Aviation Safety Systems Analysis

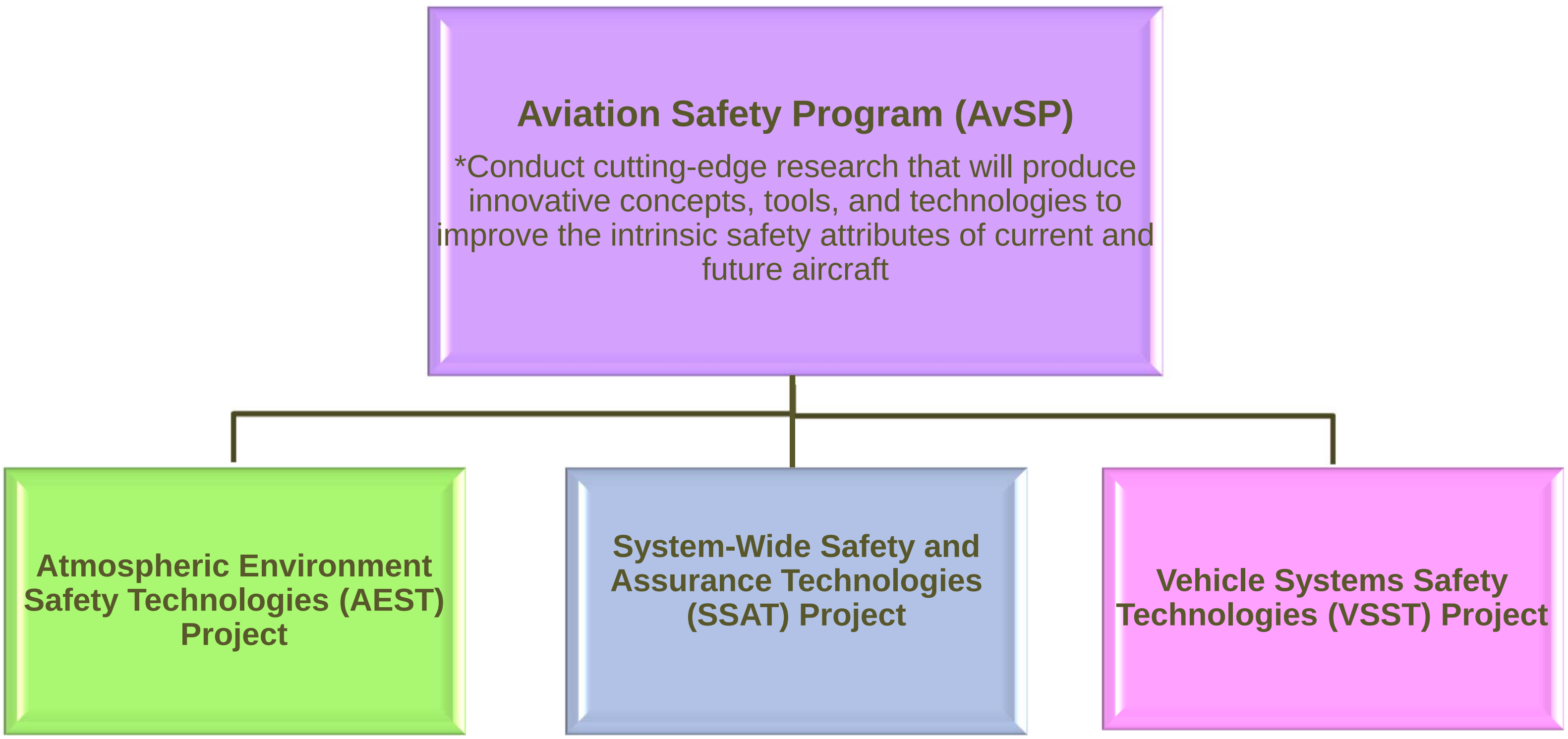
Dr. Sharon Monica Jones
Aeronautics Systems Analysis Branch

Systems Analysis and Concepts Directorate Peer Review
NASA Langley Research Center
July 2013

Outline

- Overview
- Systems Analysis of Aviation Safety Study
- Loss of Control Accident Framework (LOCAF) Model

Overview
Aviation Safety Program



*Dr. Jaiwon Shin, “NASA Aeronautics Research”, Presented at AIAA Conference on January 4, 2011, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110011741_2011012167.pdf

Aviation Safety Systems Analysis
Team Members

NASA Langley
Dr. Sharon Monica Jones (ASAB)
Aviation Safety Systems Analysis

Dr. Ann Shih (VAB)
Lawrence Green (VAB)
Aviation Safety System Modeling

Joni Evans (ASAB - AMA, Inc.) #
Aviation Safety Statistical Data Analysis

Dr. Ersin Ancel (ASAB - NIA) #
Aviation System Modeling and Systems Analysis

NASA Glenn
Mary Reveley (NASA Glenn)
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Aviation Safety Systems Analysis

NASA Ames
Dr. Santanu Das (UC Santa Cruz)
Aviation Data Mining

National Institute of Aerospace
*Dr. James Luxhoj (LCR, Inc)**
Aviation Safety Modeling Refinement and Knowledge Elicitation

Volpe National Transportation Center^
Dr. Lawrence Barr
Safety Benefits/Cost Modeling and Analysis

Sharon Monica Jones, Technical Monitor
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Aviation Safety Systems Analysis

The "Toolbox"

Systems Analyses and Methods/ Systems and Portfolio Analyses

Statistical Analyses

- Trend and Statistical Analysis of Accidents & Incidents
- Causal Factors
- Accident Precursors
- Accident Rate
- Advanced Statistical Methods

Qualitative Portfolio Analyses

- Qualitative Projected Impact on Safety Risk
- Technology Readiness Level
- Technical Development Risk
- Implementation Risk

High-Level Systems Analyses

- Top-Down/ Goal-Centered Systems Analysis
- Definition of Future Requirements
- State of the Art Assessment
- Identification of Future Safety Risks, Hazards and Issues
- Safety Effectiveness Assessment

Advanced Systems Analyses & Methods

- Data Collection using Serious Gaming
- Quantitative Safety Risk Assessment using Operations Research Methods
- System of Systems Methods
- Decision Support Tools

External Collaboration

- Commercial Aviation Safety Team (CAST)/Joint Implementation Measurement Data Analysis Team (JIMDAT)
- Joint Planning Development Office (JPDO)
- National Aviation Safety Strategic Plan (NASSP)

Aviation Safety Systems Analysis
Organization and Milestones

PROGRAM

SAM — Systems Analyses and Methods
Leads: Mary Reveley (GRC) & Ann Shih (LaRC)

Program Milestones

AvSP.3.1.SA.01 Baseline Program Assessment [FY11Q1]	AvSP3.1.SA.02 Draft Tech List & Interaction Model [FY12Q4]	AvSP3.1.SA.03 Interim Program Assessment [FY13Q4]	AvSP3.1.SA.04 Updated Tech List& Interaction Model [FY14Q4]	AvSP3.1.SA.05 Final Program Assessment [FY15 Q4]

PROJECT

SPA — Systems and Portfolio Analyses
Lead: Sharon Monica Jones (LaRC)

AEST Milestones
Technical Leads: Reveley (GRC) & Jones (LaRC)

AEST.3.1.SA.01 ID of AEST Trends [FY12Q1]	AEST.3.1.SA.02 ID of Engine ICE Trends [FY13Q1]	AEST.3.1.SA.03 Portfolio Assessment [FY14Q1]	AEST.3.1.SA.04 SOA of AEST [FY15Q1]

SSAT Milestones
Technical Lead: Mary Reveley (GRC)

SSAT.3.1.SA.01 ID of SWSAT Trends [FY11Q4]	SSAT.3.1.SA.02 Portfolio Assessment [FY12Q4]	SSAT.3.1.SA.03 SOA of SSAT [FY13Q4]	SSAT.3.1.SA.04 Update of SSAT Trends [FY14Q4]	SSAT.3.1.SA.05 Update of SSAT SOA [FY15Q4]

VSST Milestones
Technical Lead: S. M. Jones (LaRC)

VSST 4.2.1.SA01 ID of VSST Trends [FY11Q2]	VSST 4.2.1.SA012 ID of LOC Trends [FY12Q2]	VSST 4.2.1.SA03 ID of CREW Trends [FY13Q2]	VSST 4.2.1.SA04 ID of VHM Trends [FY14Q2]	VSST 4.2.1.SA05 SOA of VSST [FY15Q2]

Outline

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- Systems Analysis of Aviation Safety Study
- Loss of Control Accident Framework (LOCAF) Model

Systems Analysis of Aviation Safety Study
Team Members

- Sharon Monica Jones (NASA Langley)
- Mary Reveley (NASA Glenn)
- Colleen Withrow (NASA Glenn)
- Larry Barr (Volpe National Transportation Center)
- Joni Evans (AMA, Inc.)
- Karen Leone (Vantage Partners, LLC)

Systems Analysis of Aviation Safety Study

Study Deliverables

(1) **Aviation Statistical Data Analysis** - Report and document analysis results utilizing the most currently available aviation statistical reports and incidents and accident databases from NTSB, FAA and ASIAS associated with civilian subsonic aircraft.

