# Ecological Flight Deck Design

## -the world behind the glass-

**7th European Flight Test Safety Workshop**
**October 30, 2013**

**Max Mulder**

TU Delft
Delft University of Technology

# today

- introduce the human-machine systems group
- ecological approach to flight deck design
- example : airborne separation assistance
- closing statements

# aerospace human-machine systems @ TU Delft



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# aerospace human-machine systems

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Aerospace Engineering

Control & Simulation



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# know-how

create, integrate and validate knowledge from various domains

1) engineering sciences
   - systems and control theory
   - computer science
   - real-time simulation
2) cognitive sciences
   - (ecological) psychology
   - cognitive systems engineering




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# ecological approach to flight deck design

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


enormous cost reductions through automation…



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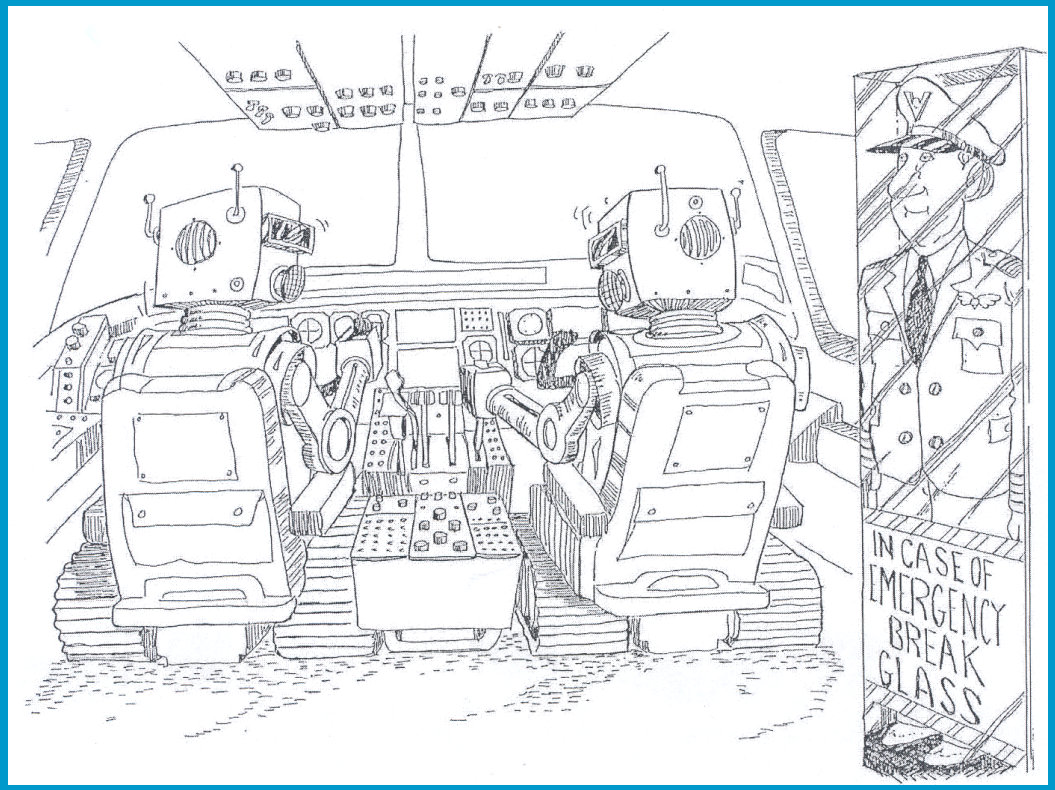
# why do we need to study humans in the aerospace domain?




...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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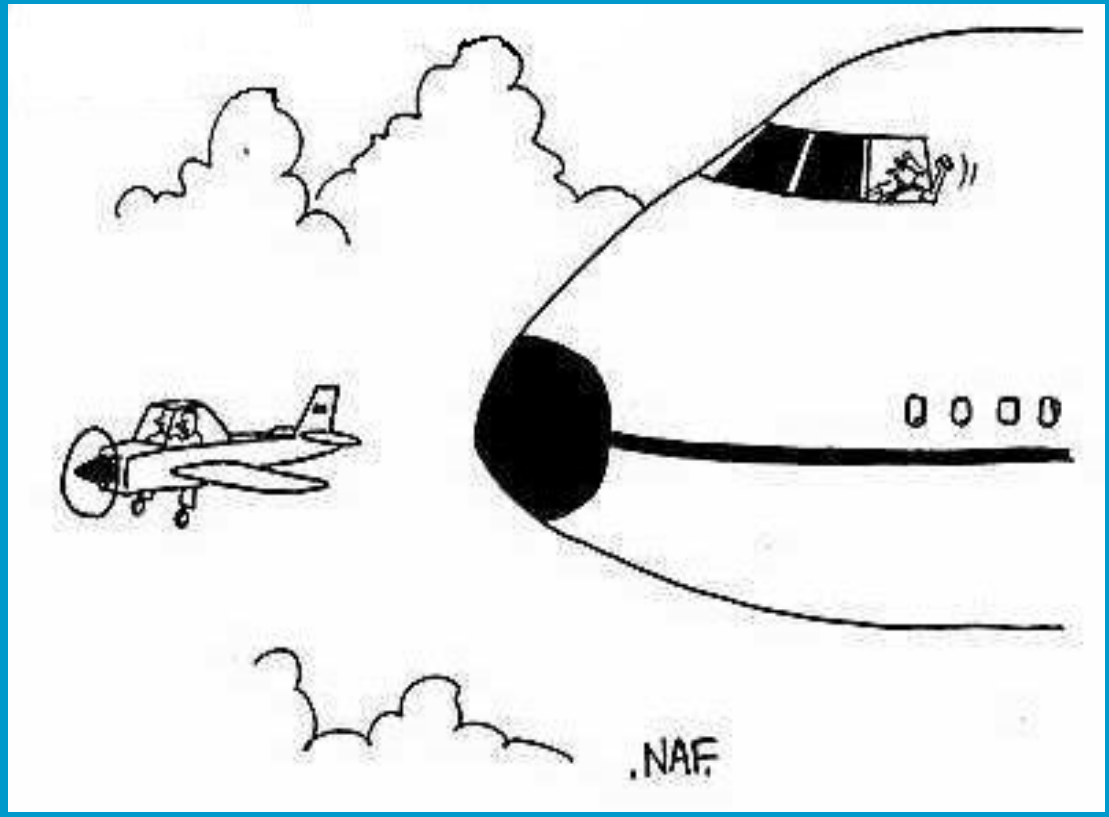
# the flight deck is . . .

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

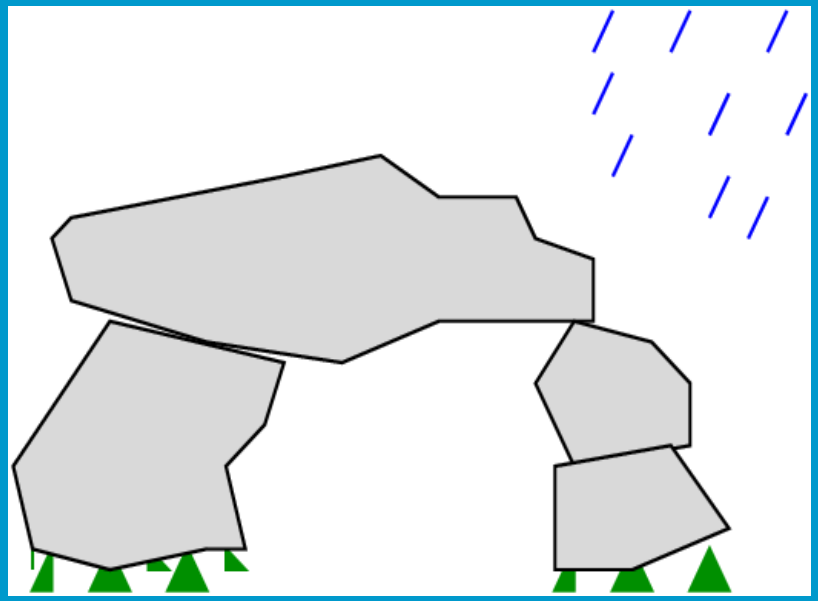

. . . a workplace for **cognitive** (team)**work**

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





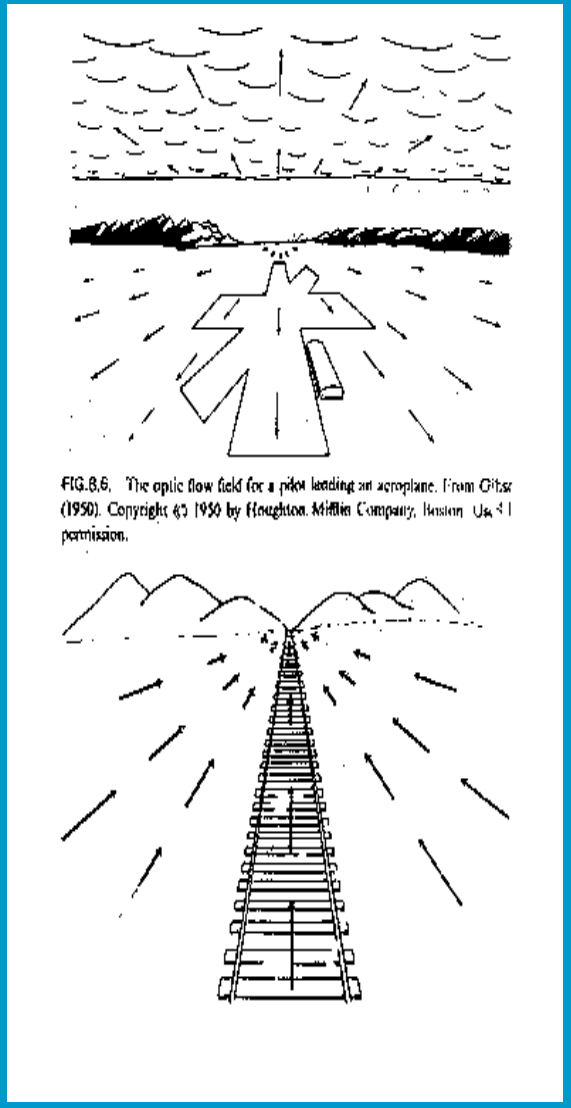
# human capabilities
# "direct perception" – Gibson



affording

perception-action coupling

specifying



# ecological interface design

(Vicente & Rasmussen, 1992)

Basic idea: "*make visible the invisible*"

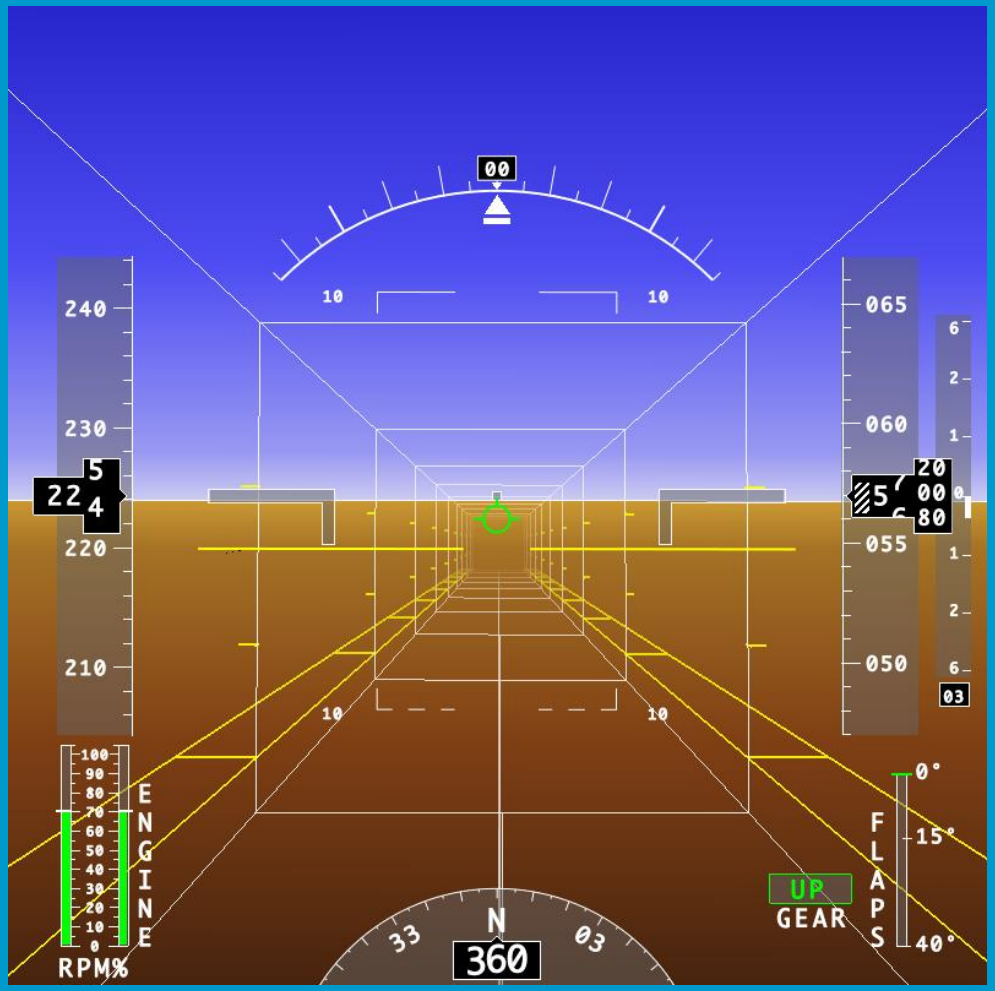
Use technology to create an interface that provides meaningful information and that allows humans to directly act on the information to achieve their goals

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

# some “Delft” ecological interfaces




**Aircraft control**
Total Energy Management



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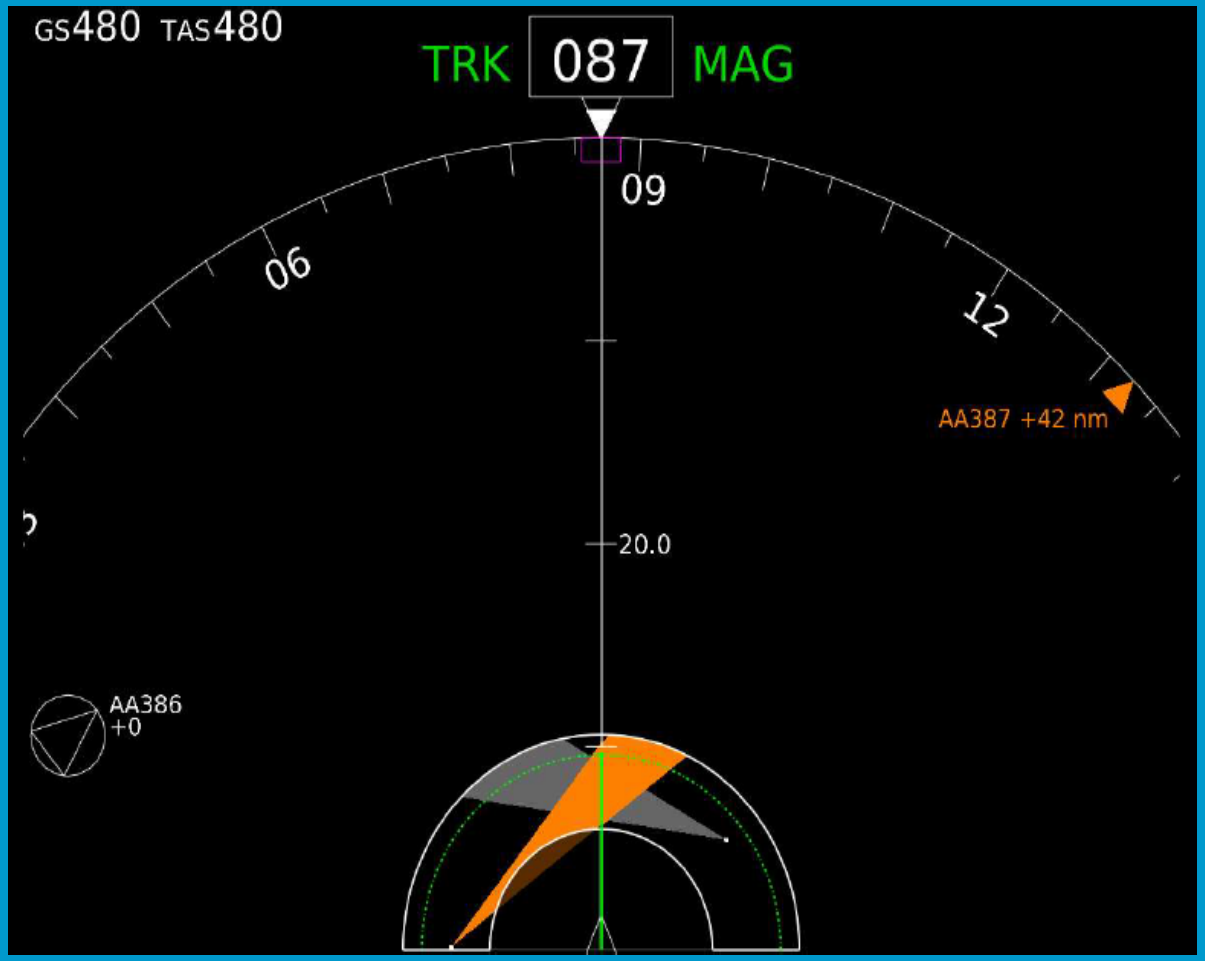
# some “Delft” ecological interfaces




