



Experimental Quantification of Times Needed to Comply with Air Traffic Control Advisories (FCU & MCDU Interaction)

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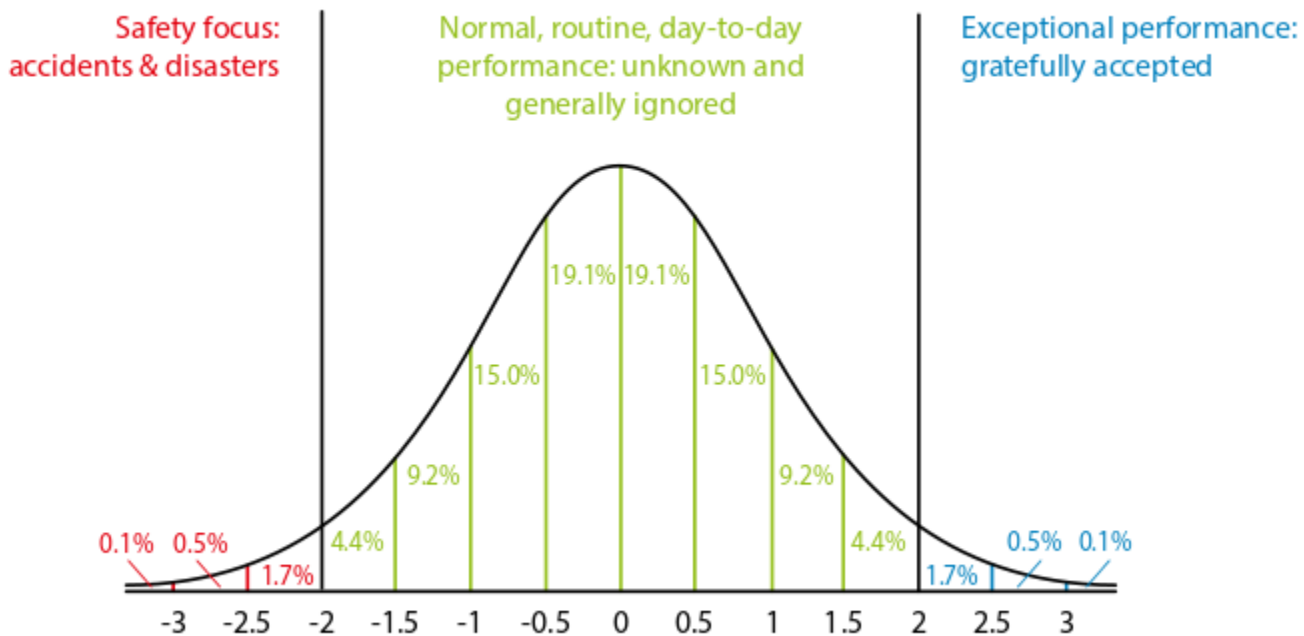


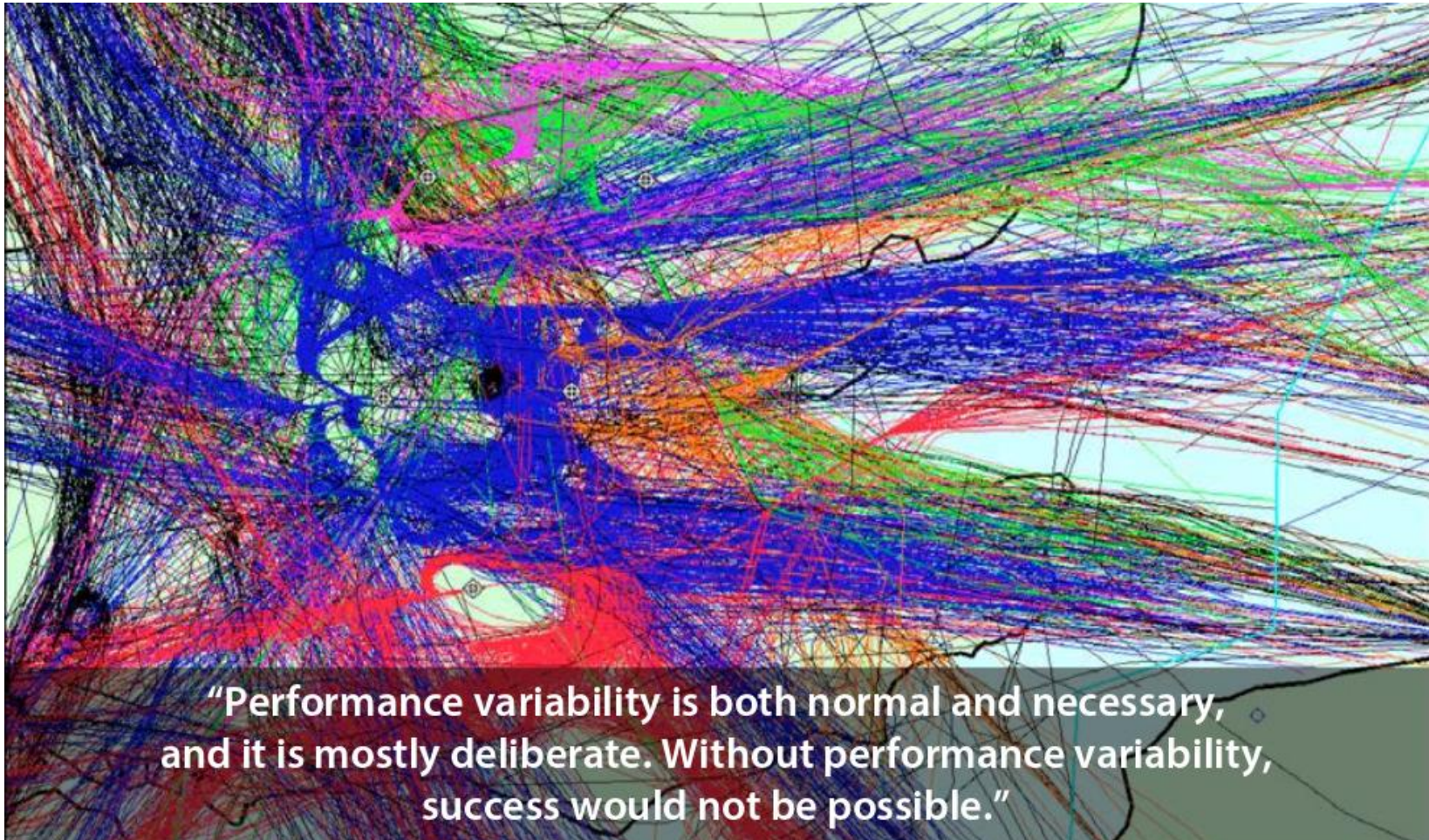
Agenda / Outline

- 1 Overview: Safety Assessment Approach
- 2 Discussion of MCDU vs. FCU Use Cases
- 3 HIL-Experiment and Results
- 4 Conclusion & Outlook

Safety Quantification for ATM Procedures

- SESAR Performance Targets (D2 of 2005) 10 x Safety – 3 x Capacity
- EUROCONTROL / E. Hollnagel (2013) Safety I - Safety II Whitepaper

