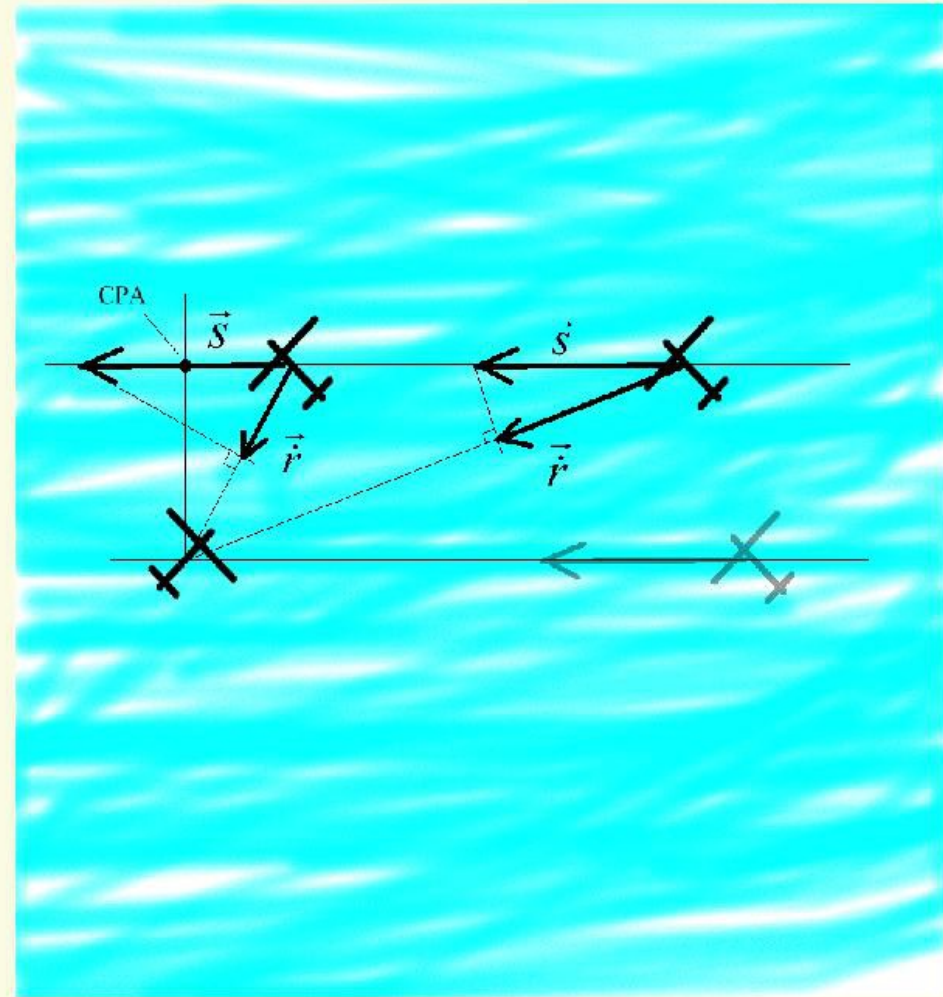
Near Miss

Part 2

- ✓ While the relative speed s is constant the range rate \dot{r} changes!
- ✓ s is unknown (direction is necessary)!

Alert will sound when:

$$\tau = -\frac{\vec{r}}{\dot{r}} \quad \text{or} \quad \vec{r} = -\dot{r} \cdot \tau$$

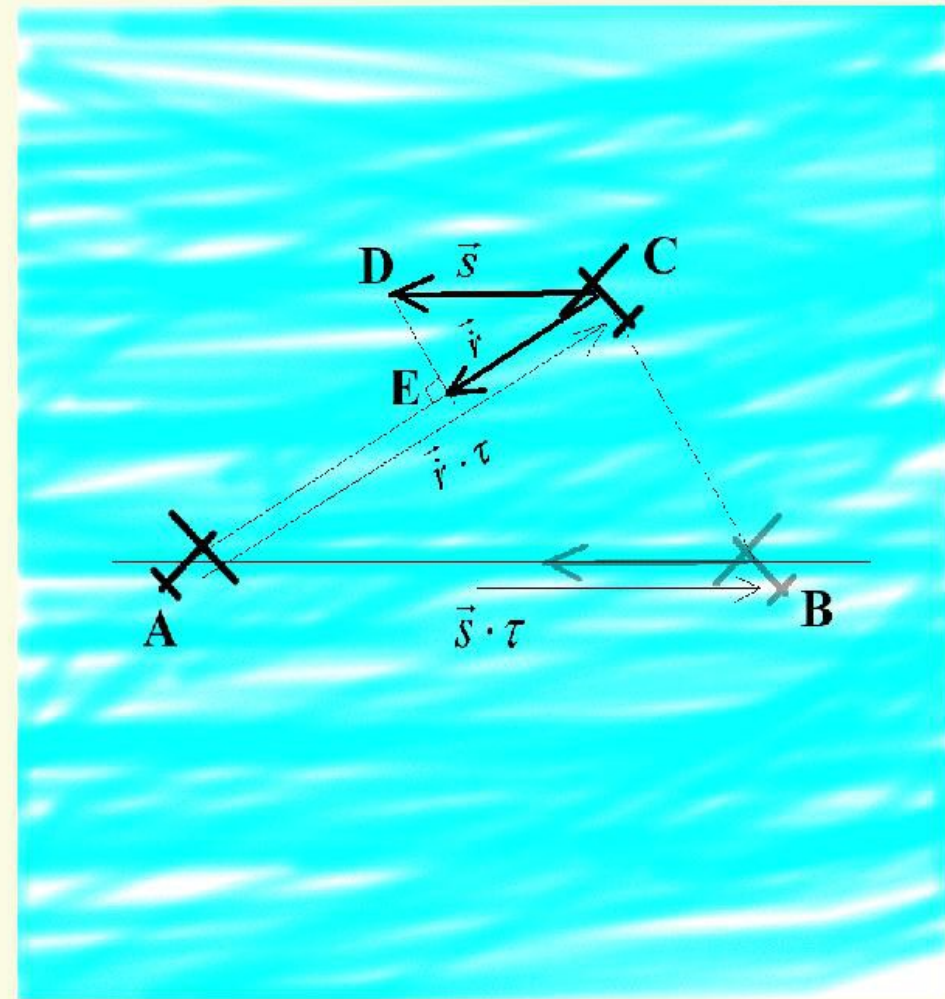


Near Miss

Part 3

- ✓ Whenever the intruder is in position B or C the alert will sound, because the τ criterion is fulfilled!

What do we know about the position C of the intruder when the alert sounds?



Near Miss

Part 4

- ✓ Triangle CDE is rectangular!

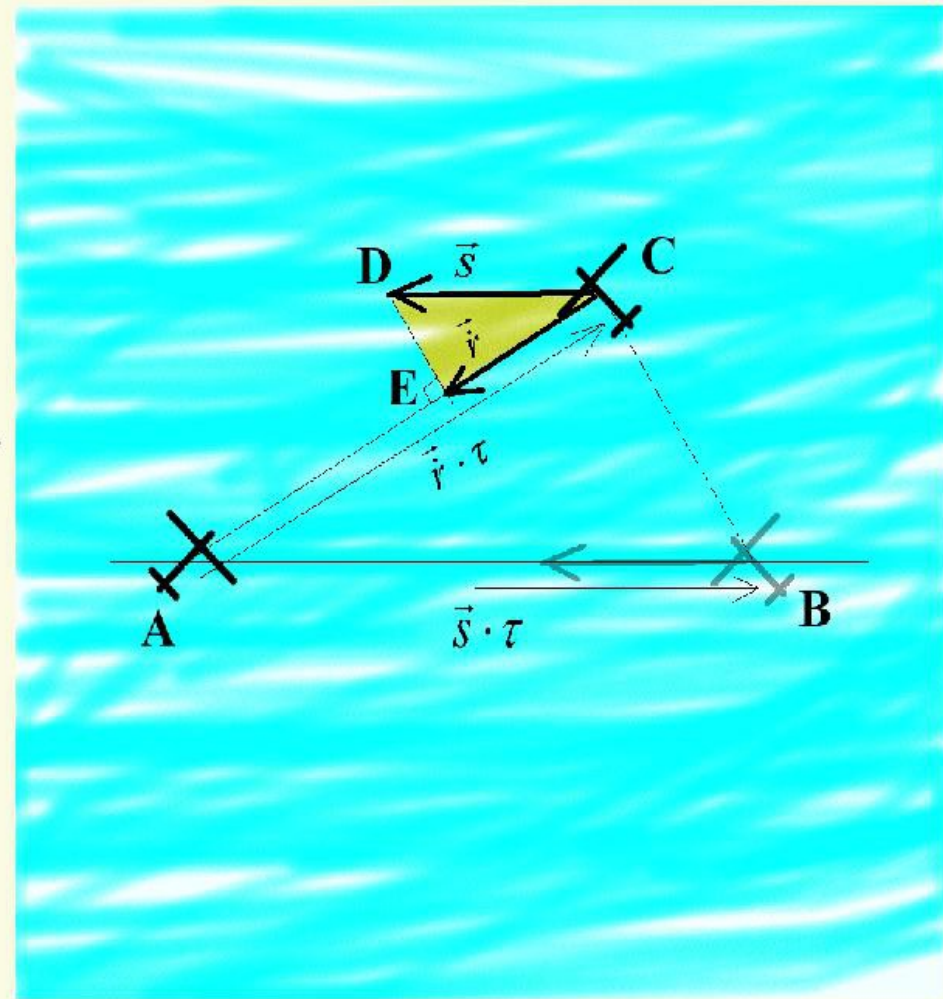
The relation between the side r' and the hypotenuse s

$$\frac{\vec{r}'}{\vec{s}} = \frac{\vec{r}'}{\vec{s}} \cdot 1 = \frac{\vec{r}'}{\vec{s}} \cdot \frac{\tau}{\tau} = \frac{\vec{r}' \cdot \tau}{\vec{s} \cdot \tau}$$

... is the same as in the triangle ABC!