**Aircraft control**
Total Energy Management

**Aircraft control**
Separation Assistance



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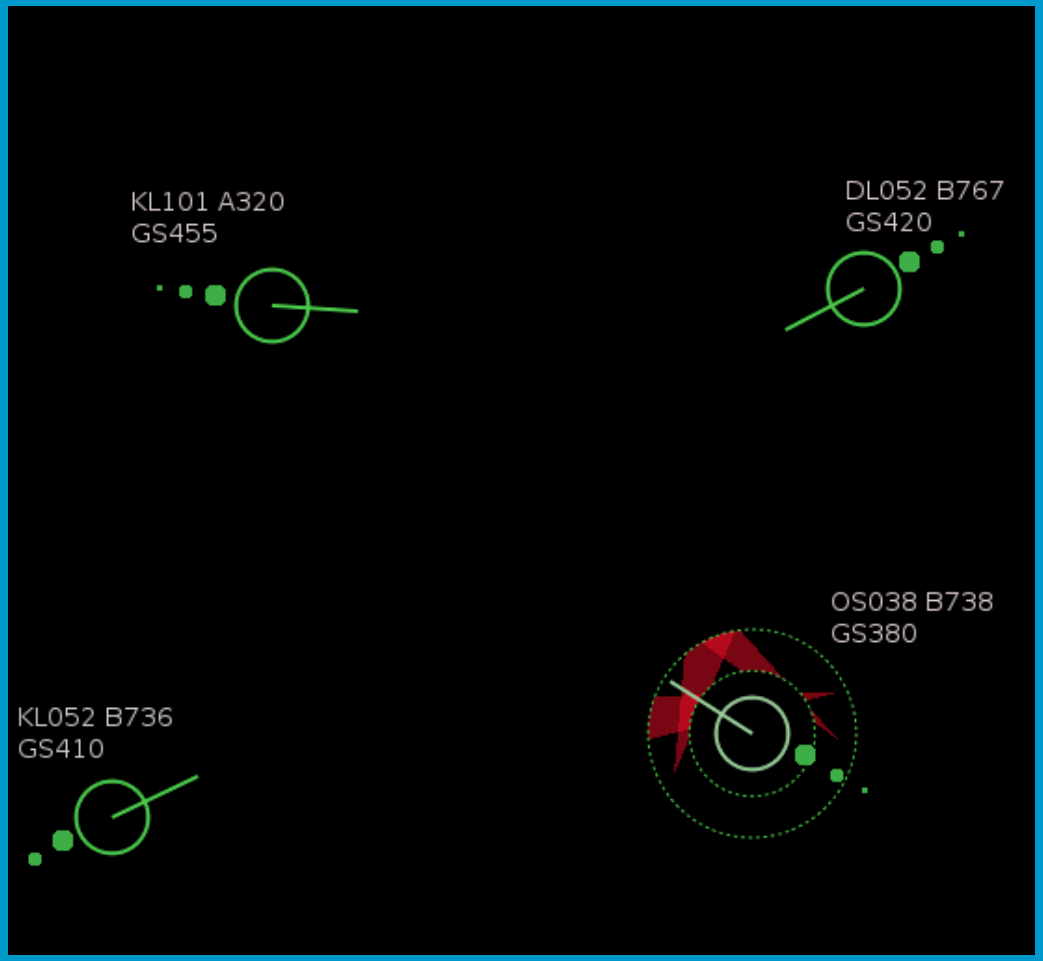
# some “Delft” ecological interfaces




**Aircraft control**
Total Energy Management

**Aircraft control**
Separation Assistance

**Air traffic control**
Separation Assistance



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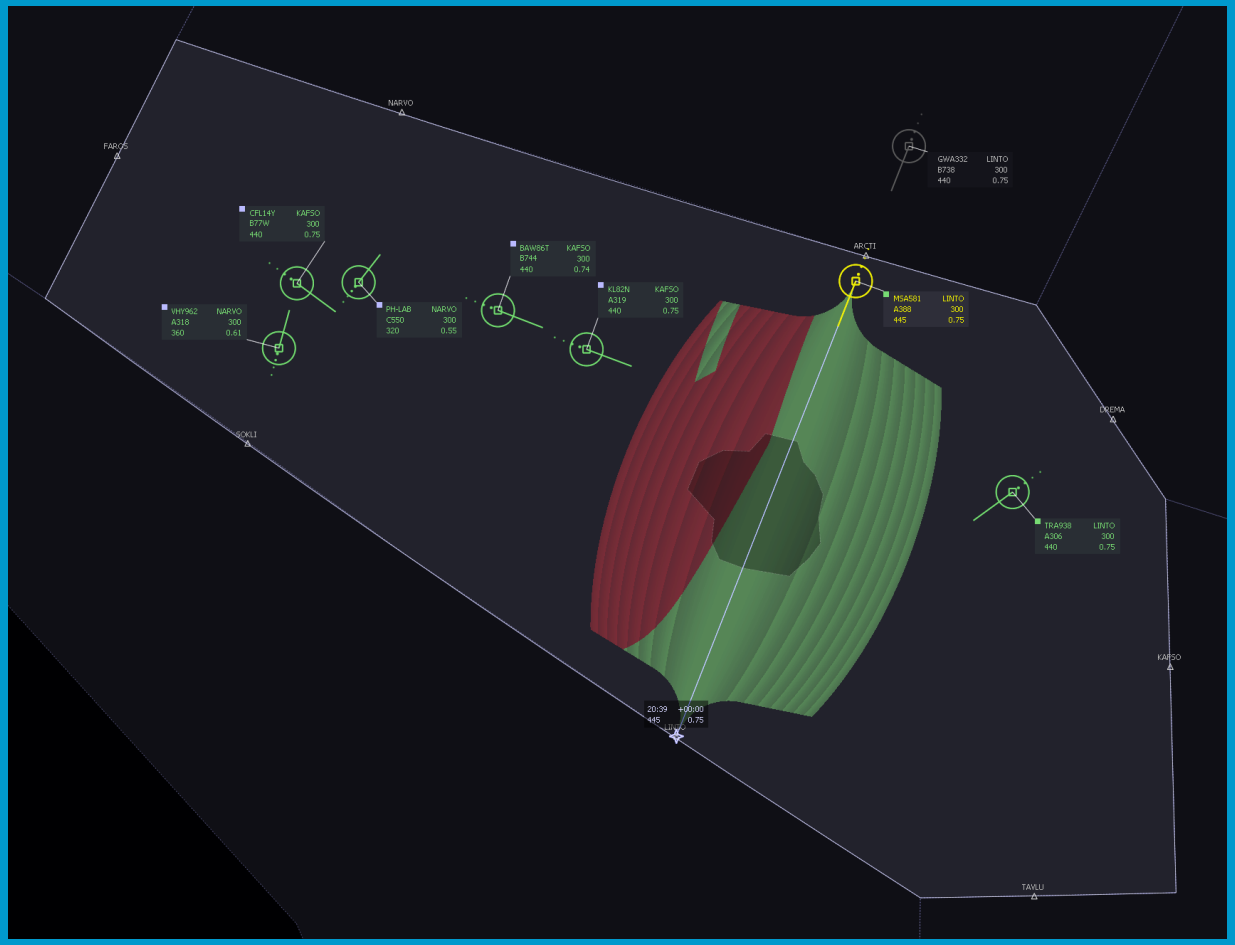


**Aircraft control**
Total Energy Management

**Aircraft control**
Separation Assistance

**Air traffic control**
Separation Assistance

**Air traffic control**
4D trajectory management



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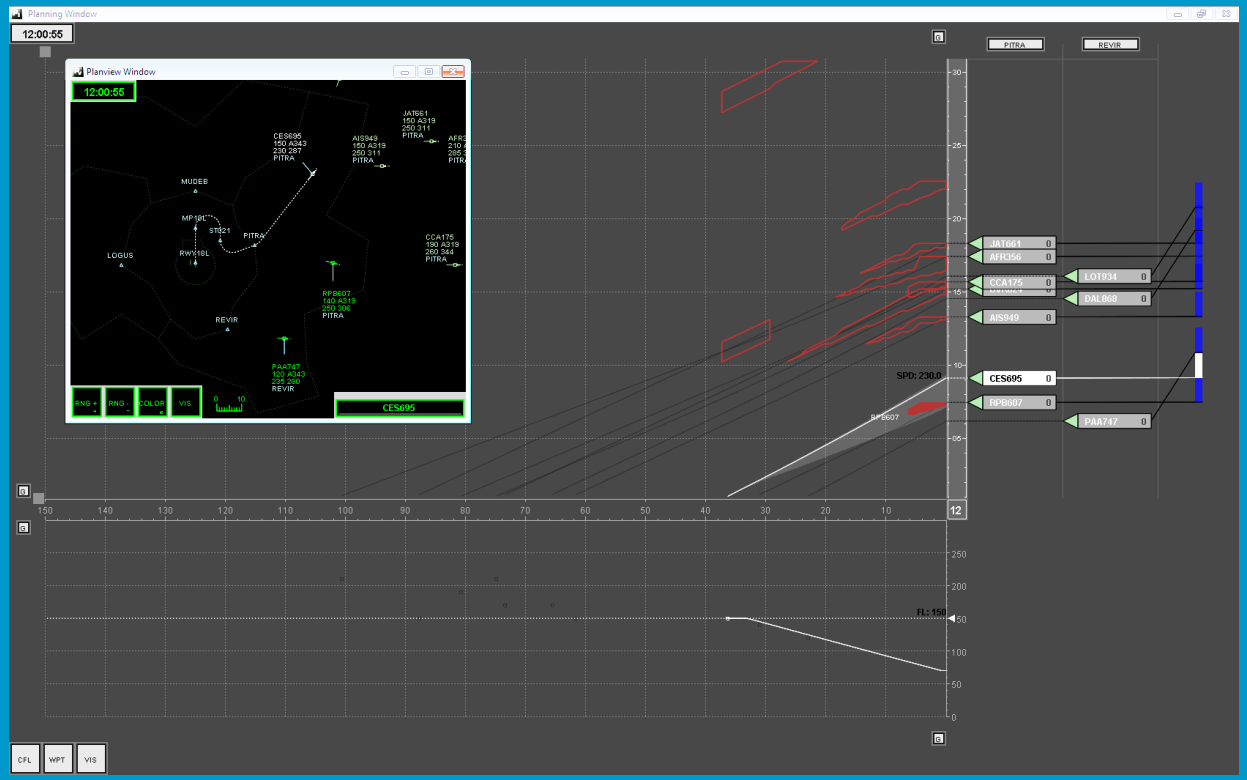
# some “Delft” ecological interfaces




**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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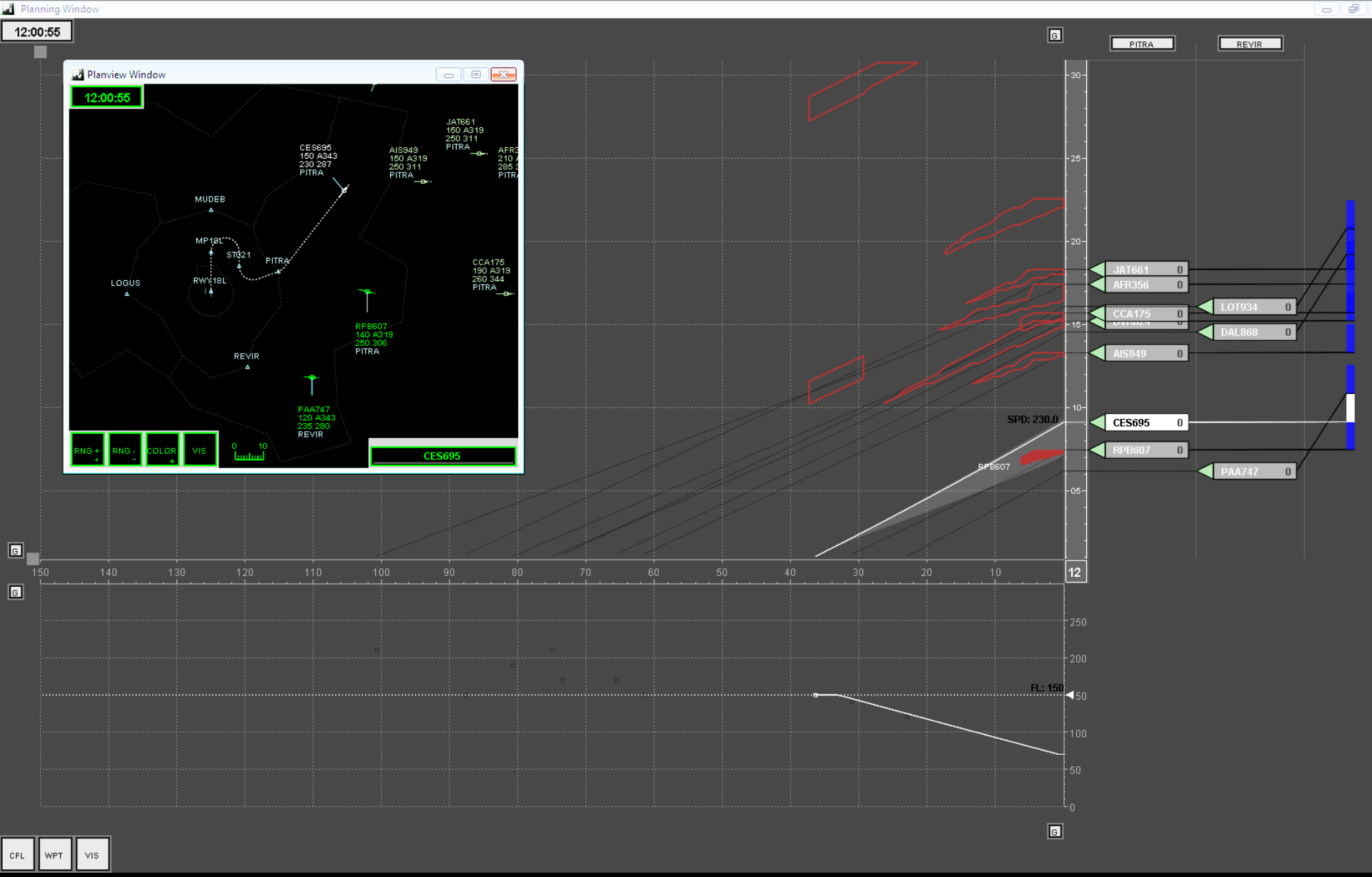
Planning Window
12:00:55
Planview Window
12:00:55
JAT661
150 A319
250 311
PITRA
CES695
150 A343
230 287
PITRA
AIS949
150 A319
250 311
PITRA
MUDEB
MP18L
ST321
PITRA
LOGUS
RW18L
CCA175
190 A319
260 344
PITRA
RPB607
140 A319
250 306
PITRA
REVIR
PAA747
120 A343
235 280
REVIR
RNG +
RNG -
COLOR
VIS
CES695
PITRA
REVIR
JAT661 0
AFR356 0
CCA175 0
AIS949 0
CES695 0
RPB607 0
LOT934 0
DAL868 0
PAA747 0
SPD: 230.0
RPB607
FL: 150
CFL
WPT
VIS



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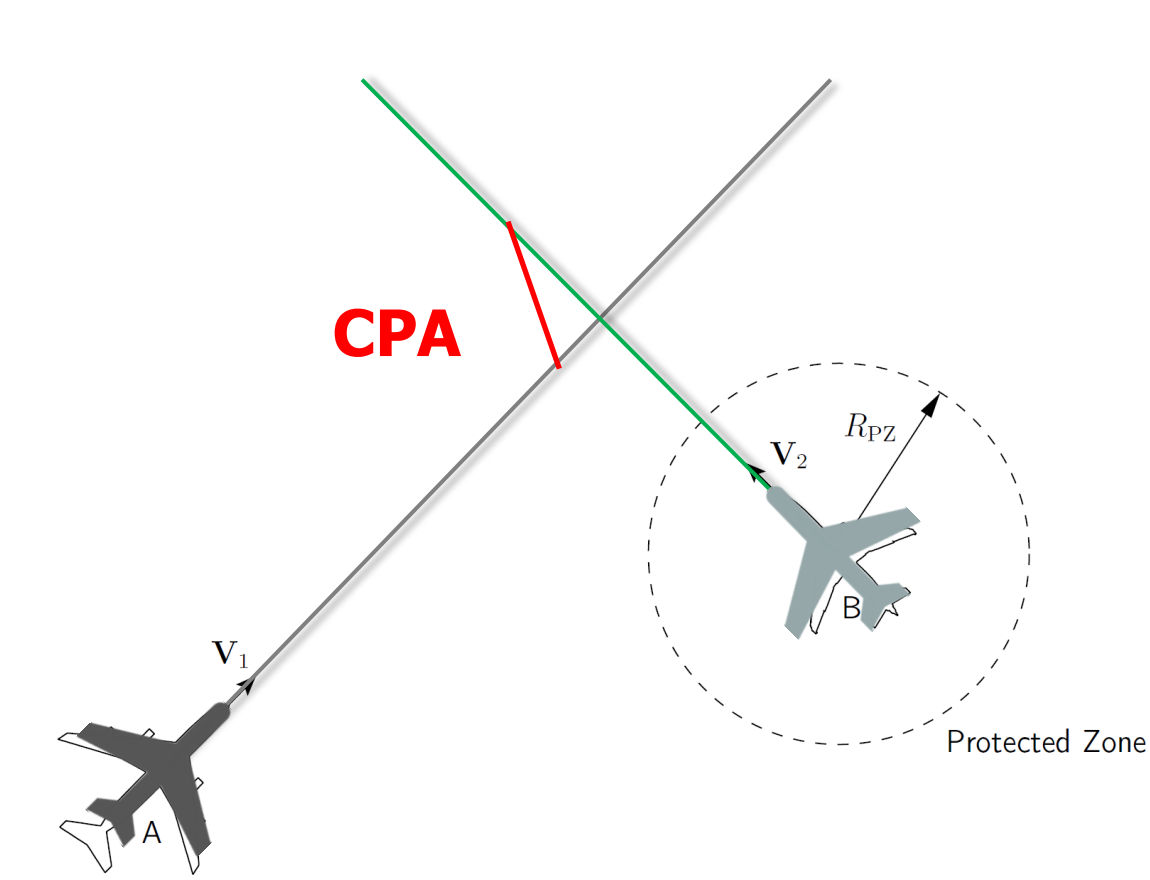
# airborne separation assistance

