Lessons Learned In Cognitive Systems Engineering

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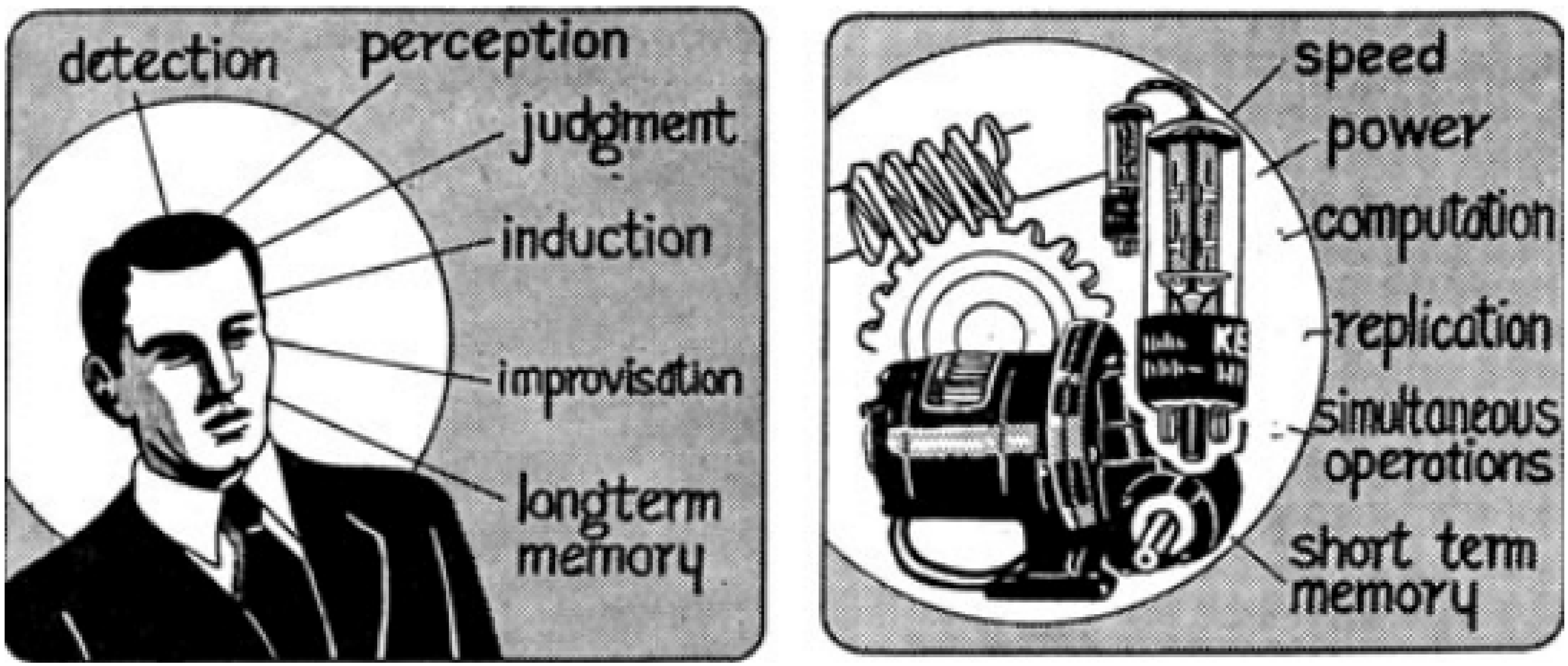
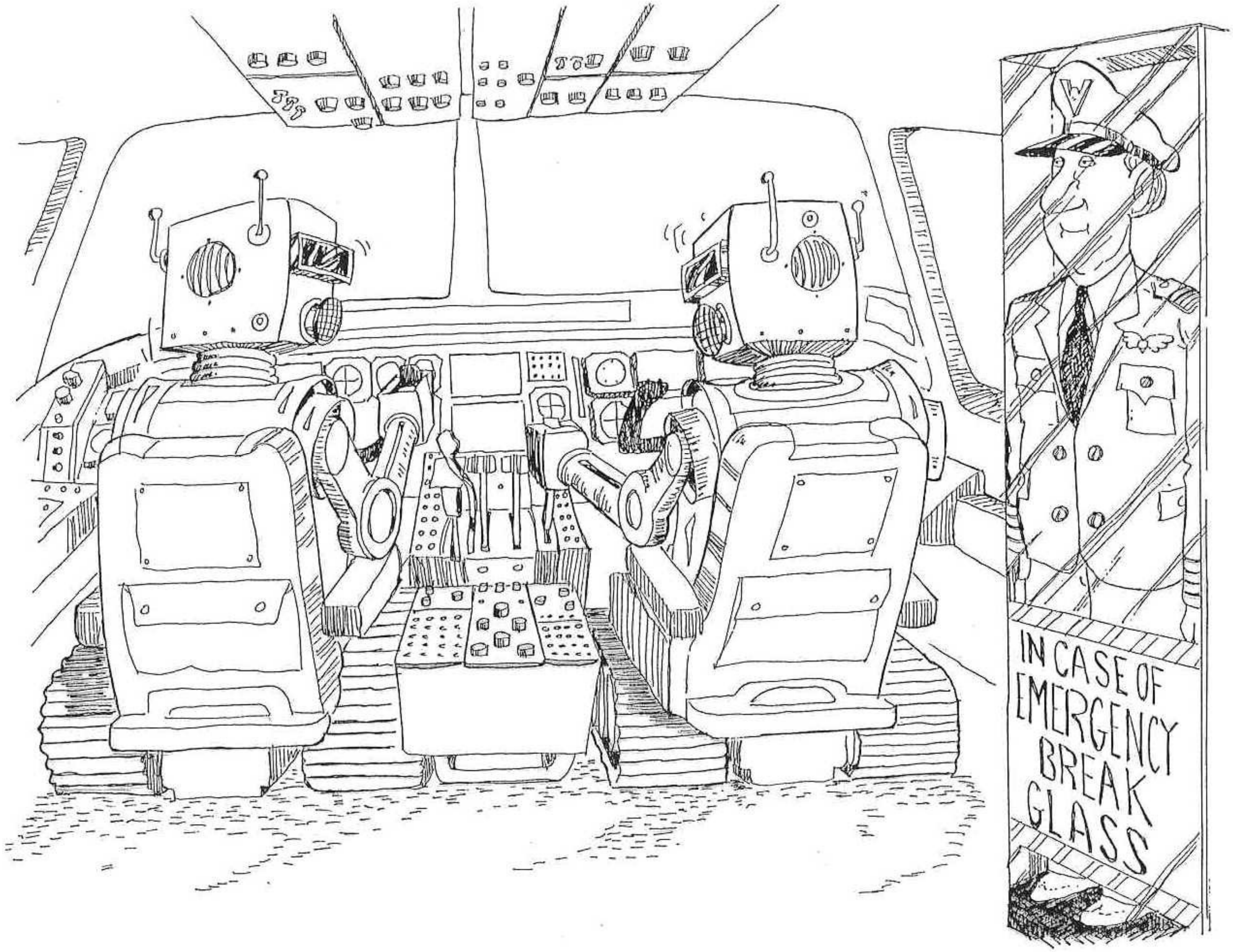
JULY 5, 2016

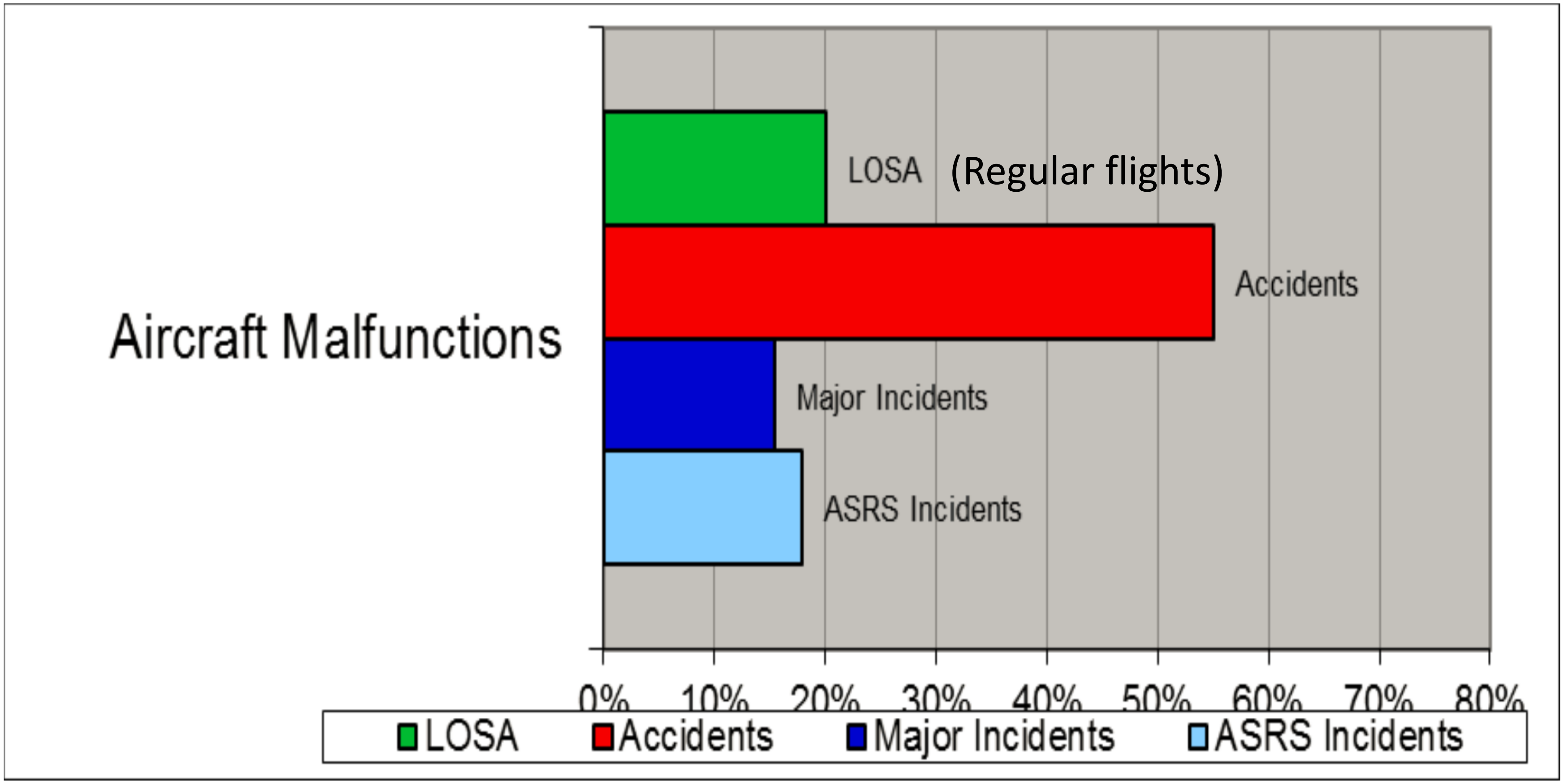
Cognitive Engineering Circa 1951



Fitts PM (ed) (1951) Human engineering for an effective air navigation and traffic control system. Published by: National Research Council, Washington, DC.