- ✓ Therefore:

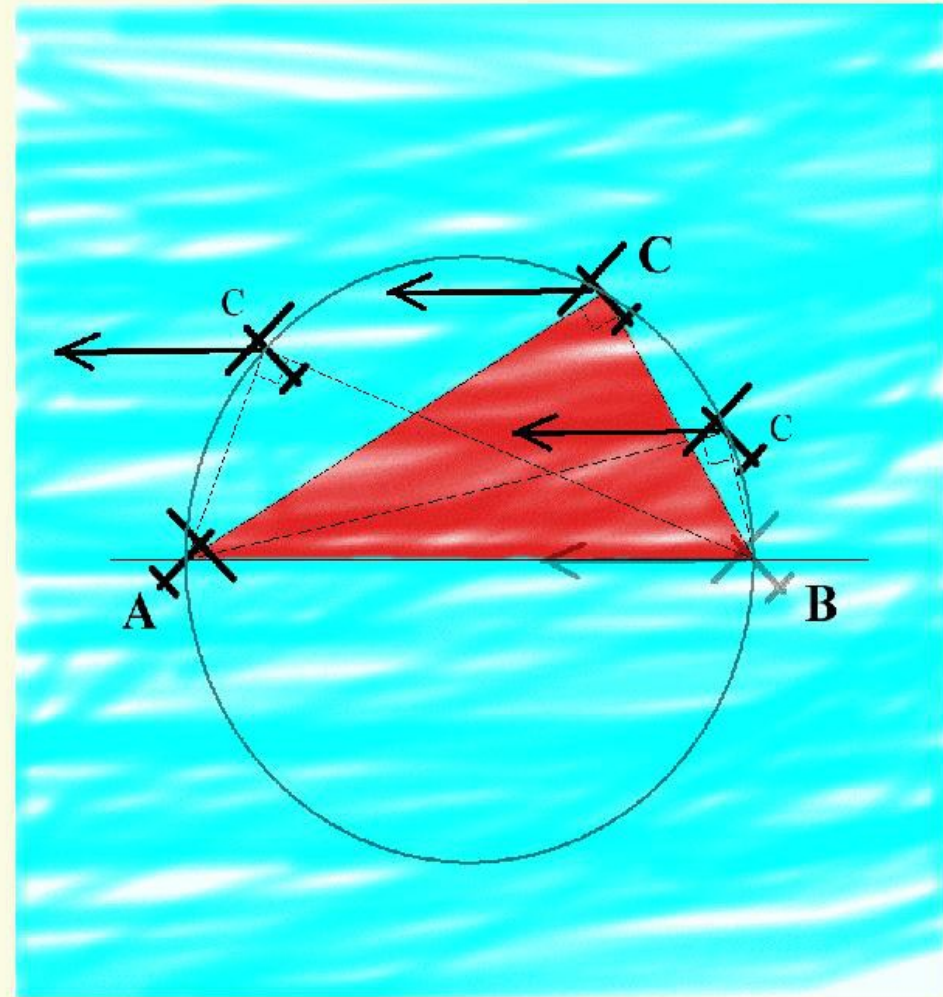
Triangle ABC is also rectangular!



Near Miss

Part 5

- ✓ The Alert sounds whenever the intruder is at the rectangular corner of the triangle ABC.
- ✓ This means: it is on a *Circle of Thales*!
- ✓ So: This circle is the *alarm boundary* of the τ criterion!

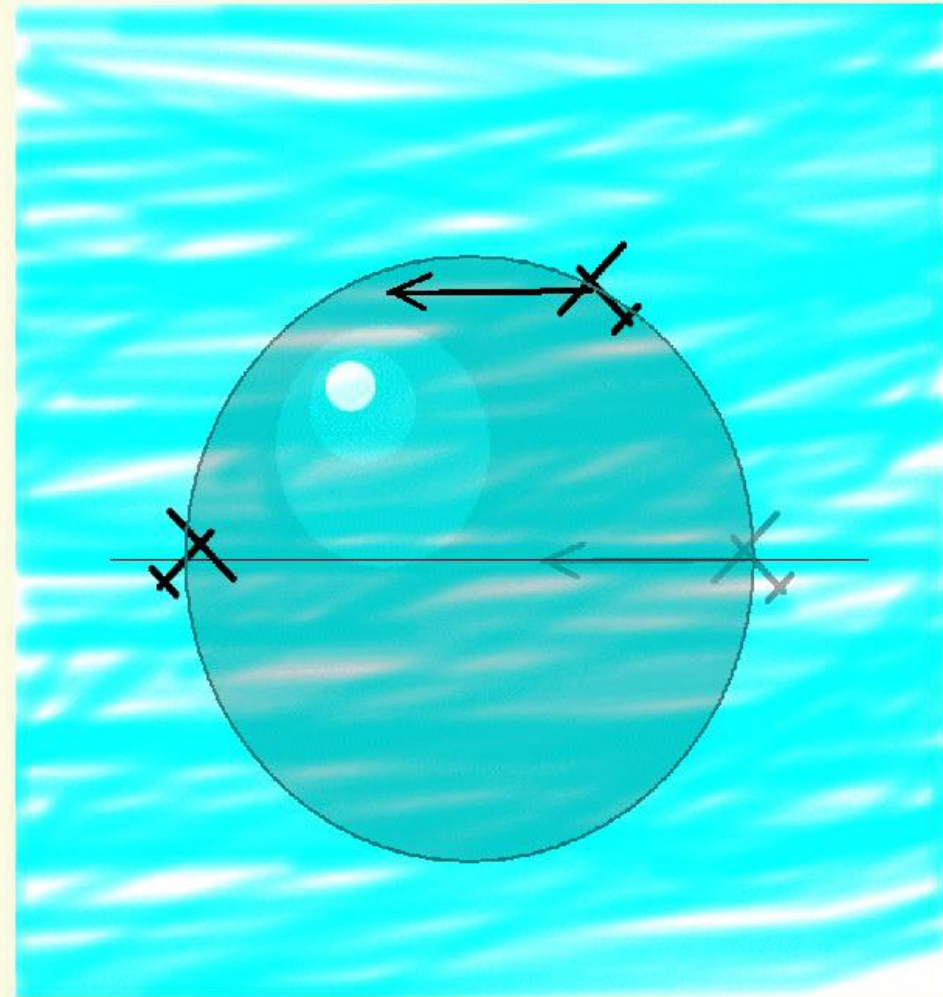


Near Miss

Part 6

- ✓ The Collision Plane is not necessarily horizontal: the alarm boundary is actually a sphere:

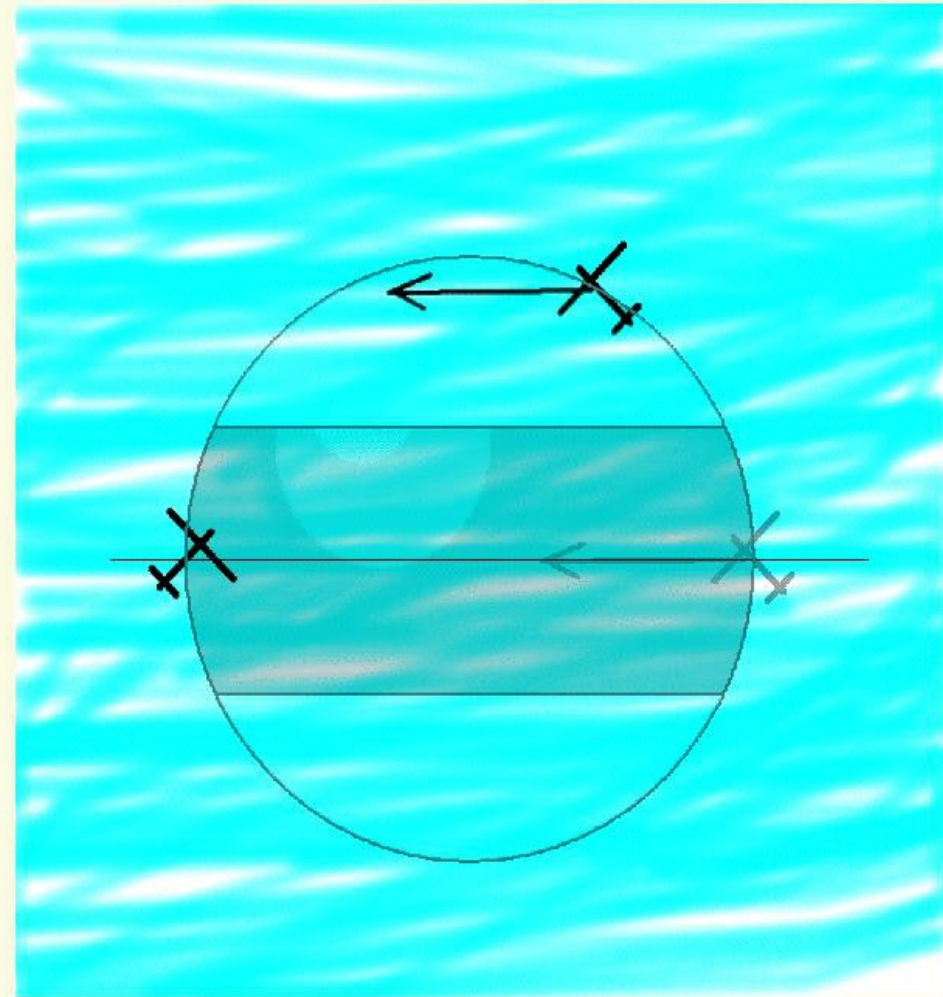
The *Protected Volume of Airspace*



Near Miss

Part 7

- ✓ Actually, this sphere is too large.
- ✓ A slice is cut out via a *Vertical τ Criterion*.
- ✓ **Altitude Test**
- ✓ The intruder has to pass both the Range Test and the Altitude Test to trigger an alarm.