# airborne separation assistance

## What is the problem?



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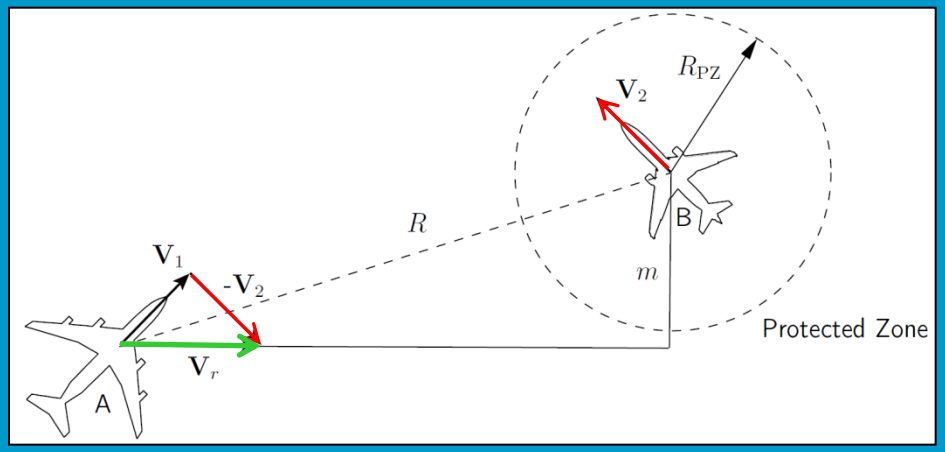
# typical engineering approach





**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!!??**

# EID: work domain analysis

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

WHY?

**WHAT??**

HOW?



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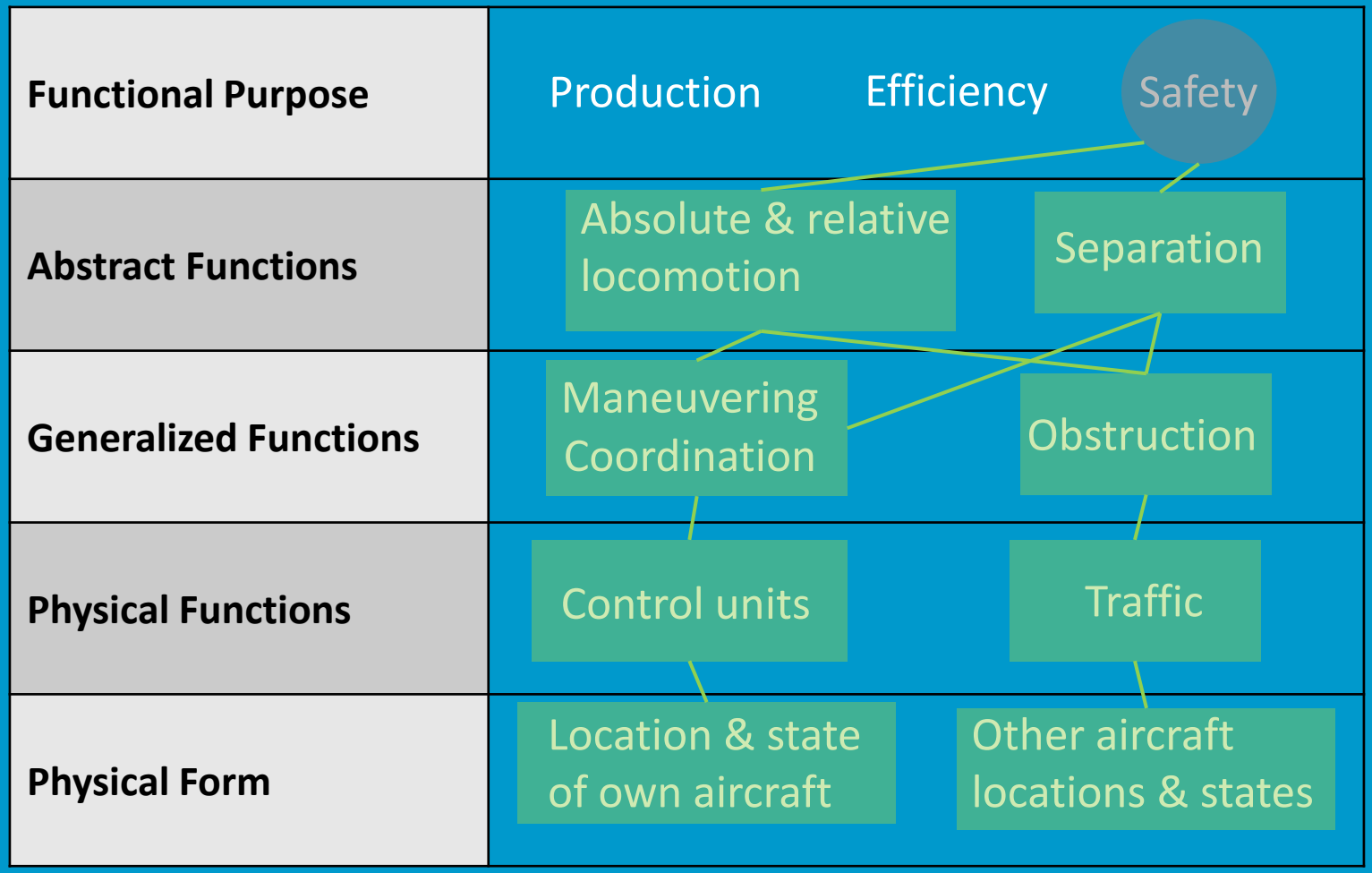
# EID: work domain analysis



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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!

# 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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# … improve the interface

**Show the conflict zone**

- Affordance 'hit' is clear, *but it changes when maneuvering*
- Affordance 'avoidance' is clear, *but only for heading, not for speed*
- Result: new conflicts triggered by maneuvers




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# … engineers' answer: *predictive* ASAS

**Show the conflict zone**

- Affordance 'hit' is clear, *but it changes when maneuvering*
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**Add 'heading' and 'speed' bands, *computed by automation***




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# … engineers' answer: *predictive* ASAS

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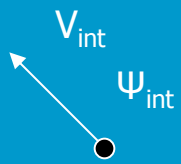
# p-ASAS issues

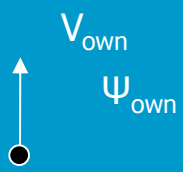
- yes, we can see how to avoid aircraft,
- but *we* cannot see how to do it efficiently, and
- the computer-aided solution can be within a no-go heading or speed zone....
- so how can we check that the computer is right??
- no-go bands for multiple aircraft??

# let's take another look at a conflict situation

assume we have two aircraft



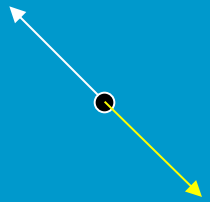

intruder




own

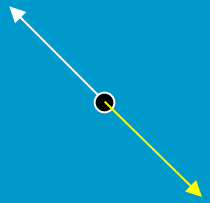
# and create an ecological interface

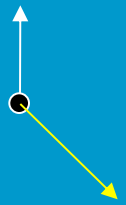
....set intruder aircraft to stand still



# ecological ASAS

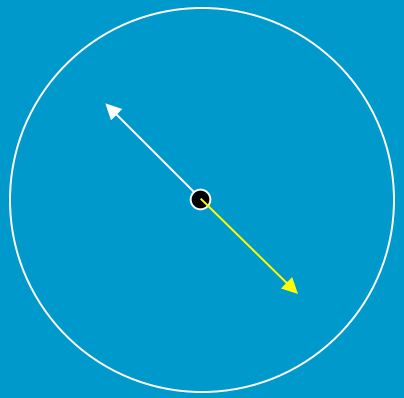
...then we should also change the speed of own...

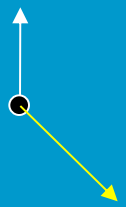




# ecological ASAS

...add the protected zone...