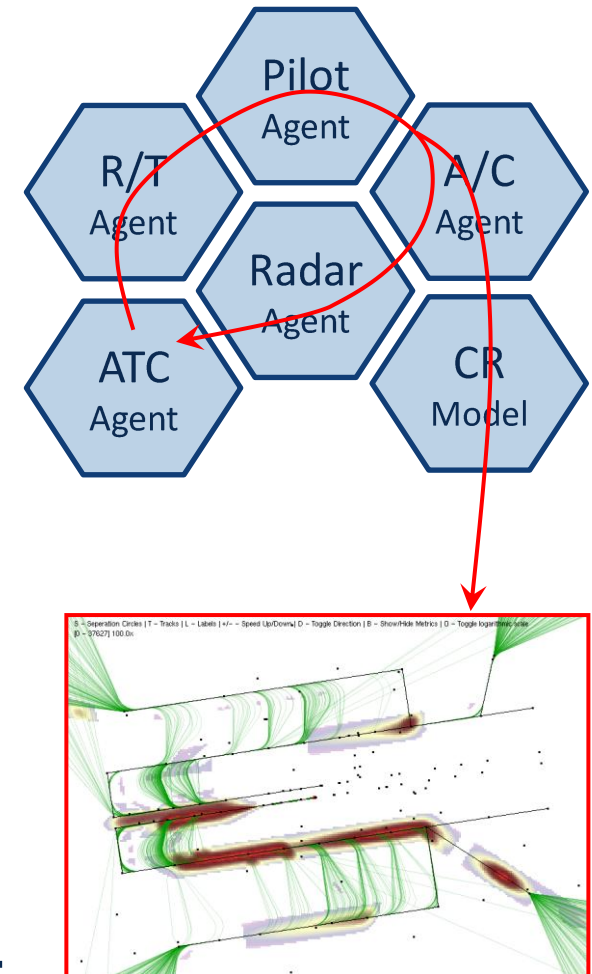




Source: EUROCONTROL (2014) „Systems Thinking for Safety: a White Paper“

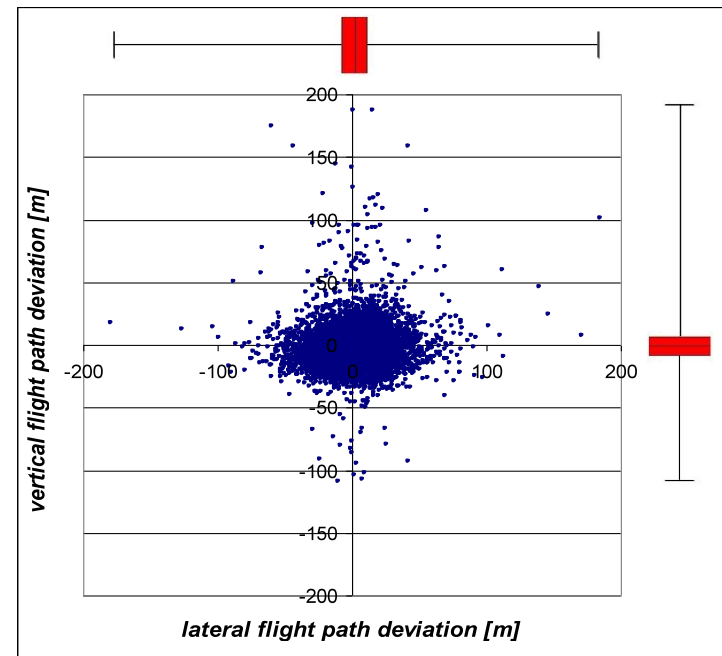
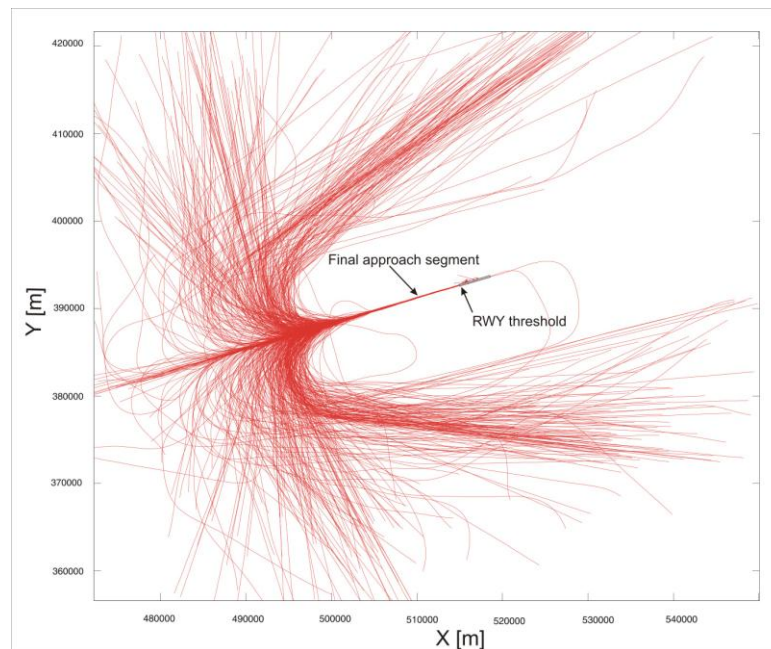
Integrated Approach

- Fast-time agent-based simulation
 - technical / environmental,
 - procedural, and
 - human factors
- Reduced parameter-set determined by
 - sensitivity (relevance)
 - consequence (risk)
- Vision
 - CAD for ATM procedures
 - model-based safety assessment
 - to be used in regulation, certification, aeronautical studies, etc.



Macroscopic View via Collision Risk Model [1]

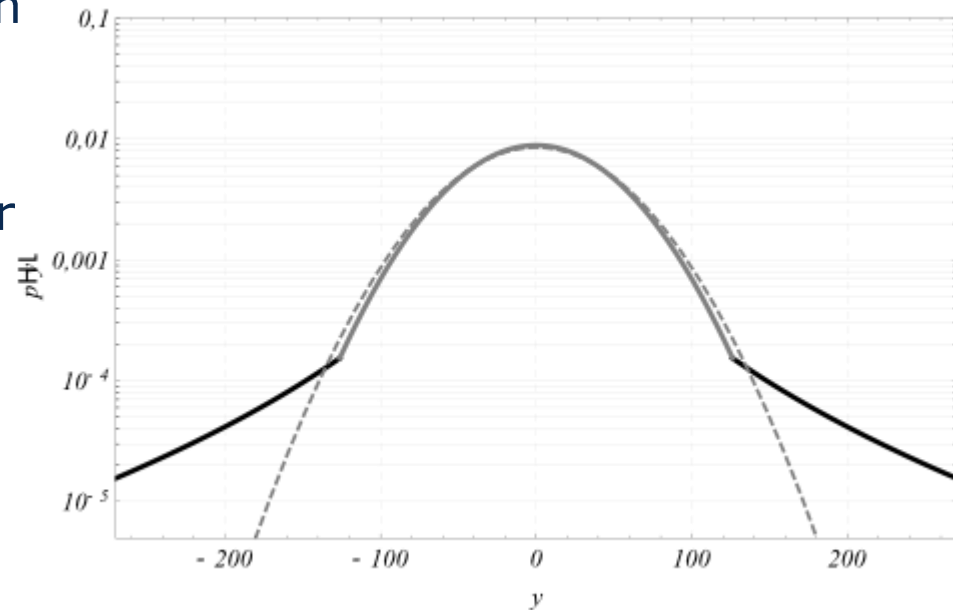
Total system error = path definition error + navigation system error + flight technical error