IN CASE OF EMERGENCY BREAK GLASS

Example: 20% of regular commercial flights have a (usually small) malfunction requiring pilot intervention

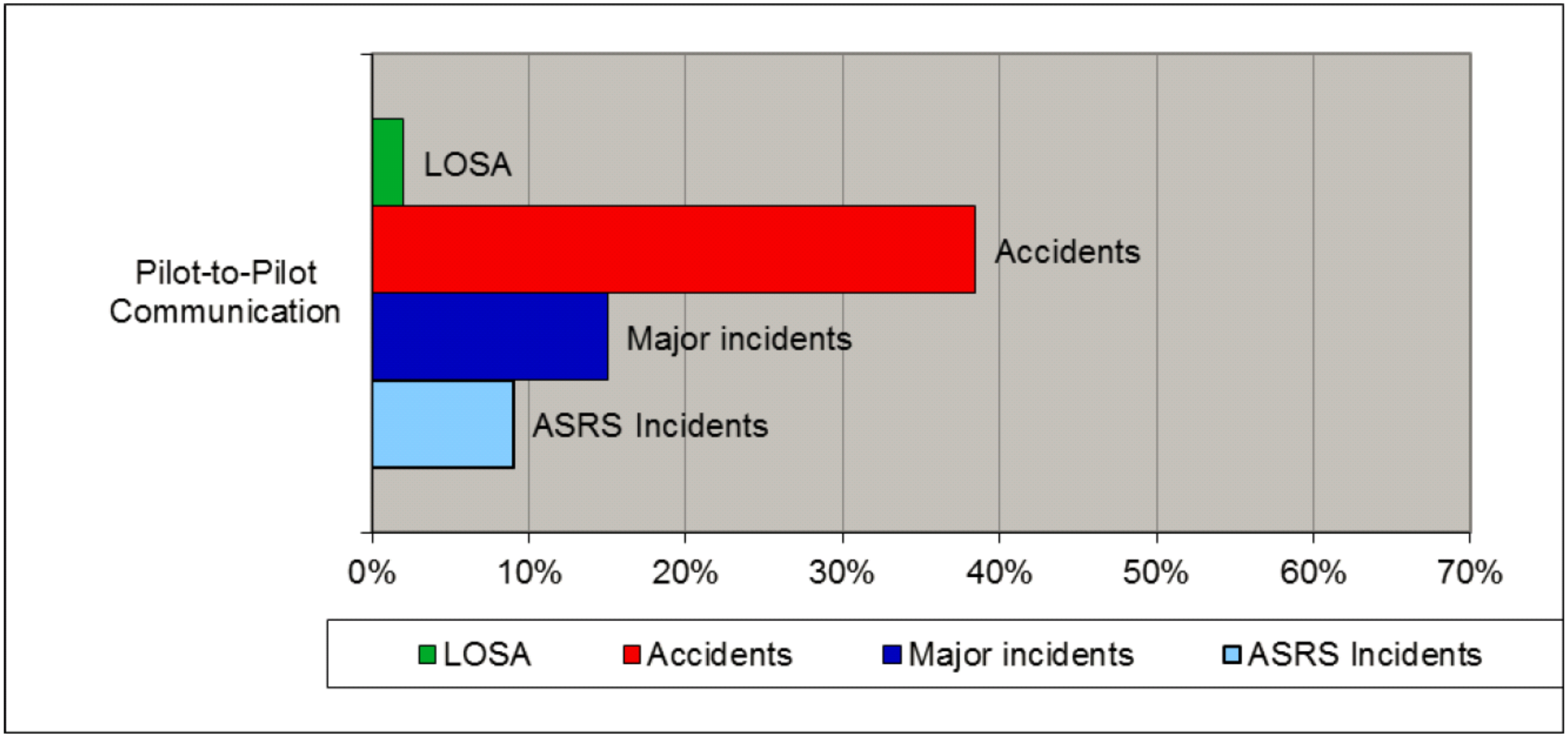


Operational Use of Flight Path Management Systems: Final Report of the Performance-based operations Aviation Rulemaking Committee / Commercial Aviation Safety Team Flight Deck Automation Working Group, September 5, 2013

So What Is the Human Not Good At?

- Passive monitoring
- Understanding when to intervene
  - Particularly the machine performs the task differently
  - Particularly when the machine is correct 99.9% of the time
- Working with non-communicative team mates
- "Feeding the monster"
  - Programming and providing all input data for a machine algorithm to make a decision for them

Accidents Tend to Involve Breakdowns in Communication and Coordination



Operational Use of Flight Path Management Systems: Final Report of the Performance-based operations Aviation Rulemaking Committee / Commercial Aviation Safety Team Flight Deck Automation Working Group, September 5, 2013

Cognitive Engineering Circa 1968

Controlled Element	Pilot	Combined OL near Crossover Frequency
K_c	$\frac{K_p e^{-s\tau_e}}{(T_I s+1)}$	$\cong \frac{K e^{-js\tau_e}}{s}$
$\frac{K_c}{s}$	$K_p e^{-s\tau_e}$	$\cong \frac{K e^{-js\tau_e}}{s}$
$\frac{K_c}{s^2}$	$K_p (T_L s+1) e^{-s\tau_e}$	$\cong \frac{K e^{-js\tau_e}}{s}$
$\frac{K_c}{s(Ts+1)}$	$K_p (T_L s+1) e^{-s\tau_e}$	$\cong \frac{K e^{-js\tau_e}}{s}$

How to describe human control behavior…

My own personal belief, particularly in aviation:

The human is a model-referenced adaptive controller with input shaping, acting upon high-quality estimation of state

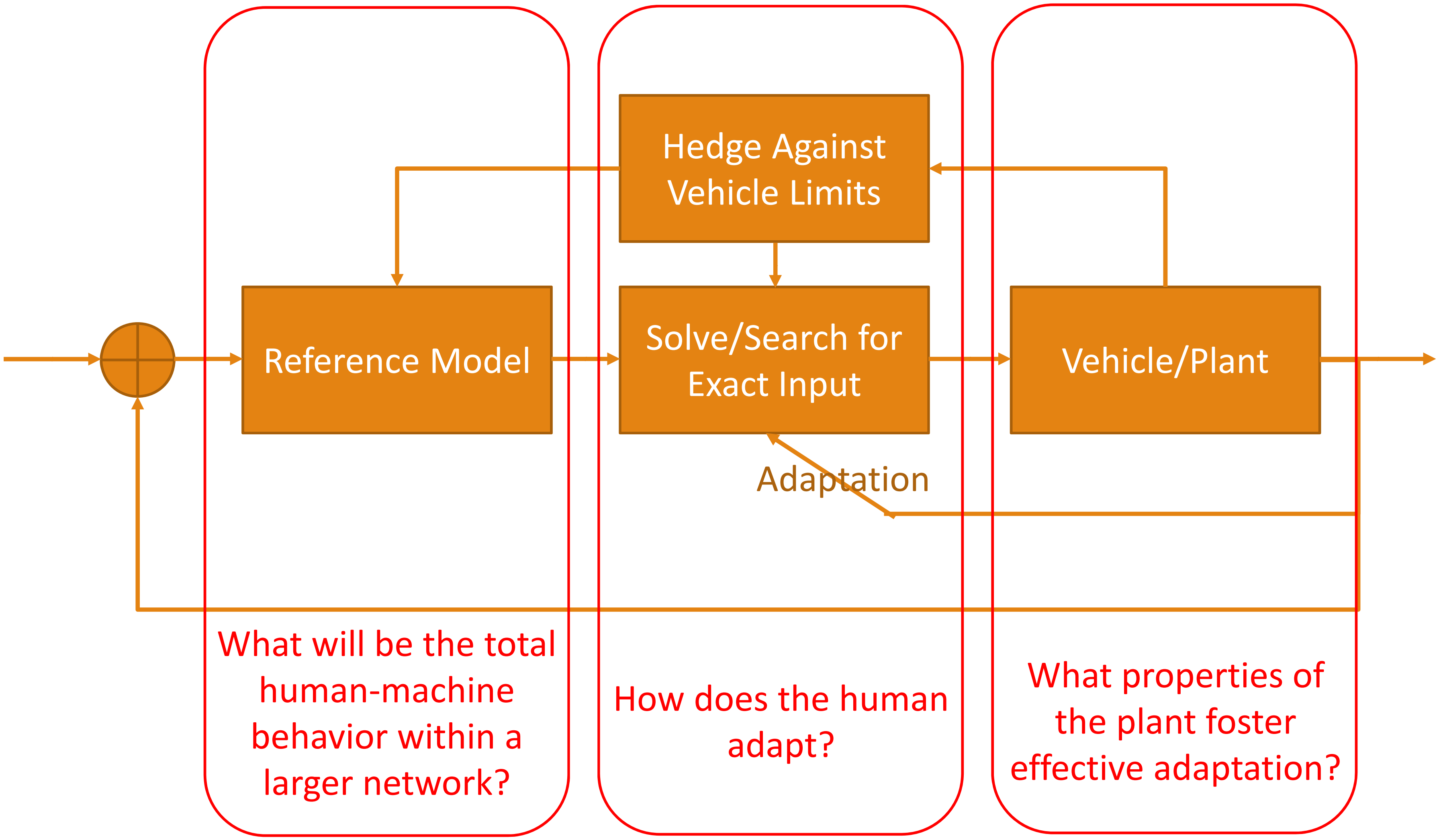
Put another way, (1) the human will adapt to the dynamics of the controlled element to achieve the desired closed-loop behavior (reference model)