(2) **Qualitative Future Safety Risk Identification and Assessment** – Report and document the results of a high-level qualitative identification of future safety risks and an assessment of the potential impact(s) of NASA Aviation Safety research on these risks.

(3) **Top-Down Analysis** – Report and document the results of a detailed top-down analysis of the NASA Aviation Safety Program using an established and peer-reviewed systems methodology.

Methodology
Aviation Statistical Data Analysis

- Two databases:
  - NTSB Aviation Accident and Incident Data System
  - FAA Accident/Incident Data System
- All recorded accidents and incidents involving commercially built fixed-wing airplanes operating under FAR Part 121 (scheduled air carriers) , Part 135 (air charter) or Part 91 (general aviation)
- Period of accidents and incidents examined was 1997-2006
- Organized using CAST/ICAO Common Taxonomy

Methodology
Qualitative Future Safety Risk Identification

- Compilation of future safety issues/risks identified by multiple sources:
  - Decadal Survey of Civil Aeronautics (National Research Council, 2006)
  - National Plan for Aeronautics Research and Development and Related Infrastructure (National Science and Technology Council, December 2007 & February 2010)
  - National Transportation Safety Board Most Wanted Aviation Safety Improvements
  - Flight Safety Foundation Safety Initiatives
  - Joint Planning and Development Office (JPDO) Safety Working Group Safety Issues Database, 2008
  - Future Aviation Safety Team (FAST) Areas of Change, 2007 & 2010
  - CAST/JIMDAT/ASIAS SEs and Directed Studies

Methodology

Overview of Gibson Systems Analysis Methodology

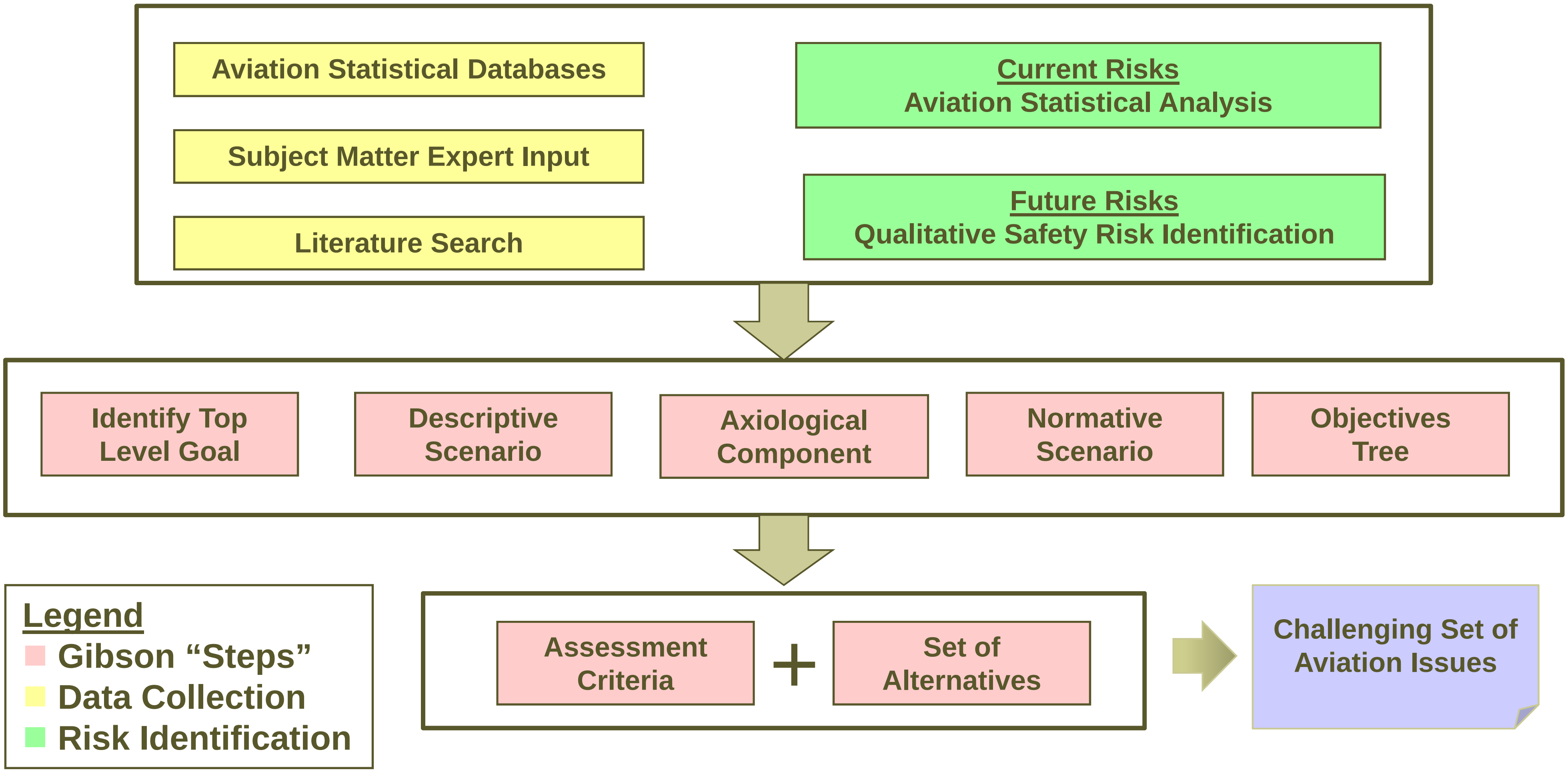
- **Goal Development**
- **Index of Performance (Metrics)**
- **Develop Alternative Scenarios**
- **Rank Alternatives**
- **Iteration**
- **Action**

GOAL DEVELOPMENT STEPS

1. Generalize the Question
2. Descriptive Scenario
3. Normative Scenario
4. Axiological Component
5. Objectives Tree
6. Validate
7. Iterate

Source: "How to Do Systems Analysis" by John E. Gibson, William T. Scherer and William F. Gibson (2007)

Methodology
Top Down Analysis



Aviation Statistical Data Analysis

Number of Events by Flight Operation (1997-2006)

	Part 121	Scheduled Part 135	Non-Scheduled Part 135	Part 91
Total Accidents	459	78	540	12247
Total Injuries	1756	142	585	9846
Fatal Accidents	25	15	122	2328
Fatal Injuries	752	80	292	4535
Incidents	3752	188	1117	12773

