Designing for Situation Awareness

the world behind the glass

Max Mulder

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TU Delft

Delft University of Technology

aerospace human-machine systems

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Aerospace Engineering

Control & Simulation

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today

- brief recap : situation awareness
- our work : ***ecological*** flight deck design
- example : airborne separation assistance
- closing statements

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situation awareness

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literature on SA

Endsley (1995): *"the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their status into the future"*

27 definitions of SA, and this number is still growing

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ecological
flight deck design

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why do we need to study humans in the aerospace domain?

>70 % of all accidents is attributed to *human error*

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response options

- fire the pilot
- improve training
- better maintenance, improve reliability
- adapt procedures
- add automation/warning systems (TCAS, EGPWS)
  traffic terrain
- **improve the interface**

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why do we need to study humans in the aerospace domain?

enormous cost reductions through automation…

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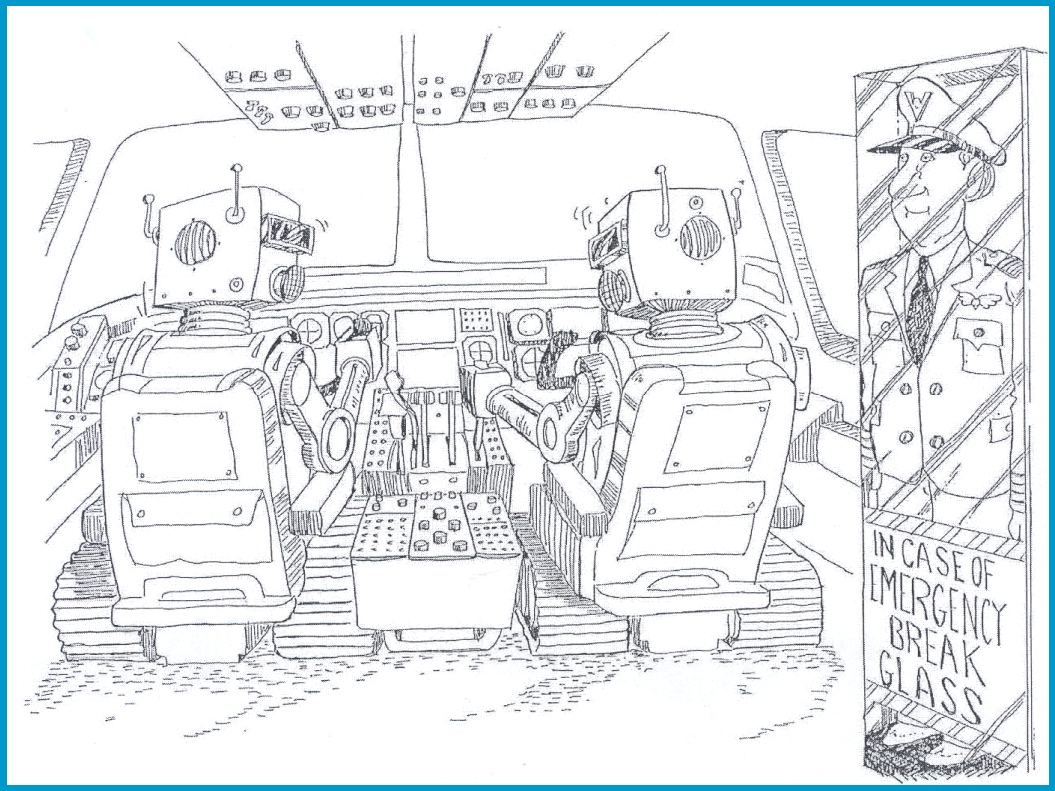
why do we need to study humans in the aerospace domain?



...changing roles of humans

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the evolving cockpit

Yes, all information is presented to the pilot. But, in doing so, all cognition needs to be done by the human

High workload, low performance

Yes, most tasks are automated. But, in doing so, only a small part of the cognition needs to be done by the human

Low workload, low situation awareness

our approach: design systems
in which cognition is a *joint* process

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levels in interface design

- illumination, readability, colors, symbols
- integrated displays, configural displays, emergent features, principle of moving part
- ...so, what's next?

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the flight deck is . . .

- an “OPEN” system (Vicente)
  - extensive + complex interaction with the environment
- “the airborne office”

. . . a workplace for **cognitive** (team)**work**

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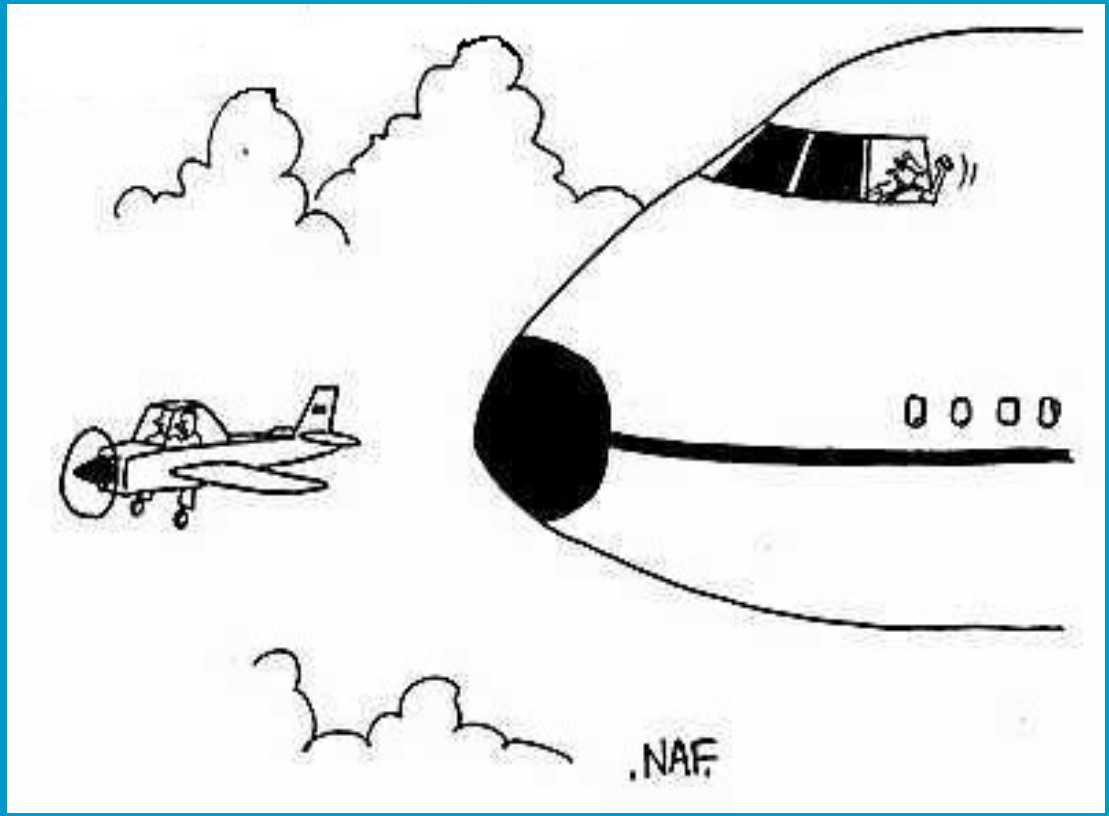
. . . is there an approach to automation and interface design that helps pilots with their (cognitive) tasks?

signal

sign

symbol



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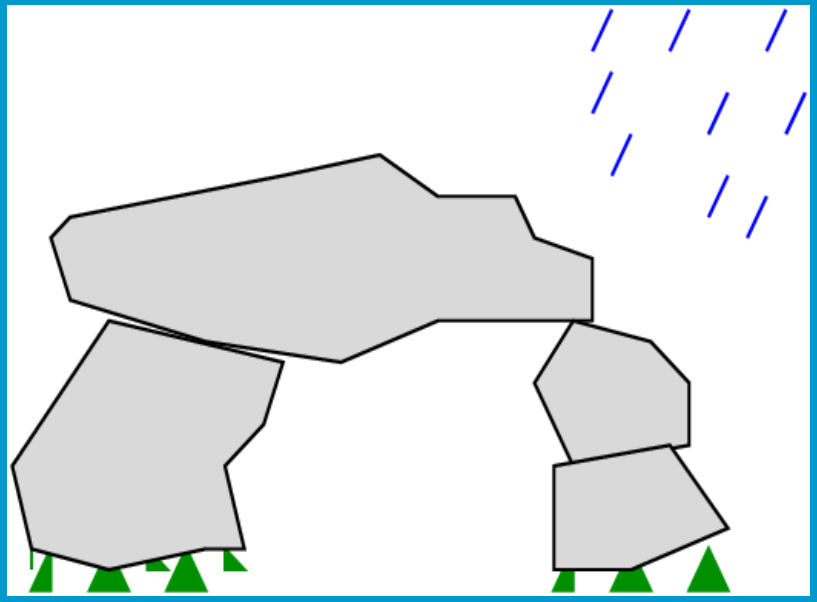
human capabilities
"direct perception" – Gibson



affording

specifying

perception-action coupling

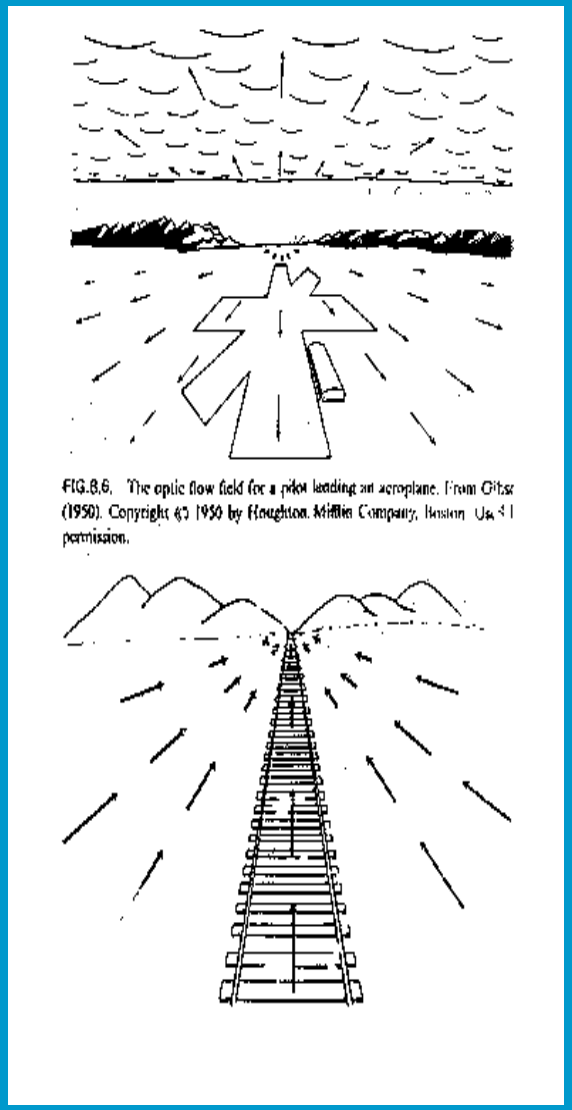


FIG.8.6. The optic flow field for a pilot landing an aeroplane. From Gibs (1950). Copyright © 1950 by Houghton Mifflin Company, Boston. Us permission.

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ecological interface design

(Vicente & Rasmussen, 1992)

Basic idea: "*make visible the invisible*"

Use technology to create an interface that provides meaningful information and that allows humans to directly act on the information to achieve their goals

Transfer a cognitive process into a perceptual process

Work Domain Analysis + Control task analysis
Strategies analysis
Social organization and cooperation
Worker competencies analysis

→ Interface design

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some “Delft” ecological interfaces

Aircraft control
Total Energy Management

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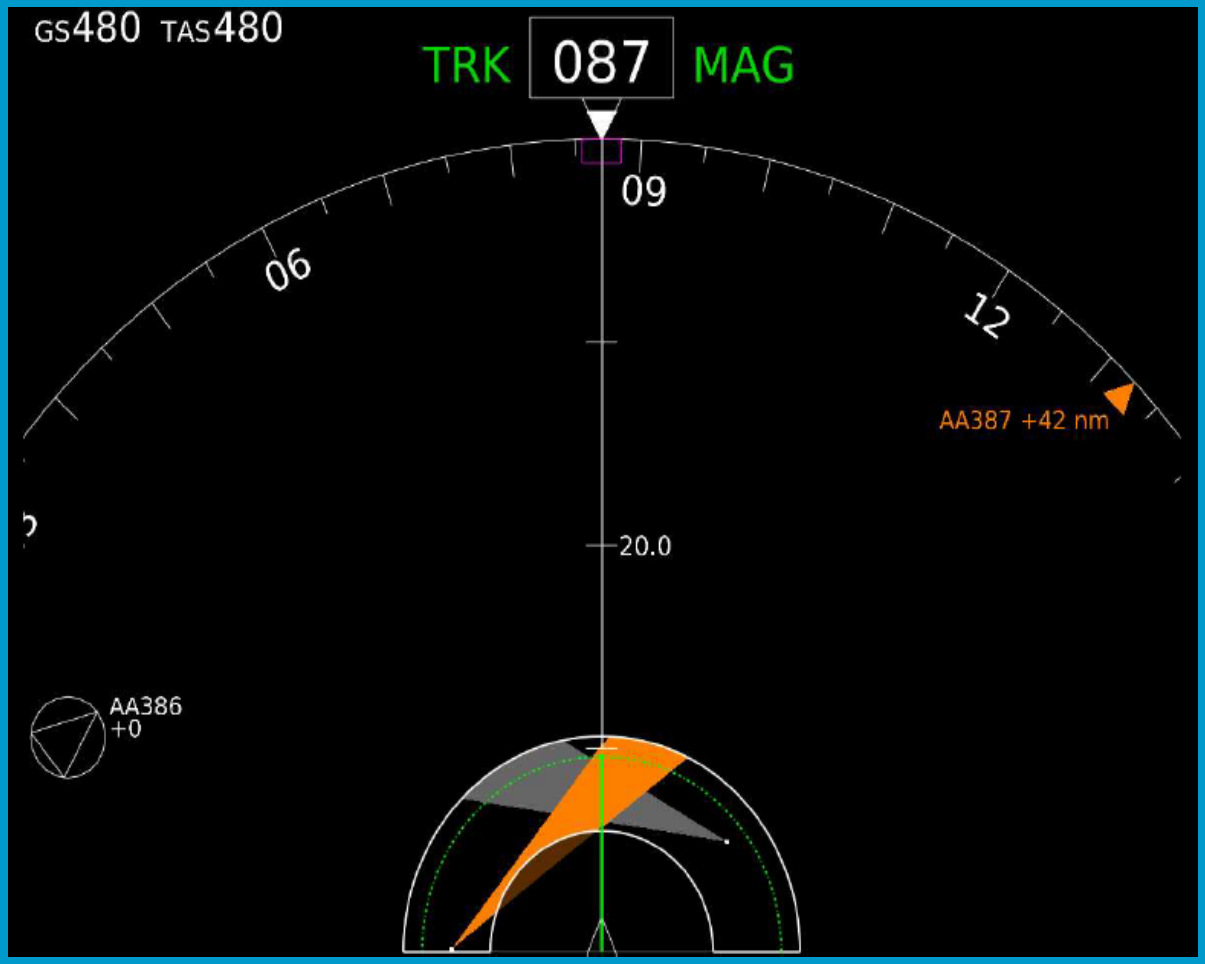
some “Delft” ecological interfaces



Aircraft control
Total Energy Management

Aircraft control
Separation Assistance

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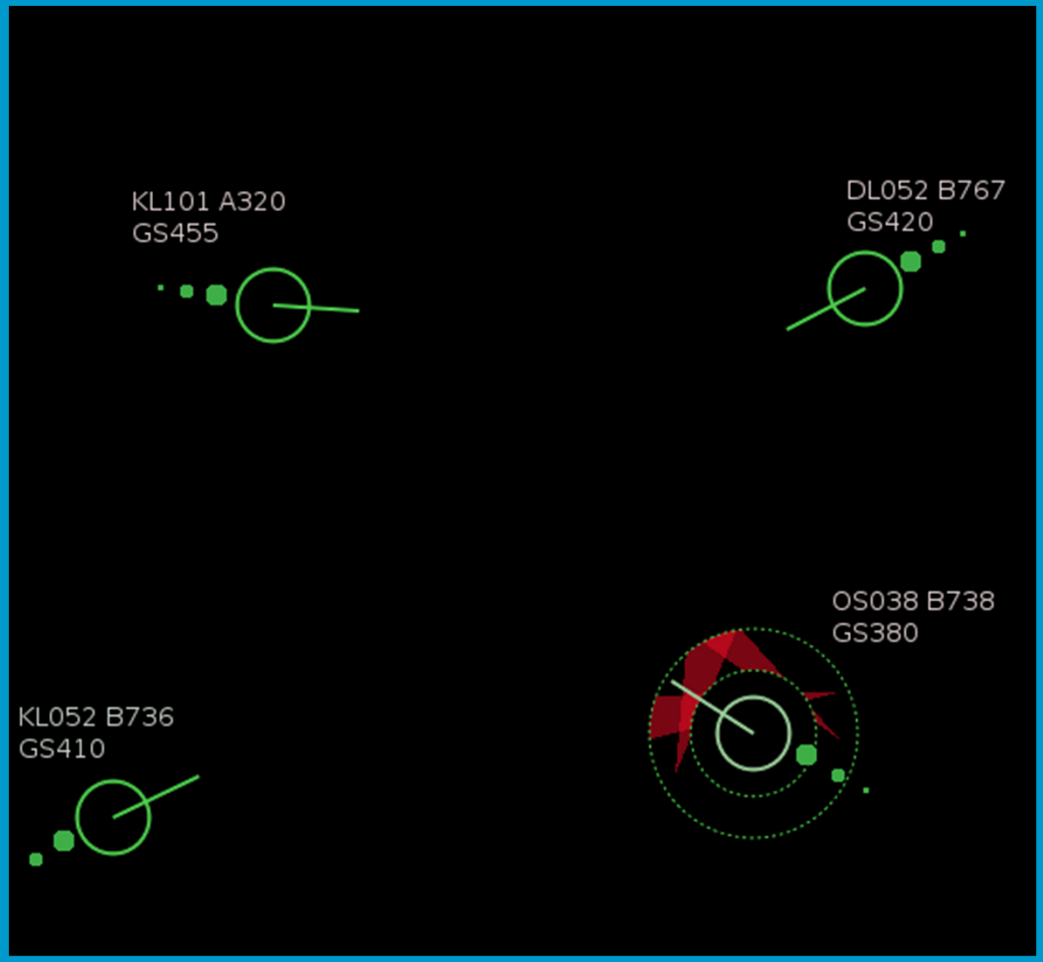
some “Delft” ecological interfaces



