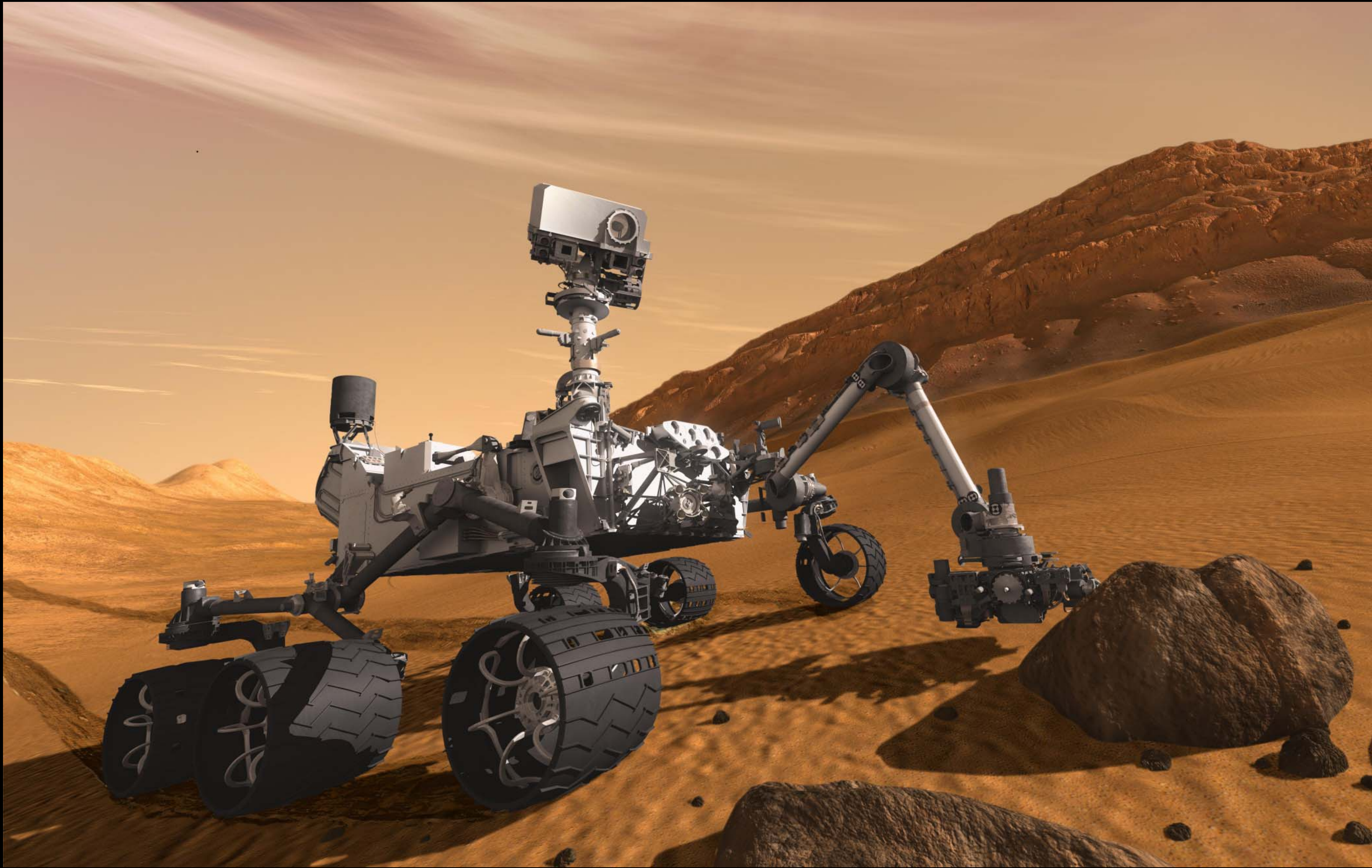
Distraction, Inattention, and Monitoring
Some Observations from Aviation

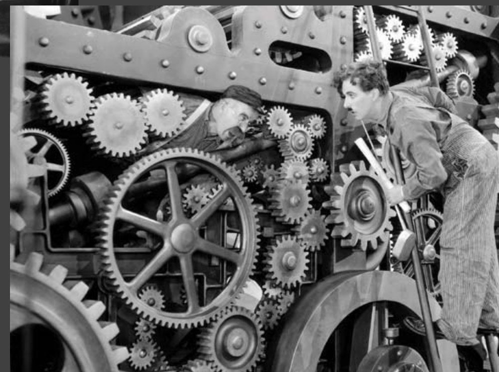
Asaf Degani
General Motors R&D
Advanced Technical Center, Israel

Mechanized Assembly Line



Automation Difficulties (aviation):

- *Monitoring*



- *Need for correct understanding*
- *Information organization and integration*

- *"Out-of-the-loop"*

Outline of the Talk

3 Examples

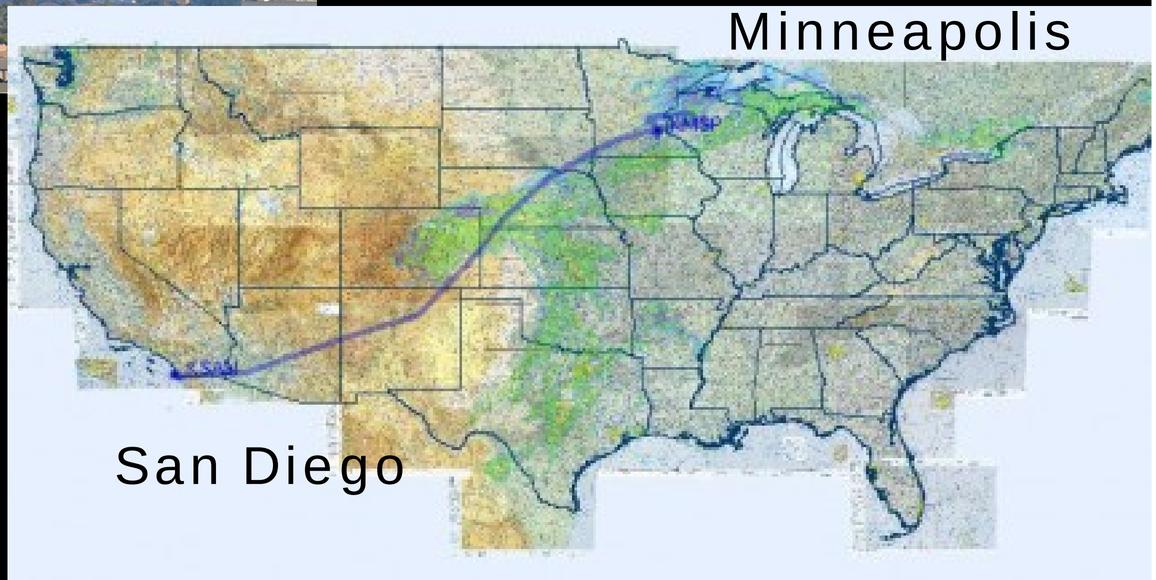
4 Difficulties

2 Challenges

1 Conclusions

Northwest Airlines Flight 188

Wednesday, 21 October, 2009



Overflow Minneapolis by 150 Miles

37,000 feet

A-320 Cockpit

A-320 Cockpit

Analysis of Flight 188

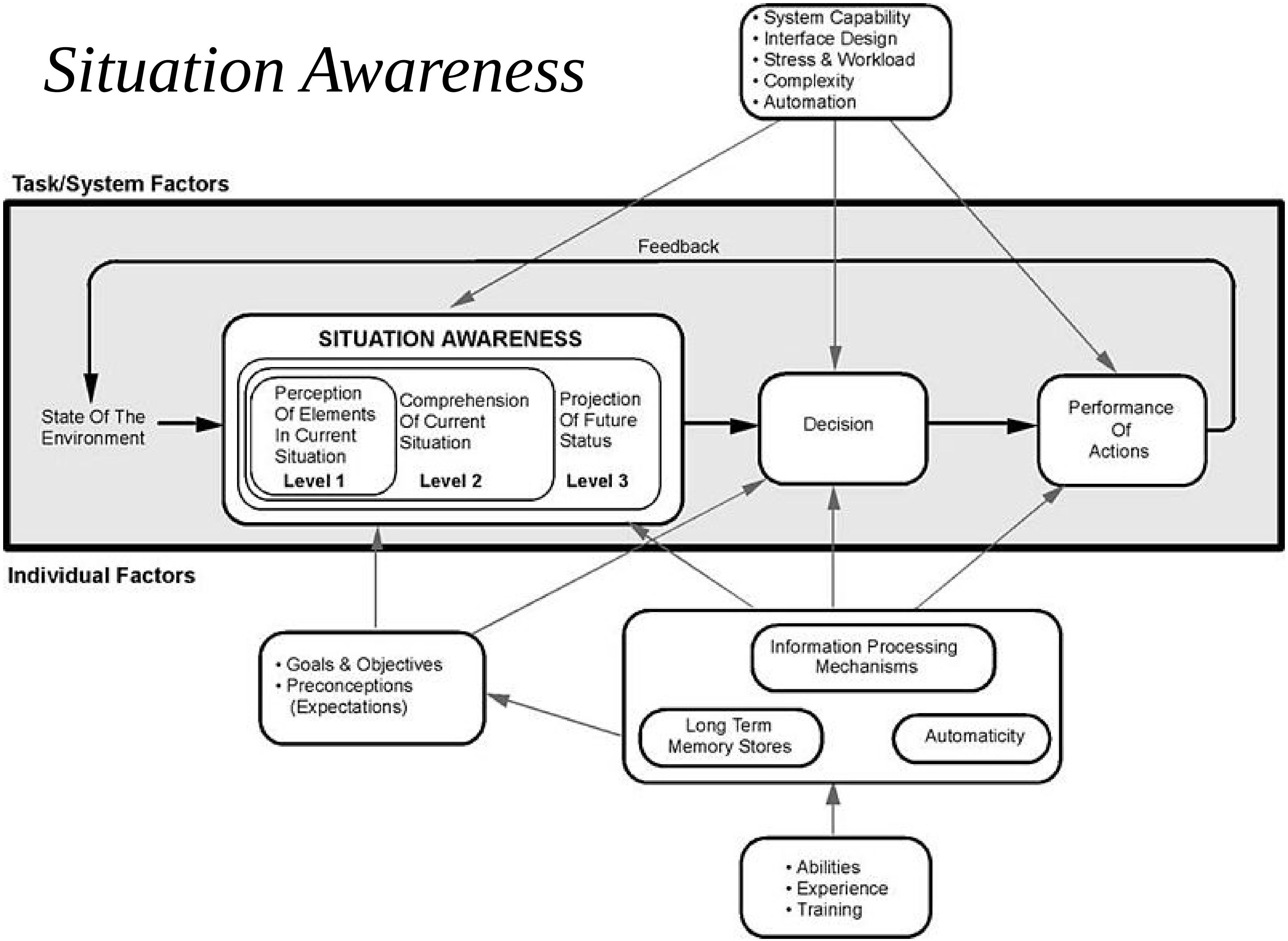
- Deviation from company policies and procedures
  - *No laptop in the cockpit*
  - *Engaged in non-operational business during flying*
- Disengaged from activities to complete unawareness
  - Communicate, Monitor
- Distraction from their *Monitoring* tasks
  - *Navigate, Aviate (autopilot, engines, sub systems)*
- Lost track of time
  - *78 minutes with no ATC contract, yet for the crew it was about "five minutes."*

National Transportation Safety Board (2011). *Northwest Flight 188*. Report DCA10IA001. Washington DC.

The Monitoring Problem

- "*The role of the pilot has changed significantly from being someone who primarily manipulates flight controls to someone who primarily monitors these systems*." (APA, in press)
- "Right Stuff" vs. Monitoring
  - *"pilot monitoring" job description*
- Training on how to monitor
  - *Situation awareness, team processes, evaluations and check-rides*
- Redesign of the flying task
  - *Defining times of high vigilance and low, design of procedures*
  - *No feedback ("good" vs. "bad")*
- Link to Automation (*Use, misuse, disuse…* –Parasuraman & Riley, 1997)

Situation Awareness



Endsley, M. (1995). Towards a Theory of Situation Awareness in Dynamic Situations. Human Factors, 37(1)

Automation Philosophies

Boeing

- The pilot is the final authority for the operation of the airplane;
- Both crew members are ultimately responsible for the safe conduct of flight.
- Flight crew tasks, in order of priority, are safety, passenger comfort, and efficiency.
- Design for crew operations based on pilots past training and operational experience.
- Design systems to be error tolerant.
- The hierarchy of design alternatives is simplicity, redundancy, and automation.
- Apply automation as a tool to aid, not replace, the pilot.
- Address fundamental human strengths, limitations, and individual differences--For both normal and nonnormal operations.
- Use new technologies and functional capabilities only when:
  - They result in clear and distinct operational or efficiency advantages
  - There is no adverse effect to the human-machine interface

Airbus

- Automation must not reduce overall aircraft reliability, it should enhance aircraft and systems safety, efficiency, and economy;
- Automation must not lead the aircraft out of the safe flight envelope and it should maintain the aircraft within the normal flight envelope;
- Automation should allow the operator to use the safe flight envelope to its full extent, should this be necessary due to extraordinary circumstances;
- Within the normal flight envelope, the automation must not work against operator inputs, except when absolutely necessary for safety.

Abbott, K. (2001). Human Factors Engineering and Flight Deck Design. In C. R. Spitzer (Ed.), *The Avionics Handbook*. Danvers, MA: CRC press.

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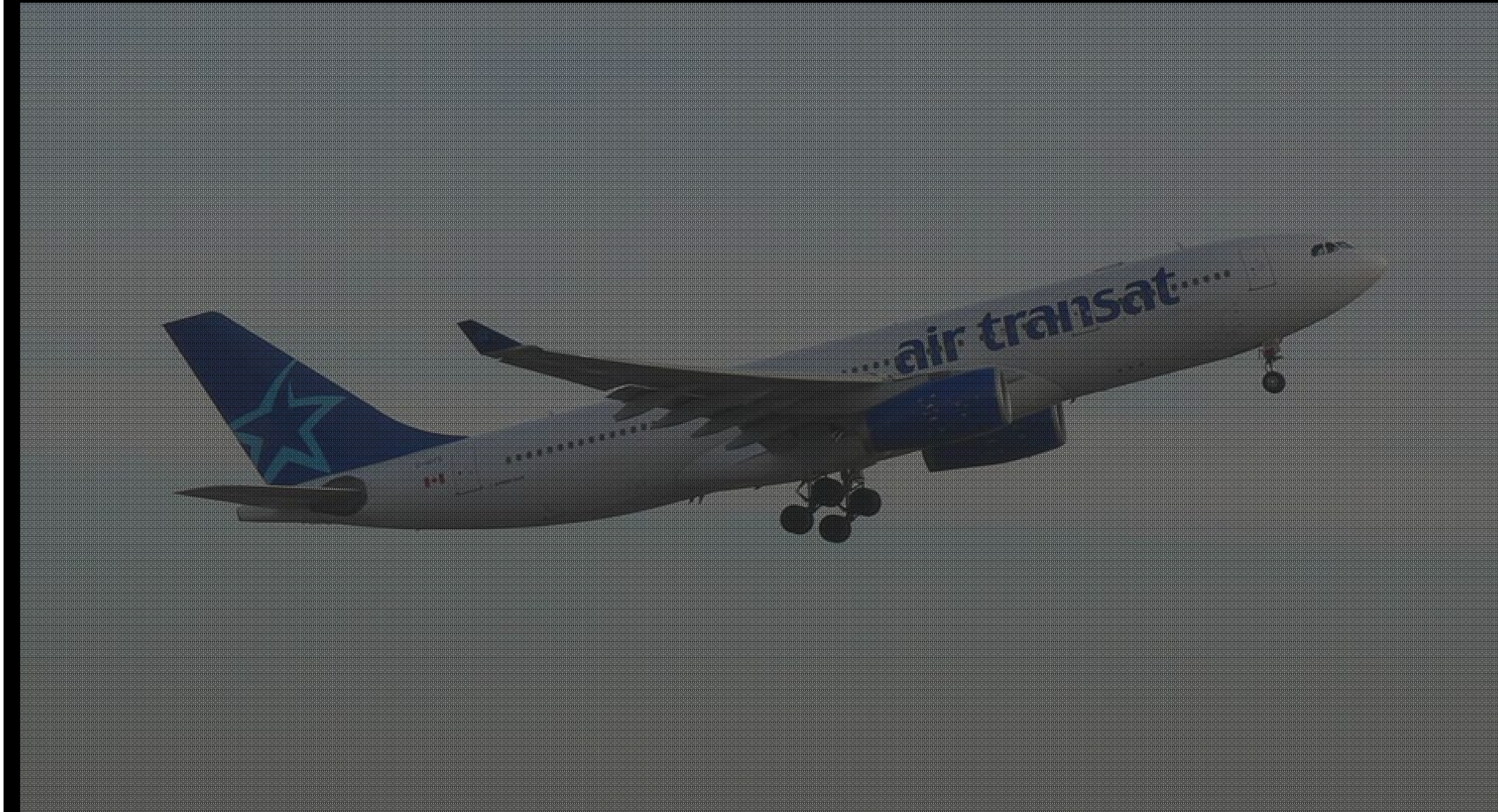
Airbus A-330

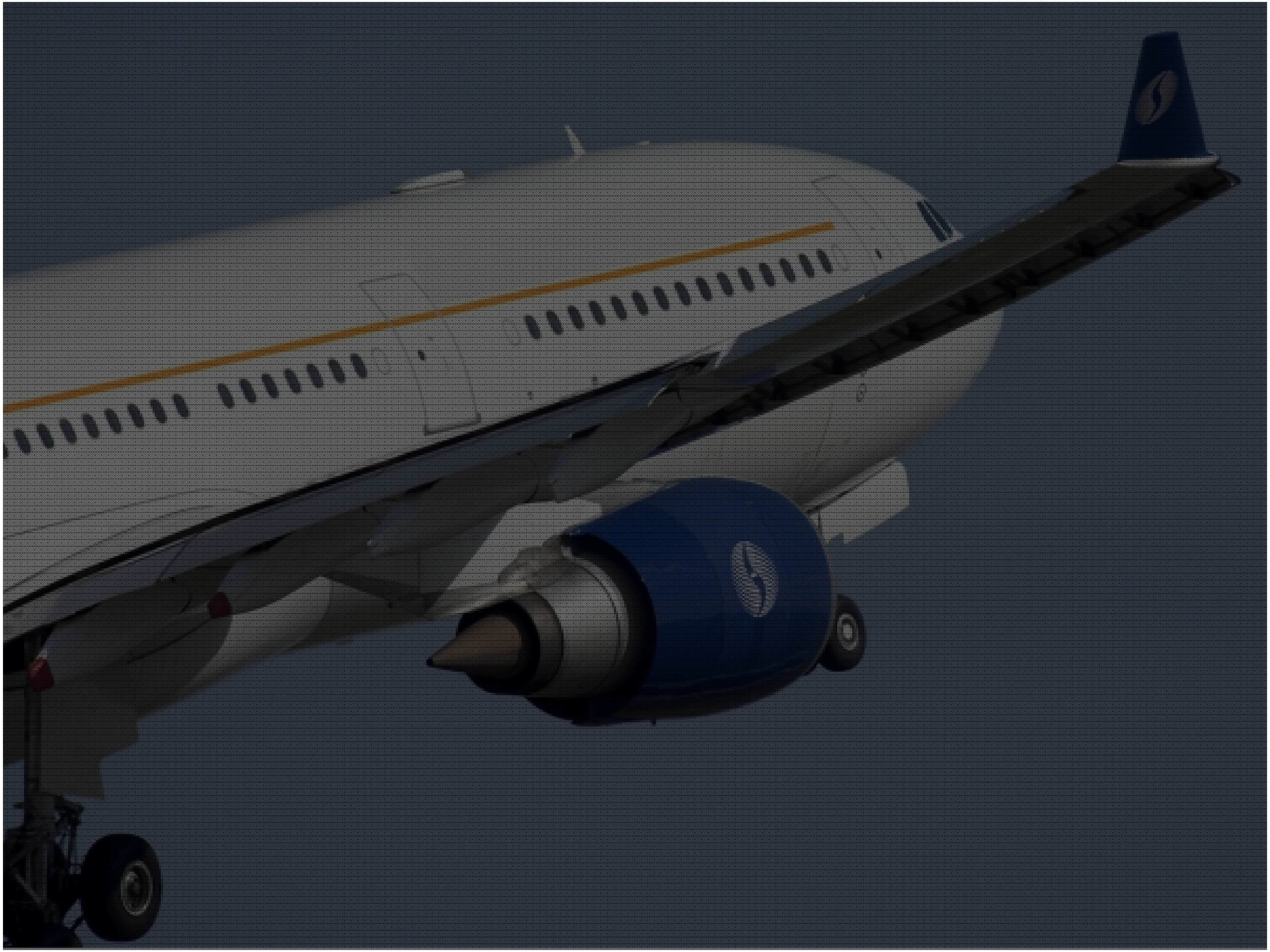
Air Transat Flight 236

August 23-24, 2004

Government of Portugal (2004). *All engines-out landing due to fuel exhaustion, Air Transat, Airbus A330-243,* 24 August 2001.

