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Towards designing graceful degradation into trajectory based operations:

A human-machine systems integration approach

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Agenda

- Research motivation
- Literature review: Aims
- Framework of graceful degradation
- Literature review: Detailed findings
- The operational envelope?
- Conclusions & Implications
- Next steps

Research motivation

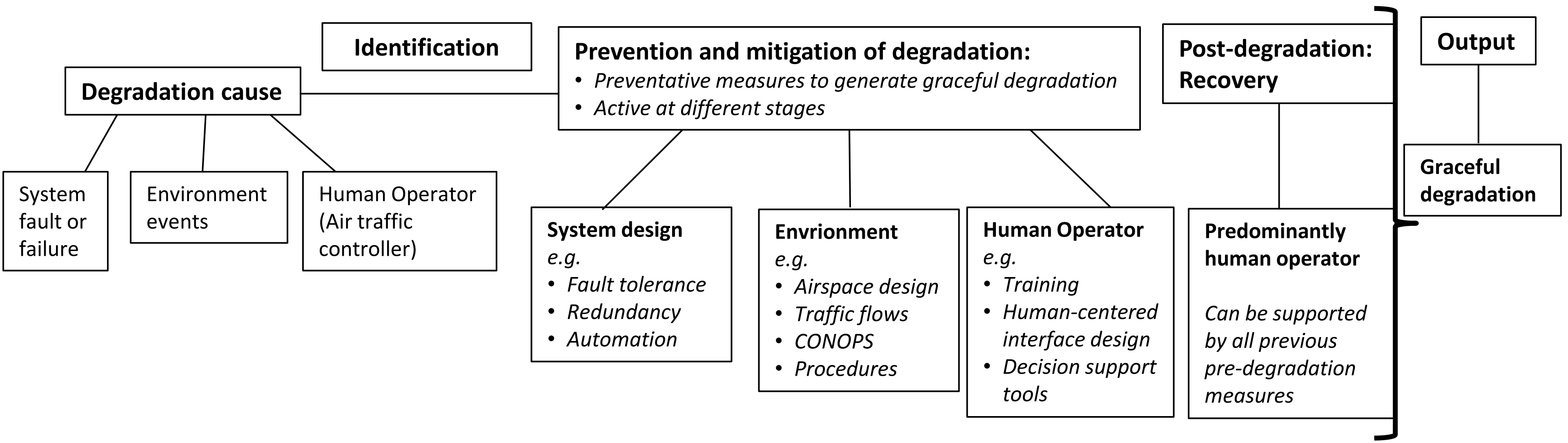
- Trajectory based operations (TBO) is an instrumental concept in the NextGen initiative
- In order for the TBO concept to be realized, there will be a "fundamental shift in ATM" (FAA, 2014):
  - Narrower tolerances (FAA, 2014)
  - More precise trajectories
  - Strategic vs tactical
- System resilience is critical
  - TBO system must be able to gracefully degrade to maintain safe operations
- Knowledge of the causes and mitigations of degradation in TBO must be understood

Literature review

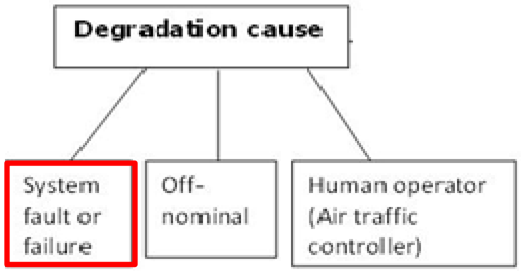
- Aims:
  - Identify causes of degradation in ATC and associated solutions
  - Identify the role of ATCOs in a gracefully degrading system
  - Develop a framework of graceful degradation from the literature

- Expected outcomes
  - Identify causes of degradation and associated solutions applicable to TBO
  - Identify literature gaps and inform future research
  - Implications for ecologically valid understanding of graceful degradation of TBO systems