Aviation Statistical Data Analysis

Current "Tall Poles" Based on Historic Safety Data

CICTT Accident Category	Part 121	Part 135-S	Part 135-NS	Part 91
Abrupt Maneuver	35% of TF			
Abnormal Runway Contact		13% of TA		13% of TA; 25% of TI
Bird Strike		10% of TA		
Controlled Flight Into Terrain		12% of TA; 27% of FA 18% of TF	19% of TAI; 26% of FA 27% of TF	13% of FA; 13% of TF
Collision with Object – Takeoff or Landing				15% of TAI
Fire – Post Impact	26% of TAI ; 28% of FA 48% of TF	33% of TAI; 20% of FA 50% of TF	13% of TA; 30% of TAI; 41% of FA; 41% of TF	24% of TAI; 36% of FA 38% of TF
Ground Handling	26% of TA; 40% of FA 11% of TI	12% of TI		
Icing		10% of TA; 35% of TAI 20% of FA ;59% of TF		
Low Altitude Operations				11% of TAI ;18% of FA 16% of TF
Loss of Control – In Flight	21% of TAI; 24% of FA 54% of TF	14% of TA; 49% of TAI 53% of FA; 76% of TF	17% of TA; 33% of TAI; 46% of FA ; 51% of TF	20% of TA; 40% of TAI 55% of FA; 56% of TF
Loss of Control – On Ground				15% of TA
Power Loss – Fuel				13% of TA; 15% of TAI
Runway Excursion		18% of TA	15% of TA	20% of TA; 9% of TI
SCF – Powerplant	16% of TI	13% of TI	14% of TI	10% of TI
SCF – Non Powerplant	20% of FA; 44% of TI	10% of TA; 37% of TI	40% of TI	27% of TI
Security	35% of TF			
Turbulence	25% of TA; 30% of TAI			

TA = Total Accidents; **TAI** = Total Accident Injuries; **FA** = Fatal Accidents; **TF** = Total Fatalities; **TI** = Total Incidents

Qualitative Future Safety Risk Identification

Future “Tall Poles”

- Runway Safety
  - Runway incursions
  - Runway excursions
  - Runway confusion (wrong runway or taxiway takeoffs/landings)
- Approach and Landing Accident Reduction
  - Unstabilized approaches
  - Attitude and energy state awareness
  - Hard/heavy and long/fast landings

Qualitative Future Safety Risk Identification

Future "Tall Poles" (cont'd)

- Icing/Ice Detection
  - Ice detection and alerting
  - Engine events and air data system failures in high ice water content conditions
- Loss of Control – In Flight
  - Aircraft stall
  - Icing-related event
  - System/component malfunction or failure
  - Lack of attitude awareness

Qualitative Future Safety Risk Identification

Future "Tall Poles" (cont'd)

- Super Density Operations
  - Reduced separation minima
  - Performance based navigation
  - Innovative air traffic management procedures
  - Increased use of automated systems and flight crews for aircraft separation
- Human Fatigue
  - Flight crews, air traffic controllers, and maintenance personnel

Qualitative Future Safety Risk Identification

Future “Tall Poles” (cont’d)

- Increasing Complexity and Reliance on Automation
  - Mode and energy state awareness
  - Impact on operator workload and situational awareness
  - Operational procedures
- Aircraft Mixed Fleet Equipage
  - Procedures to manage mix of legacy and advanced technology aircraft
  - High performance airspace
  - “Best equipped, best served”

Qualitative Future Safety Risk Identification

Future “Tall Poles” (cont’d)

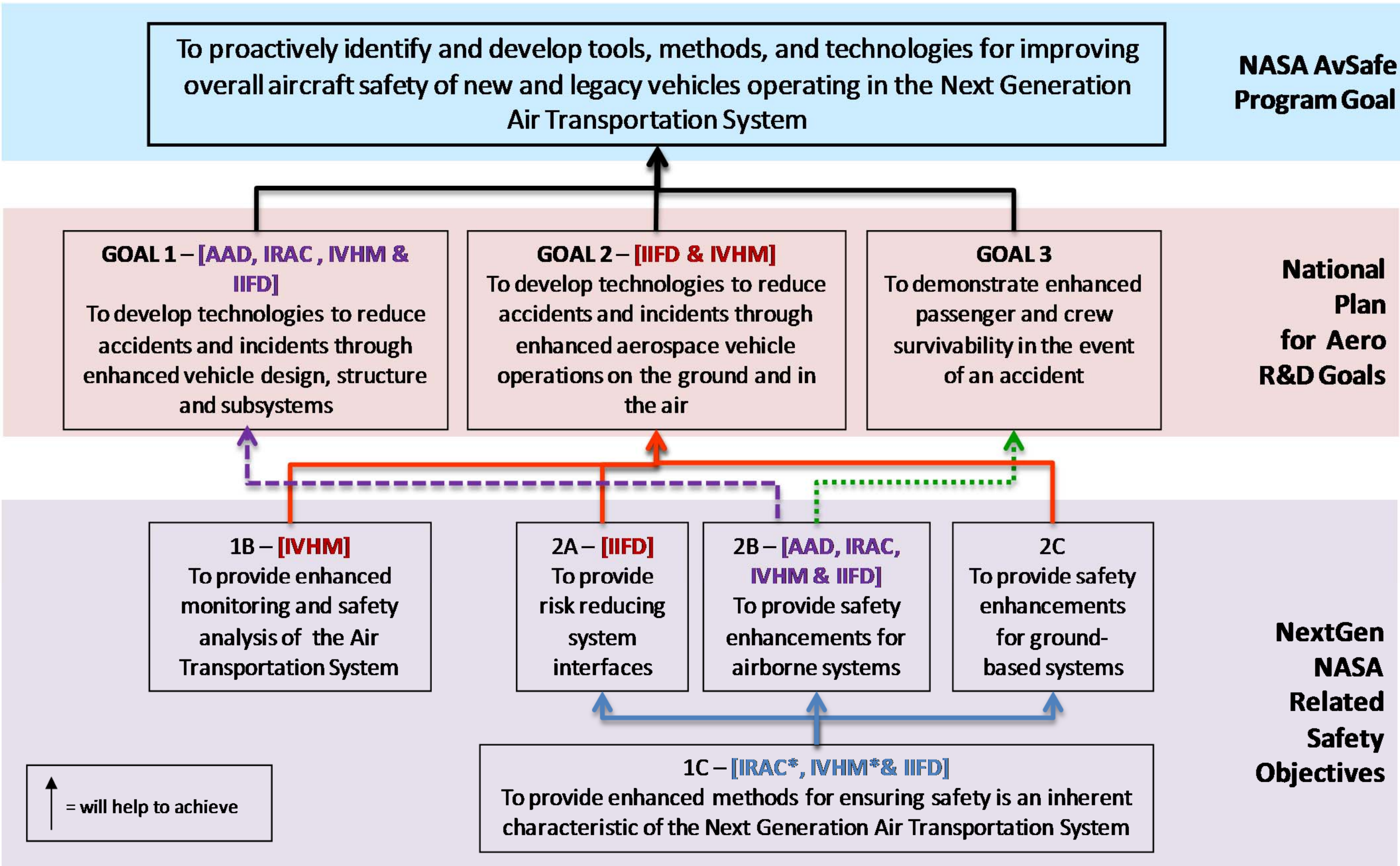
- Inadequate Protection, Analysis and Dissemination of Safety Data
  - Global collection/sharing of data among operators, manufacturers, and regulators
  - Data mining algorithms to support automated data analysis
  - Prognostic identification of safety risk
- Enhanced Survivability in the Event of an Accident
  - Post-impact fire/smoke
  - Improved crash survivability of aircraft structures
  - Improved evacuation and accident response procedures

Top Down Analysis
NASA Aviation Safety Research Goals and Objectives

- "To improve the safety of current and future aircraft operating in the NAS" *[www.aeronautics.nasa.gov/programs_avsafe]*
- "To identify and develop tools, methods and technologies for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System" *[NASA Strategic Plan - Outcome 3E.1 and Oct. 2009 AvSafe Program Plan]*
- "The Aviation Safety Program will take a proactive approach to safety challenges with new and current vehicles and with operations in the nation's current and future air transportation system. In addition, the Program will continue the effort to examine key challenges in verifying and validating flight critical systems." *[NASA FY 2011 Budget Request]*
- "The Aeronautics research portfolio is closely aligned with this National Plan* and includes research content as the key areas called outreach plan [sic] of mobility, energy and environment, safety and national security" *[NASA FY 2011 Budget Request]*