Taking off from Toronto





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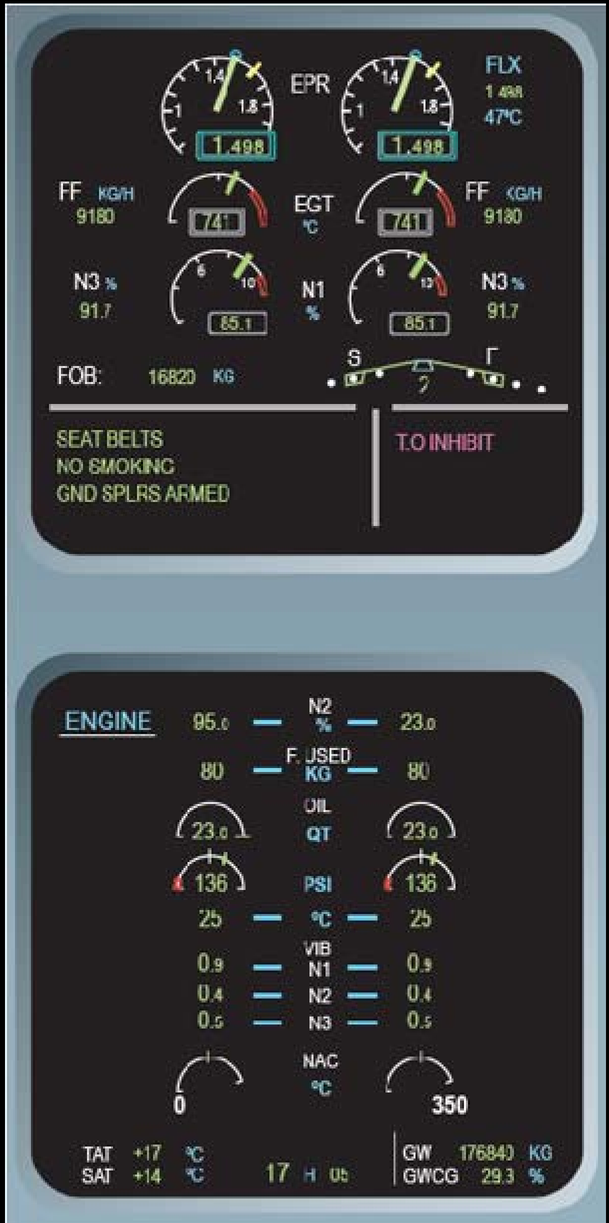
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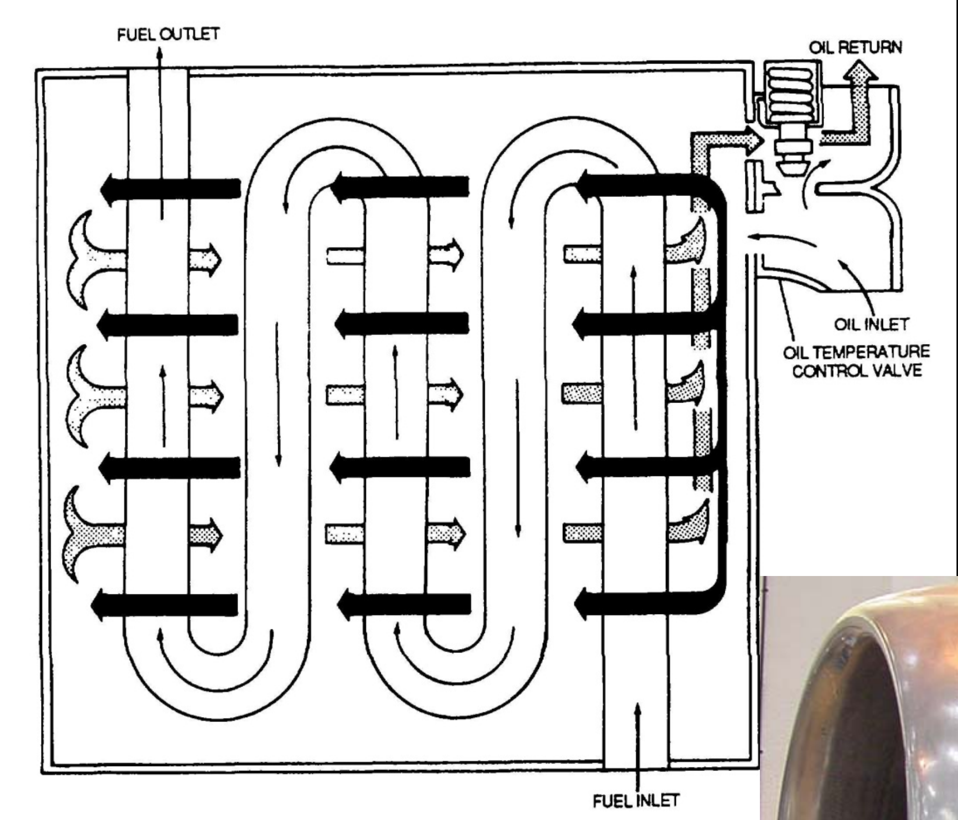
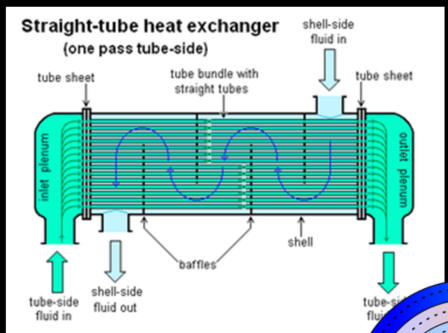
Oil Indications (4 hours into flight)

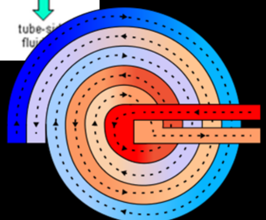
	Left Engine	Right Engine
Oil Quantity	18.2 Liters	14.5 Liters
Oil Pressure	80 psi	150 psi
Oil Temperature	110^{o} Celsius	65^{o} Celsius

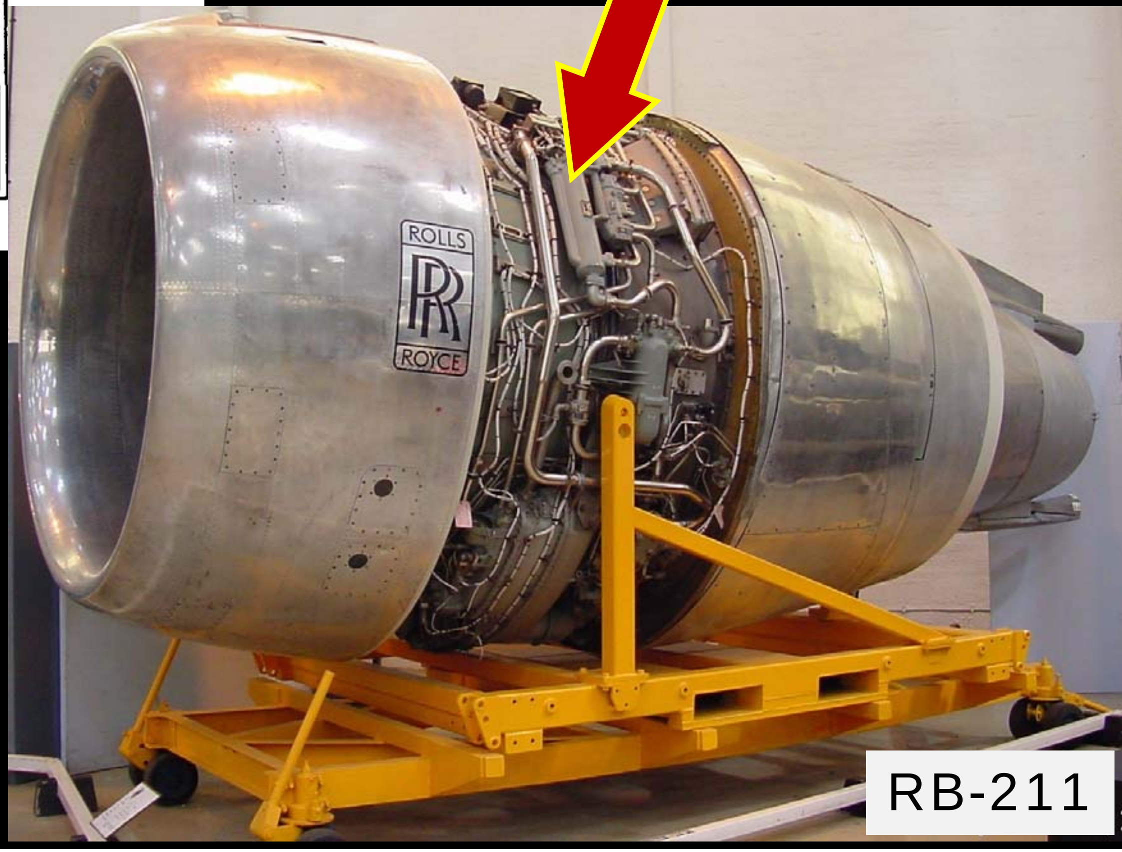
3.5 Inch long crack → 13.5 Tons of Fuel/hour

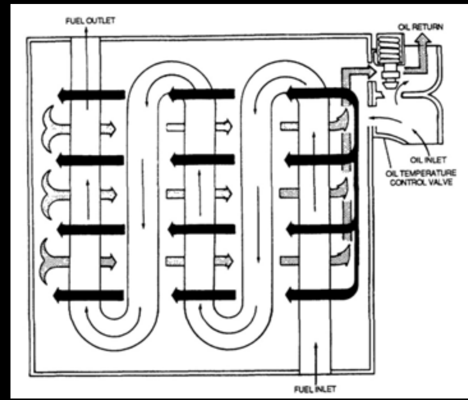
Fuel/Oil Heat-Exchanger Unit











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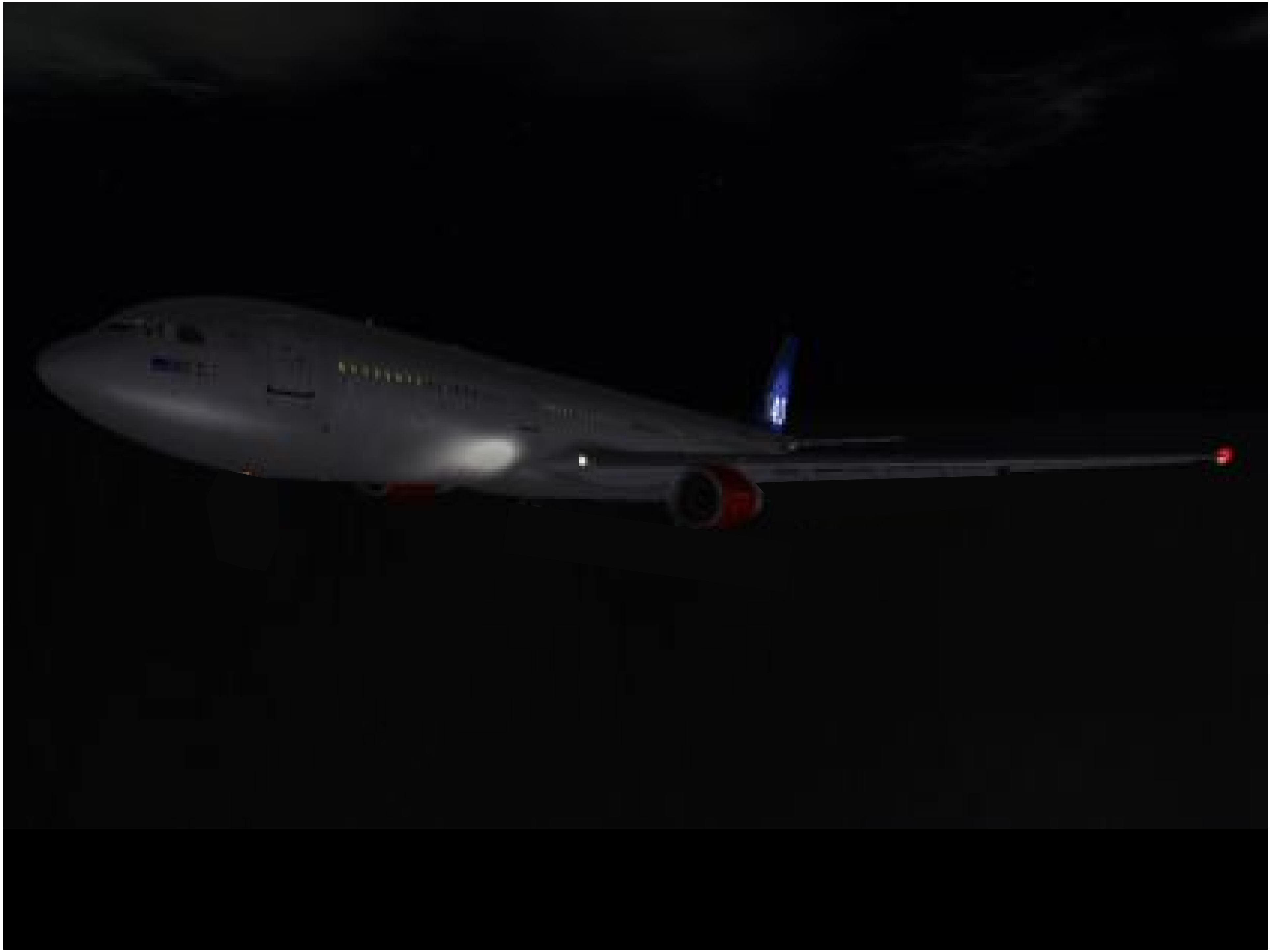

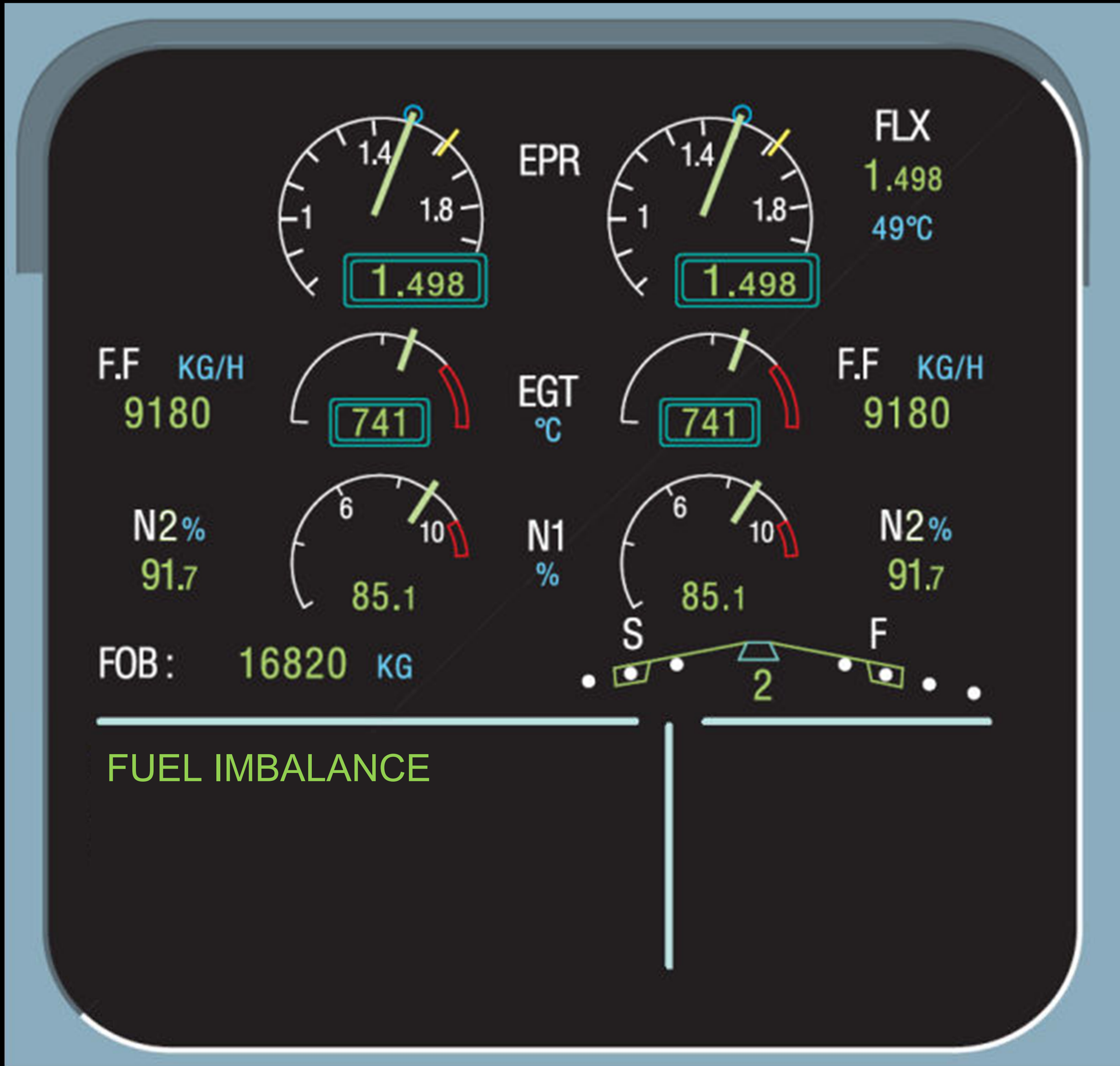

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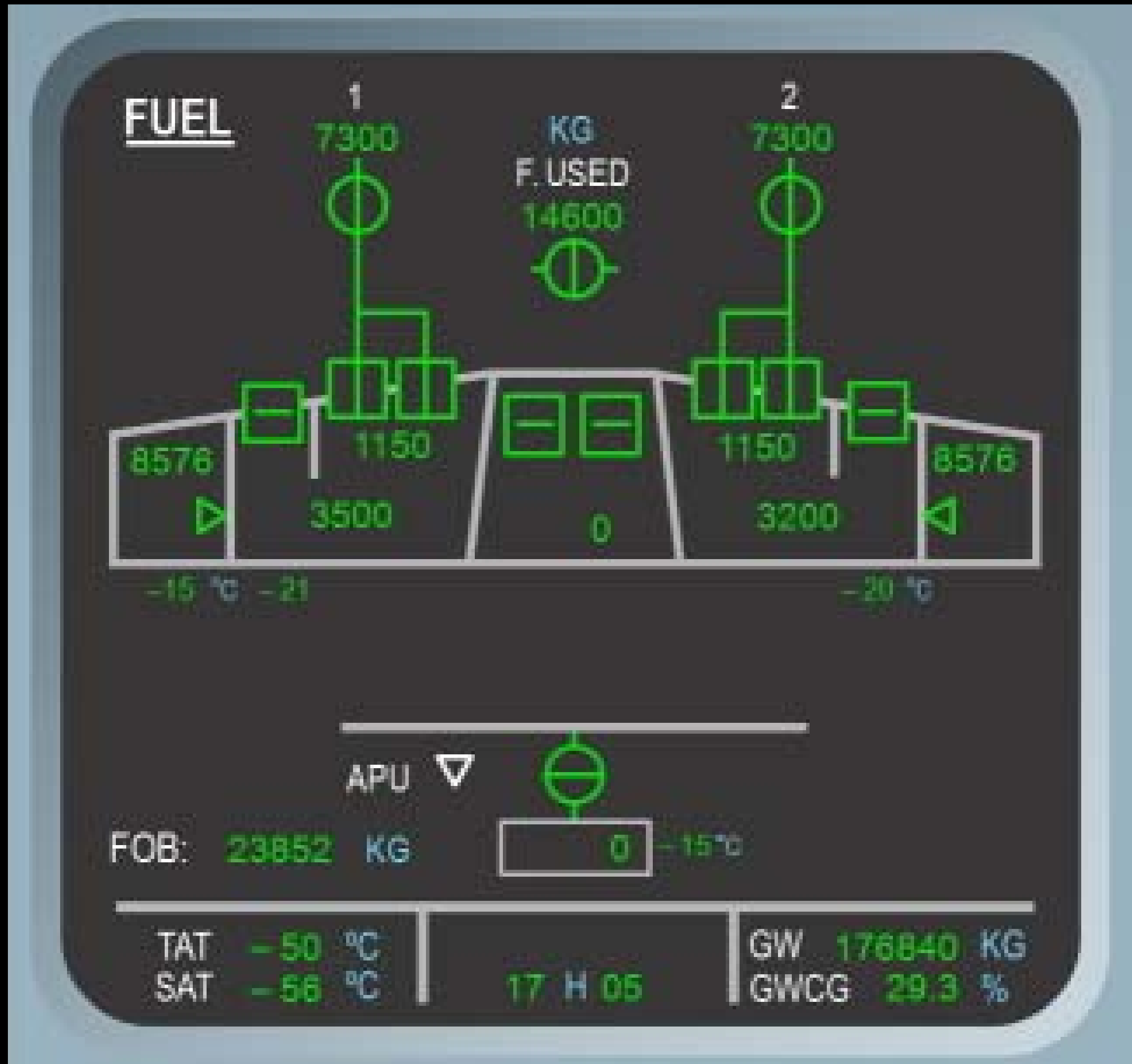
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air transat