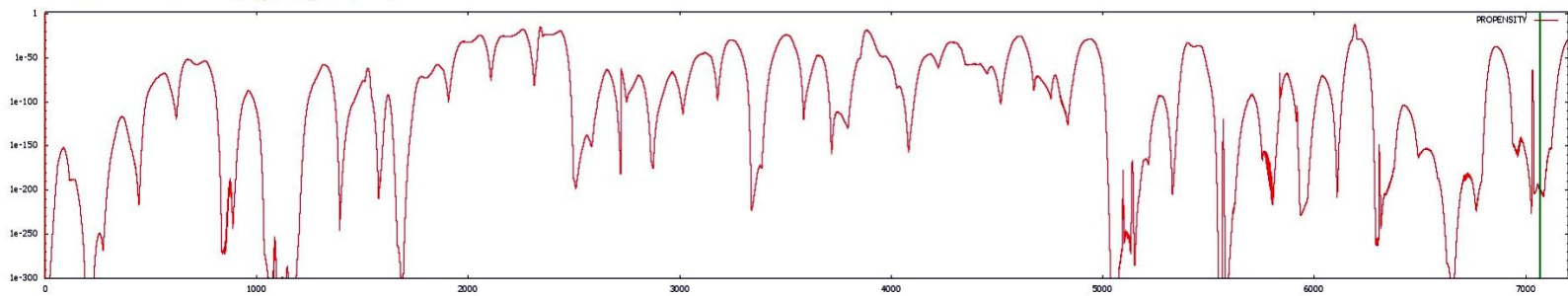
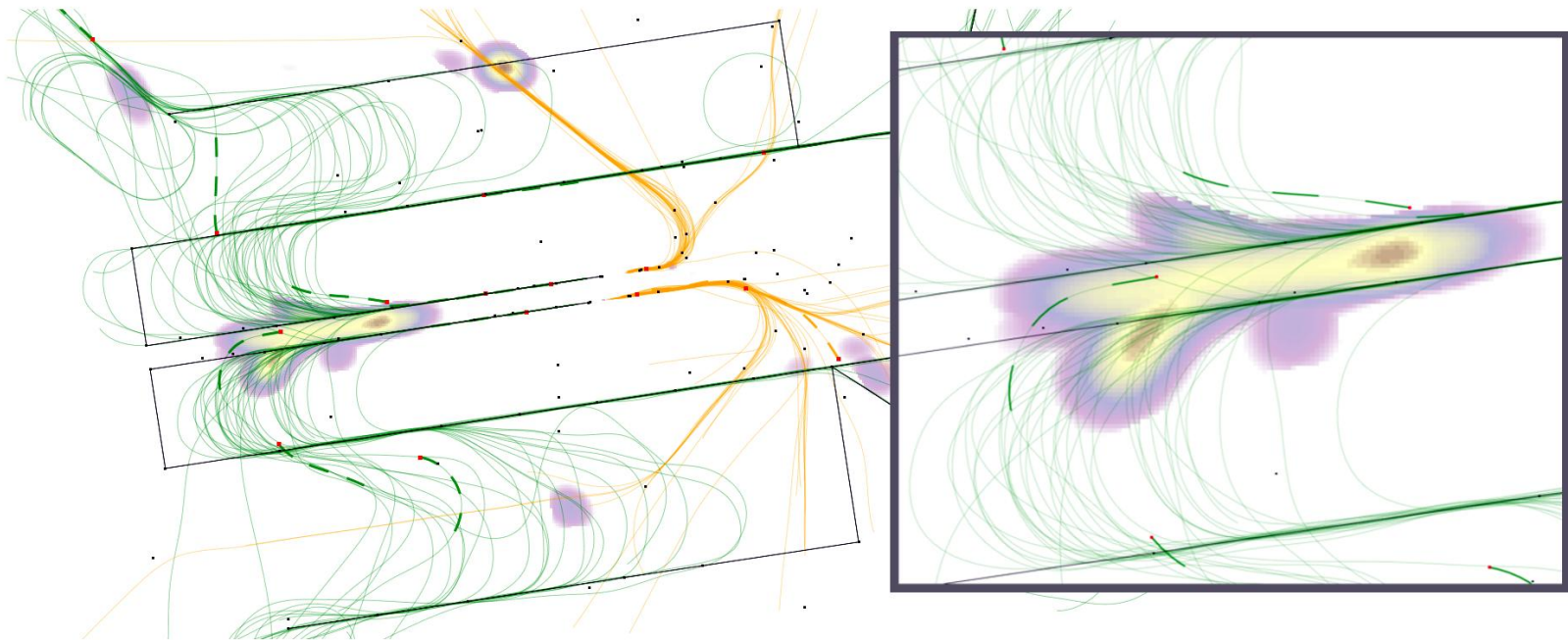


Macroscopic View via Collision Risk Model [2]

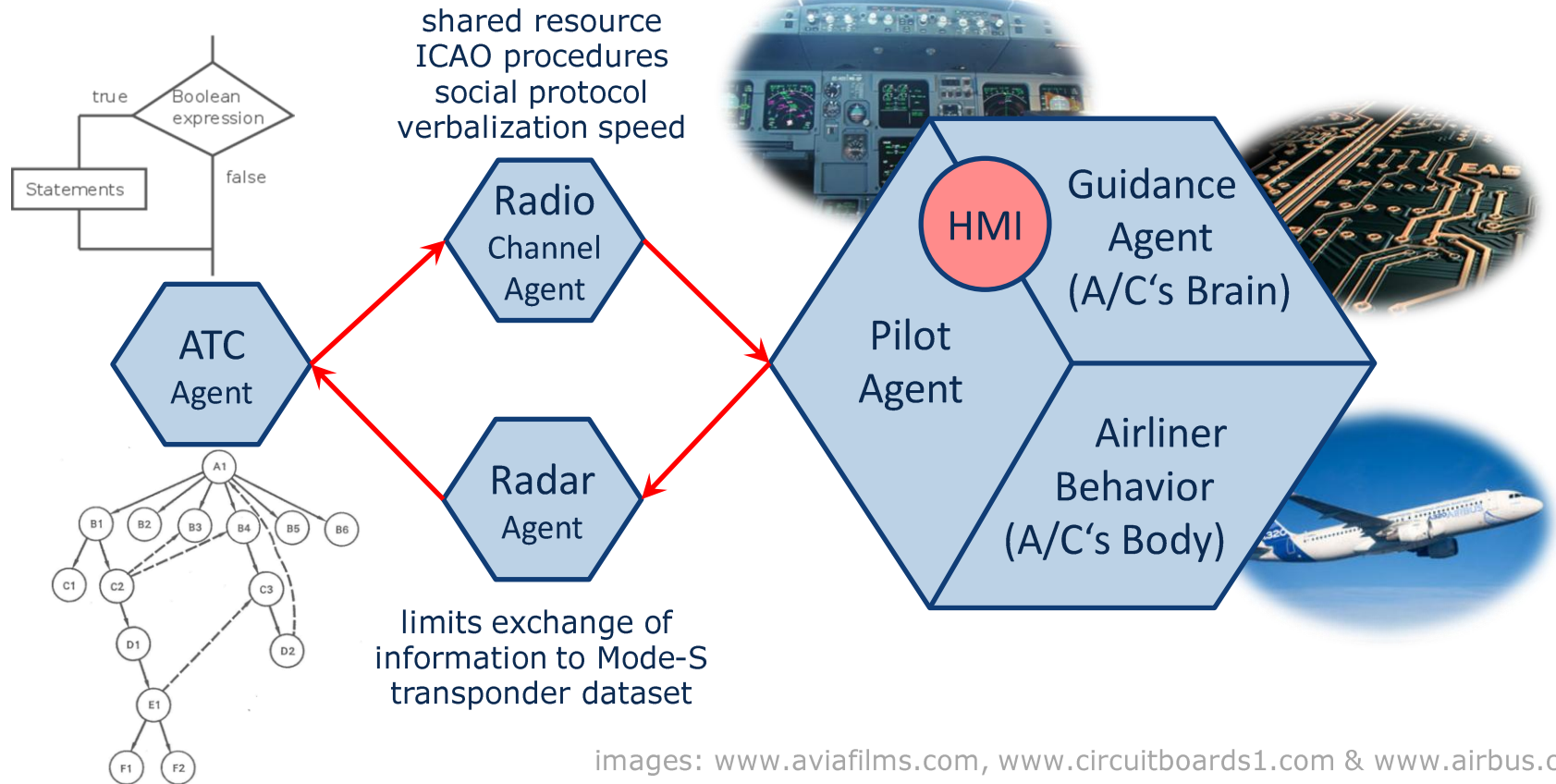
Total system error = path definition error + navigation system error + flight technical error

- core + tail distribution
 - bimodal
- fat tail
 - e.g. exp. power
- gaussian core
 - e.g. normal





Microscopic View via Agent-Based Simulation



ATC Path Shortening/Stretching Ruleset [1]

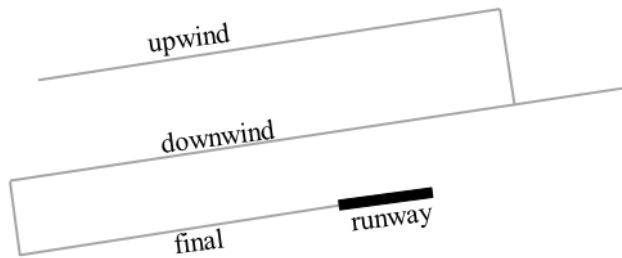
ATC
Agent

- what controllers do
 - apply years of training and experience
 - act very conservatively
 - refer to *distance-based rules of thumb* in verbal descriptions
- what the model does
 - estimates time-of arrival at suitable target waypoint
 - detects conflicts in arrival sequence
 - applies *time-based* rule-set

