Safety in Single-Pilot Operations: STPA Analysis on the Use of Voice Commands for Aircraft Landing Configuration

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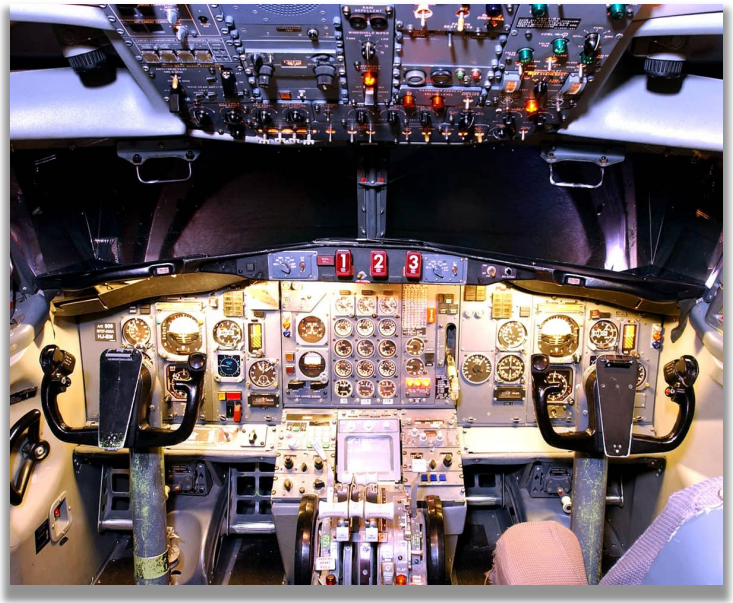
PRESENTATION OVERVIEW

1. Introduction
2. Objective and goals
3. Voice command concept
4. Methodology
5. Results
6. Conclusion

INTRODUCTION

Flight Deck Evolution

- Advancements over time improving operational safety
- Technological transformations: increased automation and reduced crew



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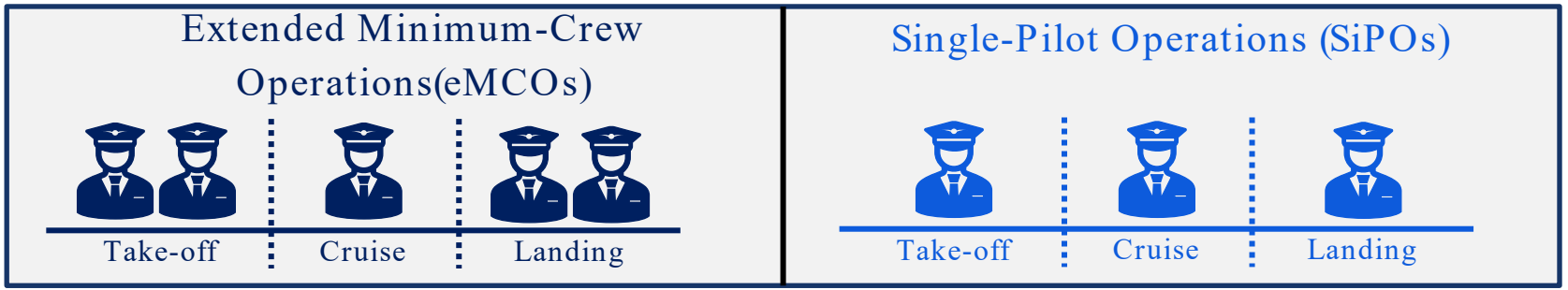
Single-Pilot Operation in Commercial Aviation

Currently, studies on single-pilot operations based on two operational concepts (EASA, 2025):