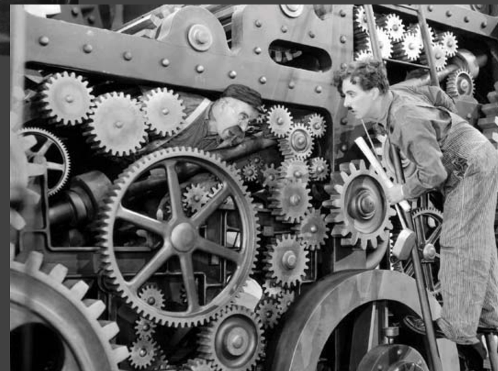

air transat

Analysis of Flight 236

- Difficulty in monitoring engine parameters (SA Level -1)
  - *Did not recognize oil situation until required waypoint check*
  - *Did not recognize fuel leak until a system alert (4 ton difference)*
  - *Automation masking fuel status and fuel transfers*
- No *correct understanding* of the situation (SA Level -2)
  - *Oil problem? Sensor problem? Fuel problem?*
  - *Led them to take improper action and deviate from procedures*
  - *Loss of system awareness* (SA- Level 3)
- Lack of integrative interfaces
  - *Relation between oil indication and fuel status not presented*
  - *Fuel management displays*

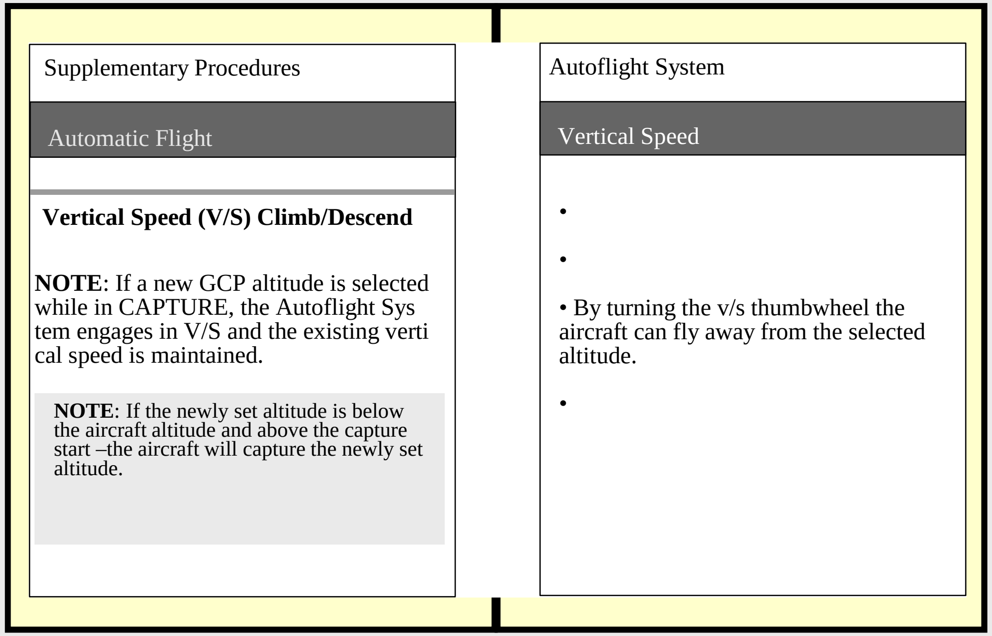
Automation Difficulties (aviation):

- *Monitoring*



- *Need for correct understanding*
- *Information organization and integration*
- *"Out-of-the-loop"*

Correctness of Interfaces


Supplementary Procedures

Automatic Flight

Vertical Speed (V/S) Climb/Descend

NOTE: If a new GCP altitude is selected while in CAPTURE, the Autoflight Sys tem engages in V/S and the existing verti cal speed is maintained.

NOTE: If the newly set altitude is below the aircraft altitude and above the capture start –the aircraft will capture the newly set altitude.

Autoflight System

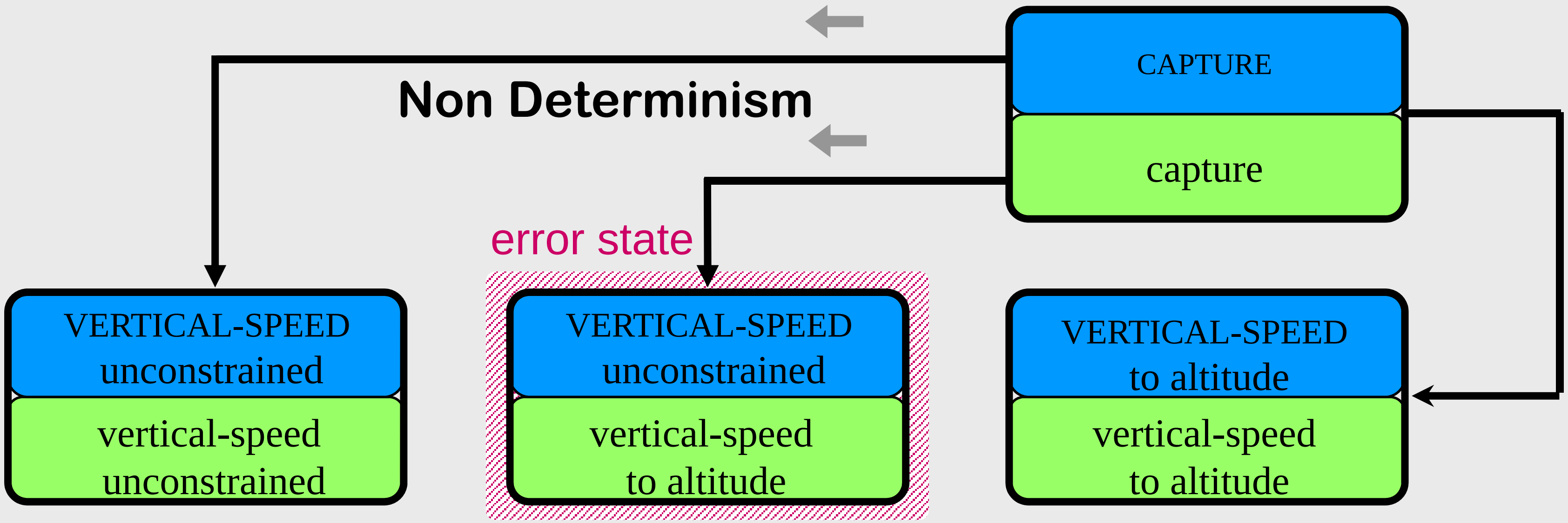
Vertical Speed

•

•

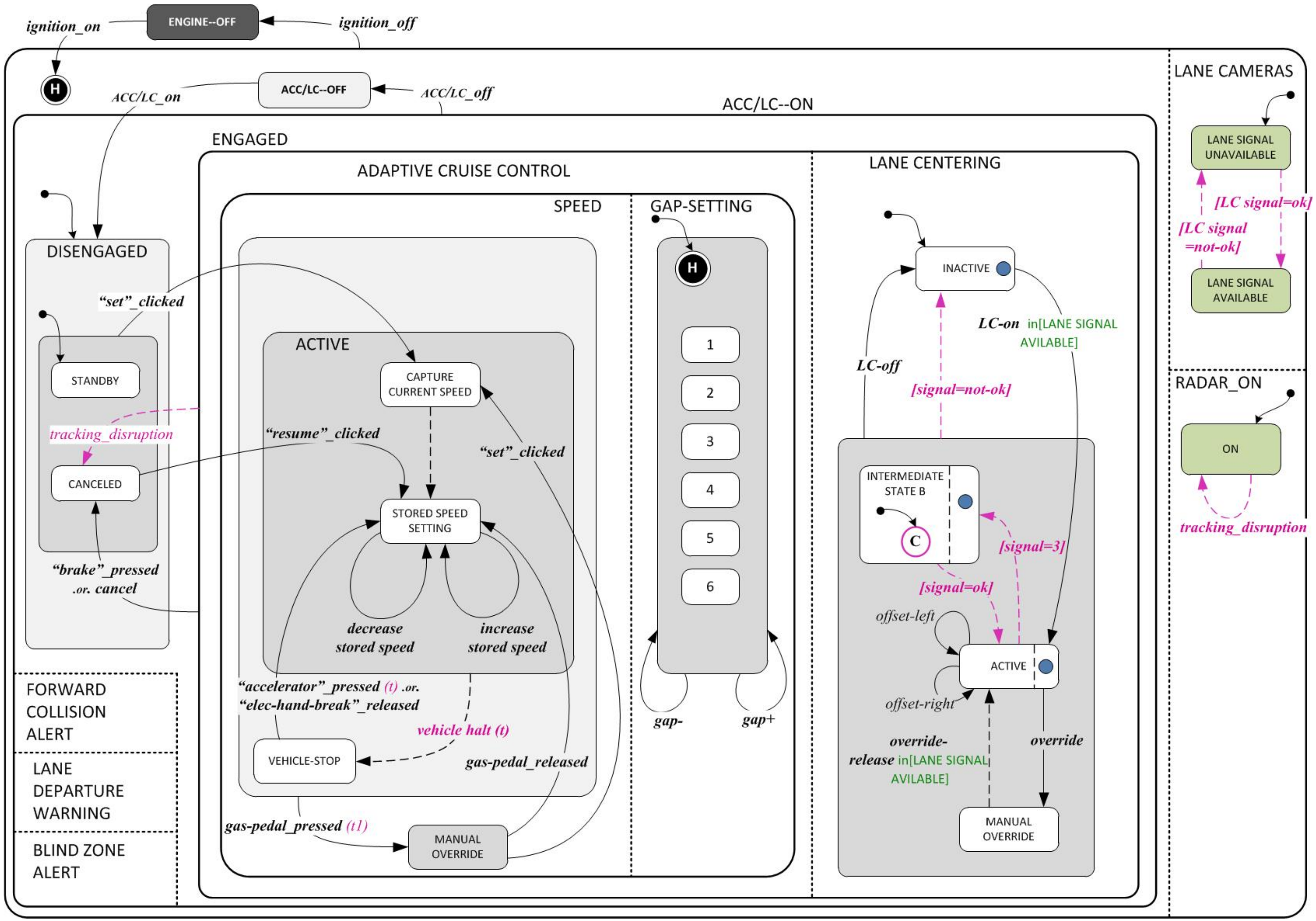
• By turning the v/s thumbwheel the aircraft can fly away from the selected altitude.

•



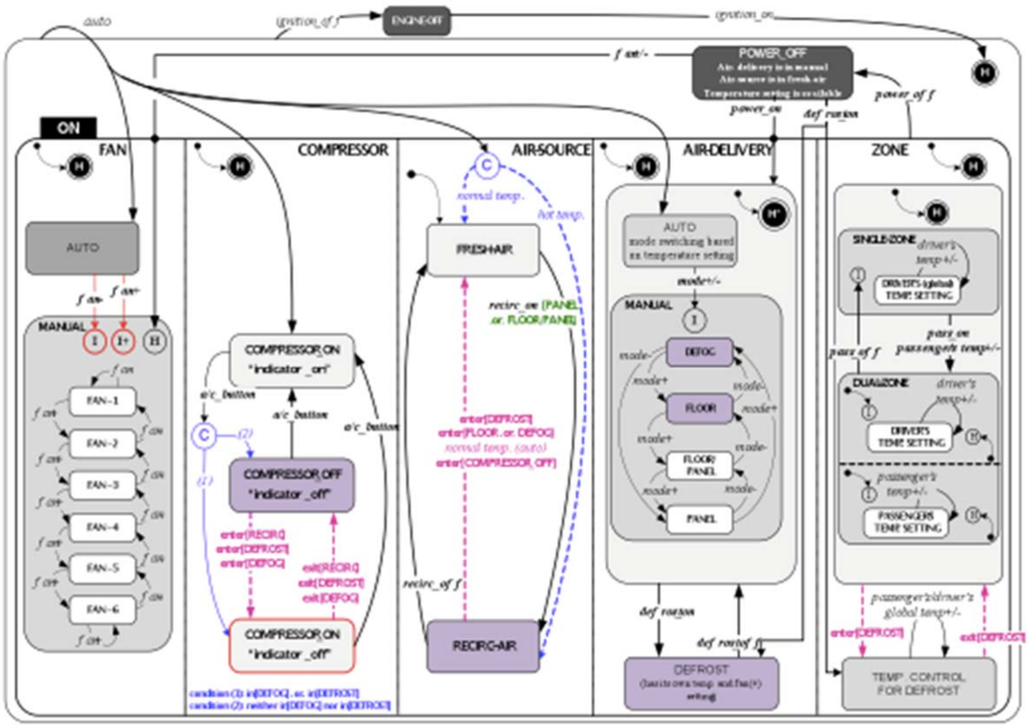
Degani, A., Heymann, M., & Shafto, M. (2013). Modeling and formal analysis of human-machine interaction. In A. Kirlik and J. Lee (Eds.), The Oxford Handbook of Cognitive Engineering. New York:

Adaptive Cruise Control and Lane Centering



Heymann, M. & Degani, A. (accepted). Automated Driving Aids: Modeling, Analysis, and Interface Design Considerations. Automotive UI Conference.

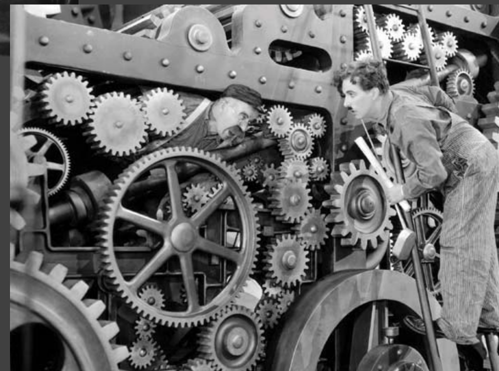
HVAC Systems and Infotainment



Degani, A., Heymann, M., & Gellatly, A. (2011). Behavioral Aspects of Automotive Climate Control Systems. Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics (SMC).

Automation Difficulties

- *Monitoring*



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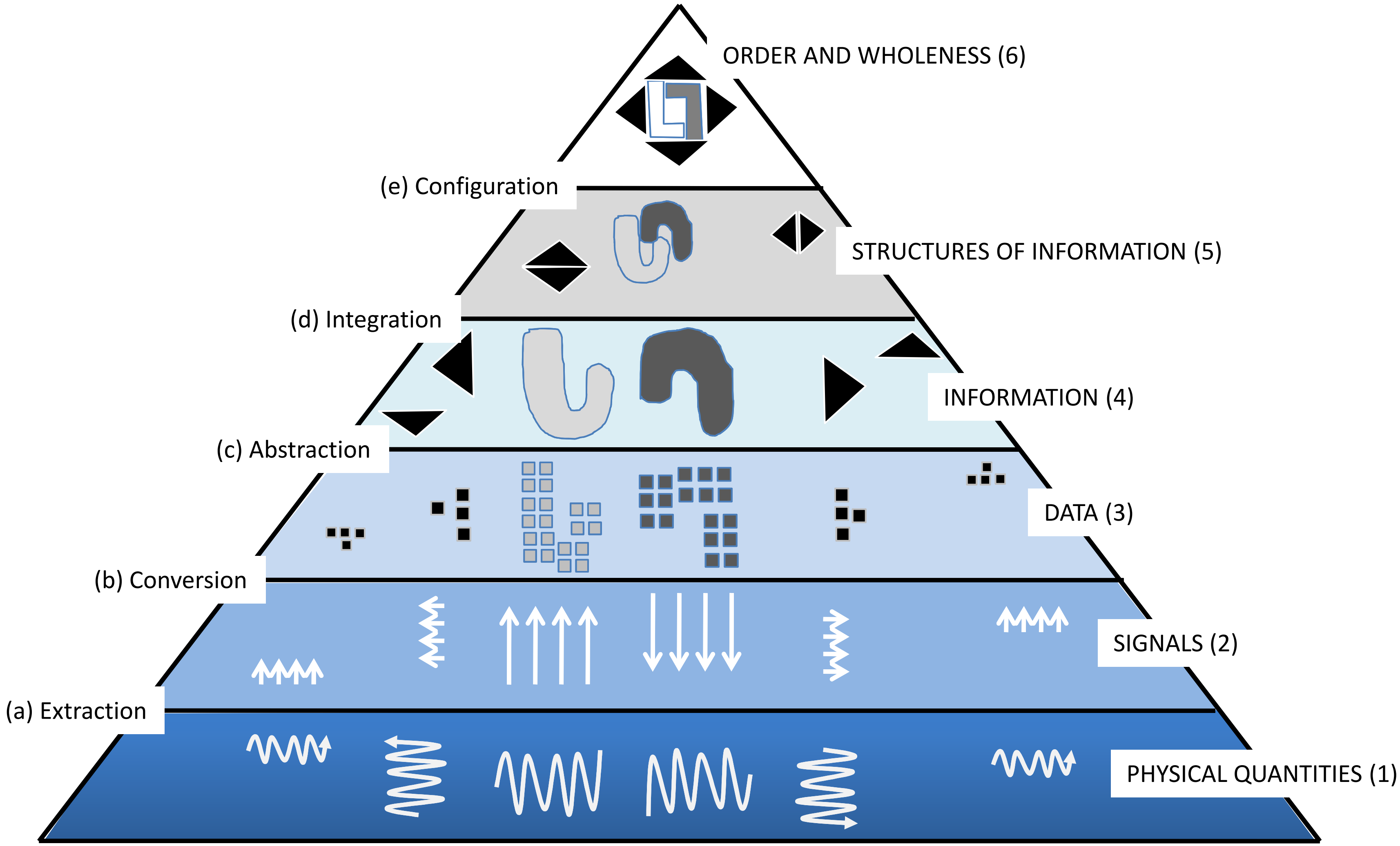
Information Organization



Card, S. K., Mackinlay, J. D., & Shneiderman, B. (1999). *Information Visualization: Using Vision to Think.* San Francisco: Morgan-Kaufmann.