Aircraft control
Total Energy Management

Aircraft control
Separation Assistance

Air traffic control
Separation Assistance

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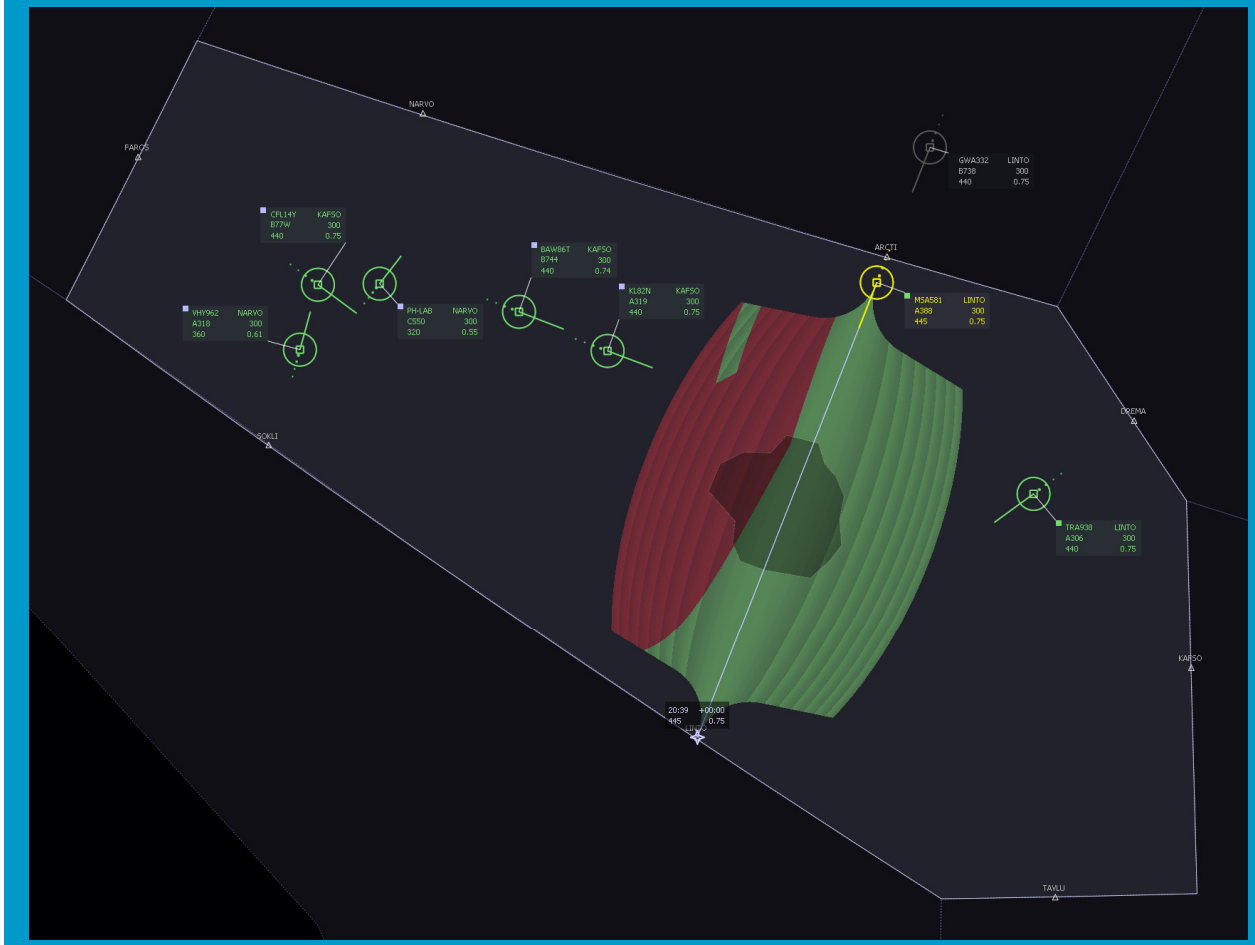
some “Delft” ecological interfaces



Aircraft control
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Air traffic control
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Air traffic control
4D trajectory management

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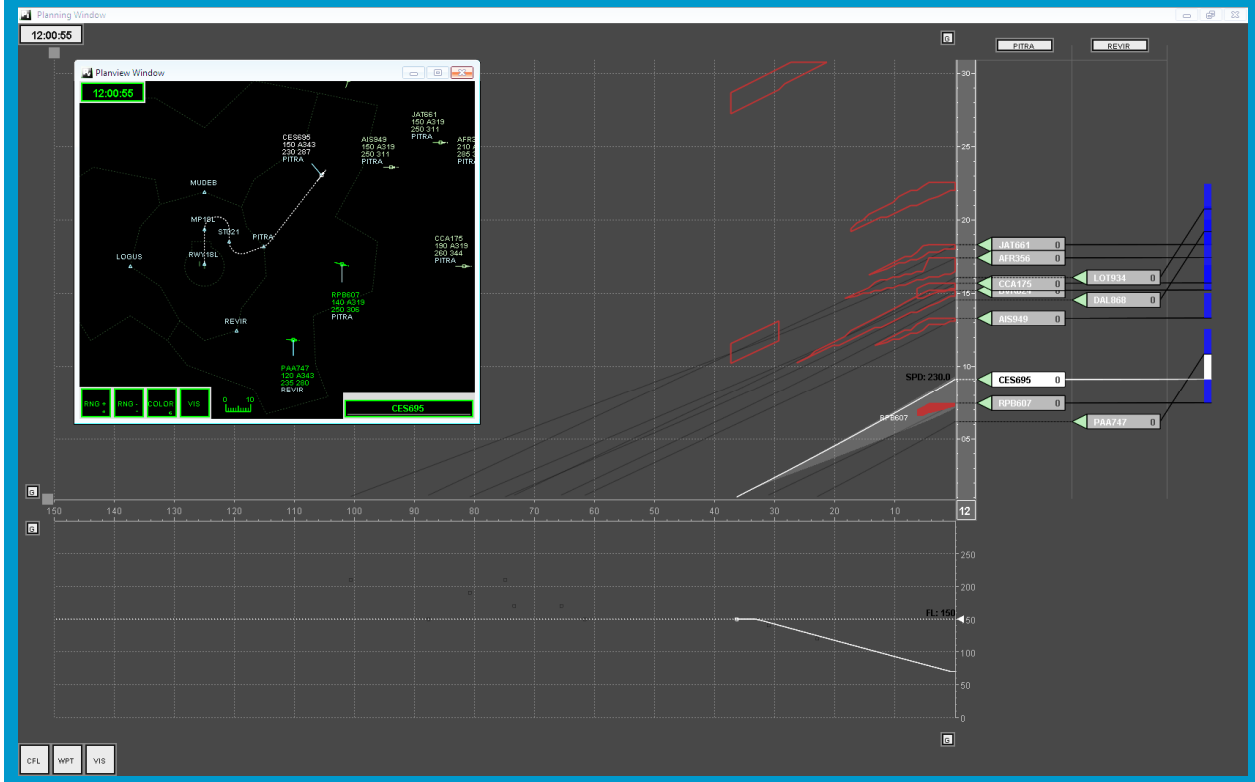
some “Delft” ecological interfaces



Aircraft control
Total Energy Management

Aircraft control
Separation Assistance

Air traffic control
Separation Assistance

Air traffic control
4D trajectory management

Air traffic control
Arrival management

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airborne separation assistance

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airborne separation assistance

Airborne Separation Assistance System (ASAS): *"The equipment, protocols, airborne surveillance and other aircraft state data, flight crew and ATC procedures which enable the **pilot** to exercise responsibility, in agreed and appropriate circumstances, for **separation of his aircraft from one or more aircraft**."* (source ICAO SICASP/6-WP/44)

ASAS functionalities:

1. Maintaining an **overview** of the surrounding traffic
2. **Detecting** potential loss of separation conflicts
3. **Resolving** conflicts
4. **Preventing** aircraft to run into new conflicts

our example
2D only

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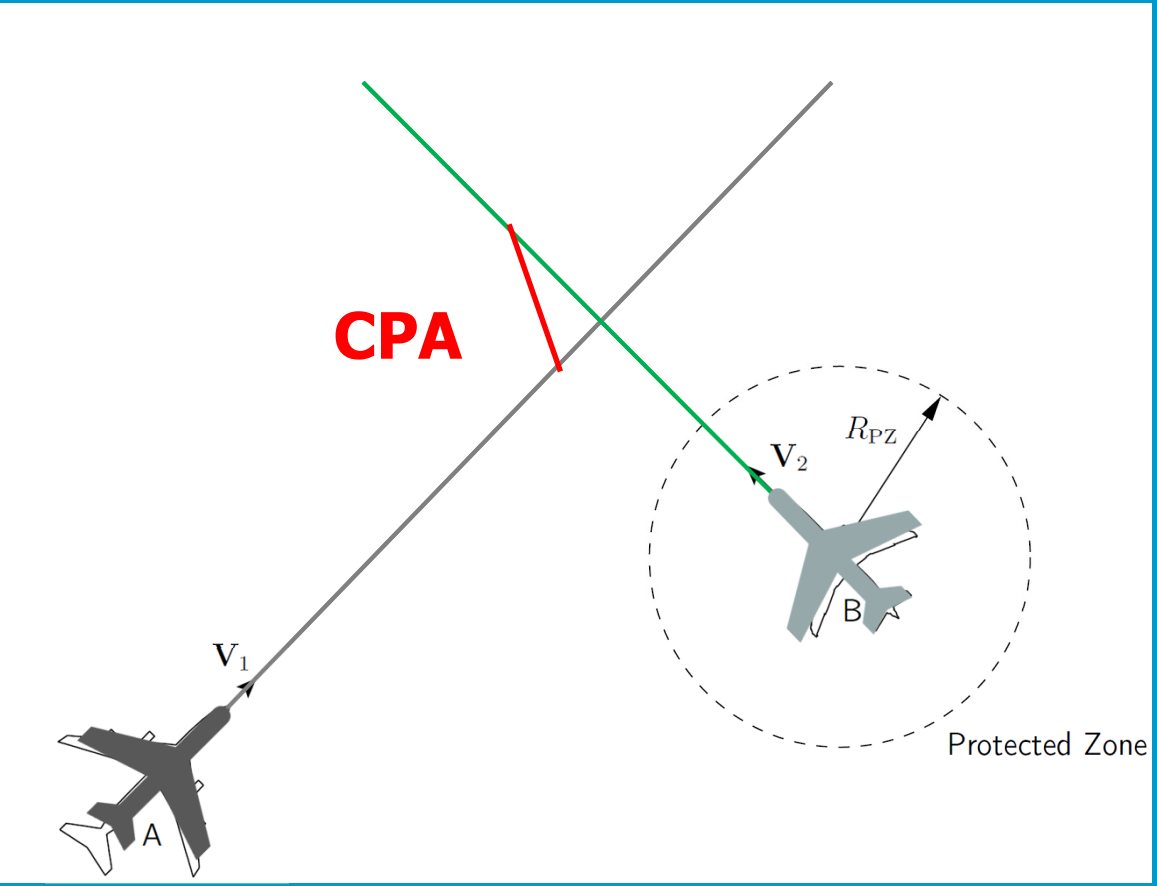
airborne separation assistance

What is the problem?



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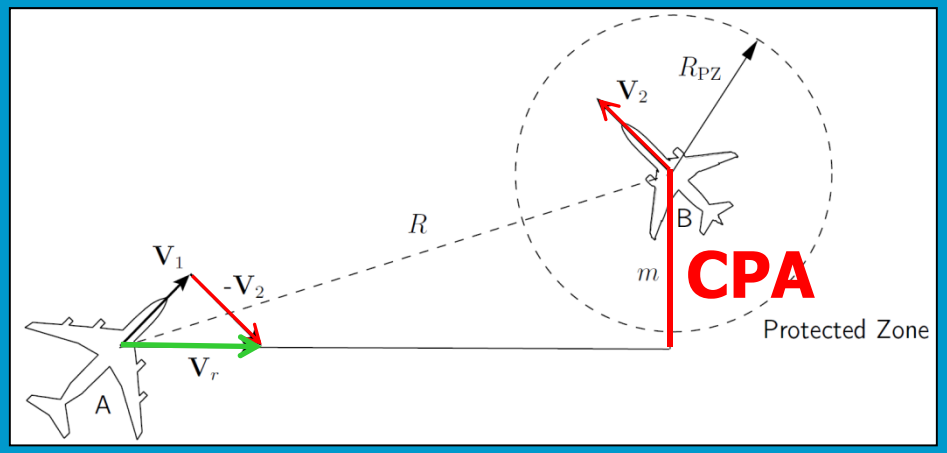
typical engineering approach



TRAFFIC!

IF ($t_m \leq$ look-ahead time) AND ($|m| < R_{PZ}$)

conflict = TRUE

ELSE

conflict = FALSE

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pitfalls of automation

- hidden rationale
- intent confusion
- reduced situation awareness
- disagreement
- overreliance
- lack of trust
- …

WHAT is it doing? WHY is it doing that? It is doing it AGAIN!!??

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EID: work domain analysis

Functional Purpose	Production	Efficiency	Safety	
Abstract Functions	Absolute & relative locomotion		Separation	WHY?
Generalized Functions	Maneuvering Coordination		Obstruction	**WHAT??**
Physical Functions	Control units		Traffic	HOW?
Physical Form	Location & state of own aircraft	Other aircraft locations & states		

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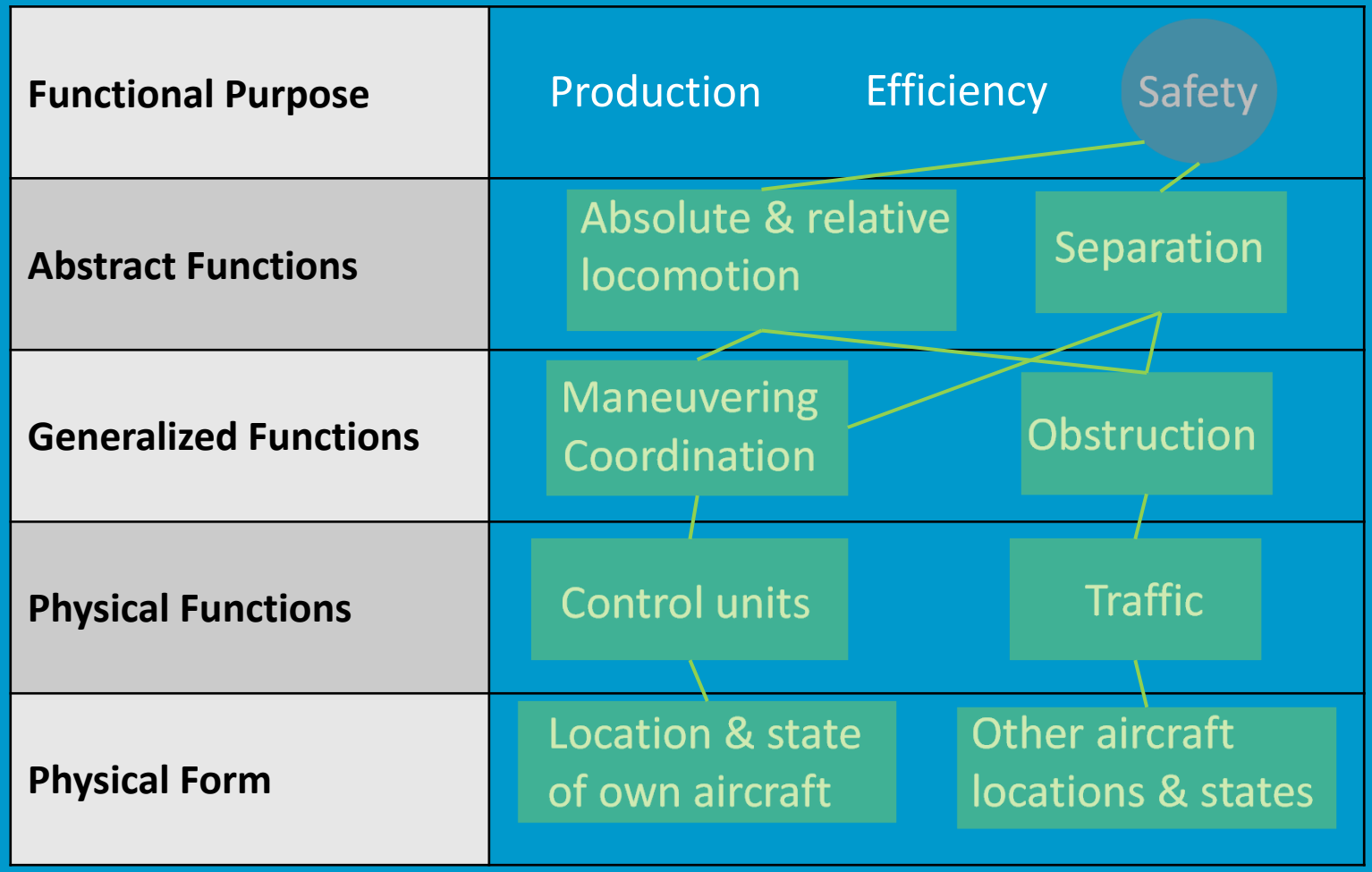
EID: work domain analysis



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typical automation & interface in the AH

Functional Purpose	Production, Efficiency, Safety
AUTOMATION	
Physical Functions	Control units, Traffic
Physical Form	Location & state of own aircraft, Other aircraft locations & states

TRAFFIC!

