Designing for Situation Awareness

the world behind the glass

Max Mulder

International Conference on Computer-Human Interaction Research and Applications (CHIRA)
Madeira, October 31, 2017
aerospace human-machine systems

TU Delft

Aerospace Engineering

Control & Simulation
today

• brief recap: situation awareness

• our work: *ecological* flight deck design

• example: airborne separation assistance

• closing statements
situation awareness
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
ecological flight deck design
why do we need to study humans in the aerospace domain?

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

• fire the pilot
• improve training
• better maintenance, improve reliability
• adapt procedures
• add automation/warning systems (TCAS, EGPWS)
• improve the interface
why do we need to study humans in the aerospace domain?

enormous cost reductions through automation...
why do we need to study humans in the aerospace domain?

...changing roles of humans
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
levels in interface design

• illumination, readability, colors, symbols

• integrated displays, configural displays, emergent features, principle of moving part

• ...so, what’s next?
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
some “Delft” ecological interfaces

Aircraft control
Total Energy Management

Aircraft control
Separation Assistance
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**
Total Energy Management

**Aircraft control**
Separation Assistance

**Air traffic control**
Separation Assistance

**Air traffic control**
4D trajectory management
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
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
airborne separation assistance

What is the problem?
typical engineering approach

IF \( t_m \leq \text{look-ahead time} \) AND \( \lvert m \rvert < R_{PZ} \)

conflict = TRUE

ELSE

conflict = FALSE

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TRAFFIC!
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

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<th>Safety</th>
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### Typical Automation & Interface in the AH

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**AUTOMATION**

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**Safety**
- Absolute & relative
- Locomotion
- Maneuvering
- Coordination
- Separation

**TRAFFIC!**

**Production Efficiency**

**make visible the invisible**

**AUTOMATION**

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**TU Delft**
**make visible the invisible**

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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
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

Add ‘heading’ and ‘speed’ bands, computed by automation
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

Add ‘heading’ and ‘speed’ bands, *computed by automation*
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??
we took another look at a conflict situation

assume we have two aircraft
and created an ecological interface

...set intruder aircraft to stand still
ecological ASAS

...then we should also change the speed of our...
ecological ASAS

calculate relative speed
ecological ASAS

....add the protected zone
ecological ASAS

....create Forbidden Beam Zone

....in *relative space*
ecological ASAS

....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
ecological ASAS

....look at another situation

own velocity
ecological ASAS

....look at another situation

velocity of the intruder aircraft

own velocity
ecological ASAS

...look at another situation

- own velocity
- relative velocity
- velocity of the intruder aircraft
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
demo: conflict with one aircraft
EID aims to show all constraints

....heading bands??
EID aims to show all constraints

....heading bands??
EID aims to show all constraints

....heading bands!
EID shows all constraints

....a whole family of heading bands!
EID shows all constraints

....speed bands??
EID shows all constraints

....speed bands!
EID shows all constraints

....a whole family of speed bands!
EID shows all constraints

....optimal solution??
EID shows all constraints

...optimal solution!
EID shows all constraints

....optimal solution!
EID shows all constraints

....multiple intruder aircraft??
EID shows all constraints

....multiple intruder aircraft!
demonstration: multiple intruders
### Functional Purpose

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### Physical Functions

- **Control units**
- **Traffic**

### Physical Form

- **Location & state of own aircraft**
- **Other aircraft locations & states**
... is there an approach to automation and interface design that helps pilots with their (cognitive) tasks?
situation awareness

“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 pass the other a/c 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
we go through lots of analysis and design iterations!!
Designing for Situation Awareness
an aviation perspective

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...current work

Merging terrain and traffic constraints
.....current work
....current work

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

Java application
cswiki.lr.tudelft.nl
ATP

....implicit coordination!
ATP

....implicit coordination!
ATP

....the FBZ is a family of circles
ATP

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