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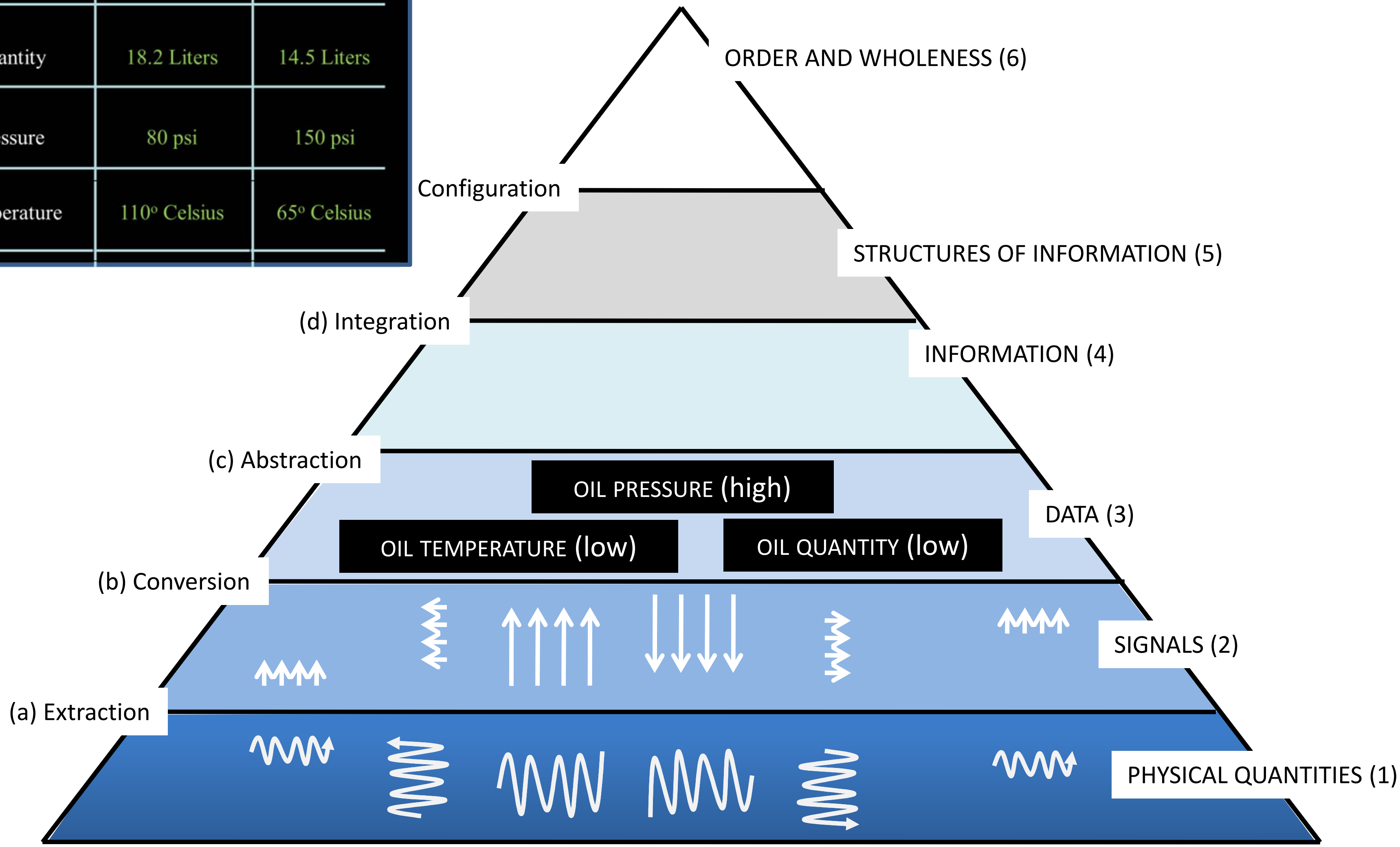
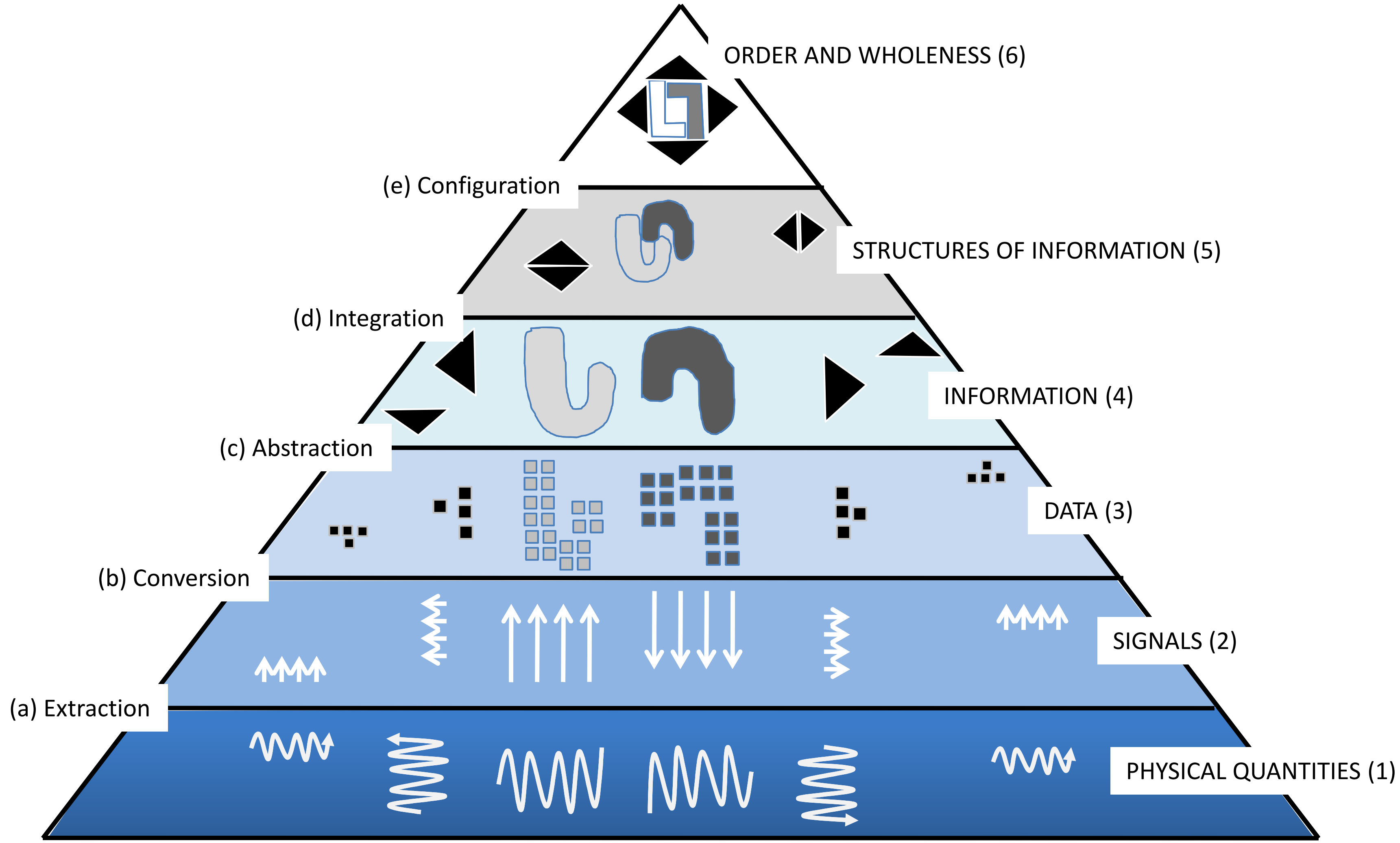
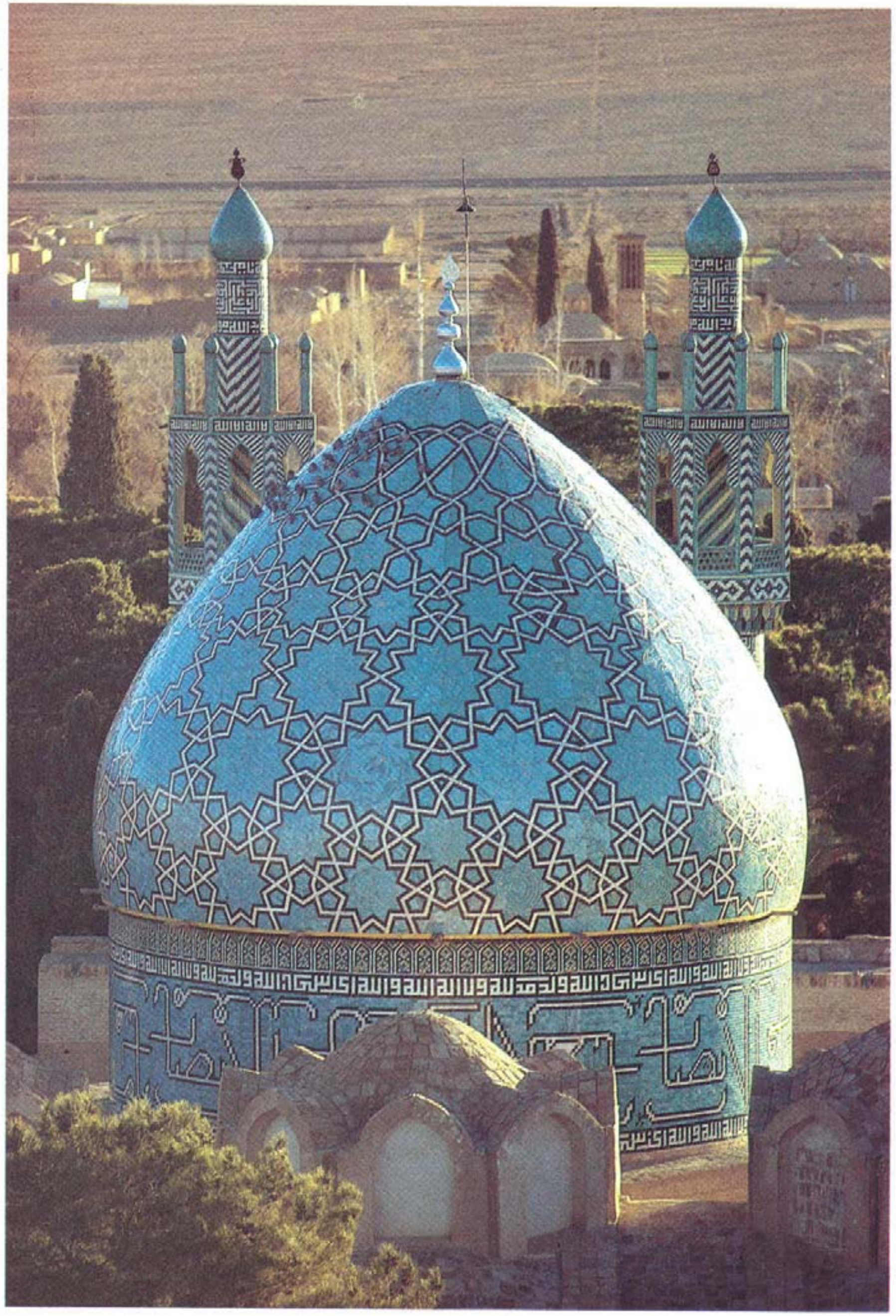


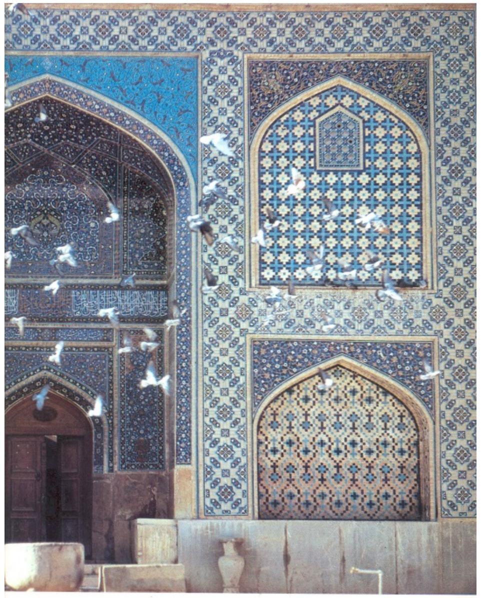
Degani, A., Barshi, I, & Shafto, M. (in press). Information Organization in the Airline Cockpit: Lessons from Flight 236. *Journal of Cognitive Engineering and Decision-Making*.

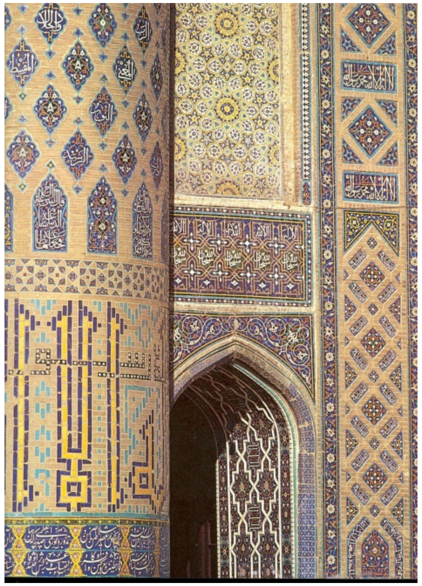
Information Organization

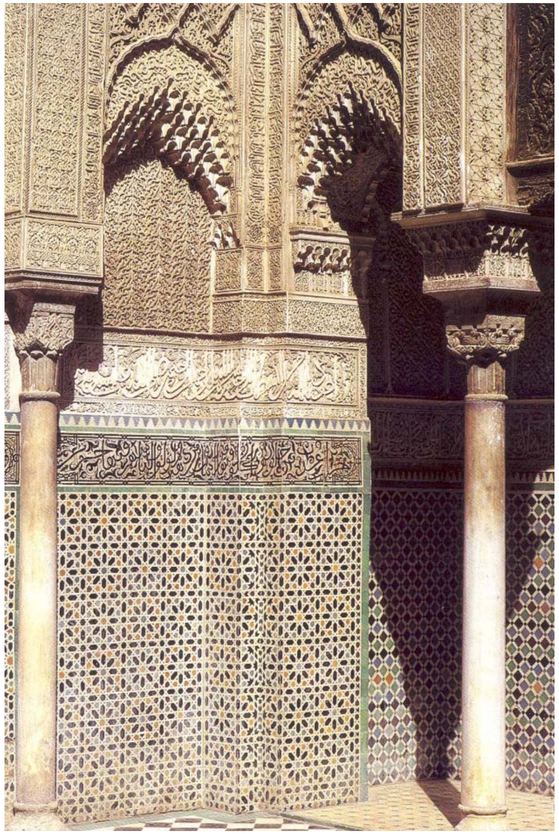


Alexander, C (2002). *The Phenomenon of Life*. Berkeley, CA: Center for Environmental Structure

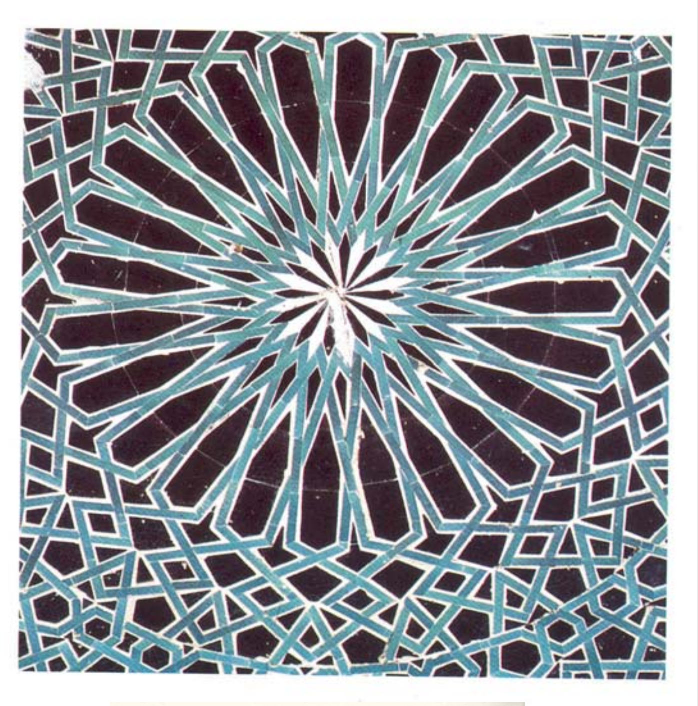


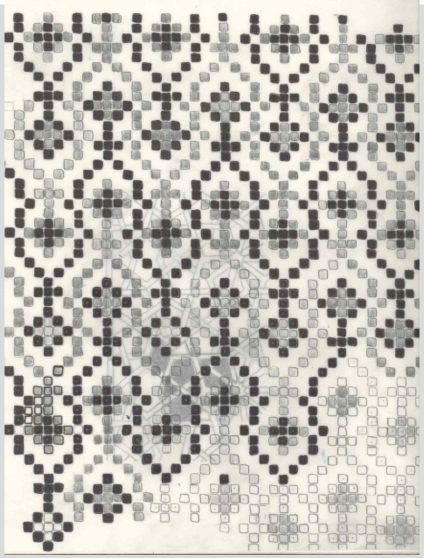


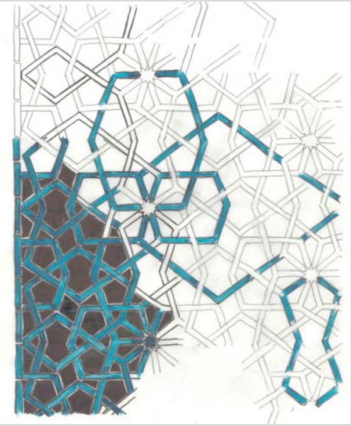




Medieval Islamic Architecture

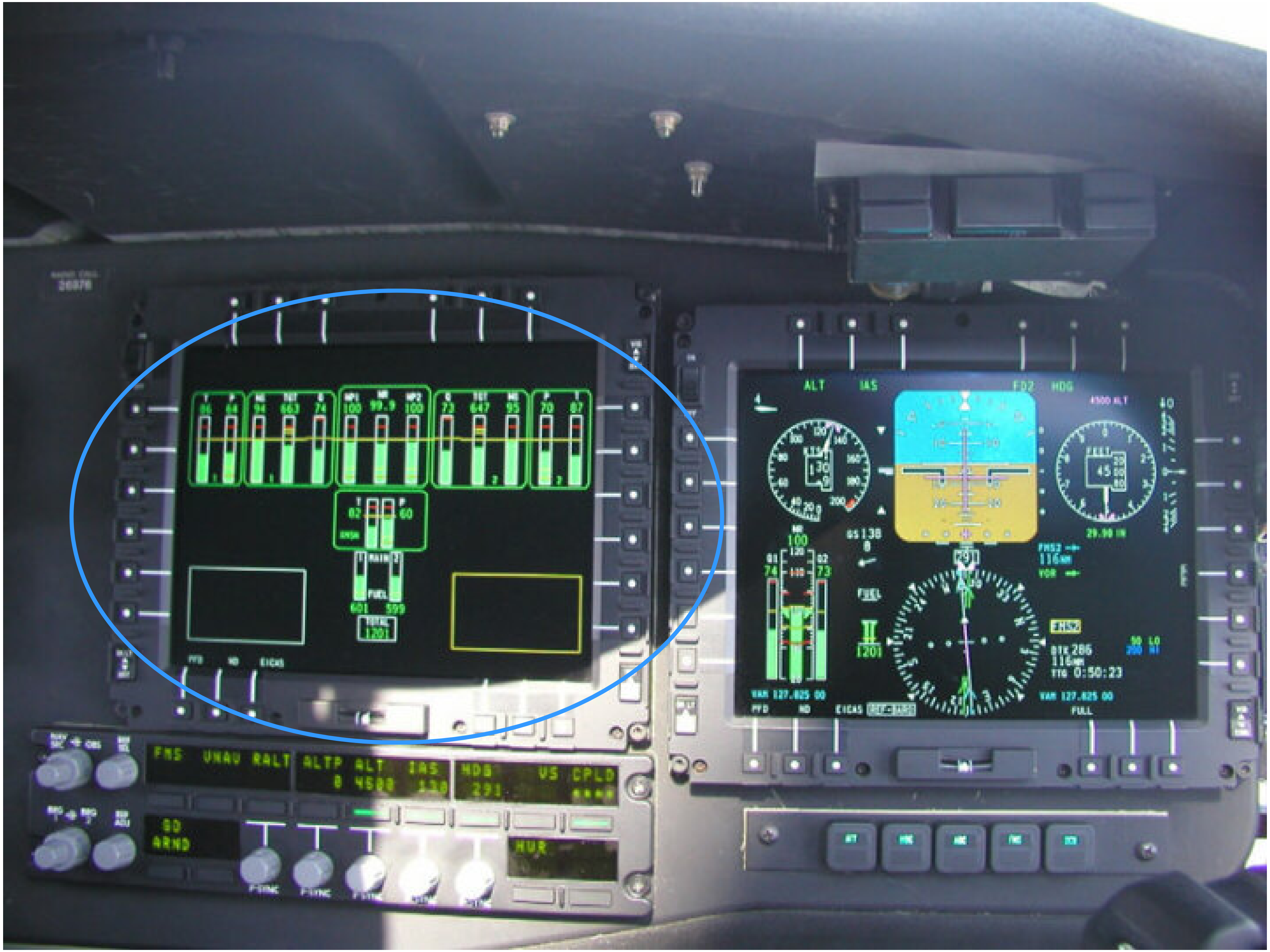






NASA's RASCAL Research Helicopter


% RPM
% TRQ
AIRVENTURE.de
Thomas Mayer 2004


FMS VNAV RALT
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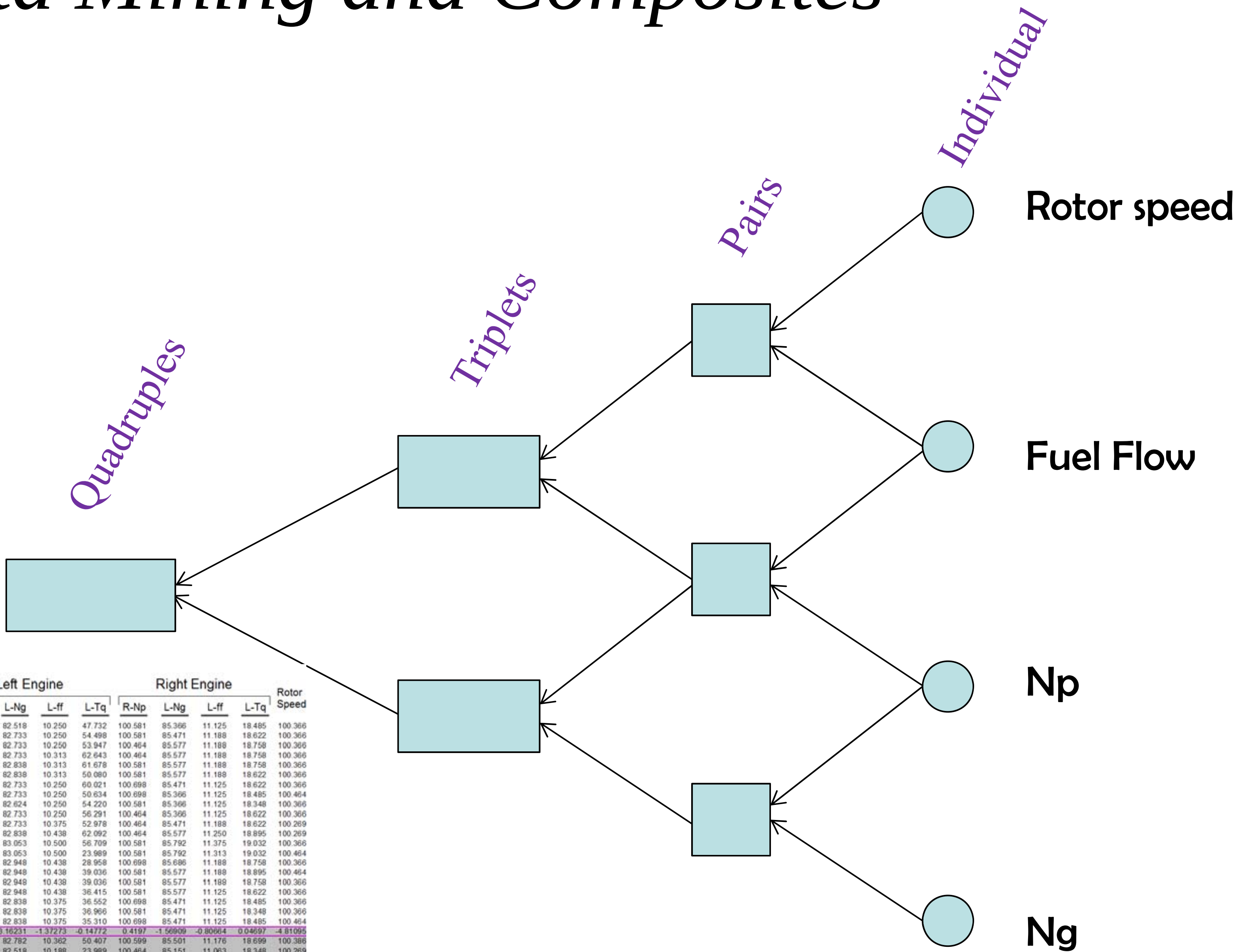
FULL

