Ecological Interface Design for the Flight Deck

The World beyond the Glass

SAE Workshop, Tahoe, March 2006

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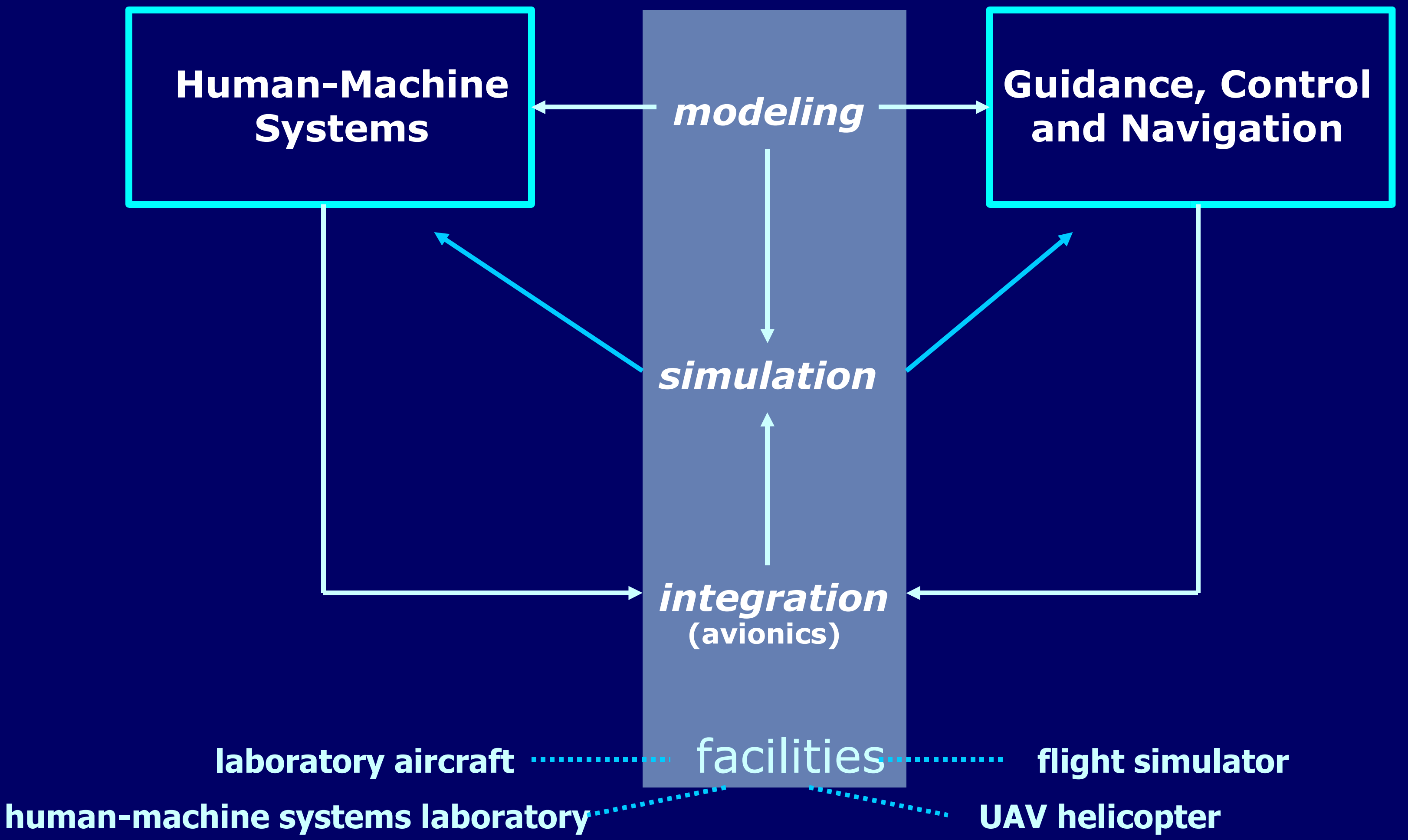
March 2, 2006

Delft University of Technology

Topics I hope to cover

- Short Introduction to Control and Simulation, Aerospace Engineering, TUDelft
- Aspects in Flight Deck Interface Design
- Cognitive Systems Engineering/ Ecological Interface Design
- Work Domain Analysis
- Some Examples
- Closed loops and the match to flight skills
- Conclusions

Control and Simulation – AE - TUDelft



people in the HMS cluster

prof. dr Bob Mulder	division head	
dr ir René van Paassen	associate professor	
dr ir Max Mulder	associate professor	
ir Xander in 't Veld	division test pilot	
	PhD candidate	noise abatement procedures

ir Frizo Vormer	PhD candidate	flexible arrival management
ir Clark Borst	PhD candidate	CSE/EID for TAWS/SVS
ir Matthijs Amelink	PhD candidate	CSE of UAV
ir Mung Lam	PhD candidate	UAV haptic interface
ir Stijn van Dam	PhD candidate	CSE/EID for VTM
ir Joost de Winter	PhD candidate	Virtual driving assistant
ir Herman Damveld	PhD candidate	H-Q of flexible aircraft
ir Peter Zaal	PhD candidate	Simulator fidelity

Approximately 25 MSc graduate students each year

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active knowledge base

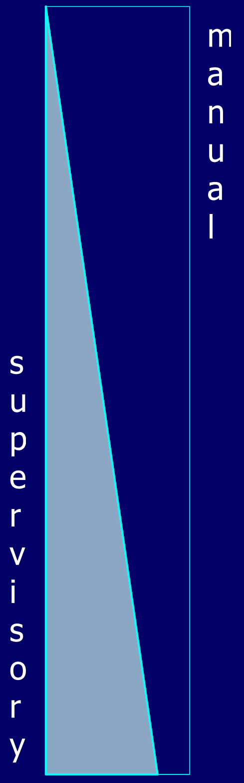
perception & psychophysics

cybernetics

artificial intelligence

cognitive systems engineering

ecological interface design



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The Flight Deck is:

- An "open" system (Vicente)
  - extensive and complex interaction with the environment
- The airborne office
- A workplace for cognitive (team)work

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Levels in Interface Design

- Illumination, readability, colors, symbols
- Integrated displays, configural displays, emergent features, principle of moving part
- Support for cognitive work ->Cognitive Systems Engineering

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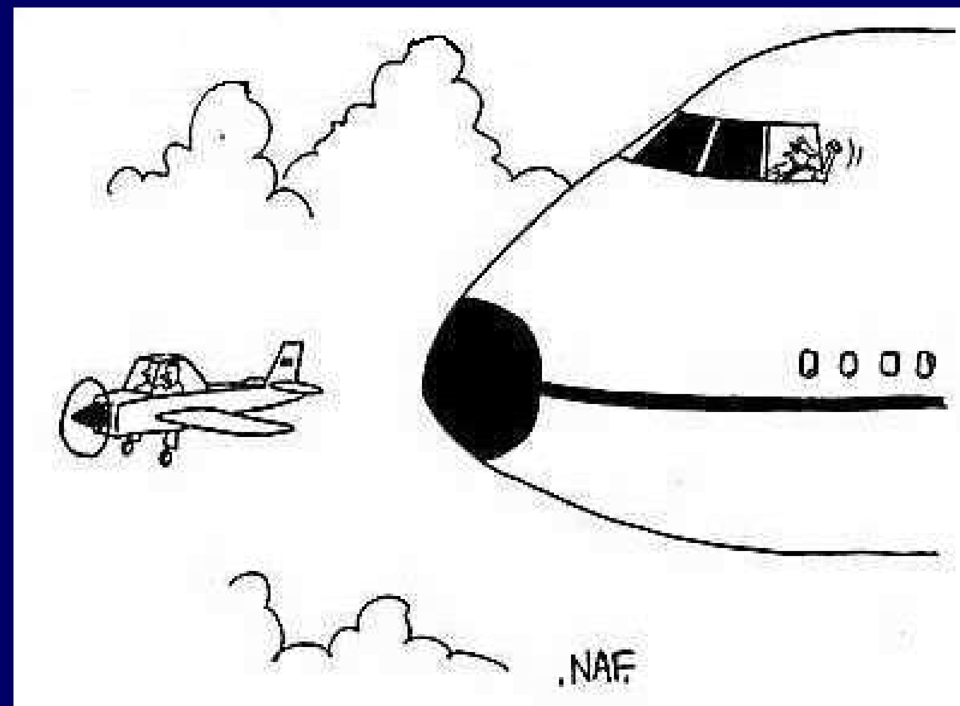
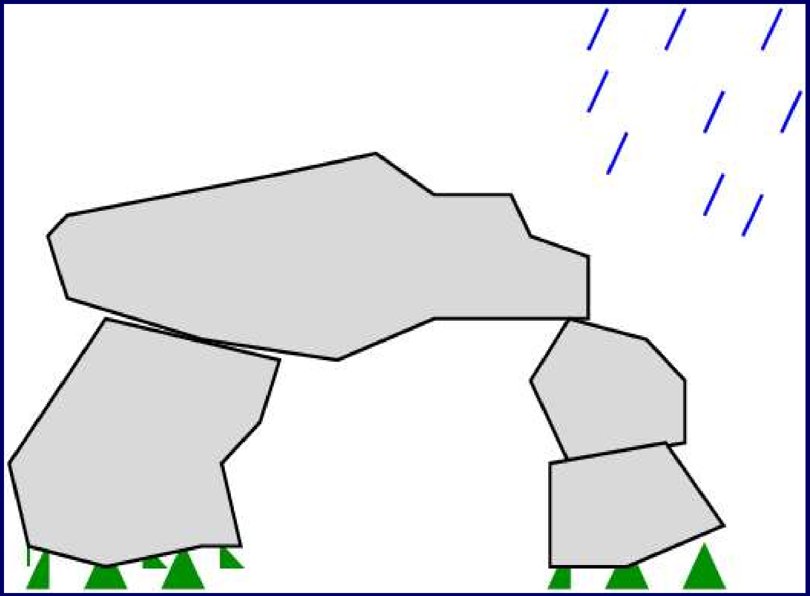
Is there a display format that helps pilots with their (cognitive) tasks?



Human Capabilities
Direct Perception – Gibson



affording

perception-action coupling

specifying

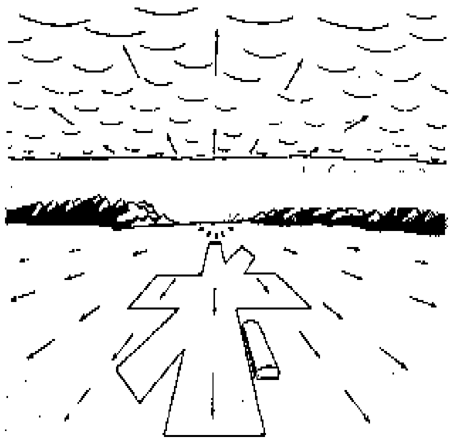
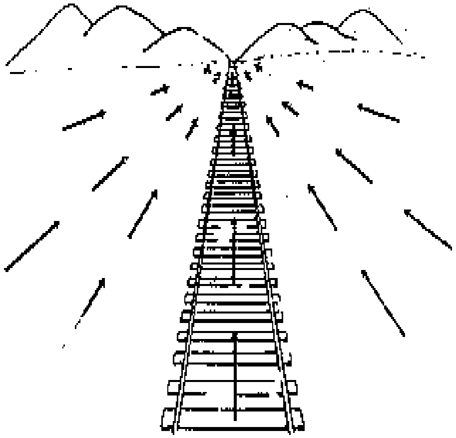


FIG.8.6. The optic flow field for a pilot landing an aeroplane. From Gibson (1950). Copyright © 1950 by Houghton Mifflin Company, Boston. Used by permission.