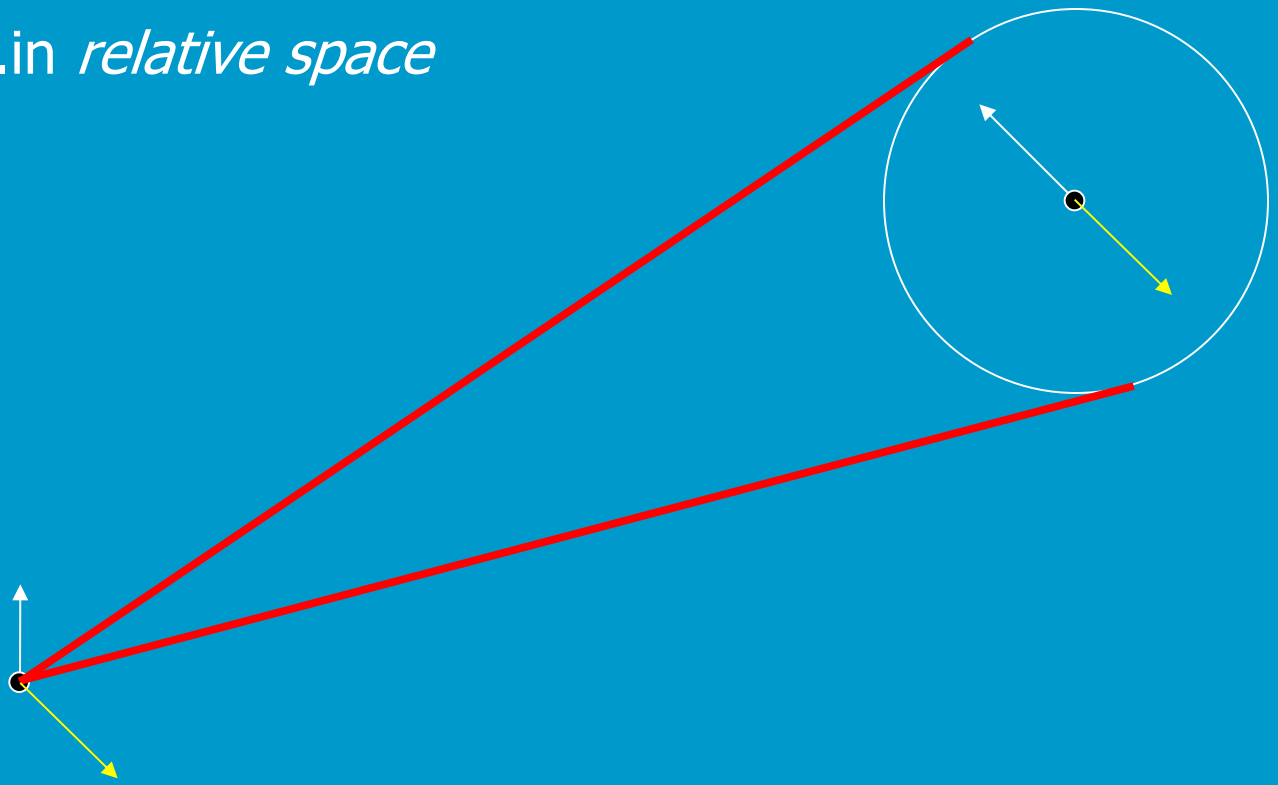




# ecological ASAS

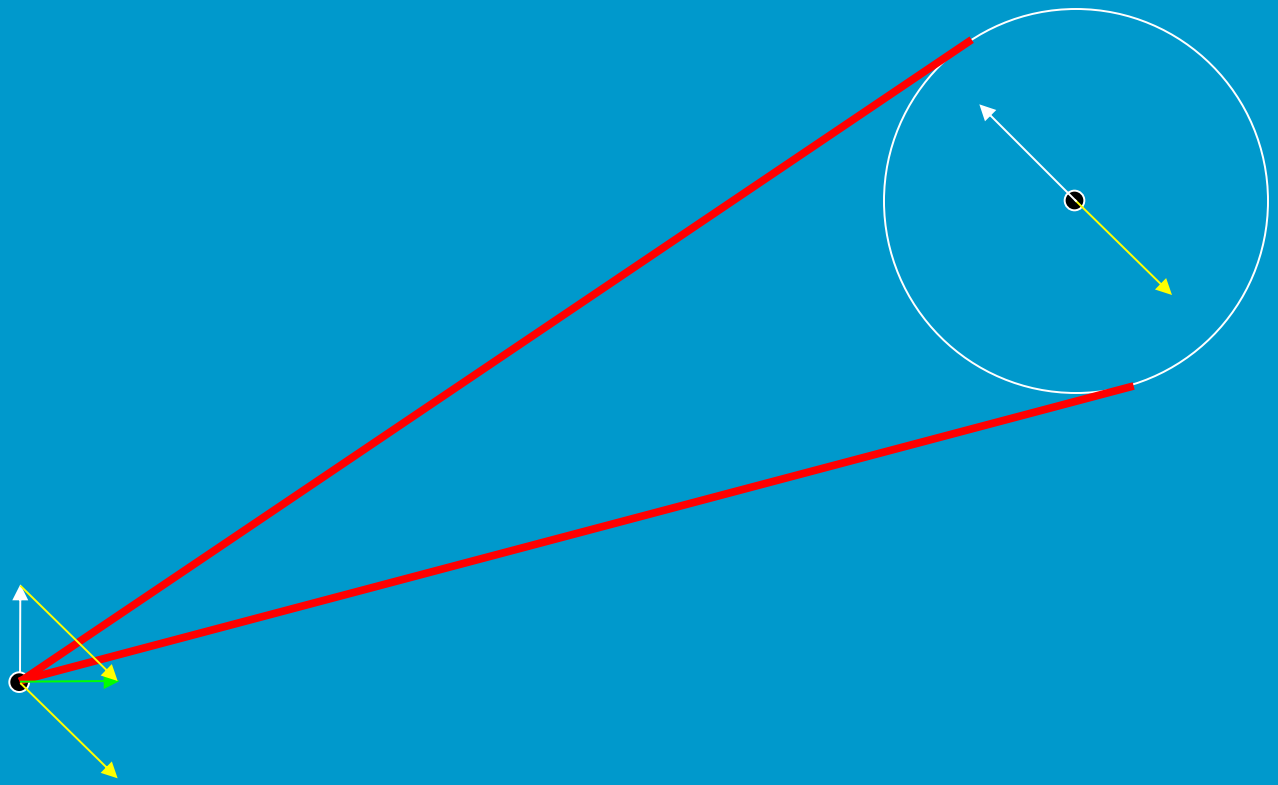
....create Forbidden Beam Zone

....in *relative space*



# ecological ASAS

....calculate relative speed



# ecological ASAS

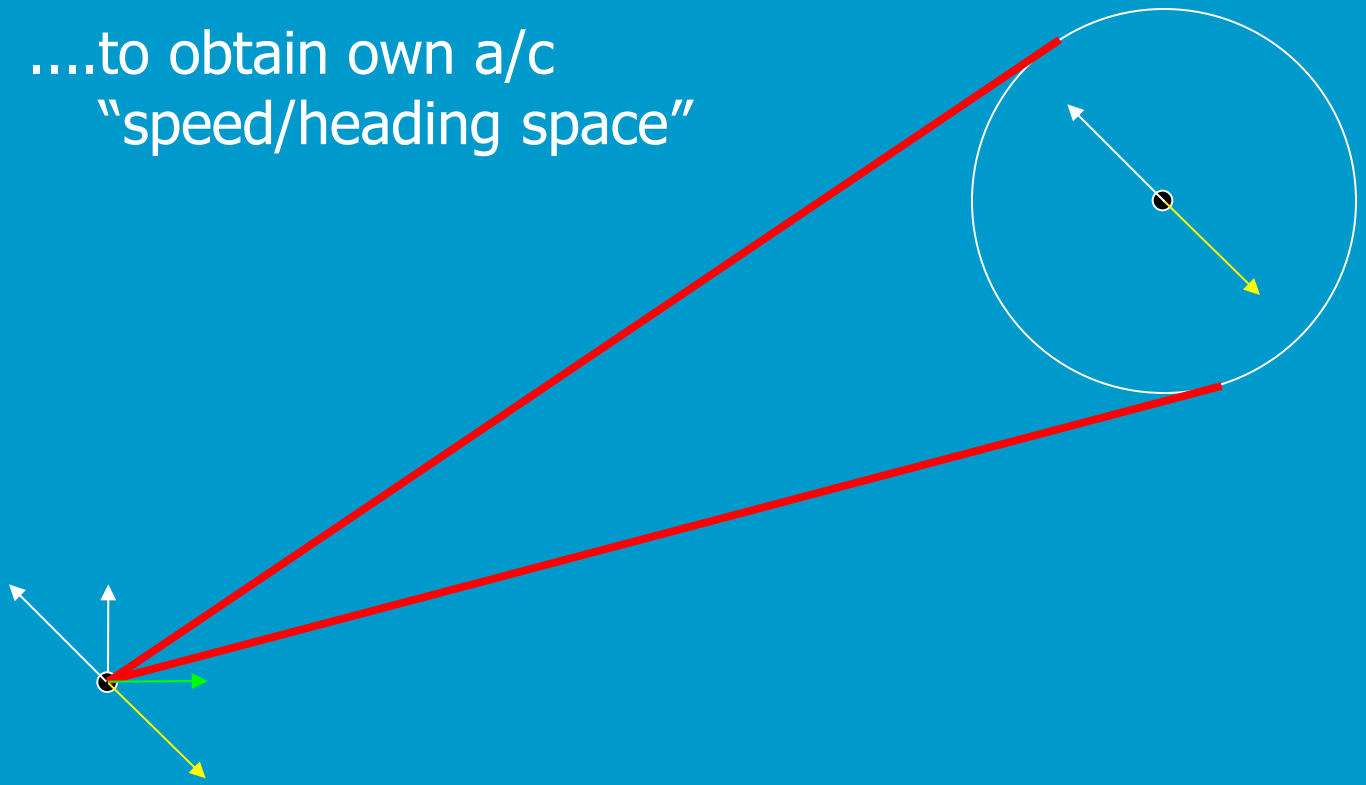
....calculate relative speed

....here: we're safe

# ecological ASAS

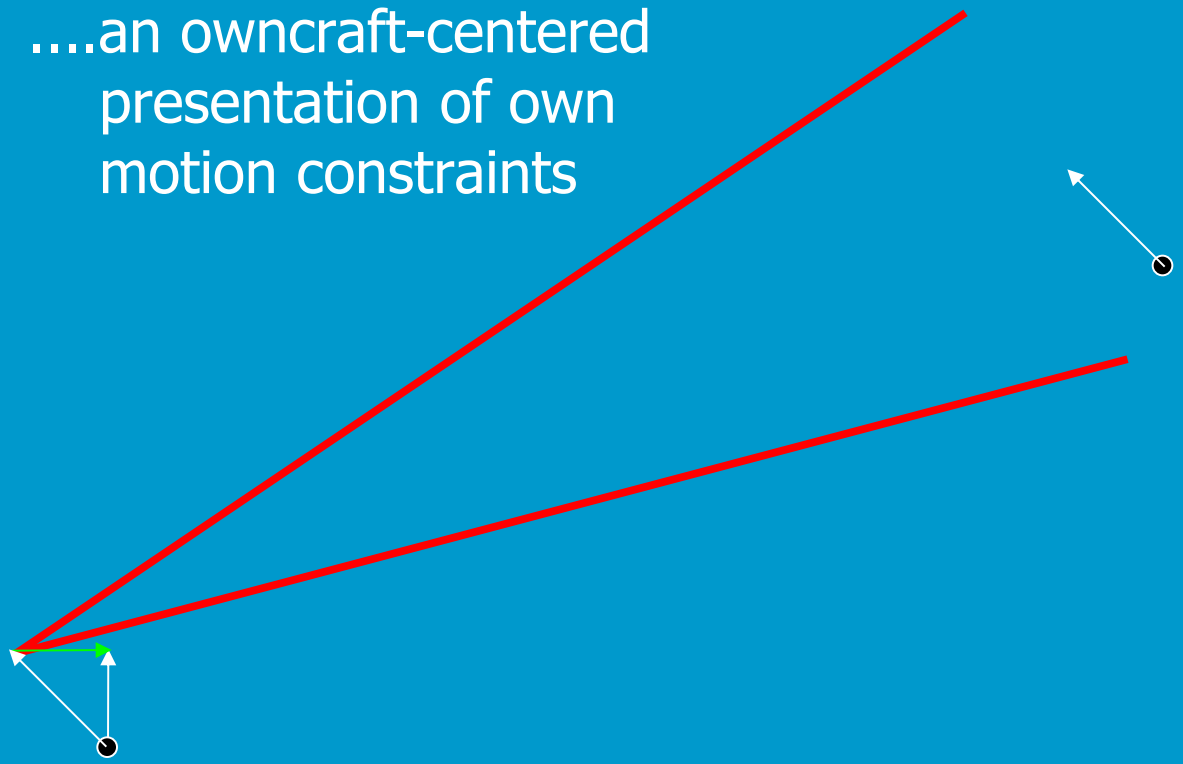
....move FBZ with intruder speed

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



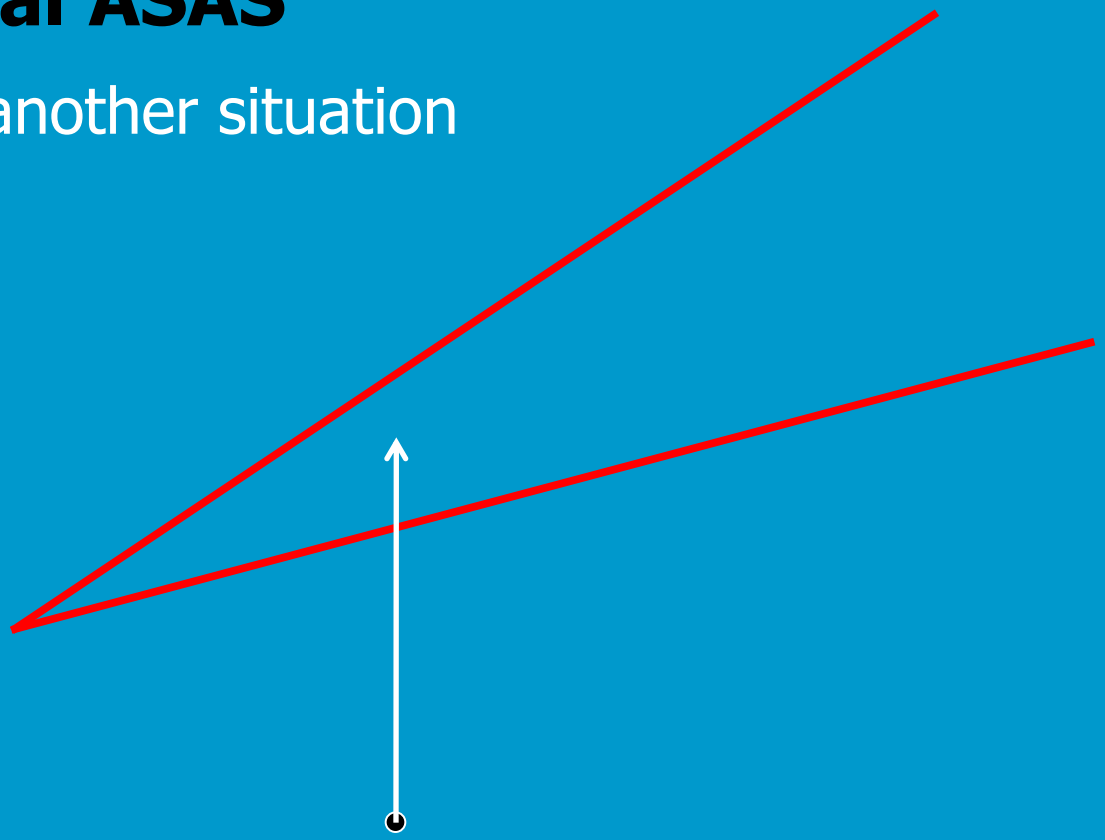
# ecological ASAS

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



# ecological ASAS

....look at another situation



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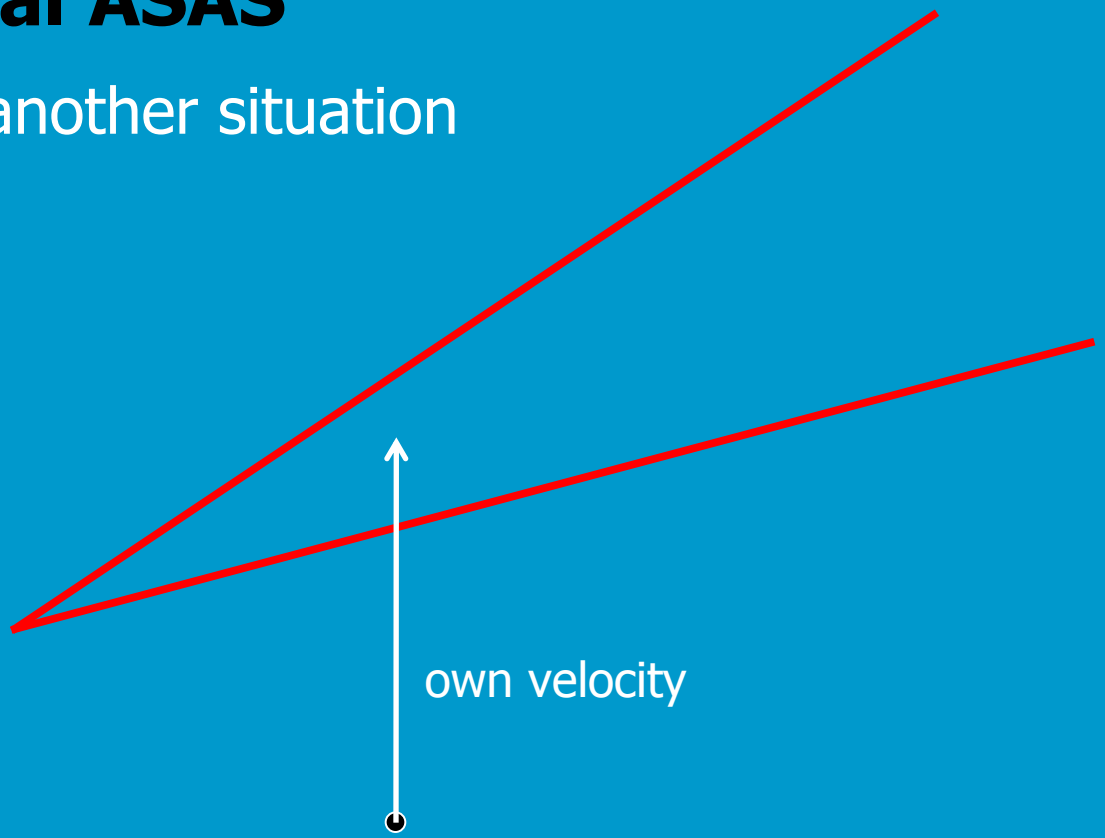

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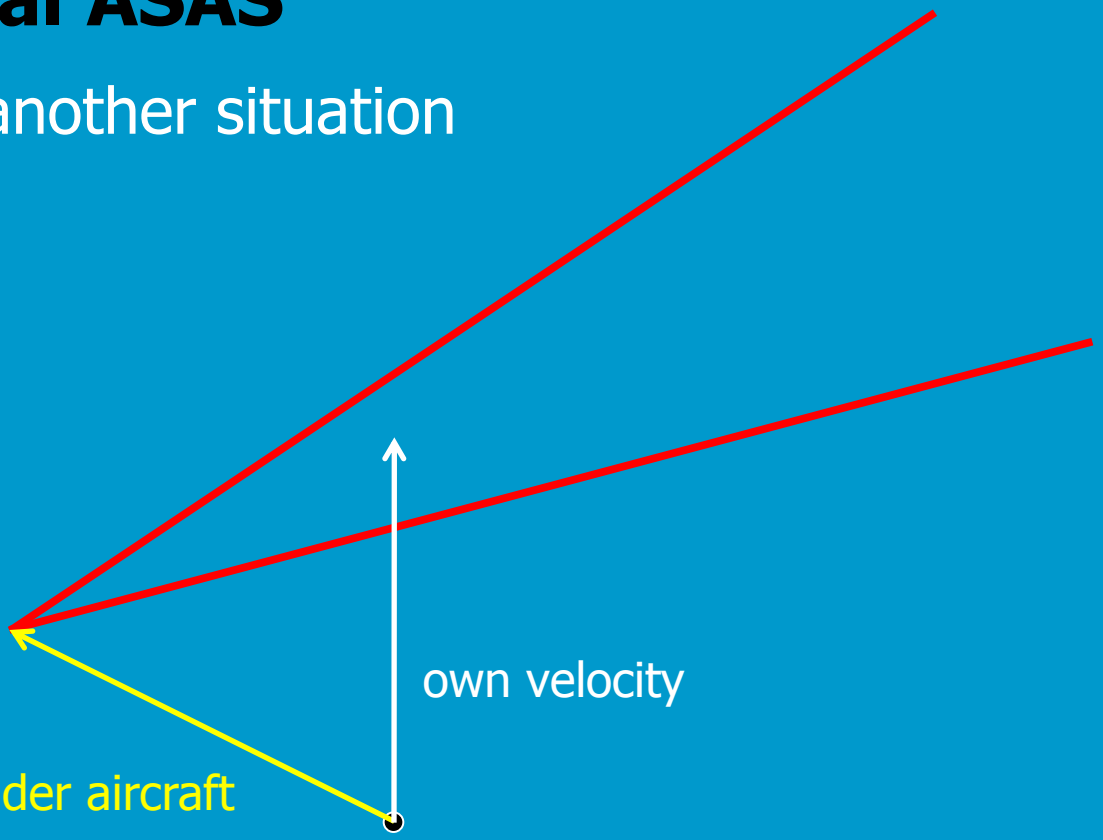




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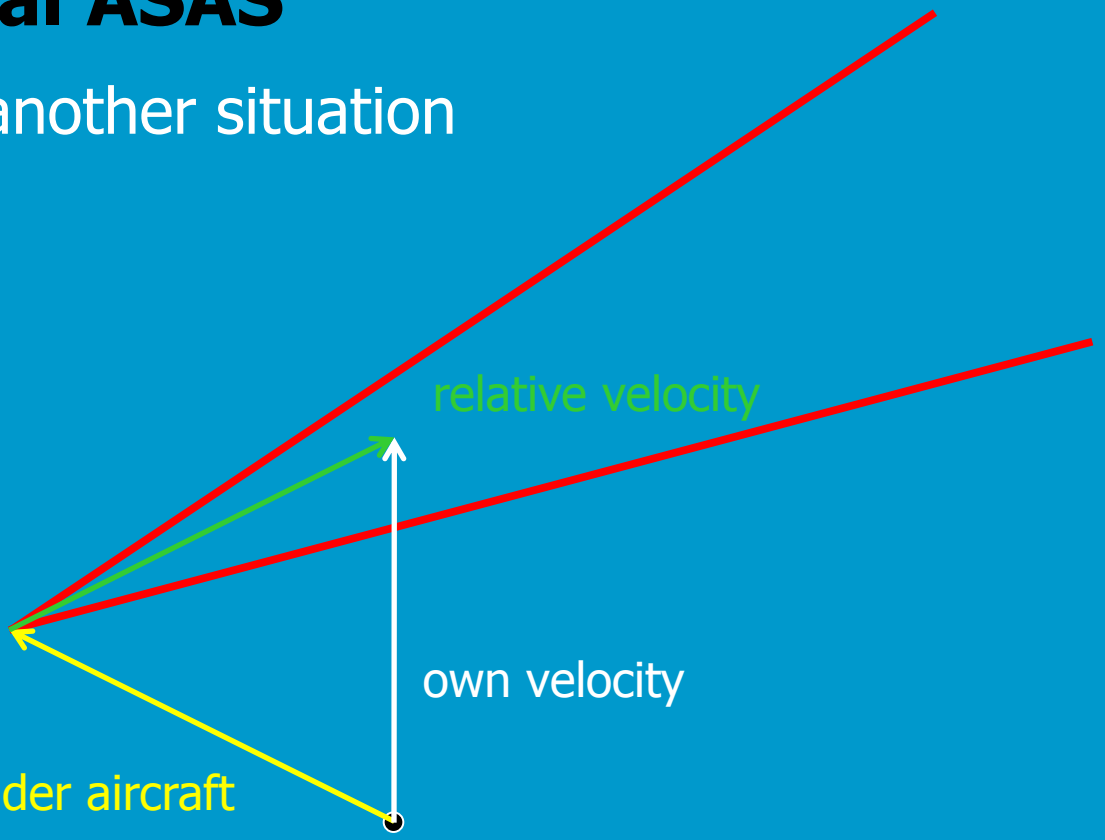
# ecological ASAS