Framework of graceful degradation

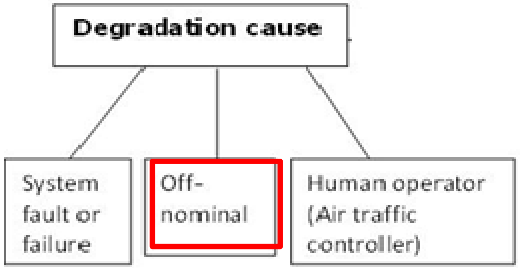


Causes: System fault/ failure



- Widest range of literature
- Primarily focuses on CNS
  - Failure can be full system or partial, such as specific algorithms
- Several categorizations documented, although no consistent agreement
- Causes of hardware failure
  - Physical damage
  - Aging
  - Accidental/malicious interference
- Software failure
  - Modelling errors
  - Integration of independent ATC software
    - Legacy technology and new technology
    - Technology with competing goals

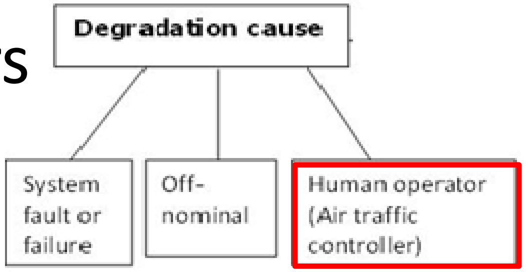
Causes: Off-nominals



- Airspace design
  - Number and type of conflict points
  - Size of available airspace
  - Complexity can increase ATCO demand, which may put performance at greater risk
- Imprecision/uncertainty
- Off nominal events
  - Aircraft emergencies
  - Medical emergencies
  - Unexpected pilot actions
- Weather
  - Widely researched
  - Leading cause of aircraft delay
  - Weather avoidance routes are pre-planned but real time updates limited
  - Consequences include manual vectoring, re-routing, delay and cancellations
  - Controllers responsible for maintaining safe operations during these demanding situations

Causes: Human operators (ATCOs)

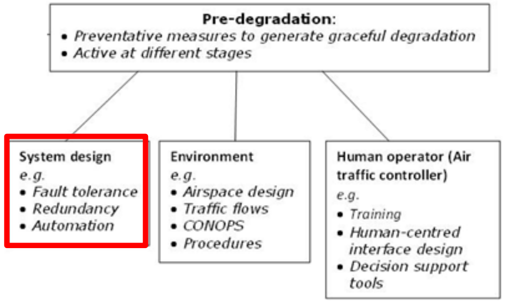
- Least researched in graceful degradation domain
  - Human error literature in Human Factors domain
- Human performance influencing factors
  - Task demand and high workload
  - Attention and perception errors
  - Communication errors
  - Procedural error
- Human performance influencing factors resulting from use of automation (human-system interaction)
  - Underload
  - Trust
  - Design of automation – transparency and reliability



Identification

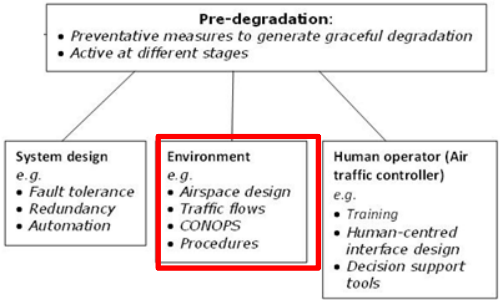
- Required prior to prevention or mitigation
- Techniques can be separated into:
  - Identifying potential causes prior to degradation
  - Identifying causes during live operations
- Techniques prior to degradation include:
  - Incident and accident analysis
  - Causal modelling
- Techniques of identification during live operations include:
  - System self-monitoring and self-identification
  - System communication to human operator
  - Human operator

Achieving graceful degradation: System-related solutions



- Well-documented in the literature
- Bertish et al. (2013) - 18 identified mitigations
  - 14/18 related to technology design and regulation
- Hardware/software solutions
  - Failure paths
  - Back up systems
  - Redundancy
- Requirements- based solutions
  - Quality standards
  - Verification and validation
- Technological solutions for environmental and human causes of degradation
  - Decision support systems
  - Automation
  - Tools to reduce uncertainty, such as enhanced weather prediction

Achieving graceful degradation: Environmental solutions



- Literature primarily focuses on reducing complexity for ATCOs
- Solutions are usually complex
- Airspace redesign
  - Standard traffic flows
  - Flight follow features
  - More efficient reroutes
  - Reduction in complexity – reduction of risk of human error
- Solutions to reduce uncertainty
  - CONOPS
  - Procedures