Joint Cognitive Systems

- Aircraft + crew = system with cognitive tasks
- Joint cognition ≠ who does what (Fitts' list)
  rather: cognitive transparency
- Display supports cognition:
  Ecological Interface Design

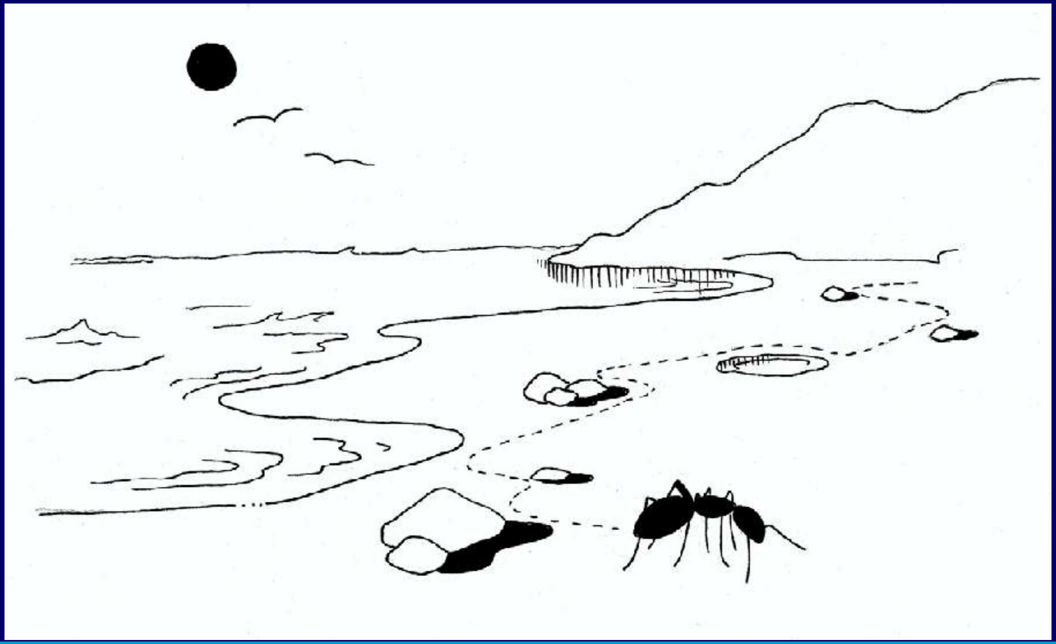
-> Cognitive Systems Engineering

Ecological Interface Design

- Basic idea + name: enable “Gibson” direct perception
- Elaboration:
  - Work Domain Analysis – Abstraction Hierarchy
  - Control task analysis – Decision Ladders
  - Strategies, Social Organization, Worker capacity
- The “design”

Work Domain Analysis

- Map the “terrain” of a specific work situation
- Identify the constraints



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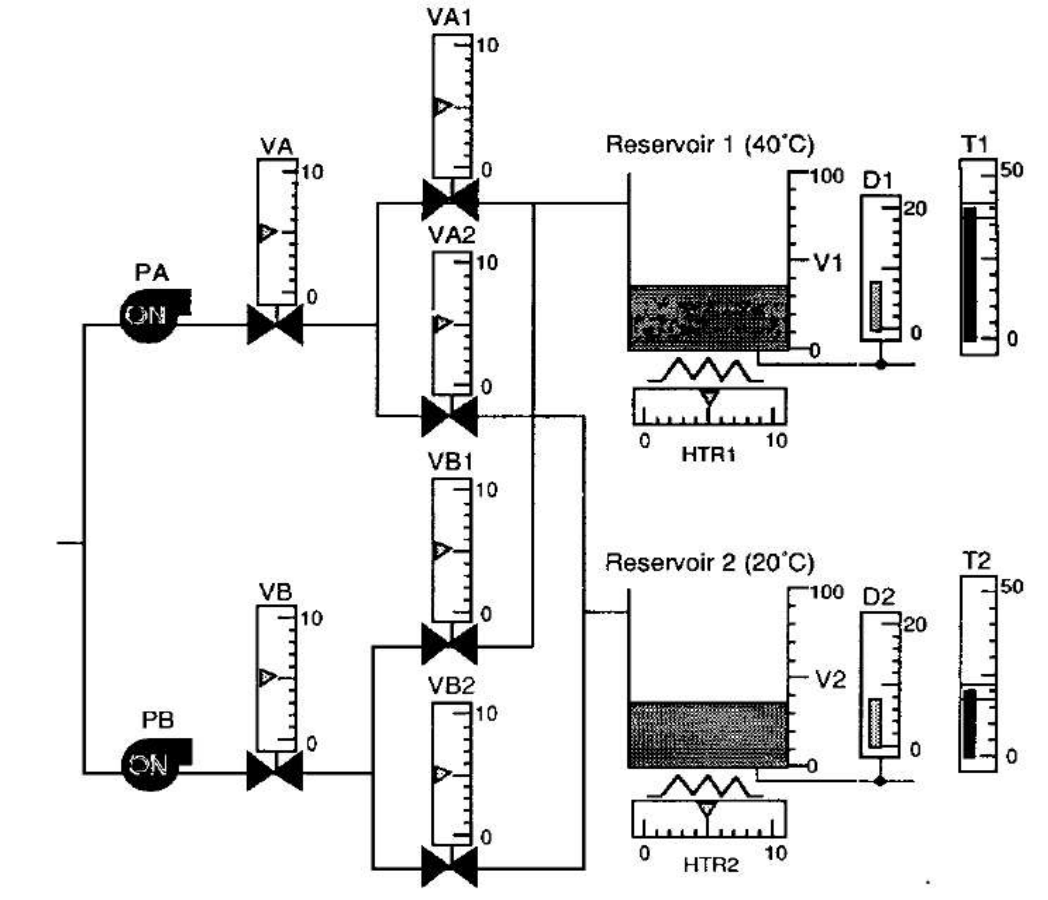
EID Archetype DURESS

- Double feedwater system
- Laboratory task



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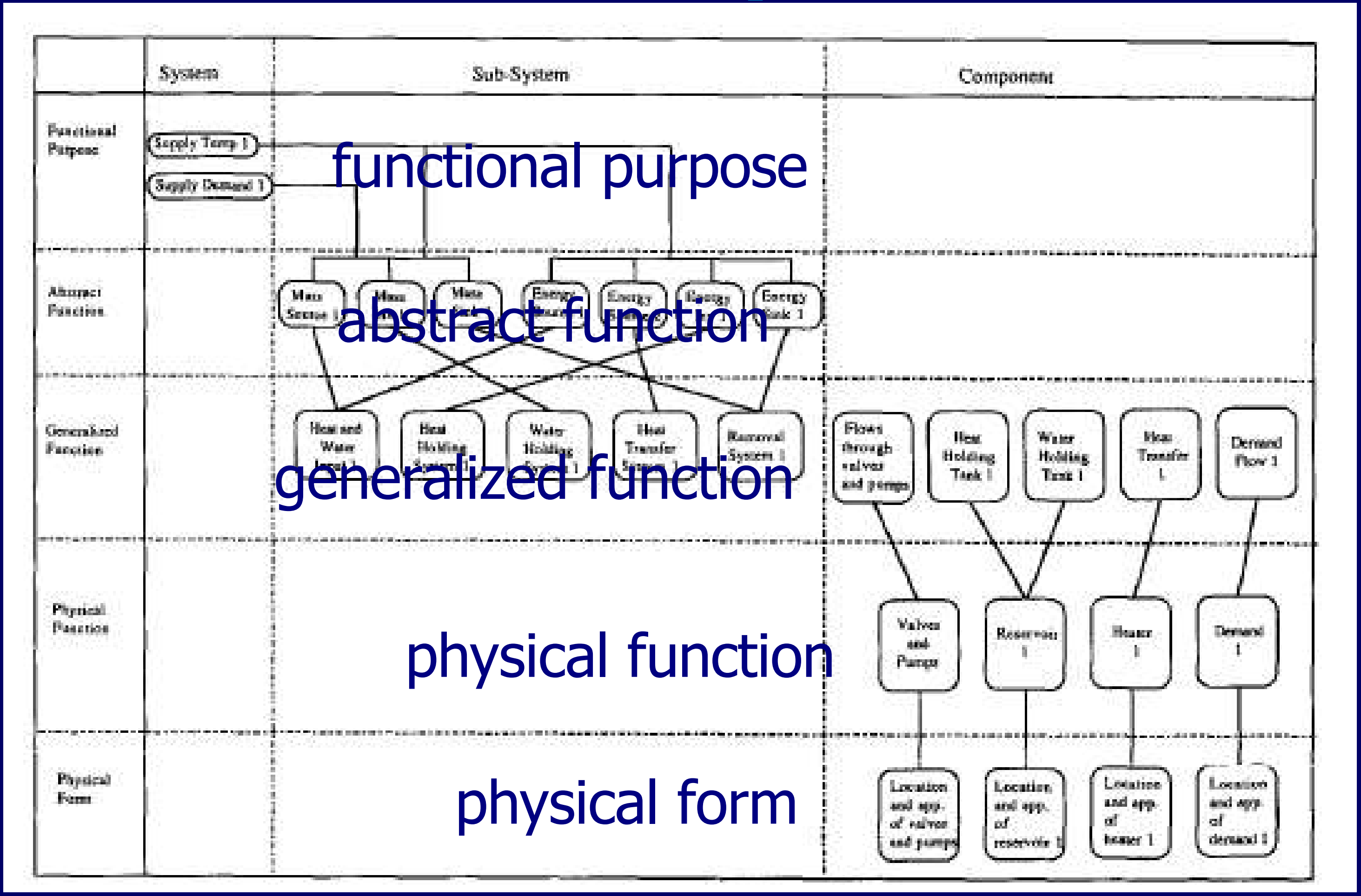
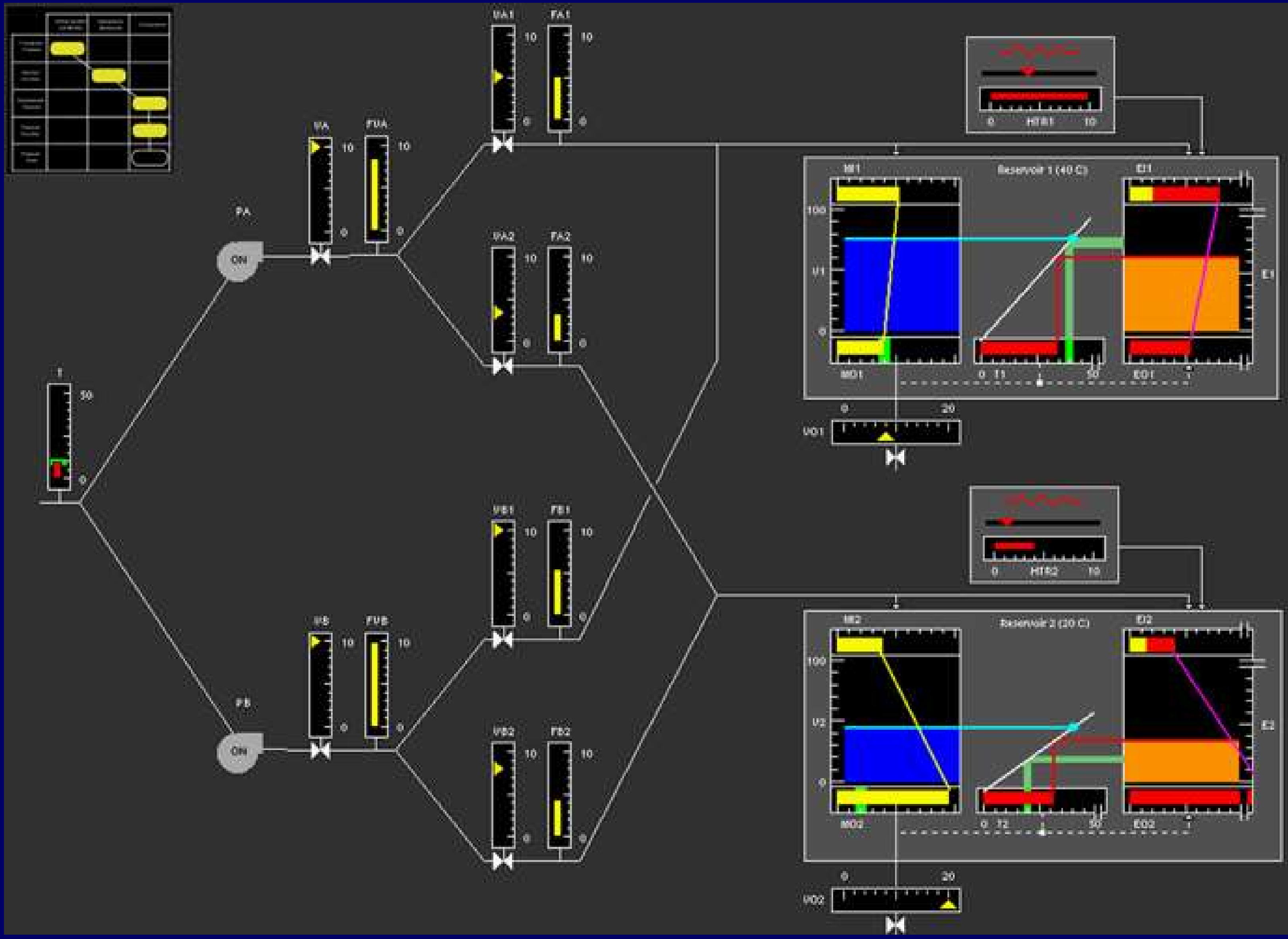
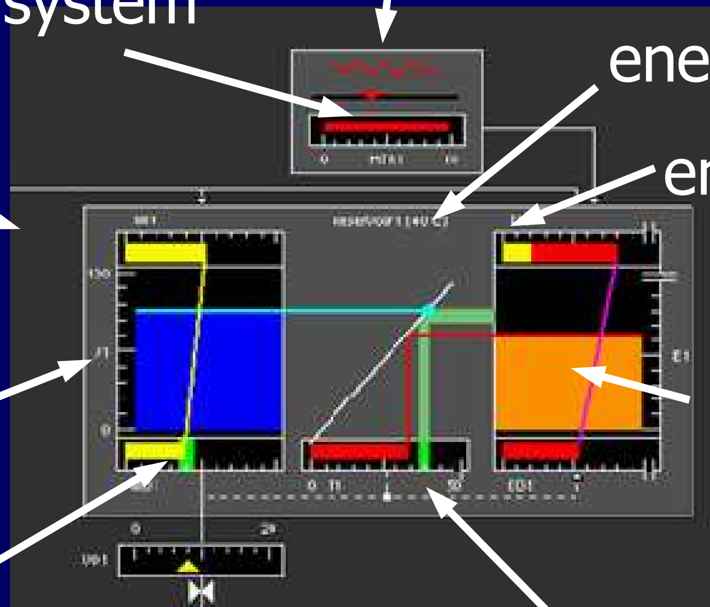
Abstraction hierarchy