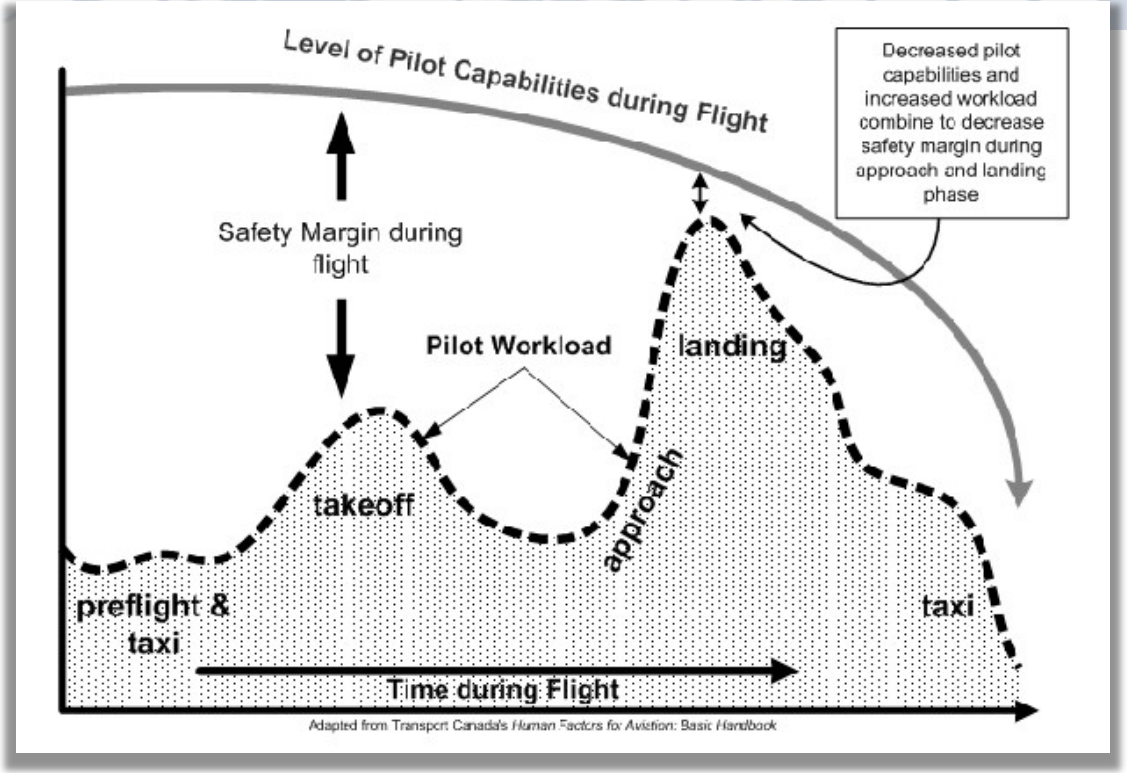


EASA (2025) concluded that it is not possible to guarantee the same level of operational safety with theses concepts compared to the current 2 pilots' configuration, given the current flight deck design.

- Preserve the pilot's role of responsibility
- Workload management

Workload

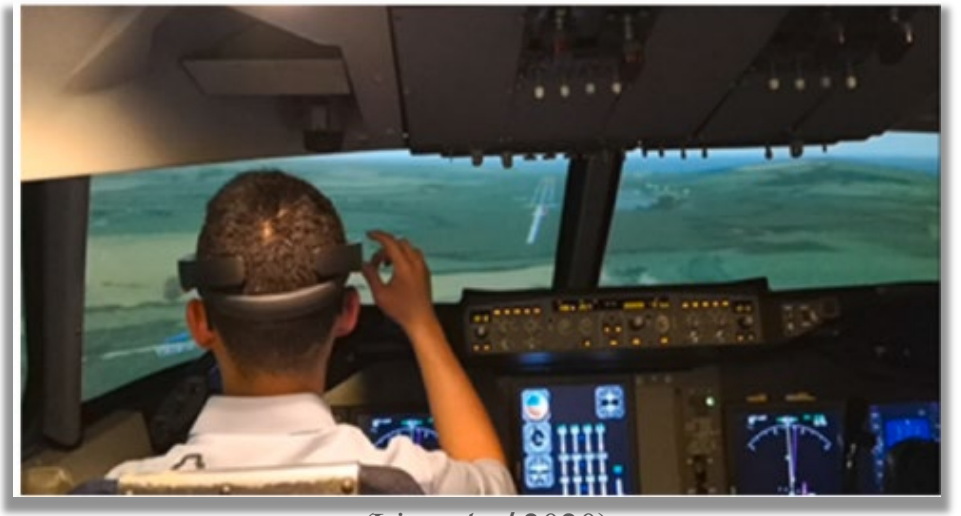
- Amount of cognitive and physical effort that an operator needs to exert to perform their tasks within a system (Gartner, 1977).
- Workload during flight phases
- Approach + Landing = 46% of fatalities (2013–2022), in 4% of exposure time (FAA, 2023).



(Transport Canada, 2018)

Voice command : Alternative to reduce physical workload

- Enables hands-free execution of activities
- Devices have advanced; the technology is becoming increasingly common.
- Study applying augmented reality to single-pilot operation: voice commands can increase situational awareness (Lin et al., 2024)
  - Great acceptance
  - New limitations



(Lin *et al*, 2020)

Technological Innovation Challenge

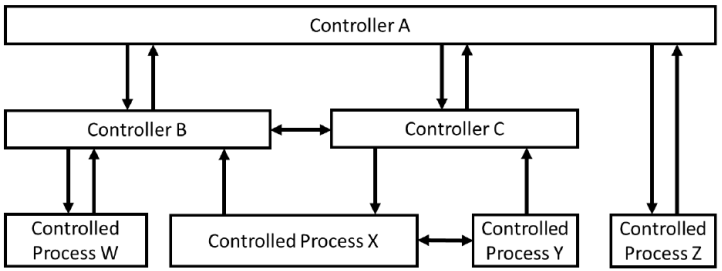
New technology introduces unknowns into complex systems that create path to losses (Leveson, 2011)

Human-Centered Design (HCD): integrate the human as part of the system (NASA, 2014)

Systems engineering in the conceptual phases to define requirements is essential (NASA, 2016)

