

Project full title: " Applying Pilot Models for Safer Aircraft "

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Web-Site: www.apimod.eu



A Safety Impact Quantification Approach for Early Stage Innovative Aviation Concepts

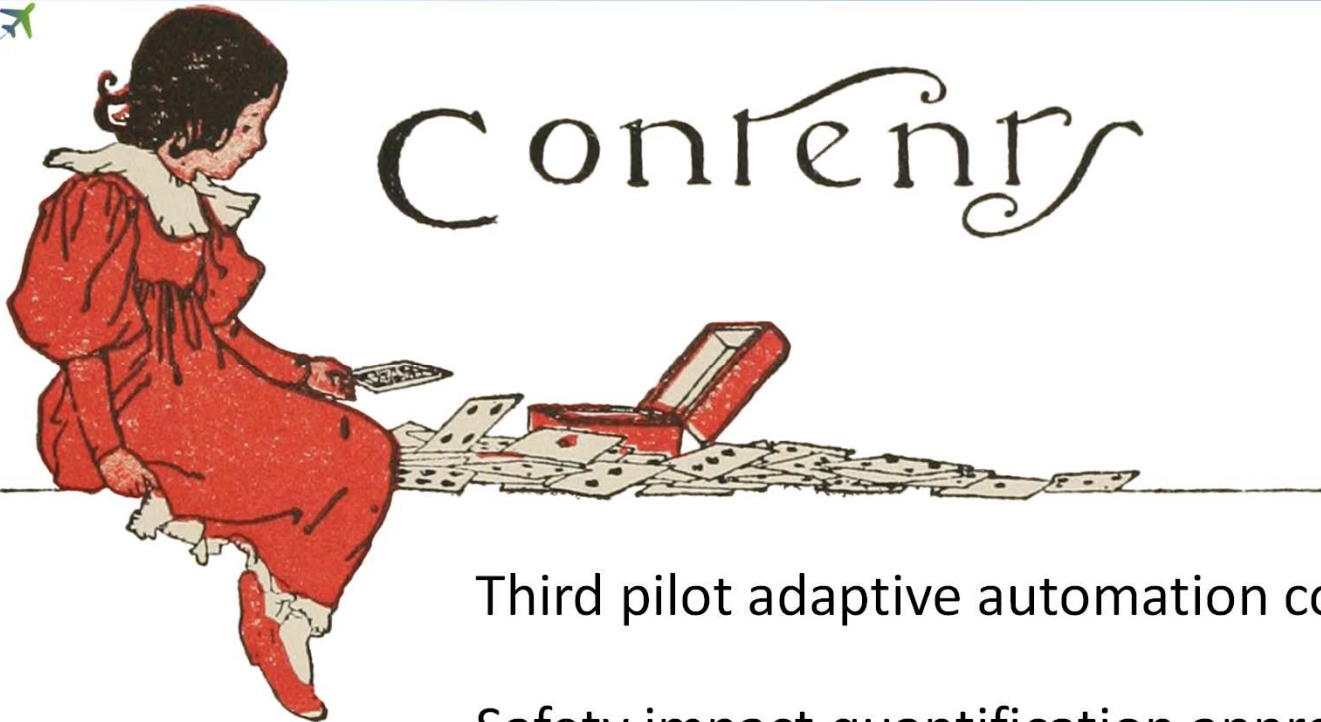
Application to a third pilot adaptive automation concept

Sybert Stroeve (NLR), Joan Cahill (TCD), Bas van Doorn (NLR)



Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

SESAR Innovation Days, Delft, The Netherlands, 8-10 November 2016



Third pilot adaptive automation concept

Safety impact quantification approach

Safety impact results for the application case

Discussion & conclusions

A-PiMod project

Applying Pilots Models for safer aircraft



Development of an innovative adaptive automation concept for the cockpit

Safety impact quantification

Implementation of tools for the concept

Evaluation of the integrated tools in flight simulations

www.apimod.eu

Innovative aviation concept



Key questions

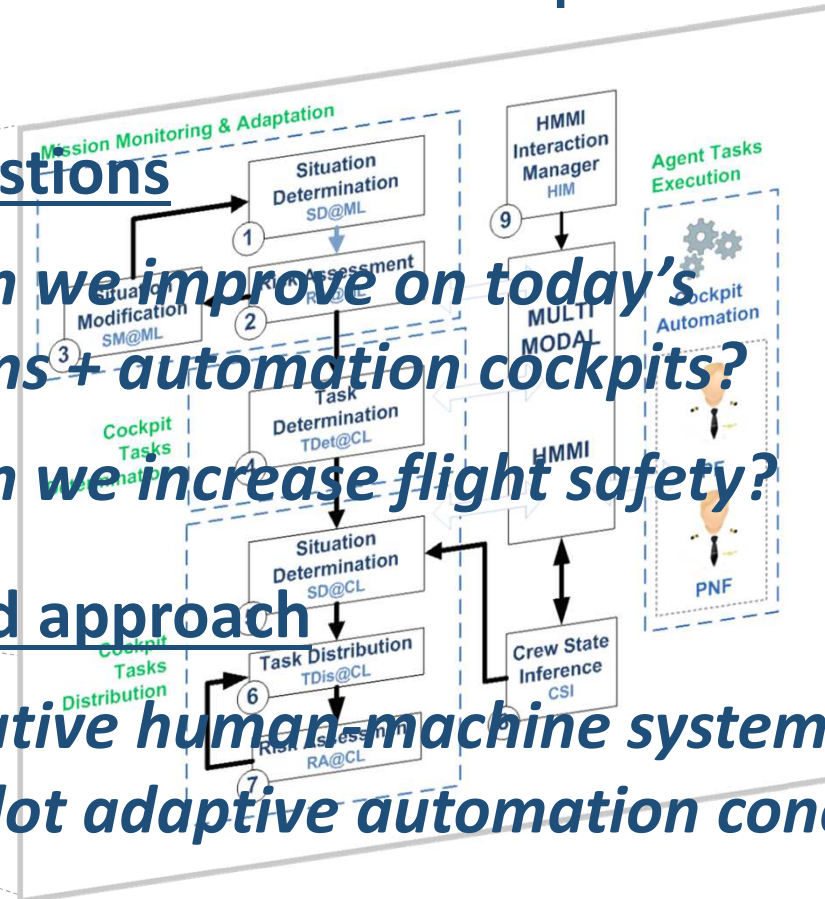
How can we improve on today's 2 humans + automation cockpits?

How can we increase flight safety?