VA1
FA1
VA2
FA2
VA
FVA
PA
ON
VB1
FB1
VB2
FB2
VB
FVB
PB
ON
HTR1
Reservoir 1 (40 C)
HTR2
Reservoir 2 (20 C)
VO1
VO2

TUDelft


heater control
heating system
energy flow water
mass flow
energy flow heater
funnel: level trend
storage
(reservoirs)
temperature goal
flow goal
outflow valve

Driving, Flying, Sailing, vs. Process plants

- Extension of natural ecological perception
- Transport is the issue
- Interaction complex environment
- Control

- Build new ecology
- Transported stuff is (nearly) anonymous
- Limited (known) number of variables
- Functionality creation and selection

Additional

- The “intentional domain” issues, are man-made laws+conventions different from the physical ones?
- Difference in nature of disturbances, probability models.

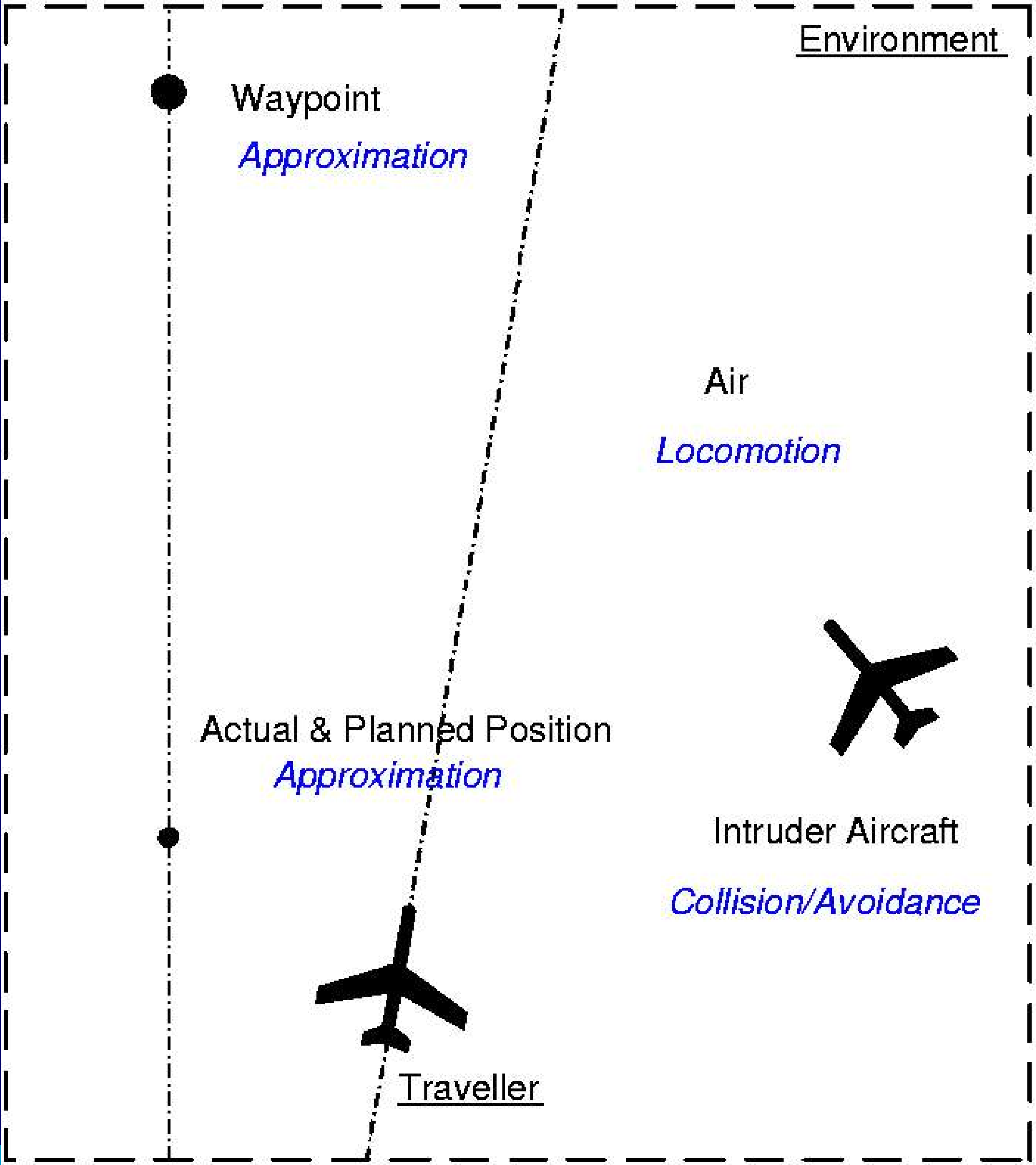
Can we get “classical” EID in an aircraft (car, ship)

- Already have Ecological Perception -> Enhance, not substitute
- Time scale is different -> not always opportunity to visually explore an interface
- Controls are not co-located with the interface
- Interaction is already multi-modal -> process control EID could learn from us there
- We cannot measure everything in the outside world -> rely on humans to read signs etc.