....look at another situation



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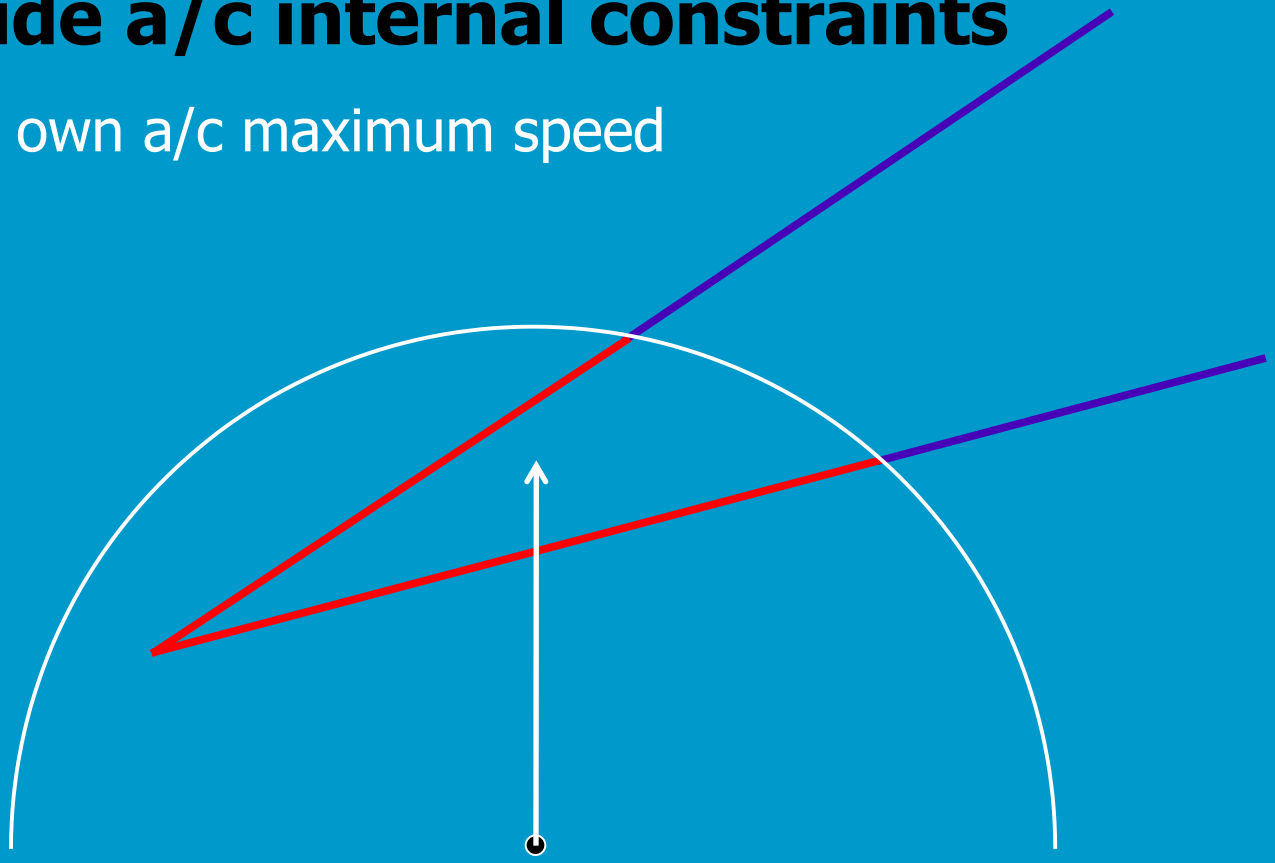
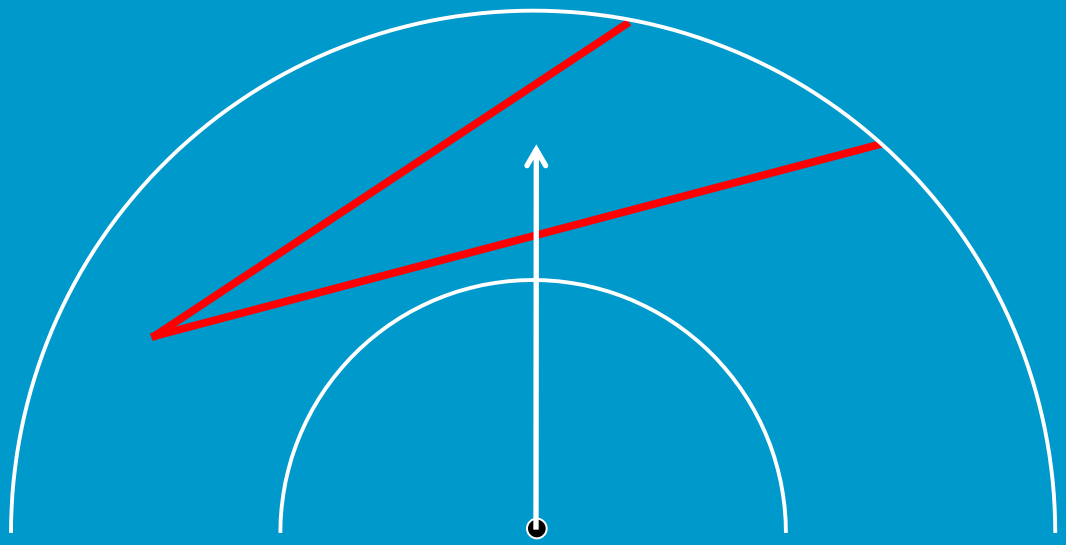
# include a/c internal constraints

....add own a/c maximum speed



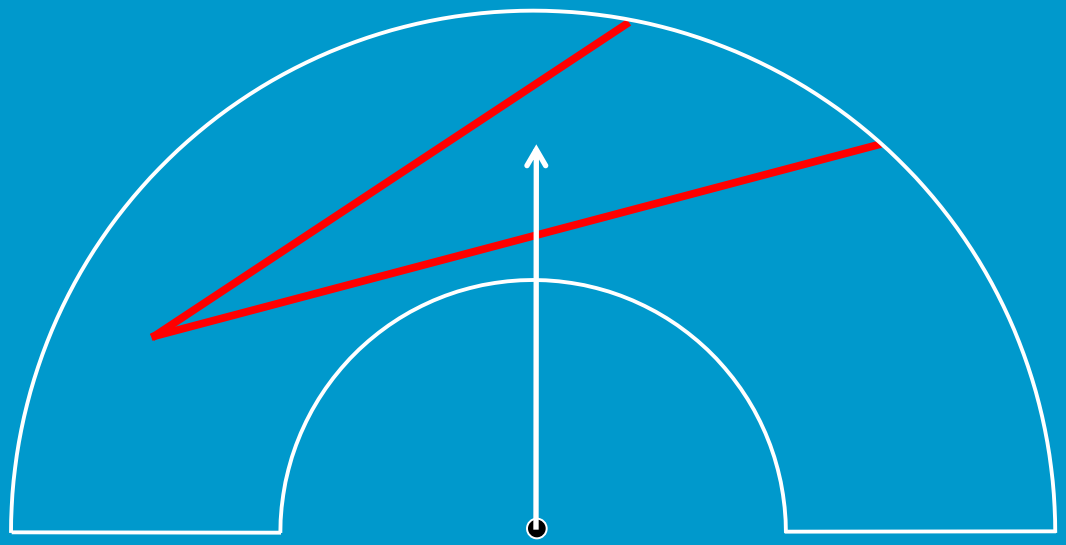
# include a/c internal constraints

....add own a/c minimum speed



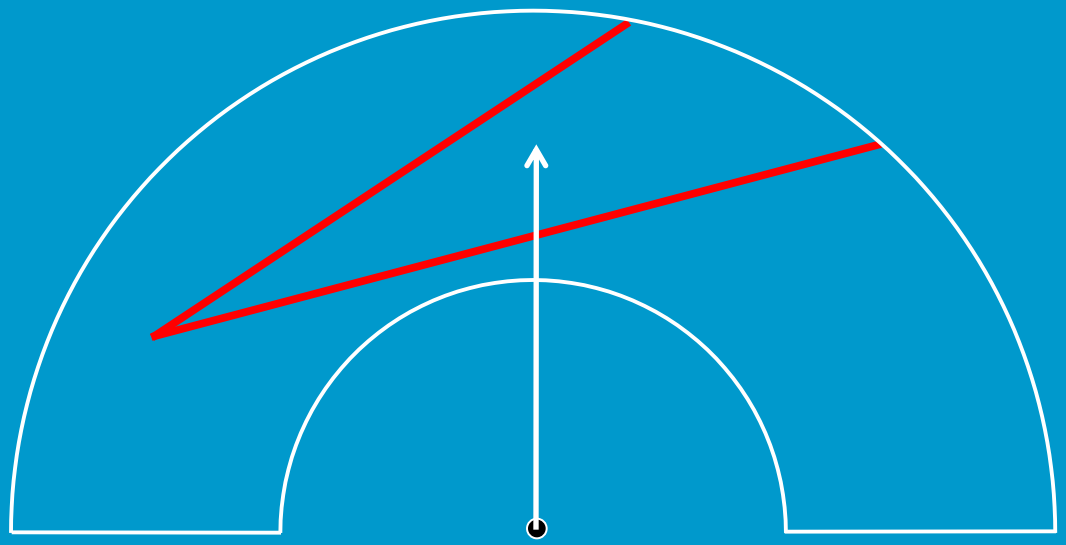
# include a/c internal constraints

....add maximum heading changes for productivity



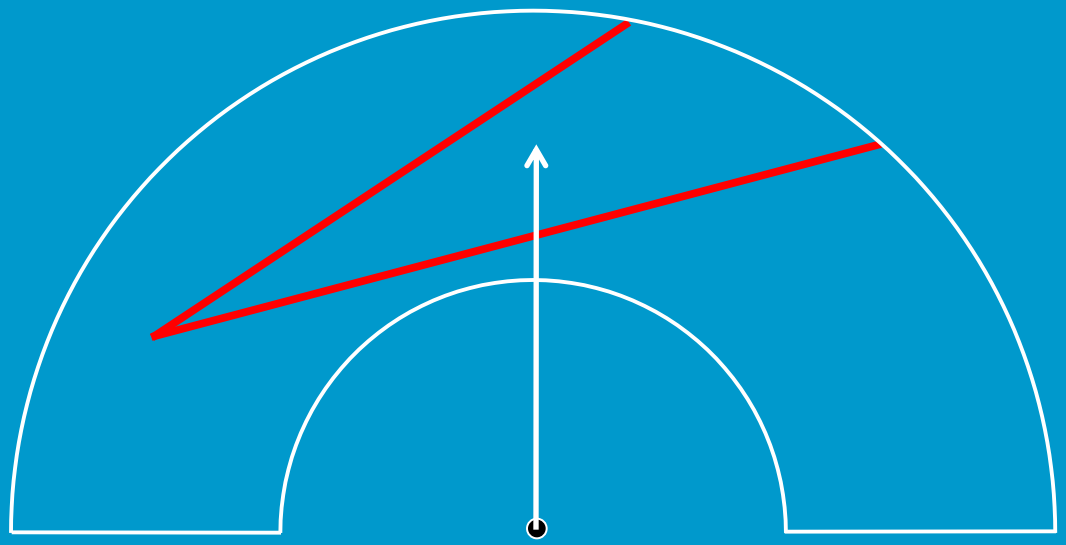
# …the ecological ASAS display

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



# EID aims to show all constraints

....heading bands??



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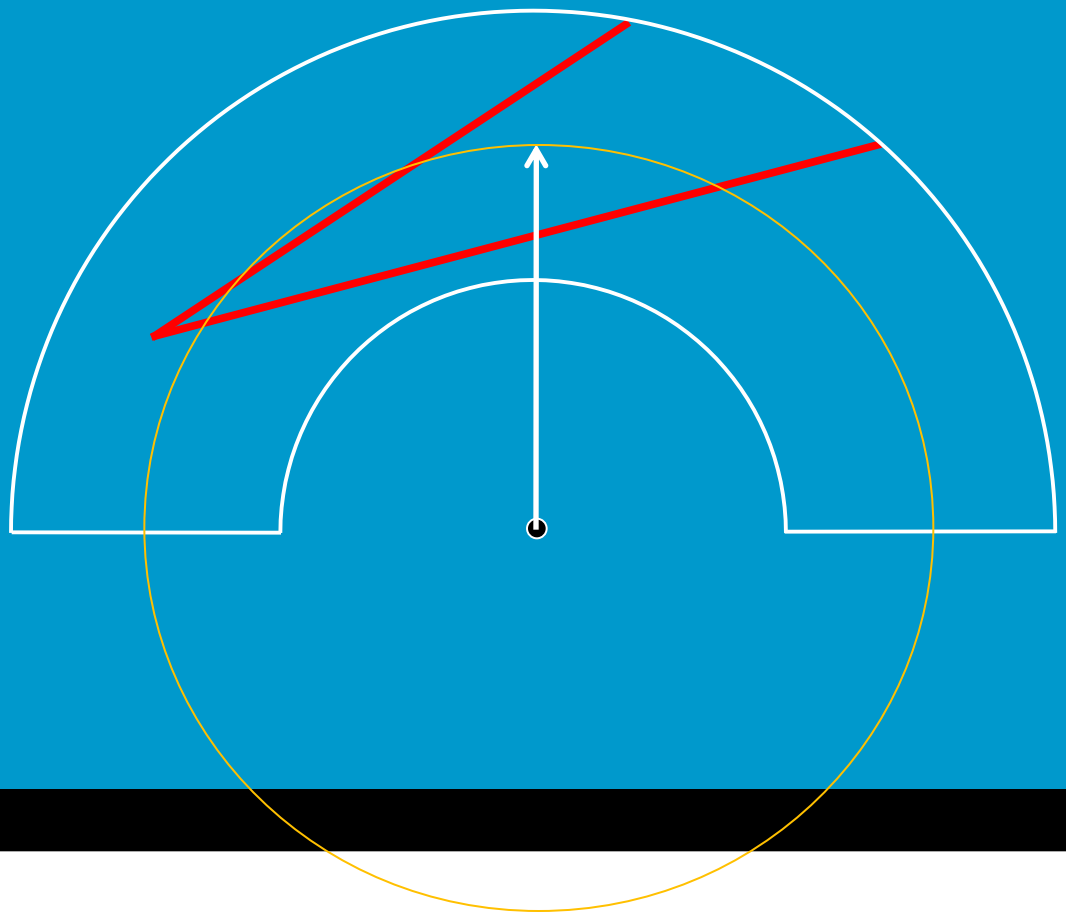
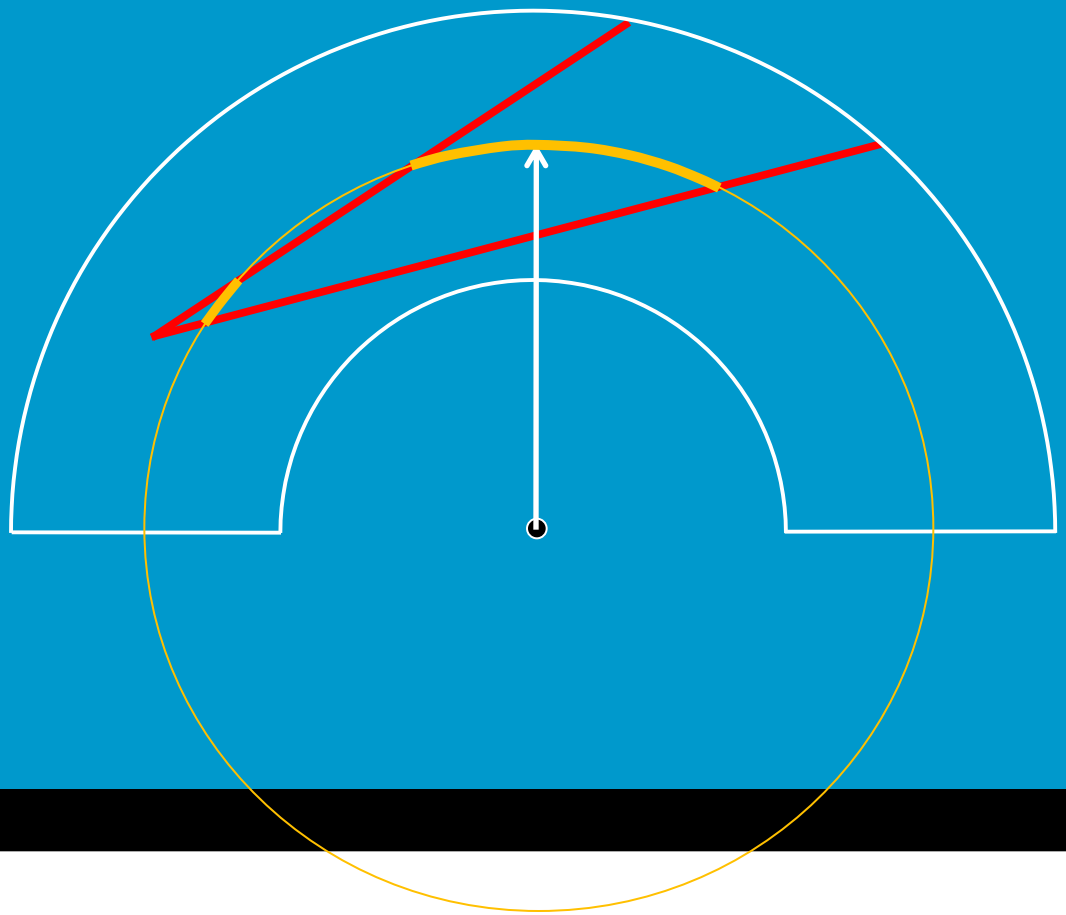