(GE T700-701)

	Left Engine				Right Engine				
	L-Np	L-Ng	L-ff	L-Tq	R-Np	L-Ng	L-ff	L-Tq	Rotor Speed
	100.472	82.518	10.250	47.732	100.581	85.366	11.125	18.485	100.366
	100.472	82.733	10.250	54.498	100.581	85.471	11.188	18.622	100.366
	100.472	82.733	10.250	53.947	100.464	85.577	11.188	18.758	100.366
	100.472	82.733	10.313	62.643	100.464	85.577	11.188	18.758	100.366
	100.589	82.838	10.313	61.678	100.581	85.577	11.188	18.758	100.366
	100.589	82.838	10.313	50.080	100.581	85.577	11.188	18.622	100.366
	100.589	82.733	10.250	60.021	100.698	85.471	11.125	18.622	100.366
	100.589	82.733	10.250	50.634	100.698	85.366	11.125	18.485	100.464
	100.589	82.624	10.250	54.220	100.581	85.366	11.125	18.348	100.366
	100.472	82.733	10.250	56.291	100.464	85.366	11.125	18.622	100.366
	100.472	82.733	10.375	52.978	100.464	85.471	11.188	18.622	100.269
	100.472	82.838	10.438	62.092	100.464	85.577	11.250	18.895	100.269
	100.472	83.053	10.500	56.709	100.581	85.792	11.375	19.032	100.366
	100.589	83.053	10.500	23.989	100.581	85.792	11.313	19.032	100.464
	100.706	82.948	10.438	28.958	100.698	85.686	11.188	18.758	100.366
	100.589	82.948	10.438	39.036	100.581	85.577	11.188	18.895	100.464
	100.589	82.948	10.438	39.036	100.581	85.577	11.188	18.758	100.366
	100.589	82.948	10.438	36.415	100.581	85.577	11.125	18.622	100.366
	100.589	82.838	10.375	36.552	100.698	85.471	11.125	18.485	100.366
	100.589	82.838	10.375	36.966	100.581	85.471	11.125	18.348	100.366
	100.589	82.838	10.375	35.310	100.698	85.471	11.125	18.485	100.464
IMS	1.71616	3.16231	-1.37273	-0.14772	0.4197	-1.56909	-0.80664	0.04697	-4.81095
averages	100.573	82.782	10.362	50.407	100.599	85.501	11.176	18.699	100.386
min	100.472	82.518	10.188	23.989	100.464	85.151	11.063	18.348	100.269
max	100.706	83.053	10.500	62.643	100.698	85.792	11.375	19.032	100.464

Data Mining and Composites



(GE T700-701)

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	L-Np	L-Ng	L-ff	L-Tq	R-Np	L-Ng	L-ff	L-Tq	
	100.472	82.518	10.250	47.732	100.581	85.366	11.125	18.485	100.366
	100.472	82.733	10.250	54.498	100.581	85.471	11.188	18.622	100.366
	100.472	82.733	10.250	53.947	100.464	85.577	11.188	18.758	100.366
	100.472	82.733	10.313	62.643	100.464	85.577	11.188	18.758	100.366
	100.589	82.838	10.313	61.678	100.581	85.577	11.188	18.758	100.366
	100.589	82.838	10.313	50.080	100.581	85.577	11.188	18.622	100.366
	100.589	82.733	10.250	60.021	100.698	85.471	11.125	18.622	100.366
	100.589	82.733	10.250	50.634	100.698	85.366	11.125	18.485	100.464
	100.589	82.624	10.250	54.220	100.581	85.366	11.125	18.348	100.366
	100.472	82.733	10.250	56.291	100.464	85.366	11.125	18.622	100.366
	100.472	82.733	10.375	52.978	100.464	85.471	11.188	18.622	100.269
	100.472	82.838	10.438	62.092	100.464	85.577	11.250	18.895	100.269
	100.472	83.053	10.500	56.709	100.581	85.792	11.375	19.032	100.366
	100.589	83.053	10.500	23.989	100.581	85.792	11.313	19.032	100.464
	100.706	82.948	10.438	28.958	100.698	85.686	11.188	18.758	100.366
	100.589	82.948	10.438	39.036	100.581	85.577	11.188	18.895	100.464
	100.589	82.948	10.438	39.036	100.581	85.577	11.189	18.758	100.366
	100.589	82.948	10.438	36.415	100.581	85.577	11.125	18.622	100.366
	100.589	82.838	10.375	36.552	100.698	85.471	11.125	18.485	100.366
	100.589	82.838	10.375	36.966	100.581	85.471	11.125	18.348	100.366
	100.589	82.838	10.375	35.310	100.698	85.471	11.125	18.485	100.464
IMS	1.71616	3.16231	-1.37273	-0.14772	0.4197	-1.56909	-0.80664	0.04697	-4.81095
averages	100.573	82.782	10.362	50.407	100.599	85.501	11.176	18.699	100.386
min	100.472	82.518	10.188	23.989	100.464	85.151	11.063	18.348	100.269
max	100.706	83.053	10.500	62.643	100.698	85.792	11.375	19.032	100.464

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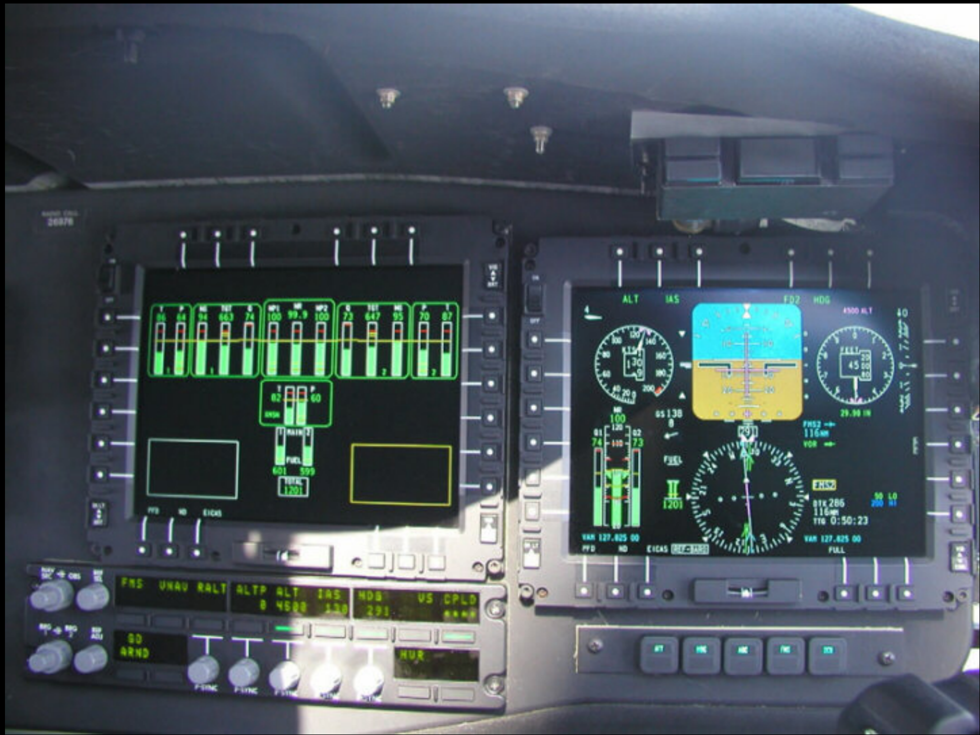

(GE T700-701)

	Left Engine				Right Engine				Rotor Speed
	L-Np	L-Ng	L-ff	L-Tq	R-Np	L-Ng	L-ff	L-Tq	
	100.472	82.518	10.250	47.732	100.581	85.366	11.125	18.485	100.366
	100.472	82.733	10.250	54.498	100.581	85.471	11.188	18.622	100.366
	100.472	82.733	10.250	53.947	100.464	85.577	11.188	18.758	100.366
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	100.589	82.733	10.250	50.634	100.698	85.366	11.125	18.485	100.464
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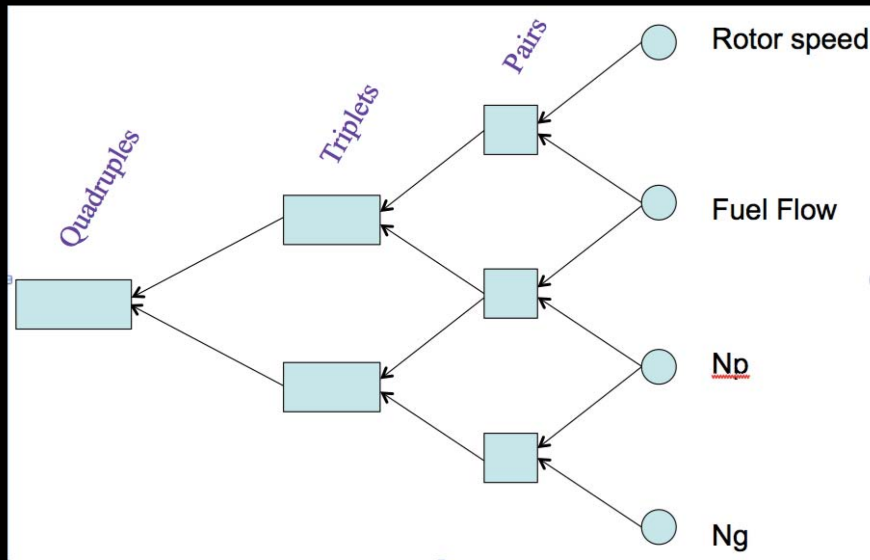
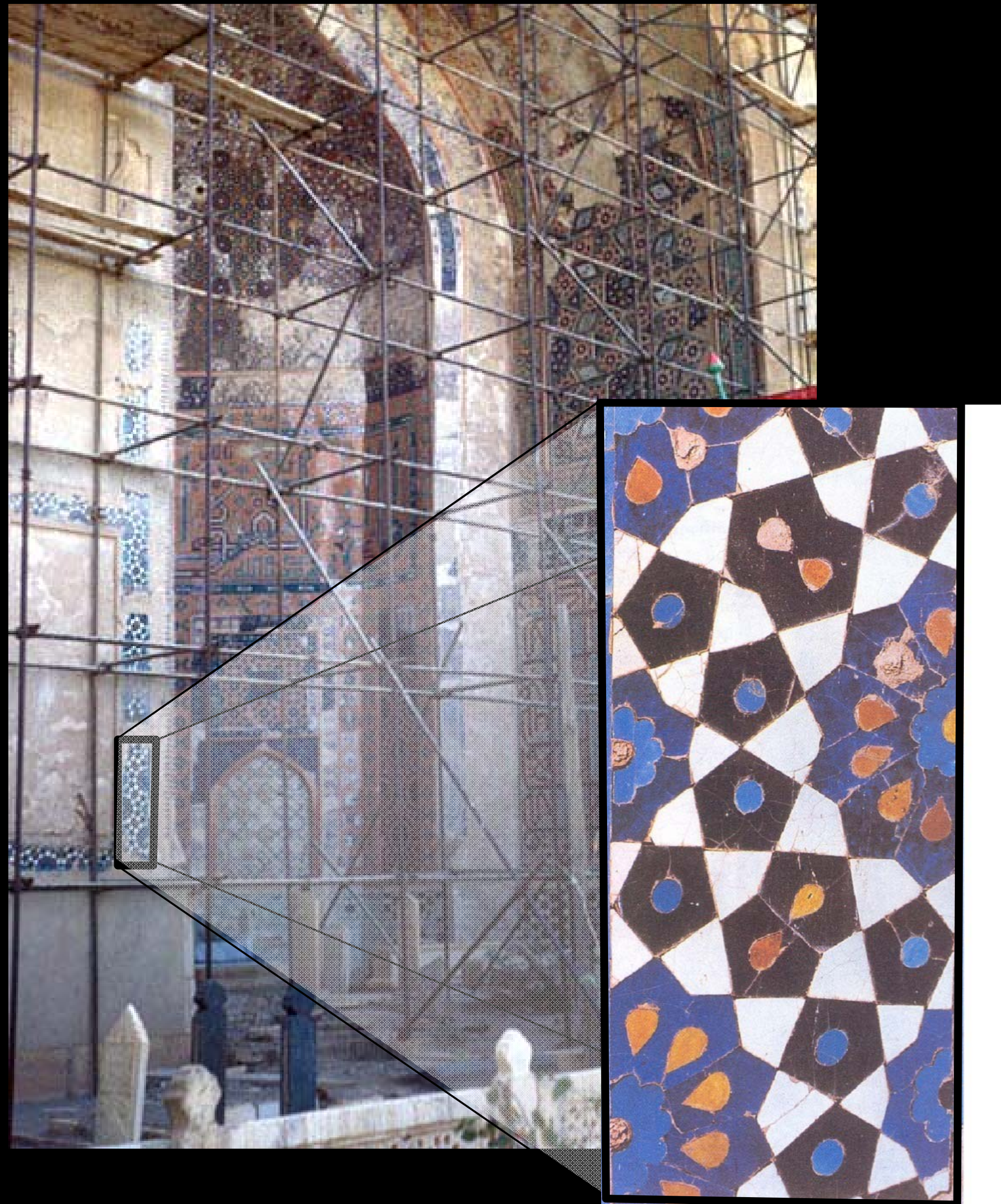
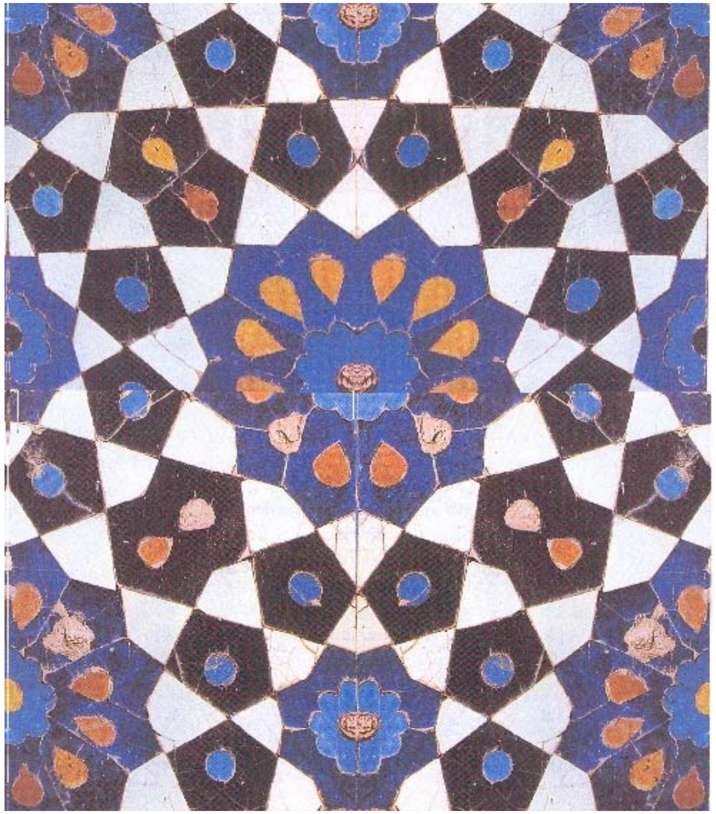
	100.589	82.838	10.375	35.310	100.698	85.471	11.125	18.485	100.464
IMS	1.71616	3.16231	-1.37273	-0.14772	0.4197	-1.56909	-0.80664	0.04697	-4.81095
averages	100.573	82.782	10.362	50.407	100.599	85.501	11.176	18.699	100.386
min	100.472	82.518	10.188	23.989	100.464	85.151	11.063	18.348	100.269
max	100.706	83.053	10.500	62.643	100.698	85.792	11.375	19.032	100.464