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make visible the invisible

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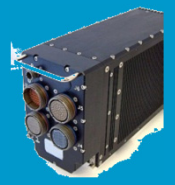

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improve the interface: visualise the CPA

- conflict location moves when maneuvering
- affordance 'hit' is clear, affordance 'avoidance' is not
- only heading, no speed
- new conflicts triggered by manoeuvres

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improve the interface: visualise the CPA

- conflict location moves when maneuvering
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- new conflicts triggered by manoeuvres

Add 'heading' and 'speed' bands, *computed by automation*

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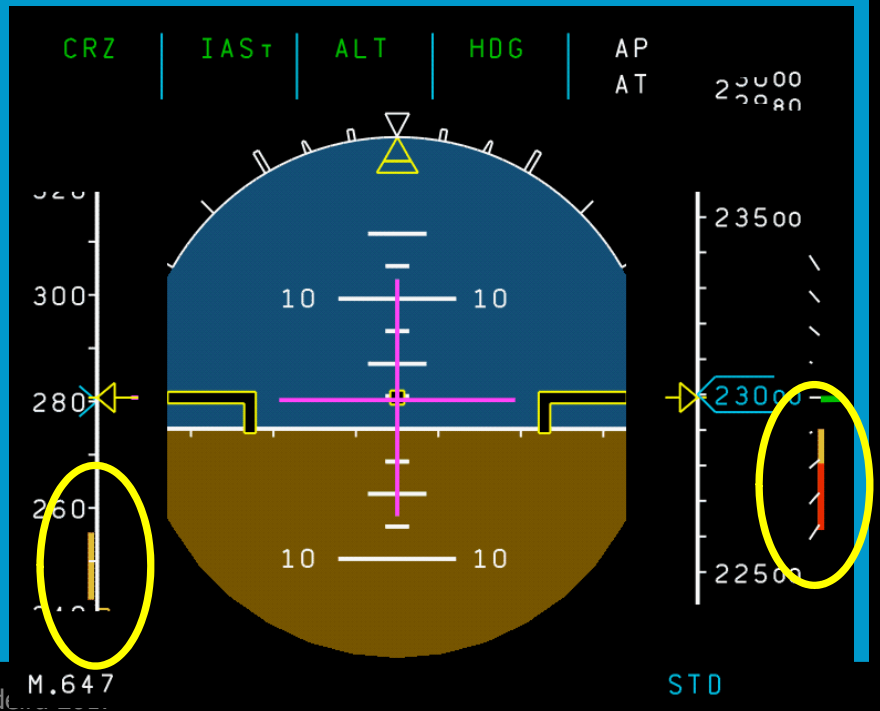
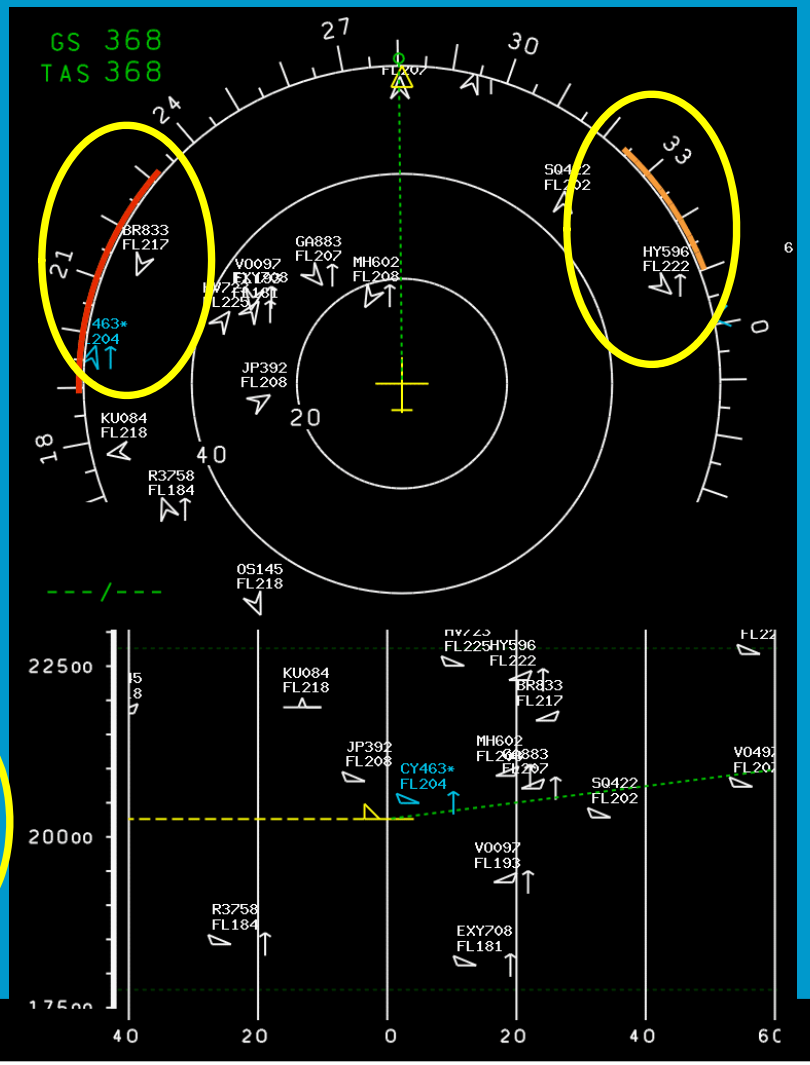
predictive ASAS (1)

ADD "no-go" bands for

- track/heading
- vertical speed and speed





predictive ASAS (2)

- conflict location moves when maneuvering
- affordance 'hit' is clear, affordance 'avoidance' is not
- only heading, no speed
- new conflicts triggered by manoeuvres

optimal maneuver
when speed also changes

Add 'heading' and 'speed' bands, *computed by automation*

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predictive-ASAS issues

- yes, we can see how to avoid aircraft,
- but *we* cannot see how to do it efficiently, and
- the computer-aided optimal solution can be *within* a no-go heading or speed zone....

- **so how can we check that the computer is right??**

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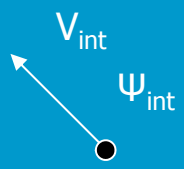
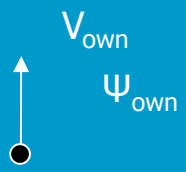
we took another look at a conflict situation

assume we have two aircraft



intruder



own

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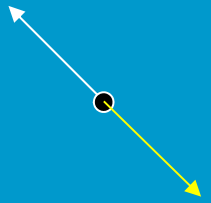
and created an ecological interface

....set intruder aircraft to stand still



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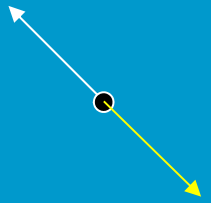
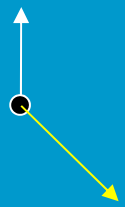
ecological ASAS

...then we should also change the speed of own...





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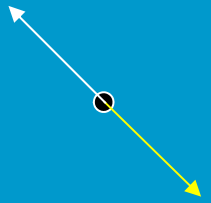
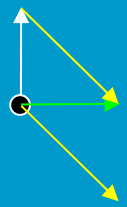
....calculate relative speed





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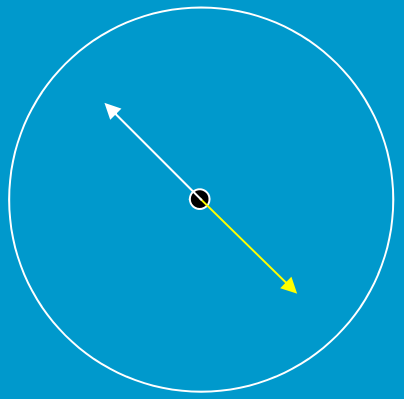
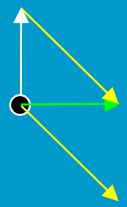
ecological ASAS

....add the protected zone





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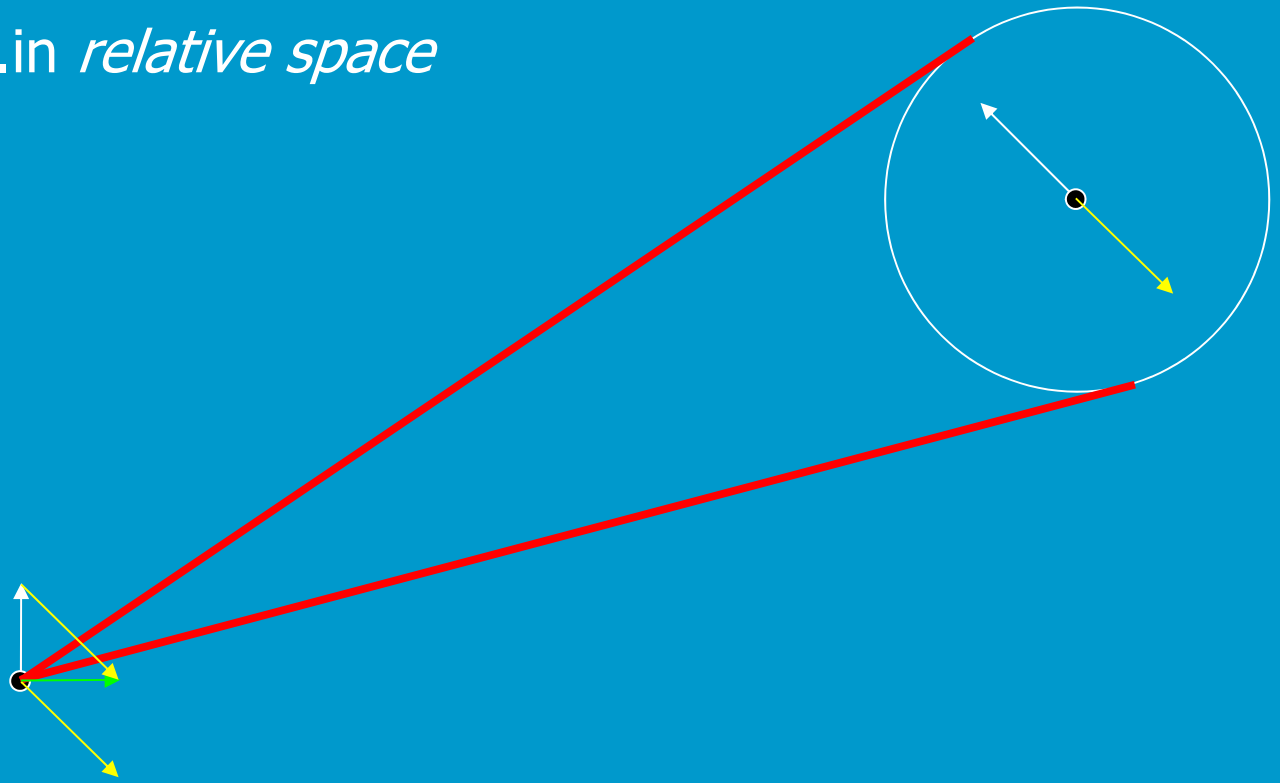
....create Forbidden Beam Zone

....in *relative space*



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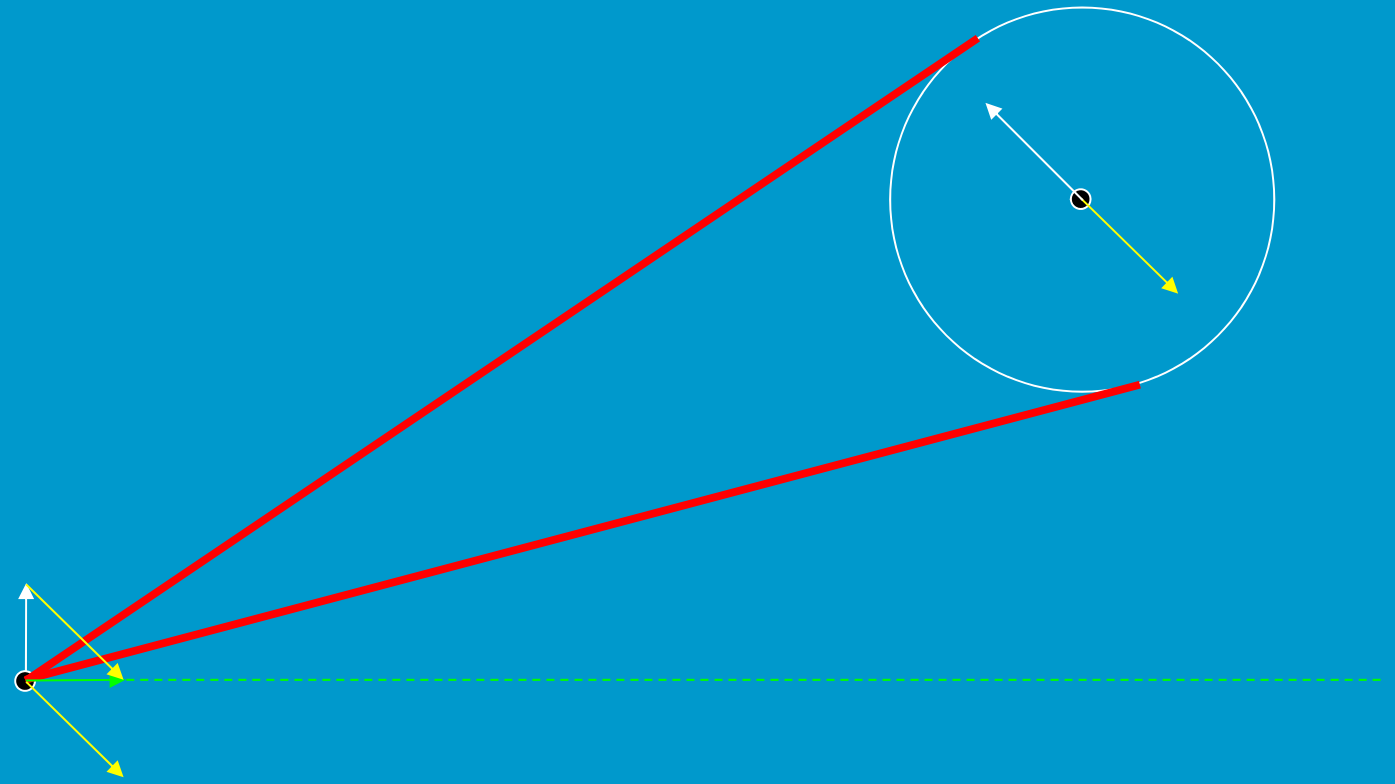
....here: we're safe



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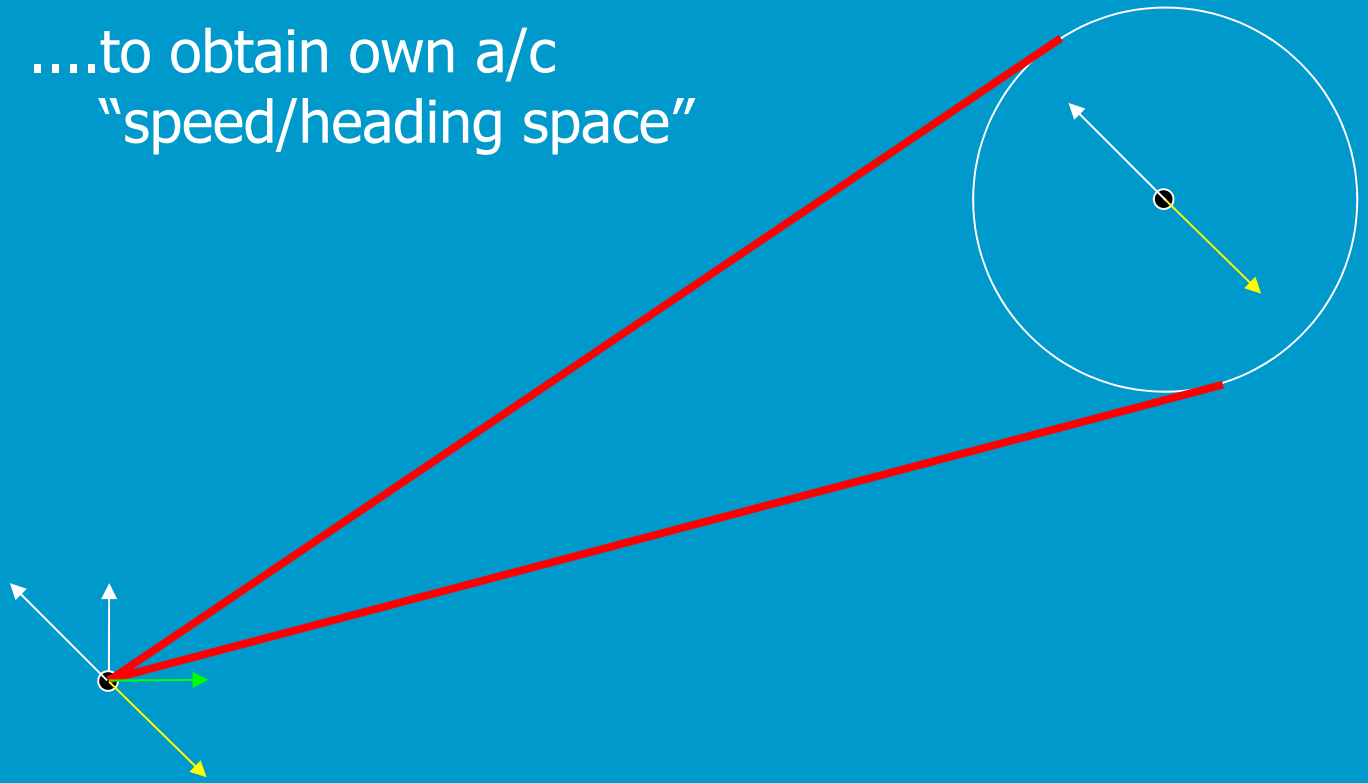
....move FBZ with intruder speed