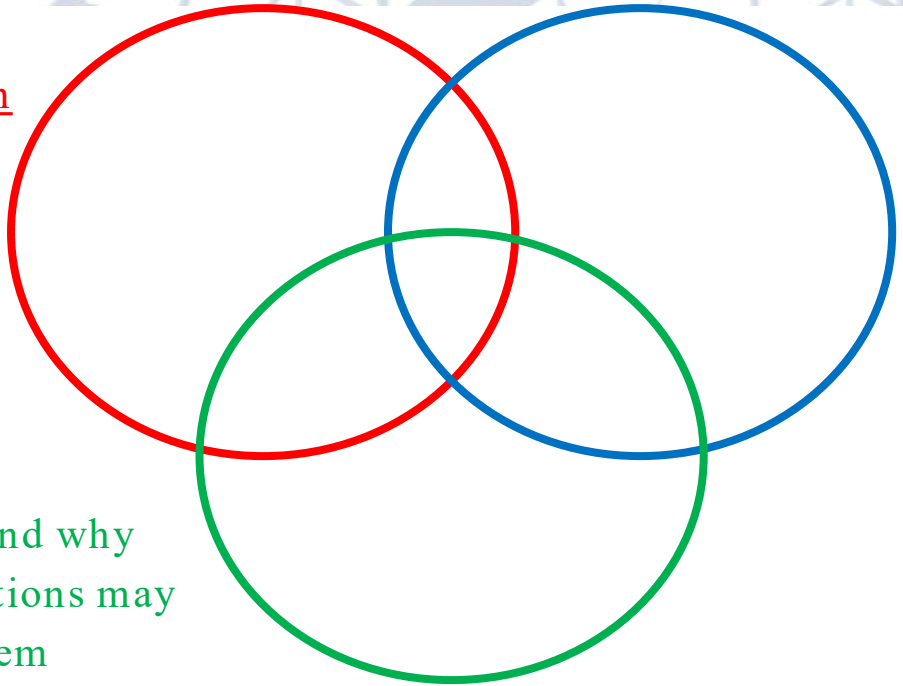
System-Theoretic Process Analysis (STPA)

- Analyze unsafe interactions by modeling control relationships of a system
- Allow analysis at a high level of abstraction: conceptual stage of project development
- Essential to increase safety in aviation (Thomas, 2024)



HCD, Systems Engineering & STPA

Human-Centered Design
Inclusion of the human aspect in system development



Systems Engineering
Definition of requirements from the conceptual phases in complex systems

STPA
Identify how and why unsafe interactions may occur in a system

OBJECTIVE AND GOALS

Objective and Goals

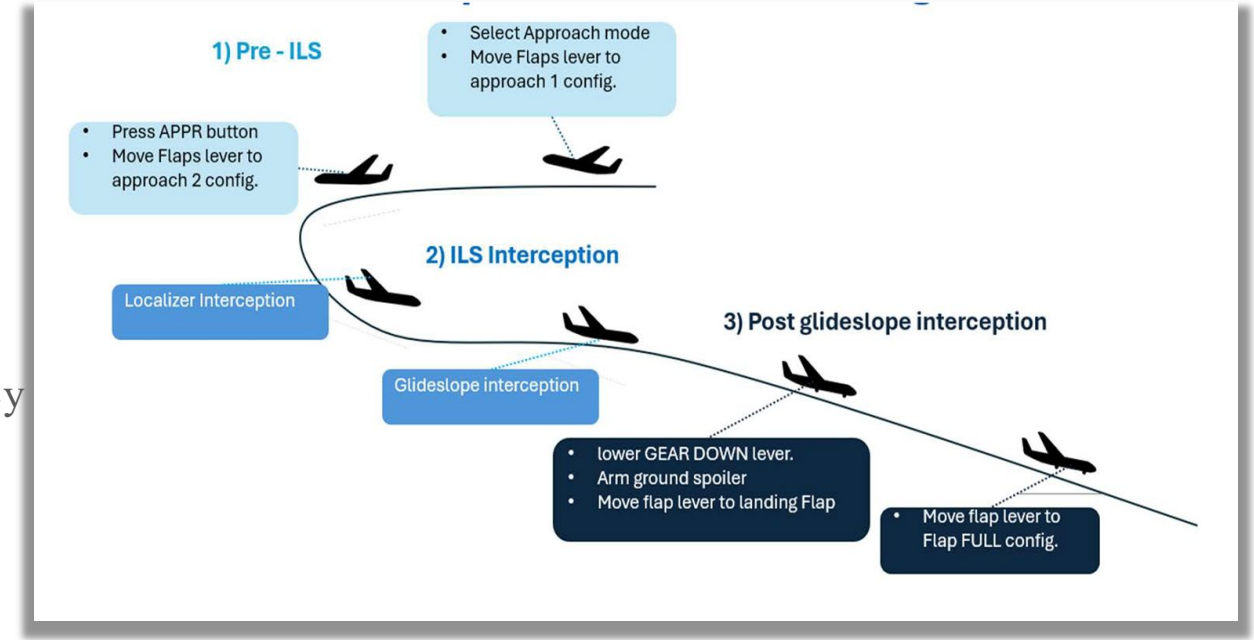
Apply the STPA methodology to analyze a high-level implementation of voice command in the flight deck, from the perspective of an aircraft manufacturer, as a multimodal alternative during final approach and landing phases.

- Support the development of operational configurations for voice command usage, identifying human-machine interface safety concerns by generating requirements
- Contribute to future implementation trade-offs, practical applications, discussing STPA application