**National Plan for Aeronautics R&D (December 2007)*

Goals and Objectives



** = V & V of FCS technologies*

Top Down Analysis
Assessment Criteria

- Expected impact on historic “tall poles”
  - Part 121
  - Part 135
  - Part 91
- Expected impact on future safety risk “tall poles”
- Expected impact on National Aeronautics R&D goals
- Expected impact on JPDO NextGen goals

Top Down Analysis

Assessment Definitions

	Direct impact
	Indirect impact
	Very little or no impact

- Assessments assume that technologies in portfolio are fully realized
- Methodology used was modeled after 2008 NRC assessment of "NASA Aeronautics Research"

- **Direct impact** – NASA technology will directly impact the potential either for reducing a future occurrence of this accident category or risk area or for achieving a technical goal. This technology will significantly advance the state of the art
- **Indirect impact** – NASA technology will indirectly impact the potential either for reducing a future occurrence of this accident category or risk area or for achieving a technical goal. Research described if successful would only make moderate advances in the state of the art of relevant technologies, although the results would still be substantial
- **Very Little or No Impact** - NASA technology will have very little to no impact on reducing a future occurrence of this accident category, risk area or achieving this technical goal.

Top Down Analysis

Part 121 Historic Risk Assessment – Current Portfolio

Part 121 Tall Poles	**Aviation Safety Projects**			
	IIFD	IRAC	IVHM	AAD
Abrupt Maneuver				
Fire – Post Impact				
Loss of Control – In Flight				
SCF – Powerplant				
SCF – Non-powerplant				
Turbulence Encounter				

IVHM 2.3
Propulsion Health
Management

Top Down Analysis

Part 135 Historic Risk Assessment – Current Portfolio

Part 135 Tall Poles	Aviation Safety Projects			
	IIFD	IRAC	IVHM	AAD
Abnormal Runway Contact				
Bird Strike				
Controlled Flight Into Terrain				
Fire – Post Impact				
Icing				
Loss of Control - In Flight				
Runway Excursion				
SCF - Powerplant				
SCF – Non Powerplant				

Top Down Analysis

Part 91 Historic Risk Assessment – Current Portfolio

Part 91 Tall Poles	**Aviation Safety Projects**			
	IIFD	IRAC	IVHM	AAD
Abnormal Runway Contact				
Controlled Flight Into Terrain				
Collision with Object – Takeoff or Landing				
Fire – Post Impact				
Low Altitude Operations				
Loss of Control - In Flight				
Loss of Control – On Ground				
Power Loss - Fuel				
Runway Excursion				
SCF – Powerplant				
SCF – Non Powerplant				

Top Down Analysis

Future Risk Assessment – Current Portfolio

Future Safety Risk Tall Poles	**Aviation Safety Projects**			
	IIFD	IRAC	IVHM	AAD
Runway Safety				
Approach and Landing Accident Reduction				
Icing/Ice Detection				
Loss of Control – In Flight				
Super Density Operations				
Human Fatigue				
Increasing Complexity and Reliance on Automation				
Aircraft Mixed Fleet Equipage				
Inadequate Protection, Analysis and Dissemination of Safety Data				
Enhanced Survivability in the Event of an Accident				

Top Down Analysis
Suggested Additional Assessment Criteria

- Uniqueness of Research →

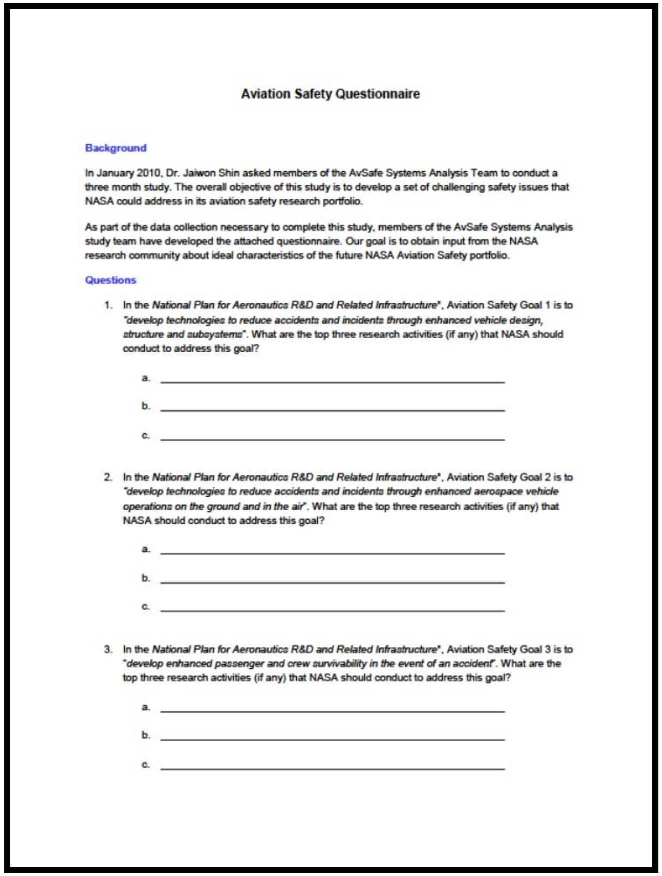
Totally unique to NASA (only U.S. researcher)
Collaboration with FAA or other agency
Duplication of other U.S. research without collaboration

- Correlation to NASA Skill Set
- Technology Readiness Level
- Technical Development Risk
- Implementation Risk
- Cost
  - Expected Implementation Cost
  - Programmatic Cost

Top Down Analysis

Research Alternatives - Overview

- List of research alternatives were generated from a variety of sources
  - Literature review
  - JIMDAT suggestions
  - Internal questionnaire responses
- Alternatives selected based on their potential to have a direct impact on the assessment criteria
- Additional analysis necessary to determine feasibility and necessity of these research alternatives



Aviation Safety Questionnaire

Background

In January 2010, Dr. Jaiwon Shin asked members of the AvSafe Systems Analysis Team to conduct a three month study. The overall objective of this study is to develop a set of challenging safety issues that NASA could address in its aviation safety research portfolio.

As part of the data collection necessary to complete this study, members of the AvSafe Systems Analysis study team have developed the attached questionnaire. Our goal is to obtain input from the NASA research community about ideal characteristics of the future NASA Aviation Safety portfolio.

Questions

1. In the *National Plan for Aeronautics R&D and Related Infrastructure*", Aviation Safety Goal 1 is to "*develop technologies to reduce accidents and incidents through enhanced vehicle design, structure and subsystems*". What are the top three research activities (if any) that NASA should conduct to address this goal?
   a. ______
   b. ______
   c. ______
2. In the *National Plan for Aeronautics R&D and Related Infrastructure*", Aviation Safety Goal 2 is to "*develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air*". What are the top three research activities (if any) that NASA should conduct to address this goal?
   a. ______
   b. ______
   c. ______
3. In the *National Plan for Aeronautics R&D and Related Infrastructure*", Aviation Safety Goal 3 is to "*develop enhanced passenger and crew survivability in the event of an accident*". What are the top three research activities (if any) that NASA should conduct to address this goal?
   a. ______
   b. ______
   c. ______

Aviation Safety Questionnaire

Top Down Analysis

Research Alternatives – Goal 3 Excerpt

“Develop enhanced passenger and crew survivability in the event of an accident”

Post-Impact Fire/Smoke
Materials and structures that are fire resistant and do not emit significant smoke
Improved fuel containment methods and reduced-volatility fuels to prevent fires and explosions
Improved cabin materials for reduced flammability and automated fire detection/protection systems
Develop passenger-safe fire suppression systems

Improved Crash Survivability of Aircraft Structures
Materials and structures that fail in pre-designed manner to maximize energy absorption (similar to automobiles)
Improved crash simulation capabilities for evolving composite structures to assess crashworthiness under various accident scenarios

Improved Evacuation and Accident Response Procedures
Egress research for evacuation of cabins
Management and reduction of risk to other vehicles and persons and property on the ground from UAS accidents