Ecological Support Interface Design

- Analyze work domain (AH)
- Analyze control tasks (cybernetics)
- Identify what affordances are not sufficiently specified
- Enhance

Example problem: Avoiding aircraft



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History of approaches

- ASAS, pASAS, various support tools
- Modified Voltage Potential
- NLR, Eurocontrol, FAA, others

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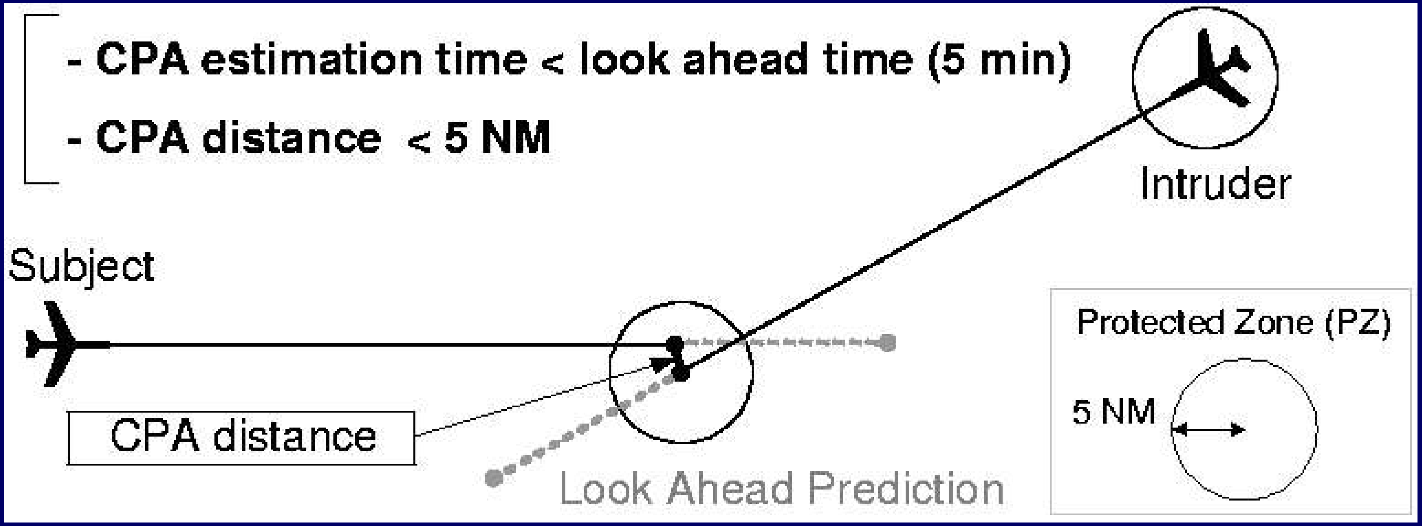
ASAS (NLR)

Calculation CPA



CPA < look-ahead time AND distance < CPA dist = conflict

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Problems

- Conflict location moves when maneuvering
- Affordance hit is clear, affordance avoidance not
- Conflicts triggered by maneuvers -> engineering approach answer pASAS

Our answer rooted in Functional Modeling and EID/Cognitive Systems Engineering

Abstraction Hierarchy conflict avoidance

functional purpose	production, safety, economy	
abstract function	absolute (loco-)motion	relative motion
generalized function	path control	flight

Solving some of these issues took us several Msc students

- Identification of abstract functions
- Chosen representation of the "world+aircraft"

John Flach's point: What you express at the AF level describes the "state" of the system, and you should be able to check goal achievement on this basis.

René's point: The selection of your state variables determines how you can shape your representation into an interface

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Choosing state representation

$$\underline{\mathrm{x}} = \begin{pmatrix} p \\ q \\ r \\ \phi \\ \theta \\ \psi \\ u \\ v \\ w \\ x \\ y \\ z \end{pmatrix} \quad , \ \dot{\underline{\mathrm{x}}} = f(x, u, t)$$

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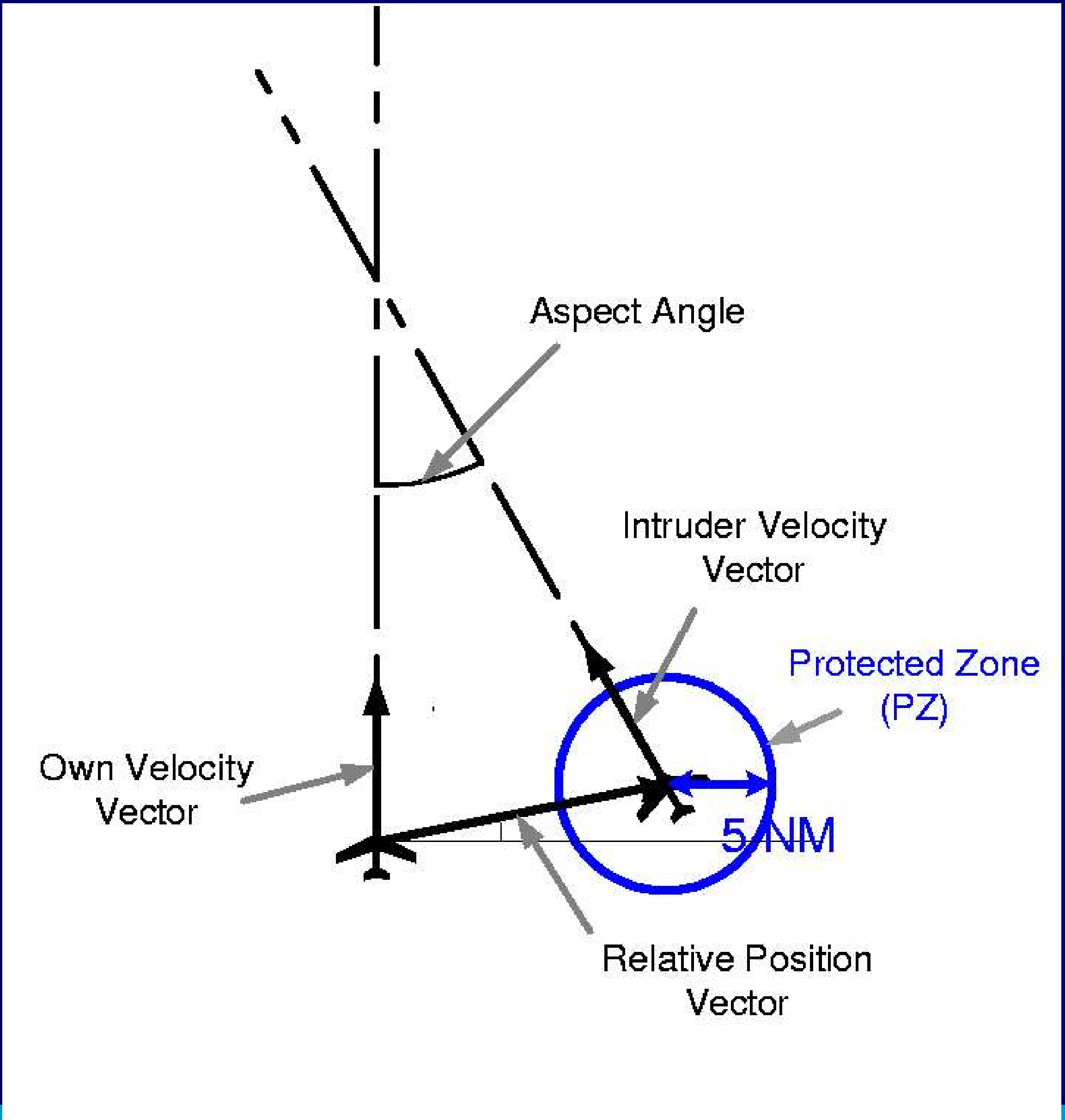
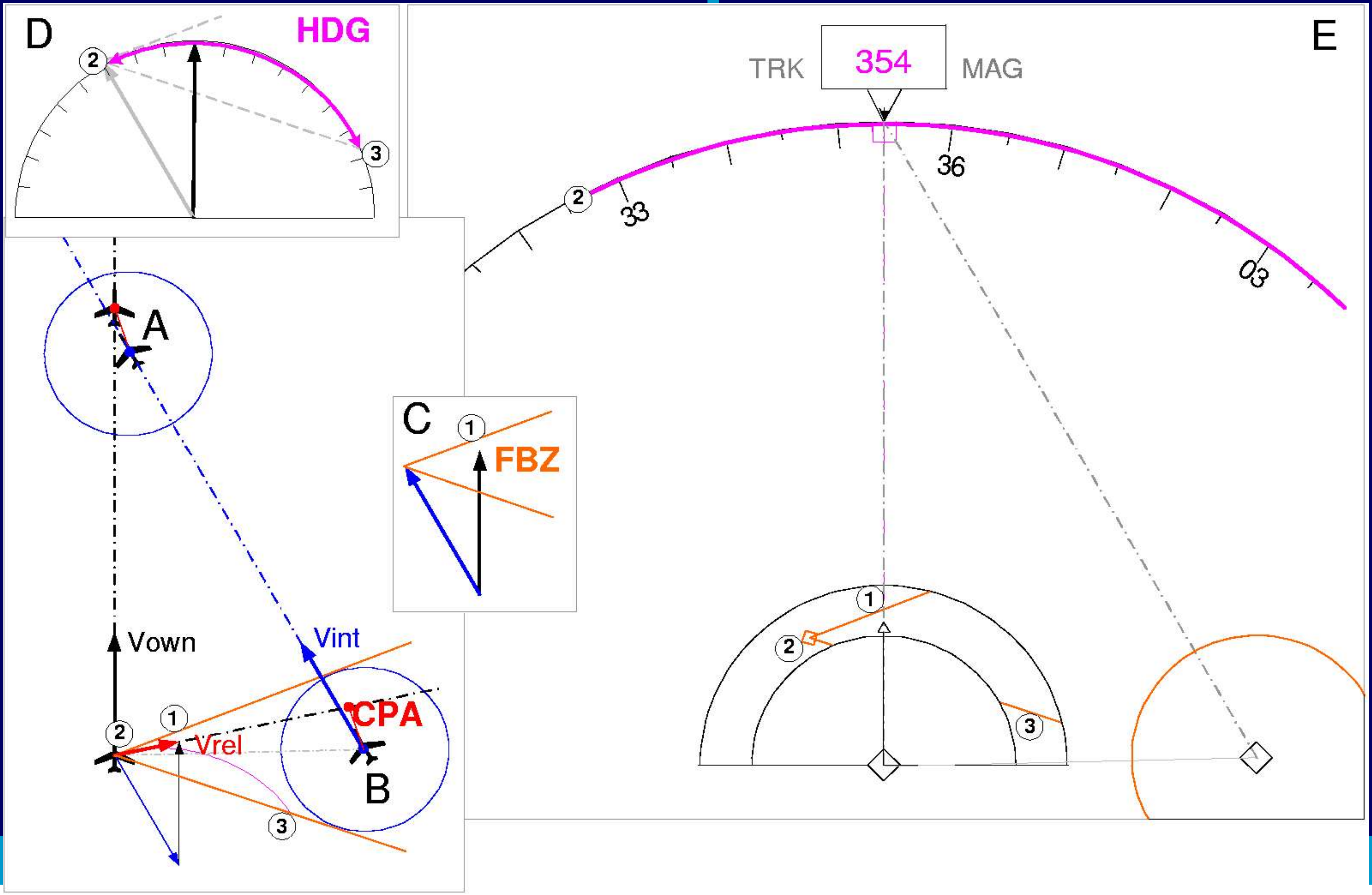
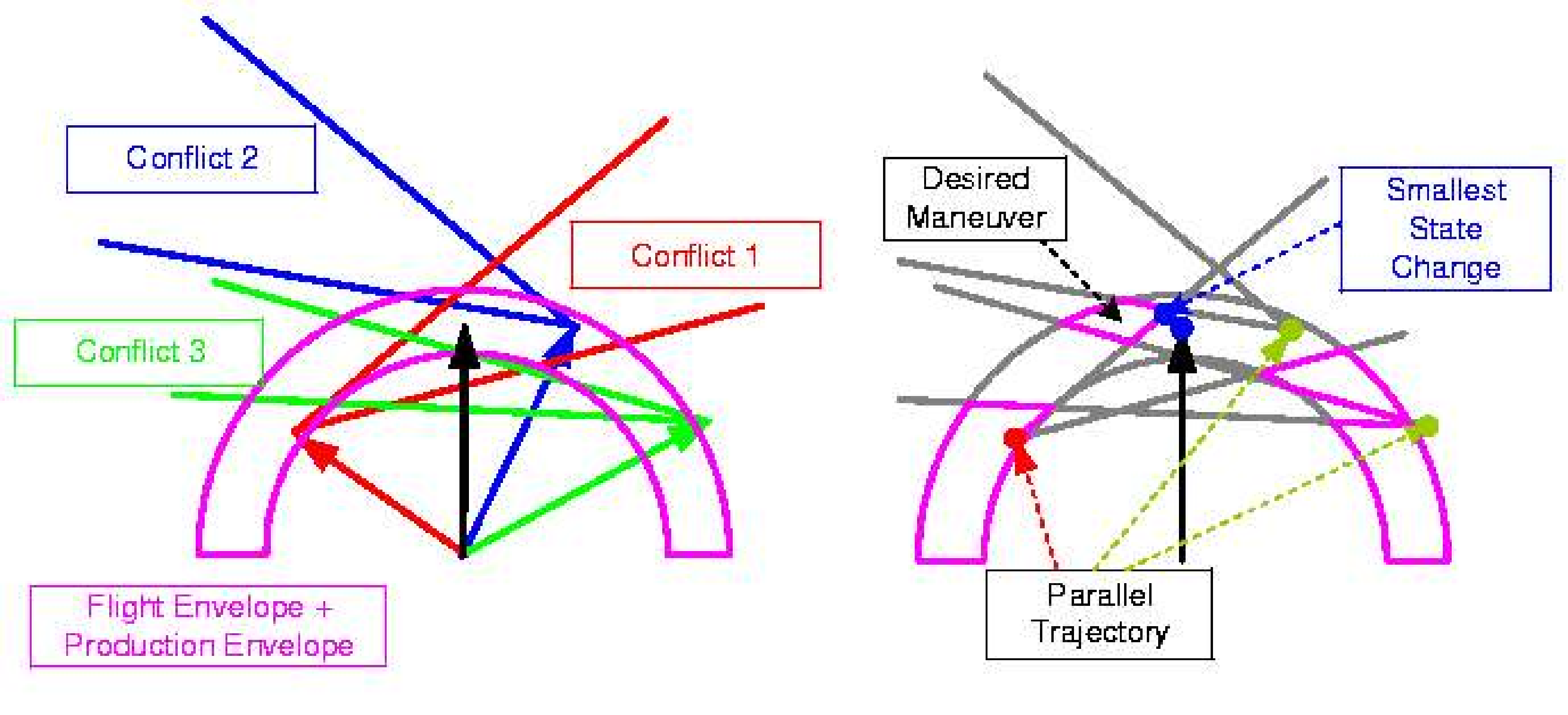