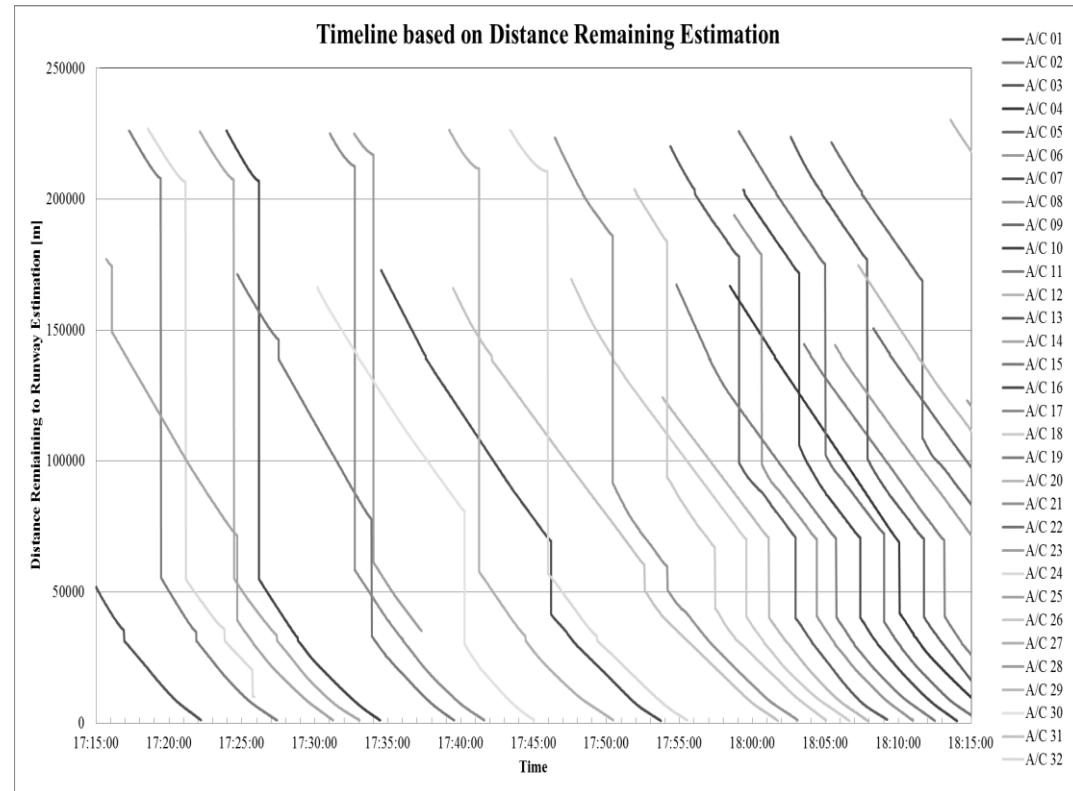
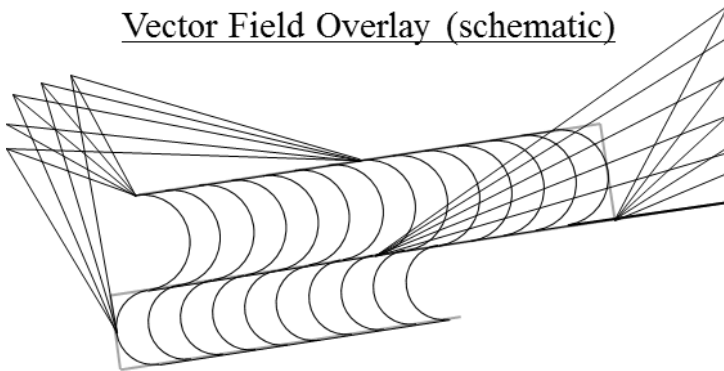
ATC Path Shortening/Stretching Ruleset [2]



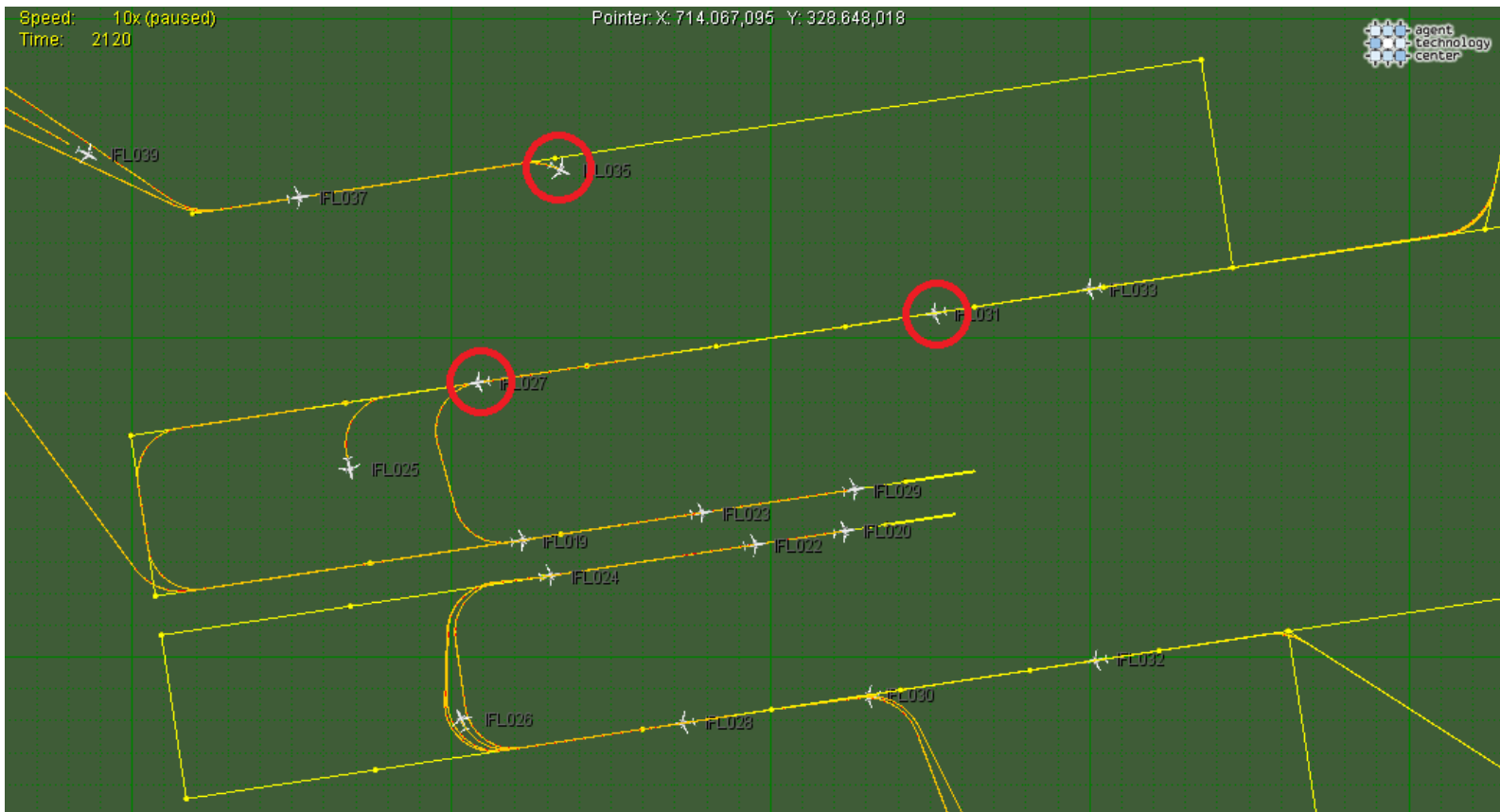
RNAV Arrival Transitions (as defined)