A-PiMod approach

Cooperative human-machine system:

Third pilot adaptive automation concept



Three levels of flight management

Mission level

- High level tasks for gate to gate flight phases
- Flight plan adaptation to circumstances

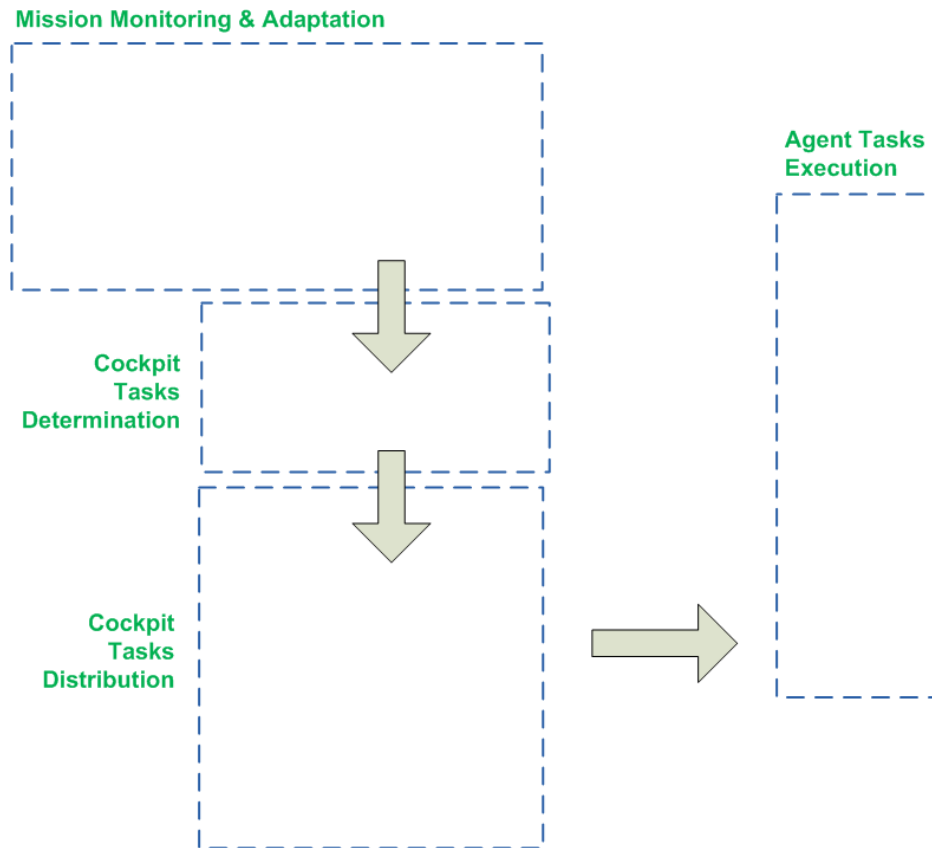
Cockpit level

- Tasks of the cockpit joint human-machine system
- Mission monitoring, aviation, navigation, communication

Agent level

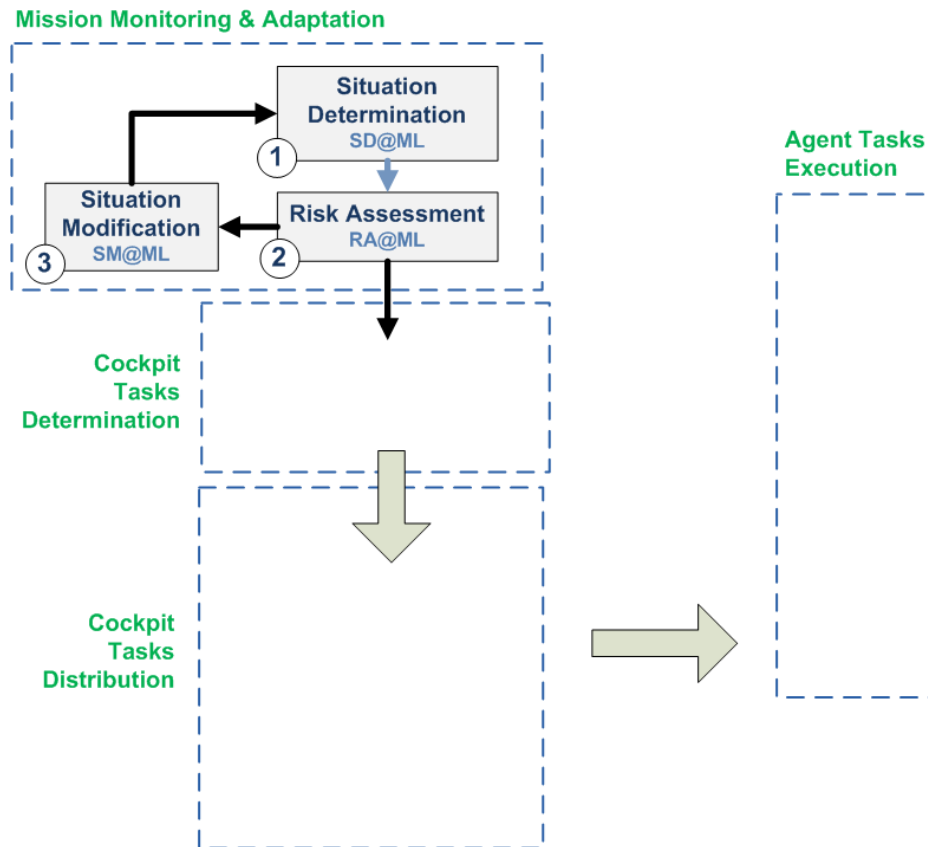
- Task execution by pilot flying, pilot monitoring, and technical systems (automation)