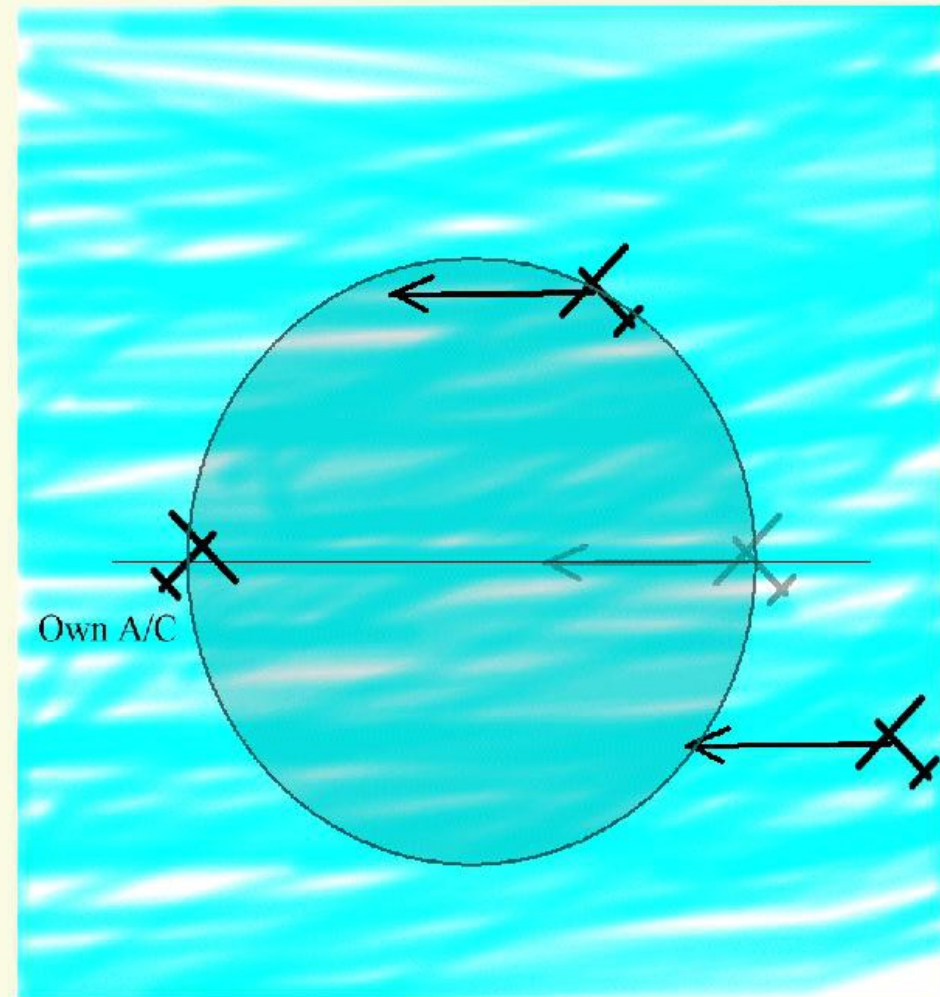


Near Miss

Part 8

Summary:

- ✓ The Protected Volume of Airspace is always **between** the aircrafts.
- ✓ Own A/C is **on the surface** of the sphere, not in the center.
- ✓ The Protected Volume is oriented **towards the relative motion** of the intruder.
- ✓ The **radius** depends on the relative speed.

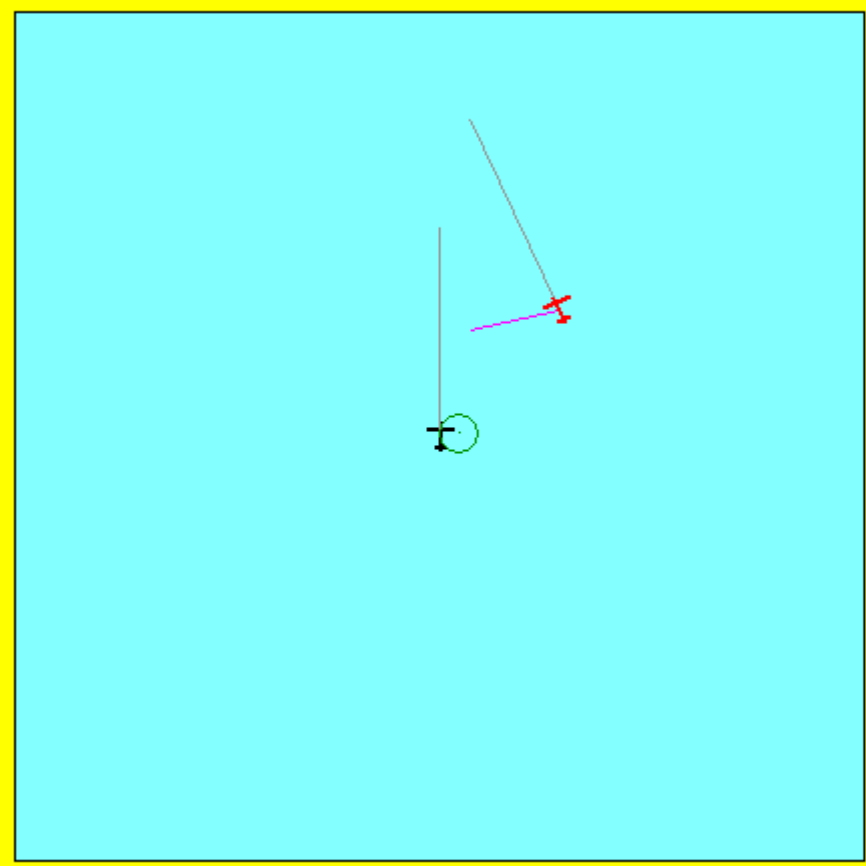


Protected Volume *Properties & Limits*

- ✓ The *simple τ Criterion* is not always safe
... An intruder could come close without alert.
- ✓ A *Modified τ Criterion* was developed
... But caused too much nuisance alerts.
- ✓ Now the *New τ Criterion* is implemented
... Which avoids the former flaws.

Protected Volume *Properties & Limits*

- ✓ If an aircraft has no transponder it cannot be detected at all.
- ✓ The alert time τ can deteriorate in some cases.
- ✓ Horizontal collision avoidance manoeuvres are difficult to program
... and are sometimes tricky!



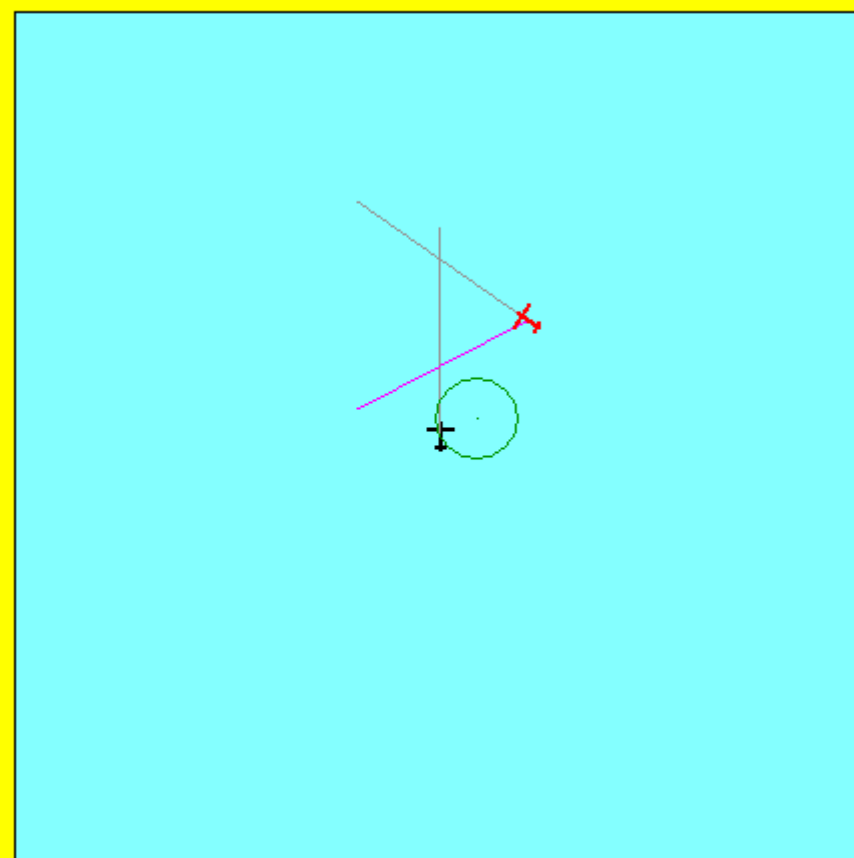
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.2 NM
Dmod = 0.5 NM

INTRUDER:
TH = 335 °
TAS = 150kt
Range:
2.1 NM
Range Rate:
0 kt
Relative Speed:
65 kt
CPA = 1.2 NM
TCPA = 0 : 1 : 34