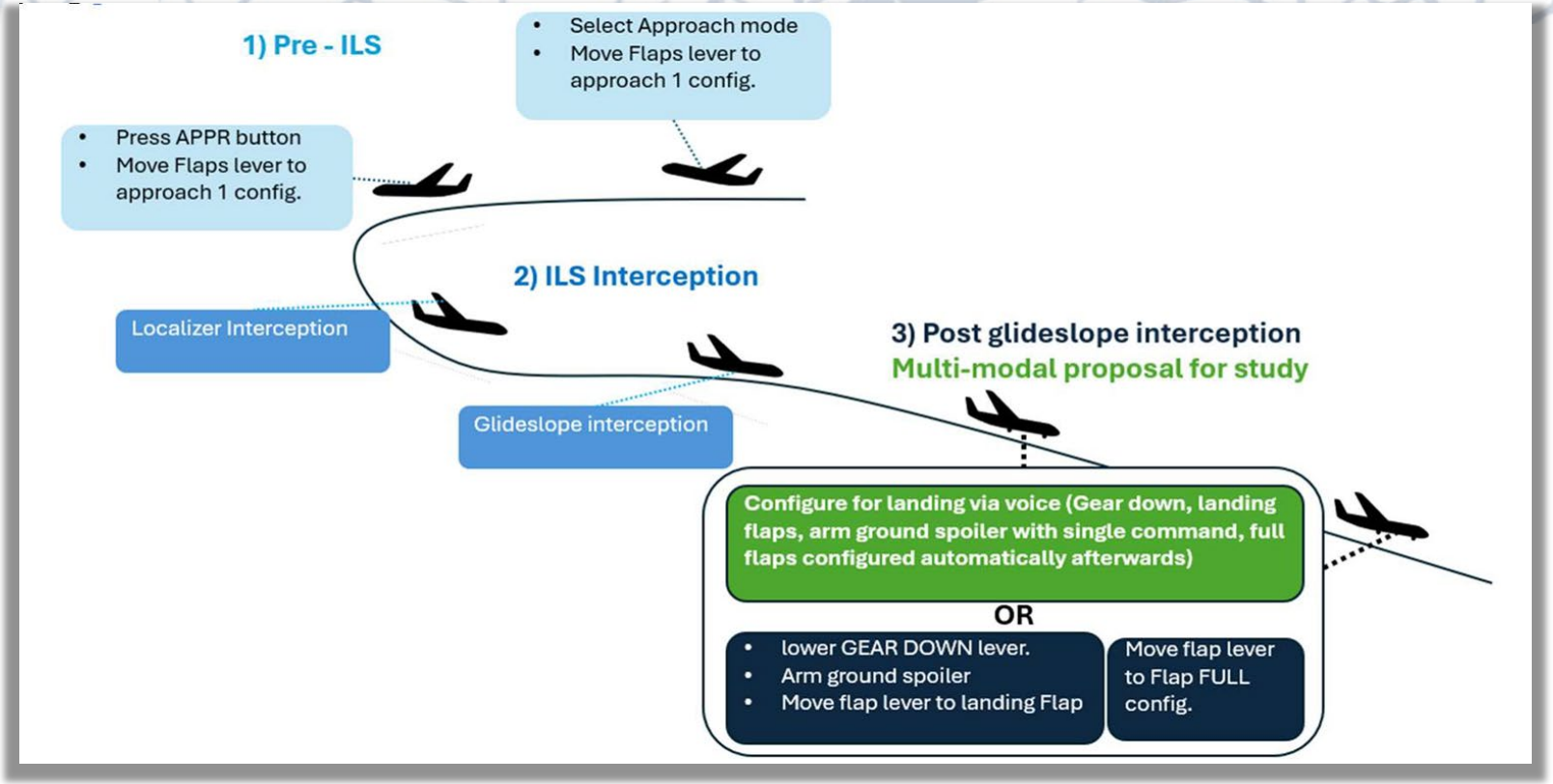
VOICE COMMAND CONCEPT

Current final approach tasks(*Autoland*+ILS)

- Task decomposition during final approach (Carugati et al, 2015)
- Unstable approaches critic for operation(IATA, 2016)
- General aviation: Avionics with autonomous emergency landing system (Garmin, 2022)

