

**National Aeronautics and Space Administration**



# Aircraft Loss of Control Study

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# Outline

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- ! Introduction
- ! NASA Loss of control study team approach
- ! Background on Aircraft loss of control Accidents
- ! Causal factors
- ! Recommended mitigations
- ! Supporting Research



# Abstract

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Loss of control has become the leading cause of jet fatalities worldwide. Aside from their frequency of occurrence, accidents resulting from loss of aircraft control seize the public's attention by yielding large numbers of fatalities in a single event. In response to the rising threat to aviation safety, NASA's Aviation Safety Program has conducted a study of the loss of control problem. This study gathered four types of information pertaining to loss of control accidents: (1) statistical data; (2) individual accident reports that cite loss of control as a contributing factor; (3) previous meta-analyses of loss of control accidents; and (4) inputs solicited from aircraft manufacturers, air carriers, researchers, and other industry stakeholders. Using these information resources, the study team identified causal factors that were cited in the greatest number of loss of control accidents, and which were emphasized most by industry stakeholders. For each causal factor that was linked to loss of control, the team solicited ideas about what solutions are required and future research efforts that could potentially help avoid their occurrence or mitigate their consequences when they occurred in flight.



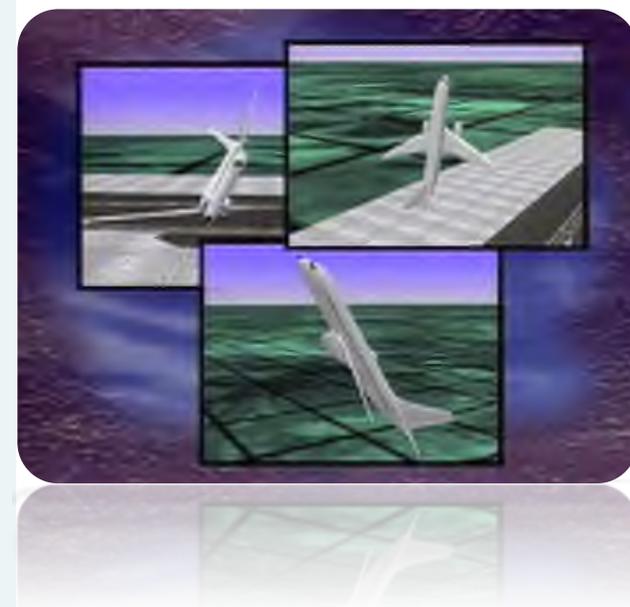
# Loss of Control defined

| Source                                   | Definition   |
|--|--|
| 2000 CAST JSAT Report on Loss of Control | <p><b>Loss of control to includes significant, unintended departure of the aircraft from controlled flight, the operational flight envelope, or usual flight attitudes, including ground events.</b> "Significant" implies an event that results in an accident or incident. This definition excluded catastrophic explosions, CFIT, runway collisions, complete loss of thrust that did not involve loss of control, and any other accident scenarios in which the crew retained control. <b>This does include loss of control, due to aircraft design, aircraft malfunction, human performance, and other causes</b></p> |