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



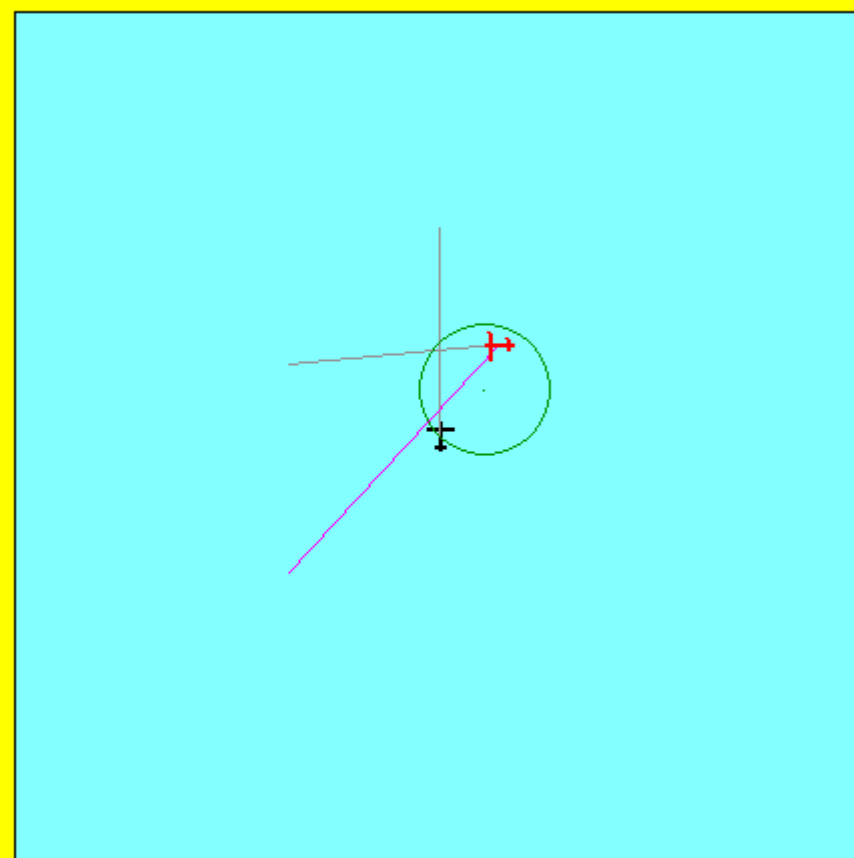
Simulation Time
0 : 0 : 17

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.5 NM
Dmod = 0.5 NM

INTRUDER:
TH = 305 °
TAS = 150kt
Range:
1.7 NM
Range Rate:
0 kt
Relative Speed:
139 kt
CPA = 0.7 NM
TCPA = 0 : 0 : 40

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



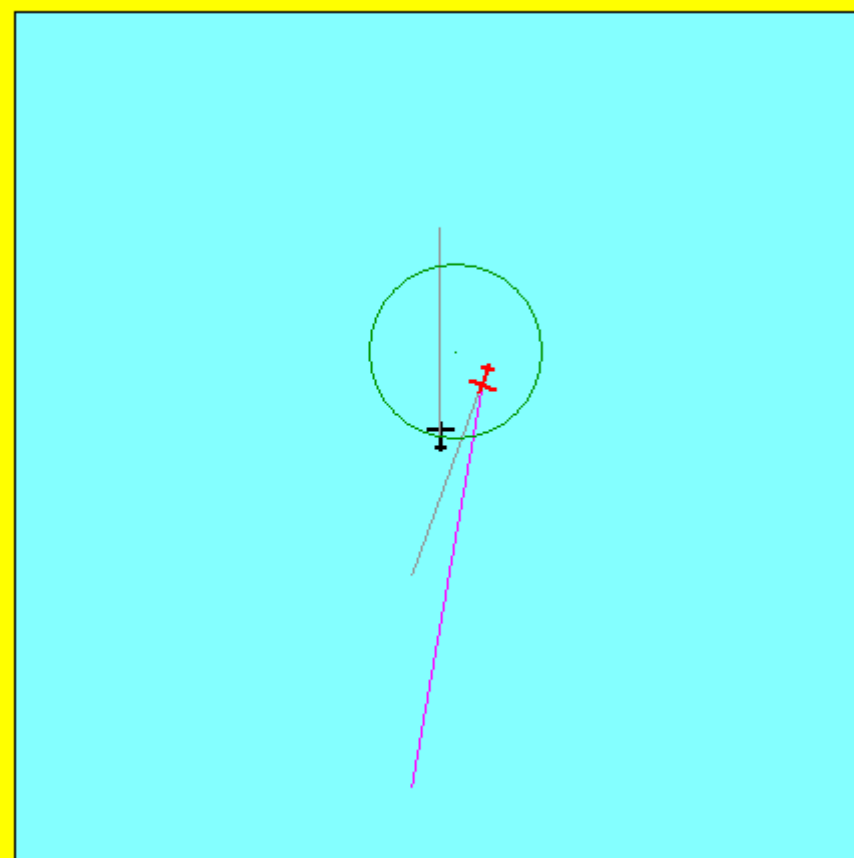
Simulation Time
0 : 0 : 26

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.8 NM
Dmod = 0.5 NM

INTRUDER:
TH = 265 °
TAS = 150kt
Range:
1.3 NM
Range Rate:
0 kt
Relative Speed:
221 kt
CPA = 0.2 NM
TCPA = 0 : 0 : 21

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



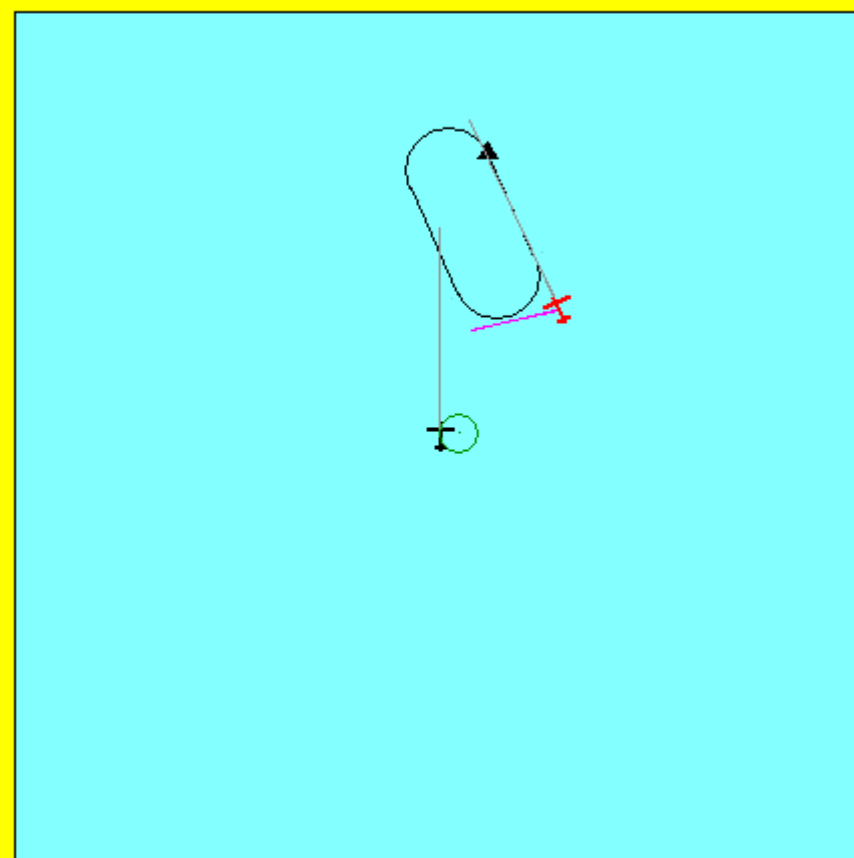
Simulation Time
0 : 0 : 32

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 1 NM
Dmod = 0.5 NM

INTRUDER:
TH = 200 °
TAS = 150kt
Range:
0.9 NM
Range Rate:
0 kt
Relative Speed:
295 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 9

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



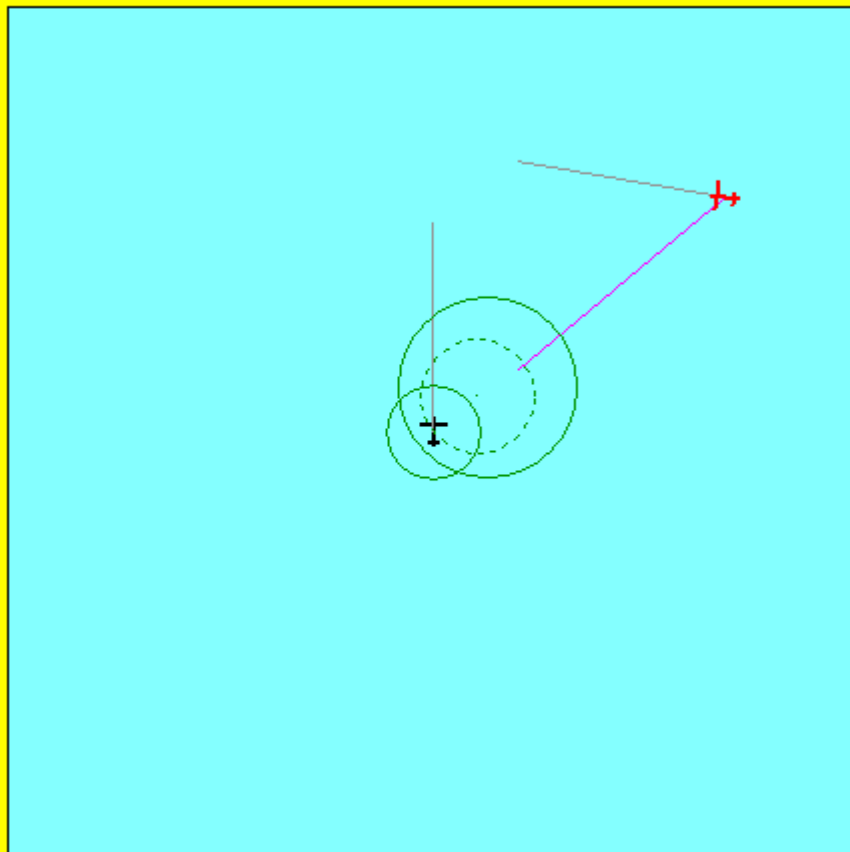
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.2 NM
Dmod = 0.5 NM