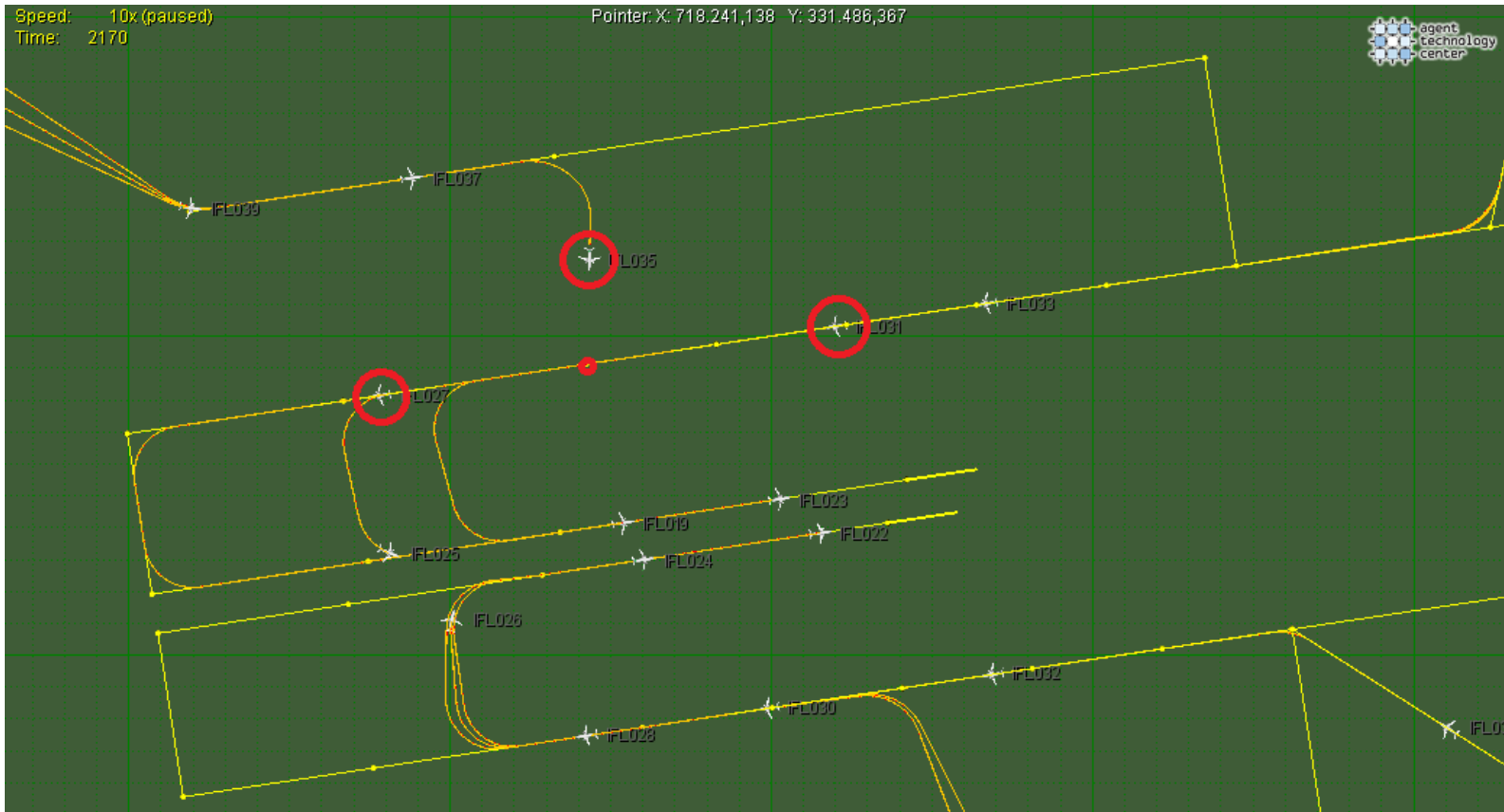
Vector Field Overlay (schematic)



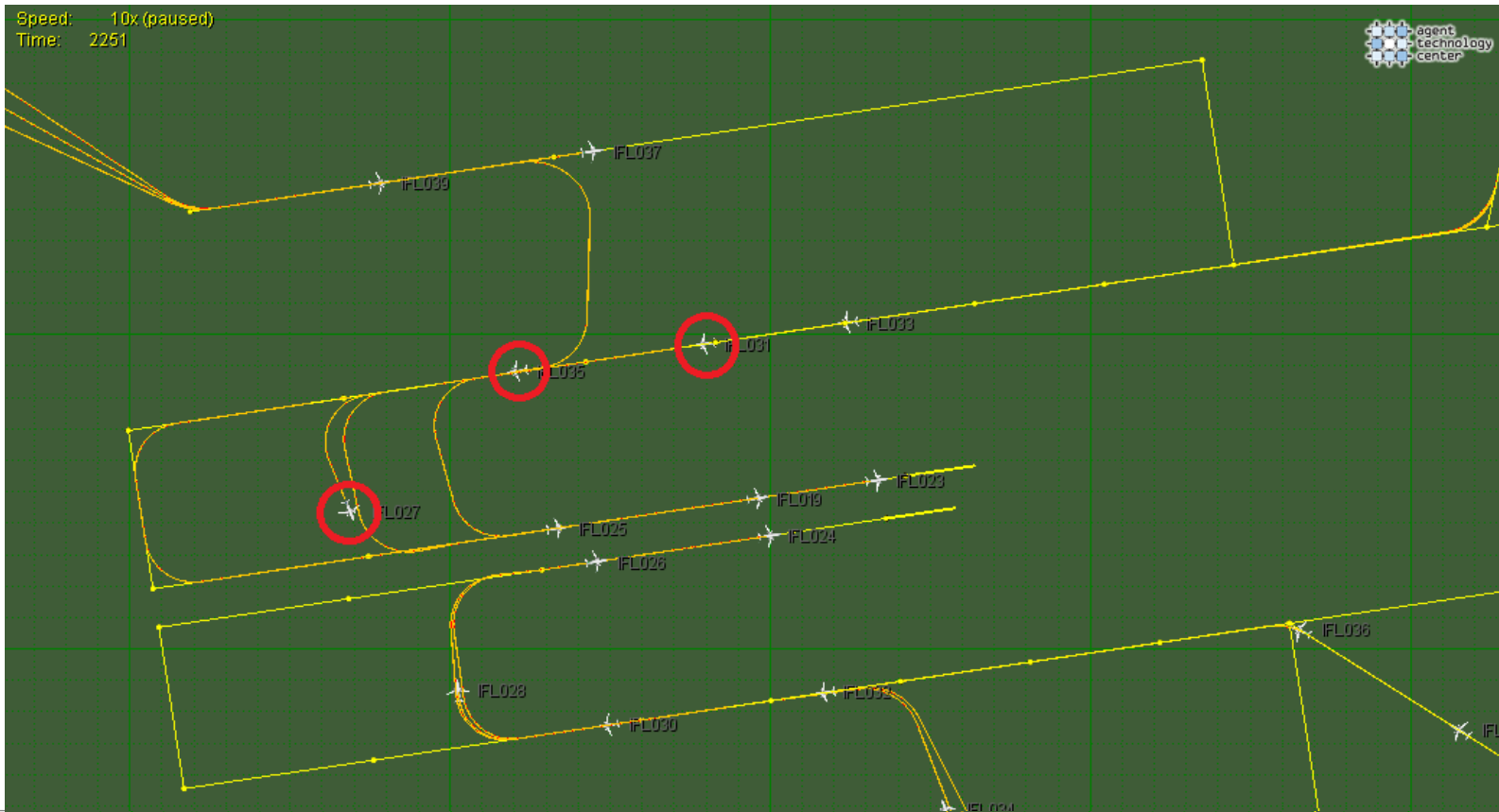
ATC Path Shortening/Stretching Ruleset [3]



ATC Path Shortening/Stretching Ruleset [4]



ATC Path Shortening/Stretching Ruleset [5]

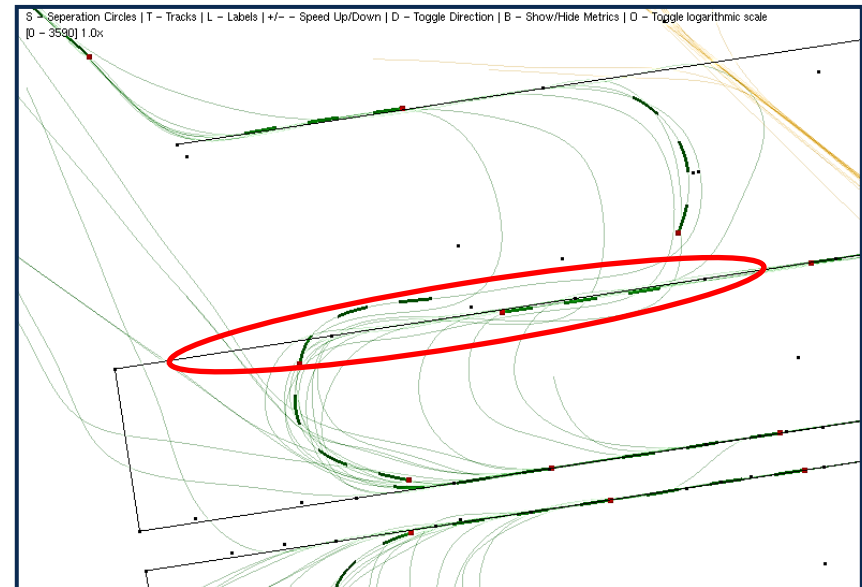
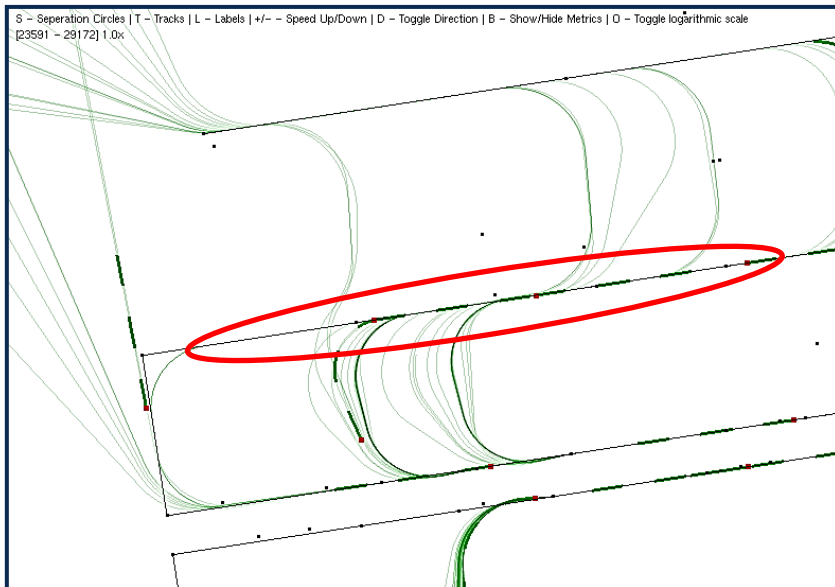