(2) Further, the human will adjust the reference model in response to context

- Desired performance (e.g. higher gain, faster response during landing)
- Competing concerns (e.g. smooth passenger ride versus tracking performance)

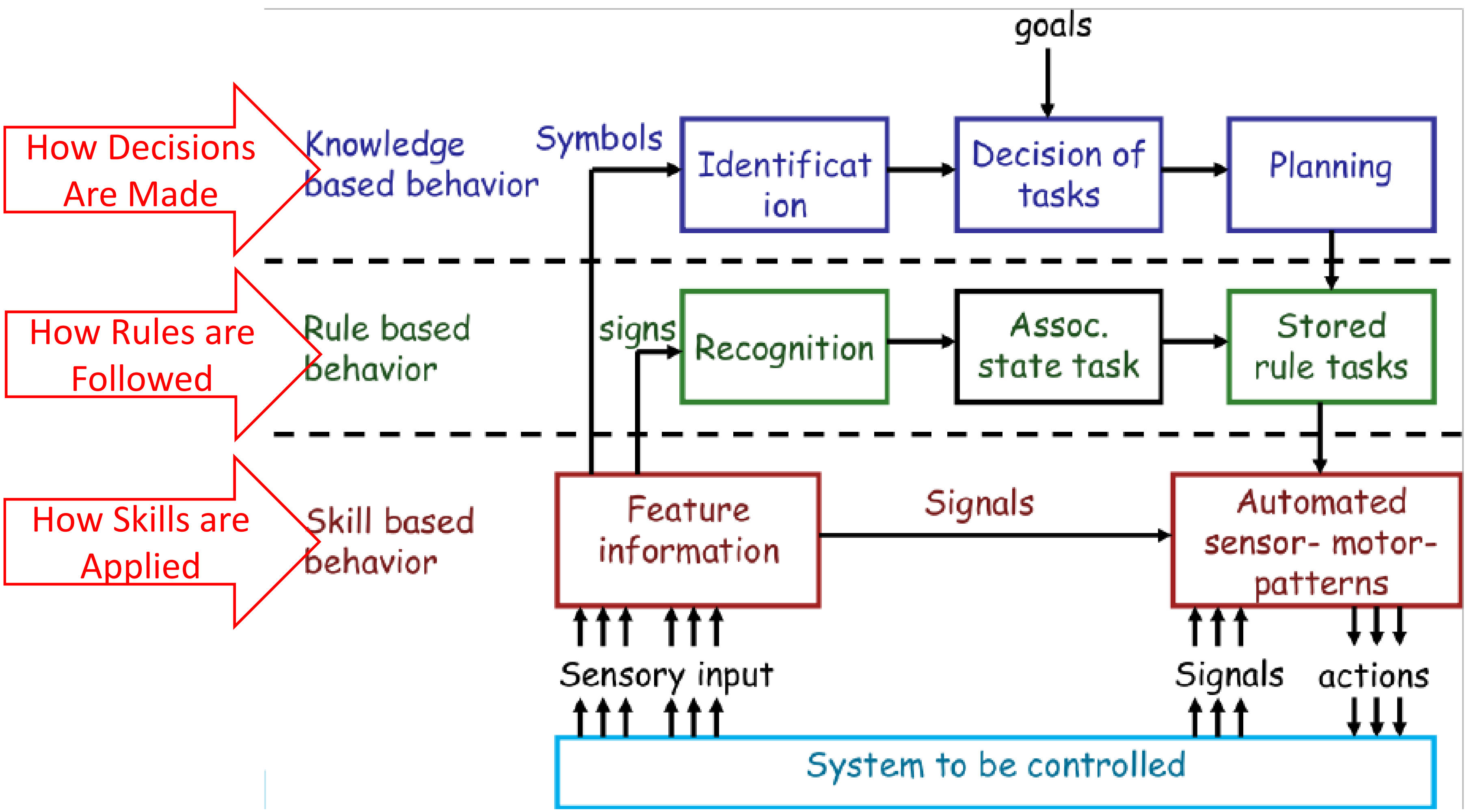
(3) The human is sensitive to time delay – and adds time delay when observation and estimation are difficult

… indeed, what specific question are you asking?



Johnson & Pritchett, Generic Pilot and Flight Control Model for Use in Simulation Studies, 2002

… and, skill-based control is not the only adaptive behavior

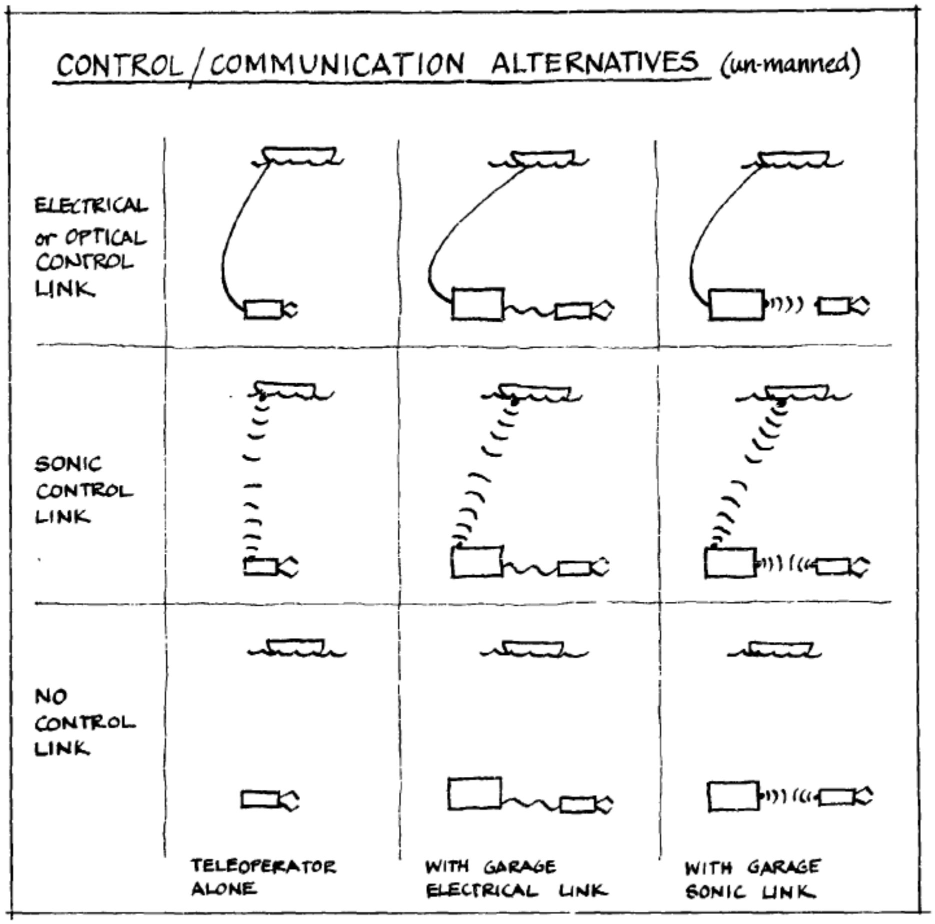


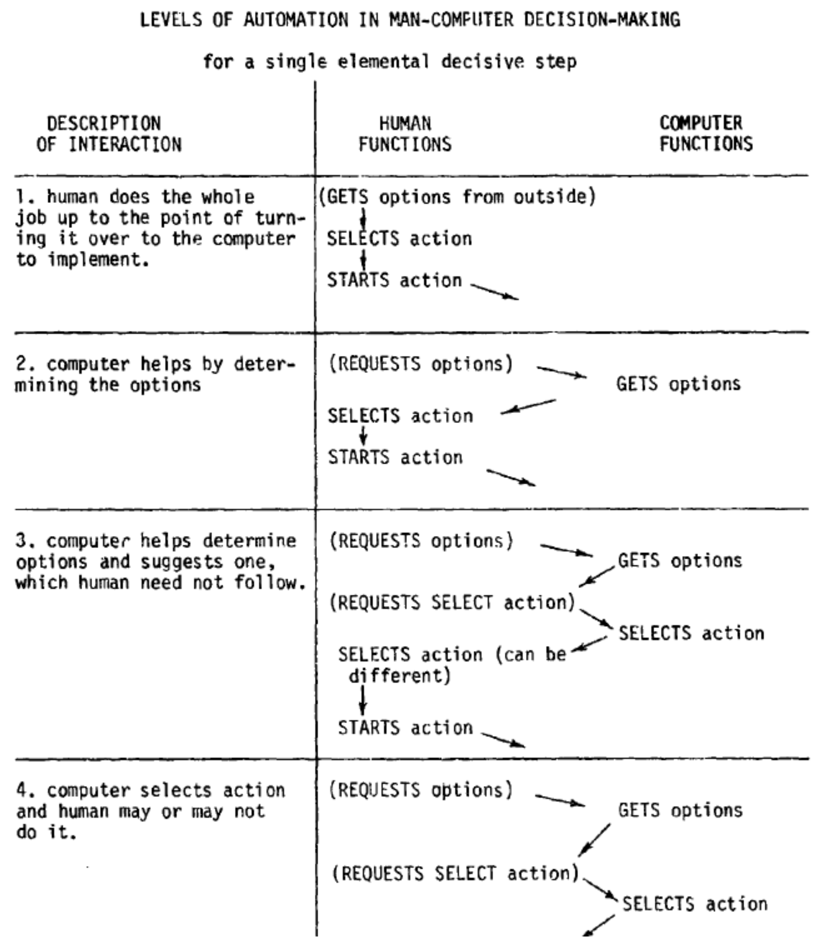
Rasmussen, IEEE SMC, 1983

What Work Will You Do?
Will You Always Do It The Same Way?