INTRUDER:
TH = 335 °
TAS = 150kt
Range:
2.1 NM
Range Rate:
0 kt
Relative Speed:
65 kt
CPA = 1.2 NM
TCPA = 0 : 1 : 34

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



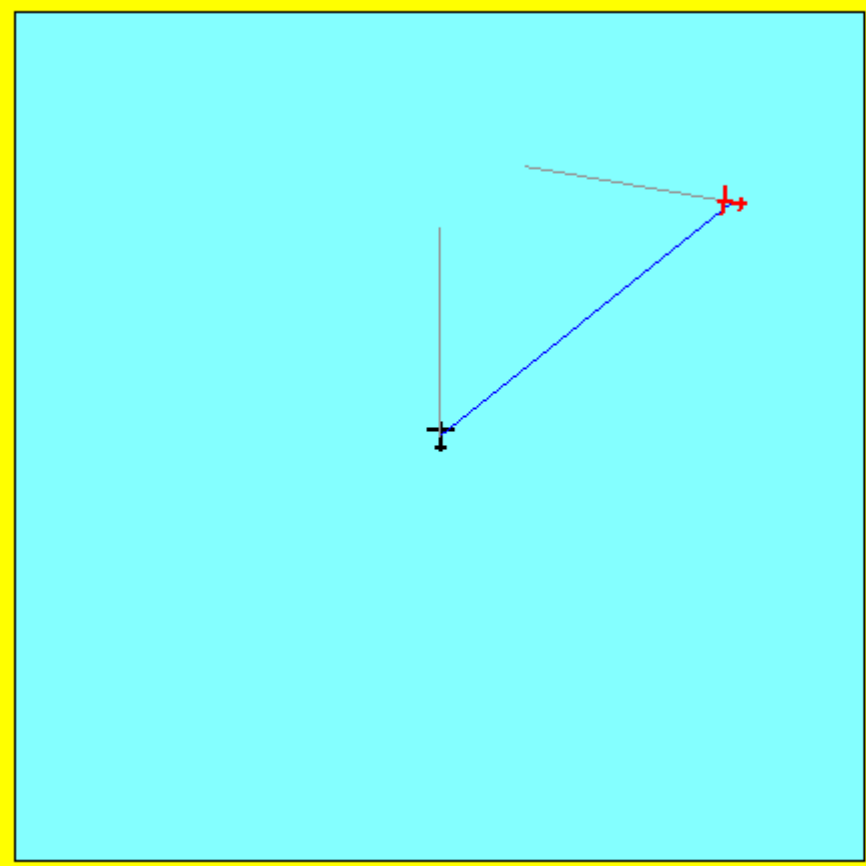
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
4.4 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 23

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



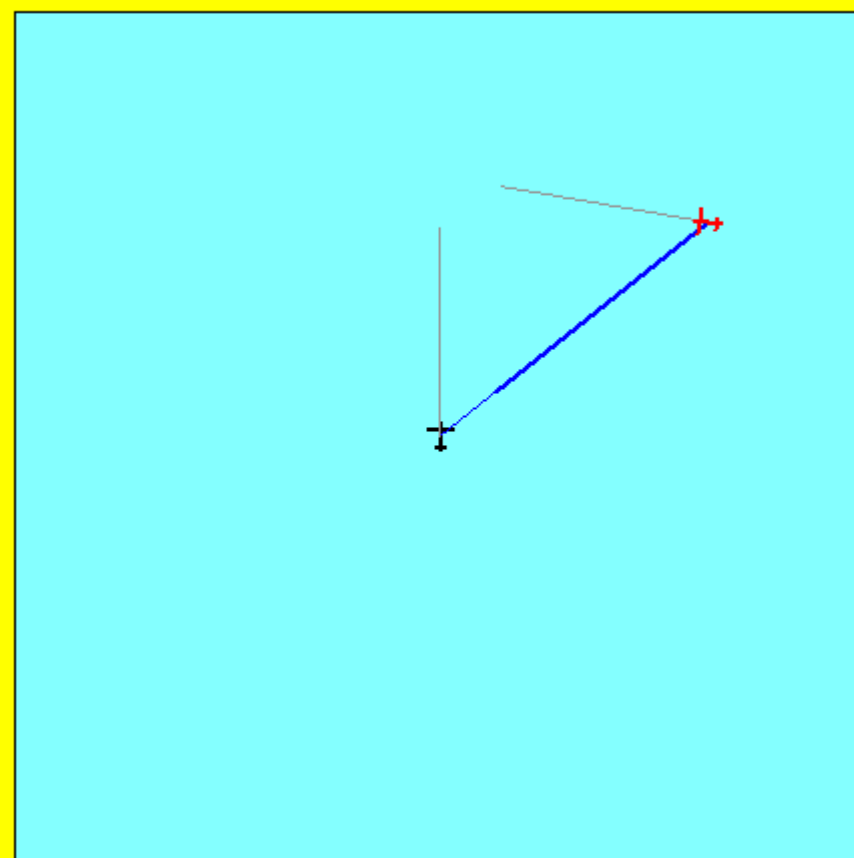
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
4.4 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 23

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



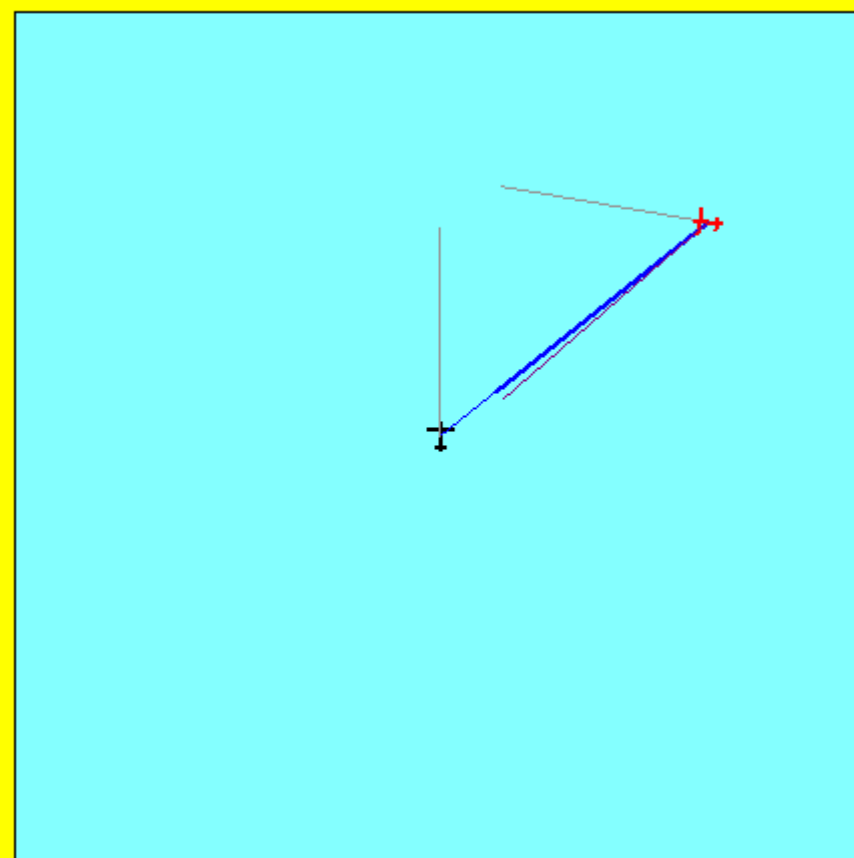
Simulation Time
0 : 0 : 7

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
4 NM
Range Rate:
-193 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 16

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



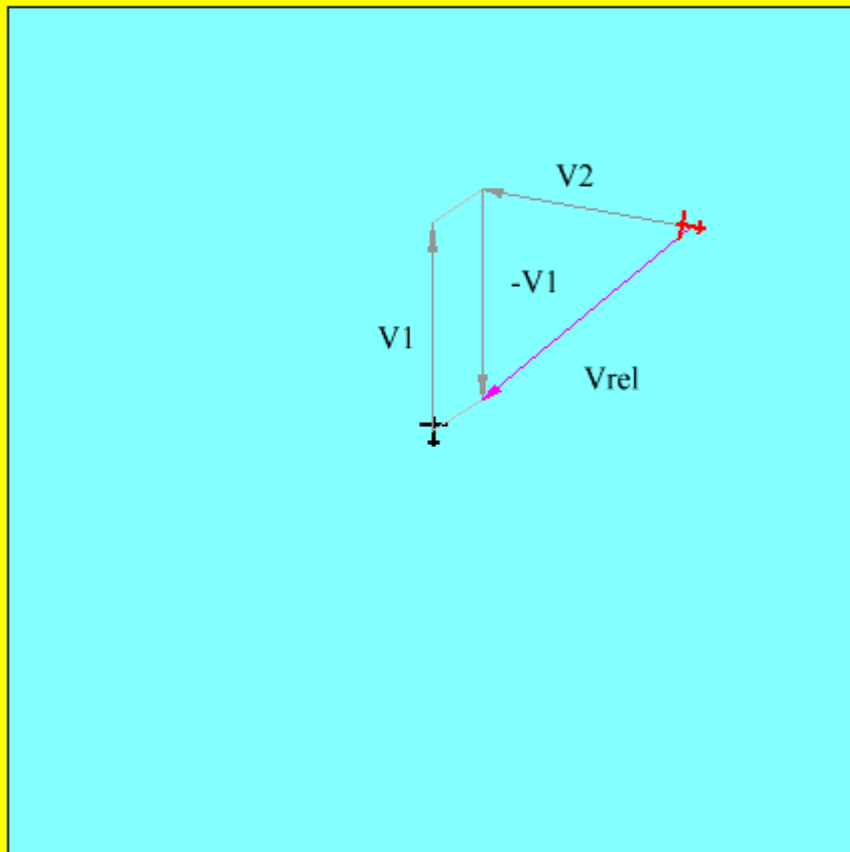
Simulation Time
0 : 0 : 7

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
4 NM
Range Rate:
-193 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 16