# Loss of Control defined

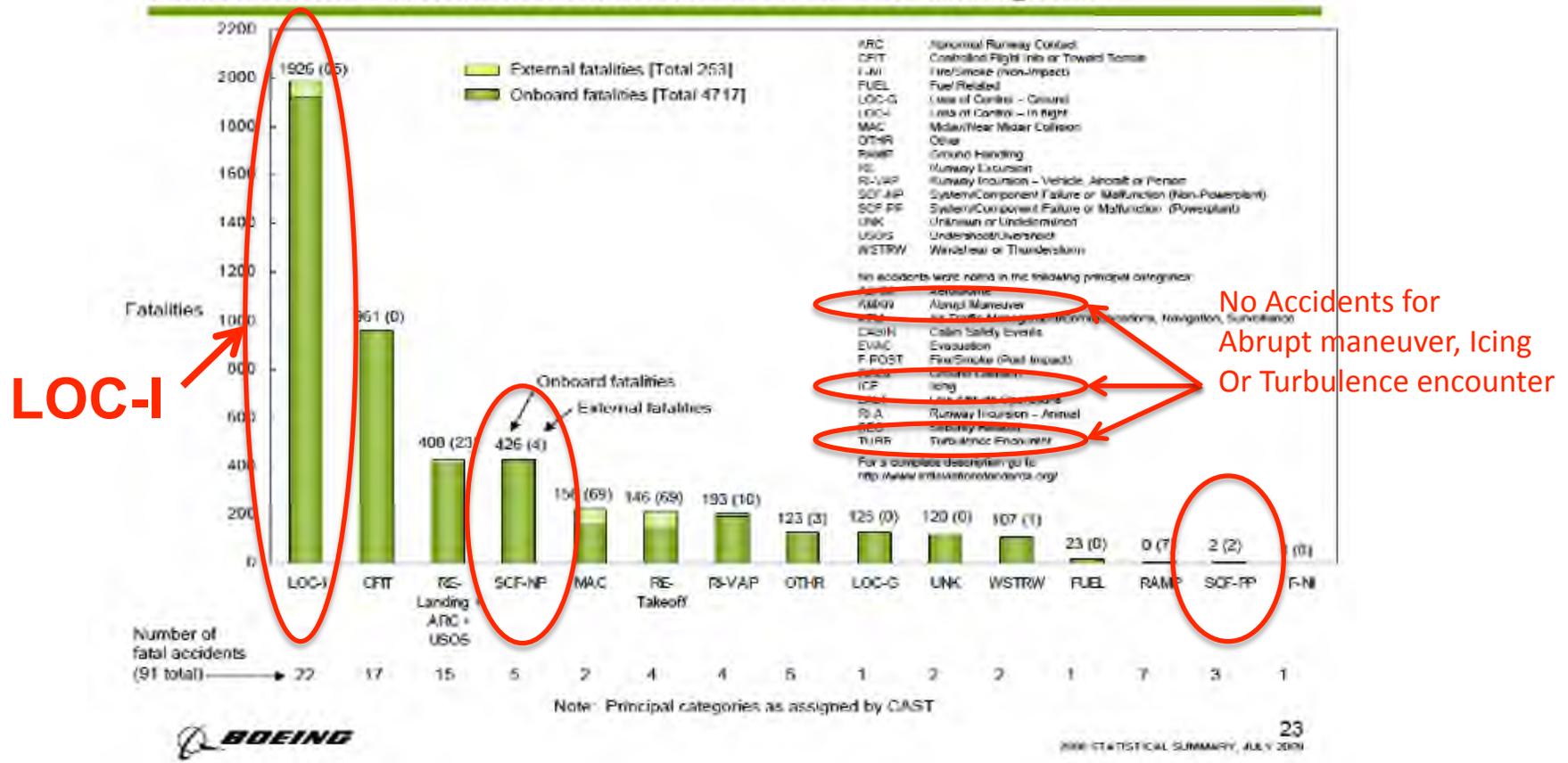
| Source                                      | Definition   |
|---|--|
| Airplane Upset Recovery Training Aid (2008) | <p>While specific values may vary among airplane models, the following unintentional conditions generally describe an airplane upset:</p> <ul style="list-style-type: none"><li>• Pitch attitude greater than 25 deg, nose up.</li><li>• Pitch attitude greater than 10 deg, nose down.</li><li>• Bank angle greater than 45 deg.</li><li>• Within the above parameters, but flying at airspeeds inappropriate for the conditions.</li></ul> |



# Boeing's Annual Report (International accidents included)



**Fatalities by CAST/ICAO Common Taxonomy Team (CICCT)  
Aviation Occurrence Categories  
Fatal Accidents – Worldwide Commercial Jet Fleet – 1999 Through 2008**



*So what's in there?*

# NASA AvSafe Loss of Control Study



Team Chartered in October through December

| Role             | Name             | Center    | Areas of Expertise   |
|------------------|------------------|-----------|--|
| Team lead        | Steve Jacobson   | NASA DFRC | Flight research, flight dynamics   |
| Member           | John Foster      | NASA LaRC | Flight research, flight dynamics, CAST loss of control study team                            |
| Member           | Gautam Shah      | NASA LaRC | Flight research, flight dynamics, CAST loss of control study team, API, Flight Control, IRAC |
| Member           | Gene Addy        | NASA GRC  | Icing, Icing research tunnel, API for Icing in IRAC  |
| Member           | Andy Reehorst    | NASA GRC  | Icing, flight test, CAST JSIT and JSAT (LOC and Remaining Risk)                              |
| Member (primary) | Stephen Casner   | NASA ARC  | Human factors, flight training, pilot-automation interaction                                 |
| Member (backup)  | Jessica Nowinski | NASA ARC  | Human factors, Human performance and Human Error, PM for IIFD                                |