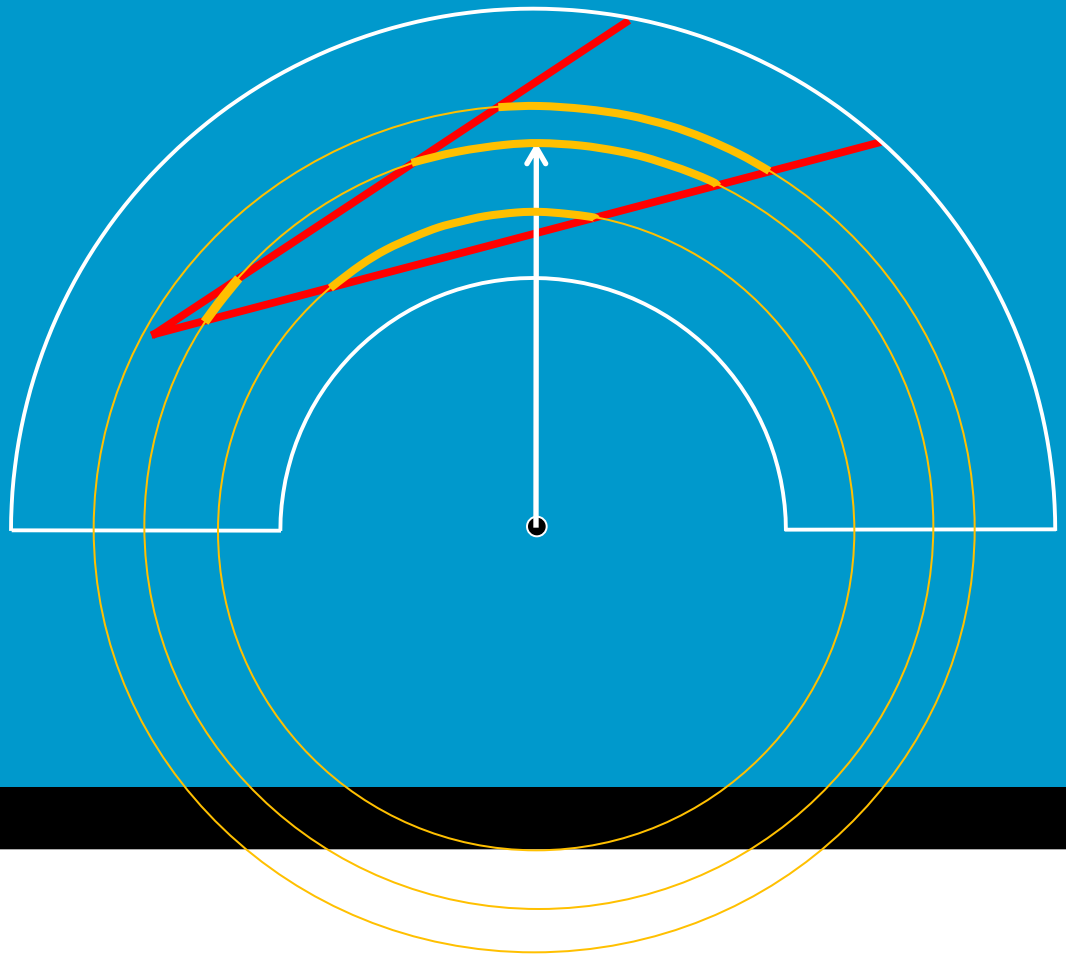
# EID aims to show all constraints

....heading bands!



# EID shows all constraints

....a whole family of heading bands!





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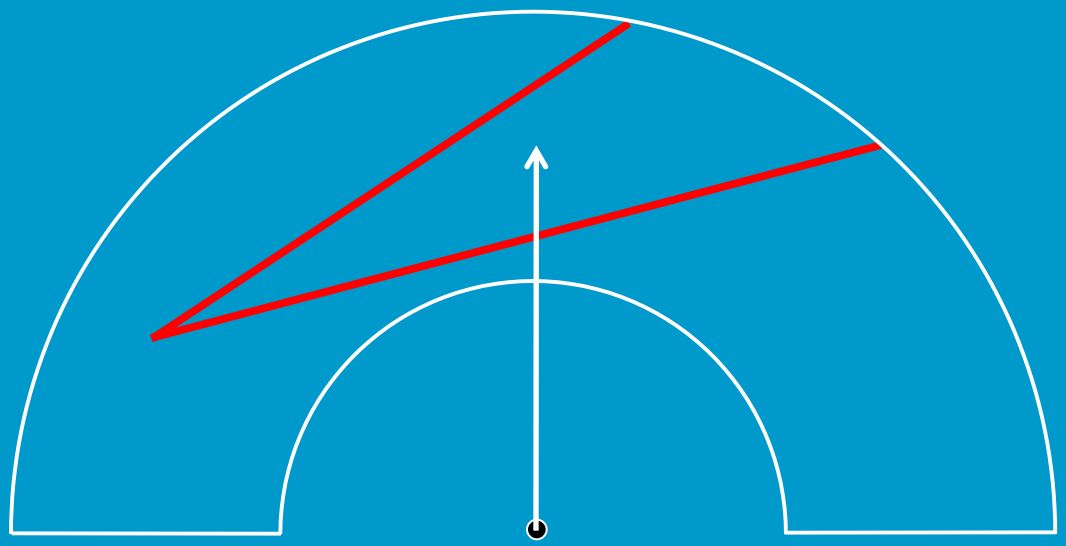
# EID shows all constraints

....speed bands??



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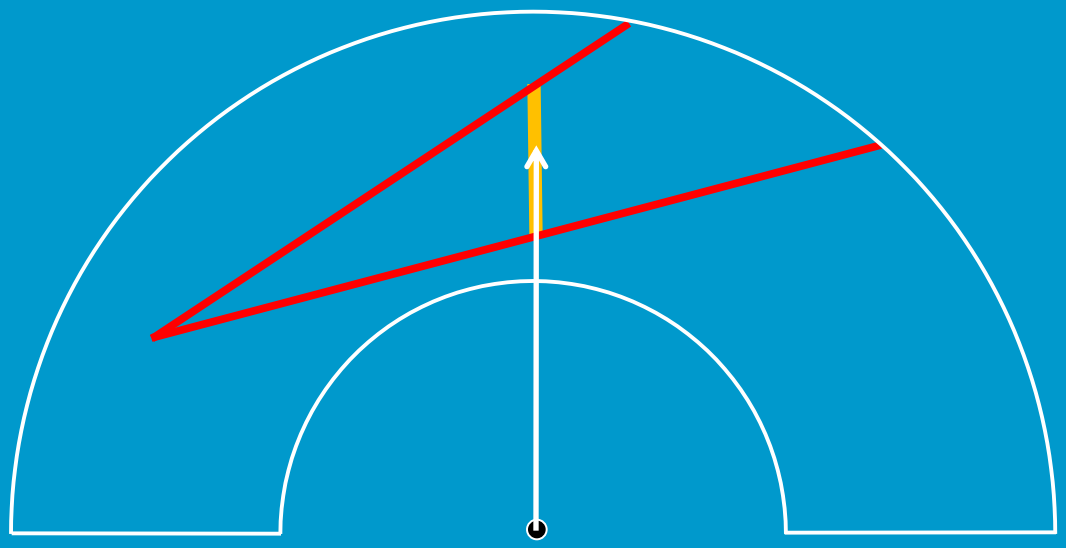
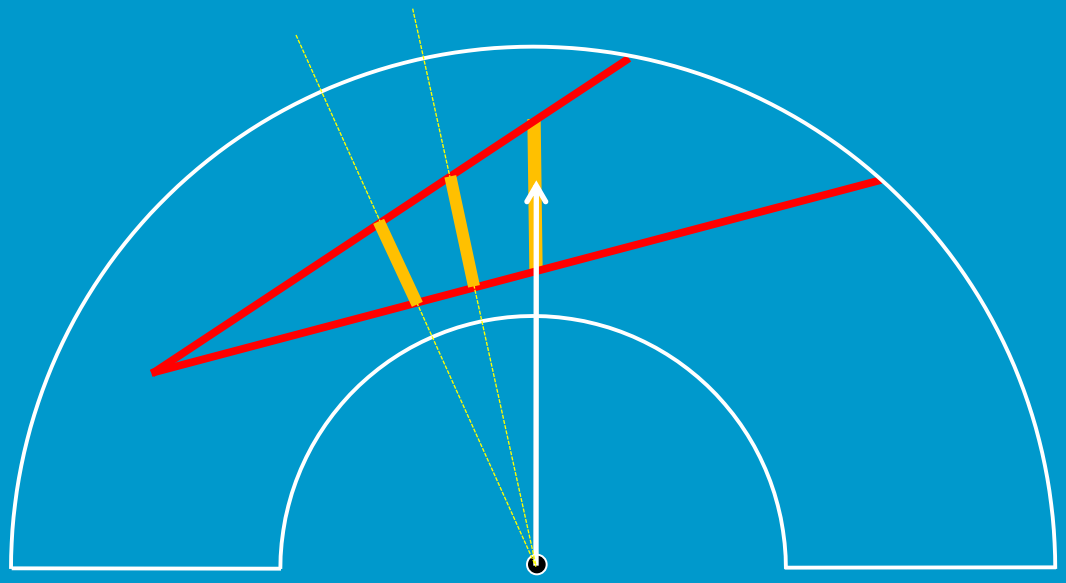


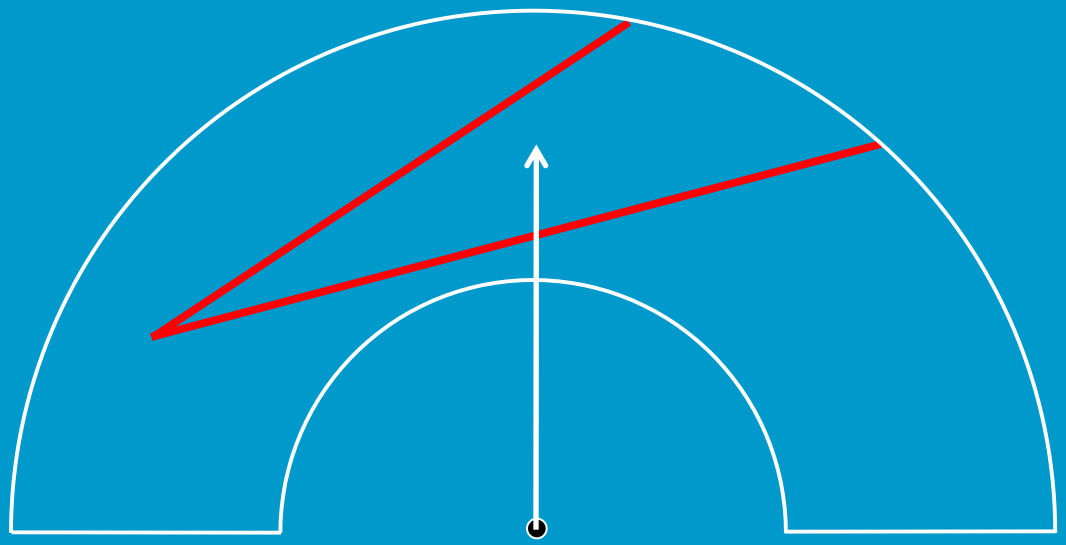
# EID shows all constraints

....a whole family of speed bands!



# EID shows all constraints

....optimal solution??



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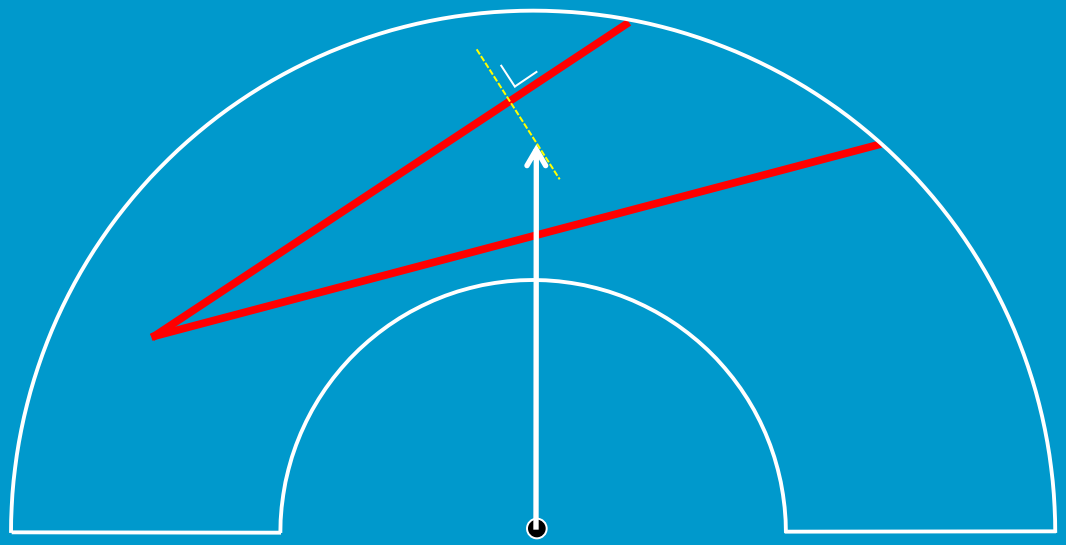
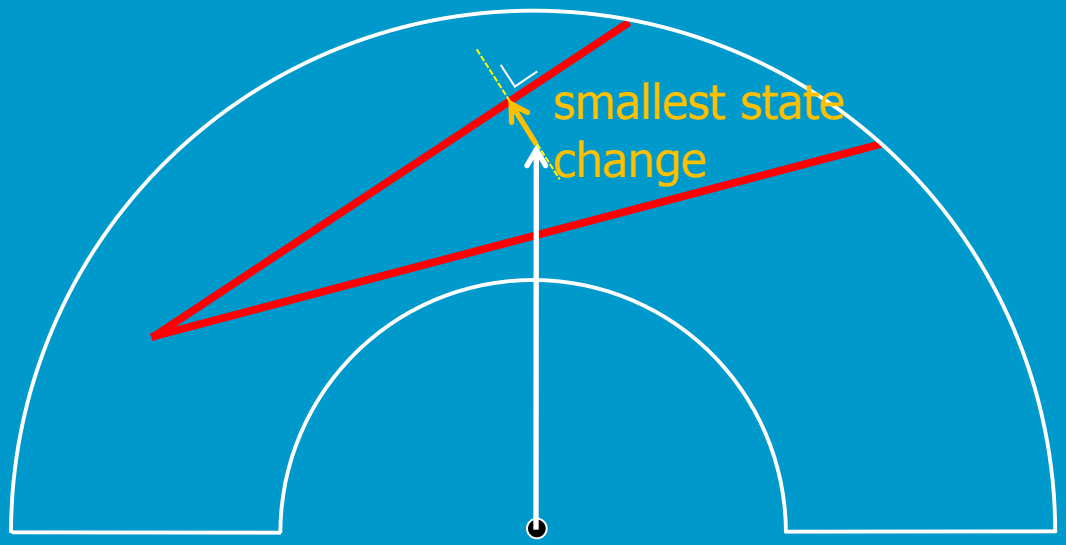


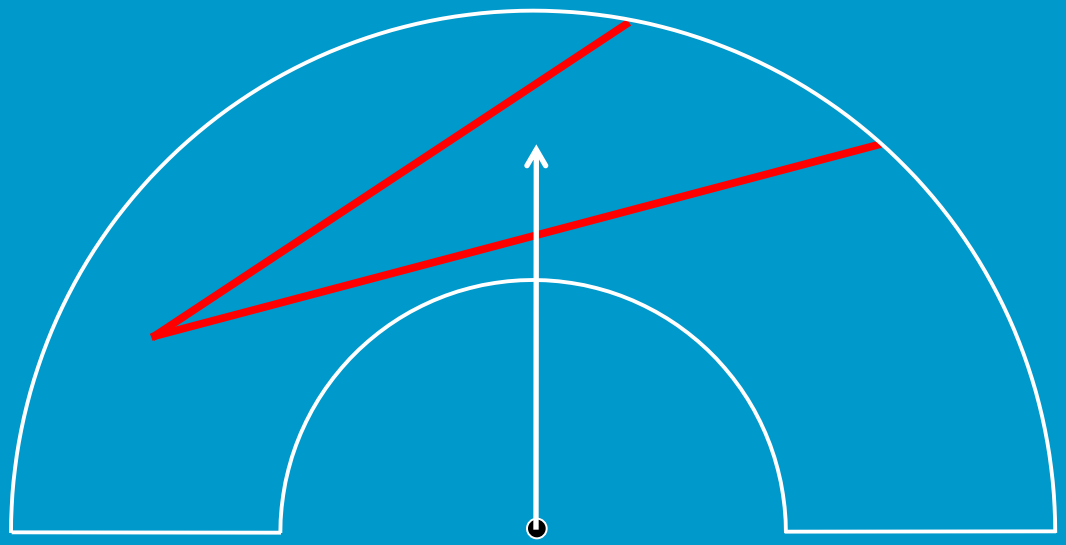
# EID shows all constraints

....optimal solution!