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



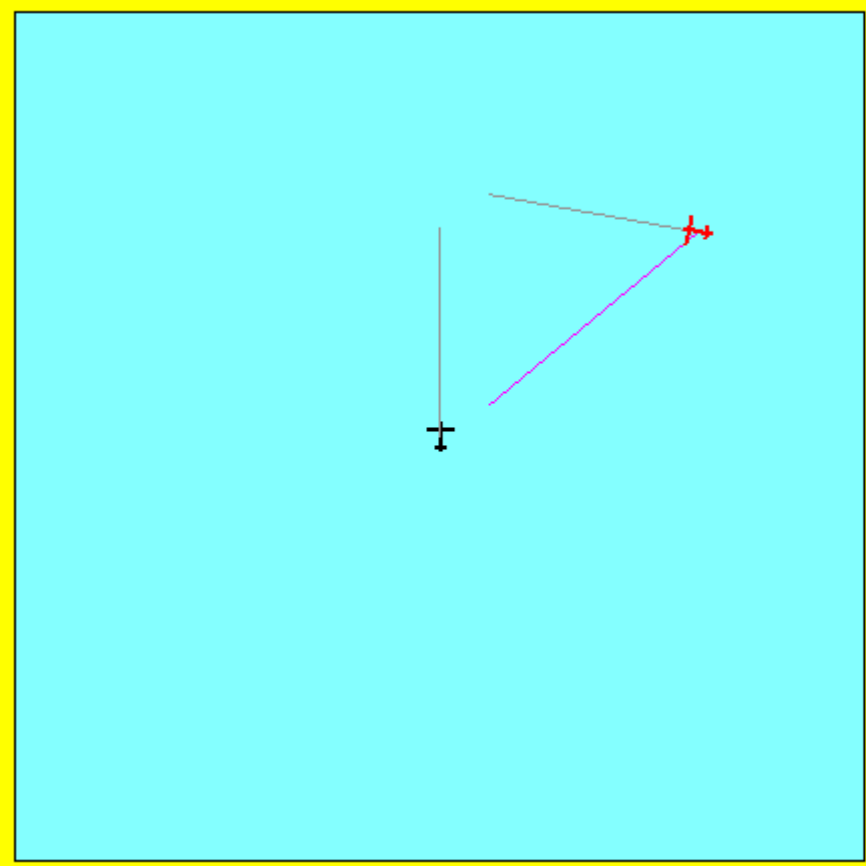
Simulation Time
0 : 0 : 10

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
3.9 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 13

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



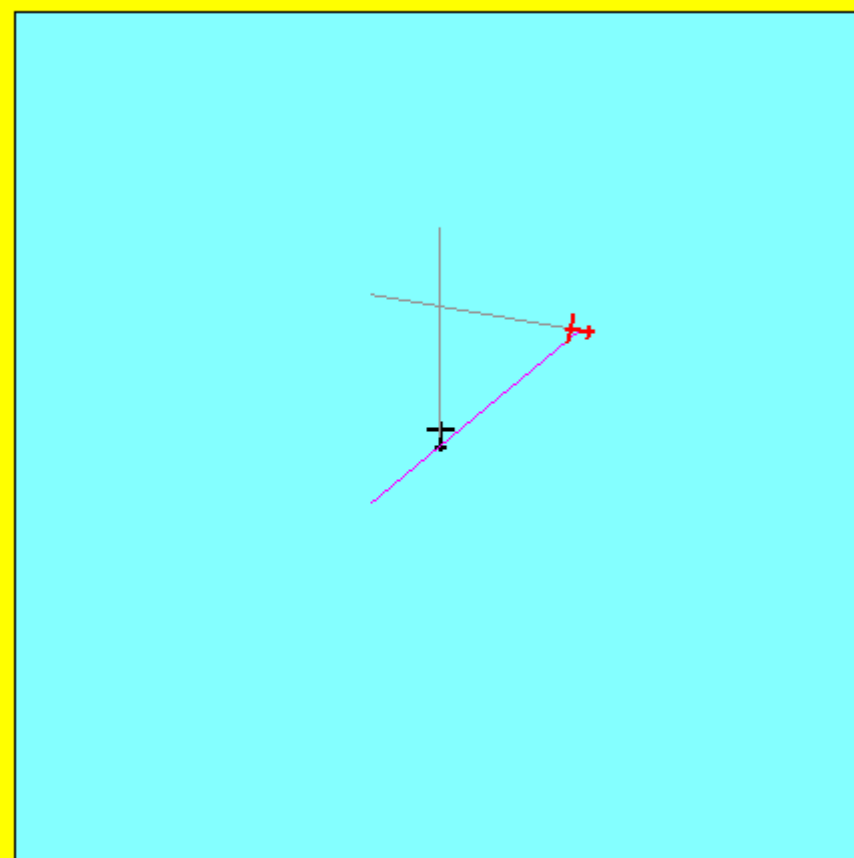
Simulation Time
0 : 0 : 10

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
3.9 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 1 : 13

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



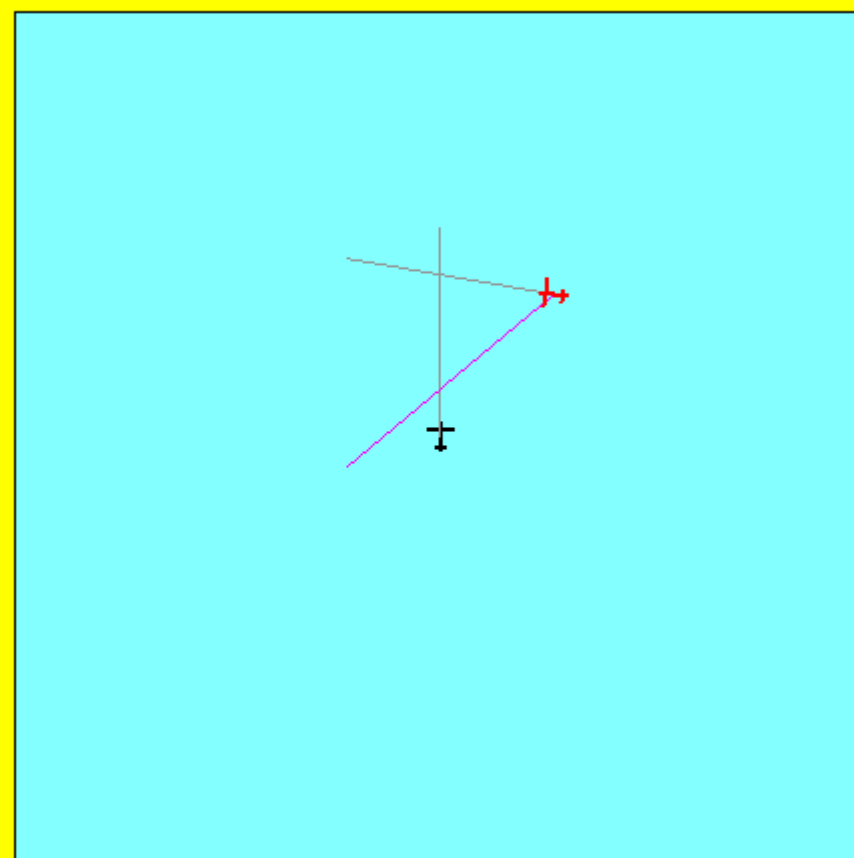
Simulation Time
0 : 0 : 44

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
2.1 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.1 NM
TCPA = 0 : 0 : 39

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



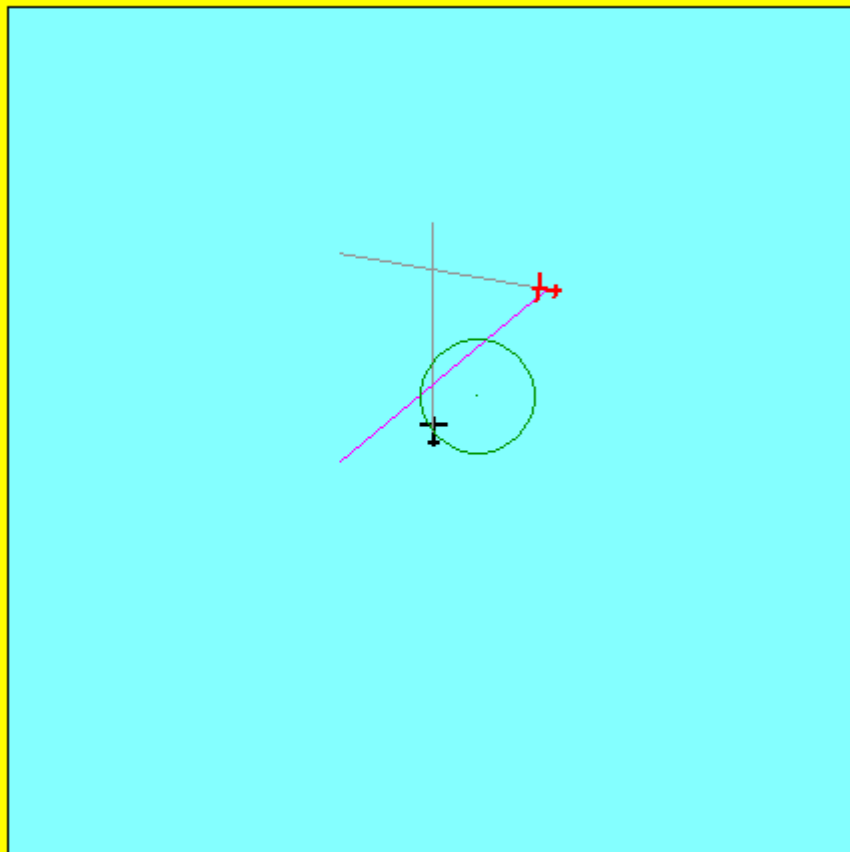
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
2.2 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 39