A Peculiarity

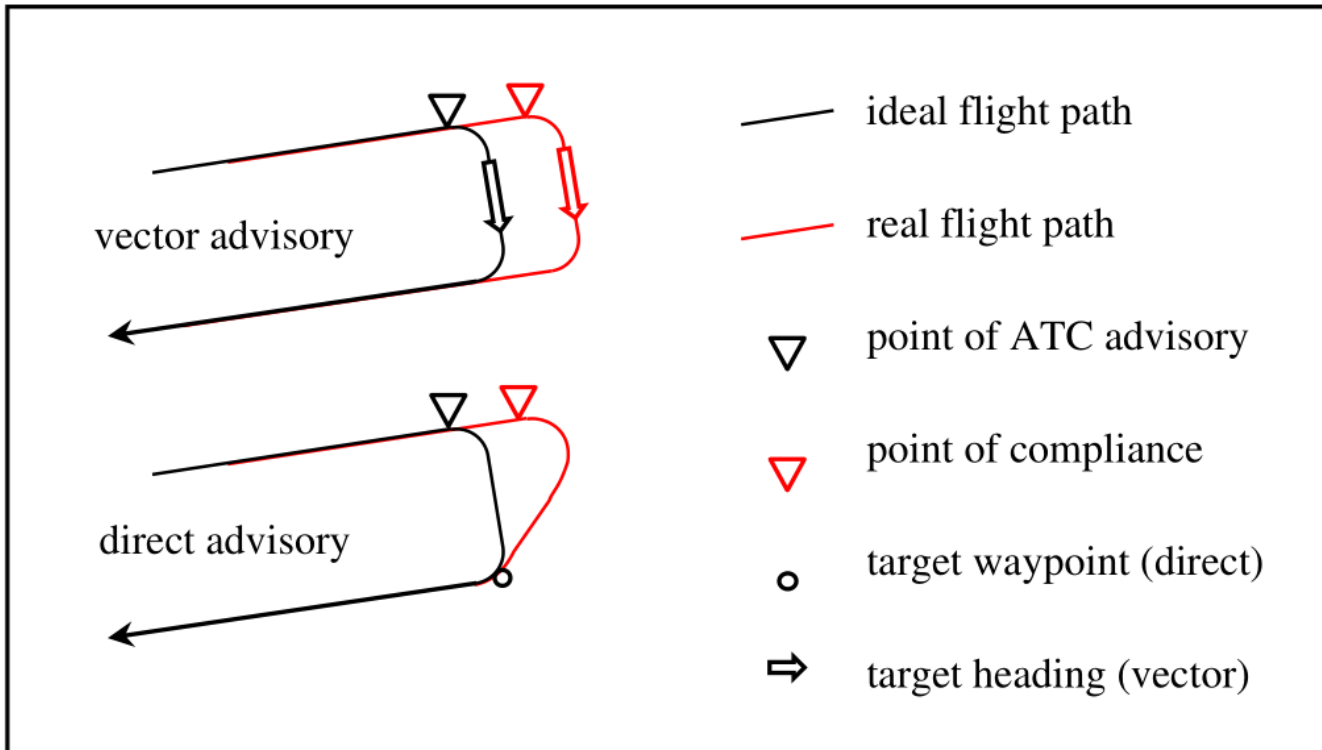


simulated trajectories

real trajectories



Validation Interview with ATCo [1]



Validation Interview with ATCo [1]



- what we expected controllers to do
 - direct: „proceed direct to DM422“
 - why: full RNAV procedure, FMS in the loop
- what controllers do whenever conditions allow
 - vector: „turn right, heading 170“
 - further vectors „turn right, heading 260“
 - why: quicker, more flexible, controller in the loop
 - cons:
 - navigation accuracy sacrificed
 - contradiction to trajectory-based operations

Task Analysis: ‚vector‘ advisory



Flight Control Unit (FCU):

3-digit displays and dial knobs

- speed (SPD, left) and
- heading (HDG, right)

1. move hand to FCU heading dial knob,
2. in parallel: determine direction of turn
 1. usually, explicitly advised by ATC
 2. already anticipated (approach procedures)
 3. visual comparison (navigation display)
 4. numerical comparison (3-digit display)
3. then, turn knob in desired direction
4. *<aircraft starts turning>*
5. in parallel, adjust target heading accurately

time demand:

well below 5 seconds

chance of error:

remote

Task Analysis: ‚direct‘ advisory



Flight Management System (FMS), Multi-purpose Control and Display Unit (MCDU):
screen, line-selector keys and scratch pad
- ‚direct‘ key (first row, leftmost key)
- waypoint list (on screen)

1. move hand to MCDU keypad
2. then, push the DIR(ECT) button
3. then, select the target waypoint
 1. locate it on screen (flight plan page) and select it by using the appropriate Line Selector Key (LSK)
 2. if not visible, scroll through the flight plan using arrows keys, then a.
 3. type in the waypoint name manually using the scratch pad
4. then, select intercept maneuver using LSK
5. optionally, check setup on NAV display
6. finally, commit waypoint selection using LSK6
7. *<aircraft starts turning>*

time demand: **usually below 10 seconds**
chance of error: **high (+ 5..10 seconds)**

Experiment

- Part-Task (PF, inputs)
- Human-In-The-Loop
- Micro-World approach
- subjects: 7 students
- intensive training
- pilots for comparison

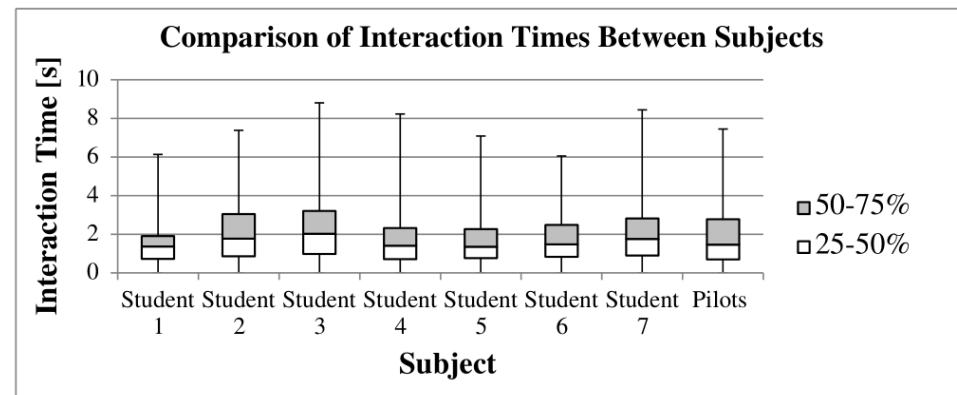
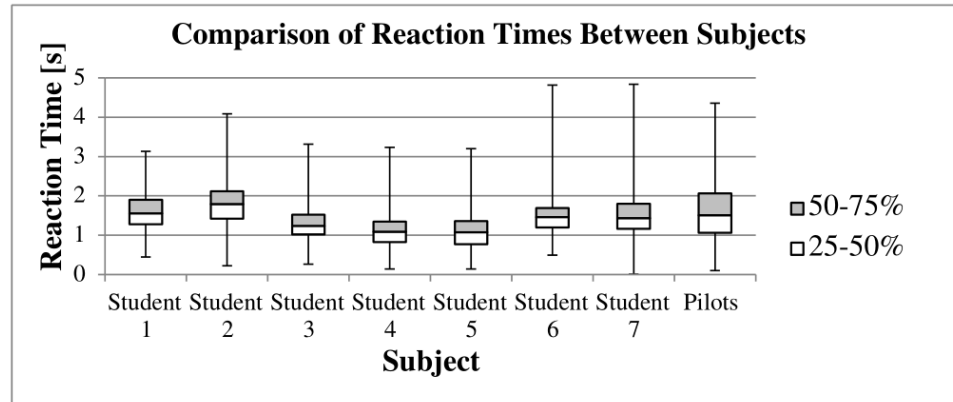
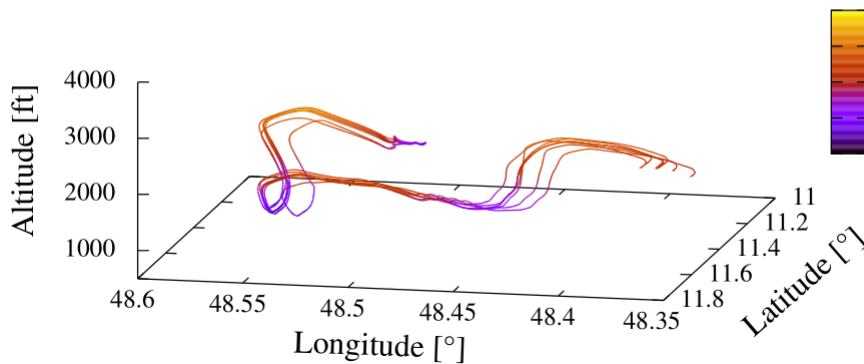