....to obtain own a/c
"speed/heading space"



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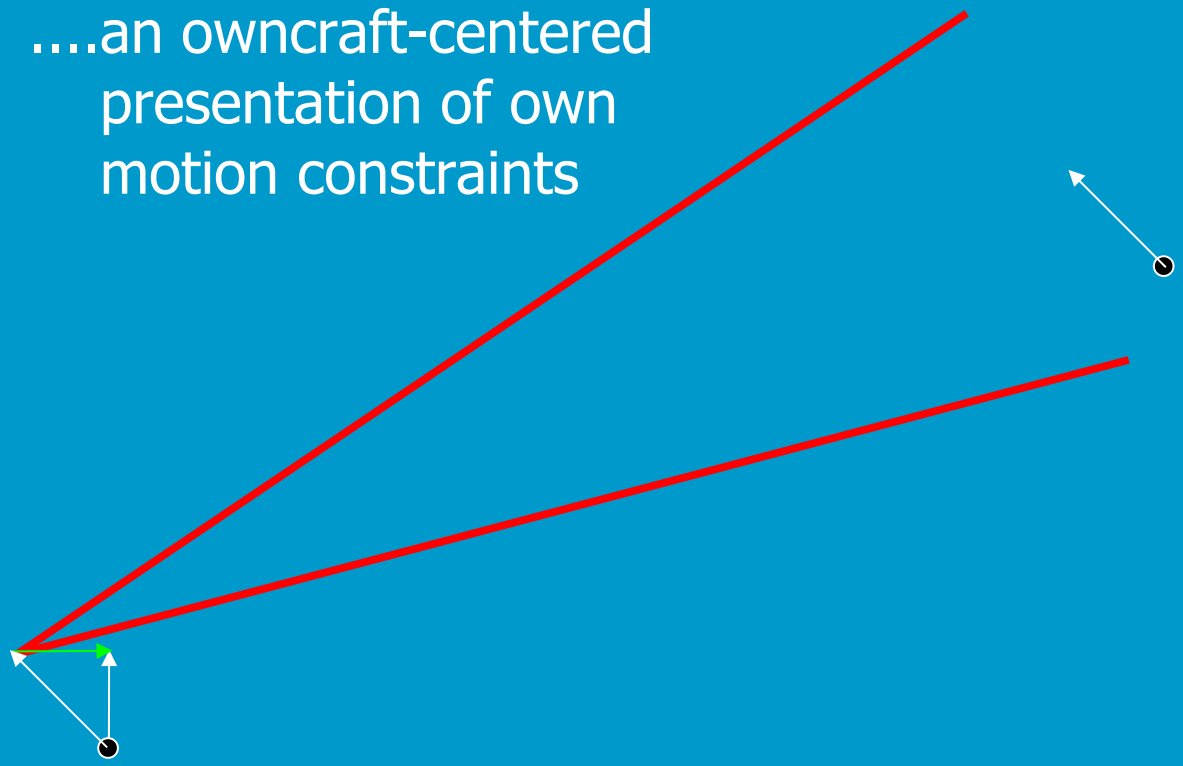
ecological ASAS

....an owncraft-centered
presentation of own
motion constraints



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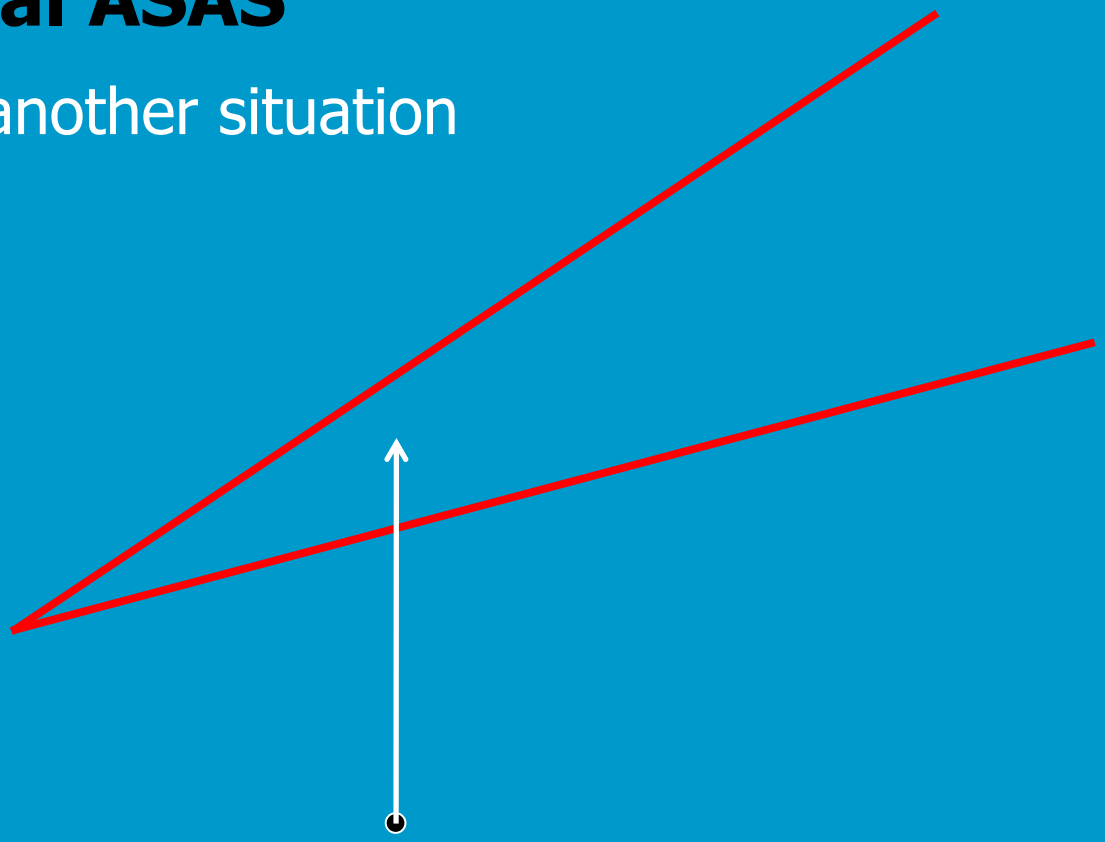
ecological ASAS

....look at another situation



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ecological ASAS

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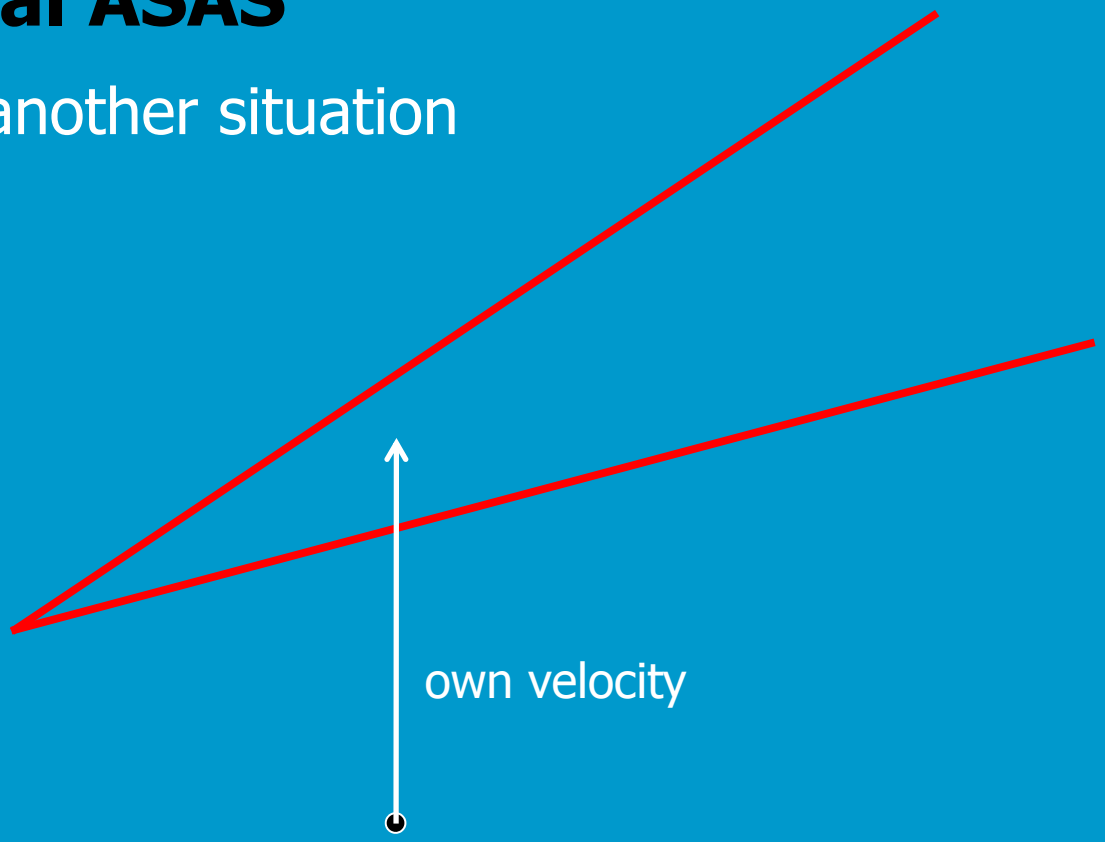

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ecological ASAS

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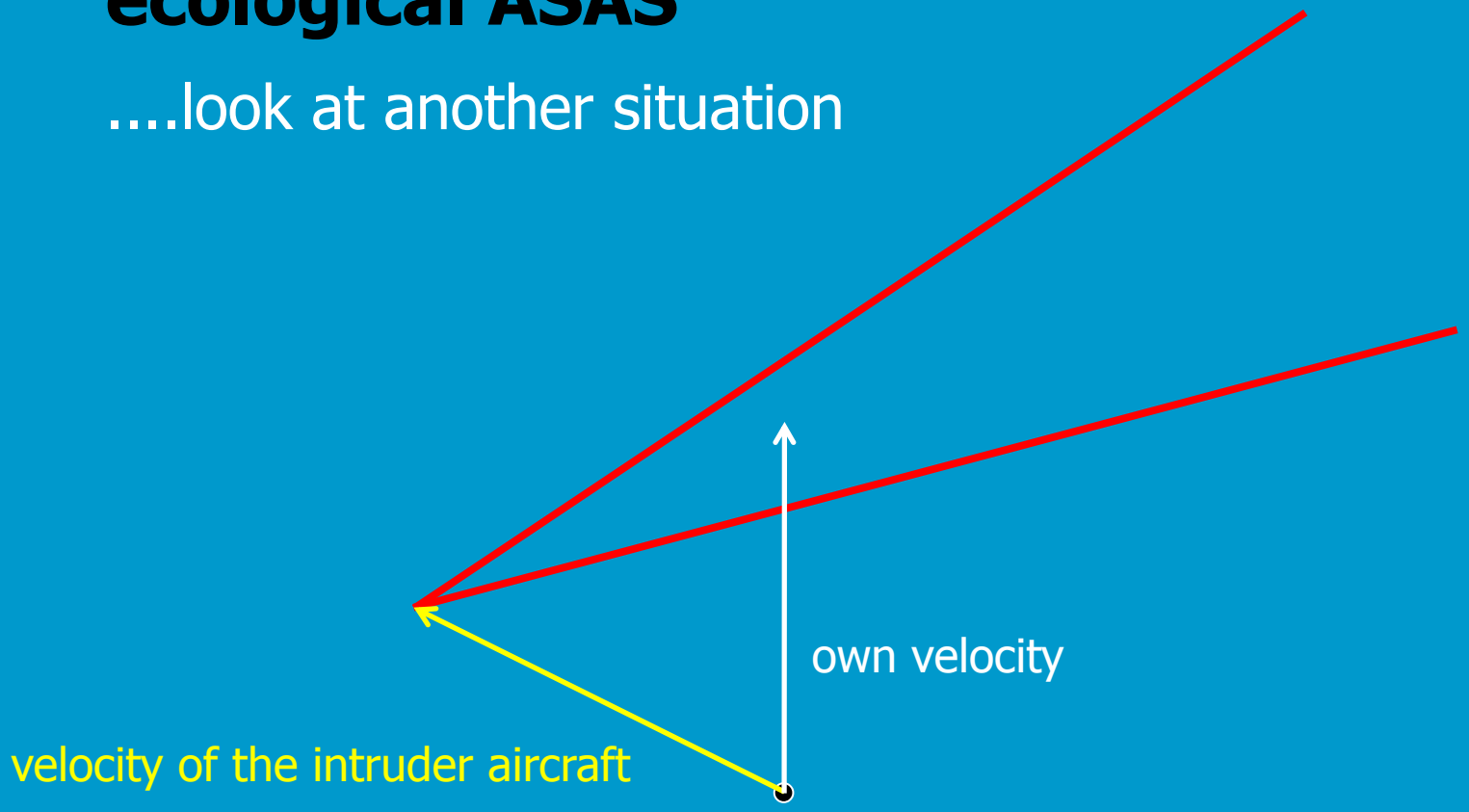

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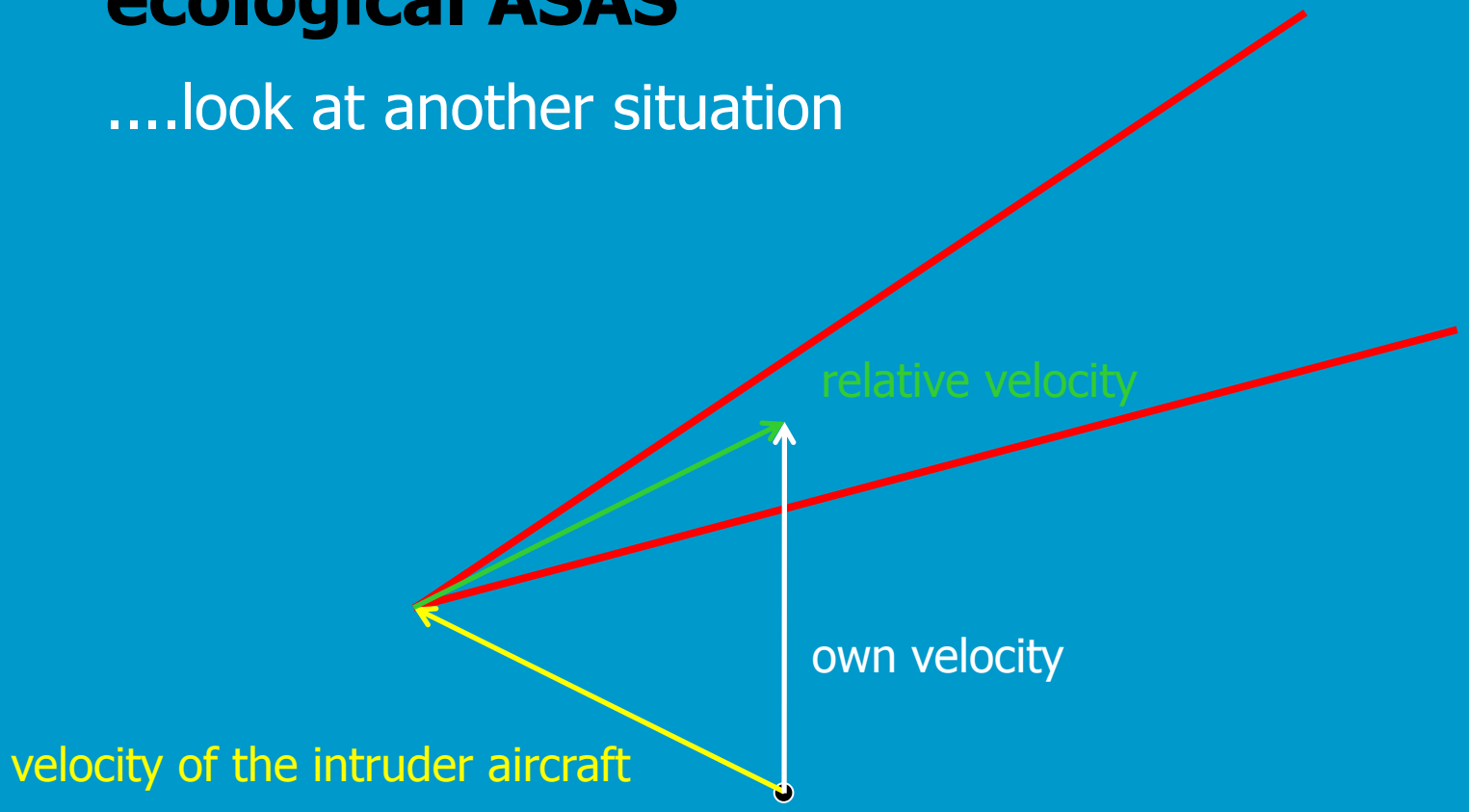