Adaptive automation concept

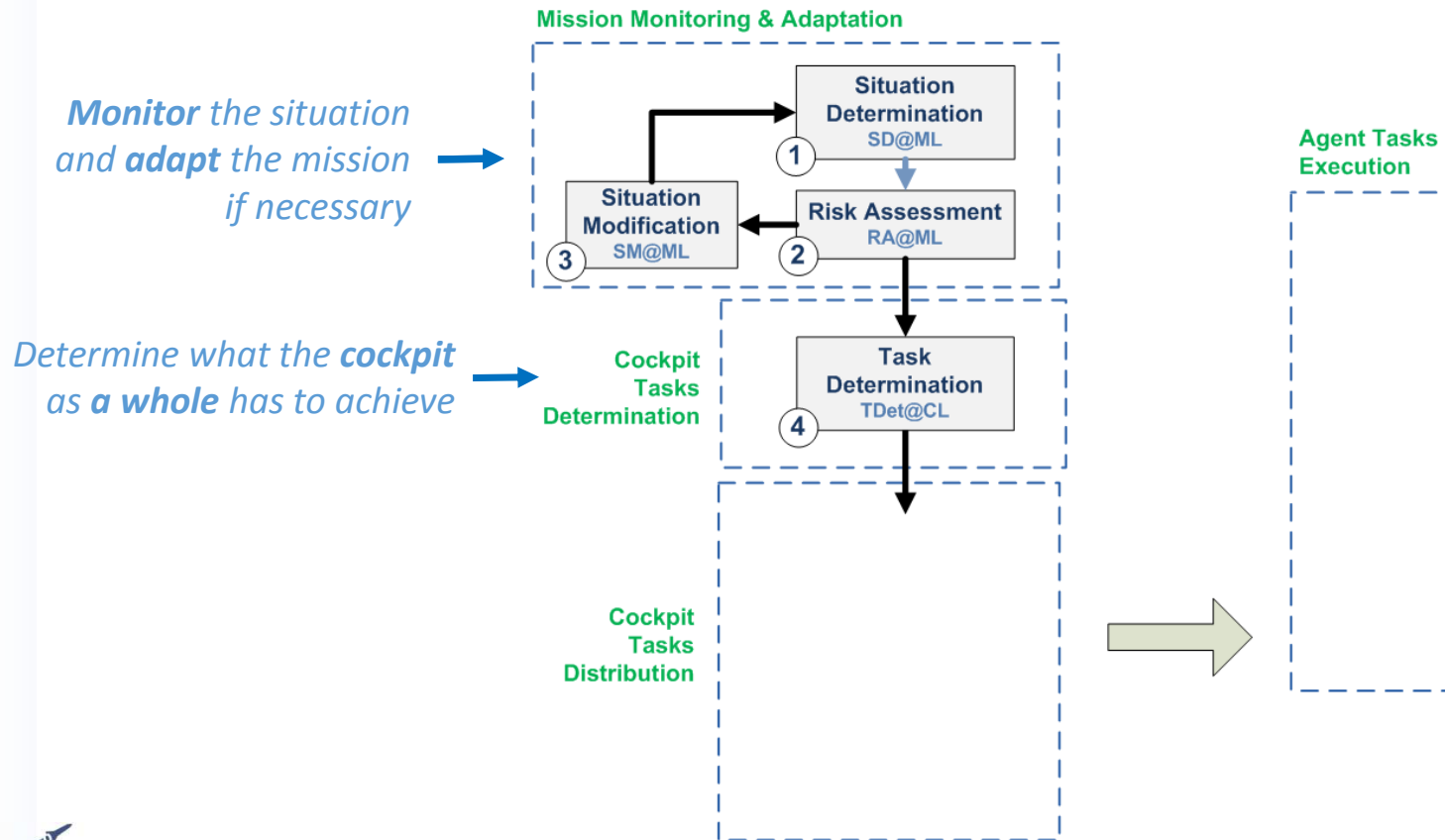


Adaptive automation concept

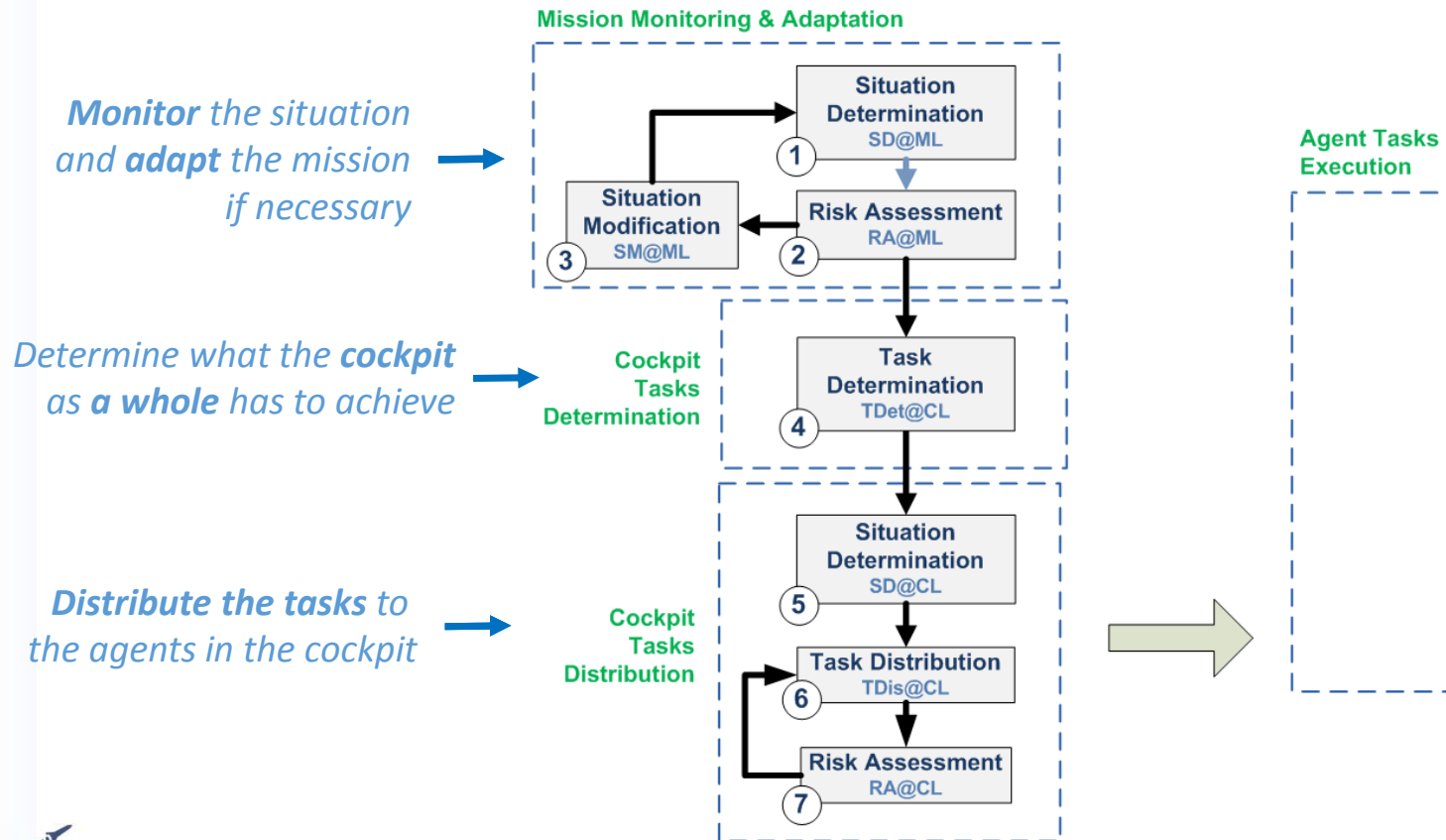
*Monitor the situation
and **adapt** the mission
if necessary*