# LOC Study team objective

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- ! This study team is to provide a systematic, data-driven analysis of the fundamental research required to address loss of control,
- ! There is a lot of data out there and three months is not enough time to thoroughly analyze the data with seven people
- ! A hybrid approach was adopted

# LOC Study Team Approach (3 months)

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- ! Review statistical data; Statistics are good at categorizing accidents but don't provide much insight into mitigations
- ! Review some individual accident reports that cite loss of control as a contributing factor;
- ! Review previous meta-analyses of loss of control accidents;

# LOC Study Team Approach (cont...)

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- ! Identified causal factors that were cited in the greatest number of loss of control accidents, and which were emphasized most by industry stakeholders.
- ! For each causal factor that was linked to loss of control, the team solicited ideas about what solutions are required and future research efforts that could potentially help avoid their occurrence or mitigate their consequences when they occurred in flight
- ! Recommend priority to NASA on Mitigations and Research (not discussed in this presentation)

# Background on Aircraft Loss of Control

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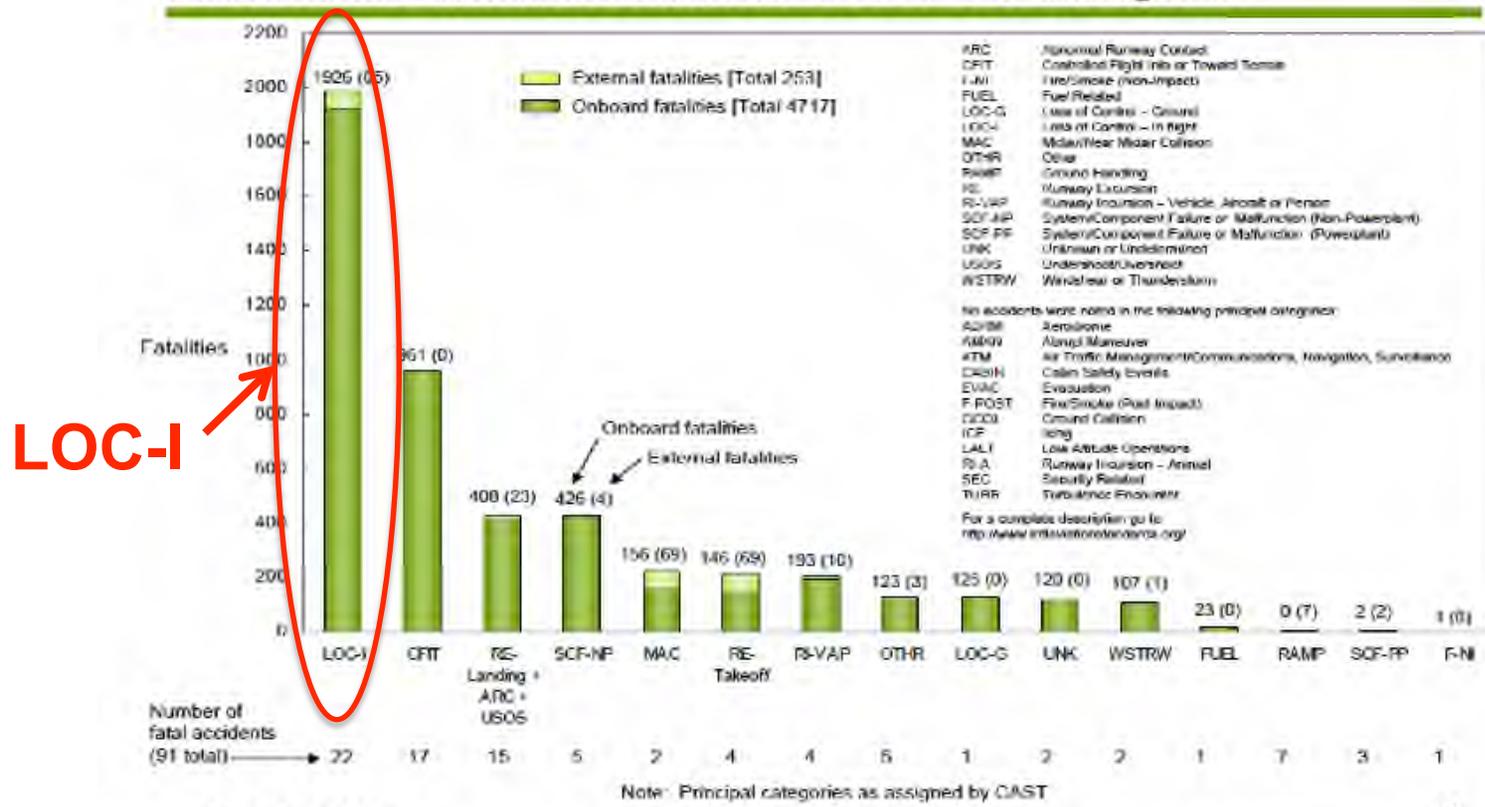