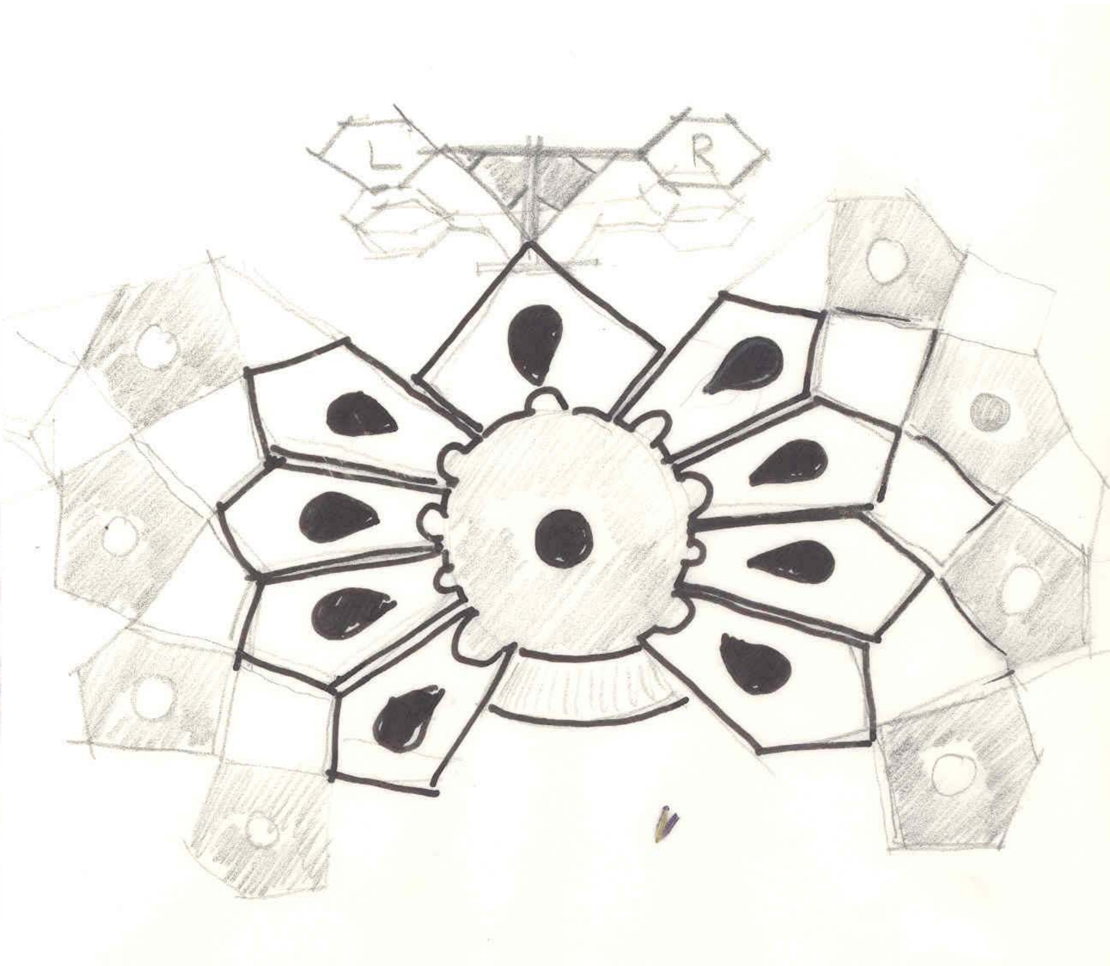


Gazarghah, Afghanistan

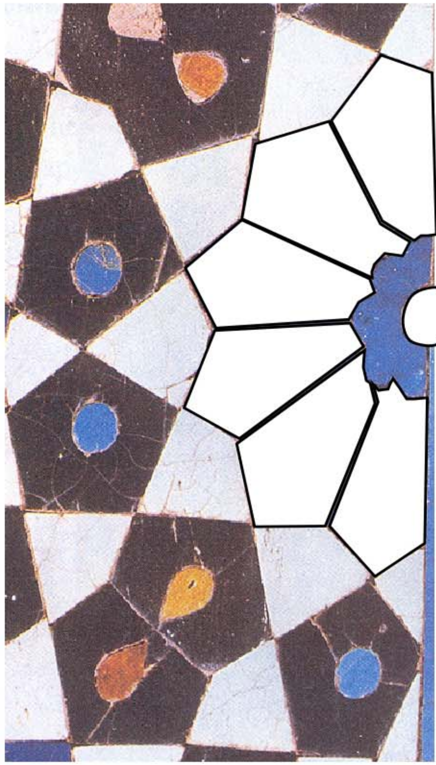


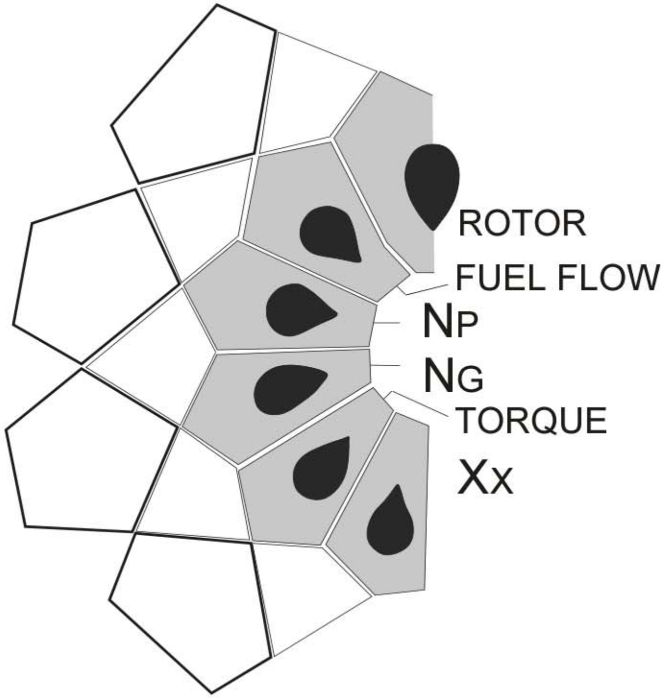
Initial Design Concepts





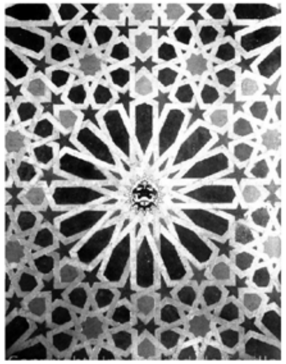
From Tilework to Parameter Arrangements

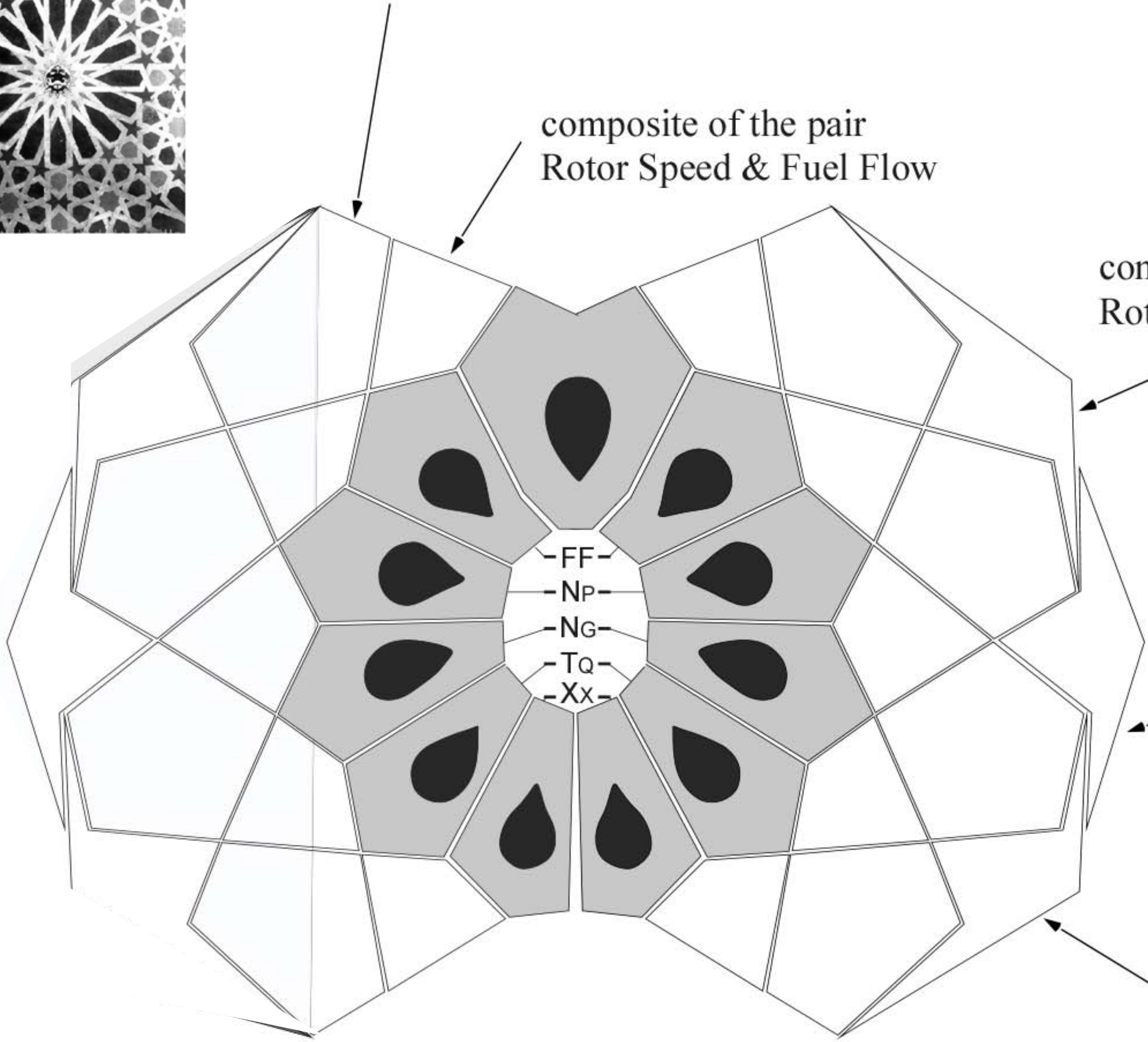


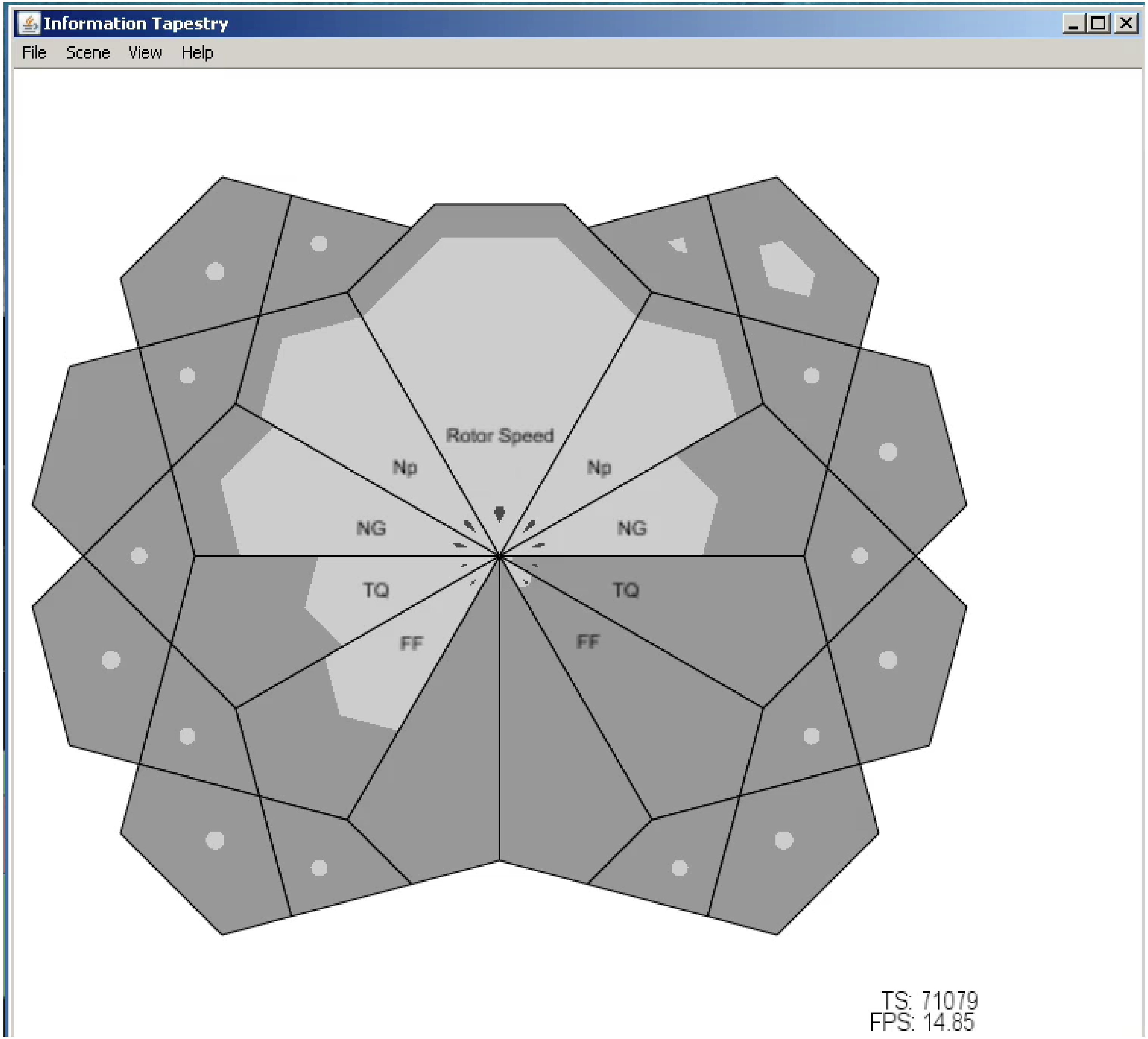


Barshi, I, Degani, A., Iverson, D, & Lu, P.J. (2012). Using medieval architecture as inspiration for display design: Parameter interrelationships and organizational structure. *Proceedings of the Human Factors*

Integration (creating structures of information)






Information Tapestry
File
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View
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TS: 71079
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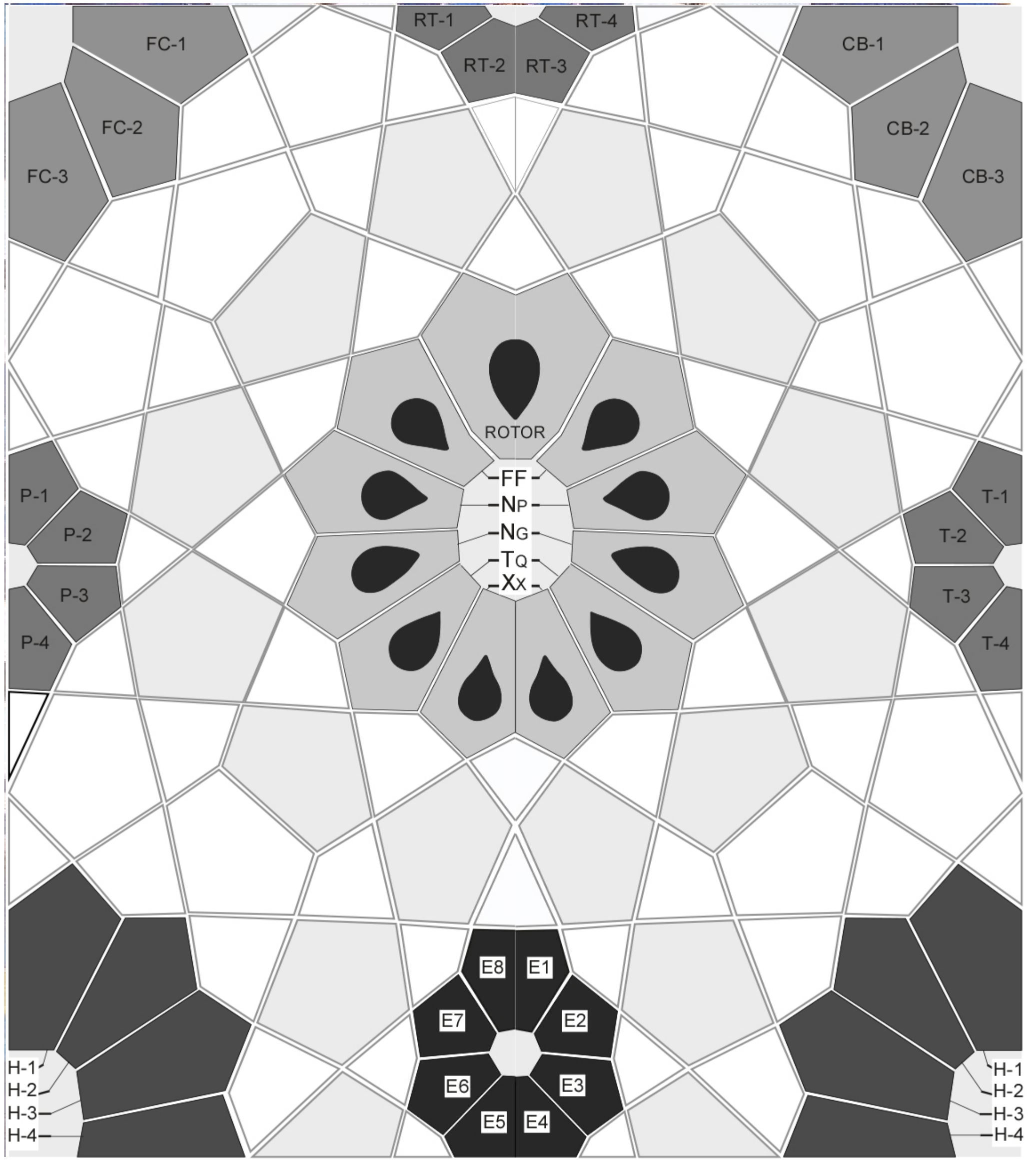
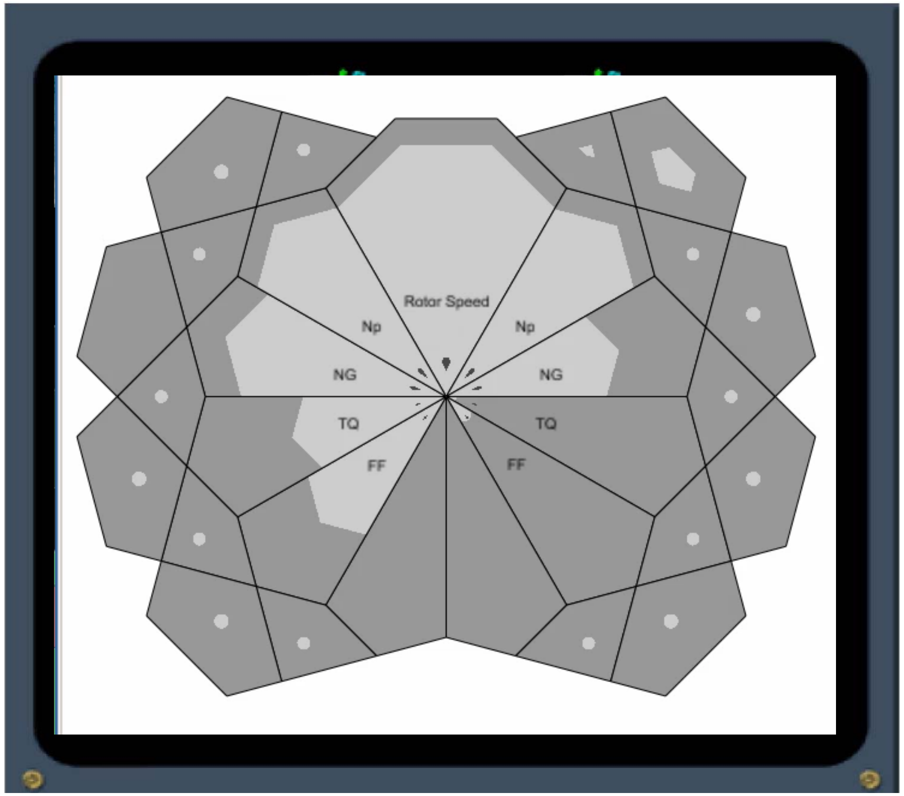
Order and Wholeness



Information Integration and Organization

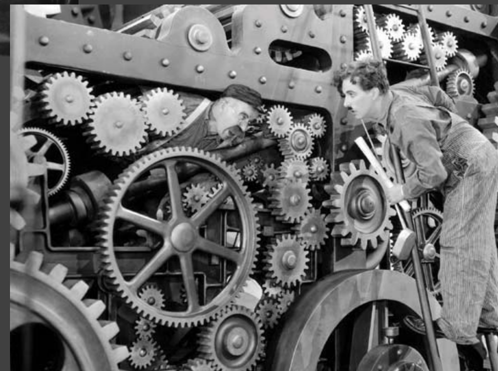


Lu, P. J. & Steinhardt, P. (2007). Decagonal and Quasi-Crystalline Tilings in Medieval Islamic Architecture. Science 315, p. 1106.