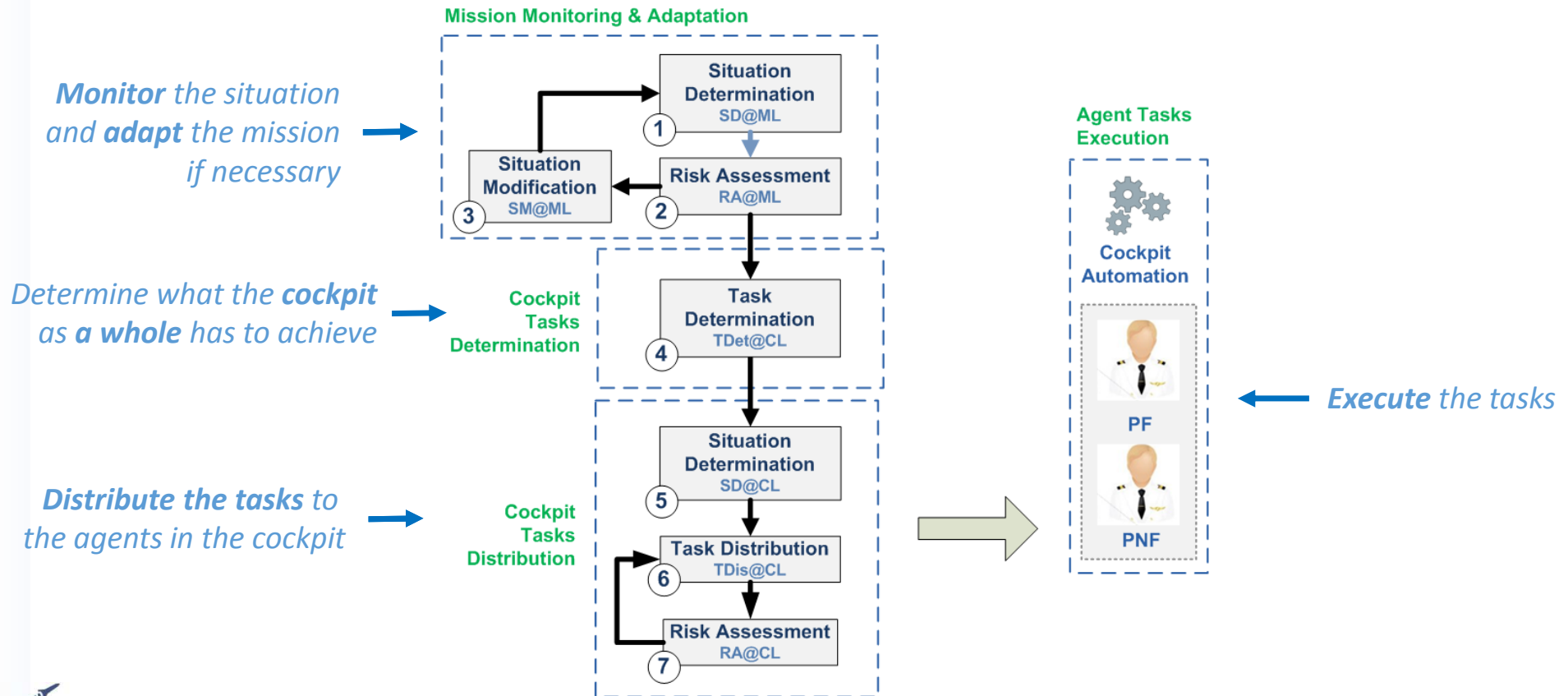
Adaptive automation concept



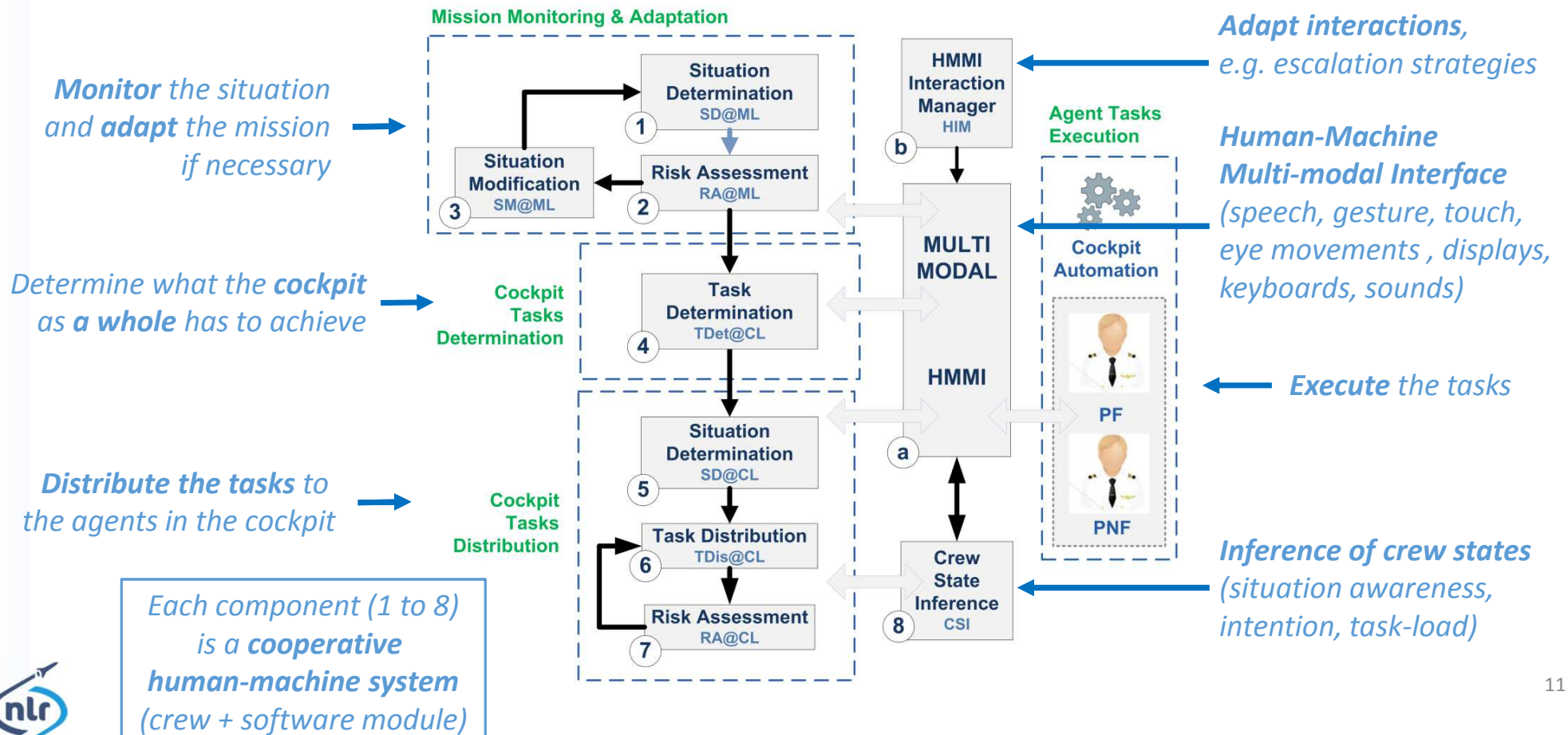
Adaptive automation concept



Adaptive automation concept



Adaptive automation concept

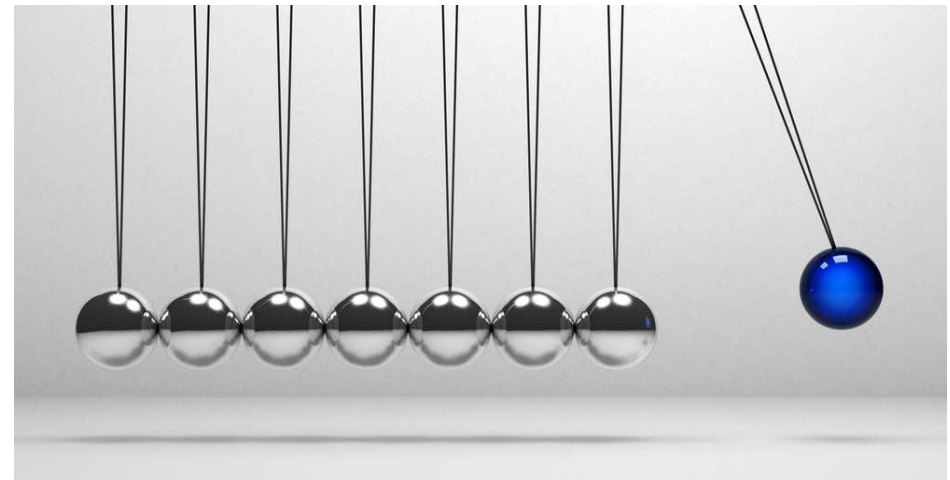


Safety impact quantification approach

Total aviation system risk model

Scoping

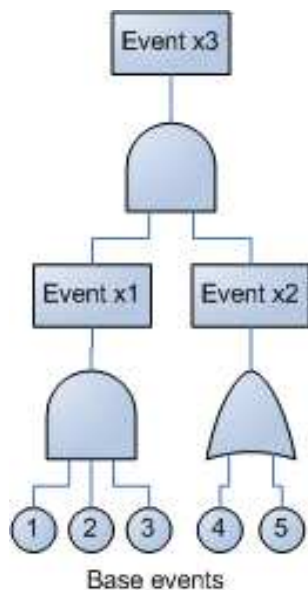
Assessing accident risk change



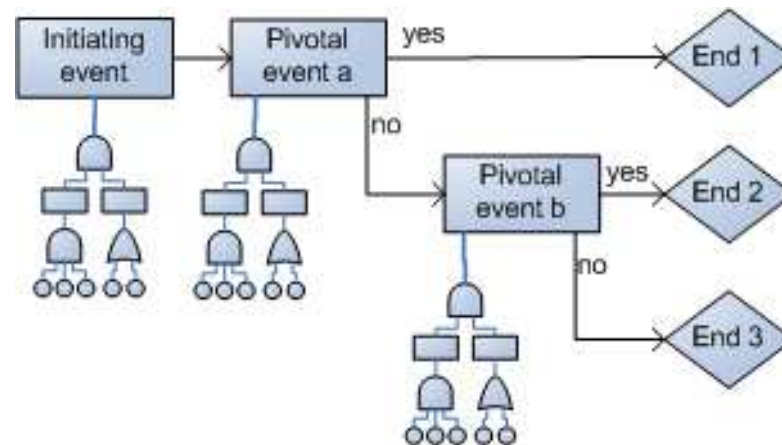