- ! Much of the research focus has been on scheduled commercial transport aircraft (Part 121 operations)
- ! Other considerations for LOC
  - !Part 135 (Commuter and on demand operations)
  - !Part 91 (private operations or GA)

# Boeing's Annual Report (International accidents included)



## Fatalities by CAST/ICAO Common Taxonomy Team (CICCT) Aviation Occurrence Categories Fatal Accidents – Worldwide Commercial Jet Fleet – 1999 Through 2008



*So what's in there?*



# Boeing Statistical data

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| Causal factor category | # Accidents as Primary CF | # Accidents as Contributing CF |
|------------------------|---------------------------|--------------------------------|
| Pilot/human induced    | 16                        | 22                             |
| Environmental induced  | 4                         | 5                              |
| Systems induced        | 2                         | 7                              |

LOC-I Accidents that occurred in each causal factor category 1999-2008

Based on Boeing Statistical Summary of Commercial Jet Airplane Accidents 1999 - 2008



# Boeing Statistical data

| Causal factor             | # Accidents w/CF |
|---------------------------|------------------|
| Pilot/human induced       |                  |
| Improper Procedure        | 10               |
| Spatial disorientation    | 6                |
| Poor energy management    | 6                |
| Distraction               | 5                |
| Improper training         | 5                |
| Poor design               | 2                |
| Environmental induced     |                  |
| Weather                   | 3                |
| Icing                     | 2                |
| Wake vortex               | 1                |
| Systems induced           |                  |
| Aircraft systems failures | 5                |
| Poor Design               | 2                |

Causal factors contributing to LOC-I commercial aircraft fatalities 1999 - 2008

Based on Boeing Statistical Summary of Commercial Jet  
Airplane Accidents 1999 - 2008



# Boeing Statistical data

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| Region                  | Number of fatal accidents |
|-------------------------|---------------------------|
| Asia (ex China)         | 6                         |
| Europe                  | 5                         |
| Africa                  | 4                         |
| Latin America/Caribbean | 3                         |
| CIS                     | 2                         |
| Middle East             | 1                         |
| USA/Canada              | 1                         |
| China                   | 0                         |

Regions where fatal LOC-I commercial aircraft fatalities occurred 1999-2008

Based on Boeing Statistical Summary of Commercial Jet Airplane Accidents 1999 - 2008



# Boeing Statistical data

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| Phase of flight  | Number of fatal accidents |
|------------------|---------------------------|
| Climb            | 6                         |
| Take off         | 5                         |
| Final approach   | 3                         |
| Initial climb    | 2                         |
| Cruise           | 2                         |
| Initial approach | 2                         |
| Landing          | 2                         |

Flight phase where fatal loss of control accidents occur 1999 - 2008

Based on Boeing Statistical Summary of Commercial Jet  
Airplane Accidents 1999 - 2008

# Observations from the accidents in the Boeing Statistical Data

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- ! Finding 1: Out of the 22 accidents in the LOC-I occurrence category, the leading causal factors come from pilot/human induced category
- ! Finding 2: For large aircraft, the majority (95%) of recent LOC-I fatal accidents occur outside of the United States and Canada.
- ! Finding 3: The majority (81%) of recent LOC-I accidents occur during flight phases where the aircraft is relatively close to the ground where there is little time for action, and where circumstances are unforgiving of mistakes.

# Observations from the accidents in the Boeing Statistical Data

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- ! Finding 4: Flight crew deviation from prescribed procedure is a very significant factor in loss of control accidents.
- ! Finding 5: Spatial disorientation is a problem, but it occurs primarily outside of the United States.
- ! Finding 6: Poor energy management (e.g. aerodynamic stall) is a significant factor in loss of control accidents.