Systems Analysis of Aviation Safety Study
Validation of Results

- Presentation of “Aviation Safety Program Assumptions” to Doug Rohn and John Orme on February 24, 1010
- Presentation of initial “Aviation Statistical Analysis” and “Qualitative Safety Risk Identification “results to JIMDAT on March 30, 2010
- Presentation of “Systems Analysis Methodology” to Old Dominion University on March 31, 2010
- Discussion of preliminary results and next steps with Tom Irvine at NASA HQ on April 6, 2010

Systems Analysis of Aviation Safety Study

Summary

- Information from this study was used to formulate the Aviation Safety Program in 2010
- "Current Tall Poles" and "Future Tall Poles" metrics developed in this study have been for the following:
  - "Quick Tall Poles Study" for Dr. Jaiwon Shin (September 2011)
  - Aviation Safety Program "Baseline Program Assessment" milestone (December 2011)
  - Systems analysis for VSST Project's Independent Review Panel (IRP) response (March 2012)
  - Aviation Safety Program "Interim Program Assessment" milestone (due September 2013)
- FAA is considering using the "Tall Poles" metric for their analyses

Outline

- Overview
- Systems Analysis of Aviation Safety Study
- Loss of Control Accident Framework (LOCAF) Model

Loss of Control Accident Framework
Team Members

- Ersin Ancel, Ph.D. (NIA at NASA Langley - ASAB)
- Ann T. Shih, Ph.D. (NASA Langley – VAB)
- Sharon Monica Jones, Ph.D. (NASA Langley – ASAB)
- Mary S. Reveley (NASA Glenn)
- James T. Luxhøj, Ph.D. (NIA/LCR)
- Joni K. Evans (AMA, Inc. at NASA Langley - ASAB)

Loss of Control Accident Framework

Purpose of Generalized LOC Model

Is to

- Describe the aircraft LOC scenarios by a generic, high-level, system-integrated model
- Capture the multi-dependencies (interactions) of causal and contributing factors from three domains: **human, aircraft systems, and atmospheric environments**
- Compute the likelihood of LOC in the current & future aviation operations
- Assess the impact of safety technology portfolio on LOC risk reduction

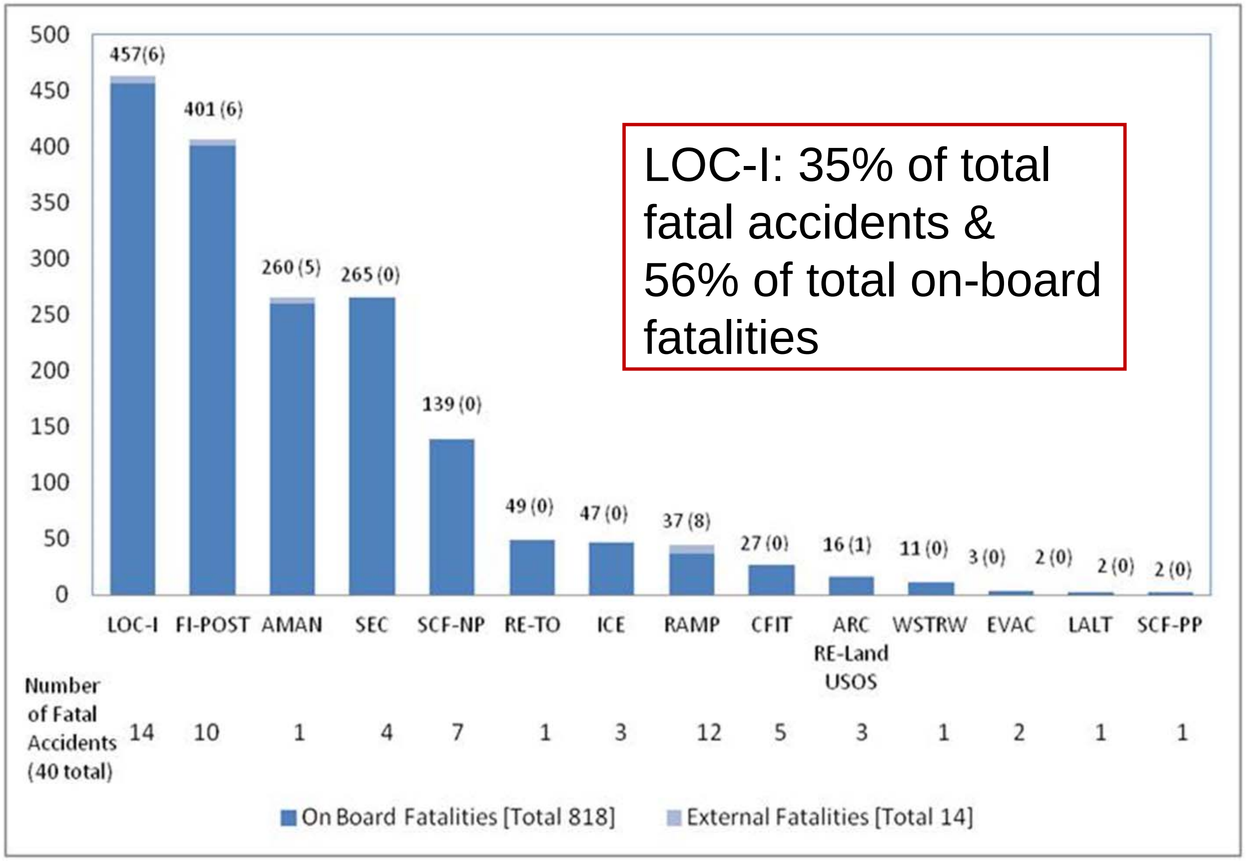
Is NOT to

- Represent a specific accident case
- Perform a detailed simulation analysis on aircraft LOC

Loss of Control Accident Framework
Why Are LOC Accidents Important?

LOC Accidents

- Low probability but high consequence of aviation accidents
- Fatal accidents statistics: U.S. Part 121 and scheduled Part 135 (Commercial) operations, 1997-2006



Loss of Control Accident Framework

Overall LOC Modeling Steps

- Conduct a LOC accident database review to determine the causality and develop a generalized LOC framework
- Model the framework using appropriate system modeling
- Conduct subject matter expert (SME) sessions to evaluate the model and elicit data
- Insert AvSP safety technology products from AEST, SSAT, and VSST projects into the model for portfolio assessment
- Assess the impact of new technologies on the reduction of future risk of LOC, i.e., the likelihood of LOC accidents

Loss of Control Accident Framework
Accident Database Review

Review Constraints

- In-flight LOC definition for this modeling: LOC followed by system component failures or malfunction, pilot induced oscillations, maneuvers and stall; also including uncontrolled altitude deviation, aerodynamic stall, in-flight collision with terrain, or uncontrolled descent
- 1987-2009 within FAR Part 121 & Part 135 scheduled and non-scheduled

Database Sources/References

- Aviation Safety Information Analysis and Sharing (ASIAS) – based on NTSB database, maintained by the AvSP Systems Analysis team
- National Transportation Safety Board (NTSB) factual and detailed reports
- Commercial Aviation Safety Team/International Civil Aviation Organization (CAST/ICAO) Common Taxonomy Team (CICTT) taxonomy

Total # of LOC accidents on the initial list: 315

Loss of Control Accident Framework
Accident Database Review (cont'd)