- timed ATC audio playback (advisory in ICAO phraseology)
- device acquisition time (contains reaction time, hand movement duration, and first input to device)
- device interaction time (input of compliant value)

Results [1] – Overview

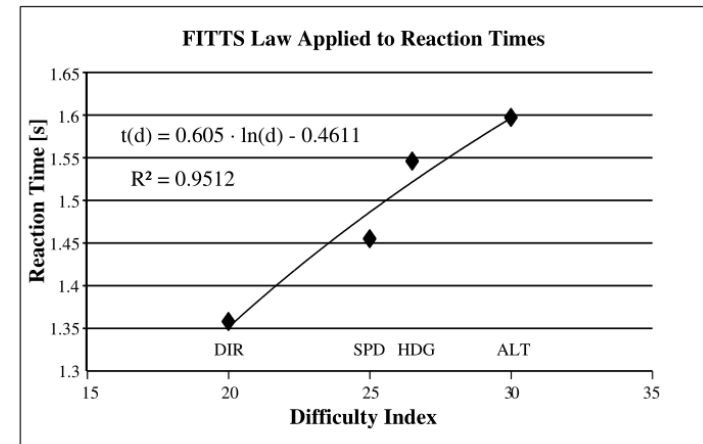
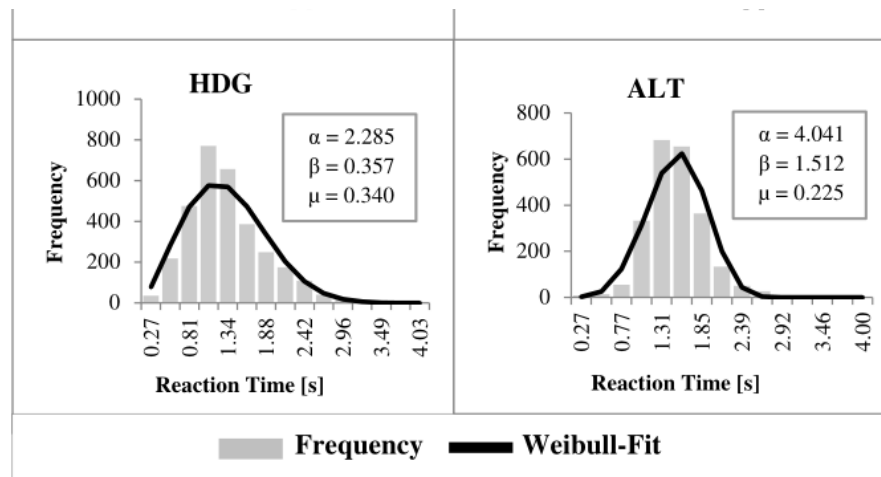
number of measurements acquired
(separated by scenario task load)

type	low	medium	high	Σ
SPD	572	916	433	1921
HDG	398	809	432	1639
ALT	472	607	359	1438
DIR	130	196	62	388
Σ	1572	2528	1286	5386

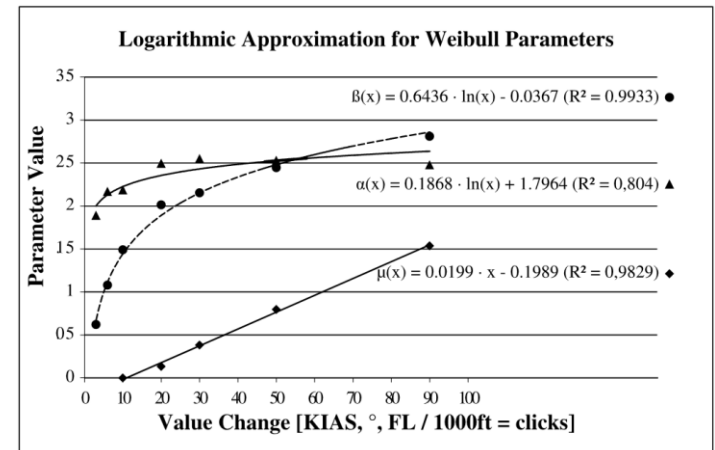
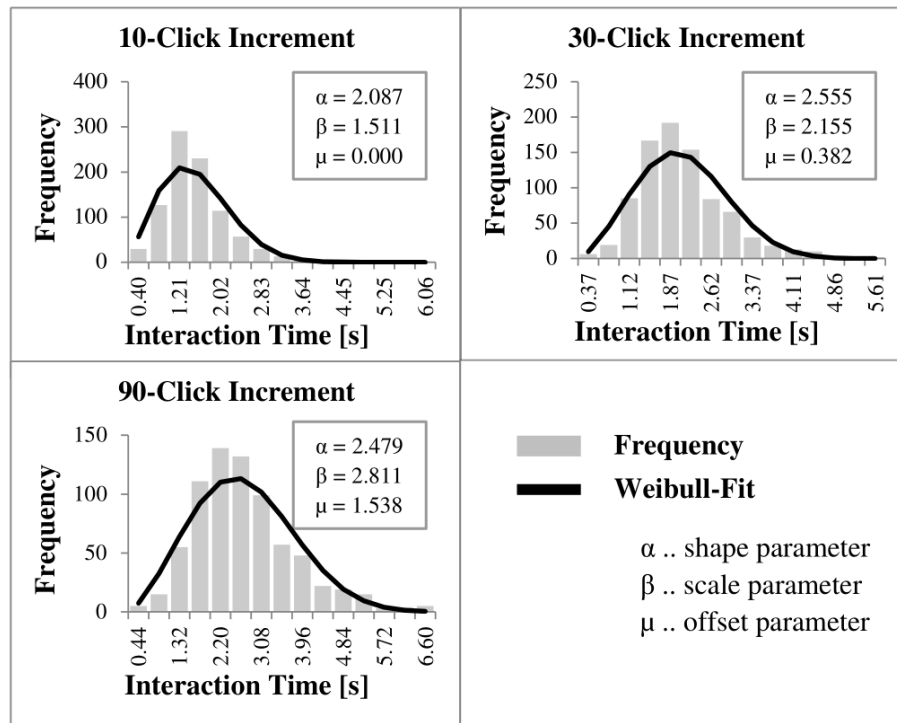


Results [2] – Device Acquisition Time

device	distance	width	width measurement	difficulty index
DIR	0.30 m	0.015 m	DIR key diagonal	20
SPD	0.50 m	0.020 m	knob base diameter	25
HDG	0.53 m	0.020 m	knob base diameter	26.5
ALT	0.60 m	0.020 m	knob base diameter	30