	Actions of the Flight Crew	Cognitive Control Mode		
		Opportunistic	Tactical	Strategic
Configuration	Confirm Configuration Change		Periodically	Anticipated
Position	Monitor Altitude	As Required	Periodically	Anticipated
	Monitor Vertical Deviation		Periodically	Anticipated
	Monitor Distance to Waypoint		Periodically	Anticipated
	Verify TOD Location			Anticipated
	Verify Crossing Restriction			Anticipated
	Monitor Green Arc		Periodically	Anticipated
	Confirm Target Altitude		Periodically	Anticipated
	Confirm Target Airspeed		Periodically	Anticipated
Direction	Monitor Heading Trends		Periodically	Anticipated
	Monitor Waypoint Progress		Periodically	Anticipated
	Confirm Active Waypoint		Periodically	Anticipated
Speed	Monitor Descent Airspeed	As Required	Periodically	Anticipated
	Reduce Airspeed for Late Descent			Anticipated
Communication	Confirm Data Communication		Periodically	Anticipated
	Request Clearance			Anticipated

Cognitive Engineering Circa 1978





LEVELS OF AUTOMATION IN MAN-COMPUTER DECISION-MAKING

for a single elemental decisive step

DESCRIPTION OF INTERACTION	HUMAN FUNCTIONS	COMPUTER FUNCTIONS
1. human does the whole job up to the point of turning it over to the computer to implement.	(GETS options from outside) → SELECTS action → STARTS action →	
2. computer helps by determining the options	(REQUESTS options) → SELECTS action → STARTS action →	GETS options
3. computer helps determine options and suggests one, which human need not follow.	(REQUESTS options) → (REQUESTS SELECT action) → SELECTS action (can be different) → STARTS action →	GETS options; SELECTS action
4. computer selects action and human may or may not do it.	(REQUESTS options) → (REQUESTS SELECT action) →	GETS options; SELECTS action

Note: There are other variations possible. For example, in each of the ten steps the original human request may either not be necessary or be ignored by the computer. Step 10 can have several variations where it tells the human necessarily, or on his request, or etc.

Looking Forward to Design – What Is The ‘Best’ Level of Automation?

1 The computer offers no assistance

2 The computer offers a complete set of decision/action alternatives, or

3 …narrows the selection down to a few, or

4

5

6

> None of these really specify what the human is to do!
> Many machines don’t fit into these levels anyways
> Many machines do multiple things

7 The computer executes automatically, then necessarily informs humans, or

8 … informs the human only if asked, or

9 … informs the human only if it, the computer, decides to.

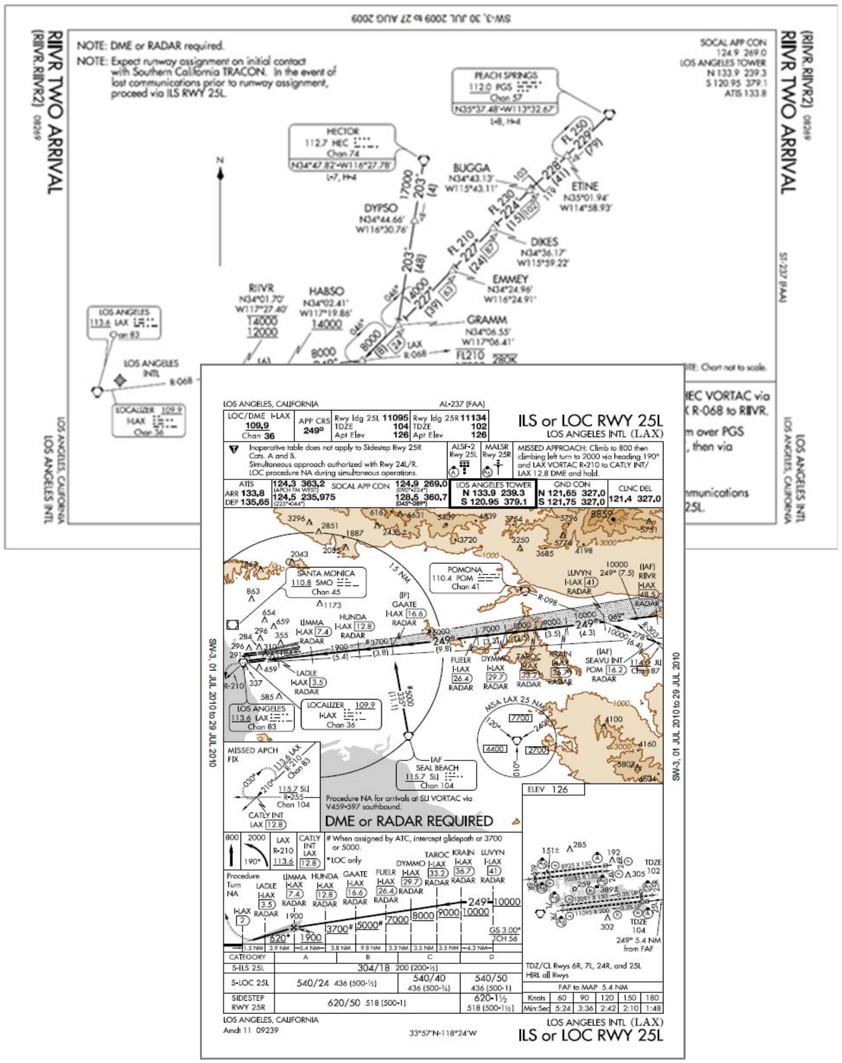
10 The computer decides everything and acts autonomously, ignoring the human

Issues with Human-Automation Team Design

1) Workload
2) Incoherency in Function Allocations
3) Mismatches Between Responsibility and Authority
4) Interruptive Automation
5) Automation Boundary Conditions
6) Function Allocation Preventing Human Adaptation to Context
7) Function Allocation Destabilizing the Humans' Work Environment
8) Mission Performance

How to model and assess these issues?