Assumptions and ground rules

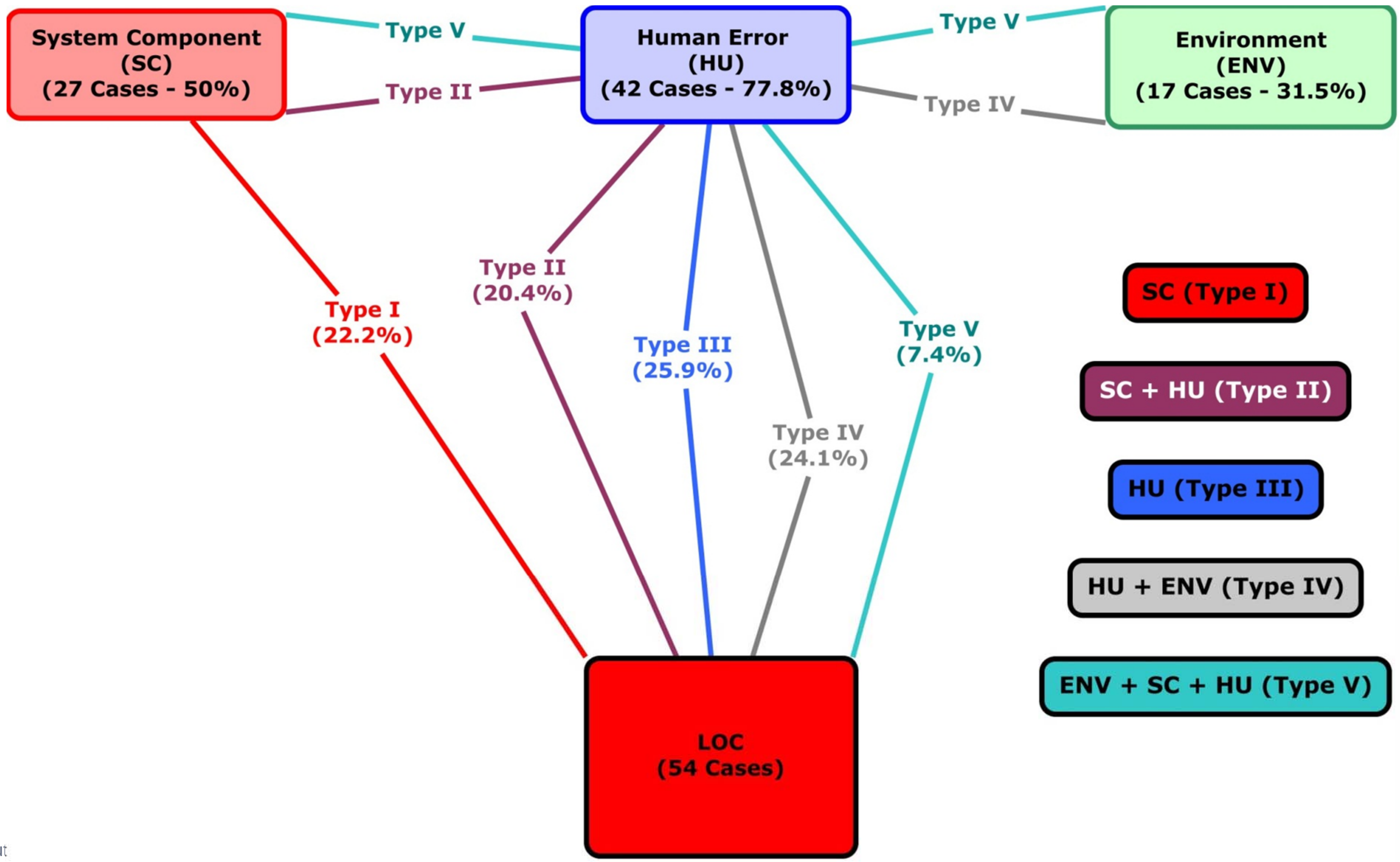
- US accidents
- Aircraft take-off-weight > 5700kg (12500 lbs)
- Security-related accidents are excluded
- Excluded LOC accidents with DC-3 aircraft due to its age and limited use (all system component related)

Total # of LOC accidents on the final list: 54

Loss of Control Accident Framework
Development of the Generalized Framework

Identify the event sequence for 54 LOC accident cases

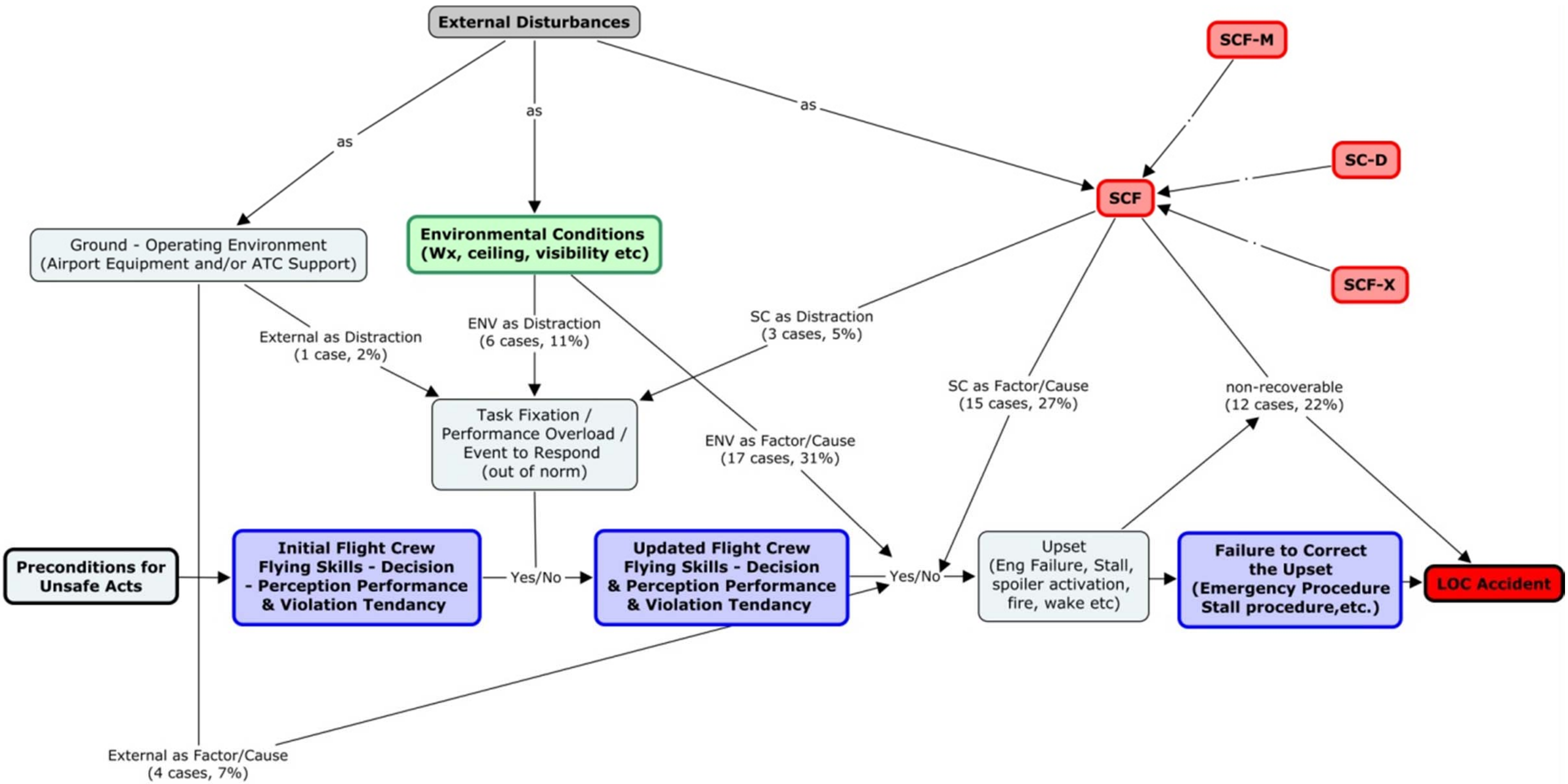
Categorize five generalized LOC accident types based on LOC primary causes



Loss of Control Accident Framework

Development of the Generalized Framework (cont'd)