Aspect Angle
Intruder Velocity Vector
Protected Zone (PZ)
Own Velocity Vector
5 NM
Relative Position Vector

State Vector Envelope



Combining for different intruders



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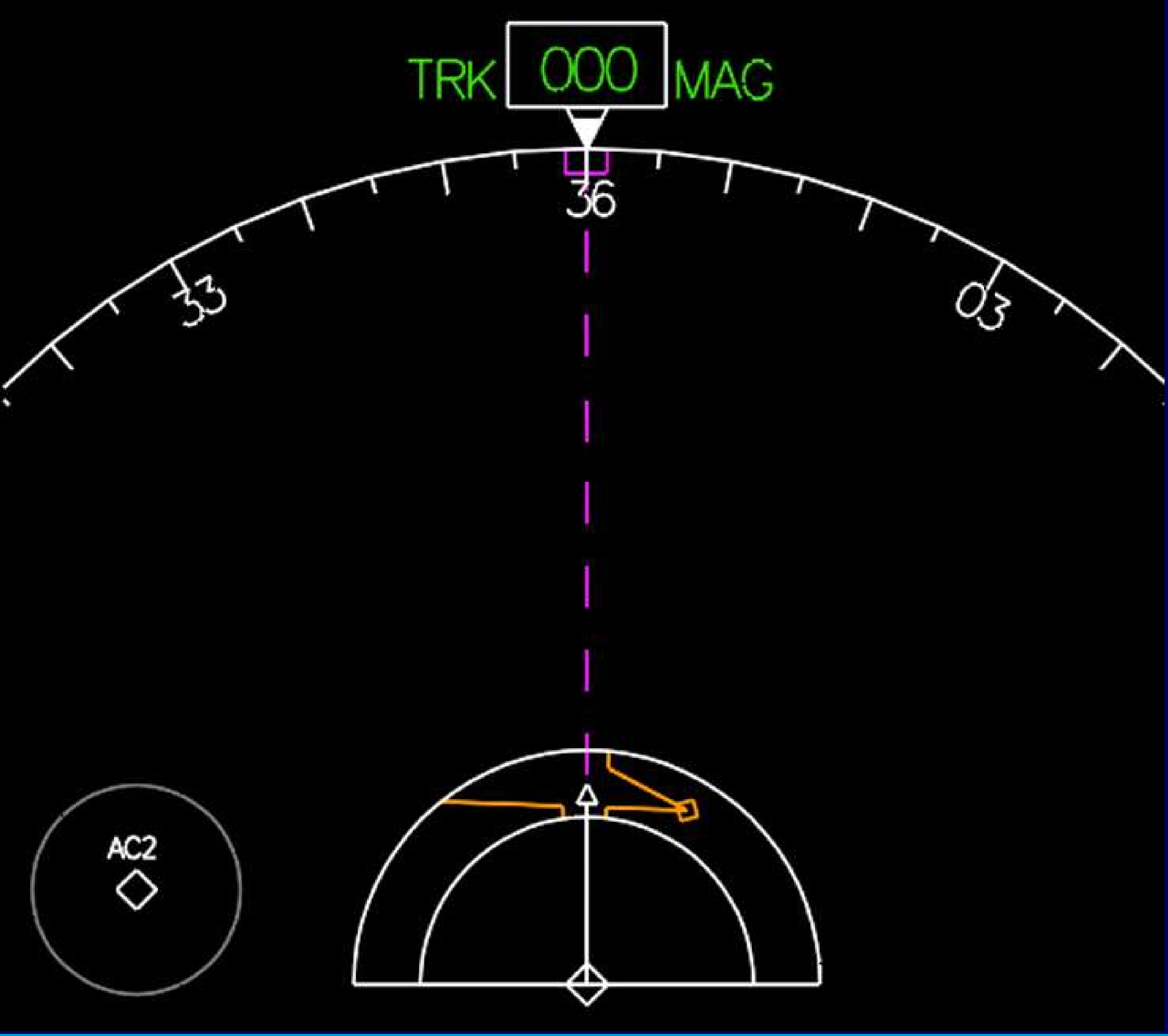
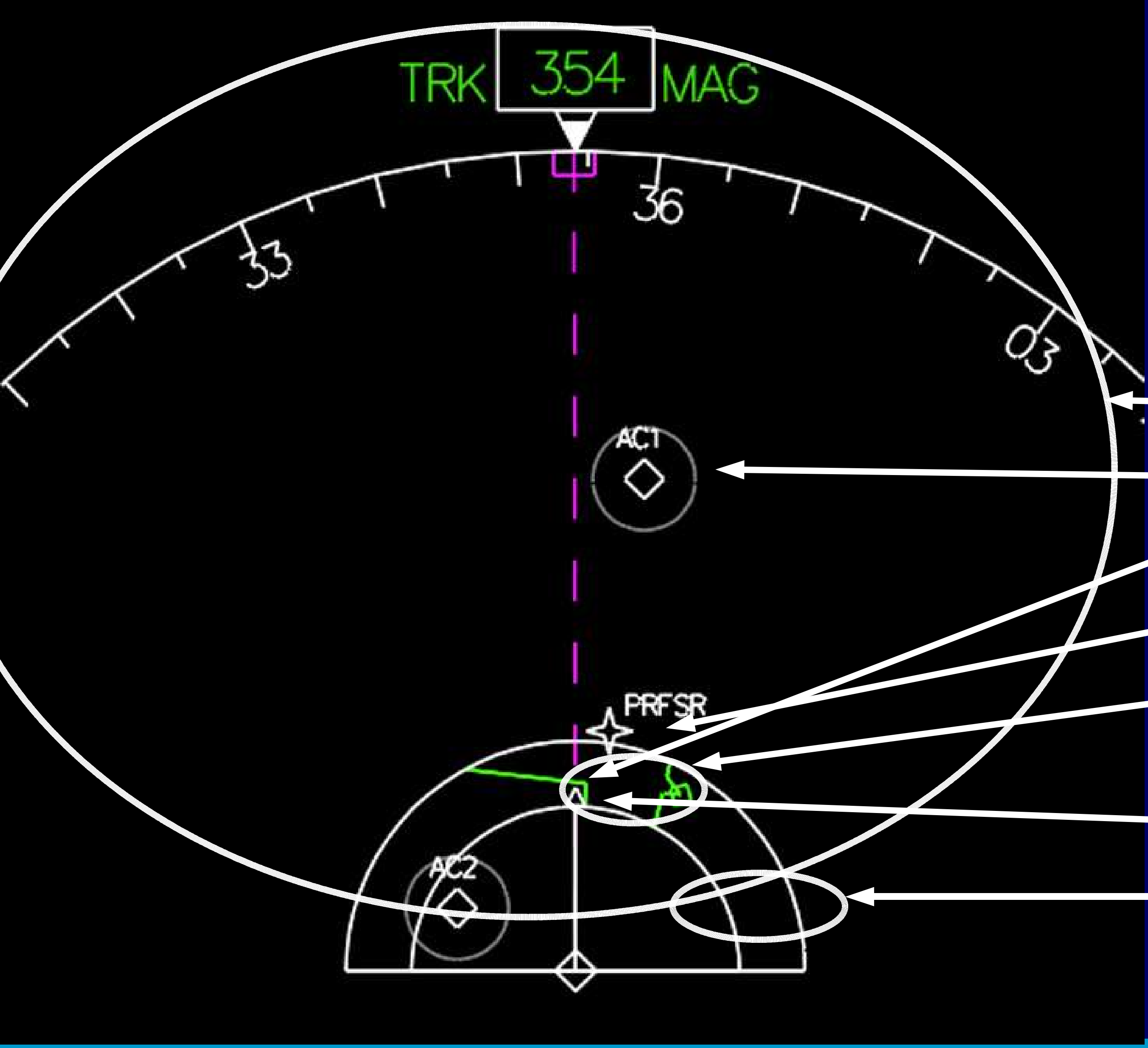

TRK
000
MAG
36
33
03
AC2



flight and control
safety
locomotion
production
relative motion
efficiency
aircraft limits

SVE, what can you see

- Other ships, protected zones of other ships
- Surrounding airspace
- Destination waypoints/headings
- "Shape" of surrounding airspace (function morphology), in terms of heading+speed

Vertical path+speed control

- Common task in flying, following speed+altitude profile
- Limited focus, on part of flying task
- AH for aircraft basic motions