Total Aviation System Risk Model

- Developed in CATS and ASCOS projects
- All kinds of accident scenarios, except security related accidents
- 29 accident scenarios
- 51 end states
- 425 base events

Fault tree



Event sequence diagram + fault trees



Resulting accidents

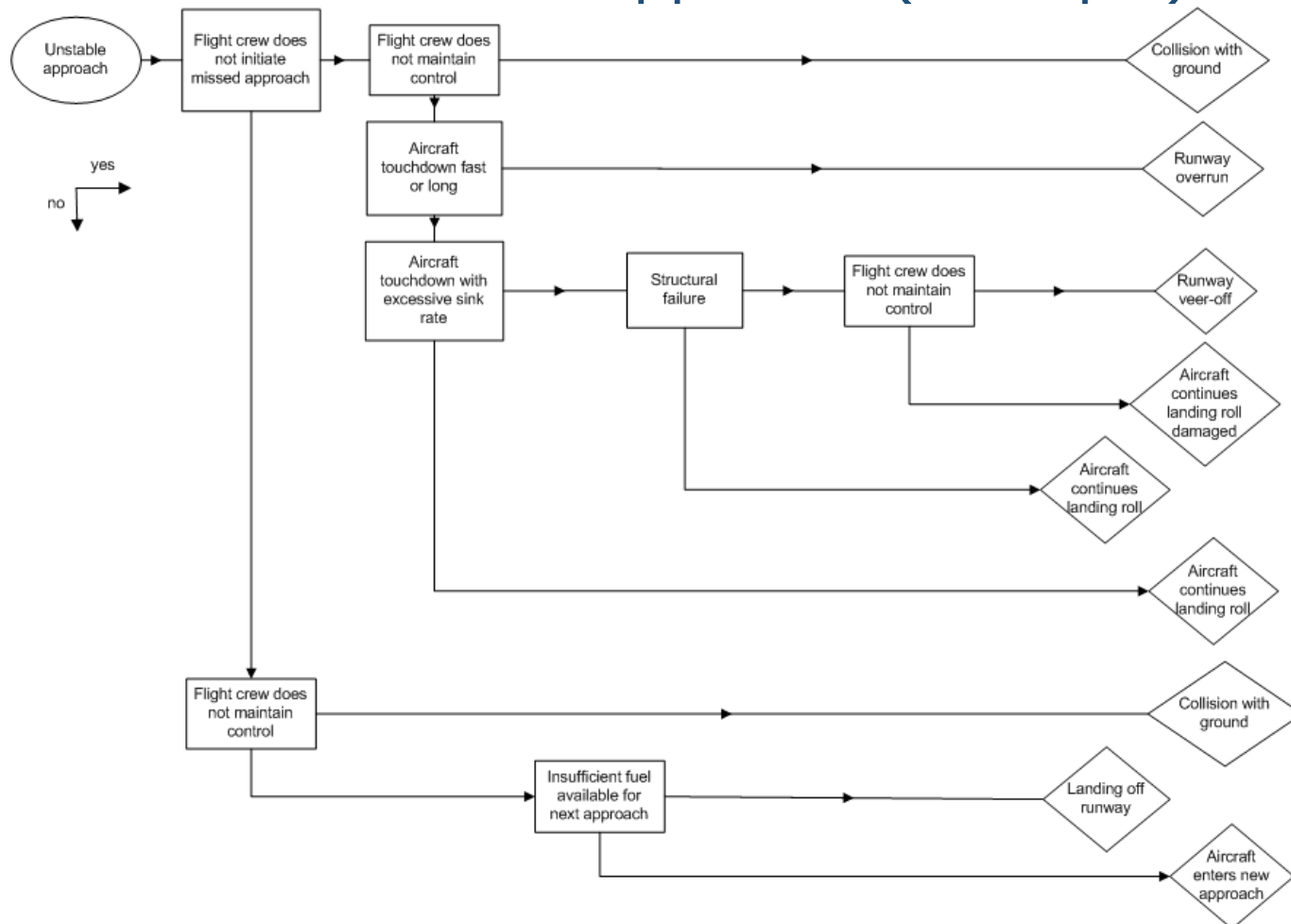
- runway excursion
- mid-air collision
- controlled flight into terrain
- loss of control in flight
- ground collision