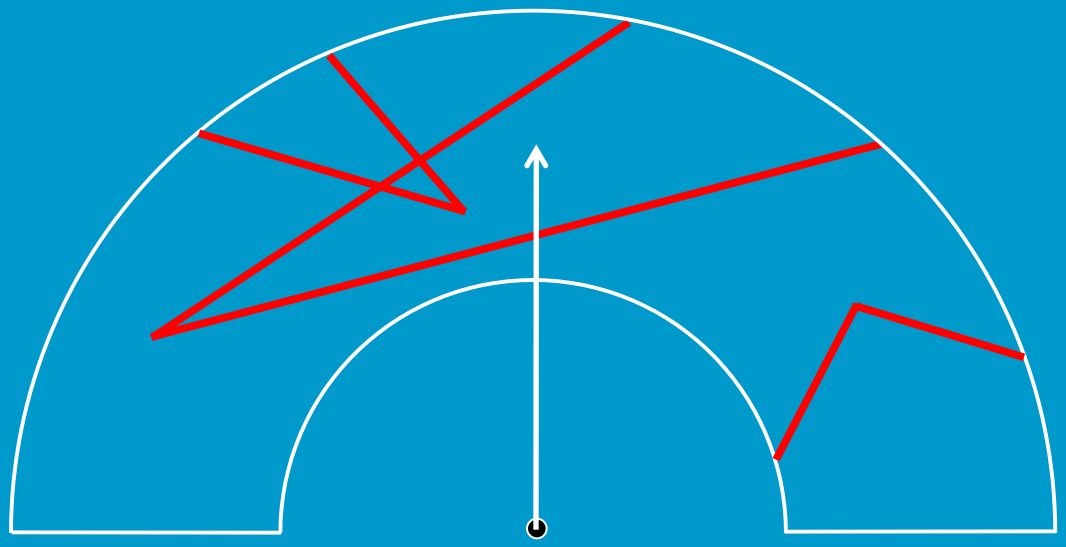
# EID shows all constraints

....multiple intruder aircraft??



# EID shows all constraints

....multiple intruder aircraft!



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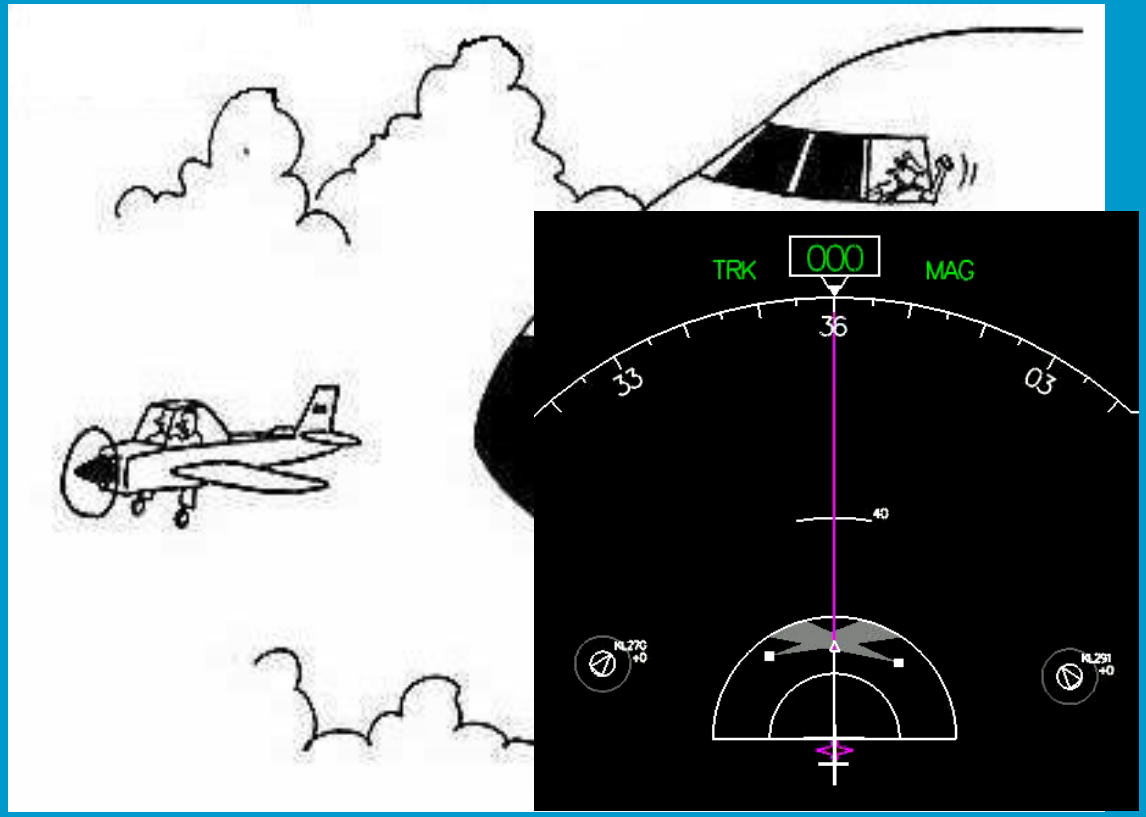
# . . . is there an approach to automation and interface design that helps pilots with their (cognitive) tasks?





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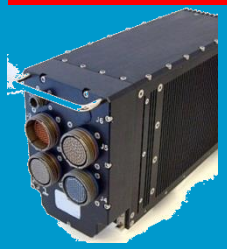
# the world behind the glass

**TRAFFIC!**



*"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 cross the intruder from the front or back side?"*



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# closing statements

# 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

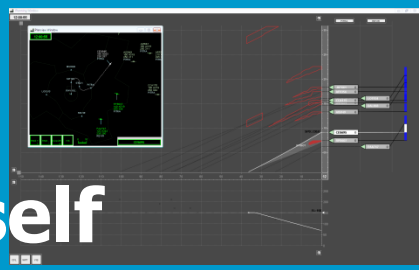
**"make visible the invisible"**

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

# our approach to interface design

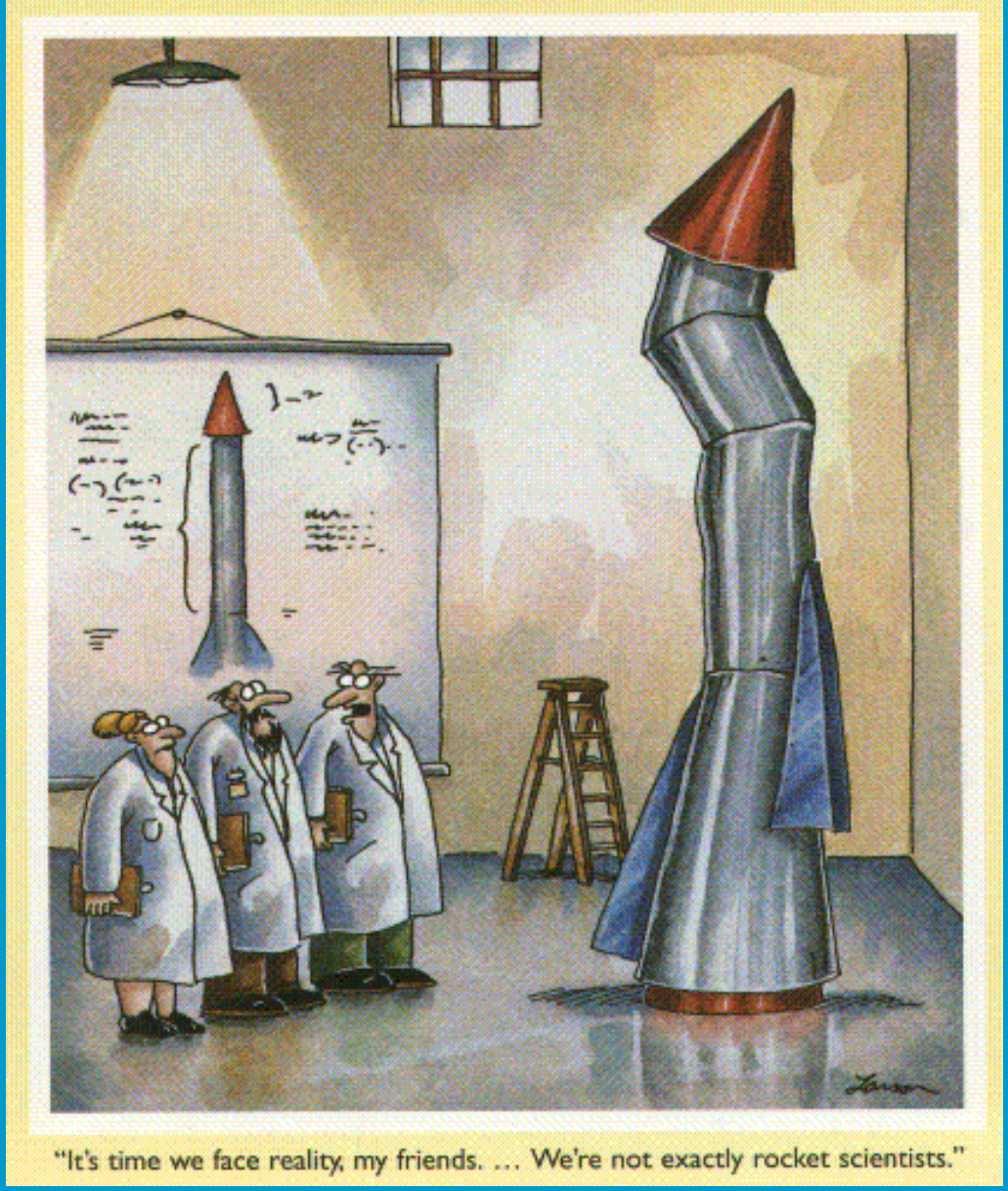
...usually starts out with engineering analysis, modelling and describing the system

...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



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

we go through lots of analysis and design iterations!!

# Ecological Flight Deck Design

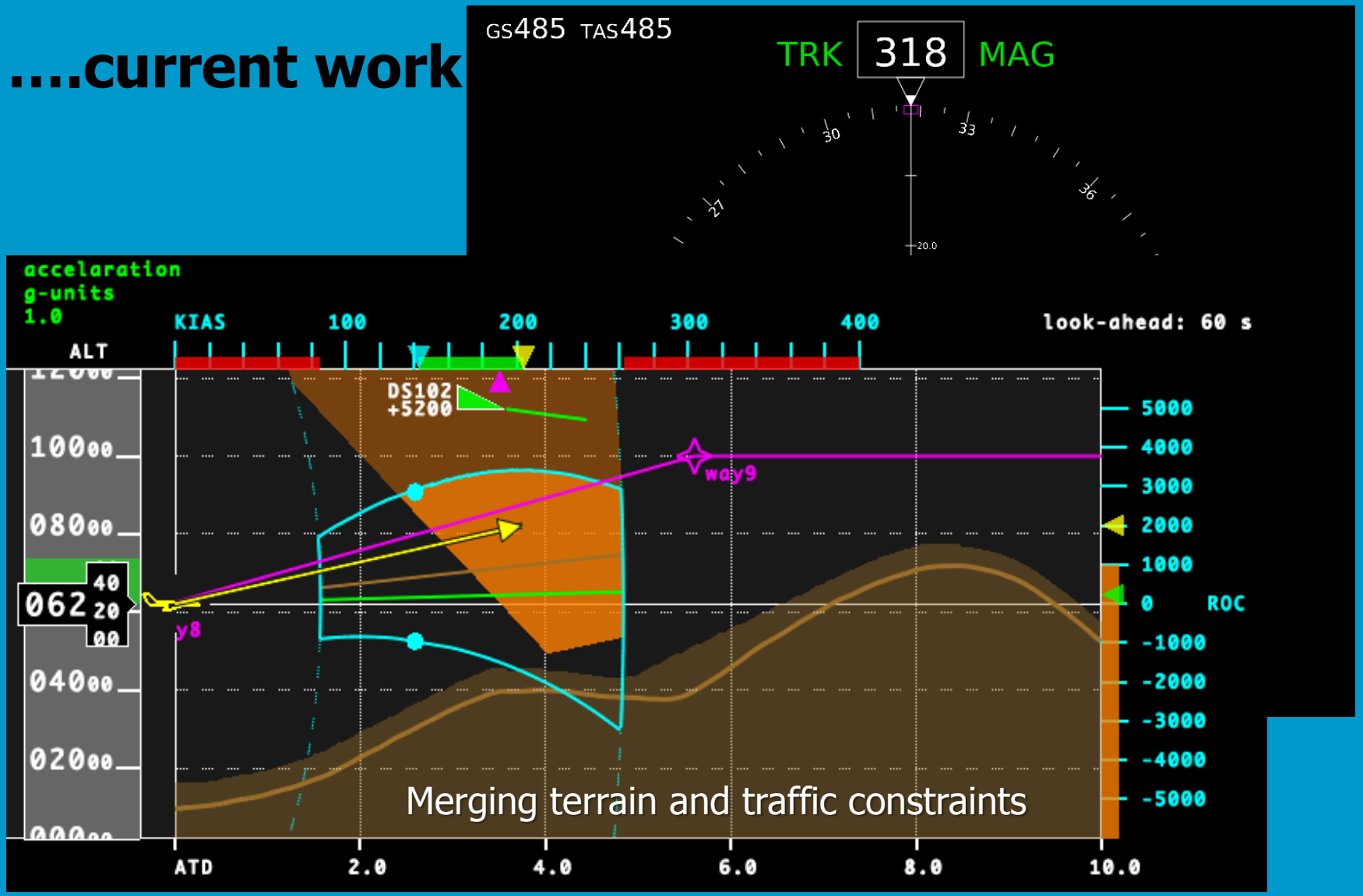
## -the world behind the glass-

**7th European Flight Test Safety Workshop**
**October 30, 2013**

**Max Mulder**

TU Delft
Delft University of Technology

# ....current work



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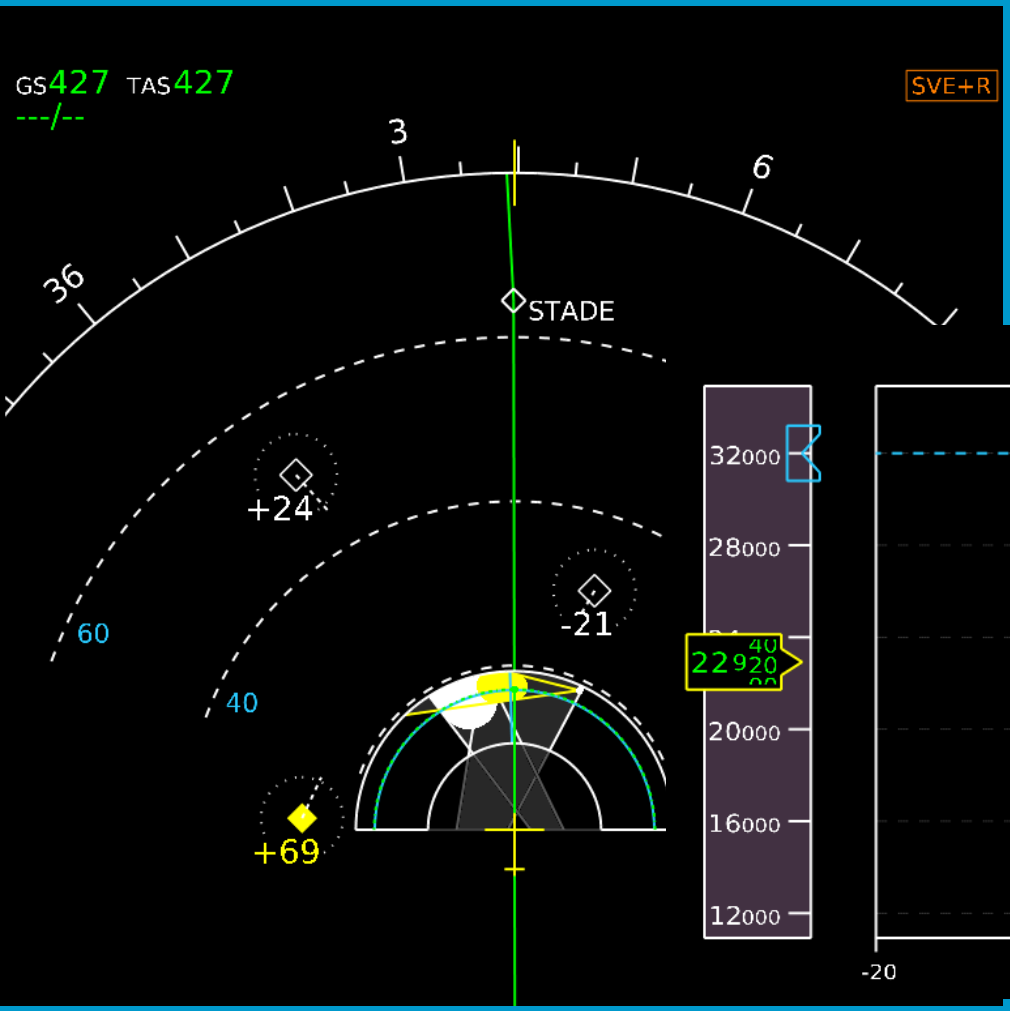
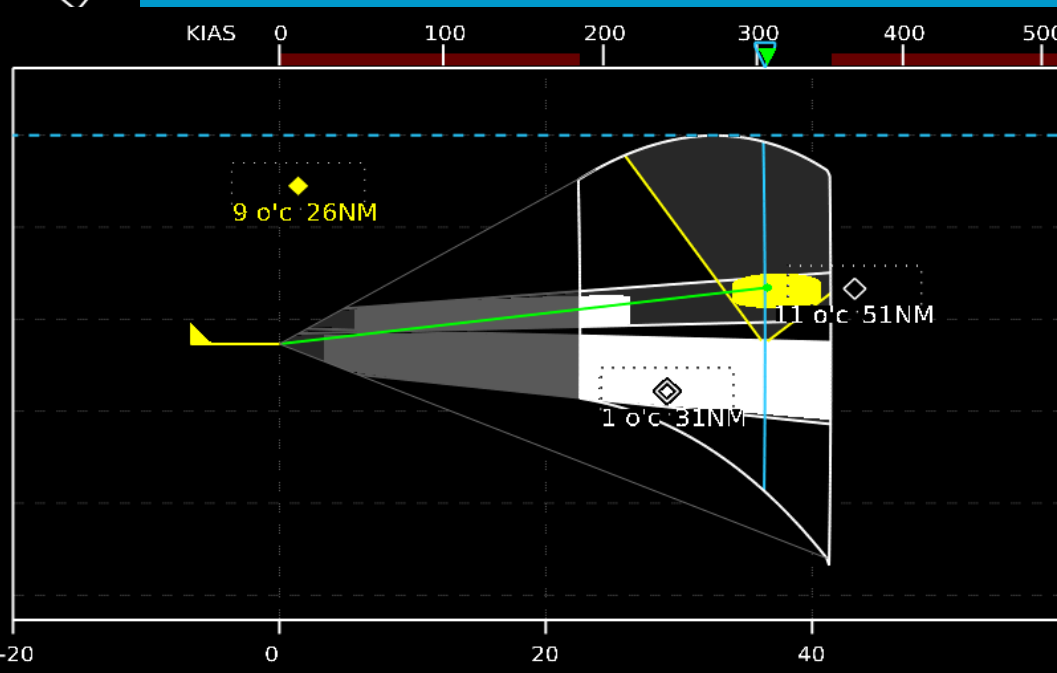
# ....current work