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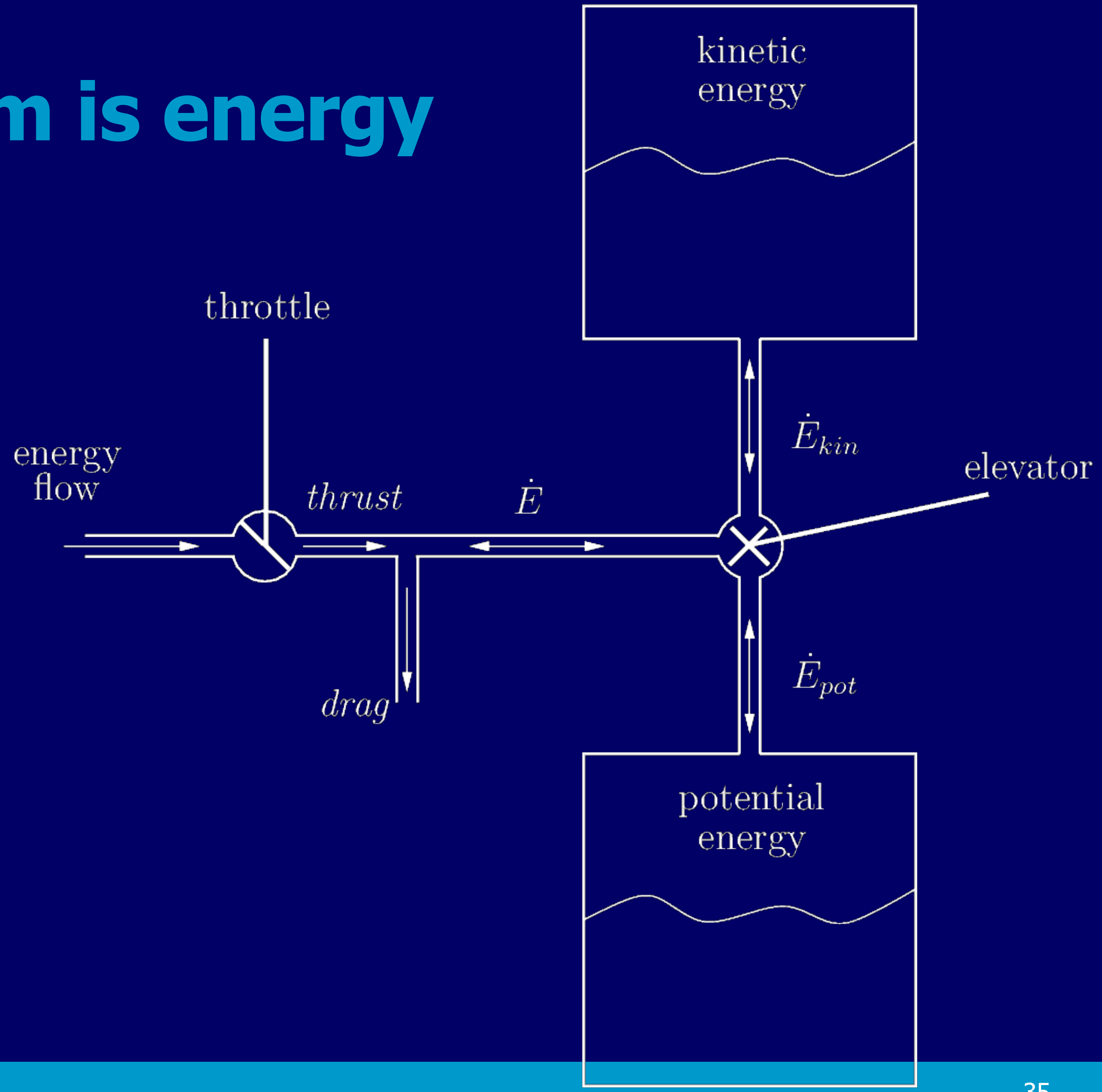
The problem is energy



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Aircraft dynamics+kinematics

- Flight path determines potential energy rate
- Throttle -> (mainly) total energy rate
- Stick -> (mainly) pitch rotation, indirectly flight path angle

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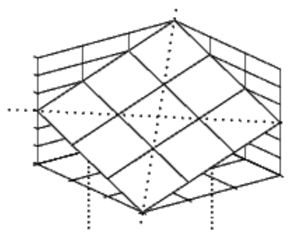
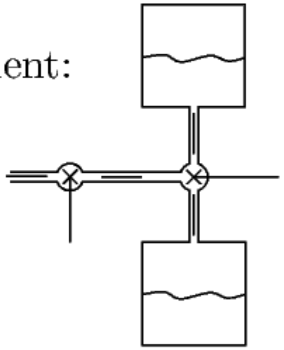
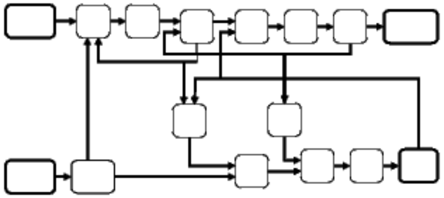
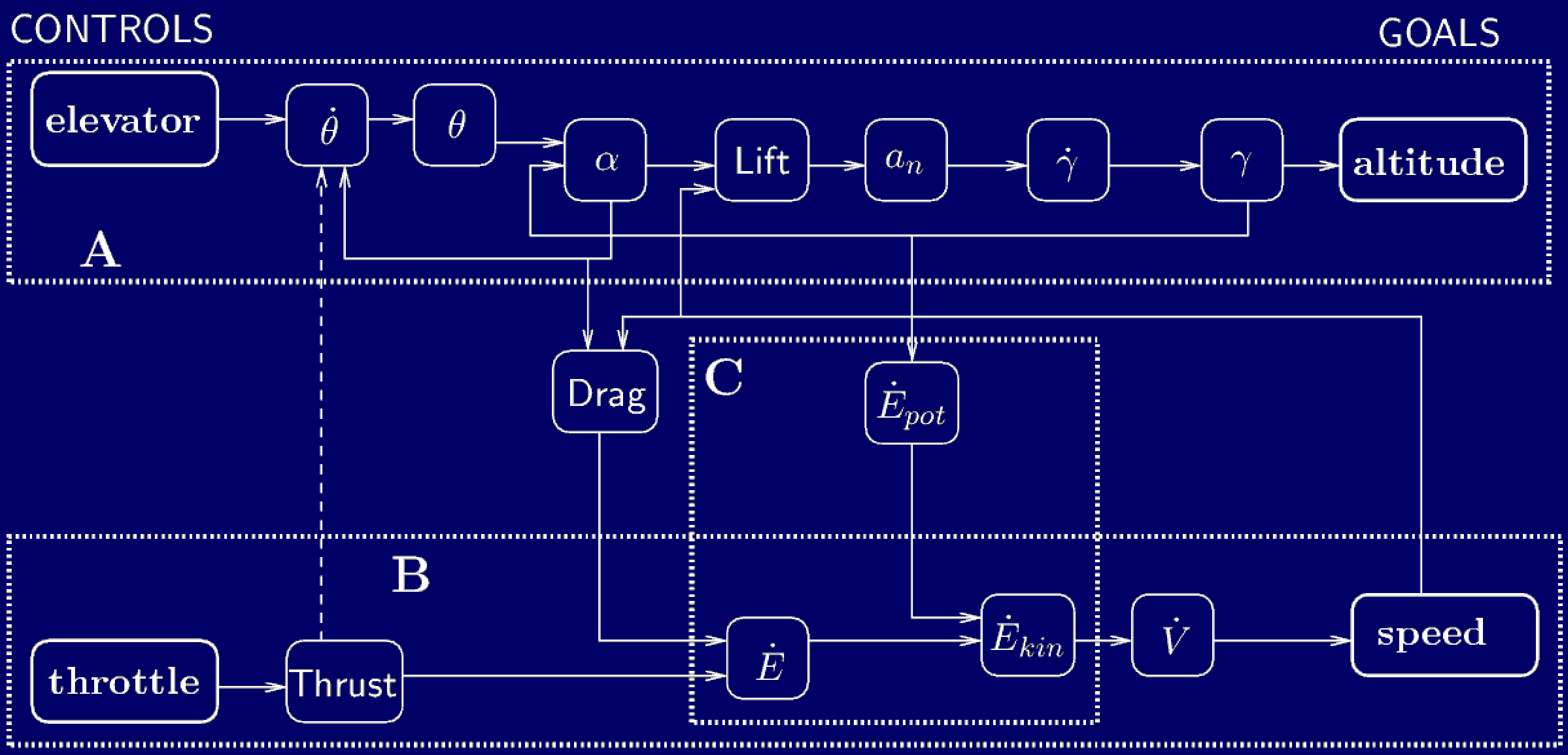
LEVELS OF ABSTRACTION

Level		
Functional purpose	fly trajectory:	follow speed profile follow altitude profile
Abstract function	law of conservation of energy	altitude = potential energy speed = kinetic energy kinetic + potential = total energy
Generalized function	energy awareness: 	energy management: 
Physical function	controlling the state variables	cause-effect of control for a generic aircraft 
Physical form	aircraft-specific components and configuration	

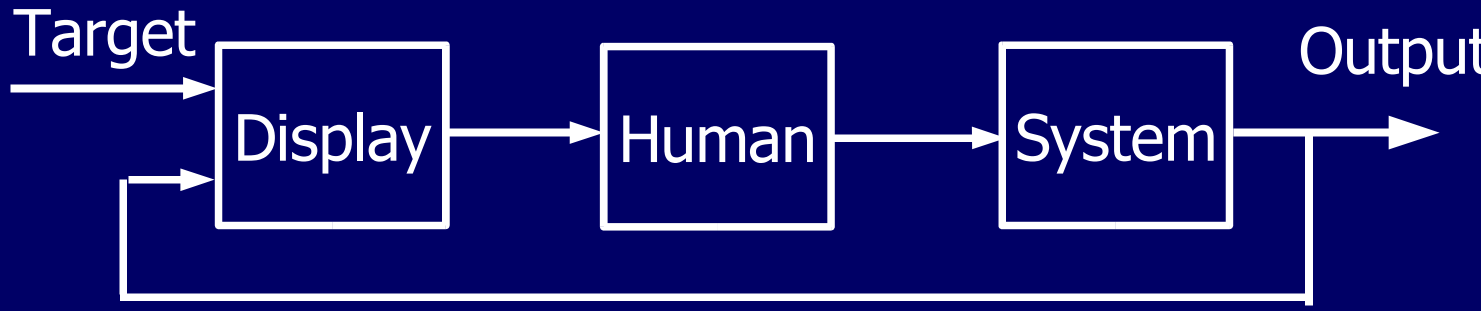

CONTROLS
GOALS
elevator
$\dot{\theta}$
θ
α
Lift
a_n
$\dot{\gamma}$
γ
altitude
A
Drag
C
$\dot{E}_{pot}$
B
throttle
Thrust
$\dot{E}$
$\dot{E}_{kin}$
$\dot{V}$
speed


85.1
0
131
11 40
2000
1 500
1 000
0500
150
140
120
7
150

Causality and Block Diagrams

- Cannot follow the block diagram and reason
- Translates into constraints for the system
- Control actions are a result from properties of the actor (human) and the system (car)

CSE/EID alone is not enough: Pilot in closed loop control



But this only applies to laboratory tasks and fliying with a flight director!