Arrival and Approach Phases of Flight



Aircraft Control

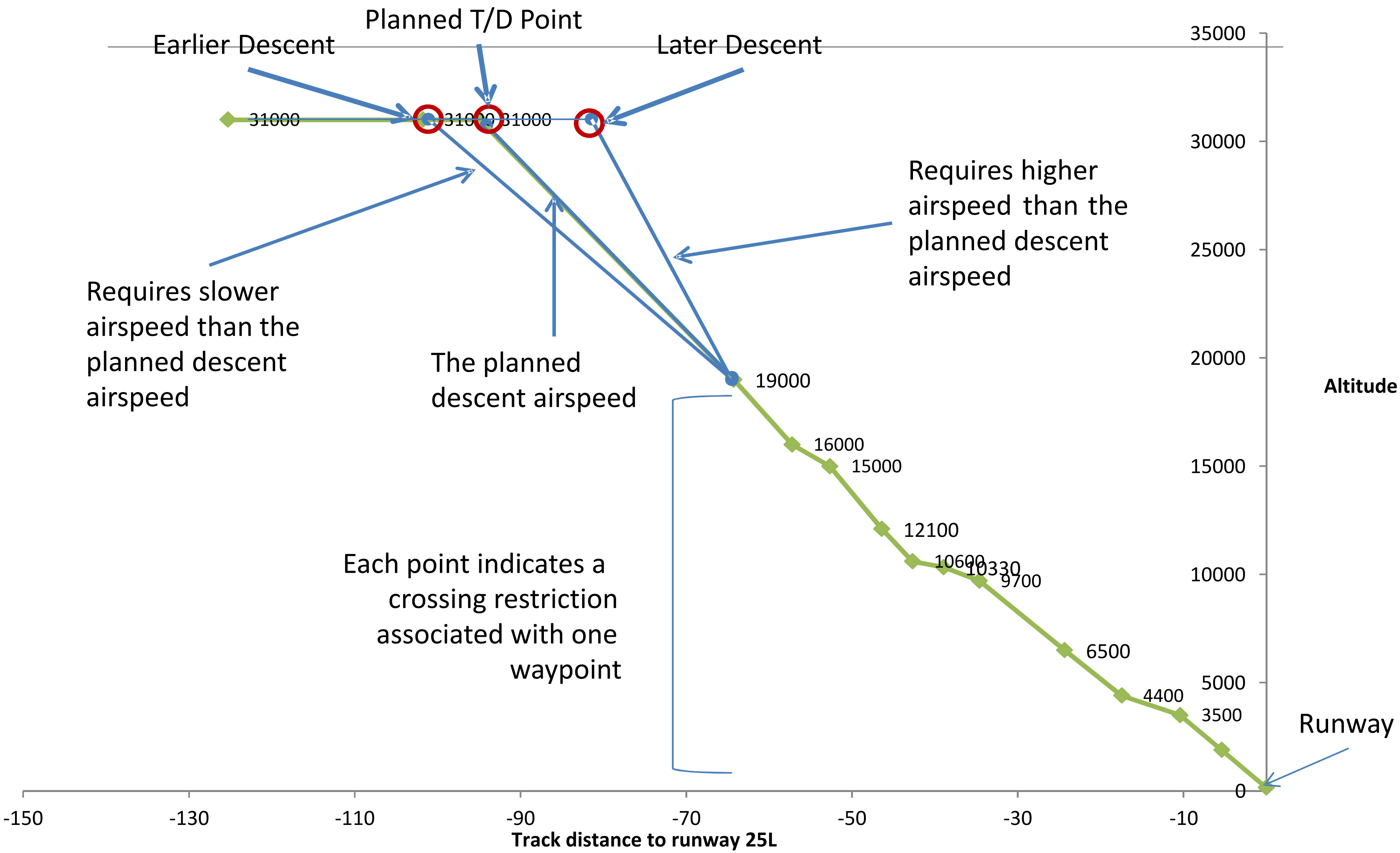
Trajectory Management

Communication Management

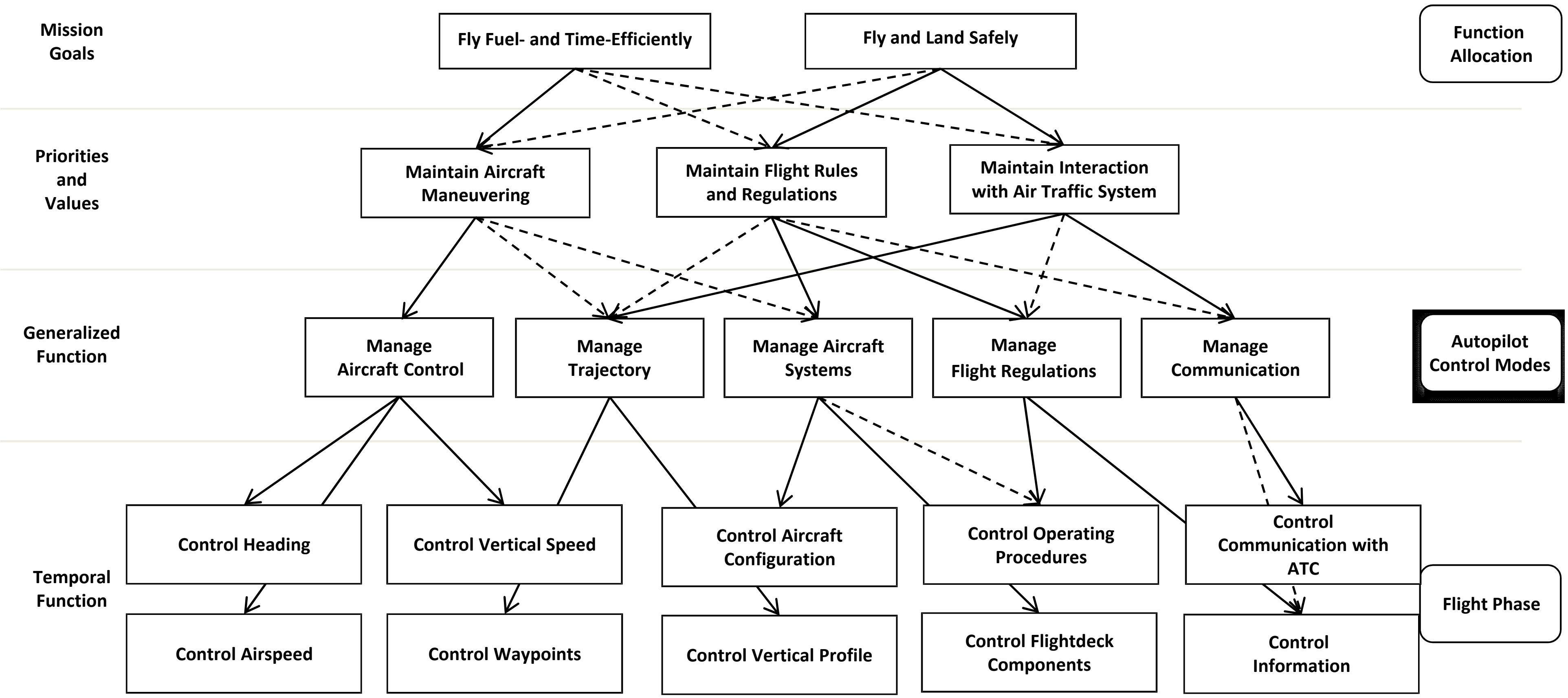
Flight Regulation Management

How to Design the Human-Automation Team?

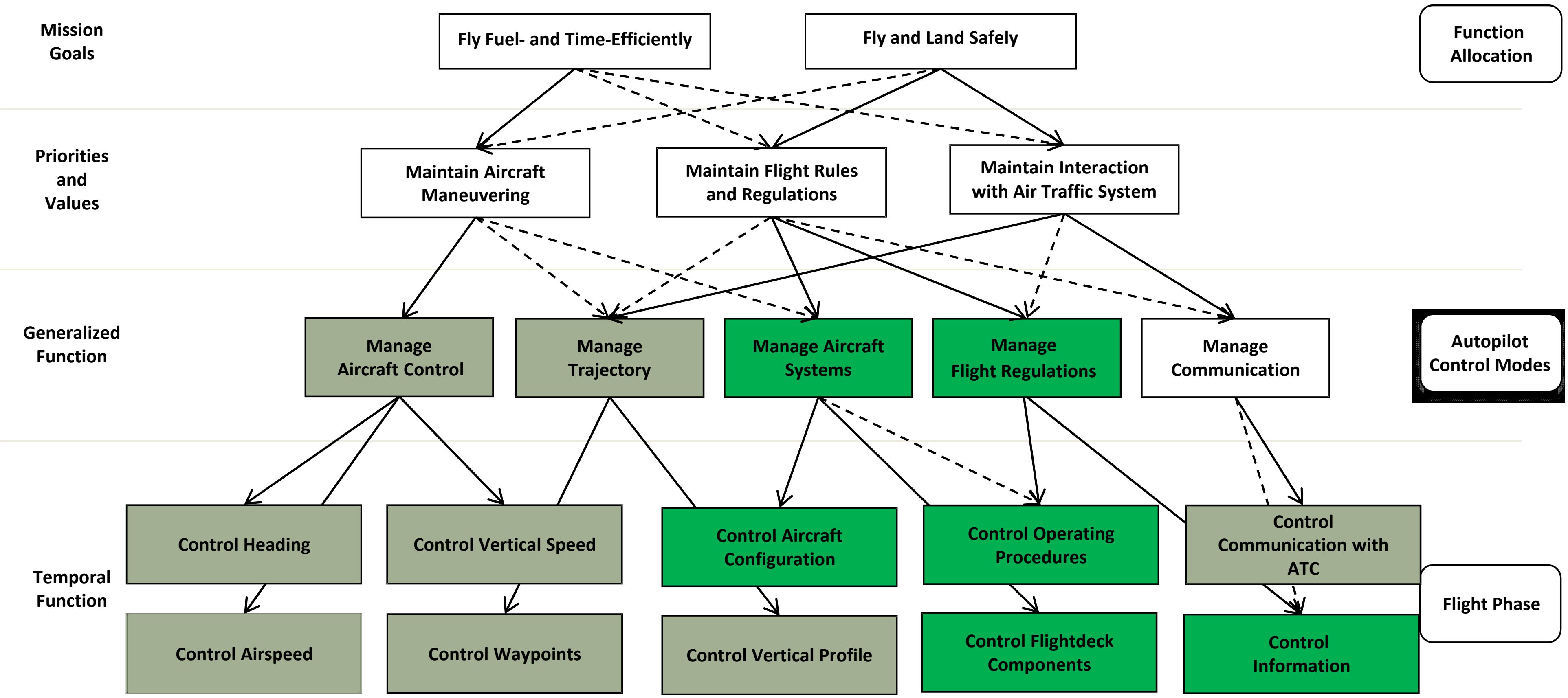
Case Study: Arrival and Approach



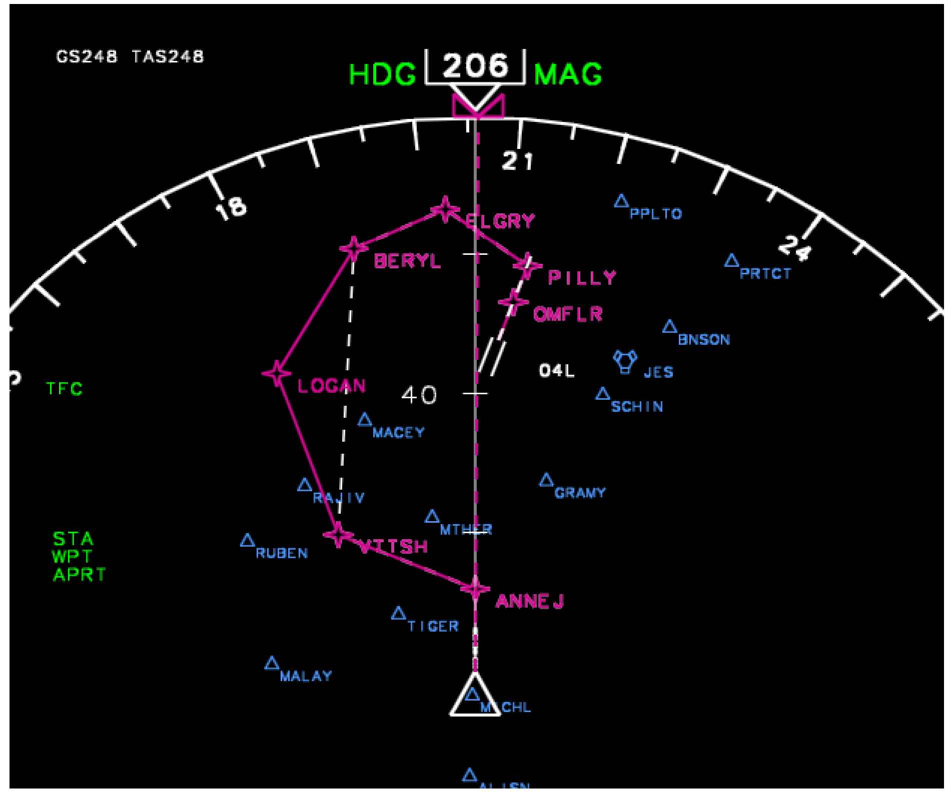
Modeling at Multiple Levels of Abstraction