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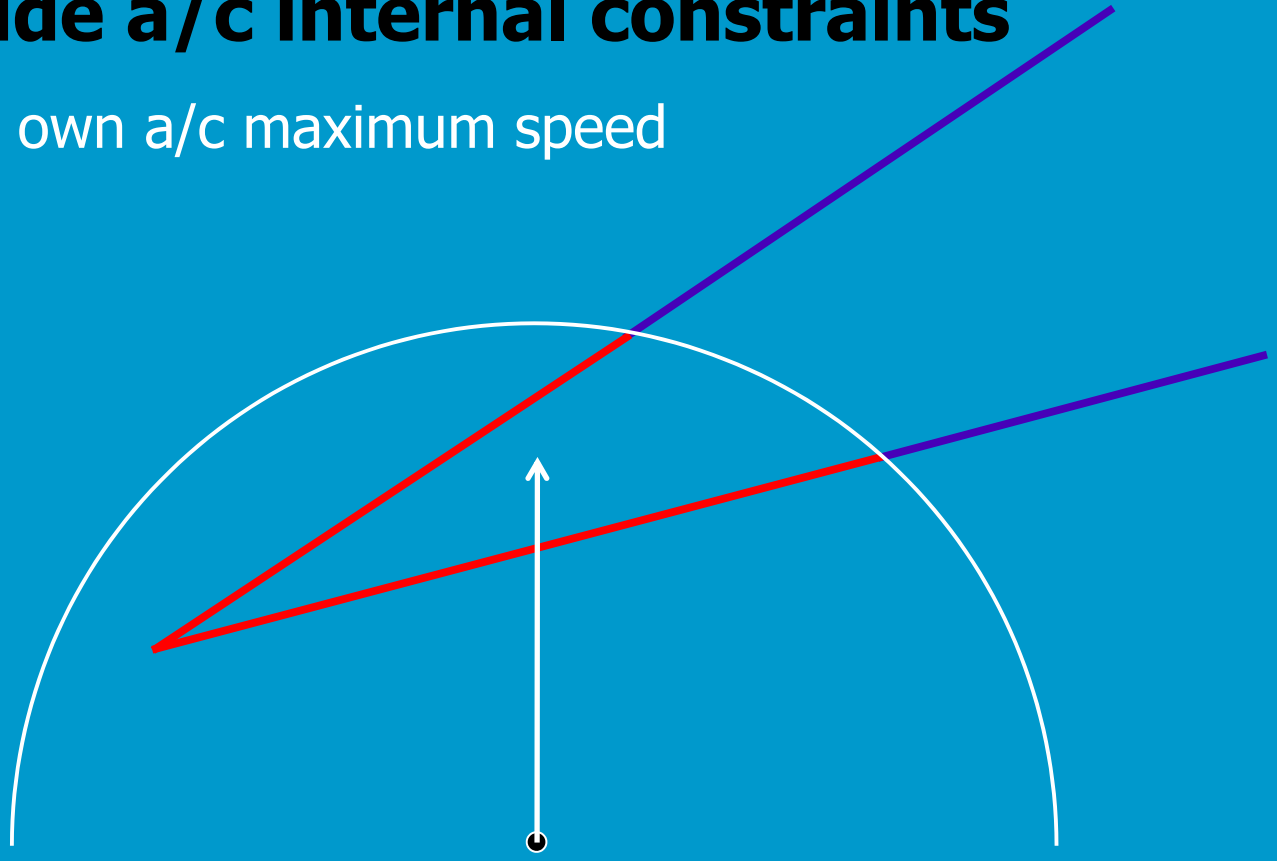
include a/c internal constraints

....add own a/c maximum speed



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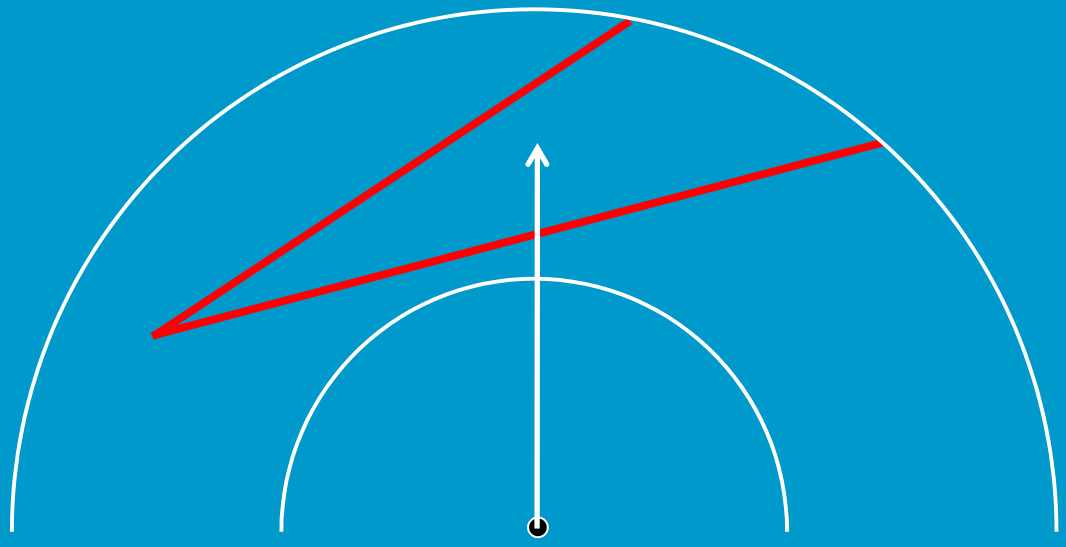
include a/c internal constraints

....add own a/c minimum speed



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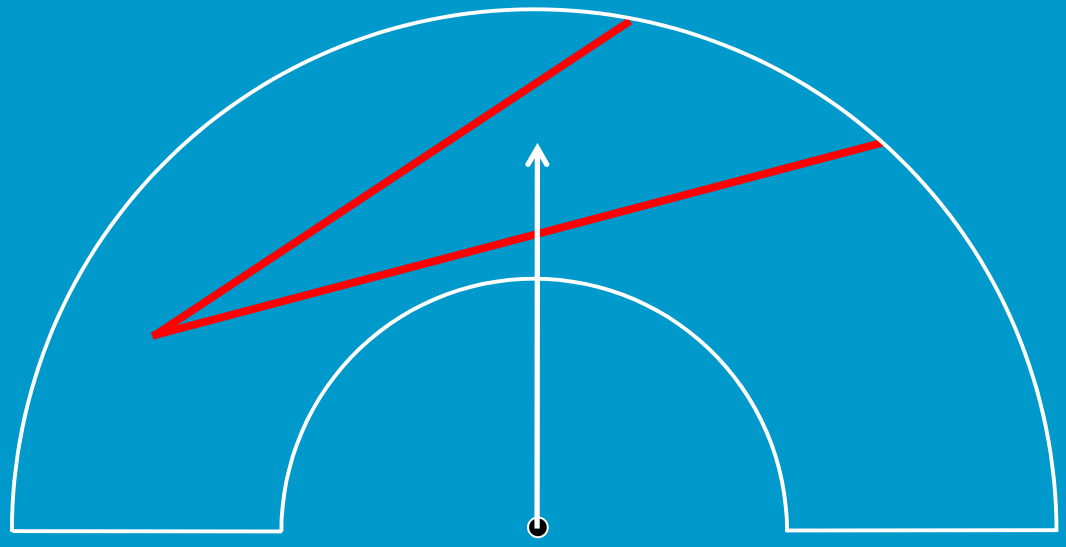
include a/c internal constraints

....add maximum heading changes for productivity



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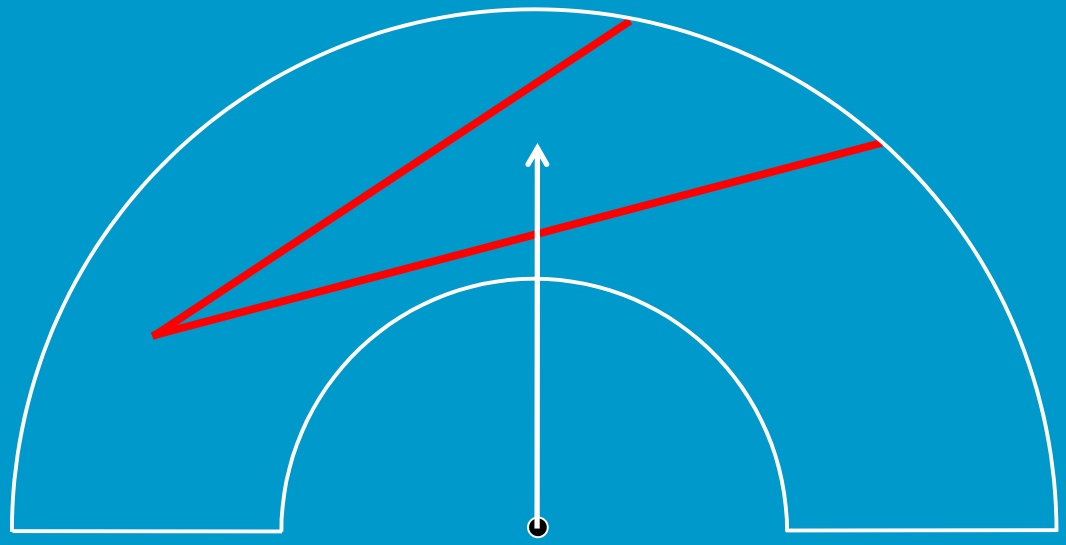
…the ecological ASAS display

….the result is the “state vector envelope” for 2D motion



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demo: conflict with one aircraft

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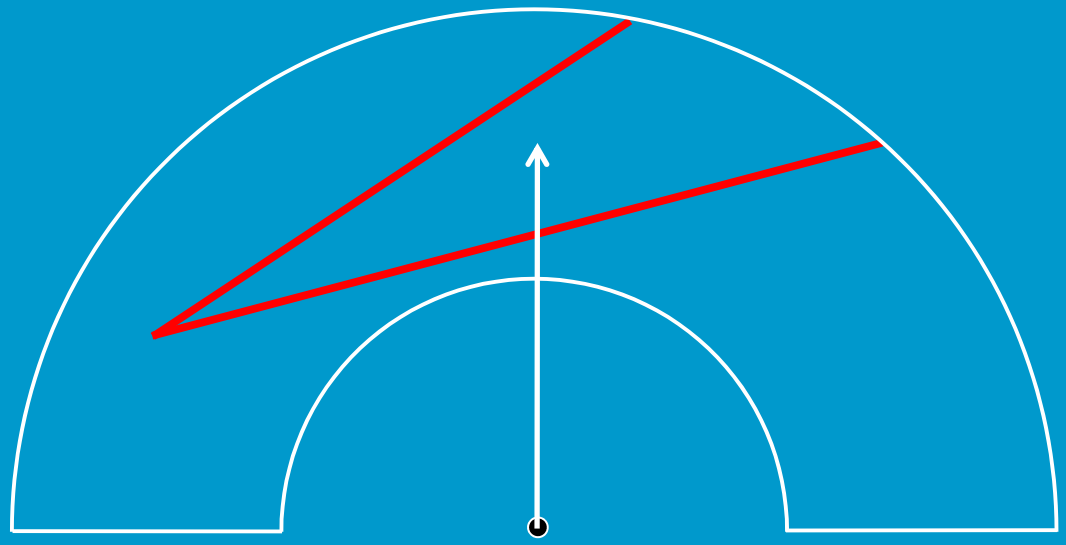
EID aims to show all constraints

....heading bands??



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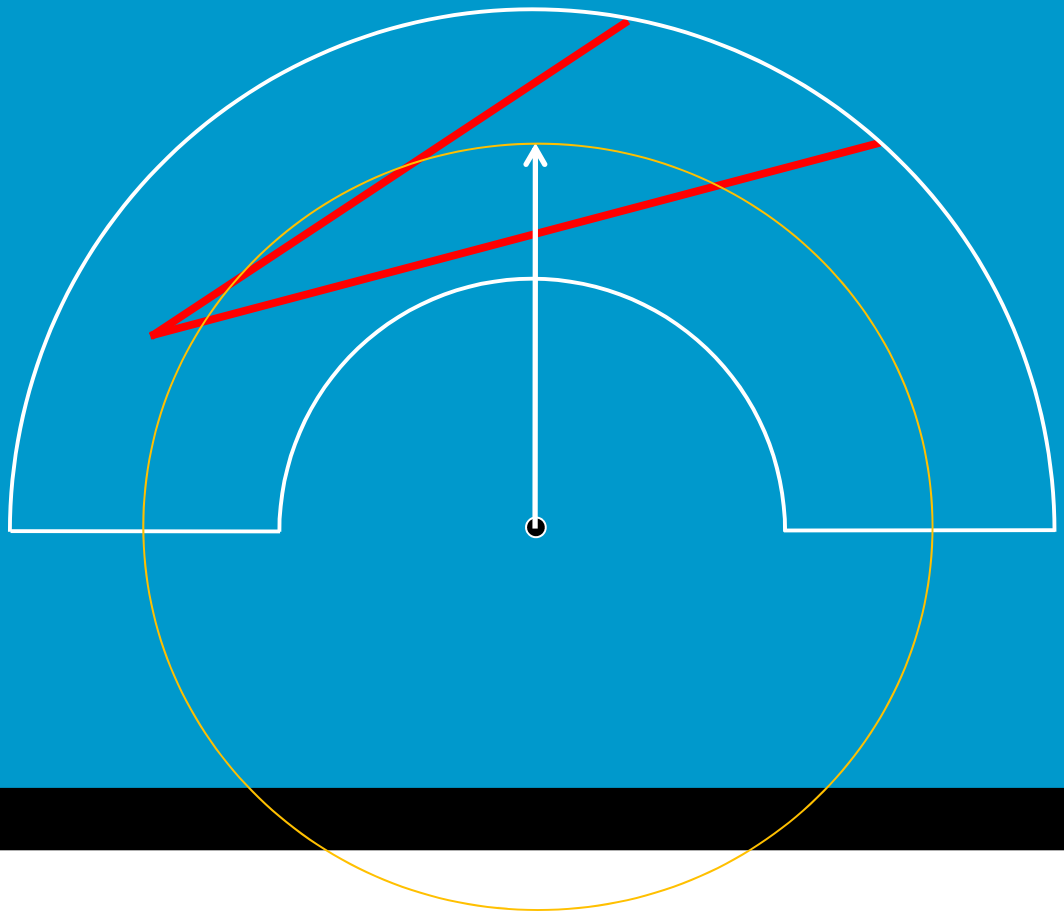

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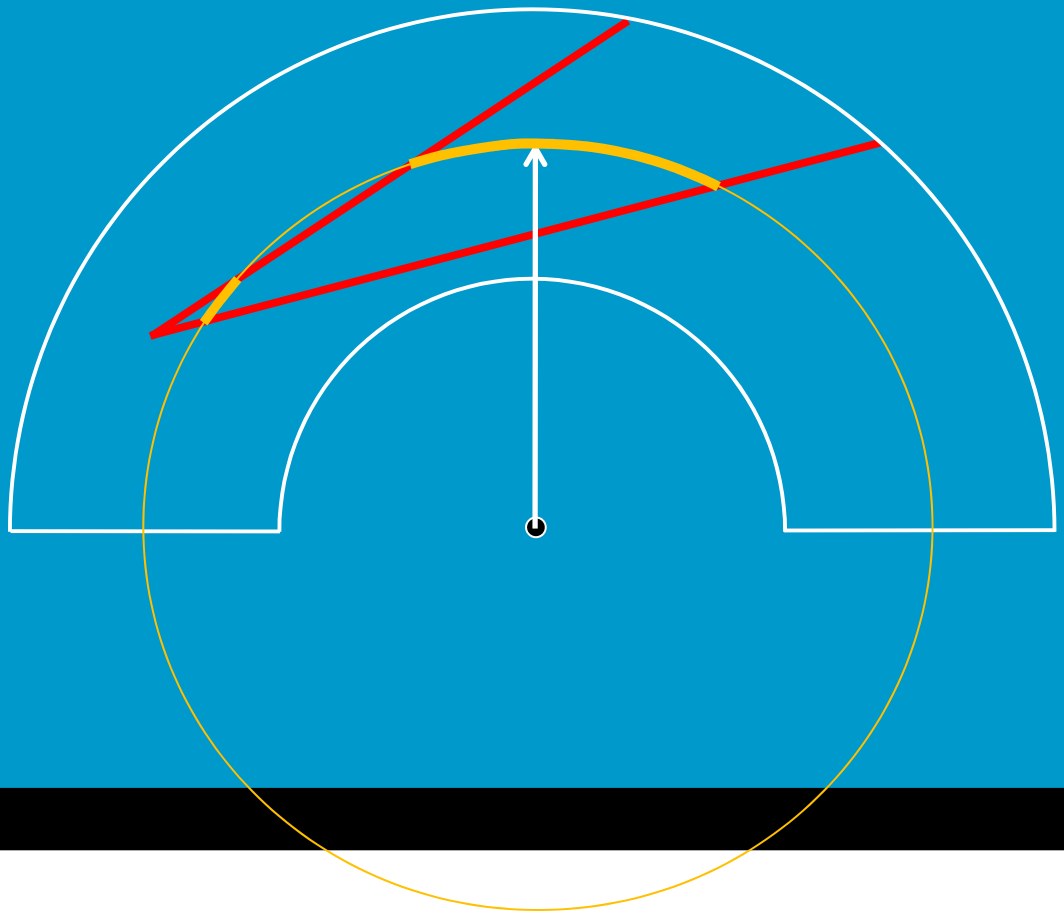
EID aims to show all constraints

....heading bands!