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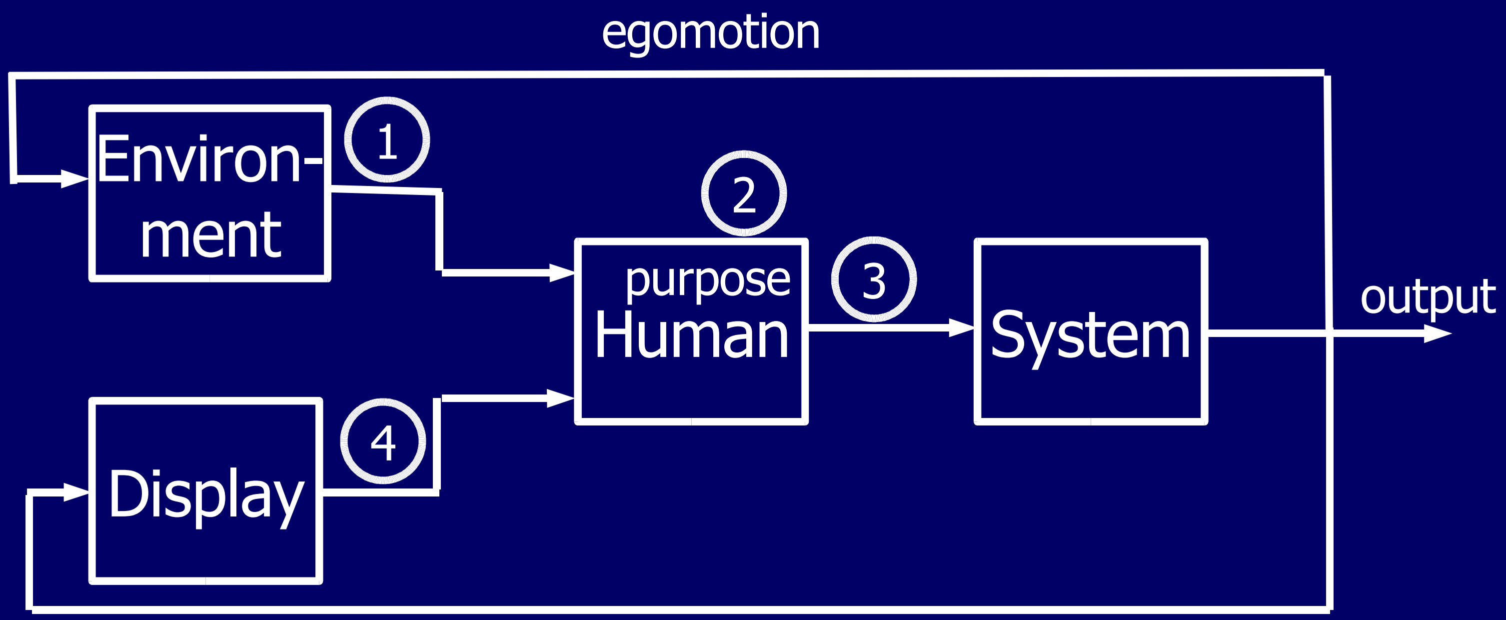
Pilot in real-world control



No 4, the EID display, must be compatible with 1, environment cues, and show the workspace in which 2, the pilot's purpose, is realized, under control of 3.

safety

production

efficiency

joy

comfort

locomotion

publication of travel

travel space

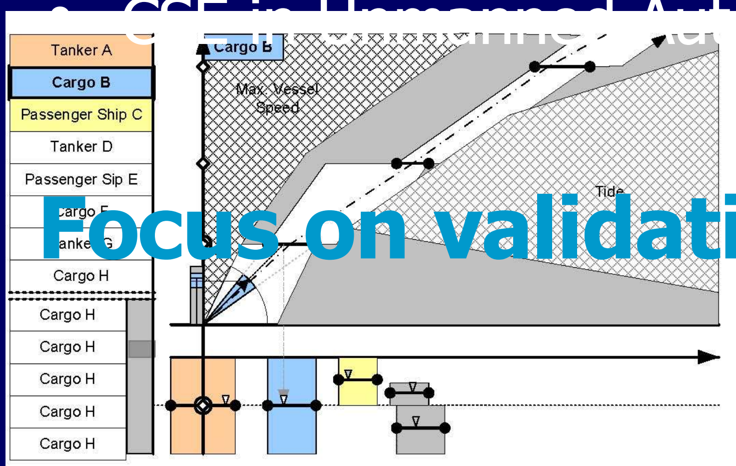
roadway

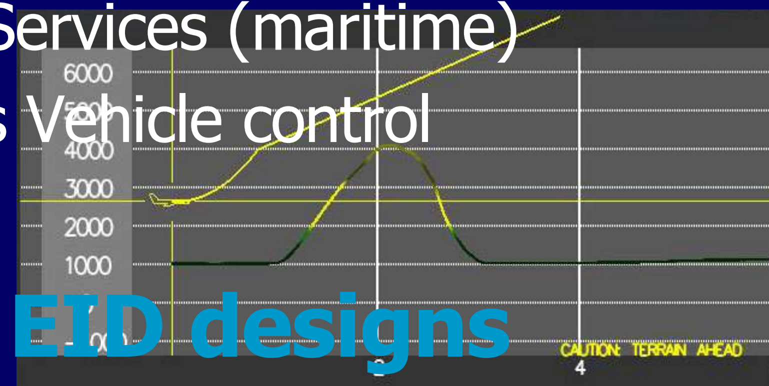
fixed boundaries

moving objects

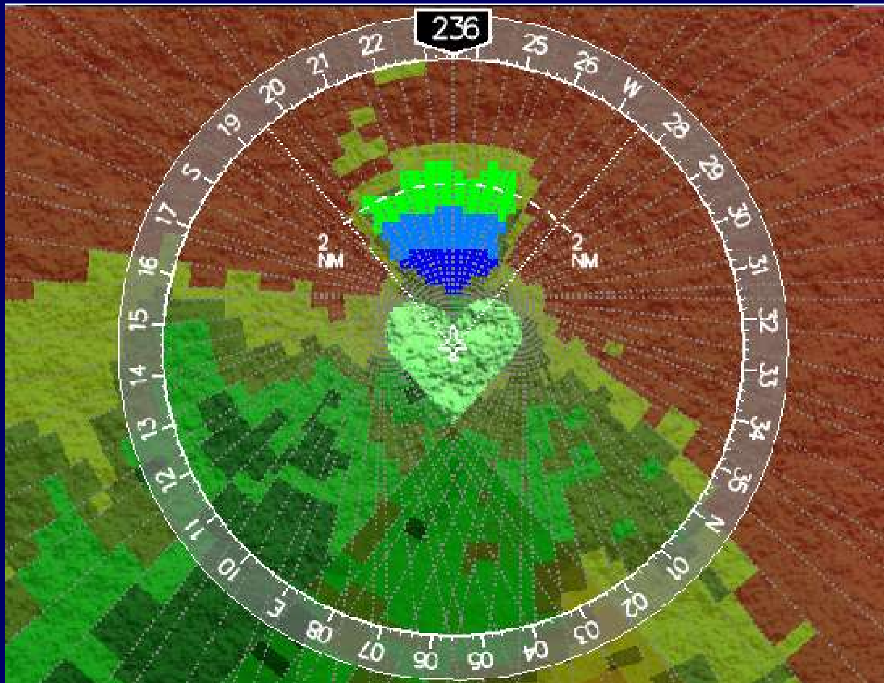
Other designs

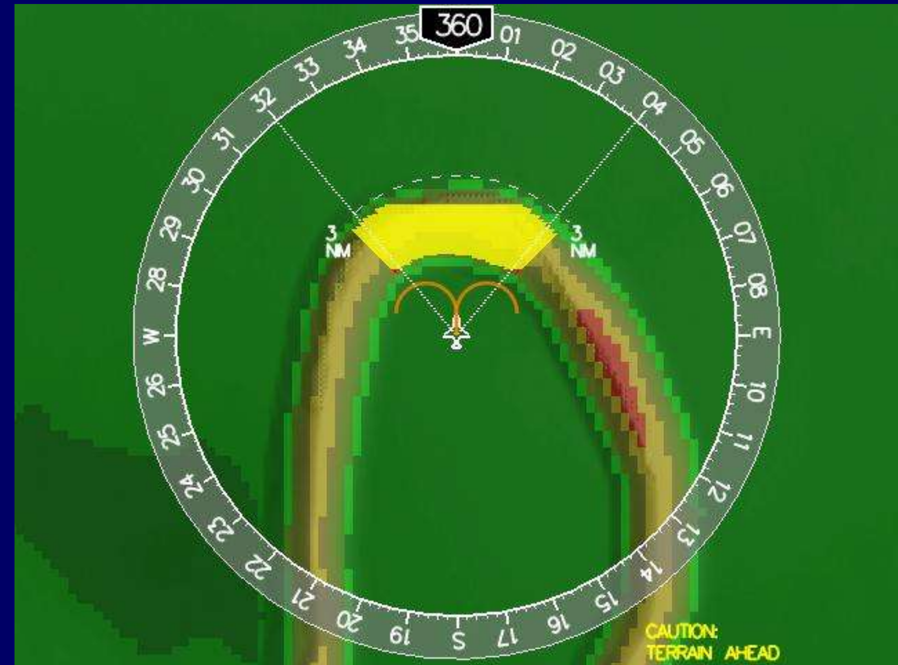
- Free-path decelerating approaches
- Emergency landing guidance system
- Terrain information in Synthetic Vision
- Vertical ASAS with energy/altitude trade-off
- Applications for Vessel Traffic Services (maritime)
- CSE in Unmanned Autonomous Vehicle control