Accident scenarios in the risk model

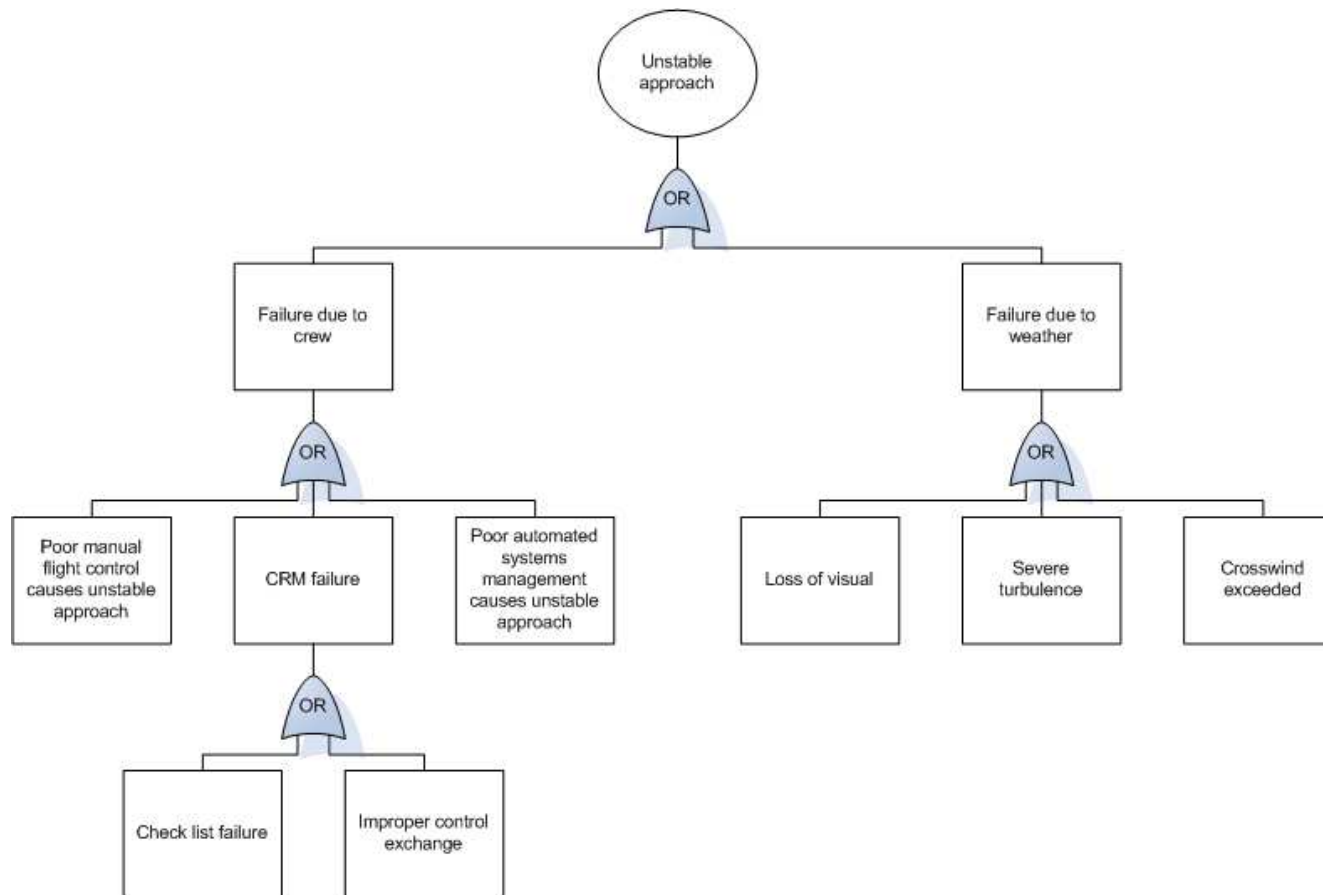
Aircraft system failure during take-off
ATC event during take-off
Aircraft directional control by flight crew inappropriate during take-off
Aircraft directional control related system failure during take-off
Incorrect configuration during take-off
Aircraft takes off with contaminated wing
Aircraft encounters wind shear after rotation
Single engine failure during take-off
Pitch control problem during take-off
Fire, smoke, fumes onboard aircraft
Flight crew member spatially disoriented
Flight control system failure
Flight crew member incapacitation
Ice accretion on aircraft in flight
Airspeed, altitude or attitude display failure

Aircraft encounters thunderstorm, turbulence, or wake vortex
Single engine failure in flight
Unstable approach
Aircraft weight and balance outside limits during approach
Aircraft encounters wind shear during approach or landing
Aircraft handling by flight crew inappropriate during flare
Aircraft handling by flight crew inappropriate during landing roll
Aircraft directional control related system failure during landing roll
Aircraft are positioned on collision course in flight
Runway incursion
Cracks in aircraft pressure cabin
TAWS alert
Conflict on taxiway or apron
Loss of control due to poor airmanship