*The Boeing Data only focus on Aircraft greater than 60,000 lbs.  
Further Insight into smaller AC were needed*

# NASA Systems Analysis Report of Aircraft Loss of Control

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- ! “Causal Factors and Adverse Conditions of Aviation Accidents and Incidents Related to Integrated Vehicle Aircraft Control” NASA TM-2010-216261
- ! Currently completing the review process
- ! Examines, Part 121, Part 135 scheduled and nonscheduled operations, and Part 91

# Data from NASA Systems Analysis Report of Aircraft Loss of Control



| Type of events                                | Operation Category |                    |                              |                               | Part 91, 135, & 121 Combined  |
|---|--------------------|--------------------|------------------------------|-------------------------------|-------------------------------|
|   | Part 121           | Scheduled Part 135 | Non-Scheduled Part 135       | Part 91                       |                               |
| Total Flight Hours                            | 251,751,143        | 25,353,146         | 49,588,000                   | 441,207,000                   | 767,896,289                   |
| Total Accidents                               | 630                | 217                | 1115                         | 24473                         | 26435                         |
| LOC Accidents                                 | 26 (4% of Total)   | 32 (15% of Total)  | 198 (18% of Total Accidents) | 4961 (20% of Total Accidents) | 5217 (20% of Total Accidents) |
| <b>LOC Accidents per million flight hours</b> | <b>0.10</b>        | <b>1.26</b>        | <b>4.03</b>                  | <b>11.24</b>                  | <b>6.79</b>                   |

# NASA LOC SA report continued



| Type of events                                | Operation Category          |                             |                              |                               |                               |
|---|-----------------------------|-----------------------------|------------------------------|-------------------------------|-------------------------------|
|   | Part 121                    | Scheduled Part 135          | Non-Scheduled                | Part 91                       | Part 91, 135, & 121           |
| Fatal Accidents                               | 62 (10% of total accidents) | 49 (23% of total accidents) | 293 (26% of Total Accidents) | 4815 (20% of Total Accidents) | 5289 (20% of Total Accidents) |
| Fatal LOC Accidents                           | 21 (81% of LOC accidents)   | 19 (59% of LOC accidents)   | 128 (65% of LOC Accidents)   | 2635 (53% of LOC Accidents)   | 2803 (54% of LOC Accidents)   |
| Total Fatalities                              | 2165                        | 328                         | 698                          | 9146                          | 12337                         |
| Fatalities in LOC Accidents                   | 1186 (55%)                  | 161 (49%)                   | 285 (41%)                    | 5178 (57%)                    | 6810 (55%)                    |
| Total Incidents                               | 7808                        | 2234                        | 2201                         | 29520                         | 41,763                        |
| LOC Incidents                                 | 38                          | 5                           | 8                            | 81                            | 132                           |
| <b>LOC Incidents per million flight hours</b> | <b>0.151</b>                | <b>0.197</b>                | <b>0.161</b>                 | <b>0.18</b>                   | <b>0.17</b>                   |

# Observations from the data in the NASA Systems Analysis study on LOC

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- ! Finding 7: More than half of LOC-I events result in an accident and more than half of those accidents are fatal.
- ! Finding 8: In approximately 1/3 of Part 121 loss of control accidents, loss of control was due to a system component failure.
- ! Finding 9: Approximately 34% of all fatal Part 121 accidents are LOC accidents
- ! Finding 10: In approximately 1/3 of Part 121 accidents, the NTSB determined control was not possible.



# Mitigations

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- ! Mitigation Hierarchy
  - ! Design/Eliminate the hazard
  - ! Safety devices to minimize risk
  - ! Detect/Warn
  - ! Procedures/Training
  - ! Placards