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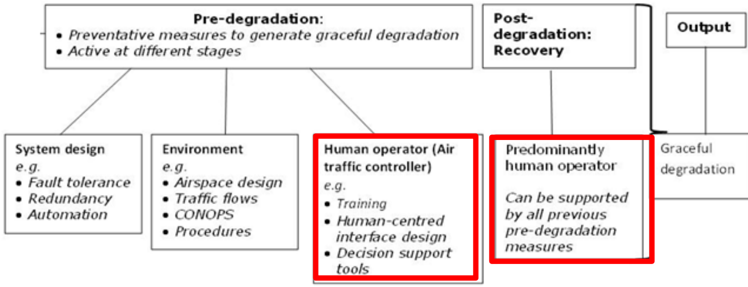
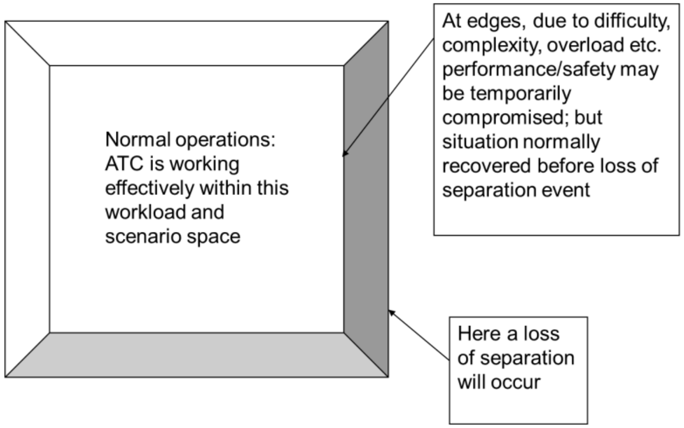
Achieving graceful degradation: Controller

NASA



- Contribution of ATCO to graceful degradation is under-researched
- ATCOs maintain safe operations through a high standard of performance
- Dominant contribution post-degradation– recovery
  - Role is an on-line defense between safe and unsafe operations
- Significant implications for TBO
  - System fault/failure when ATCOs are controlling more aircraft than they could without automation?
  - Framework supports breakdown of this issue
- Need for human – systems integration to support graceful degradation in TBO
  - When do ATCOs reach safe limits of performance?