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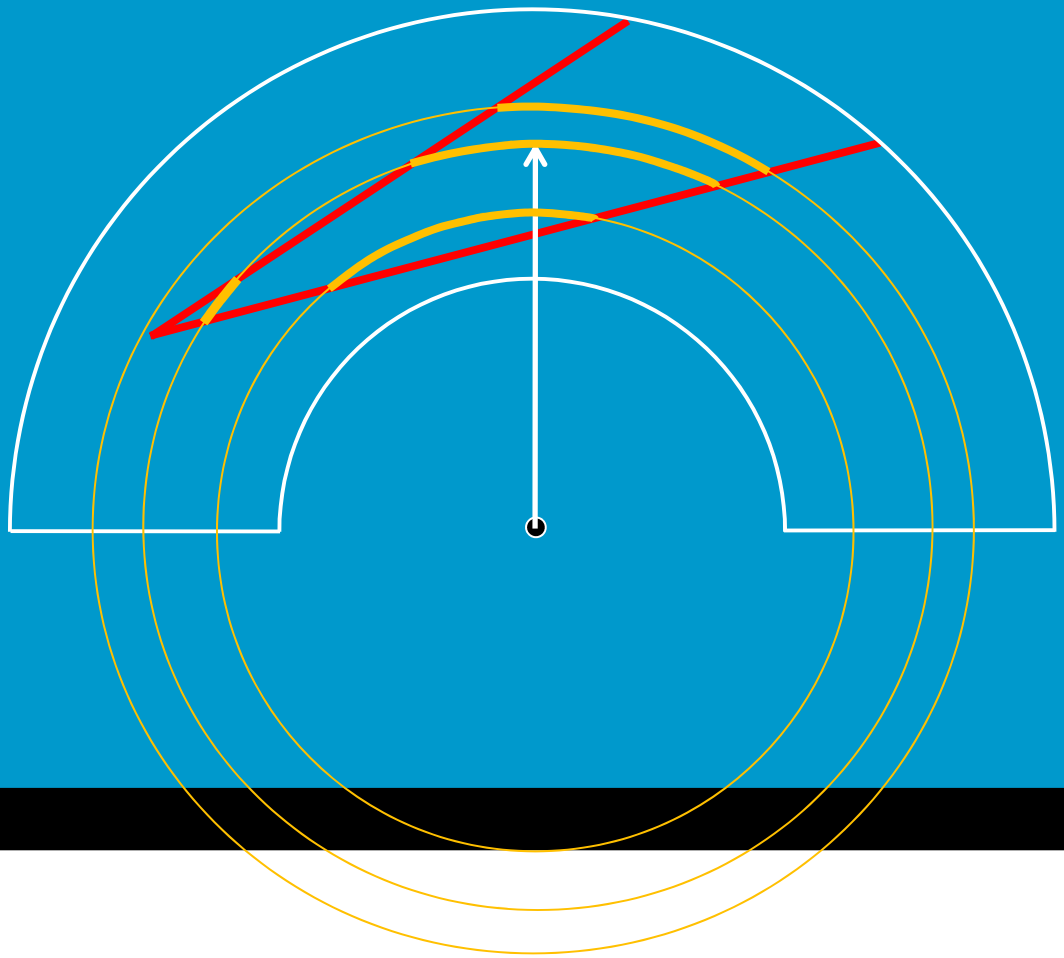
EID shows all constraints

....a whole family of heading bands!



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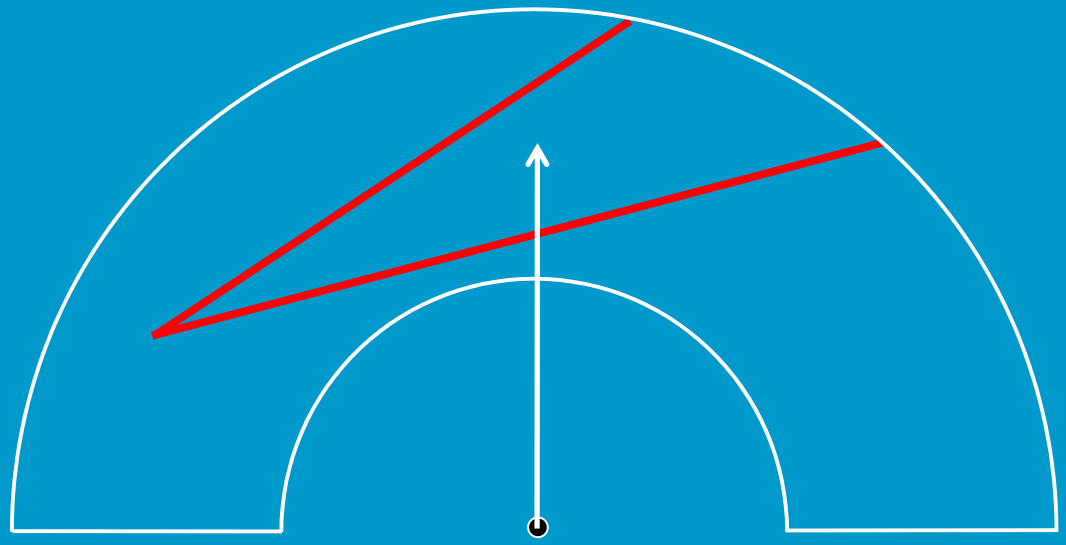
EID shows all constraints

....speed bands??



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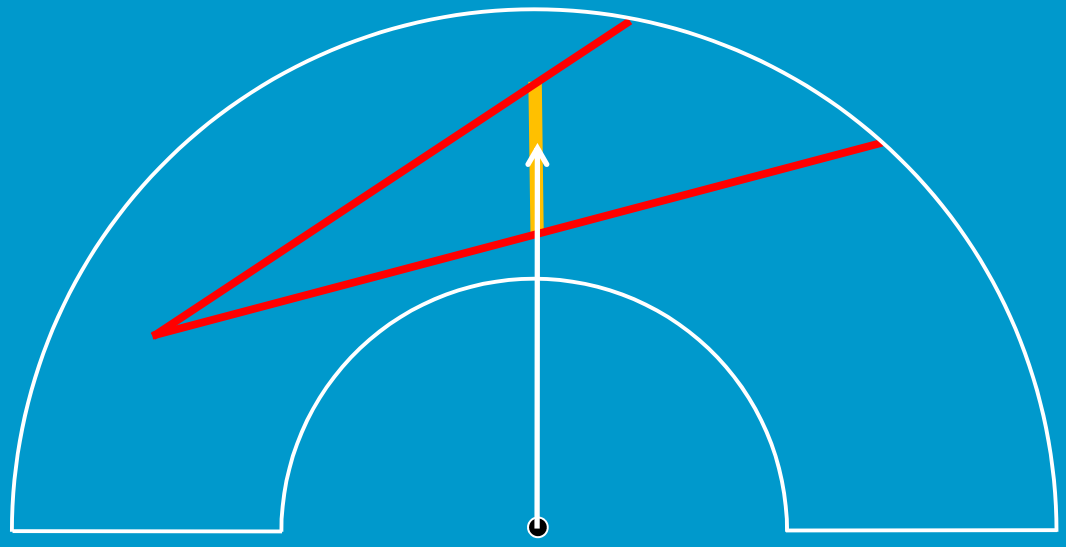

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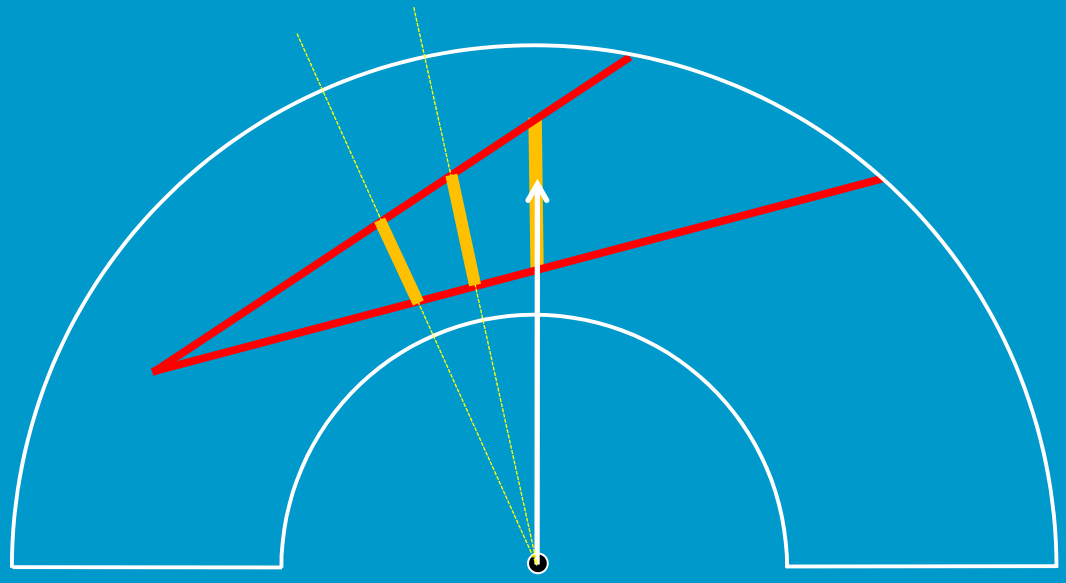

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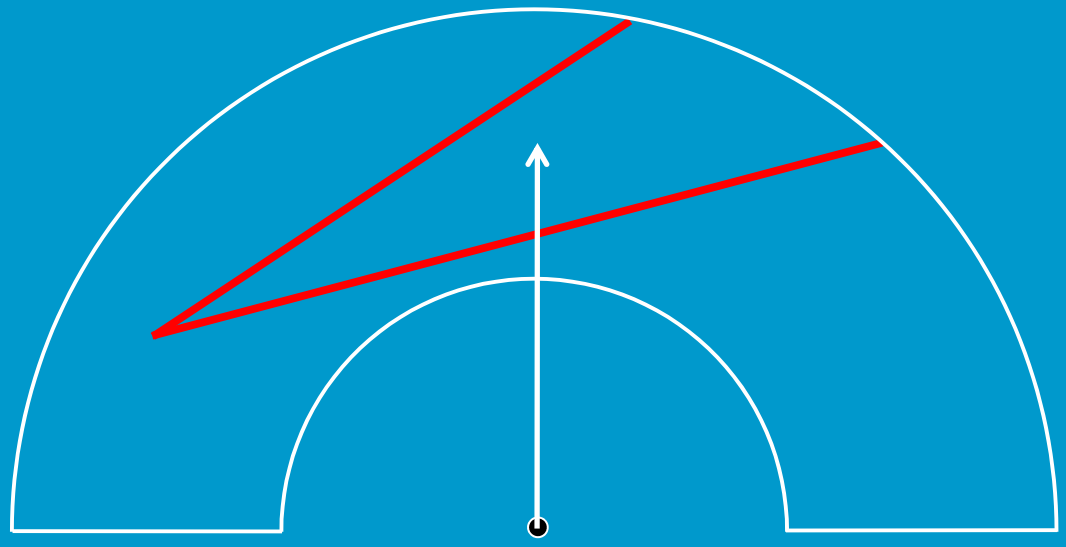
EID shows all constraints

....optimal solution??



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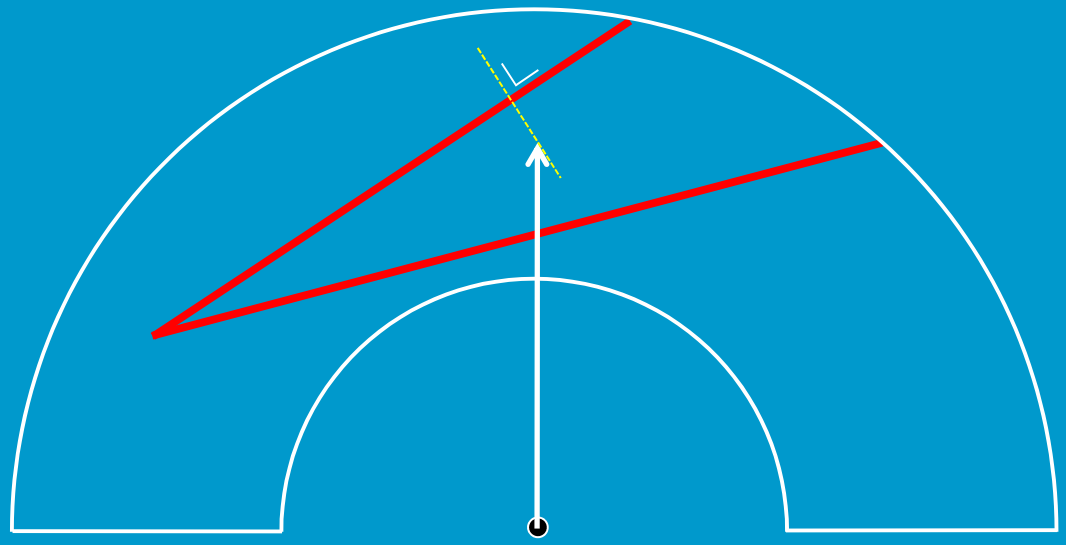
EID shows all constraints

....optimal solution!



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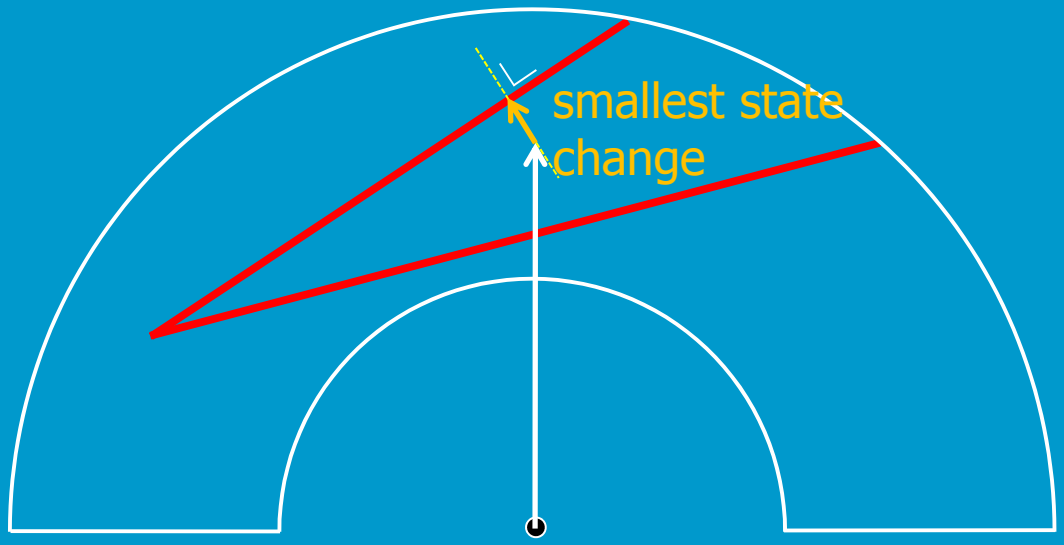
EID shows all constraints

....optimal solution!



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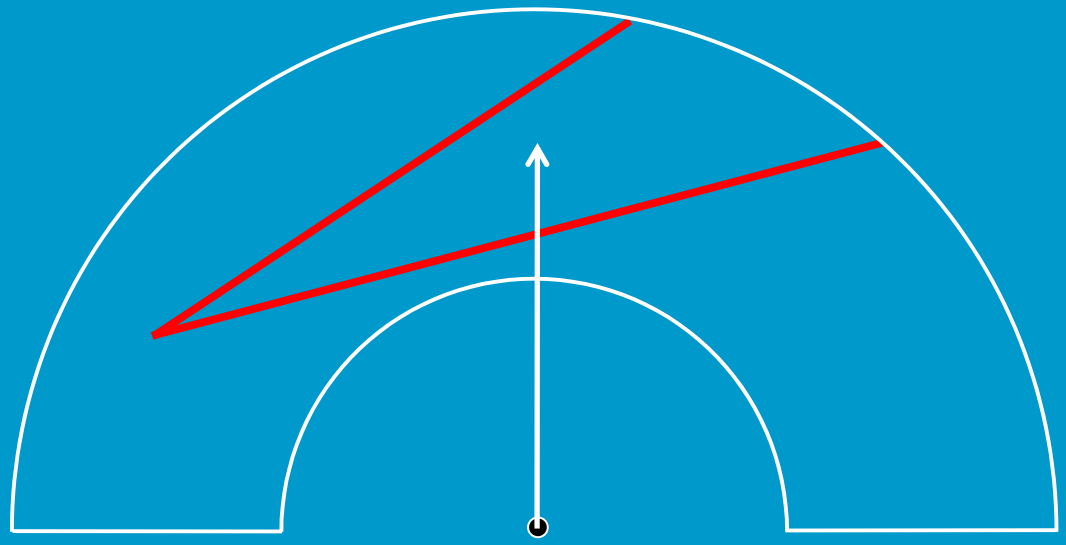
EID shows all constraints

....multiple intruder aircraft??