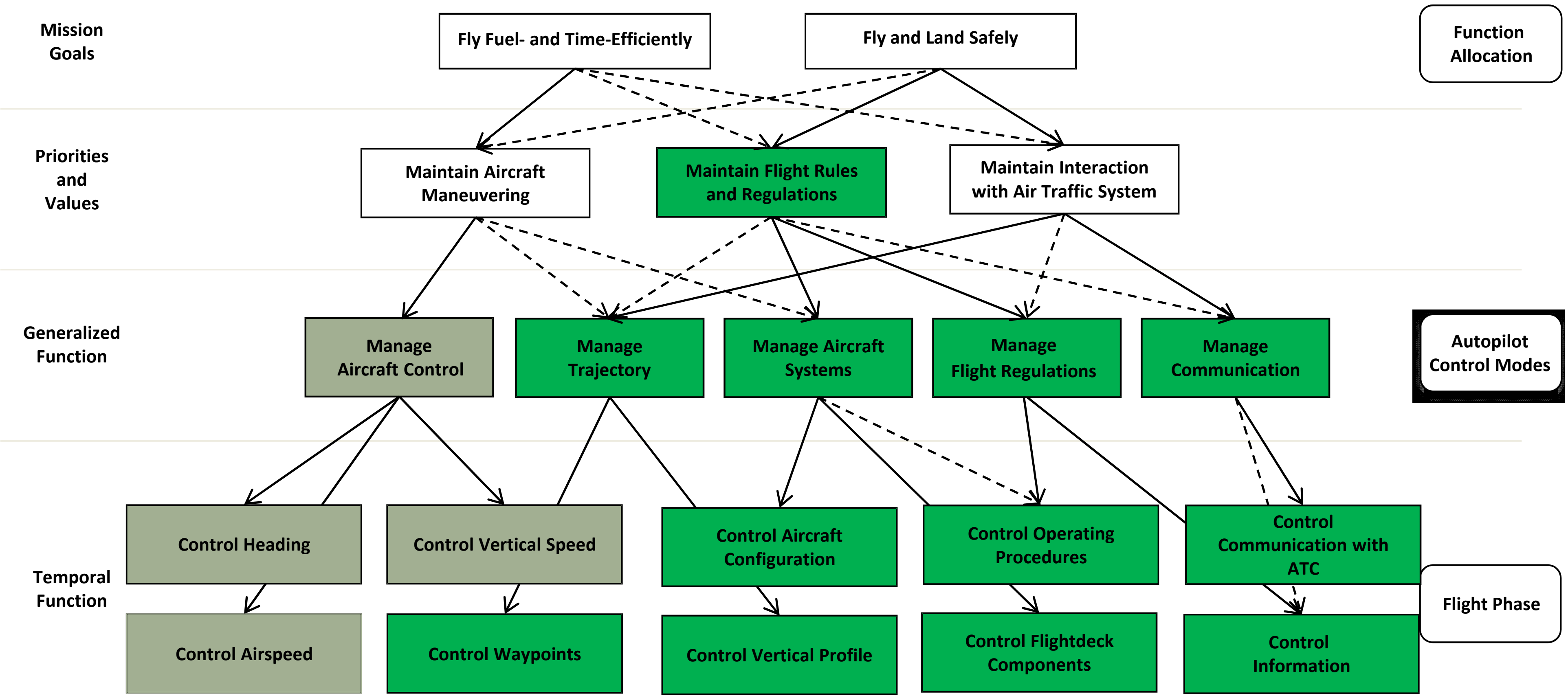
FA1, a Highly-automated Design



What the Pilot Sees…

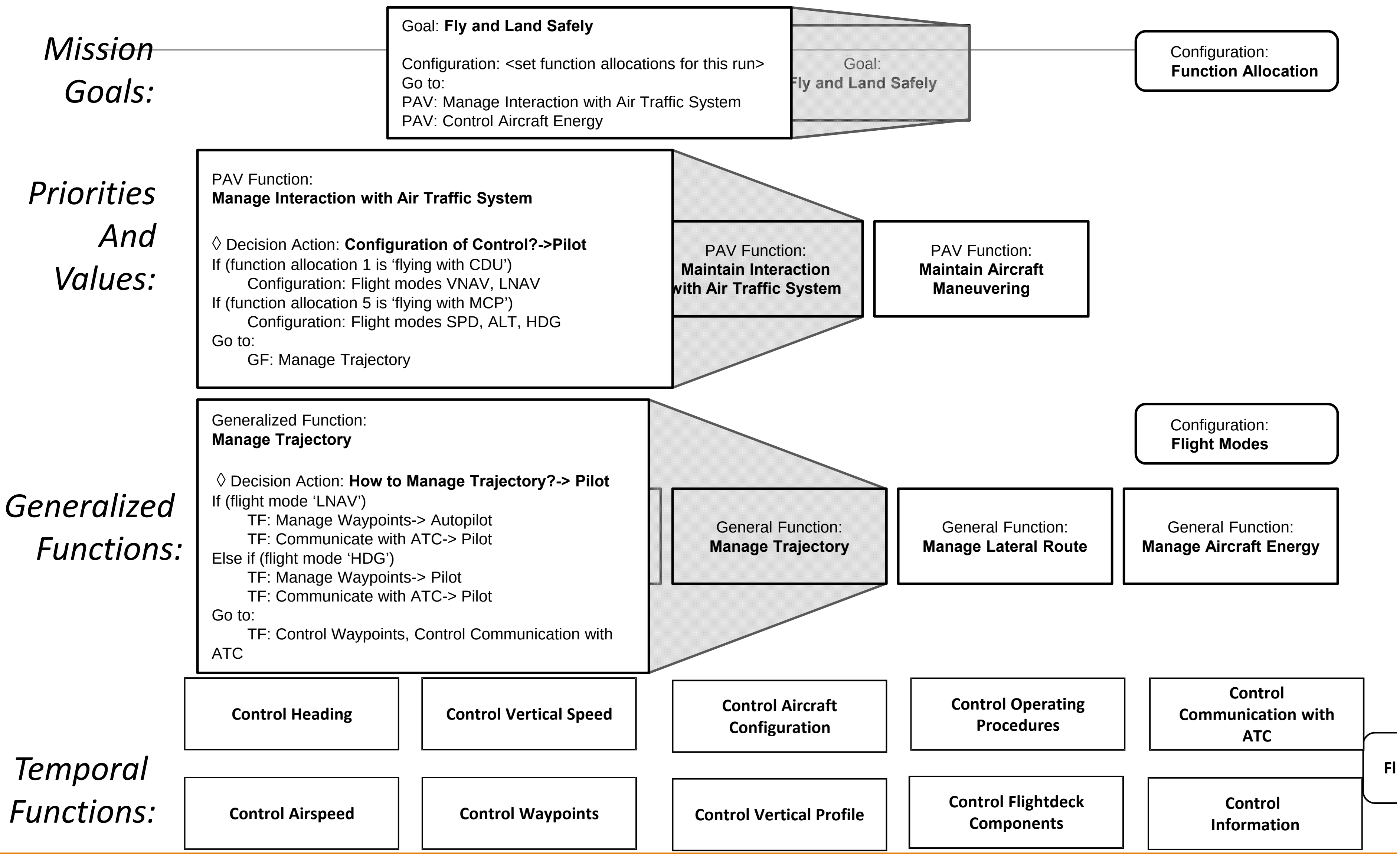


FA4, a Mostly-manual Design

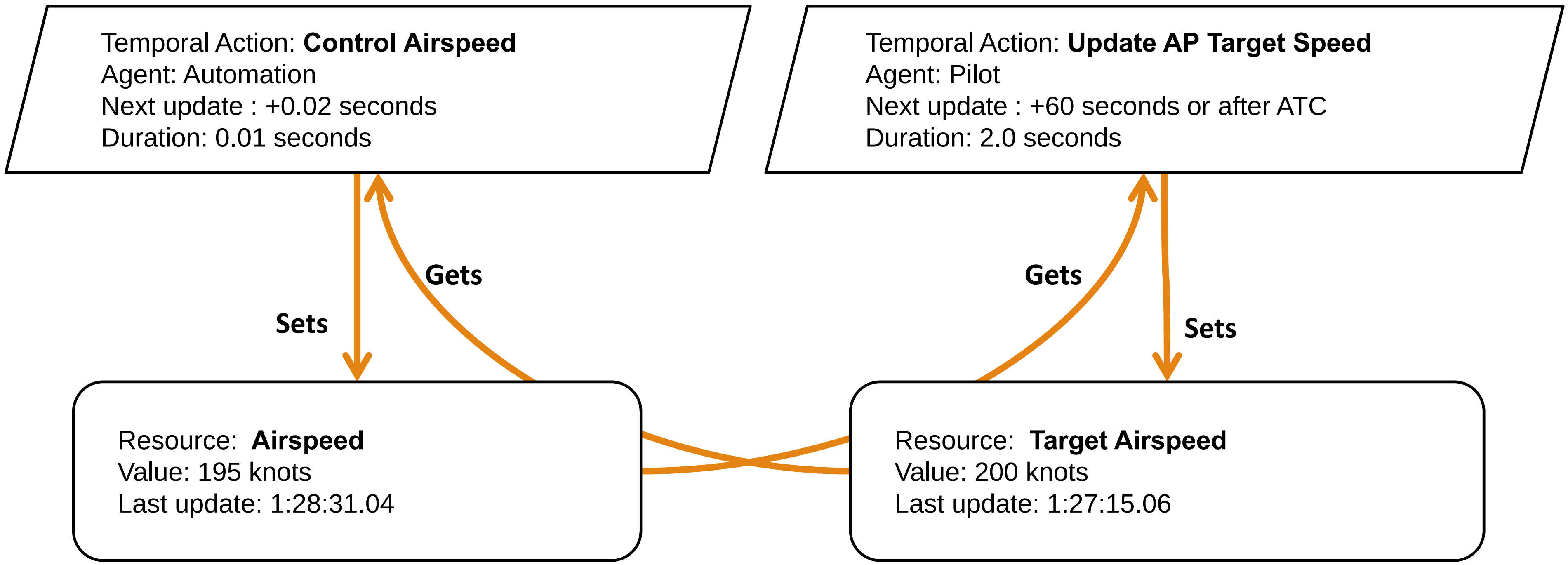


What the Pilot Sees…

Selecting Strategies in Context



Basic Building Blocks of a WMC Model



Feigh's Second Law of Cognitive Engineering: *Divvying Up the Work Creates More Work*