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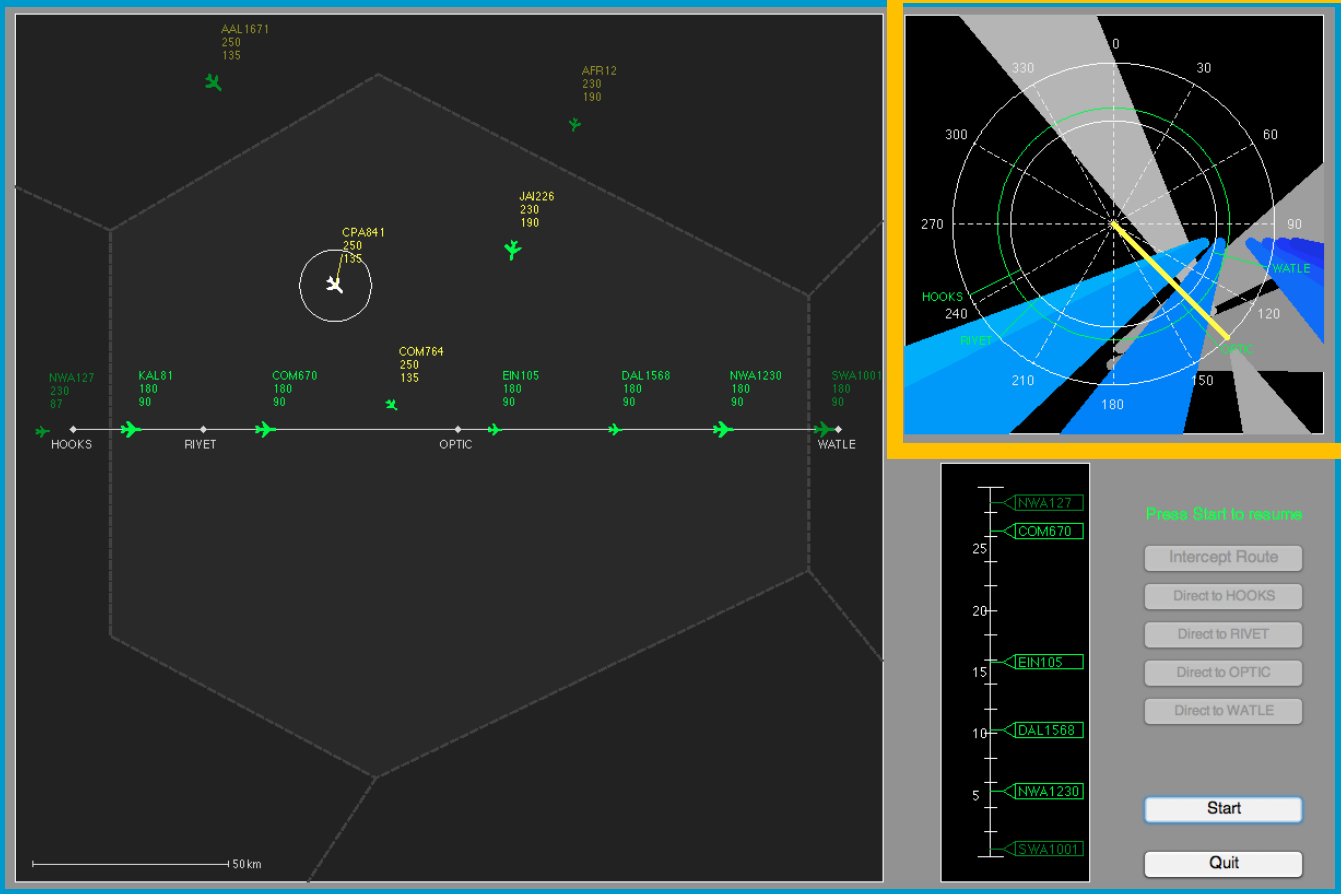
# ....current work




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

SESAR JOINT UNDERTAKING

C-SHARE



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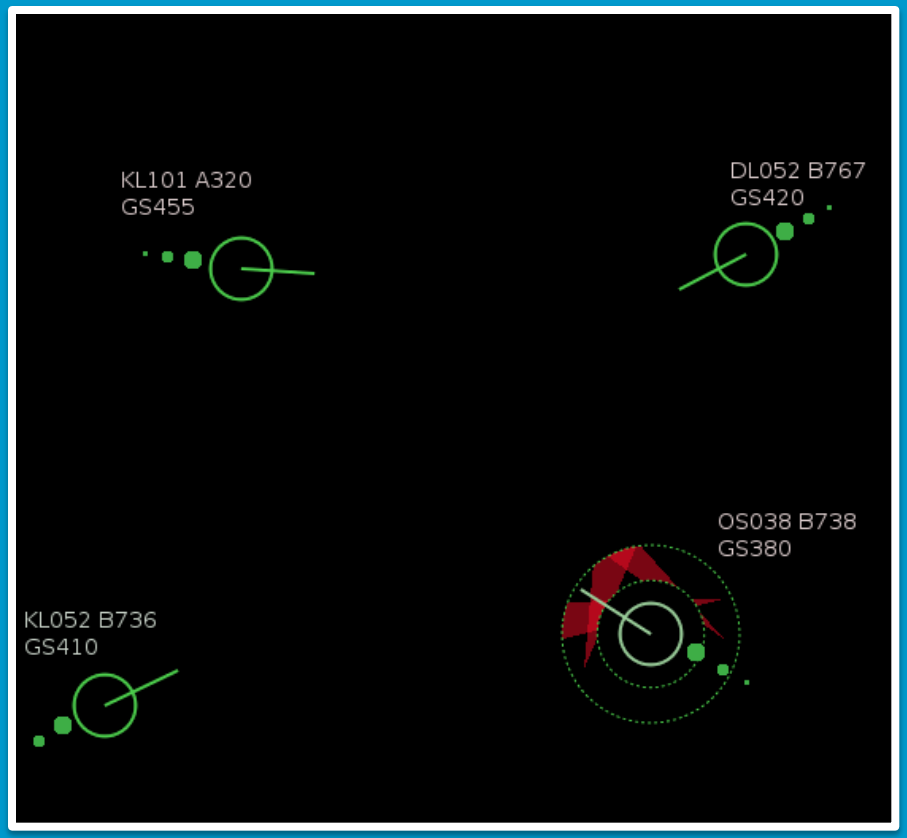
# ....current work




Java application

**cswiki.lr.tudelft.nl**



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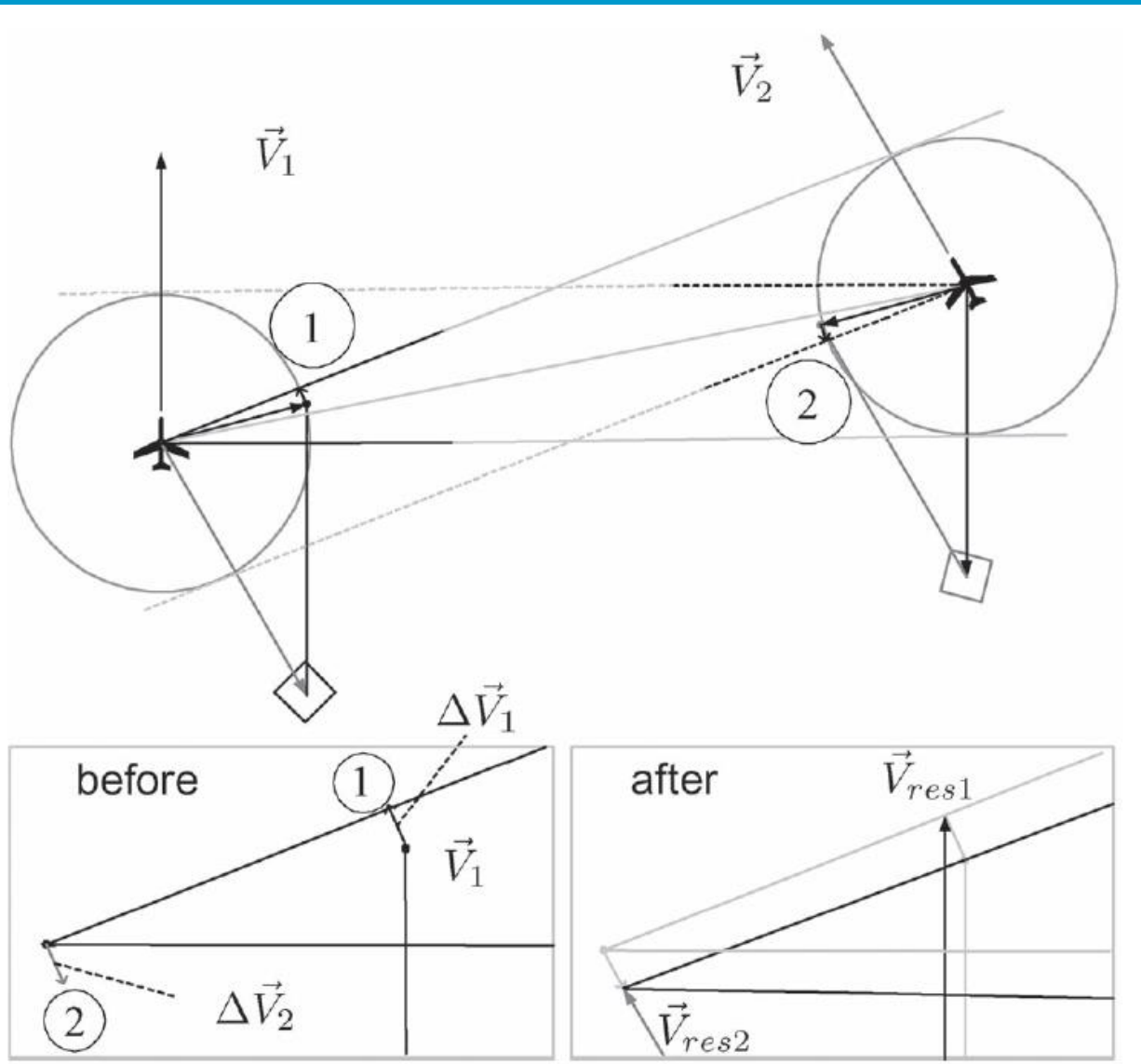
# ATP

....implicit
coordination!



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# ATP

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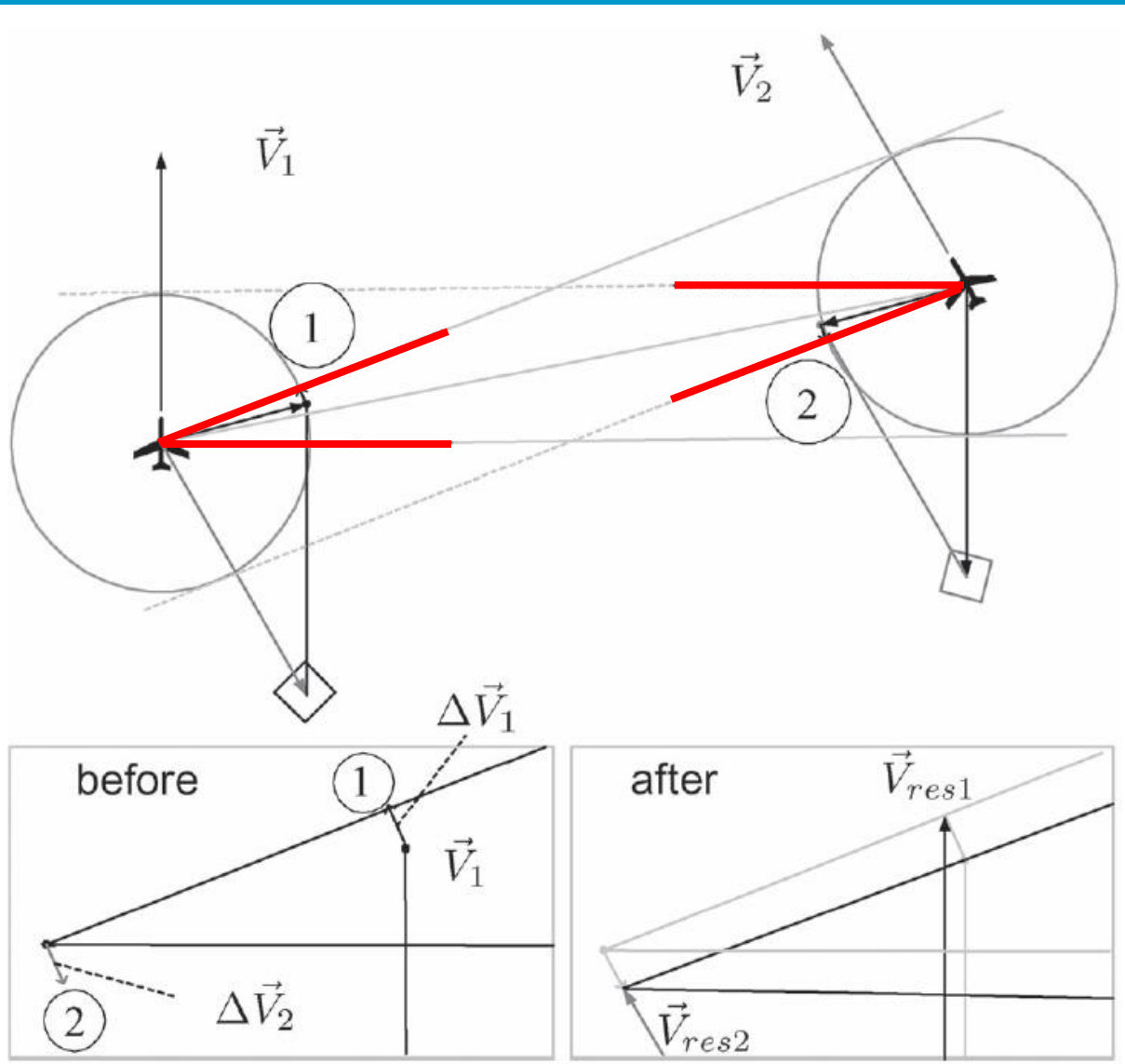




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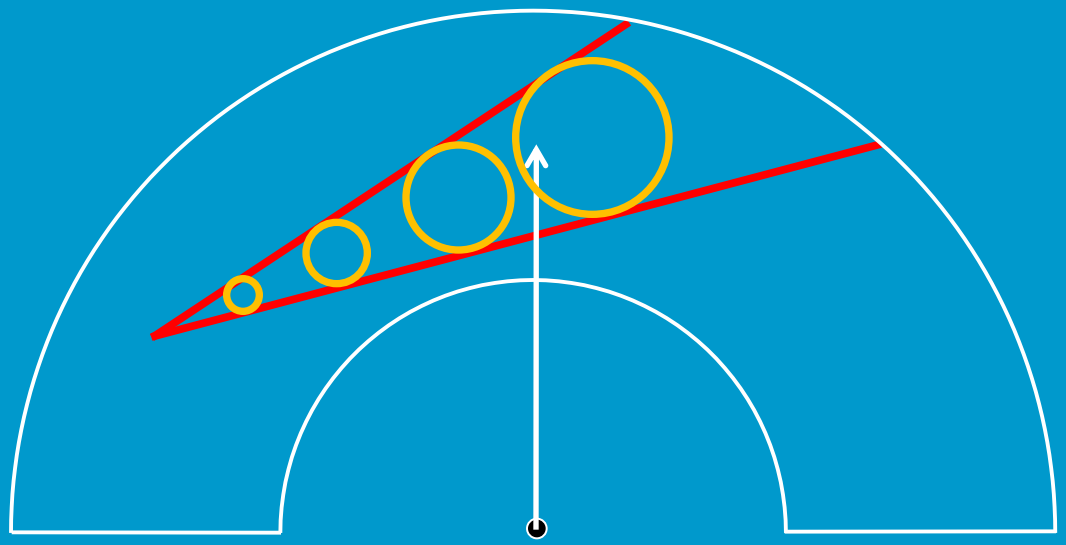
# ATP

....the FBZ is a family of circles



# ATP

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