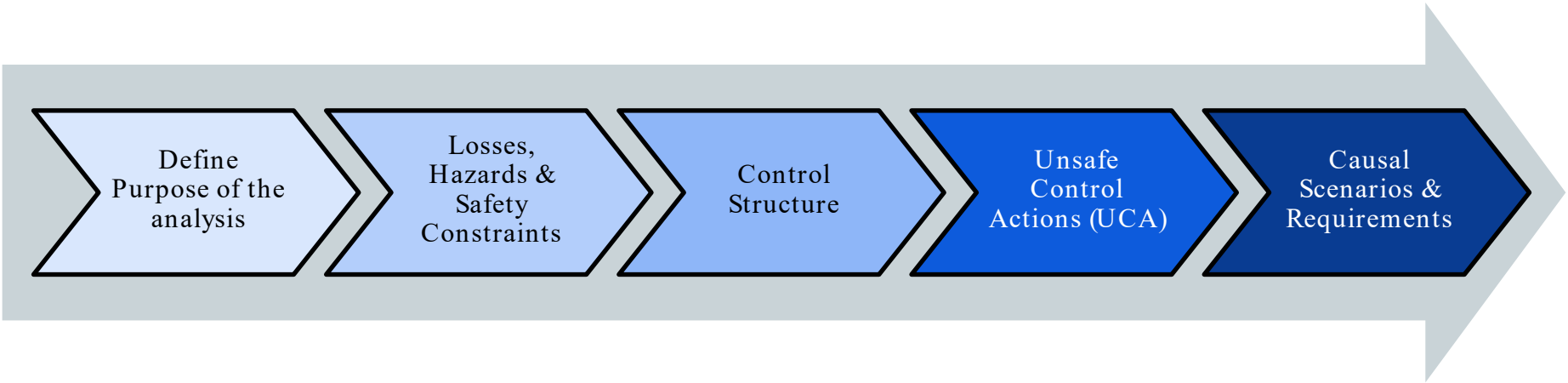


Operational concept using voice command during final approach



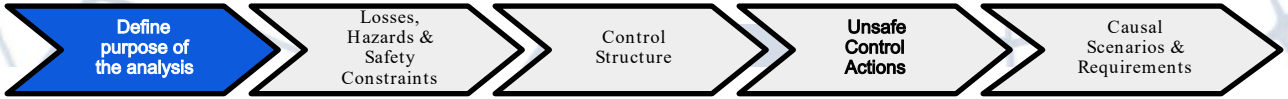
METHODOLOGY

Methodology - STPA



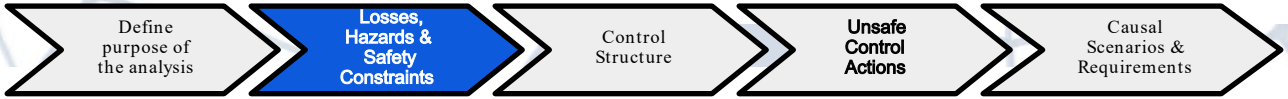
RESULTS

Define Purpose of the Analysis



- Conceptual level: the analysis was performed at a high level of abstraction, corresponding to an early project phase in which detailed design has not yet been defined
- Flight Crew can represent 1 or 2 pilots, so it applies to both single-pilot configurations (SiPOs) and two-pilot flight deck during landing (eMCOs), with specific consideration of UCAs when the operation involves only two crew members.
- Scope of analysis: the focus is on human–machine interaction with the voice-recognition system

Losses, Hazards and System Constraints

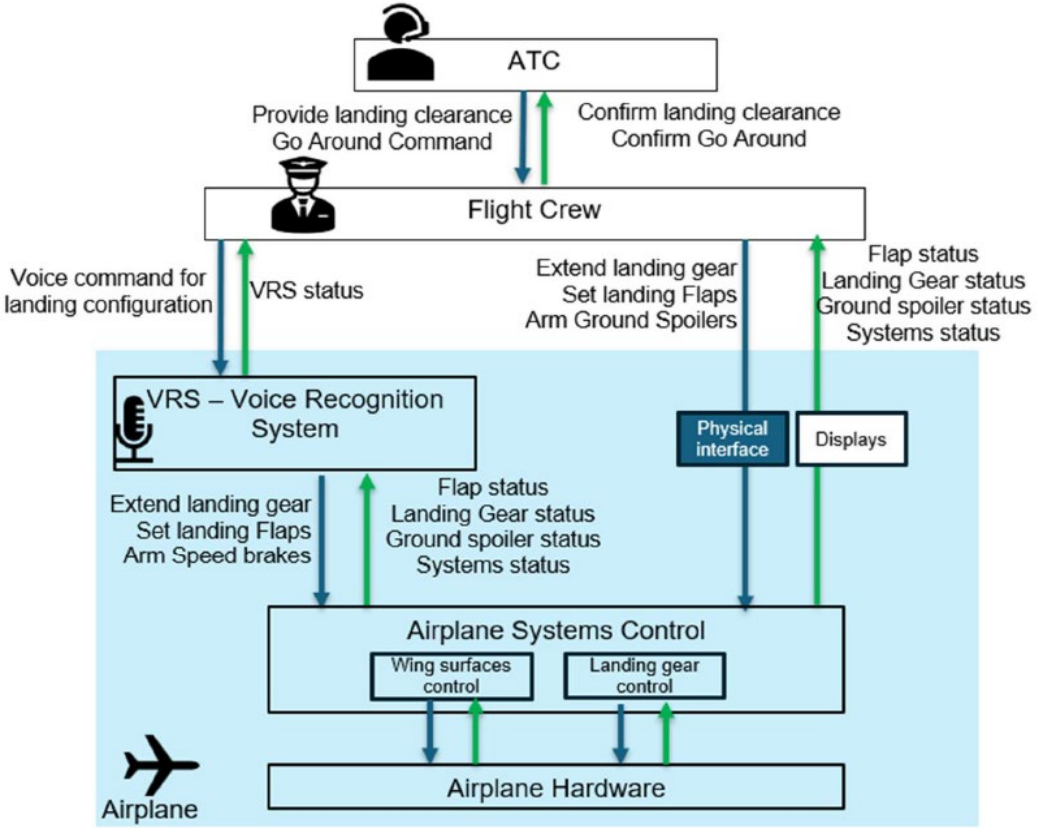


Losses
L1: Loss or damage to human life
L2: Loss or damage to airplane
L3: Loss of airplane aero performance
L4: Loss of customer satisfaction
L5: Loss of airplane control

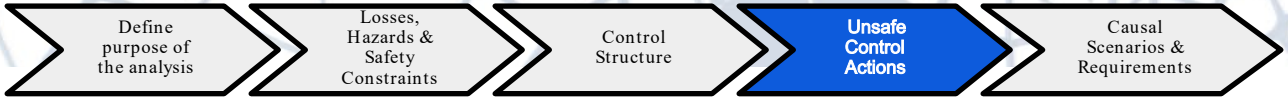
Hazards
H1: Airplane structural envelope is exceeded [L1,L2,L4,L5]
H2: Airplane not stabilized during final approach [L1, L2, L3,L5]
H3: Airplane incorrectly configured for landing during final approach [L1,L2,L3,L4,L5]
H4: Airplane not able to be fully operated by flight crew from different countries/regions/cultures [L4]