Degani, A., Jorgensen, C., Shafto, M. & Olson, L. (2009). On Organization of Information: Approach and early work. NASA Technical Memorandum No. 215368, Moffett Field, CA: NASA Ames

Automation Difficulties (aviation):

- *Monitoring*



- *Need for correct understanding*
- *Information organization and integration*
- *“Out-of-the-loop”*

Air France Flight 447

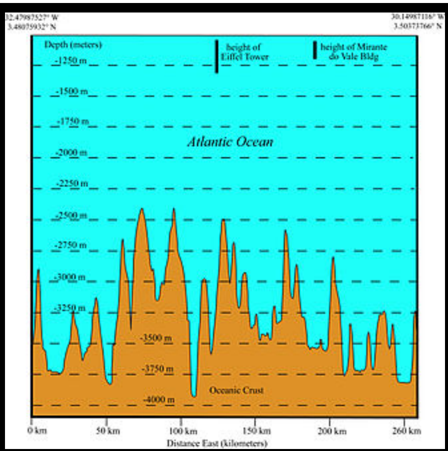
Monday, 1 June, 2009

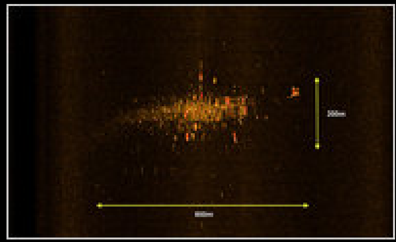

Paris
Expected at 09:10, 1 June
Last transmission at unknown location
11:14PM
Fernando de Noronha
10:33PM
Rio de Janeiro
7:33PM, May 31st

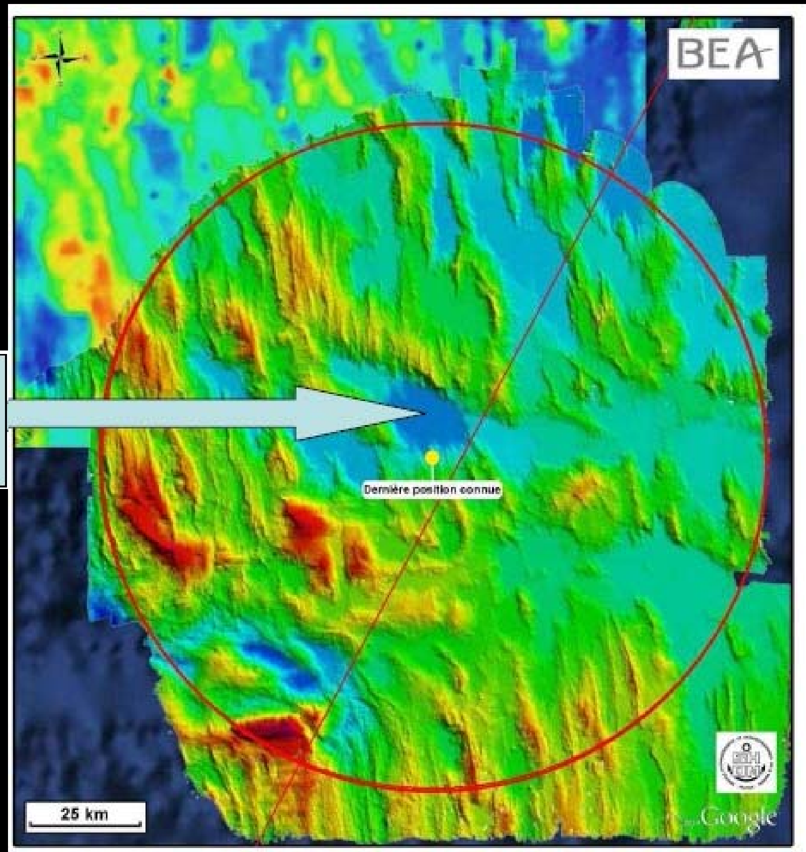

F 42


FLIGHT
RECORDER
DO NOT OPEN

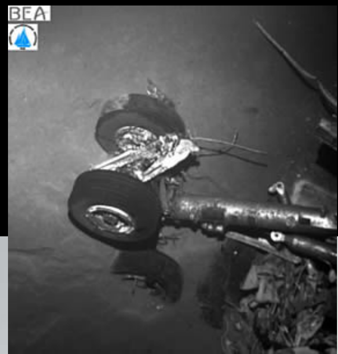

MARINHA DO BRASIL

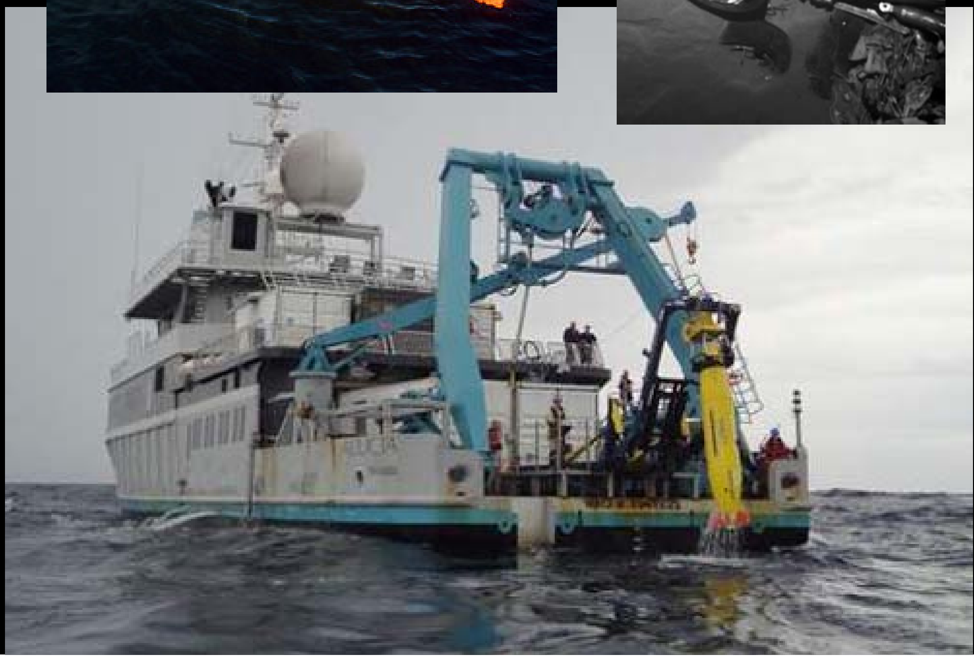






Accident site (in the area of the Abyssal plain)





Sequence of Events Flight 447

- 7:33PM. Take off The Rio de Janeiro - Paris route exceeds the maximum ten hours permitted by Air France's procedures. 3 person crew with rest period for each (Captain and two copilots: Head-pilot & Junior-Pilot).
- 11:01PM. The captain leaves the cockpit to take a rest
- 11:08:06. The *Head-Pilot* warns the cabin crew that they were about to enter an area of turbulence. The two copilots turned the aircraft slightly to the left and decreased its speed from Mach 0.82 to Mach 0.8
- a strange aroma, like an electrical transformer, floods the cockpit, and the temperature suddenly increased (St. Elmo’s fire)
- The sound of slipstream suddenly becomes louder. (presumably, is due to the accumulation of ice crystals on the exterior of the fuselage)

Sequence of Events Flight 447

- Unbeknown to the pilots the pitot-tube clog with ice.
  - an alarm sounds for 2.2 seconds, indicating that the autopilot is disconnecting
- 23:10:06 – *Junior-Pilot*: “J'ai les commandes” [I have the controls].
  - He pulls back on the side stick to put the airplane into a steep climb!
  - A warning chime alerts the cockpit to the fact that they are leaving their programmed altitude (2,512 feet).
  - Then the STALL warning sounds, aircraft still ascending.
- The *Junior-Pilot* once again increases his back pressure on the stick, raising the nose of the plane and bleeding off speed. Again, the STALL alarm begins to sound.
- 23:10:55 The *Head-Pilot*: “Putain!” [Damn it!]

- Pitot-tubes begins to function; all cockpit's avionics are now normal. (11:11:06)
- 11:11:03 *Junior-pilot* :"Je suis en TOGA, hein?" [I'm in TOGA, huh?]
  - He wants to increase speed and to climb away from danger
  - The plane now reaches its maximum altitude. With engines at full power, the nose pitched upward at an angle of 18 degrees, it moves horizontally for an instant and then begins to sink… (02:11:06)
- 11:11:21 *Head-pilot*: "We still have the engines! What the hell is happening? I don't understand what's happening."
  - The side sticks on an Airbus move independently -- If the pilot in the right seat is pulling back on the stick, the person in the left seat doesn't feel it or knows about it.
- 11:11:32 *Junior-pilot* : "Damn it, I don't have control of the plane…"
  - The speed toward the ocean accelerates. The first officer is holding the stick all the way back

- The plane's nose is pitched up and it is descending at a 40-degree angle. The stall warning continues to sound.

- 11:11:43 Captain: "Eh... Qu'est-ce que vous foutez?" [What the hell are you doing?]
- 11:11:47 *Head-pilot*: "We've totally lost control of the plane. We don't understand at all... We've tried everything."
  - As the plane descends to 10,000 feet, the *Head-pilot* tries to take back the controls, and pushes forward on the stick, but the plane is in "dual input" mode, and so the system averages his inputs with those of the Junior-pilot, who continues to pull back. The nose remains high
- 11:13:40 *Junior-pilot*: I've had the stick back the whole time!
- 11:13:43 *Head-pilot* : Descend, then... Give me the controls...

Analysis of Flight 447

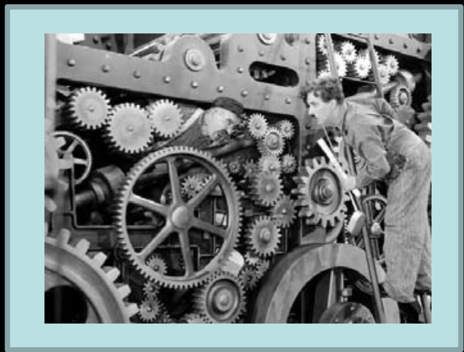
- *No correct understanding* of situation (SA 1 & 2)
  - *Autopilot disconnect due to pitot-tube icing*
  - *"Normal law" vs. "alternate law"*
  - *Side sticks uncoupled to each other.*
- *Out of the Loop* - from monitoring to manual control
  - *Startled by thunderstorms, St. Elmo's fire, transition to manual control*

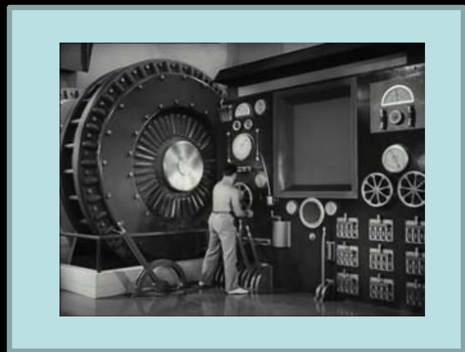
Challenges Ahead

- ***Monitoring***

- *Need for correct understanding*
- *Information organization and integration*
- ***Out-of-the-loop performanc***

In Conclusion





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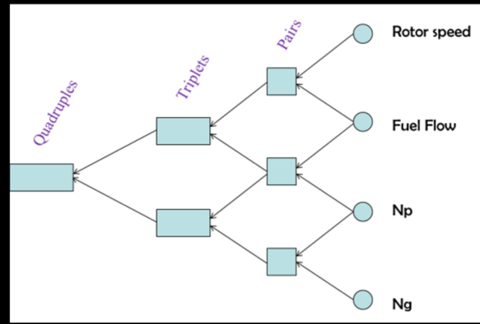

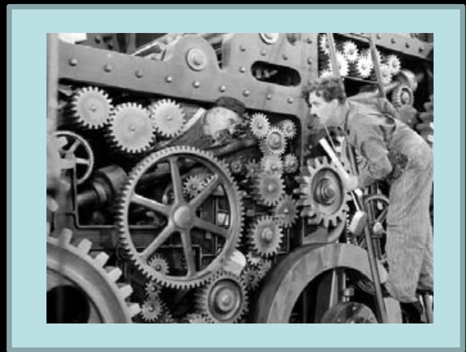

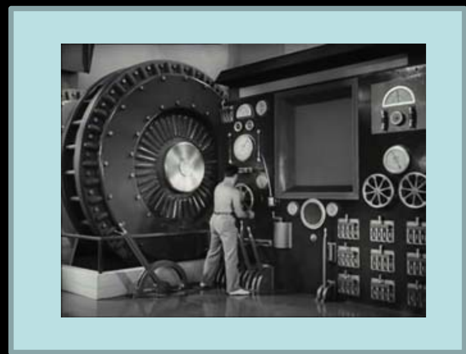

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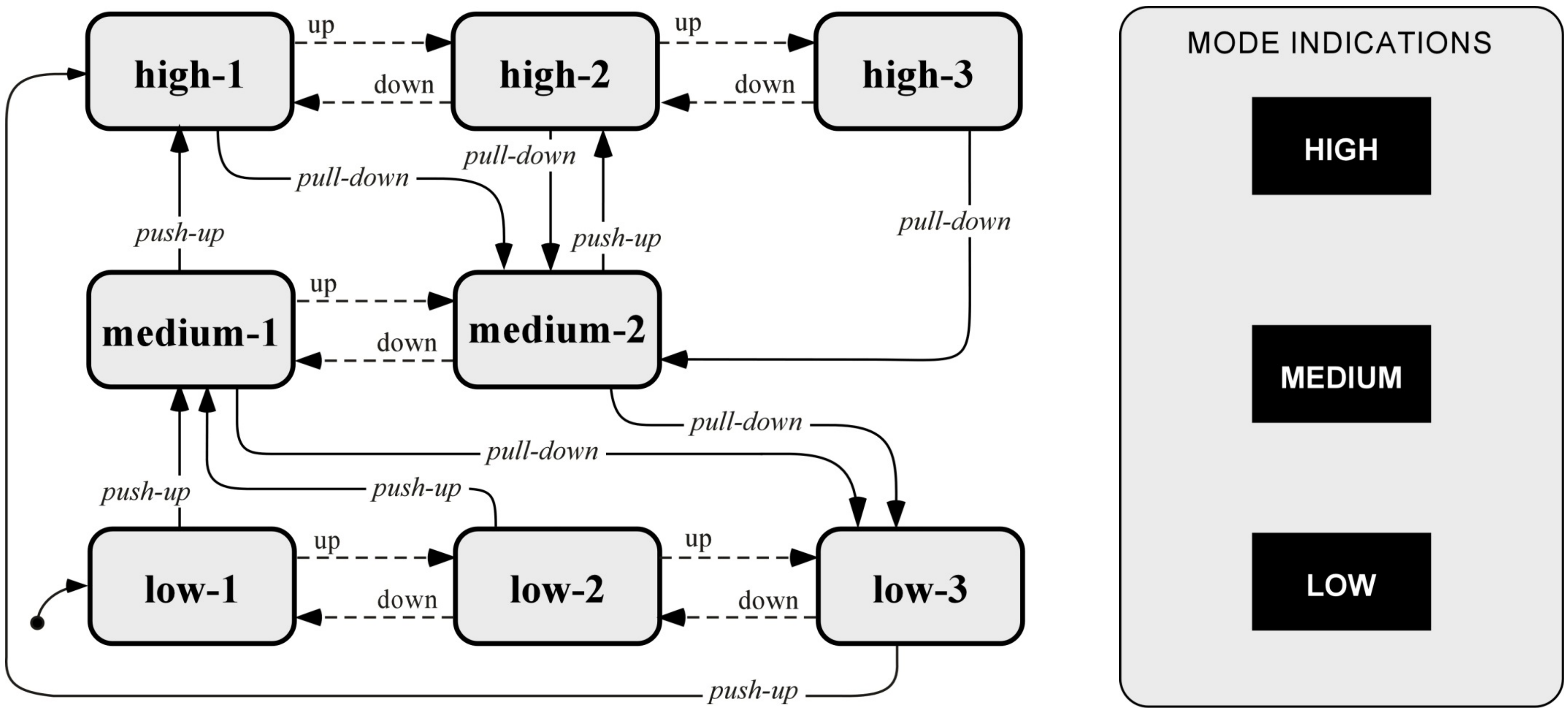
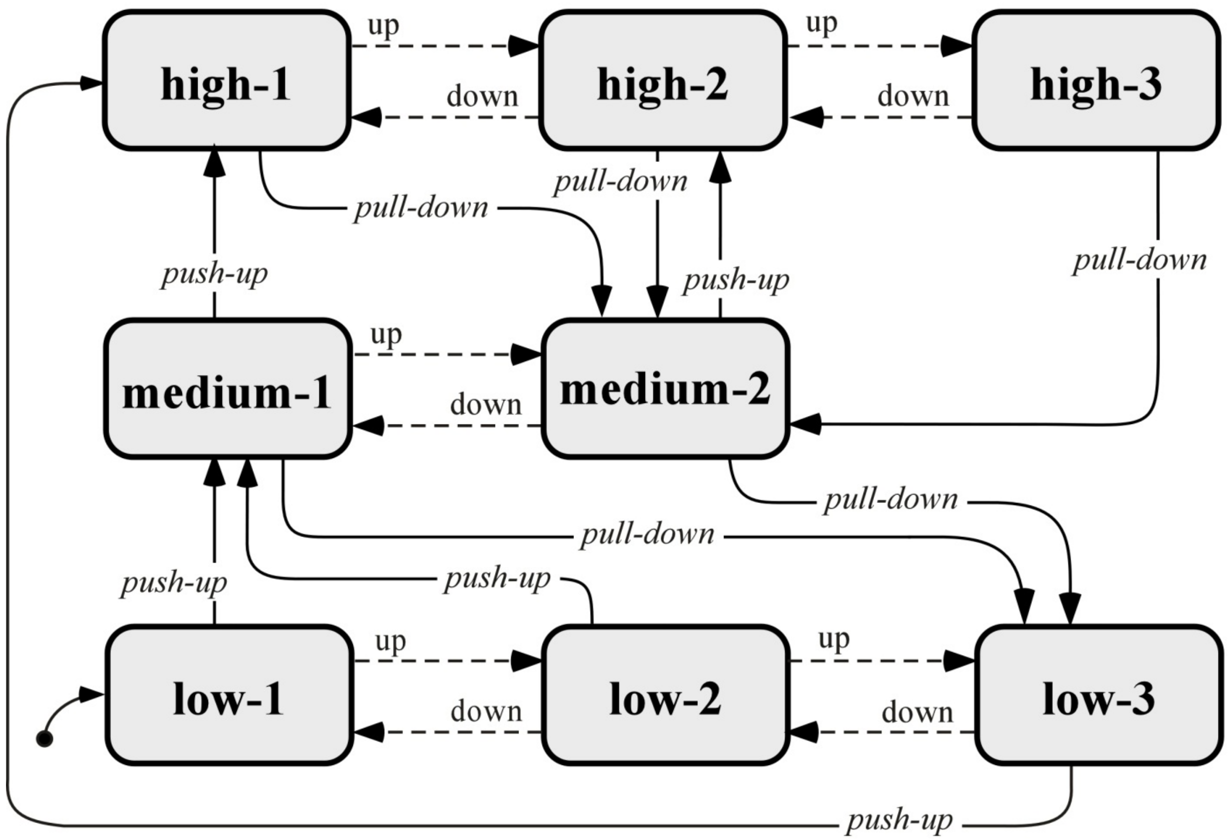
“the crash raises the disturbing possibility that aviation may well long be plagued by a subtler menace, one that ironically springs from the never-ending quest to make flying safer. Over the decades, airliners have been built with increasingly automated flight-control functions. These have the potential to remove a great deal of uncertainty and danger from aviation. But they also remove important information from the attention of the flight crew. While the airplane's avionics track crucial parameters such as location, speed, and heading, the human beings can pay attention to something else. But when trouble suddenly springs up and the computer decides that it can no longer cope—on a dark night, perhaps, in turbulence, far from land—the humans might find themselves with a very incomplete notion of what's going on. They'll wonder: What instruments are reliable, and which can't be trusted? What's the most pressing threat? What's going on? Unfortunately, the vast majority of pilots will have little experience in finding the answers.” (Wise, 2011)

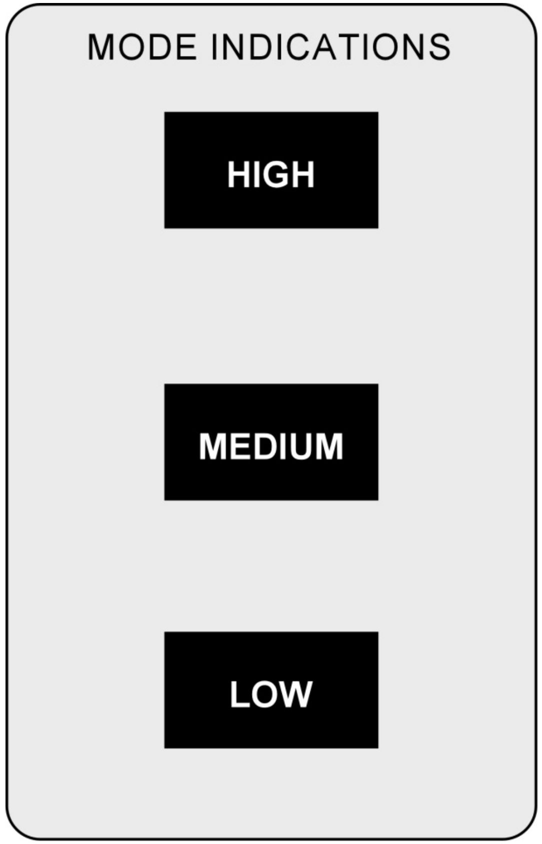
Model of a Transmission System



Model of a Transmission System



Interface



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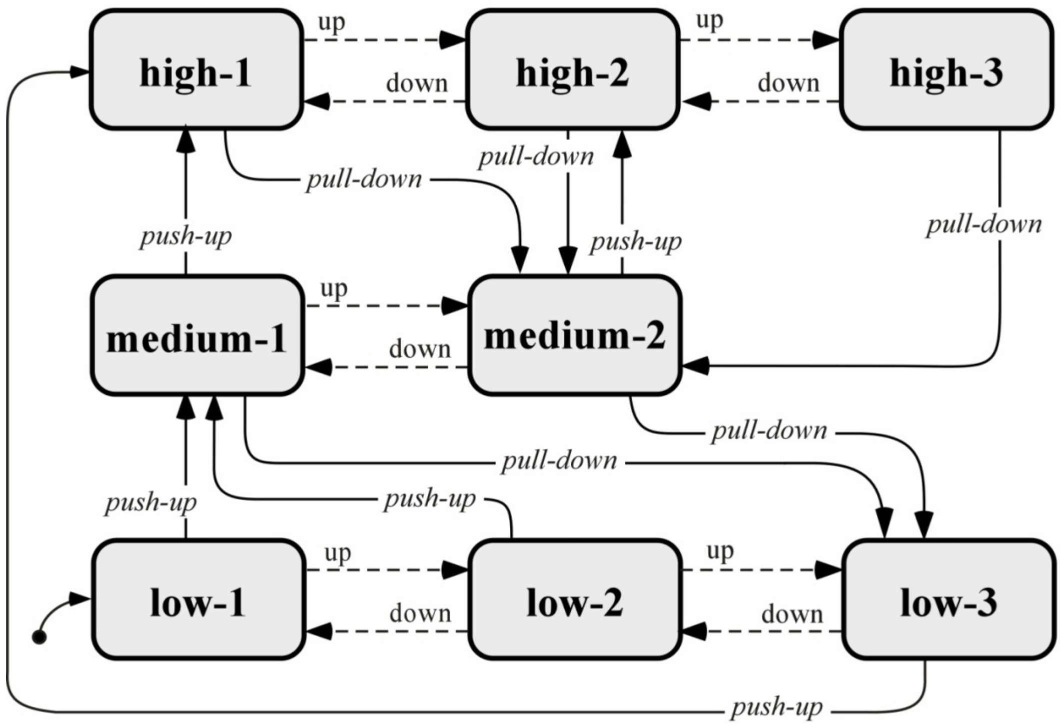