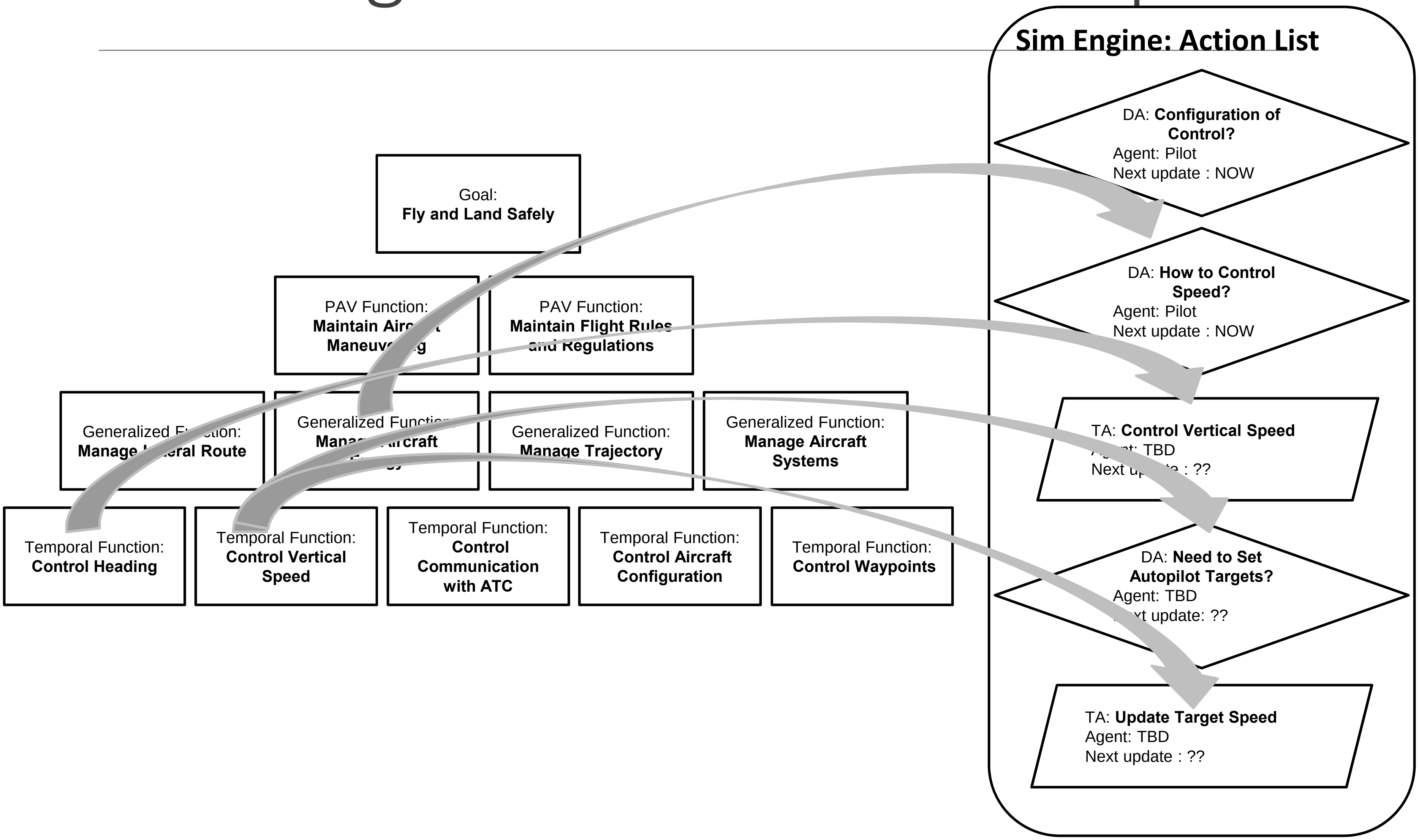
AUTOFLIGHT WITH DATALINK OF ATC CLEARANCES (FA1)

Temporal Function	Pilot	Automation
Control Vertical Profile	Modify CDU Pages Reduce Airspeed for Late Descent Confirm Target Altitude Confirm Target Speed	Manage Waypoint Progress
Control Waypoints	Modify CDU Pages Monitor Waypoint Progress Confirm Active Waypoint Monitor Dist Active Waypoint	Calculate Dist Current Waypoint Evaluate Flight Phase Manage Waypoint Progress Direct To Waypoint
Control Communication With ATC	Respond Handoff Confirm Data Communication	Receive Altitude Clearance Receive ILS Clearance Receive Waypoint Clearance
Control Heading	Monitor Heading Trends	Update Lateral Control
Control Vertical Speed	Monitor Altitude Monitor Vertical Deviation	Adjust Speed Control Update Pitch Control Evaluate Vertical Mode Evaluate VNAV Mode Transition Evaluate Alt Restriction Mode Altitude Reminder
Control Airspeed	Monitor Descent Airspeed	Update Thrust Control Calculate Speed Deviation
Control Aircraft Configuration	Deploy Flap Deploy Gear Deploy Speed Brake Retract Speed Brake Confirm Configuration Change	
Control Aircraft Information	Verify TOD Location Verify Crossing Restriction	
Control Operating Procedures	Perform Approach Briefing Perform Approach Checklist Perform Landing Checklist	
Control Flight Deck Components	Turn off Altitude Alert Respond to Drag Required	

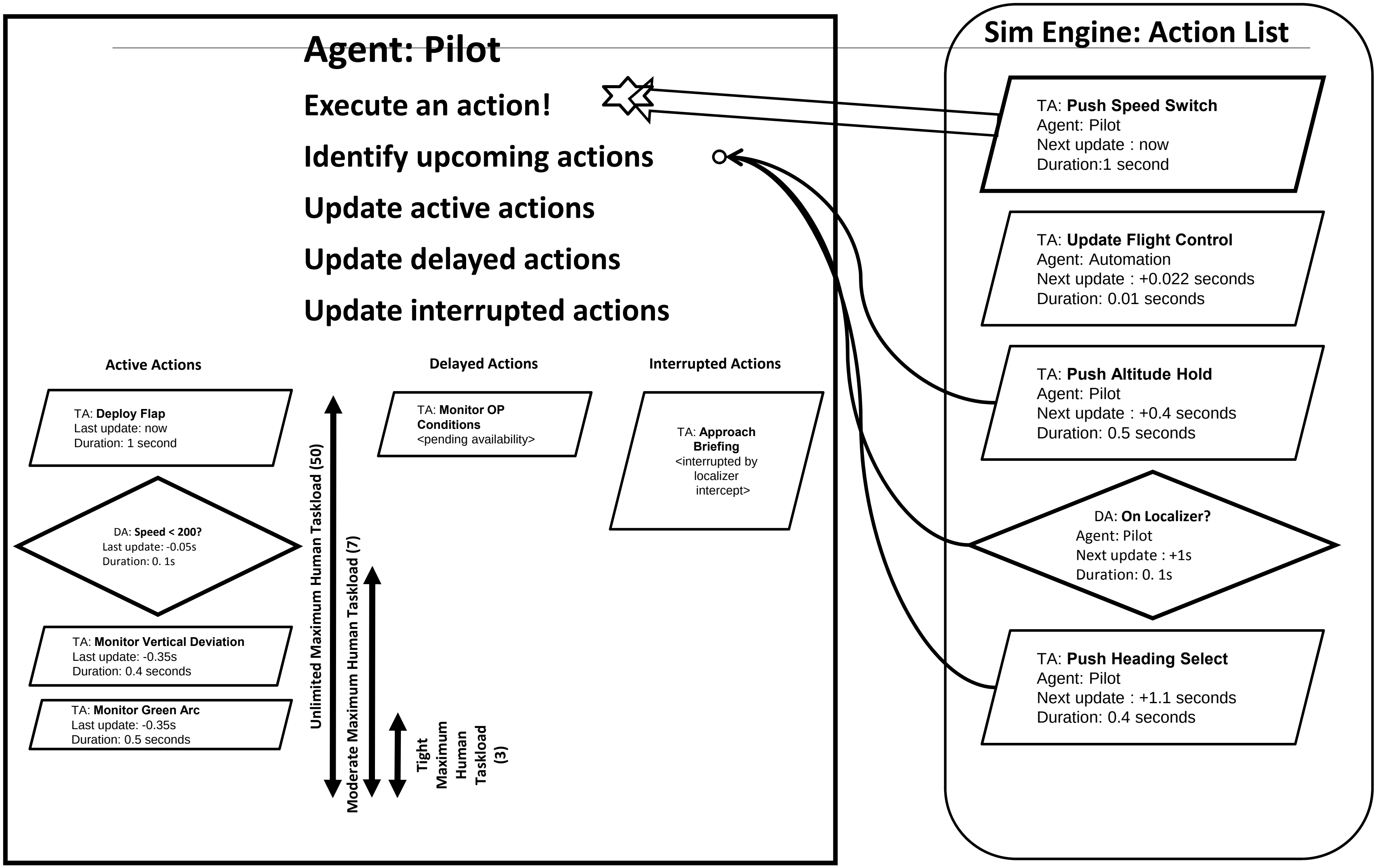
PILOT SETS MCP TARGETS (FA4)