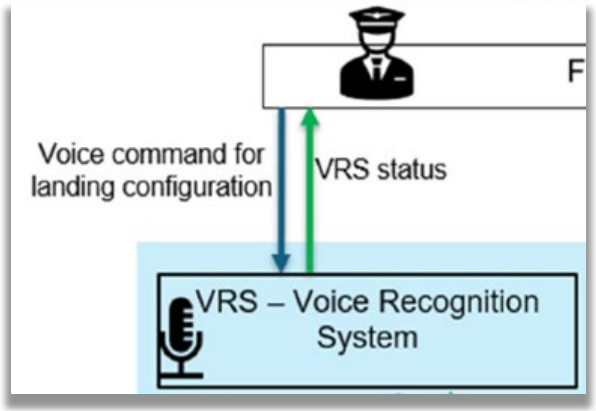
Control Structure

Define purpose of the analysis → Losses, Hazards & Safety Constraints → **Control Structure** → **Unsafe Control Actions** → Causal Scenarios & Requirements



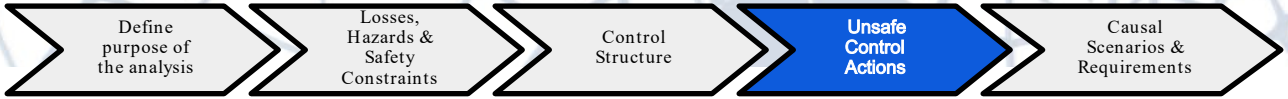
Unsafe Control Actions

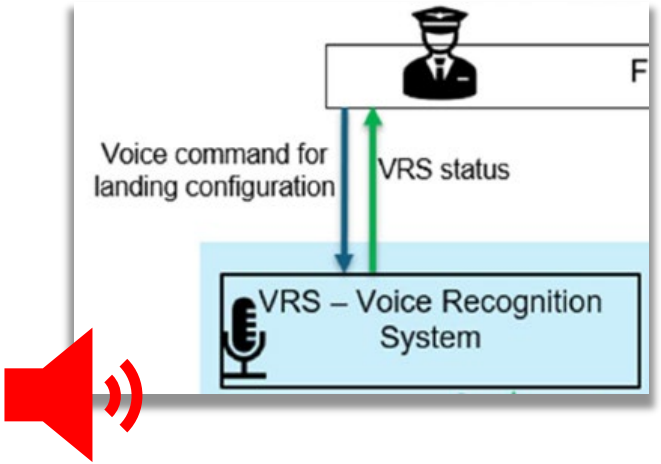




The flight Crew providing voice command for landing configuration is unsafe when...

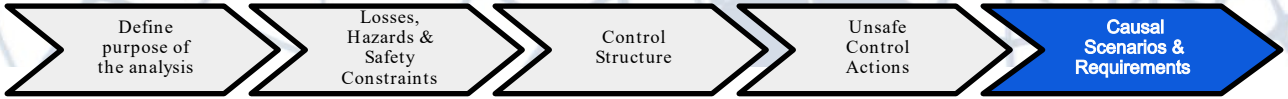
Unsafe Control Actions

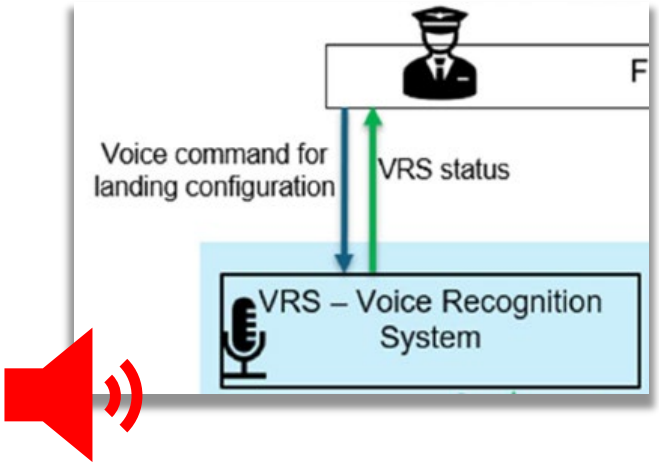




UCA1: The flight crew providing voice command for landing configuration to the VRS is unsafe when the noise level in the flight deck exceeds the threshold for VRS usage.[H2,H3].

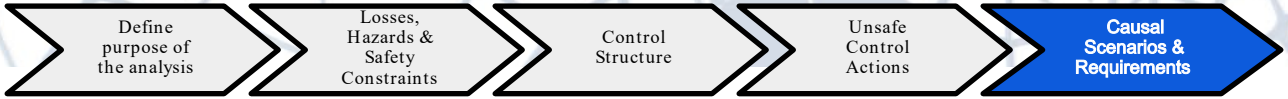
Causal Scenario (Loss Scenario)

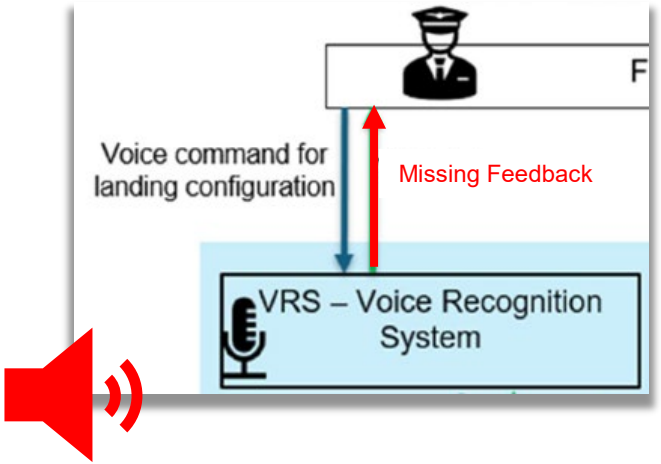




What causal factors in the control loop could lead to the UCA?