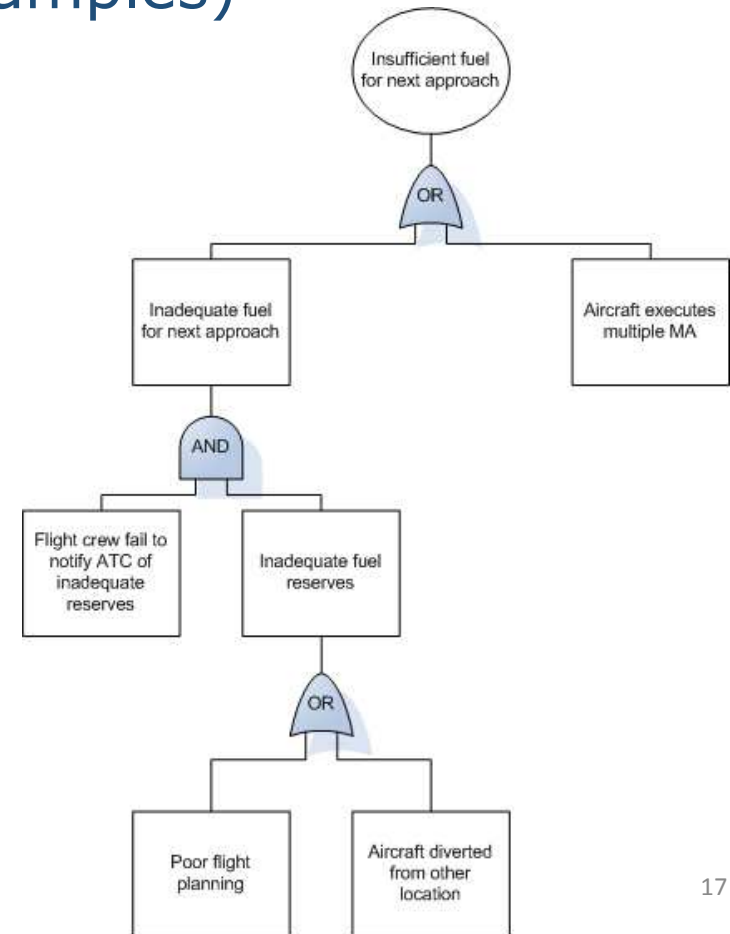
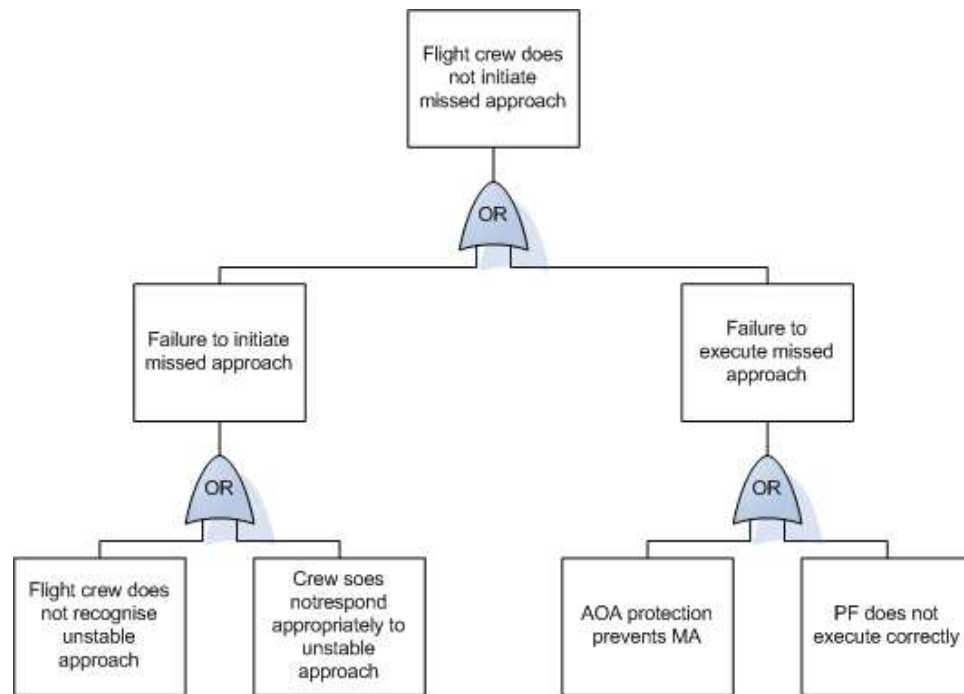
ESD for unstable approach (example)



Fault tree for initiating event of unstable approach scenario

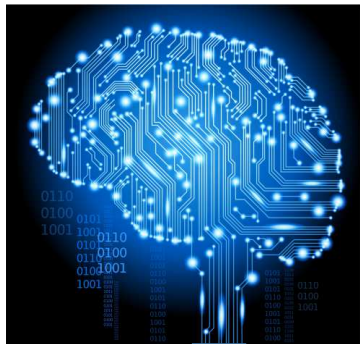


Fault trees for pivotal events of unstable approach scenario (examples)



Quantification of the risk model

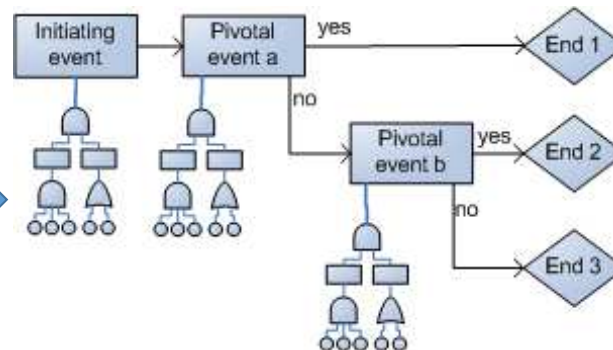
Expert judgement



Accident data



502 accidents



- European commercial aviation
- Fixed wing aircraft
- MTOW > 5701 kg
- Years 1995 – 2011
- 109 million flights

Scoping

- Choice of accident types
 - runway excursion / mid-air collision / ground collision / controlled flight into terrain / loss of control in flight
- Choice of fatality level
 - accidents / fatal accidents
- Selection of risk-relevant scenarios and/or base events
 - Choose scenarios with minimum contributions to current risk
 - Choose base events with minimum risk elasticity
- Identification of concept impressionable base events
 - Select the base events that may be influenced by the novel concept, using base event exclusion assumptions

Assessing accident risk change

- Multiplicative change factors in base event probabilities
- Assessment of change factors for in-scope base events by workshops of a Community of Practice
 - pilots, etc.
 - researchers
- Risk impact quantification
 - calculate all new base event probabilities
 - use risk tool to calculate risks for scenarios and for total risk

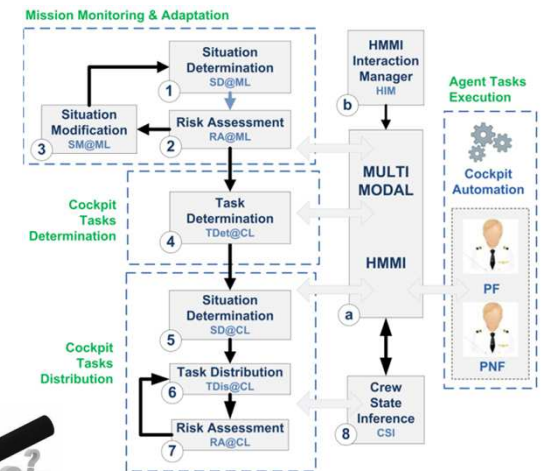
<i>Qualitative term</i>	<i>Change factor</i>	
	<i>Increase</i>	<i>Decrease</i>
Neutral	1.0	1.0
Negligible	1.1	1/1.1
Small	1.2	1/1.2
Minor	1.5	1/1.5
Significant	2.25	1/2.25
Considerable	5	1/5
Major	10	1/10