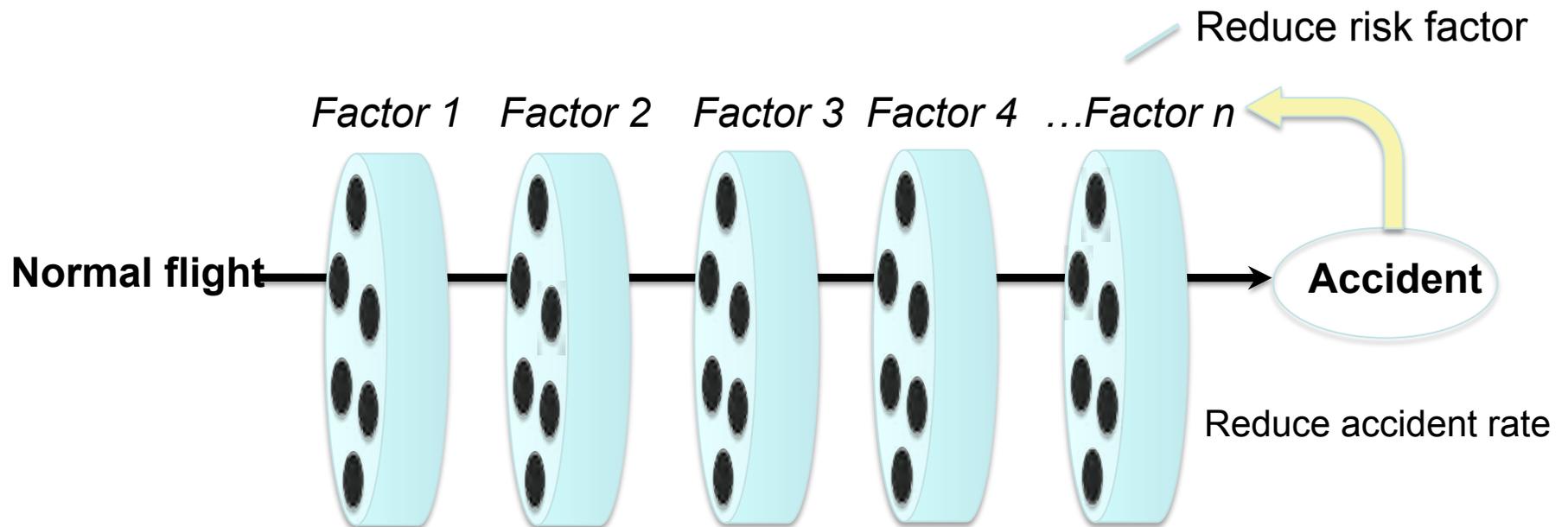


# Mitigation Classification for LOC

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- ! **Avoid:** Avoidance is usually tied to design of systems that eliminate the hazard and safety mitigations but may also include standard operating procedures and training to avoid loss of control scenarios.
- ! **Detect:** Detection is tied to the detect/warn category of mitigations and these mitigation strategies but may also include training to recognize the onset of a hazardous situation.
- ! **Recover:** Recovery is the last line of defense and has strong ties to the procedures/training category, but may also benefit from automatic systems, safety devices and warning devices to aid in the recovery of the vehicle.

# Accident elimination through elimination of multiple causal factors



*Break the chain of events at multiple points and prevent the event  
Due to the myriad of causal factors for LOC,  
multiple strategies are warranted that include ...  
Avoidance, Detection and Recovery*

# Current NASA LOC Research: IRAC-FAST Objectives



Can Modern Control  
Systems Help the Pilot Out  
Even More Than  
Traditional Methods????



- ! The above were survivable accidents; IRAC maybe able to help more.
- ! Objectives
  - ! Regain a Stable Platform
    - ! Evaluate Robustness metrics for nonlinear adaptive systems
  - ! Maneuverability (can you fly it around)
    - ! Control vehicle within new constraints / structural loads etc..
  - ! Provide the ability to safely land the airplane
    - ! Develop safest recovery trajectory

***The current IRAC work falls under the mitigation categories of  
Avoidance and Recovery***

# NASA LOC Work: IVHM and IIFD

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# Upset recovery training for civil aviation

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- ! General Aviation: Level stall recovery
- ! Commercial Aviation:
  - !Stall prevention, including stick shaker
  - !No stick pusher training in simulation
- ! Upset Recovery Training Aid
- ! FAA training rules are in the revision process

*Loss of Control training in civil aviation is almost nonexistent*



# Upset Recovery Training Aid

<http://www.faa.gov/pilots/training/>

- ! Developed by Boeing, Airbus and Flight Safety (revised Nov, 2008)
  - ! Defines Upsets
  - ! Examines Causes
  - ! Aerodynamics
  - ! Recovery techniques
- ! Report, Briefing material, Videos
- ! Optional: Not widely adopted by industry





# Mitigation Development strategy

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- ! **Near term impact (5-10 yrs):** LOC Training, Better Standard operating Procedures
- ! **Mid Term impact (5 – 20 yrs):** IVHM, improved displays, aircraft attitude and energy management tools, envelope protection/limiting, improved automation and warning systems, adaptive control
- ! **NextGen impact (Long term):** Aircraft design, system architectures, improved V&V

# Stakeholders consulted during the Aircraft LOC Study

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- ! Regulatory agencies
  - ! FAA
  - ! NTSB
- ! Operators
  - ! Air Line Pilots Association (ALPA)
  - ! Commercial pilots
  - ! Safety directors for Airlines
- ! Manufacturers
  - ! Boeing
  - ! Airbus
  - ! Honeywell
- ! Other organizations
  - ! CAST members
  - ! NASA researchers
  - ! CALSPAN
  - ! Flight Safety