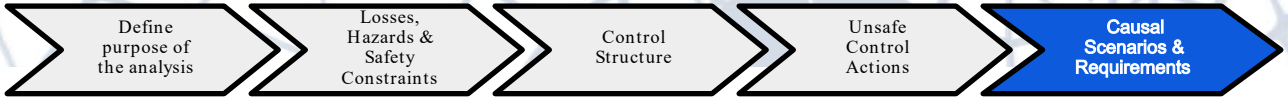
Causal Scenario (Loss Scenario)

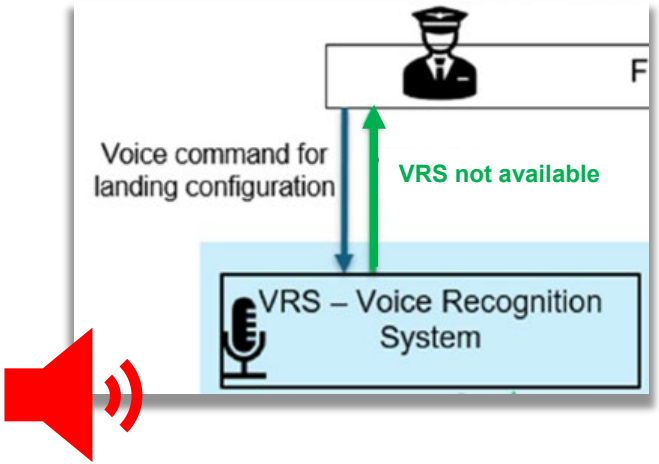




UCA1 -CS1: A missing feedback from the VRS does not inform the flight crew that the voice command for landing configuration is not available due to the noise level in the flight deck exceeding the threshold for VRS usage, causing the flight crew to not being aware of the limitation and providing voice command for landing configuration. [H2,H3]

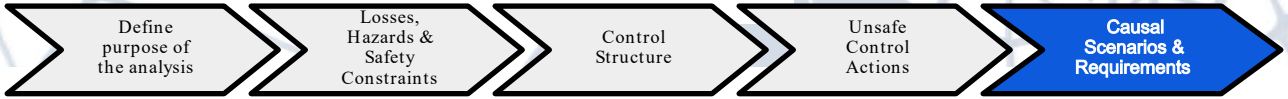
Requirement

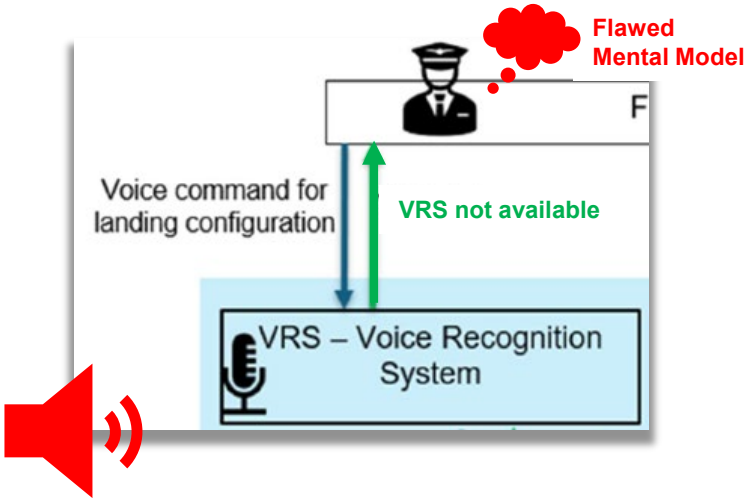




UCA1 -CS1-R1: The Voice Recognition System (VRS) shall provide feedback to the flight crew when voice command for landing configuration is not available, when the noise level in the flight deck exceeds the threshold for VRS usage. [H2,H3]

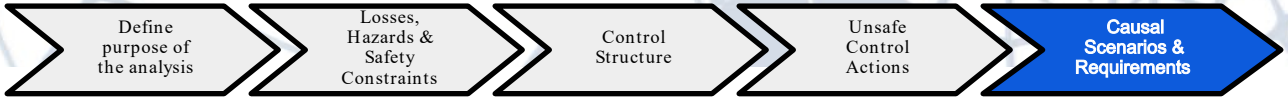
Causal Scenario 2

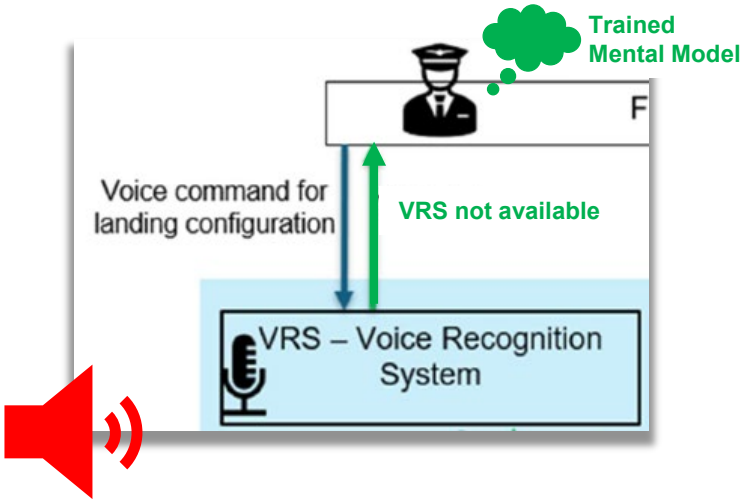




UCA1 -CS2: A flawed flight crew mental model causes them to think that the VRS is available to receive voice command for landing configuration when it isn't, due to the noise level in the flight deck exceeding the threshold for VRS usage, leading to the flight crew still providing the voice command for landing configuration. [H2,H3]