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



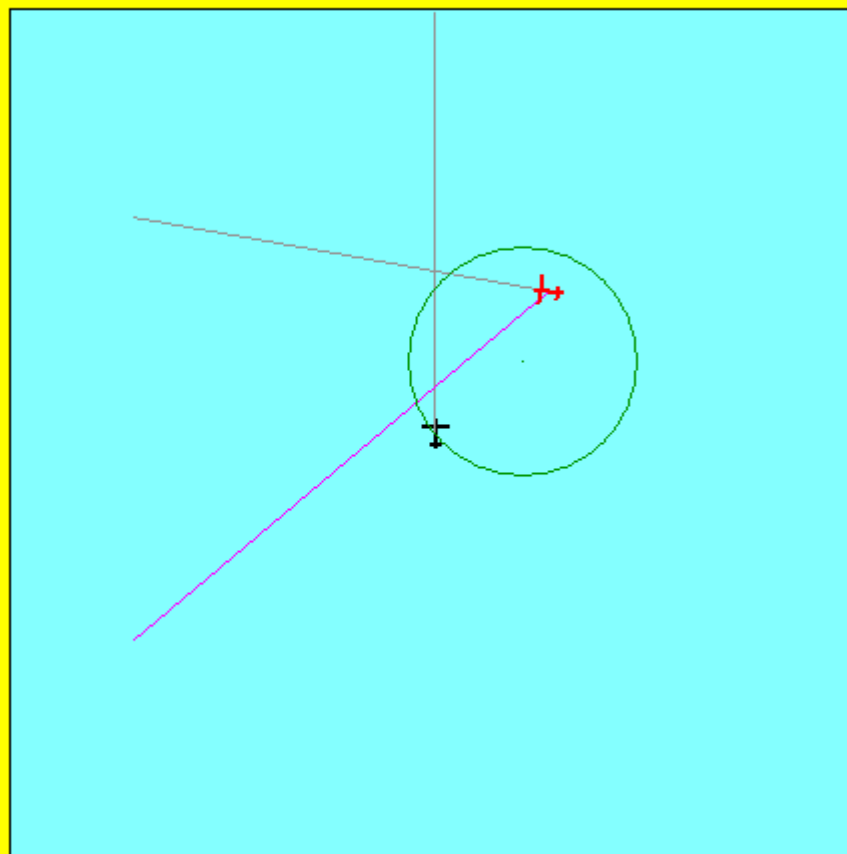
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
2.2 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 39

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



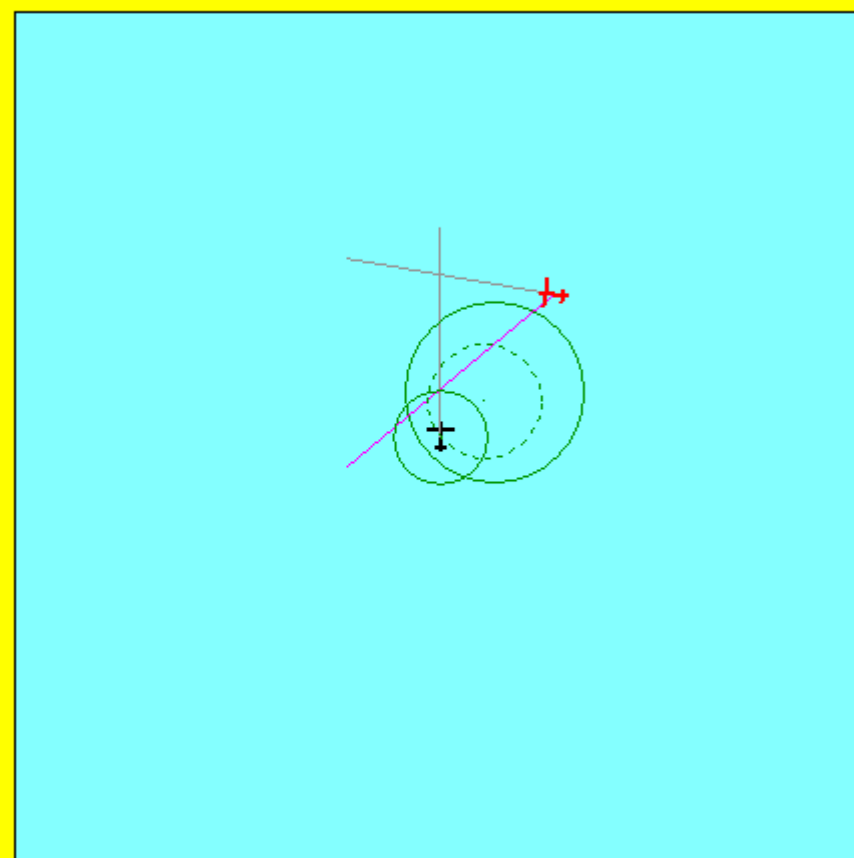
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 300kt
PROTECTED VOL.:
Radius = 1.3 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 300kt
Range:
2.2 NM
Range Rate:
0 kt
Relative Speed:
386 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 20

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



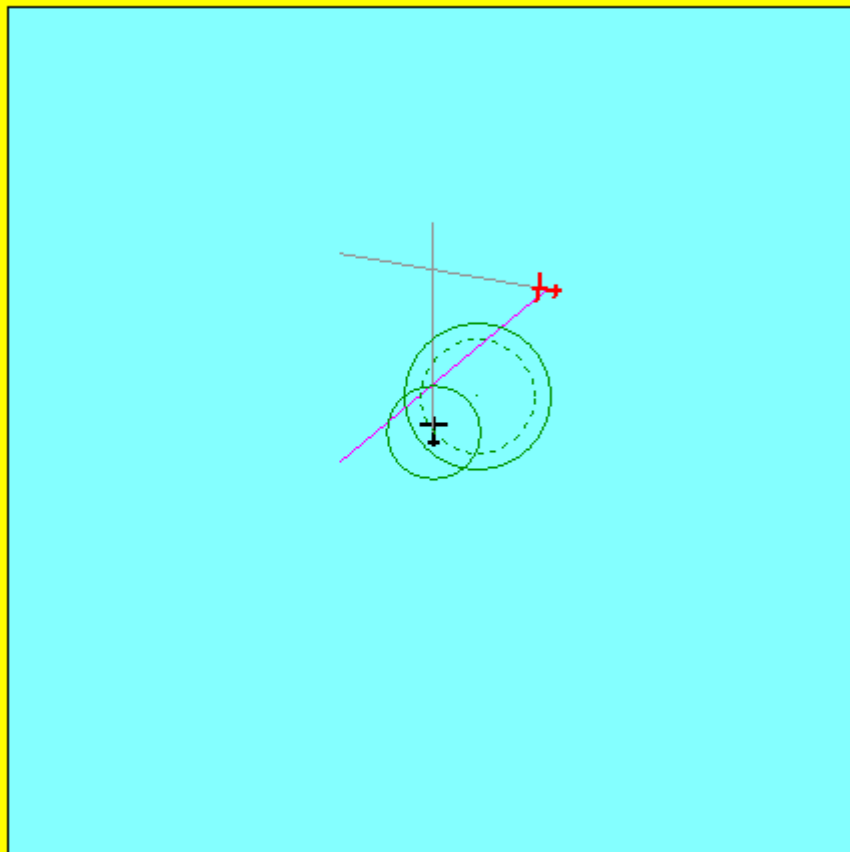
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.7 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
2.2 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 39

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



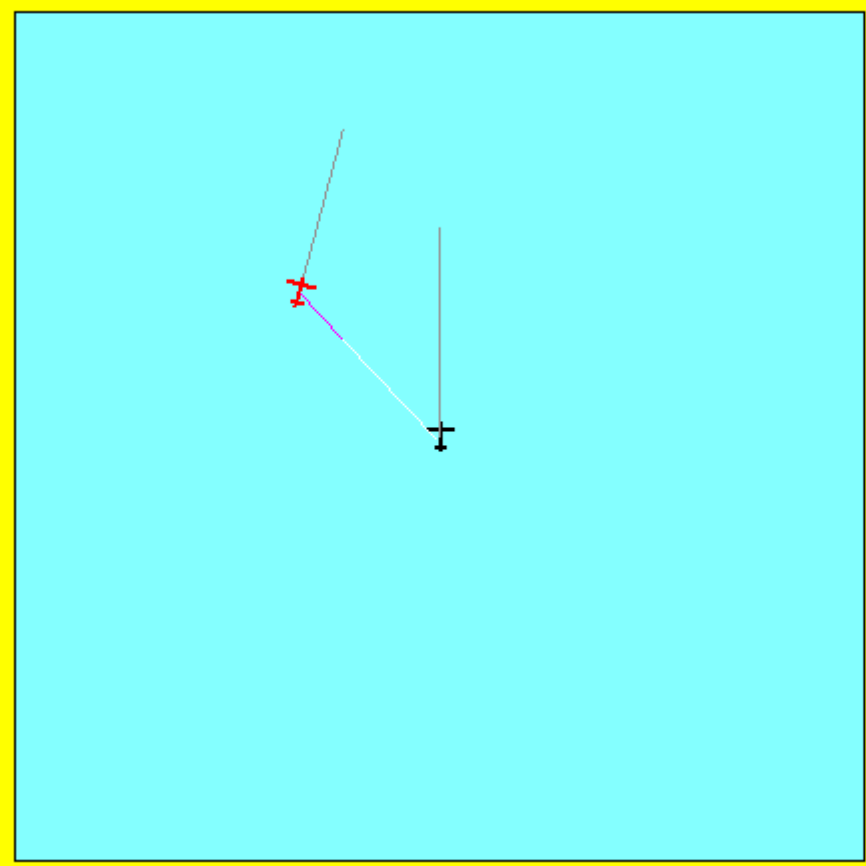
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0.9 NM
Dmod = 0.5 NM