Temporal Function	Pilot	Automation
Control Vertical Profile	Monitor Altitude Reduce Airspeed for Late Descent	
Control Waypoints	Manage Waypoint Progress Direct To Waypoint	Calculate Dist Current Waypoint Evaluate Flight Phase
Control Communication With ATC	Receive Altitude Clearance Receive ILS Clearance Receive Waypoint Clearance Respond Handoff Request Clearance	
Control Heading	Dial Heading Selector Push Heading Selector Monitor Heading Trends	Update Lateral Control
Control Vertical Speed	Dial Altitude Selector Dial VS Selector Push Alt Hold Switch Push FLCH Switch Push Vertical NAV Switch Push Vertical Speed Switch Monitor Green Arc	Update Pitch Control Evaluate Vertical Mode Evaluate Alt Restriction Mode Altitude Reminder
Control Airspeed	Dial Speed Selector Push Speed Switch Monitor Descent Airspeed	Update Thrust Control Calculate Speed Deviation
Control Aircraft Configuration	Deploy Flap Deploy Gear Deploy Speed Brake Retract Speed Brake Confirm Configuration Change	
Control Aircraft Information	Verify TOD Location Verify Crossing Restriction	
Control Operating Procedures	Perform Approach Briefing Perform Approach Checklist Perform Landing Checklist	
Control Flight deck Components	Turn off Altitude Alert Respond to Drag Required	

Simulating the Work Model: Step 1



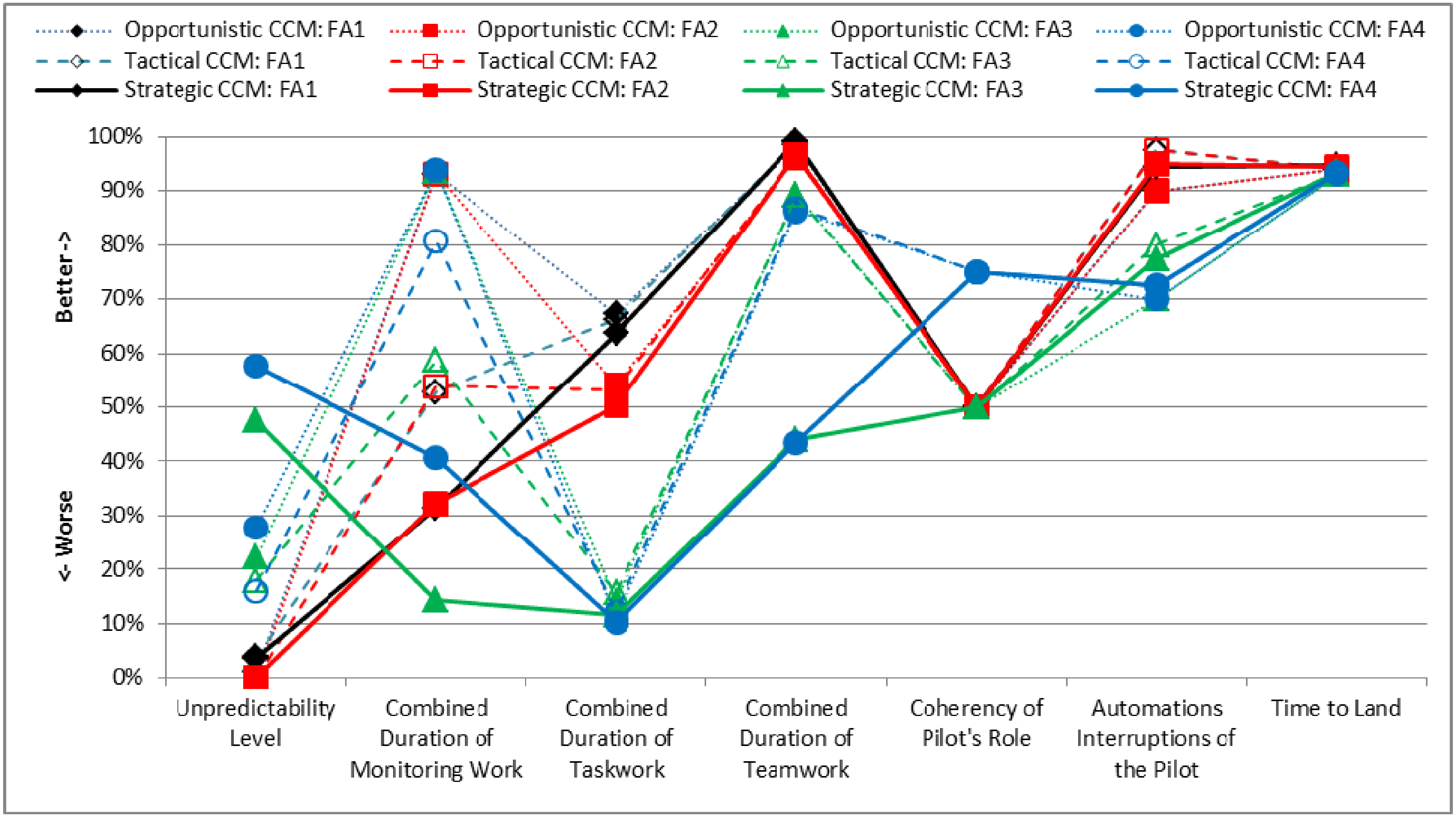
Simulating the Work: Step 2



What Measures to Make?

1) Workload / Taskload / Required Activities
2) Incoherency in Function Allocations
3) Mismatches Between Responsibility and Authority: Monitoring, Work-Arounds
4) (Unduly) Interruptive Automation
5) Automation Boundary Conditions
6) You Can't Adapt to Context: Rigid/Unrealistic Specifications on Activity
7) Your Work Environment Isn't Predictable or Stabilizable
8) Mission Performance

Which Automated System Would You Prefer?



Cognitive Engineering Concerns circa 2016

U.S. Department
of Transportation
**Federal Aviation
Administration**

SAFO
Safety Alert for Operators

SAFO 13002
DATE: 1/4/13

Flight Standards Service
Washington, DC

http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo

A SAFO contains important safety information and may include recommended action. SAFO content should be especially valuable to air carriers in meeting their statutory duty to provide service with the highest possible degree of safety in the public interest. Besides the specific action recommended in a SAFO, an alternative action may be as effective in addressing the safety issue named in the SAFO.

Subject: Manual Flight Operations

Purpose: This SAFO encourages operators to promote manual flight operations when appropriate.

Background: A recent analysis of flight operations data (including normal flight operations, incidents, and accidents) identified an increase in manual handling errors. The Federal Aviation Administration (FAA) believes maintaining and improving the knowledge and skills for manual flight operations is necessary for safe flight operations.

Discussion: Modern aircraft are commonly operated using autoflight systems (e.g., autopilot or autothrottle/autothrust). Unfortunately, continuous
knowledge and skills in manual flight operations.
improved safety and workload management, and t
continuous use of autoflight systems could lead to
aircraft from an undesired state.

Operators are
operations into both
should be developed or review
manual flying skills, such as in non-RV
policies should be developed or reviewed to ensu
systems, such as during high workload conditions
precise operations. Augmented crew operations m
in manual flight operations. Airline operational p
opportunities to exercise the aforementioned know

Recommended Action: Directors of Operations,
Center Managers, Check Pilots, Training Pilots, a
this SAFO. They should work together to ensure t
operational policy, provided to pilots during grou
proficiency checks.

Contact: Questions or comments regarding this S
Branch, AFS-210, at (202) 267-8166.

Distributed by: AFS-200 OPR: AFS-210

Operators are encouraged to take an integrated approach by incorporating emphasis of manual flight operations into both line operations and training… Operational policies should … ensure there are appropriate opportunities for pilots to exercise manual flying skills... In addition, … ensure that pilots understand when to use the automated systems

What Makes a Useful ‘Autonomous’ Crew Member?

“More autonomous” means it can do more functions*

or

“More autonomous” means it needs it needs interaction with the human less often*

or

“More autonomous” means it can report back when it needs help,* and otherwise doesn’t need to be monitored

** Correct functioning within boundary conditions*

Trust: Which quadrant is 'best'?

Pilot Self-Confidence in Context

Belief in Machine	*High*	*Low*
High	Indeterminate	Pilot will probably follow machine
Low	Pilot will probably verify or ignore machine	Indeterminate

If pilot does not "believe" machine, s/he probably shouldn't follow it

A pilot won't "believe" machine if it *appears* to be wrong

- Now or in the past
- Given what the pilot does and does not know

Some more on trust

Be careful to distinguish *belief* from *reliance*

- *Reliance* involves a cost-benefit analysis

Be careful to distinguish belief in *aggregate performance* from *confidence in immediate situation*.

Bases in human-human trust (belief):

- Without frequent interaction: *faith*
  - Influenced by credentials, recommendations
- With frequent interaction: perceived *dependability* and *predictability*
  - Can be shaped by experience – requires understanding the machine and seeing consistent behavior…

If a human is responsible for the outcome, then her/his job is to "trust, but verify" – can they verify from where they are sitting?

Summary: Some Lessons Learned

- There are things both humans and machines are NOT good at
  - Monitoring, intervening
  - Working with poor team mates
- The human is adaptive
- There is no-one best ‘level’ of automation for all contexts
- “Trust” is not a simple construct
  - It is ethically wrong to say a human should just ‘trust’ the machine

Thank You!

Thoughts? Questions?