# Stakeholder feedback: Research Needs

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- ! **Training for upset recovery and prevention**
  - ! Identify the most effective way to train pilots to mitigate loss of control events
  - ! motion based vs. fixed based simulations
  - ! Prevention vs. Recovery training:
  - ! Conduct research that may be used to develop training products
- ! **Aerodynamic and dynamic model development for upset recovery and prevention**
- ! **Envelope protection, envelope limiting and energy management**

# Causal factor categories

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## **Human Induced**

- ! Manual handling errors
- ! Poor Energy Management
- ! Automation Effects On Human Induced Loss-Of-Control
- ! Spatial Disorientation
- ! Improper Procedures

## **Externally Induced**

- ! Icing
- ! Turbulence
- ! Degrading Visibility
- ! Heavy Rain
- ! Low-Level Windshear

## **Systems Induced**

- ! Poor systems design
- ! Poor energy management
- ! Autopilot modes leading to loss of control
- ! Pilot induced oscillation
- ! Erroneous sensor data
- ! Loss of control power, authority, or effectiveness Display errors
- ! Propulsion system faults/failures/damage

# Human induced LOC: Manual Handling Errors

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## **CF: Inadequate Pilot Training for Upset Recovery**

Mitigation: Improved upset recovery training

- ! Study the impact of upset recovery training during transitional flight training
- ! Study the effectiveness of providing pilots with an enhanced understanding of the behavior of an aircraft near or outside the limits of normal flight regimes.
- ! Manual control strategies during upset recovery
- ! Development of aerodynamics and dynamic models for out of envelope conditions (including generic models)
- ! Understanding the importance of simulator motion in upset recovery training.
- ! Evaluate the use of In-flight simulators for Upset Recovery Training.

# Human induced LOC: Manual Handling Errors

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## **CF: Atrophy Of Manual Flying Skills**

Mitigation: Provide pilots with increased opportunity to exercise manual flying skills.

- ! Assess how specific automated systems, both inside and outside the cockpit, are affecting the retention of manual flying skill.
- ! Develop guidelines for frequency of manual flight time for normal and abnormal operations in order to maintain pilot proficiency.
- ! Identify ways in which manual navigation, guidance, and control skills can be regularly practiced during normal flight operations in order to keep manual skills sharp.

## **CF: Poor Aircraft Handling Qualities During Upset Events**

Mitigation: Develop automatic control mechanisms to prevent LOC, recover or aid in the recovery of the airplane

- ! Control aids for prevention and recovery from LOC .

# Human induced LOC: Poor Energy Management

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## **CF: Poor Energy Management**

Mitigation: Improve pilot awareness of energy state.

- ! Display and alerting methodologies for critical aircraft configuration states.
- ! Design criteria and methodologies for low energy alerting and warning systems.
- ! Improved envelope protection systems to maintain energy state.

# Human induced LOC: Automation Effects On HI-LOC

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## **CF: Automation Confusion/Mode Confusion**

- ***Pilot misunderstanding of automation***
- ***Poor feedback to the pilot about the state of automation systems***
- ***Lack of understanding of automation systems by the pilot***
- ***Failure of automation system***

Mitigation: Develop more simple pilot interfaces to prevent confusion about automation.

- ! Human Centric Pilot interfaces.
- ! Human Centric Verification and Validation Methods .
- ! Develop Human Centric Models of Automatic Systems
- ! Procedures-plus-concepts training
- ! Research to determine most appropriate information to display to the pilot about

# Human induced LOC: Spatial Disorientation

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## **CF: Spatial Disorientation**

Mitigation: Train pilots to better recognize, avoid, and recover from spatial disorientation

Mitigation: Enhanced pilot warning and alerting systems for spatial disorientation

Mitigation: Enhanced envelope protection and envelope limiting technologies.

- ! Understanding the causes and effects of spatial disorientation..
- ! Spatial disorientation detection and recovery aids .
- ! Strategies for using envelope protection and envelope limiting without introducing additional hazards .