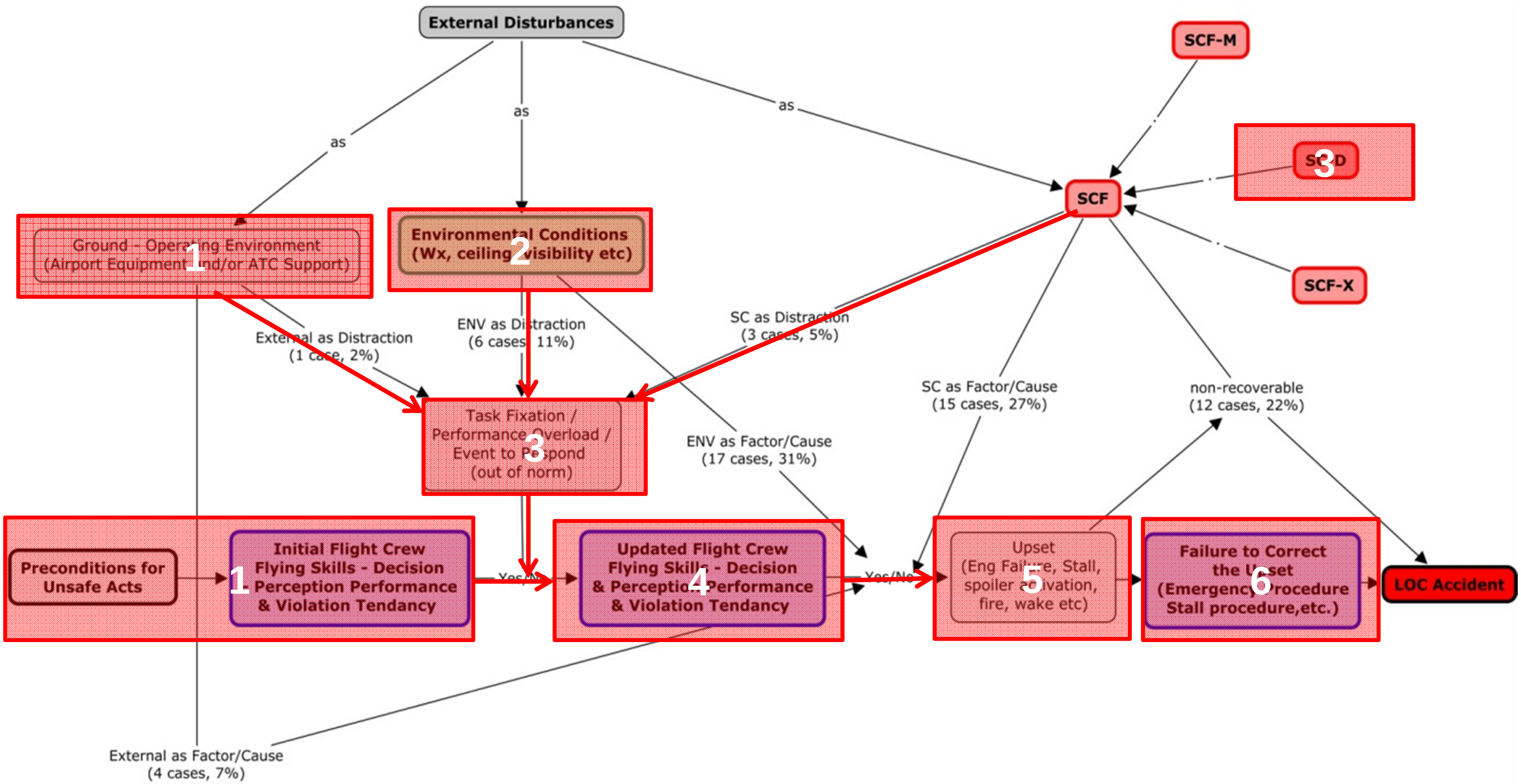
LOCAF configuration



Loss of Control Accident Framework

Development of the Generalized Framework (cont'd)

LOCAF mapping example: Colgan 3407 accident (Buffalo, NY, 2009)



Systems Modeling

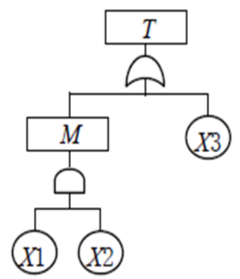
System Safety Risk Modeling Methods Criteria

- Probabilistic model
- Causal relationships/networks
- Inference and reasoning and updates
- Decision-making
- Large complex integrated system model

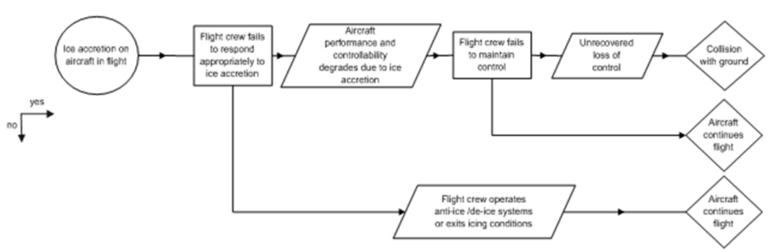
Systems Modeling

Popular Modeling Techniques

Fault Tree (FT):
Failure analysis
- Top-down approach
- AND, OR gate
- Binary logic
- For risk & reliability study of (sub)systems

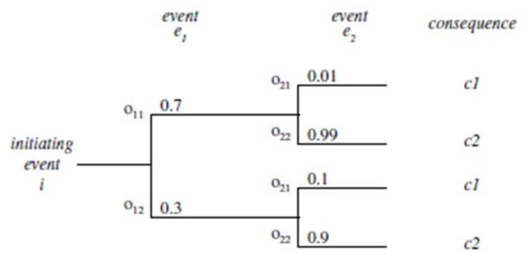


Event Sequence Diagram (ESD): Scenario analysis
- Similar to ET, but at a broader level
- Risk scenarios from an initiating event
- Pivotal events
- End state for each scenario path

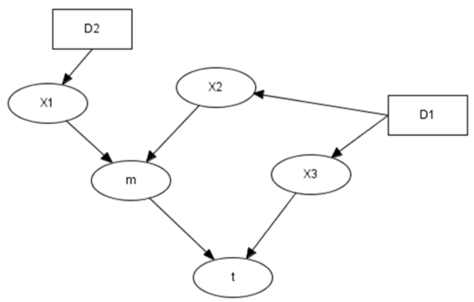


* ESD by Alfred Roelen

Event Tree (ET): Consequence analysis
- Forward method
- Initiating event with chronological sequence of events/consequences
- Linear sequence dependencies
- For multiple safeguards to mitigate risk



Bayesian Belief Network (BBN):
Causal analysis
- Reasoning under uncertainty
- Bayes' Theorem - Conditional probabilities
- Multi-dependencies between causal factors
- Decision-support tool - Influence Diagram (ID)



Systems Modeling

Review of Existing Aviation Safety Risk Models

- **Safety Methods Database***
  - Maintained by the National Aerospace Laboratory of the Netherlands (NLR)
  - Contains over 600 techniques, methods, models, and frameworks
  - Over 160 methods are related to air transportation (ATM, aviation) and 60 related to aircraft and avionics
  - Also covers techniques used in domains like nuclear and chemical industries, telecommunications, health, as well as rail/road/water transportation and logistics

- **Models evaluated**
  - Aviation Safety Risk Model (ASRM) - BBN
  - Causal model for Air Transport Safety (CATS) - ESD, FT, BBN
  - Quantitative Risk Assessment System (QRAS) - ESD, FT