The operational envelope



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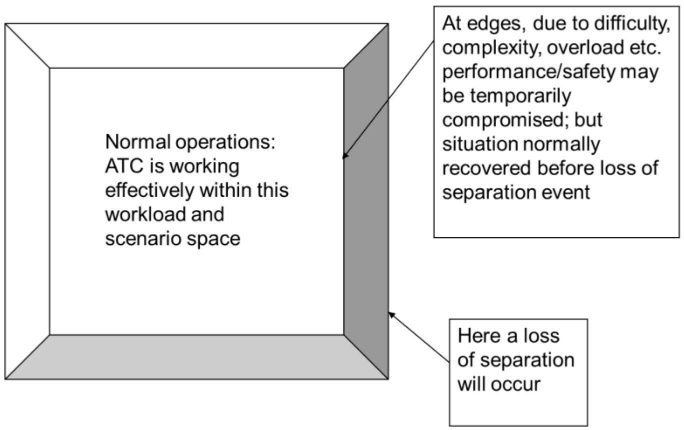
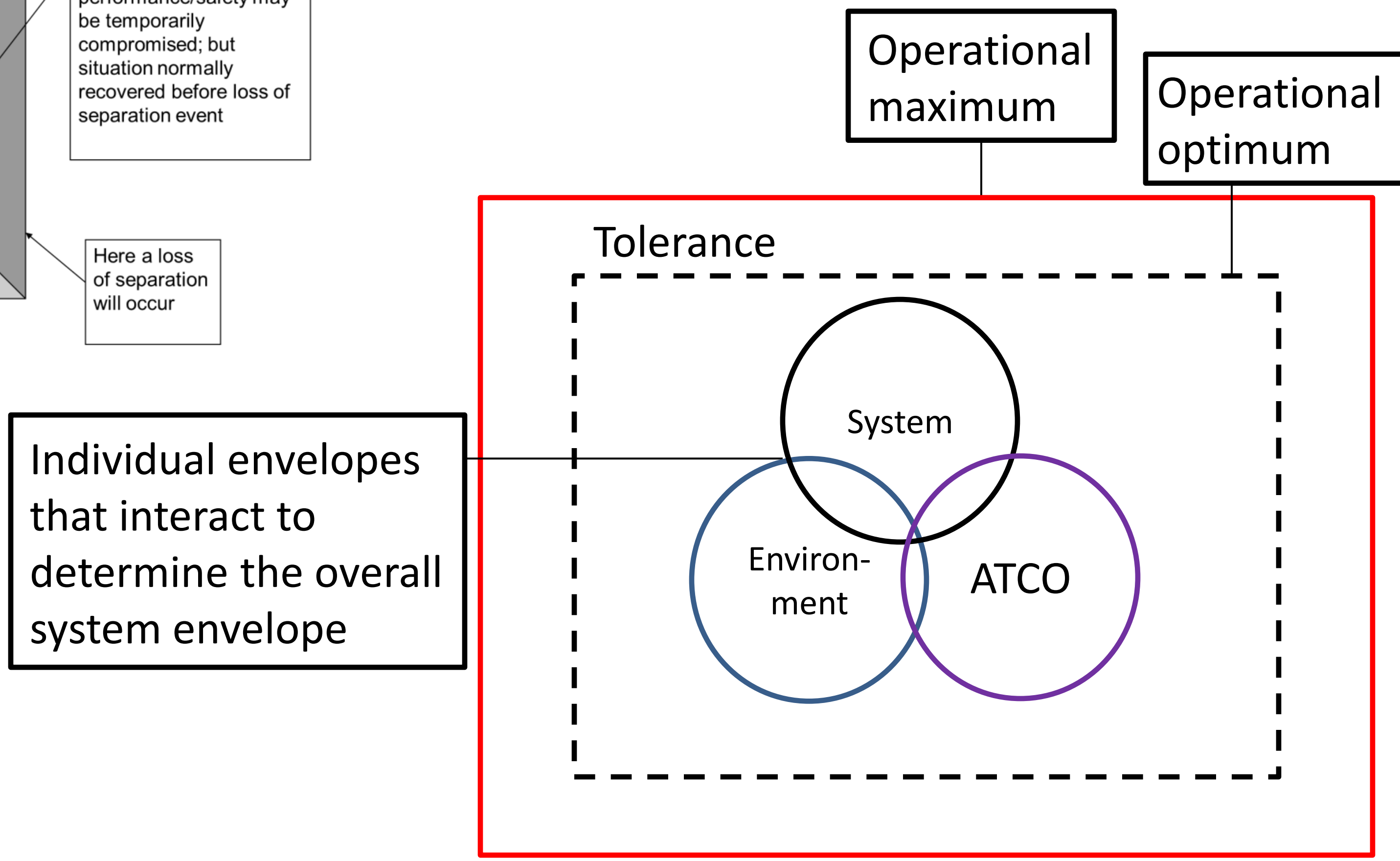
The operational envelope





Conclusions & Implications

- Findings
  - Causes of degradation and solutions categorized by systems, environment and human operators (ATCOs)
  - Solutions to degradation can be applied pre- or post-degradation
  - Most research on systems, least on role of the ATCO
  - Research dominantly considers ATCO to be responsible for maintenance of safe operations during degradation
  - No consideration in current literature of interactions between causes and solutions
- Development of graceful degradation framework can be used to:
  - Identify research gaps
  - Identify causes of degradation and solutions
  - Identify interactions
  - Guide requirements for future research
- Human-system interaction approach essential to achieve graceful degradation in TBO
- Need to understand limits of system performance **AND** human performance

Next Steps

- Literature review completed
  - Paper submitted and accepted to Aviation 2017
- Aims of future work

  Identify causes of degradation in TBO

  Identify the limits of recovery for the human operator

Cognitive walk-through

- Down selection of assumptions
- Selection of use cases
- Initial understanding of recovery strategies
- Initial understanding of limits of recovery

Human in the loop simulations

- Identification of human envelope ‘limits’
- Investigation of human and system performance envelope interaction
- Development of solutions to specific TBO issue to create graceful degradation

Future goal

Re-design of the system

- Propose potential re-design of the system, airspace, or human tasks/procedures
- Monitoring the situation prior to full breakdown
- Support the recovery phase

Thank you!

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