\* New CAST group is forming on SD and Energy management



# Environmentally Induced LOC

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- ! Not as significant of a factor as human induced LOC

| Causal Factor        | Part 121 and 135<br>Scheduled<br>(40 LOC accidents) | Part 135<br>Unscheduled<br>( 159 LOC accidents) | Part 91<br>(4287 LOC accidents) |
|----------------------|---|---|---------------------------------|
| Icing                | 54%   | 27%   | 6%                              |
| Turbulence           | 11%   | 22%   | 20%                             |
| Degrading Visibility | 9%  | 14%   | 18%                             |
| Heavy Rain           | 6%  | 5%  | 2%                              |
| Low-Level Windshear  | 4%  | 3%  | 2%                              |

# Environmentally Induced LOC: Icing

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- ! Causal Factor: In-flight or ground Icing leading to:
  - ! Increased stall speed
  - ! Nonlinear flight dynamics
  - ! Propulsion system degradation
  - ! Air data problems
- ! Mitigations:
  - ! improved weather nowcast and forecast products
  - ! remote icing weather sensors
  - ! Operator and ground crew training
  - ! Development of advanced computational icing prediction methods.
  - ! Developing experimental icing databases making aircraft icing tolerant through the improvement of certification standards
  - ! Automated detection of ice accretion

# Environmentally Induced LOC Icing

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- ! Icing Mitigations:
  - ! improved weather nowcast and forecast products
  - ! remote icing weather sensors
  - ! Operator and ground crew training
  - ! Development of advanced computational icing prediction methods.
  - ! Developing experimental icing databases making aircraft icing tolerant through the improvement of certification standards
  - ! Automated detection of ice accretion
  - ! Develop flight dynamic models for ice contaminated wings.
  - ! Automated recovery from contaminated wing stall.
  - ! Detect HIWC conditions
  - ! Detect ice buildup in rotating and reciprocating engines.
  - ! Develop air data blockage detection technology

# Systems Induced LOC: Poor design

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## Causal Factor: Poor design

- ! Lack of coordination between autopilot and autothrottles
- ! Poor use of redundancy management
- ! Poor indication to the pilot on the state of the automation
- ! Autopilot surprises the crew

## •! Mitigations

- ! Verification and Validation (V&V) of complex systems
- ! Integrated aerodynamic and propulsion control.

# Systems Induced LOC: Faults, Failures and Damage

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## Causal Factor: Poor energy management due to faults, failures or damage

- ! Improved control during system faults, failures and damage
- ! Improved modeling of flight dynamics under failure/damage conditions.
- ! Advanced Control strategies for retaining good flying qualities during a failure or damage
- ! Advanced Control strategies for low-energy conditions
- ! Flight planning and Guidance tools for operation during failures and damage
- ! Relevant Maneuvering Envelope ID Technologies
- ! Automated Identification of Stability Boundaries
- ! Identification of Maneuvering Boundaries based on Structural Limits.
- ! Adaptive Guidance Technologies

# Systems Induced LOC: Faults, Failures and Damage

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**Causal Factor: Poor energy management due to faults, failures or damage**

Loss of control prevention and recovery systems for non-fly-by-wire aircraft:

- ! Participate in the development of automatic LOC prevention and recovery systems for non-fly-by-wire aircraft
- ! Participate in the development of techniques and guidance for recovery from LOC for non-fly-by-wire aircraft.

# Systems Induced LOC: Erroneous sensor data

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**Causal Factor: Erroneous Sensor Data leads to lack of reliable airspeed, altitude and attitude**

Loss of control prevention and recovery systems for non-fly-by-wire aircraft:

- ! Improved verification and validation of complex systems.
- ! Monitoring, Recognition, and Annunciation of Erroneous Sensor Data.

# Propulsion system induced LOC

## Causal Factors (5% of LOC accidents)

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- ! Asymmetric thrust
- ! Engine core ice accretion
- ! Engine fire
- ! Blade failure
- ! Thrust reverser deployment
- ! Thrust reverser control
- ! Combustor can failure
- ! Ice ingestion
- ! Bird ingestion
- ! Fuel system malfunction
- ! Throttle/power level incorrect
- ! Speedbrake/spoiler
- ! Fuel control
- ! Propeller pitch change mechanism
- ! Engine control
- ! Propeller blade

# Propulsion system induced LOC Mitigations

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- ! Asymmetric thrust detection
- ! Automatic compensation for Asymmetric Thrust
- ! Integrated Aerodynamic and Propulsion Control
- ! Development of robust propulsion control systems
- ! Characterize and eliminate turbofan engine core icing



# Other Mitigations and Research

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- ! System Safety analysis of NextGen operations
- ! Data mining of incident/accident reports and FOQA data to identify causal factors in loss of control.



# Conclusions

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- ! NASA is currently adjusting the research portfolio within Aviation Safety
- ! NASA priority for LOC research will be based on
  - !Importance of causal factors
  - !Relevance to NASA mission
  - !Availability of resources
  - !Skill mix required to perform the research