INTRUDER:
TH = 280 °
TAS = 150kt
Range:
2.2 NM
Range Rate:
0 kt
Relative Speed:
193 kt
CPA = 0.4 NM
TCPA = 0 : 0 : 39

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



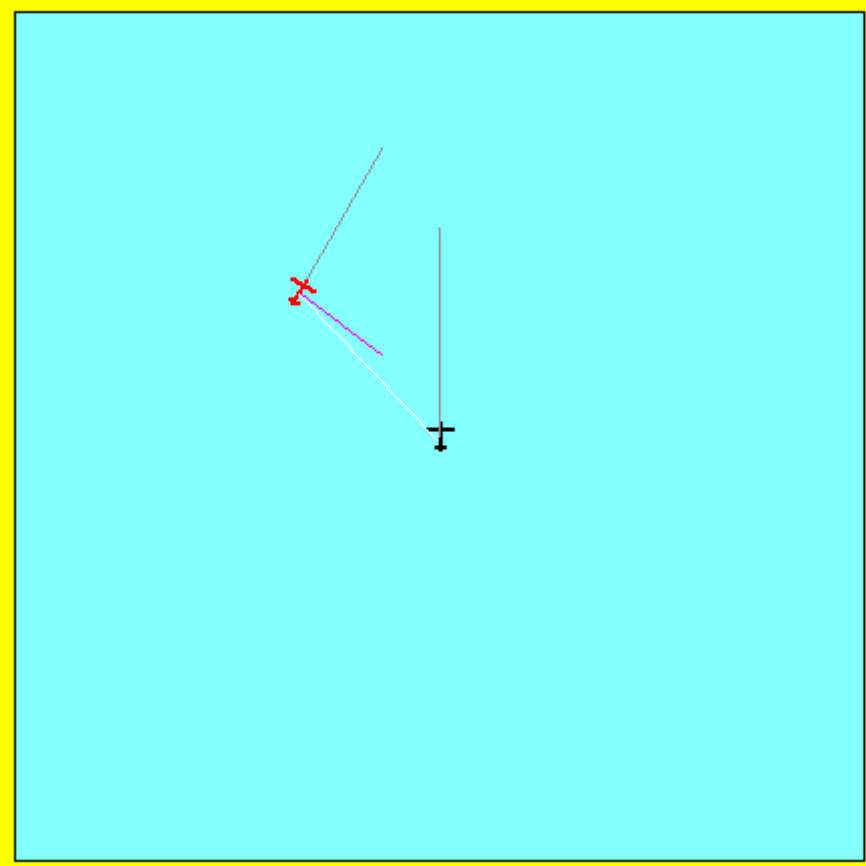
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0 NM
Dmod = 0.5 NM

INTRUDER:
TH = 15 °
TAS = 120kt
Range:
2.4 NM
Range Rate:
0 kt
Relative Speed:
46 kt
CPA = 0.1 NM
TCPA = 0 : 3 : 7

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



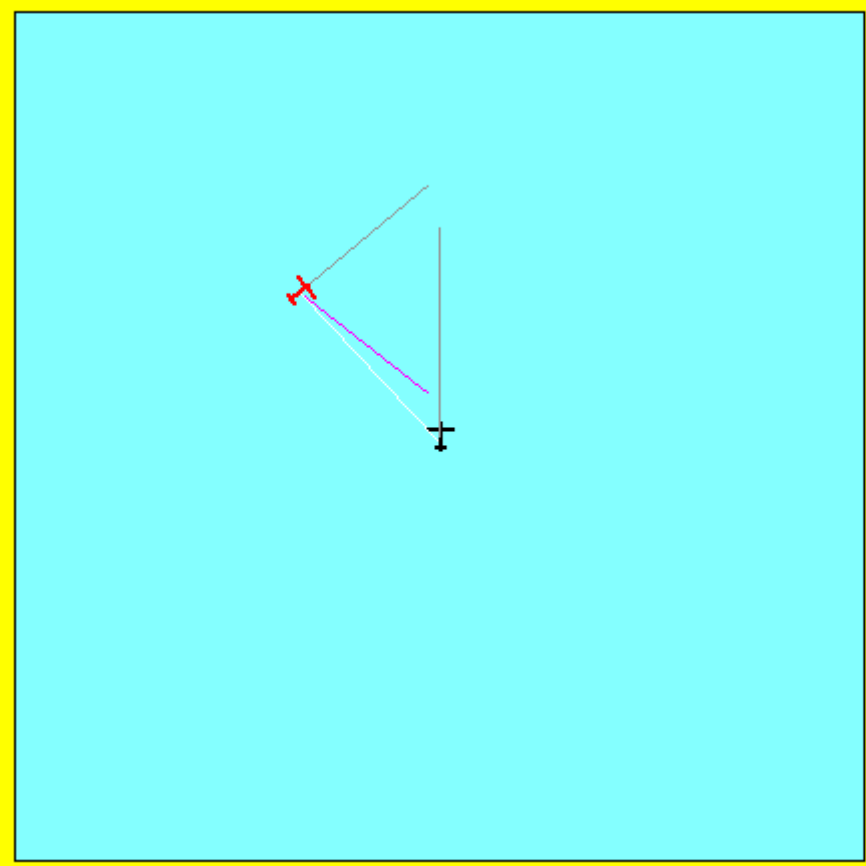
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0 NM
Dmod = 0.5 NM

INTRUDER:
TH = 30 °
TAS = 120kt
Range:
2.4 NM
Range Rate:
0 kt
Relative Speed:
76 kt
CPA = 0.3 NM
TCPA = 0 : 1 : 53

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



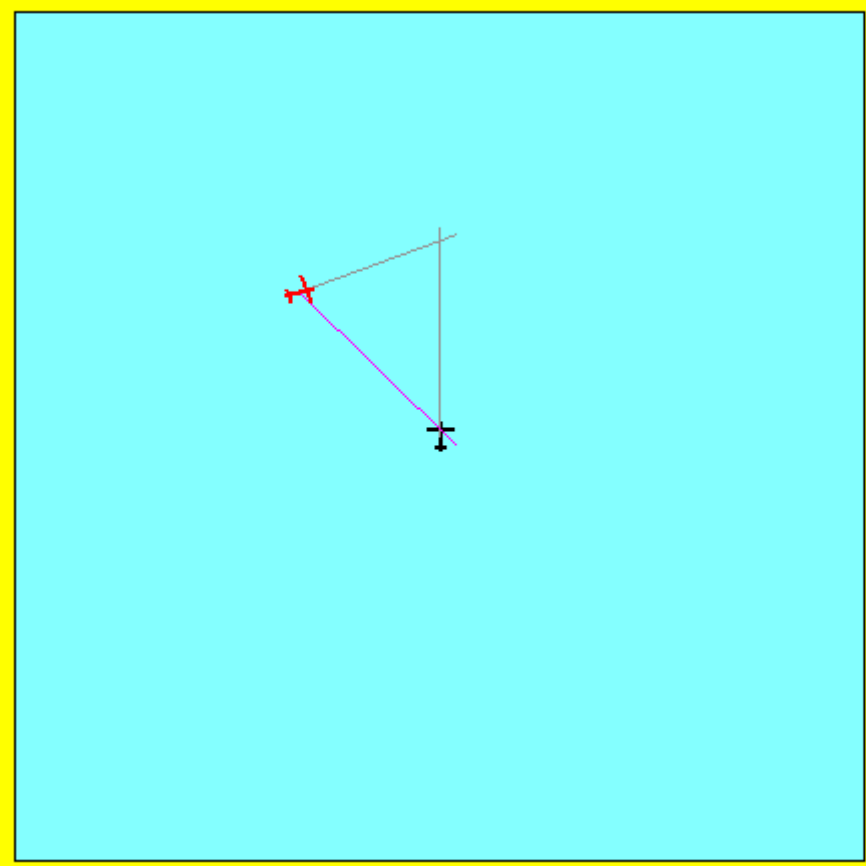
Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0 NM
Dmod = 0.5 NM

INTRUDER:
TH = 50 °
TAS = 120kt
Range:
2.4 NM
Range Rate:
0 kt
Relative Speed:
117 kt
CPA = 0.3 NM
TCPA = 0 : 1 : 13

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden



Simulation Time
0 : 0 : 0

OWN AIRCRAFT:
TH = 000 °
TAS = 150kt
PROTECTED VOL.:
Radius = 0 NM
Dmod = 0.5 NM

INTRUDER:
TH = 70 °
TAS = 120kt
Range:
2.4 NM
Range Rate:
0 kt
Relative Speed:
157 kt
CPA = 0.1 NM
TCPA = 0 : 0 : 55

- Fliegen
- Range
- Range Rate
- TAS
- V relative
- Protected Vol.

Beenden