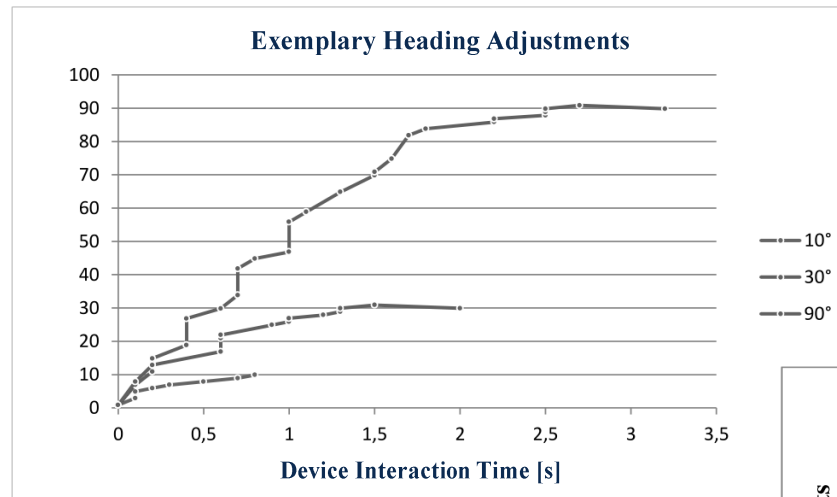


Results [3] – FCU Device Interaction Time

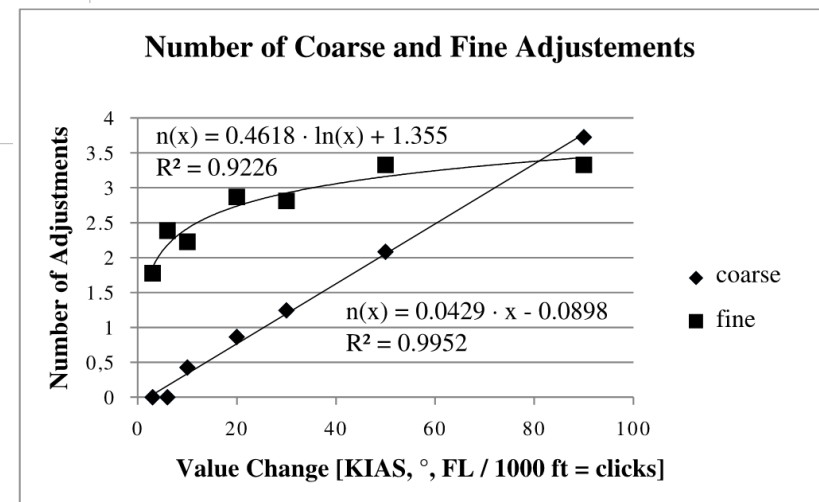


Parametric model for dial knob interaction time as $f(\text{change})$ (FCU dial knobs speed, heading, altitude combined)

Results [4] – Number of FCU Adjustments

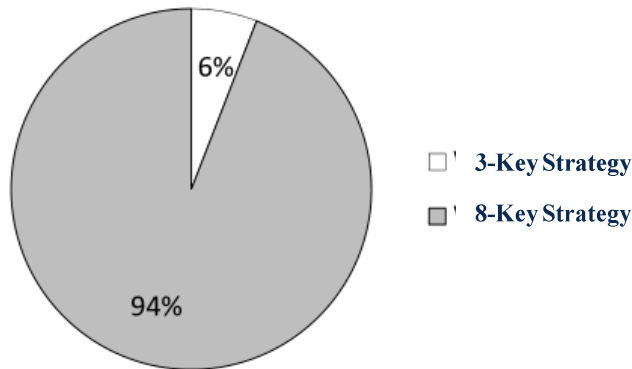


segregation of coarse (>10°) and fine (<10°) adjustments



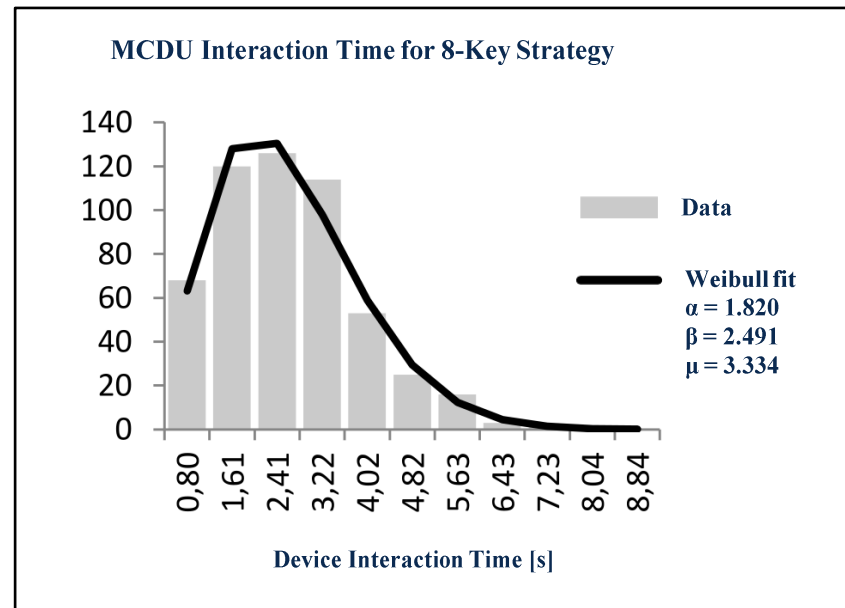
Parametric model for coarse and fine adjustments (FCU dial knobs speed, heading, altitude combined)

Results [5] – MCDU Device Interaction Time



3-key: DIR >> LSK >> LSK6

8-Key: DIR >> Type x 5 >> LSK1 >> LSK6



Results [final] – Summary of all Weibull Models

- including task-load dependent model
- with rising task load:
 - speed 👍
 - variability 🗿
 - accuracy 📏
- details: see paper

	TL	SPD	HDG	ALT	DIR
reaction time	all	$\alpha = 3.198$ $\beta = 1.447$ $\mu = 0.159$	$\alpha = 2.285$ $\beta = 1.358$ $\mu = 0.340$	$\alpha = 4.041$ $\beta = 1.512$ $\mu = 0.225$	$\alpha = 2.227$ $\beta = 0.987$ $\mu = 0.483$
	low	$\alpha = 2.278$ $\beta = 1.064$ $\mu = 0.558$	$\alpha = 2.045$ $\beta = 1.326$ $\mu = 0.428$	$\alpha = 3.747$ $\beta = 1.349$ $\mu = 0.439$	$\alpha = 1.783$ $\beta = 1.119$ $\mu = 0.483$
	med.	$\alpha = 2.811$ $\beta = 1.256$ $\mu = 0.300$	$\alpha = 2.583$ $\beta = 1.453$ $\mu = 0.200$	$\alpha = 3.604$ $\beta = 1.442$ $\mu = 0.225$	$\alpha = 1.563$ $\beta = 0.576$ $\mu = 0.776$
	high	$\alpha = 3.349$ $\beta = 1.303$ $\mu = 0.159$	$\alpha = 2.183$ $\beta = 1.112$ $\mu = 0.462$	$\alpha = 3.13$ $\beta = 1.169$ $\mu = 0.425$	dataset insufficient
interaction time	all	$\alpha(x) = 0.1868 \cdot \ln(x) + 1.7964$ $\beta(x) = 0.6436 \cdot \ln(x) + 0.0367$ $\mu(x) = 0.0199 \cdot x - 0.1989$			$\alpha = 1.820$ $\beta = 2.491$ $\mu = 3.334$
	low	$\alpha(x) = 0.3141 \cdot \ln(x) + 1.2234$ $\beta(x) = 0.7384 \cdot \ln(x) - 0.2831$ $\mu(x) = 0.0178 \cdot x + 0.0128$			$\alpha = 2.671$ $\beta = 6.792$ $\mu = 3.016$
	med.	$\alpha(x) = 0.2122 \cdot \ln(x) + 1.5648$ $\beta(x) = 0.4889 \cdot \ln(x) + 0.1949$ $\mu(x) = 0.0229 \cdot x - 0.2166$			$\alpha = 2.840$ $\beta = 4.855$ $\mu = 4.073$
	high	$\alpha(x) = 0.2521 \cdot \ln(x) + 1.507$ $\beta(x) = 0.3828 \cdot \ln(x) + 0.3264$ $\mu(x) = 0.0257 \cdot x + 0.2676$			dataset insufficient

Conclusions & Outlook

Conclusions

- device acquisition times in line with Fitts law
- parametric Weibull model for FCU device interaction
- parametric model for FCU coarse and fine adjustments
- Weibull model for MCDU input (8 keys @ $80 \sim 100 \cdot \text{min}^{-1}$)

Outlook

- significant feature for pilot agent (▪ along & cross track)
- Monte-Carlo simulation
- rare coincidence of unfavorable performance variations = sub-error source of operational risk (Safety II)
- fault-tolerance of ATM procedure (built-in safety margin)

Thank you. Questions?

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Backup: Task-Load Dependent Model