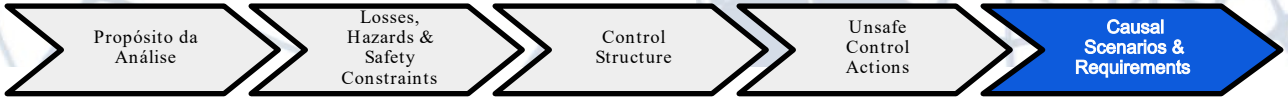
Requirements

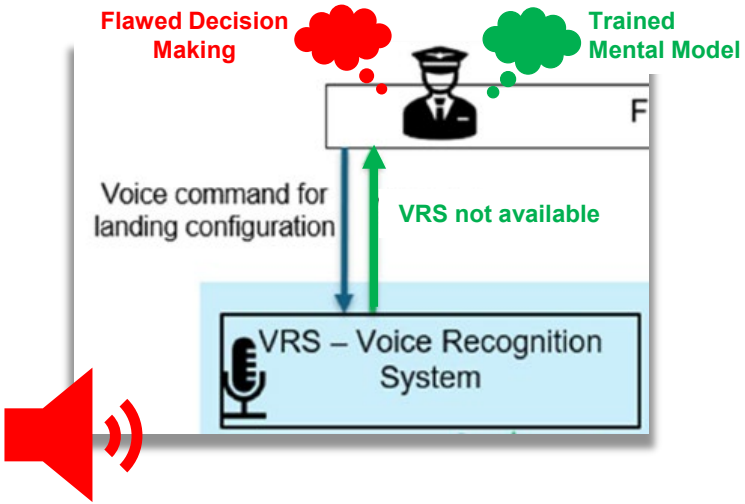




UCA1 -CS2-R1: The flight crew training program shall develop pilot's ability to recognize when the VRS is not available to receive voice command for landing configuration, when the noise level in the flight deck exceeds the threshold for VRS usage.

Requirements

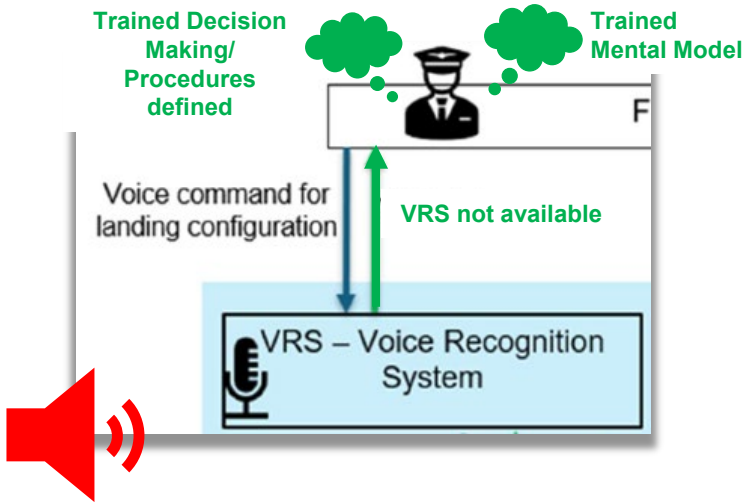




UCA1 -CS3: A flawed flight crew decision making process causes them to provide the voice command for landing configuration to the VRS, even after recognizing that the VRS is not available due when the noise level in the flight deck exceeds the threshold for VRS usage, leading to a high persistence workload and the airplane not being configured for landing. [H2, H3]

Requirements

Define purpose of the analysis → Losses, Hazards & Safety Constraints → Control Structure → Unsafe Control Actions → **Causal Scenarios & Requirements**



UCA1 -CS3-R1: The flight crew training program shall develop pilot ability to not persist in providing the voice command for landing configuration when the VRS is not available.

UCA1 -CS3-R2: The flight crew operational procedures shall define the procedure for when the VRS is not available to receive voice command for landing configuration.

Note: The solution could be promptly providing physical commands (gear, flaps and ground spoiler levers) or proceeding to go around in critical situations.

Other UCA contexts covered

- Speech pattern for voice recognition
- Speed limit for landing configuration
- Conflicting voices in the flight deck
- Command with incorrect timing

Validation performed:

- Human Factors engineering specialist and commercial pilot
- 2 flight deck operations engineers

Conclusion

- **Identified Unsafe Scenarios:** Recognized unsafe voice-command scenarios across various operational contexts.
- **Defined Requirements:** Established Voice Recognition System (VRS), training, and operations requirements reinforcing the value of an HCD approach in a human-system interface development
- **Demonstrated STPA impact:** Confirmed the impact of System-Theoretic Process Analysis (STPA) in early-concept product cycle development
- **Foundation for Future Studies:** experimental research and analyses for integrating voice commands into the flight deck.

THANK YOU!

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