Safety impact results for the third pilot adaptive automation concept

Scoping

Assess change factors of base events

Risk impact quantification



Scoping

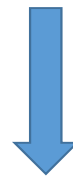
- All accident types
 - RE, MAC, GC, CFIT, LCIF
- Fatal accidents
- Scenarios with $\geq 2\%$ of total fatal accident risk
 - 16 scenarios / 236 base events retained
 - 13 scenarios / 189 base events excluded

Code	Description	Fatal accident frequency	
S18	Engine(s) failure in flight	7.13E-08	18.0%
S19	Unstable approach	4.05E-08	10.2%
S35	TAWS alert	3.23E-08	8.2%
S32	Runway incursion	2.75E-08	7.0%
S26	Aircraft handling by flight crew inappropriate during landing roll	2.55E-08	6.5%
S27	Aircraft directional control related system failure during landing roll	2.42E-08	6.1%
S31	Aircraft are positioned on collision course in flight	2.36E-08	6.0%
S16	Airspeed, altitude or attitude display failure	2.31E-08	5.8%
S13	Flight control system failure	1.76E-08	4.4%
S06	Aircraft takes off with contaminated wing	1.49E-08	3.8%
S10	Pitch control problem during take-off	1.18E-08	3.0%
S09	Single engine failure during take-off	9.82E-09	2.5%
S25	Aircraft handling by flight crew inappropriate during flare	9.78E-09	2.5%
S14	Flight crew member incapacitation	9.64E-09	2.4%
S12	Flight crew member spatially disoriented	8.04E-09	2.0%
S03	Aircraft directional control by flight crew inappropriate during take-off	7.80E-09	2.0%
	13 other scenarios	3.82E-08	9.6%
	Total	3.96E-7	100%

Scoping

Identification of impressionable base events by adoption of 12 exclusion assumptions, e.g.:

- the concept does not have any influence on base events that represent technical systems not being available or failing, or causes of technical failures (such as bad maintenance)
- the concept does not have any influence on base events that are solely caused by ATC
- etc.



- 153 base events are not influenced by the concept
- 83 base events may be influenced by the concept

Assess change factors of base events

- A-PiMod Community of Practice workshops
 - One workshop with 12 project partners
 - Two workshops with 4 airline pilots in total
 - Assessment of the concept (rather than technical implementations)
 - Viewpoints on potential safety positive and negative effects for base events
 - Viewpoints on base event change factor
- Combination of the workshop argumentation in an overall assessment of a change factor for each base event

Attained change factors

Examples

Base event	Change factor
Conflicting course due to airspace infringement	Significant decrease
Conflicting course due to level bust	Considerable decrease
Simultaneous incapacitation of all flight crew members	Major decrease
Flight crew fails to recognise unstable approach	Major decrease
Flight crew fails to respond appropriately to unstable approach	Major decrease
Improper control exchange (of pilot roles)	Small decrease
Flight crew does not execute terrain avoidance manoeuvre successfully	Major decrease

Overall assessment

Change factor	Increase	Decrease
Neutral	37	
Negligible (1.1)	0	0
Small (1.2)	0	2
Minor (1.5)	0	2
Significant (2.25)	0	16
Considerable (5)	0	7
Major (10)	0	19

Overall fatal accident frequency results

Code	Scenario description	Fatal accident frequency (per flight)					
		Baseline		Novel concept		Change (%)	
		Freq.	Perc.	Freq.	Perc.	Scen.	Total
S18	Engine(s) failure in flight	7.1E-08	18.0%	2.1E-08	9.2%	-71%	-12.8%
S19	Unstable approach	4.1E-08	10.2%	2.9E-09	1.3%	-93%	-9.5%
S35	TAWS alert	3.2E-08	8.2%	3.2E-09	1.4%	-90%	-7.4%
S32	Runway incursion	2.8E-08	7.0%	2.8E-08	12.3%	0%	0%
S26	Aircraft handling by flight crew inappropriate during landing roll	2.6E-08	6.5%	2.6E-08	11.4%	0%	0%
S27	Aircraft directional control related system failure during landing roll	2.4E-08	6.1%	2.4E-08	10.8%	0%	0%
S31	Aircraft are positioned on collision course in flight	2.4E-08	6.0%	8.0E-09	3.6%	-66%	-3.9%
S16	Airspeed, altitude or attitude display failure	2.3E-08	5.8%	7.5E-09	3.4%	-67%	-3.9%
S13	Flight control system failure	1.8E-08	4.4%	1.0E-08	4.7%	-41%	-1.8%
S06	Aircraft takes off with contaminated wing	1.5E-08	3.8%	1.5E-08	6.6%	0%	0%
S10	Pitch control problem during take-off	1.2E-08	3.0%	1.2E-08	5.3%	0%	0%
S09	Single engine failure during take-off	9.8E-09	2.5%	9.8E-09	4.4%	0%	0%
S25	Aircraft handling by flight crew inappropriate during flare	9.8E-09	2.5%	9.8E-09	4.4%	0%	0%
S14	Flight crew member incapacitation	9.6E-09	2.4%	9.6E-10	0.4%	-90%	-2.2%
S12	Flight crew member spatially disoriented	8.0E-09	2.0%	6.4E-10	0.3%	-92%	-1.9%
S03	Aircraft directional control by flight crew inappropriate during takeoff	7.8E-09	2.0%	7.8E-09	3.5%	0%	0%
	13 other scenarios (not assessed)	3.8E-08	9.6%	3.8E-08	17.0%	0%	0%
	Total	4.0E-07	100%	2.2E-07	100%		-43%

Discussion & conclusions

Safety impact quantification
approach

Third pilot adaptive
automation concept



Safety impact quantification approach

The approach is straightforward and provides a broad and structured overview for risk implications of early stage concepts

- Scenarios, base events and change factors were well grasped

Uncertainty in the risk quantification

- Limited data set & expert judgement for risk model quantification
- FTs and ESDs do not well represent dynamic interactions in scenarios
- Uncertainty in judgements about change factors

More detailed safety assessment is needed in next development stages

- Details of technical systems & human interactions
- For specific scenarios & related hazards
- Use safety methods that explicitly account for interactions and timing

Third pilot adaptive automation concept

Concept facilitates a reduction in fatal accident risk of 43%

- Largest reductions due to engine failure, unstable approach, and ground proximity
- For additional risk reduction: focus on takeoff, landing and runway incursions

High impact for critical situations where automation takes control

- Terrain / aircraft collision avoidance; Missed approach initiation/completion; etc.

Taking over of control by automation is highly sensitive

- Shift in response from pilots to automation
- Potential change in liability of aircraft and avionics manufacturers
- Acceptance by pilots, aviation community, travelling public

More detailed safety assessments are needed for sociotechnical implementations of the concept

- Use safety assessment methods that account in detail for dynamics and dependencies

Questions & discussion