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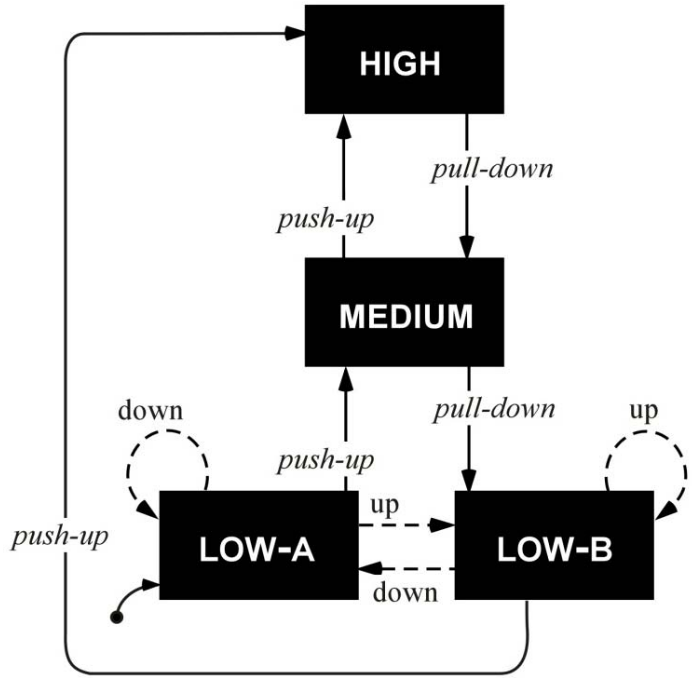
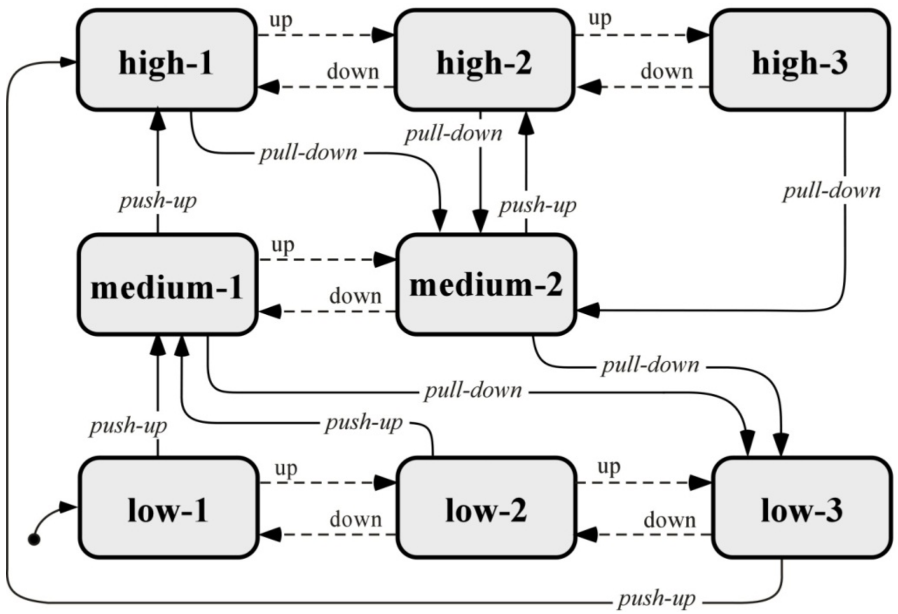
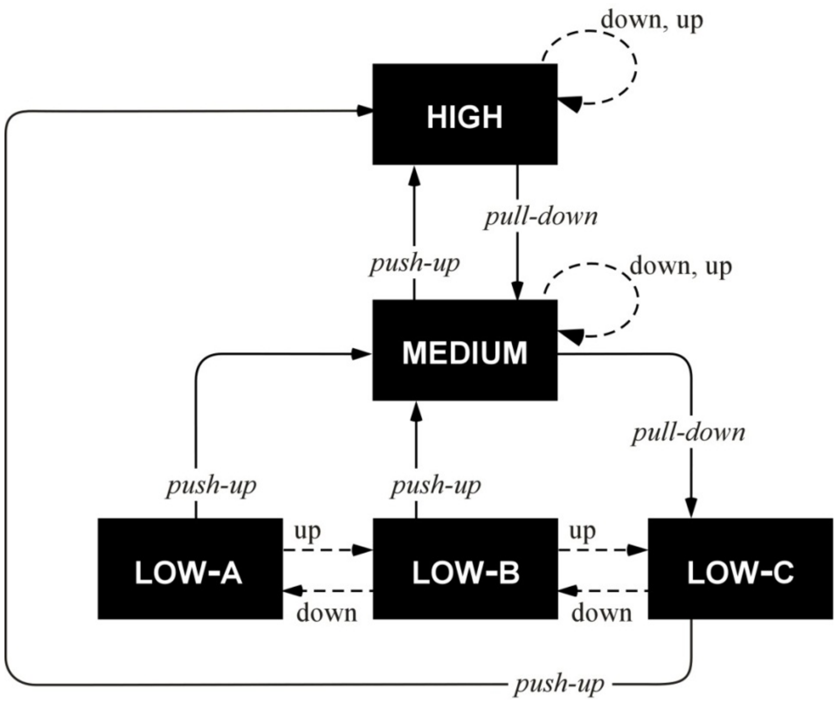


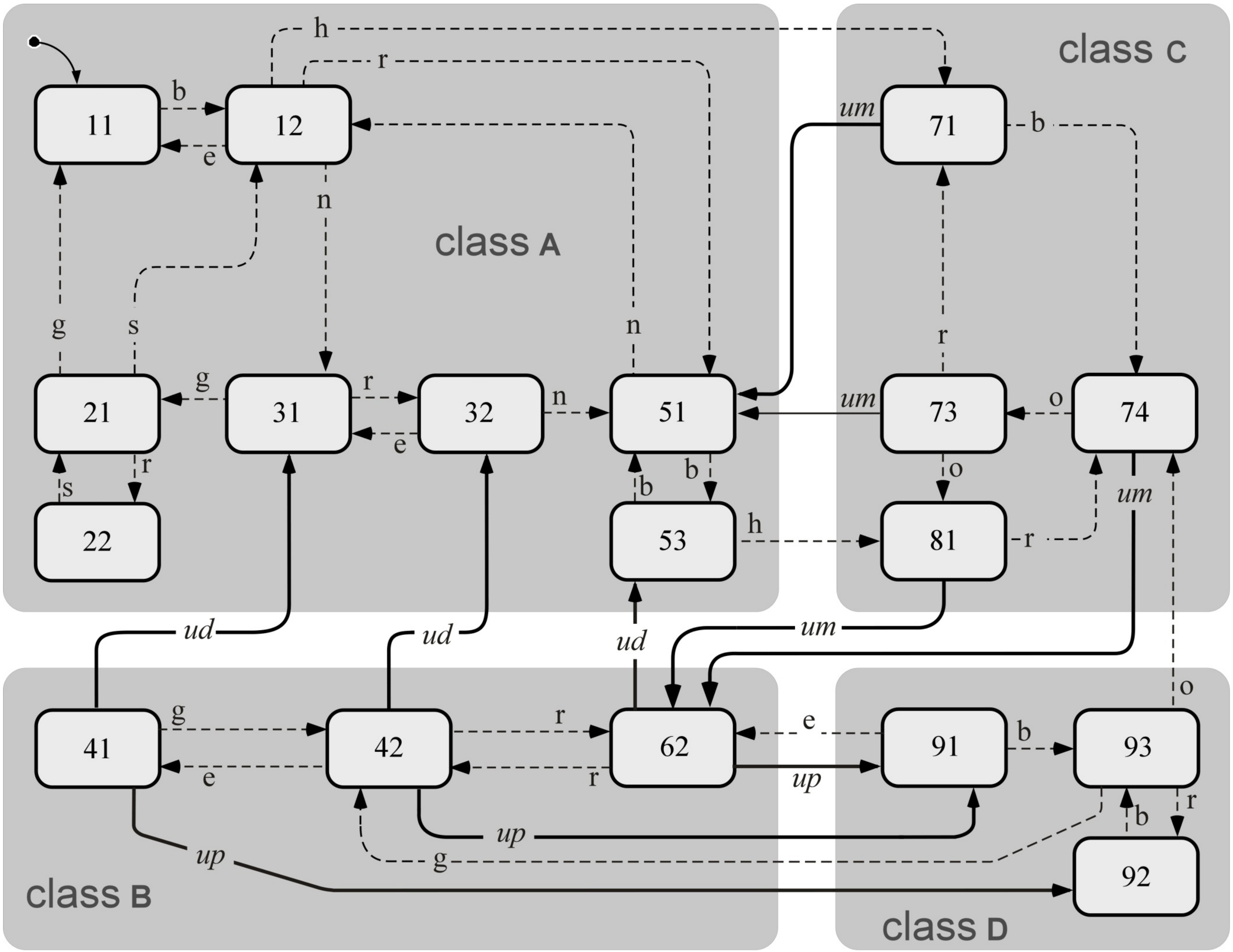
Transmission System

Correct Interface





Denni Javoux
Rushby
Degani, A., Heymann, M., & Shafto, M. (2013). Modeling and formal analysis of human-machine interaction. In A. Kirlik and J. Lee (Eds.), *The Oxford Handbook of Cognitive Engineering*. New York: Oxford University Press.


class A
class B
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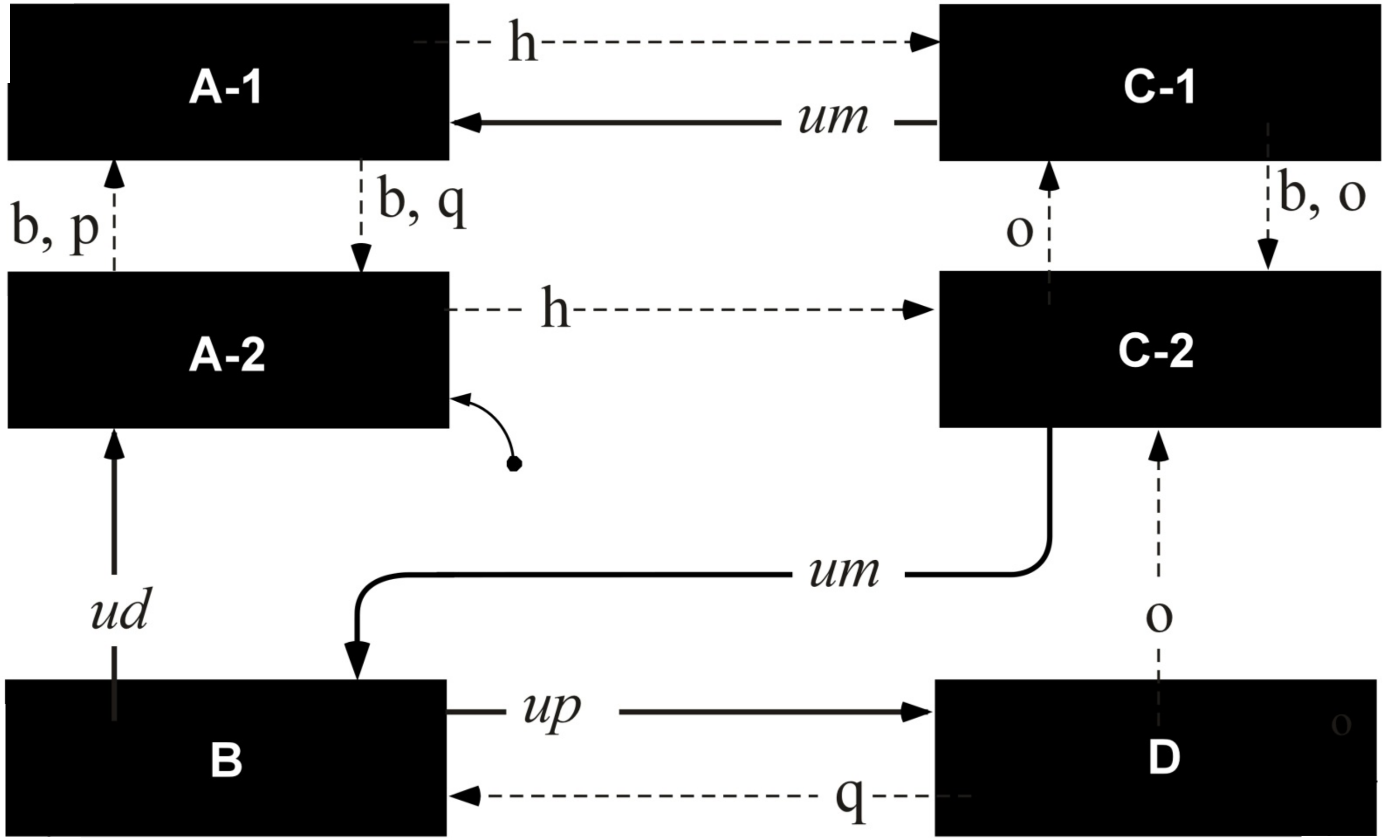
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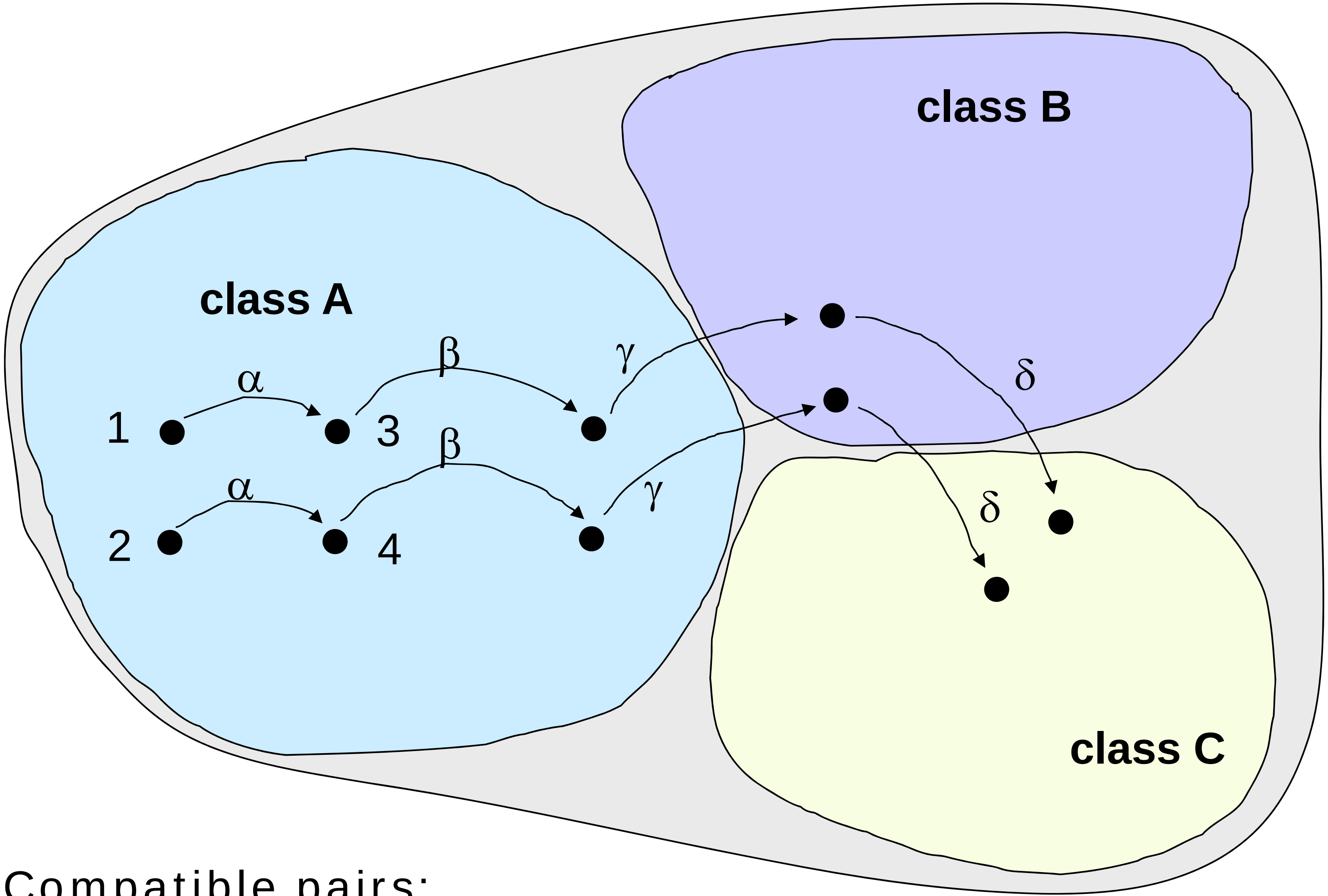
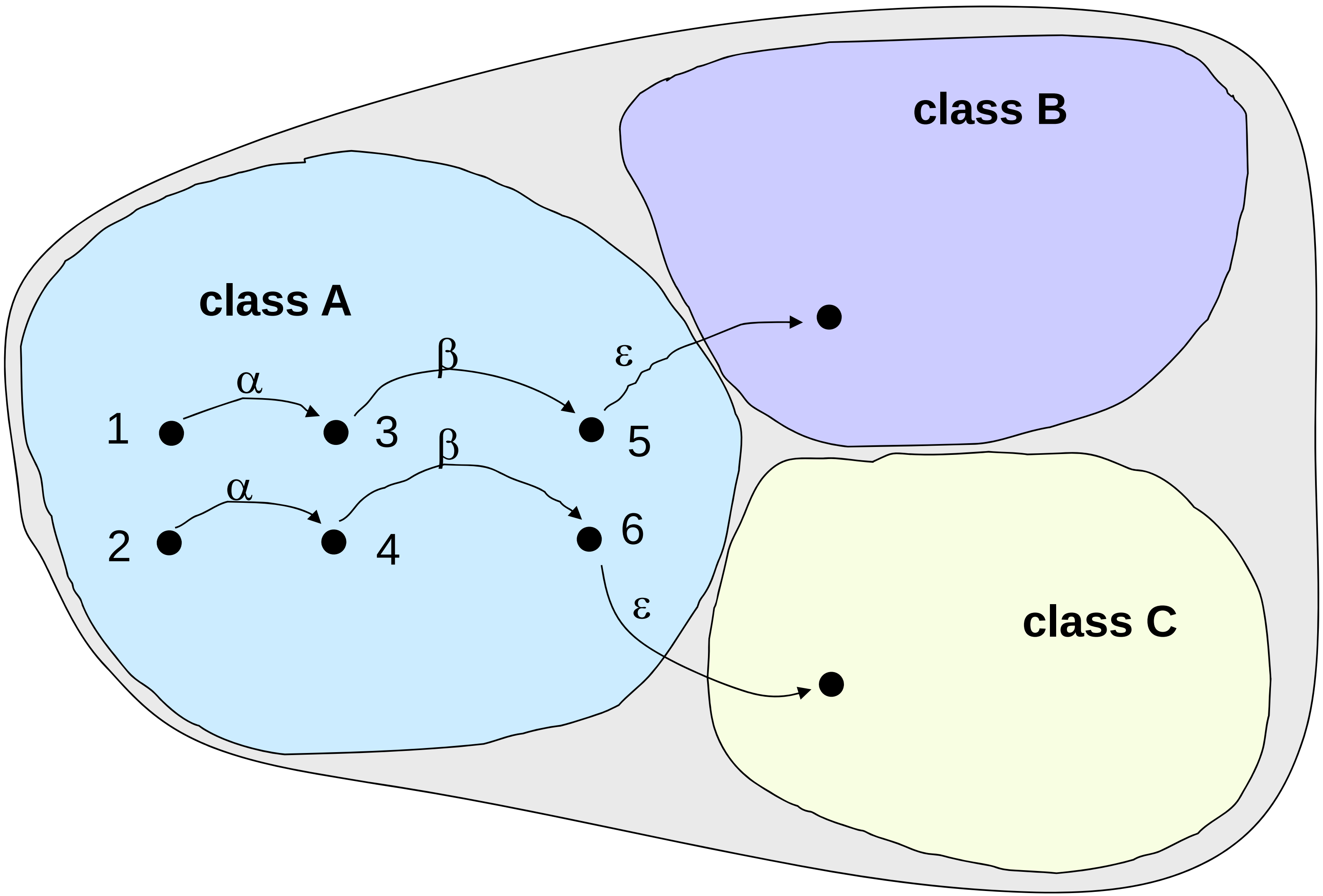


Compatible pairs:

Two internal states need not be distinguished, whenever 1) they belong to the same specification class, 2) each user triggered event that is available and active in one of the states is available and active also in the other, 3) whenever starting from either of the two states and triggered by the same event sequence, the state pairs visited, respectively, also satisfy conditions 1 and 2



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