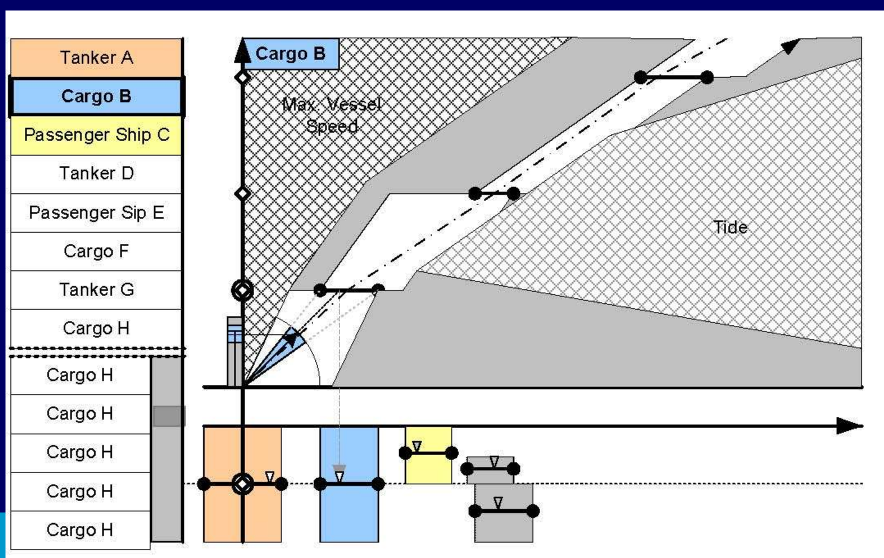


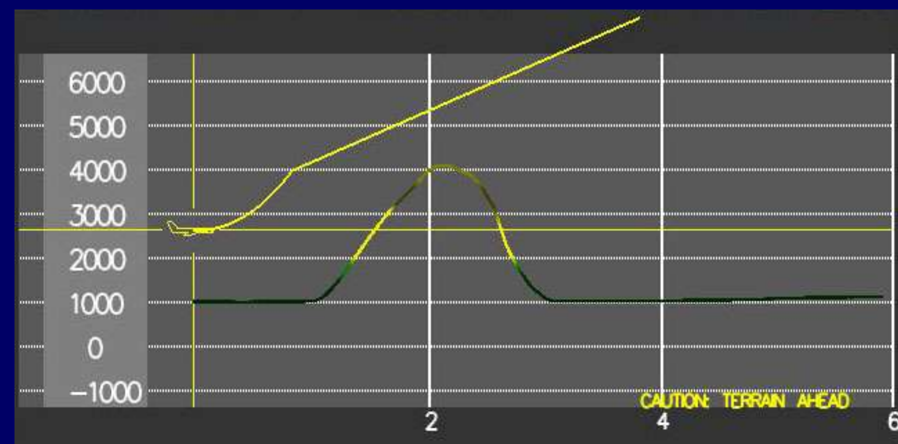


Focus on validation of EID designs


236
2 NM
2 NM


360
3 NM
3 NM
CAUTION: TERRAIN AHEAD


Tanker A
Cargo B
Passenger Ship C
Tanker D
Passenger Sip E
Cargo F
Tanker G
Cargo H
Cargo H
Cargo H
Cargo H
Cargo H
Cargo H
Cargo B
Max. Vessel Speed
Tide


6000
5000
4000
3000
2000
1000
0
−1000
CAUTION: TERRAIN AHEAD
2
4
6

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Ecological match for cybernetics of airplane control

- Compatibility between pilot goals, direct perception from environment, human control output and “display” (haptic, visual, auditory etc.)
- When dealing with a closed, high bandwidth loop with time delays, need control theoretic/cybernetic analyses
- Role of ecological approach is in discovering what the environment affords to the vehicle/driver, and what is under-specified
- Inner + outer loops, part of the faster dynamics can be handled by the human

EID is still “design”, Depends on creativity designer

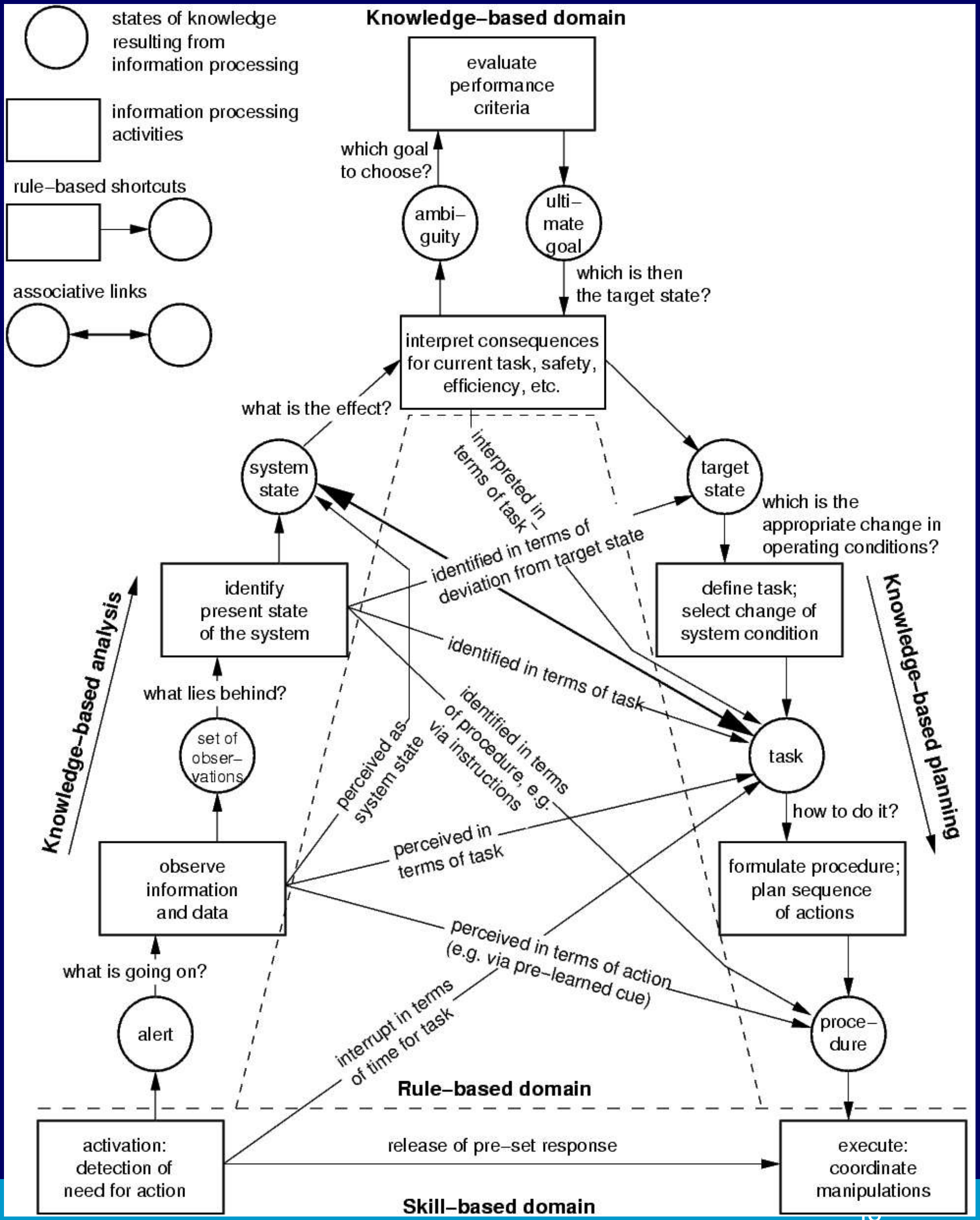
- Not any AH hierarchy representation is good enough, search for the “meaningful physics”

SKR taxonomy – Rasmussen

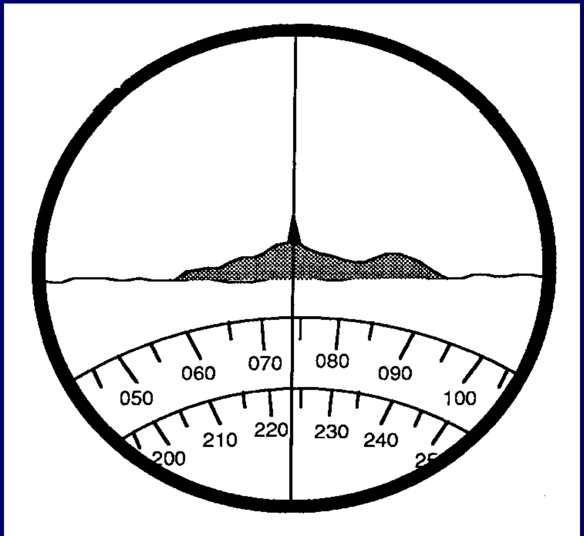
shortcuts

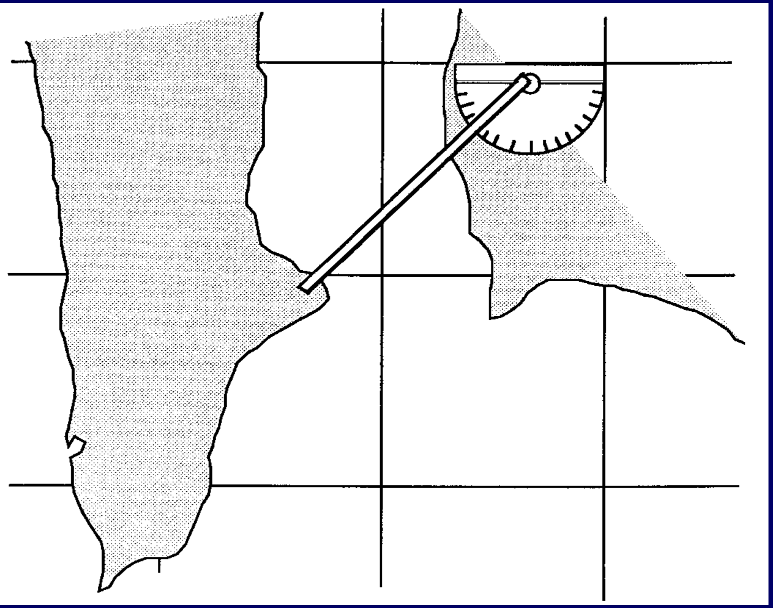
recognition

stored action



Situated Cognition – Hutchins





recognize

orient align

speak read-off

encode

align

draw compare

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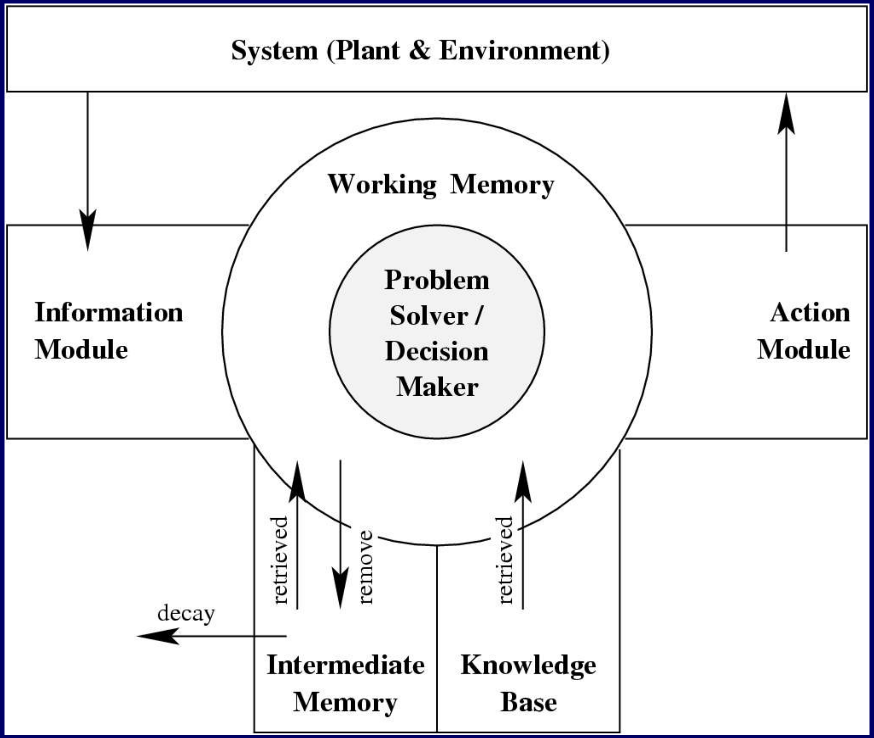
Implications for design

- Internal representation?
- Memory, reasoning?
- Models like IDA?



- Engineering units, comparison to automatic controllers, reasoning programs