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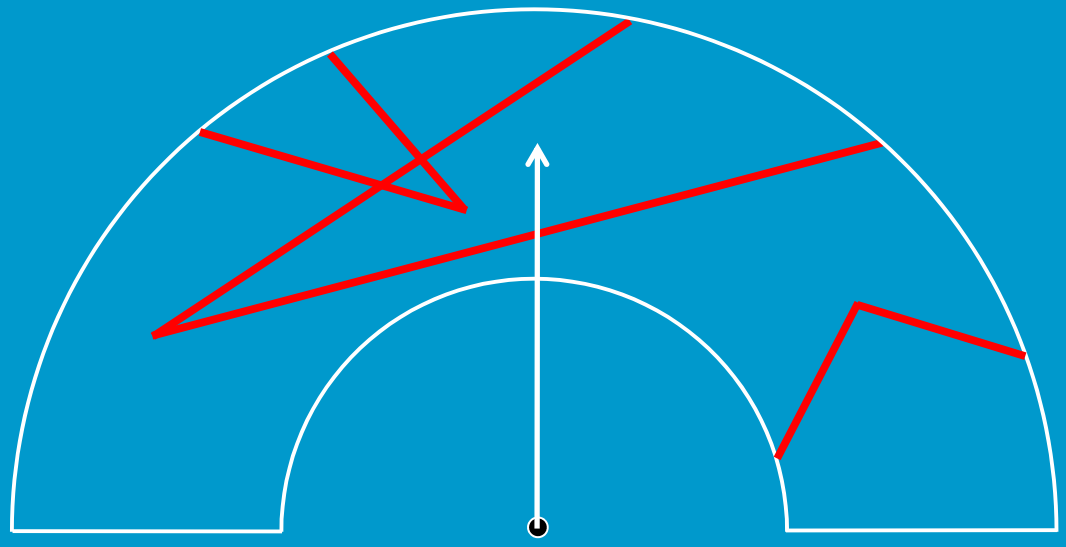
EID shows all constraints

....multiple intruder aircraft!



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demonstration: multiple intruders

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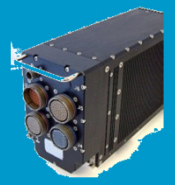
make visible the invisible

Functional Purpose	Production, Efficiency, Safety
AUTOMATION	
Physical Functions	Control units, Traffic
Physical Form	Location & state of own aircraft, Other aircraft locations & states

TRAFFIC!



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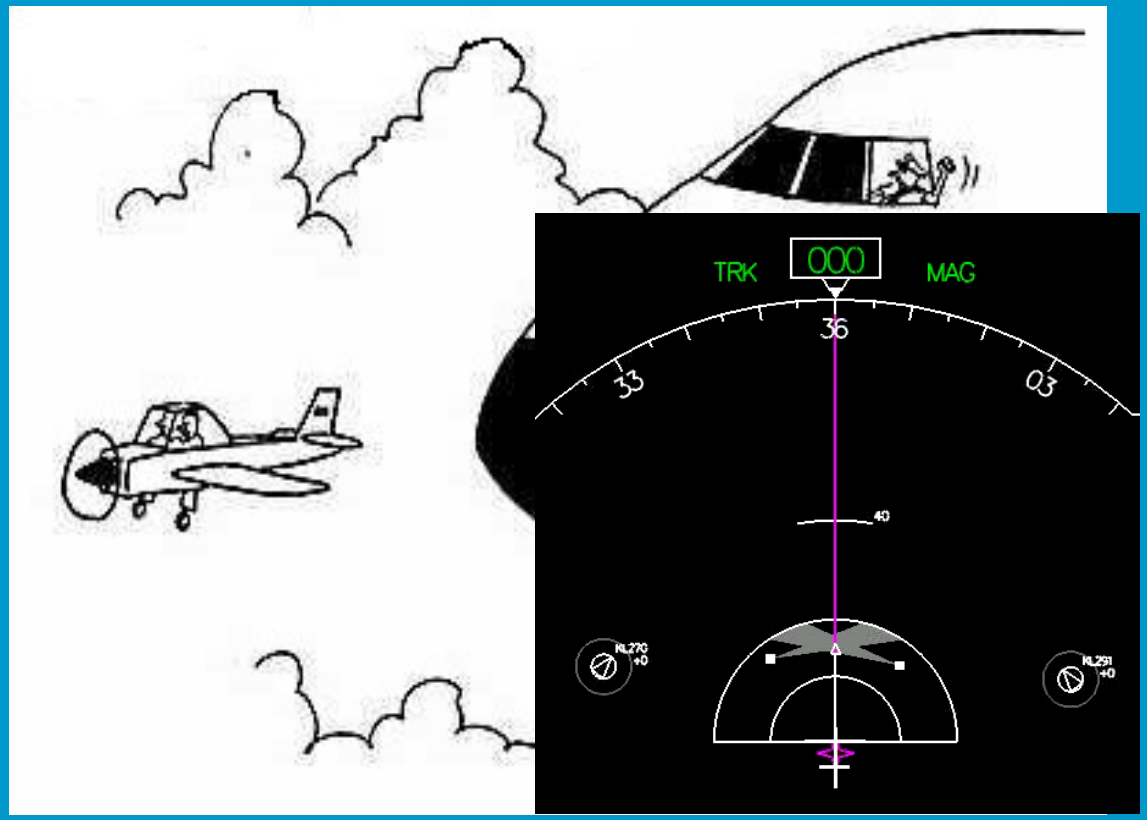
. . . is there an approach to automation and interface design that helps pilots with their (cognitive) tasks?



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situation awareness

"I am in a conflict (or not)."

VS.

"Am I in a conflict?"

"Is the conflict near?"

*"What are **my** resolution opportunities?"*

"What are the relative movements?"

"Will I pass the other a/c from the front or back side?"

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closing statements

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closing statements

Distribute the cognition between humans and the automated systems through the interface

"strive for a joint cognitive system"

EID: transform a cognitive task into a perceptual task by providing meaningful information that humans can directly perceive and act on accordingly

"make visible the invisible"

Ecological interfaces are **not (by definition) simple, intuitive**; they reflect the complexity of the work domain!

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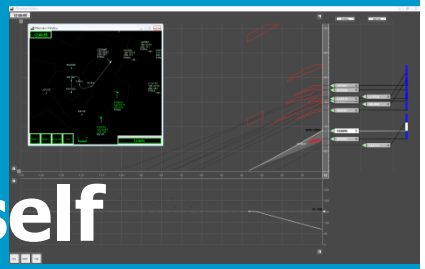
our approach to interface design

...usually starts out with engineering analysis, modelling and describing the system

...we have learned that picking the "right" representation (state variables) is crucial to the success of the automation and interface design



There is NO RECIPE for the design itself

...but, a graph that you use to *explain the problem space* to others may very well serve as a dynamic window on the system to be controlled

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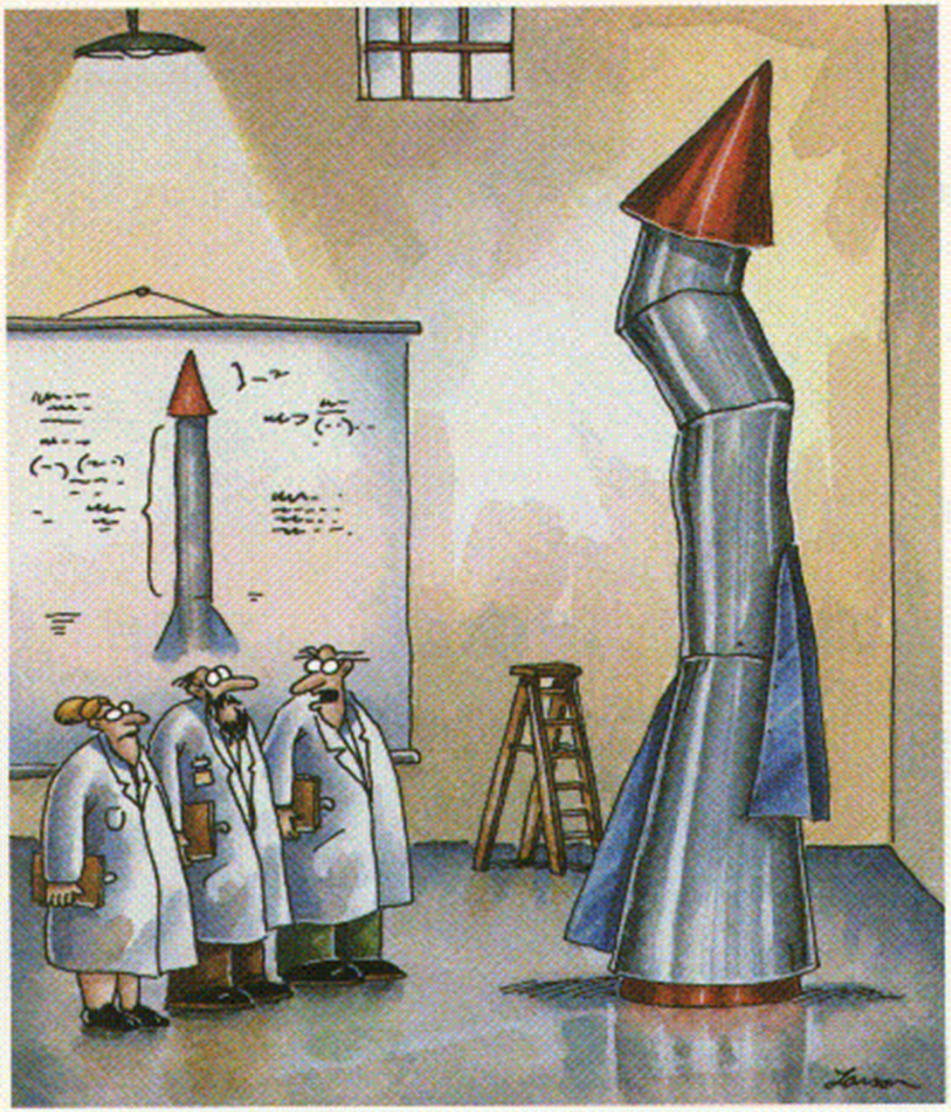

"It's time we face reality, my friends. … We're not exactly rocket scientists."

we go through lots of analysis and design iterations!!

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Designing for Situation Awareness

an aviation perspective

Max Mulder

International Conference on Computer-Human Interaction Research and Applications (CHIRA)

Madeira, October 31, 2017

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Delft University of Technology

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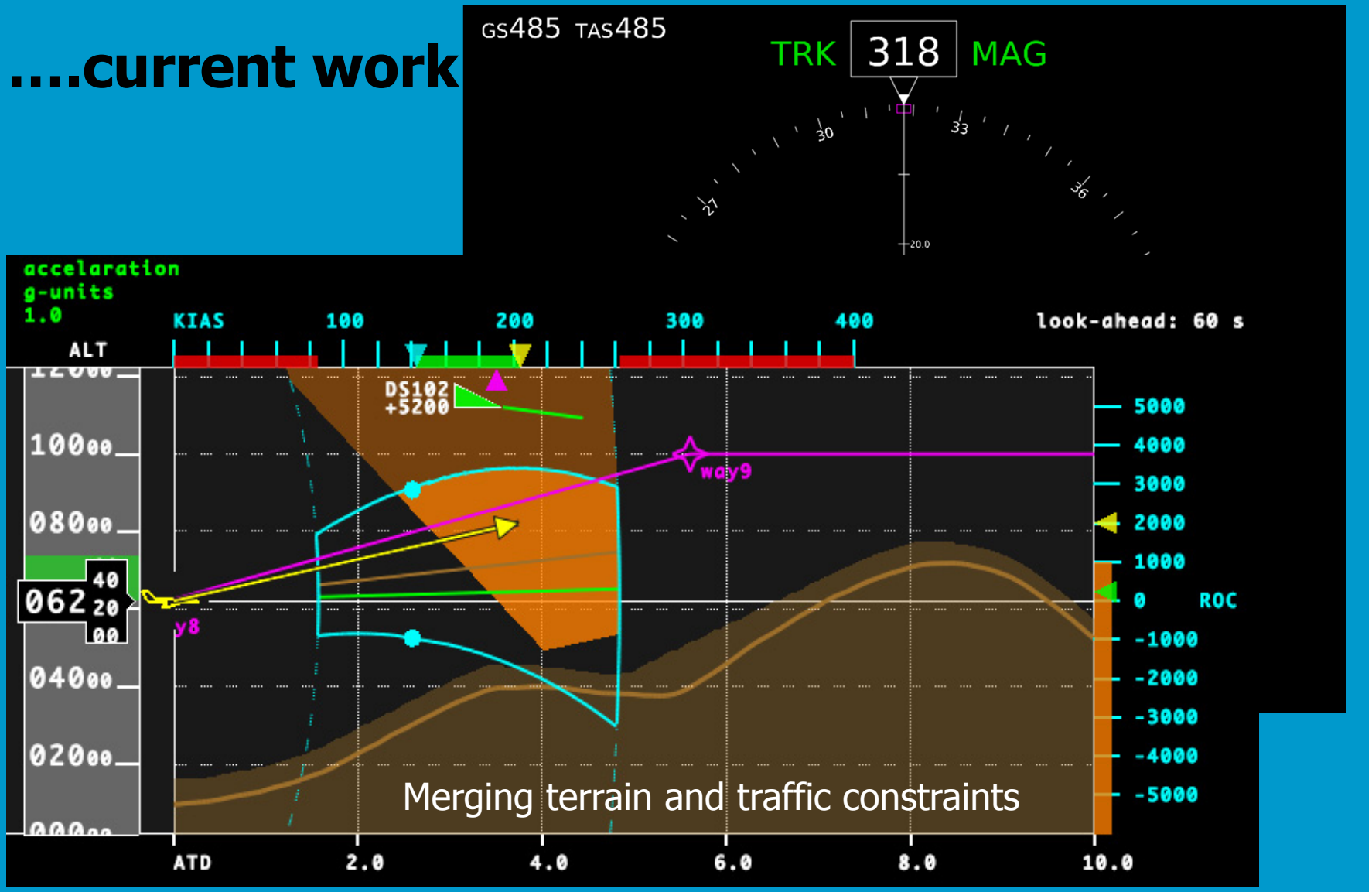
....current work



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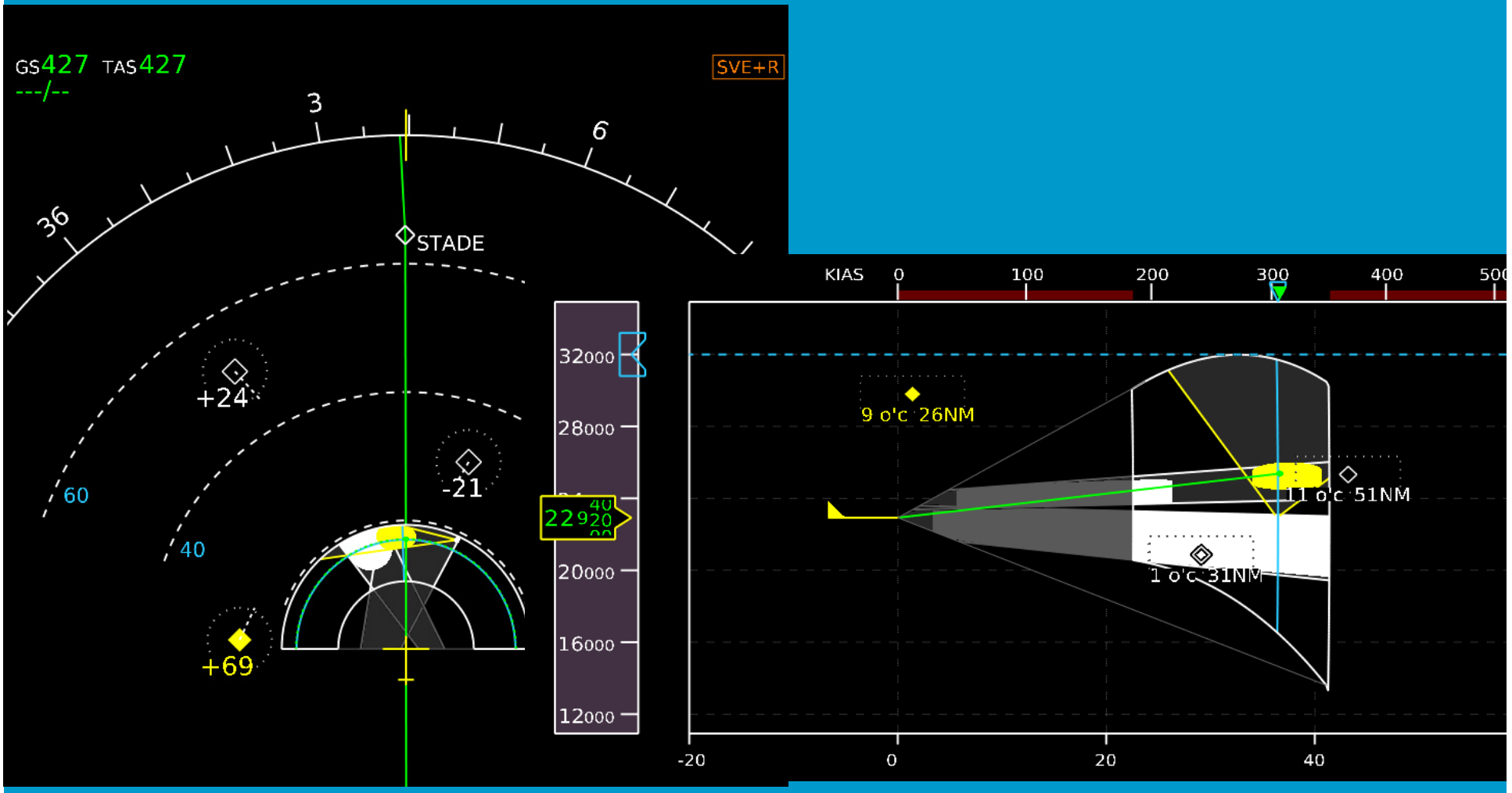
....current work



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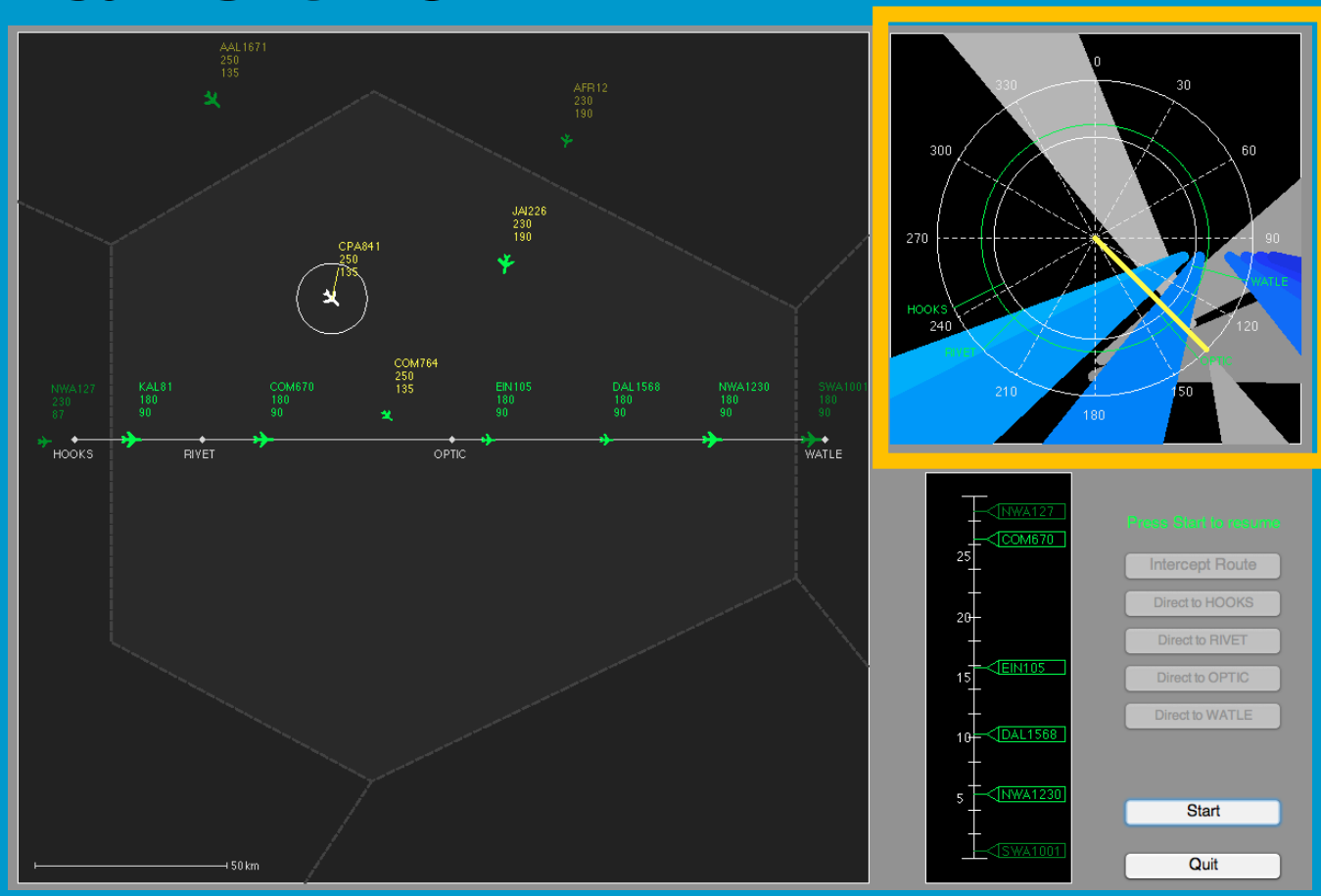
....current work



....creating **joint cognitive systems** for air traffic control through a **SOLUTION SPACE DIAGRAM** approach

SESAR JOINT UNDERTAKING

C-SHARE

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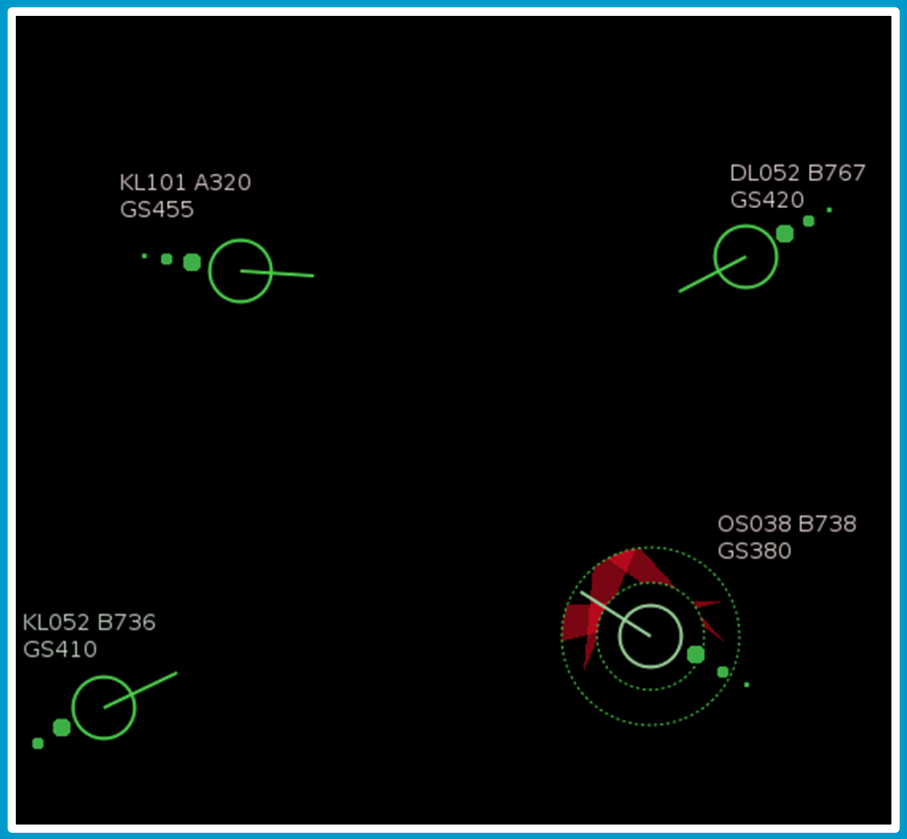
....current work



Java application

cswiki.lr.tudelft.nl

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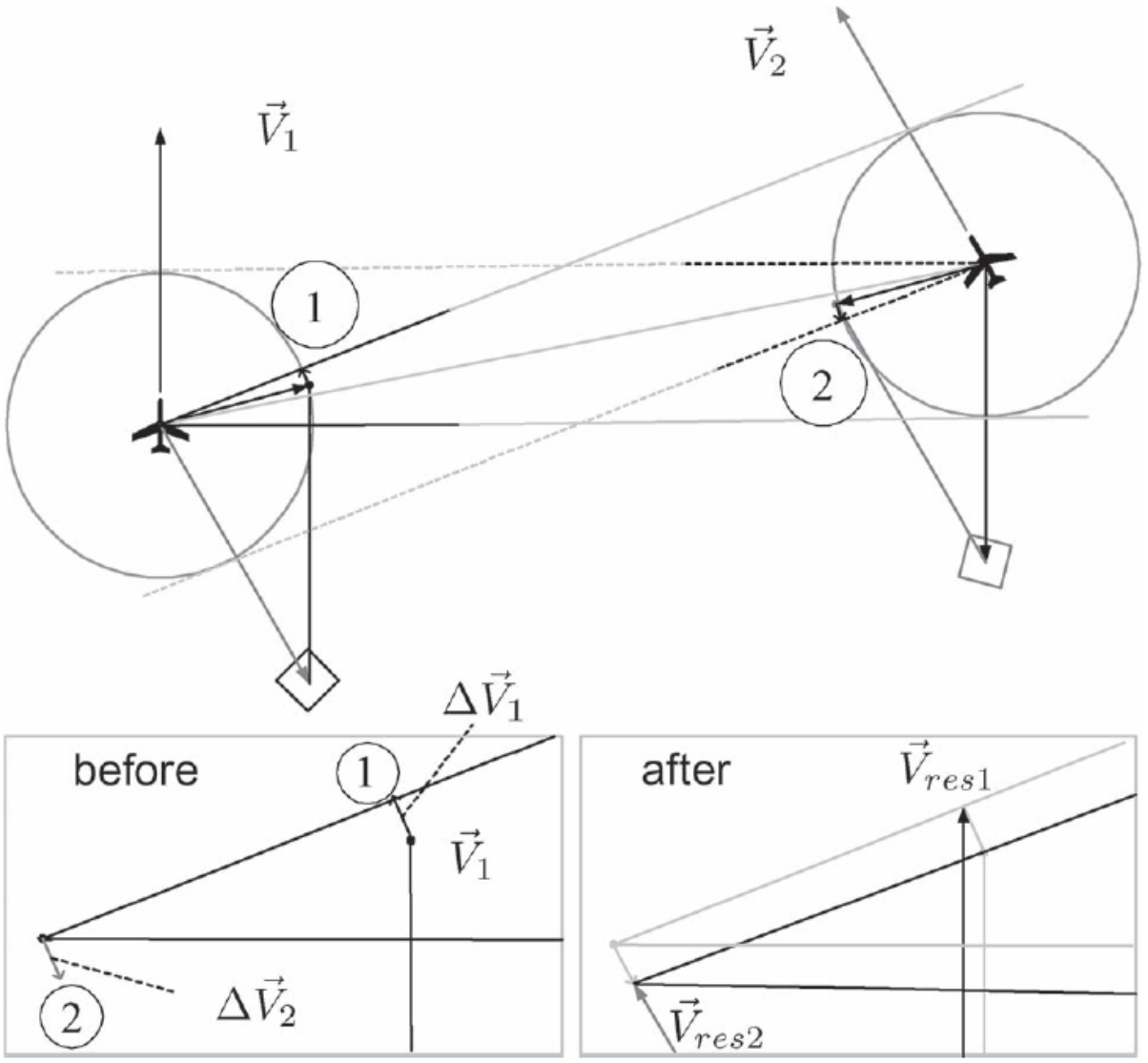
ATP

....implicit
coordination!



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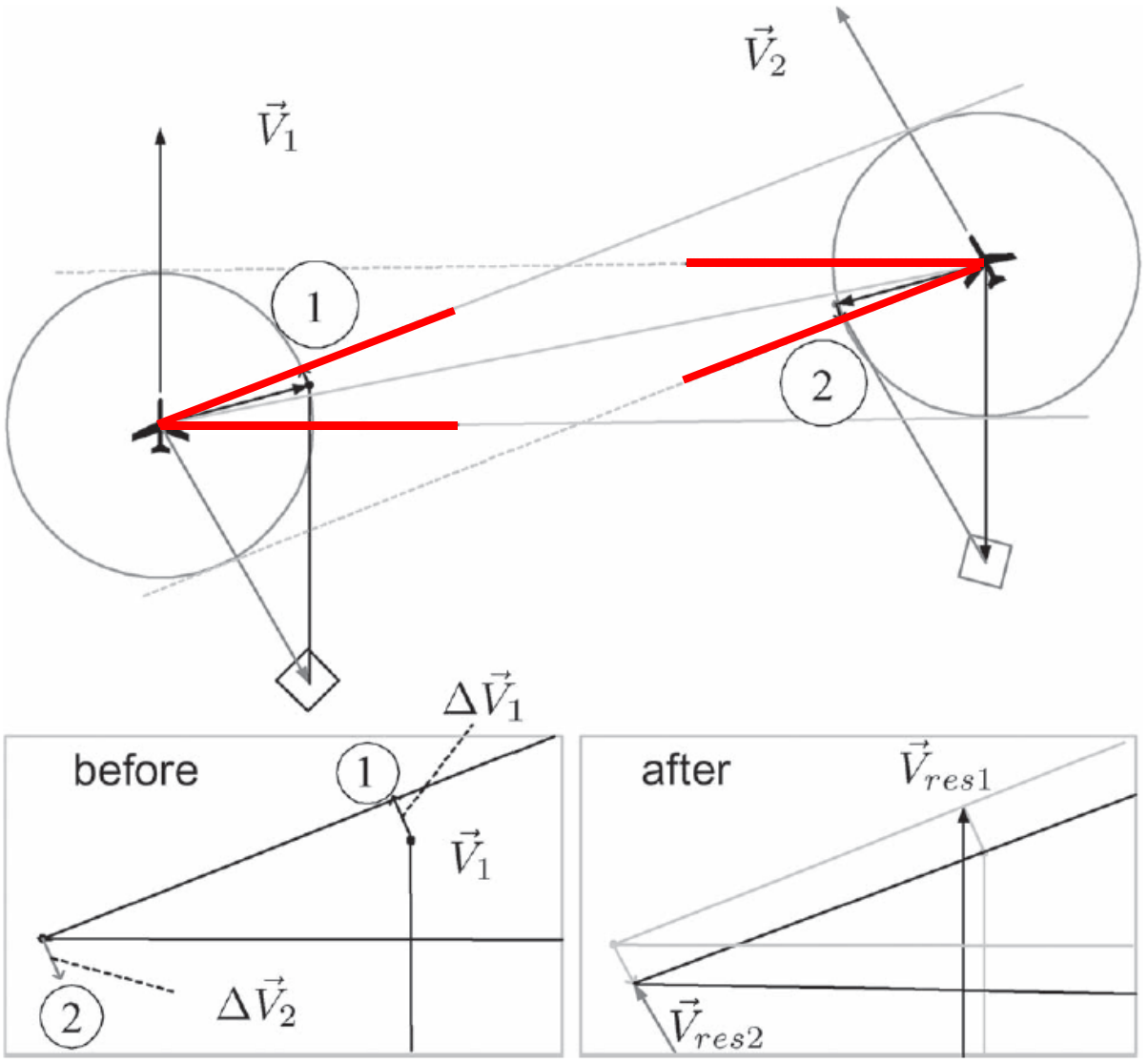

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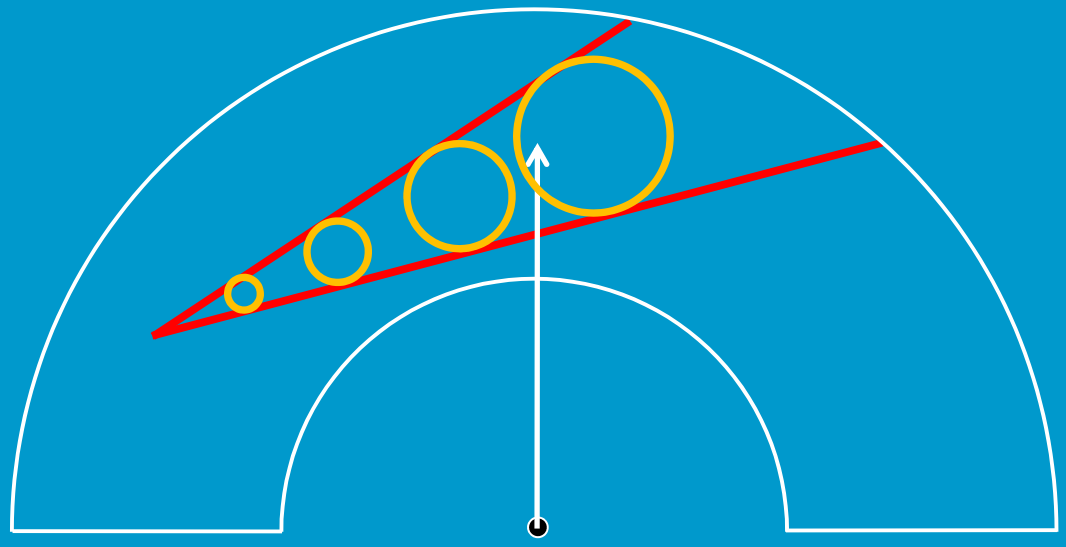
....the FBZ is a family of circles



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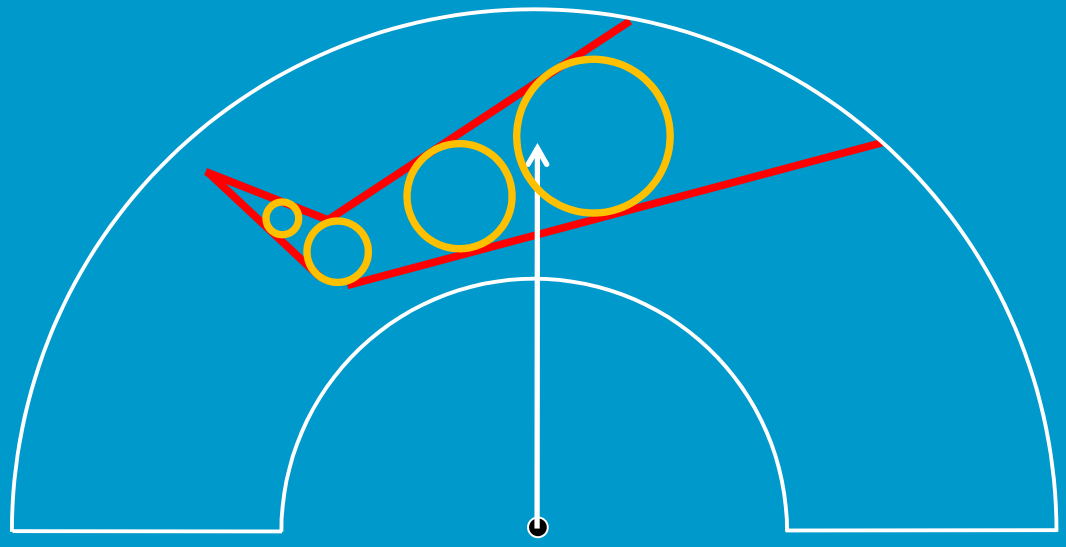
....that represent the intruder's 4D trajectory relative to own



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