Note: FT and ESD can be represented by BBN

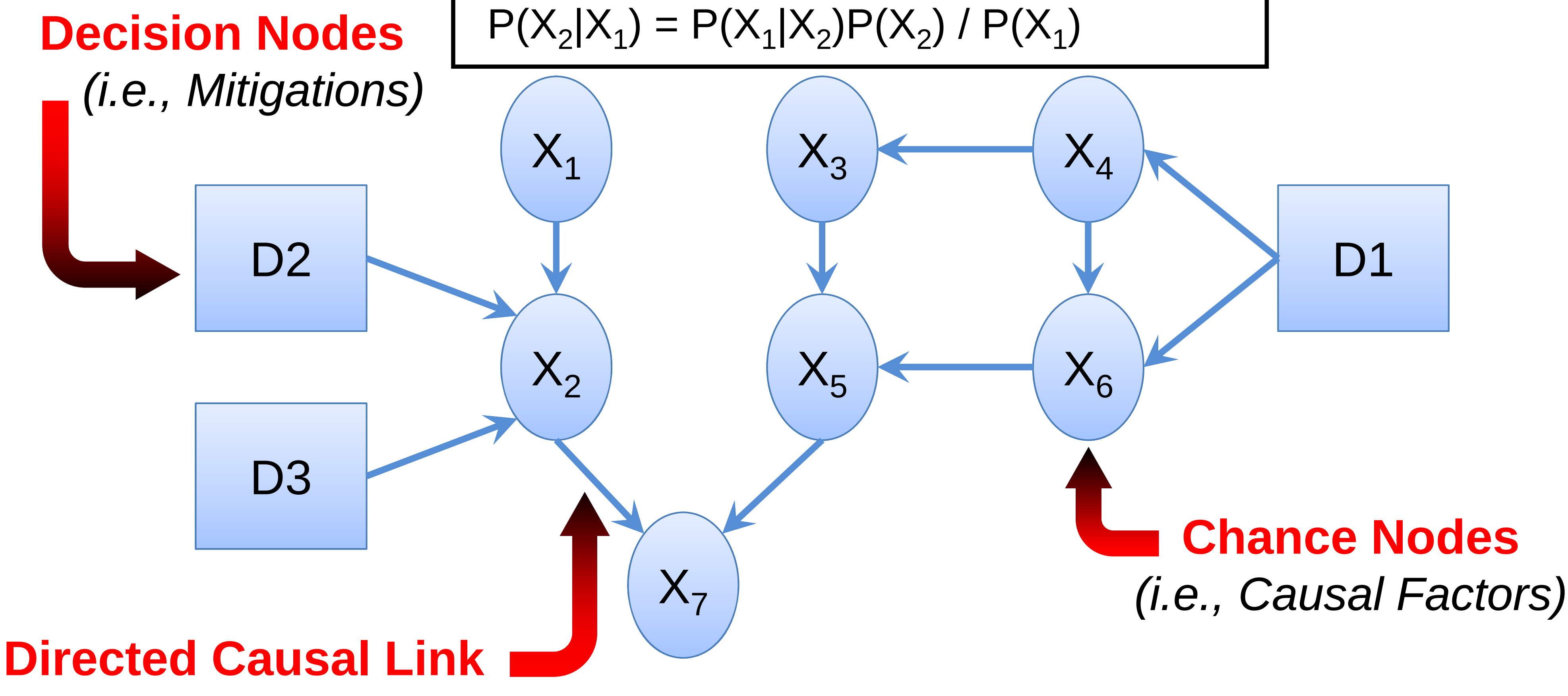
*A copy of the database can be accessed from: http://www.nlr.nl/downloads/safety-methods-database.pdf

Loss of Control Accident Framework

Bayesian Belief Networks – Terminology and Definitions

Bayes Theorem:

$$P(X_2|X_1) = P(X_1|X_2)P(X_2) / P(X_1)$$



The approach uses qualitative, probabilistic reasoning about the *interactions* of *risk factors* (chance nodes) and *mitigations* (decision nodes) to make inferences.

Loss of Control Accident Framework

BBN Software Selection Criteria*

- Influence diagrams (ID) capability
- Modular and hierarchical capability
- Computational efficiency/performance
- Maturity
- Application Program Interface (API)
- Software maintenance and technical support
- Cost for multiple licenses at different user locations

*Publication: Shih, A. T., Ancel, E., Jones, S. M., "Object-Oriented Bayesian Networks (OOBN) for Aviation Accident Modeling and Technology Portfolio Impact Assessment" *Proceedings of the American Society for Engineering Management (ASEM) 33rd International Annual Conference*, Virginia Beach, VA, October 17-20, 2012

Loss of Control Accident Framework

BBN Software Options*

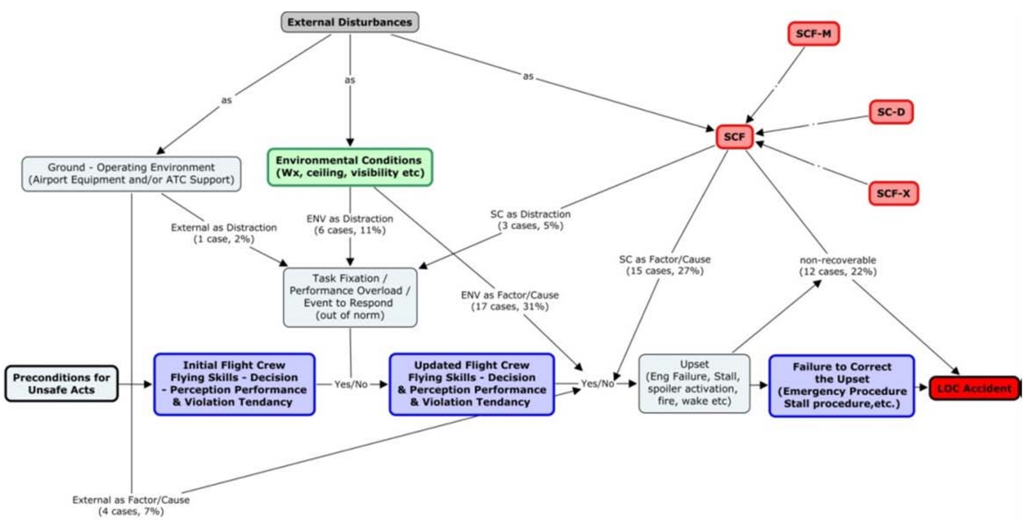
Name	Authors	Src	API	Exec	Cts	GUI	Params	Struct	Utility	Free	Undir	Inference	Comments
AgenaRisk	Agena	N	Y	W,U	Cx	Y	Y	N	N	$	D	JTree	Simulation by Dynamic discretisation
Analytica	Lumina	N	Y	W,M	G	Y	N	N	Y	$	D	sampling	spread sheet compatible
Banjo	Hartemink	Java	Y	W,U,M	Cd	N	N	Y	N	0	D	none	structure learning of static or dynamic networks of discrete variables
Bassist	U. Helsinki	C++	Y	U	G	N	Y	N	N	0	D	MH	Generates C++ for MCMC. (No longer maintained)
gR	Lauritzen et al.	R	-	-	-	-	-	-	-	0	-	-	Various packages
Grappa	Green (Bristol)	R	-	-	D	N	N)	N	N	0	D	Jtree	-
[illegible]	Dobra et al (Washington)	C++	-	-	G	N	Y	Y	N	0	U	SL	stochastic search for structure learning of GGMs
Hugin Expert	Hugin	N	Y	W	G	W	Y	CI	Y	$	CG	Jtree	-
Hydra	Warnes	Java	-	-	Cs	Y	Y	N	N	0	U,D	MCMC	-
IBAyes	Artificial Intelligence Lab @ IBA (Pakistan)	N	N	W	D	Y	N	N	N	0	D	Junction Tree, Sampling	-
Infer.NET	John Winn, Tom Minka	C#	Y	Y	Y	N	Y	N	N	0	Y	VMP, EP, Gibbs	Bayesian parameter estimation as well
JAGS	Martyn Plummer	Java	Y	-	Y	N	Y	N	N	0	Y	Gibbs	Similar to BUGS
Java Bayes	Cozman (CMU)	Java	Y	WUM	D	Y	N	N	Y	0	D	Varelim, jtree	-
LibB	Friedman (Hebrew U)	N	Y	W	D	N	Y	Y	N	0	D	SL	Structure learning
libDAI	Mooij et al.	C++	Y	-	D	N	Y	N	N	0	Fgraph	JTree,VarElim,G,VMP	also supports GBP,HAK,LCBP,TreeEP,TRWBP
MIM	HyperGraph Software	N	N	W	G	Y	Y	Y	N	$	CG	Jtree	Up to 52 variables.
Mocapy++	U. Copenhagen	C++	Y	W,U,M	G	N	Y	N	N	0	D	Gibbs sampling	Support for directional statistics
MSBNx	Microsoft	N	Y	W	D	W	N	N	Y	0	D	Jtree	-
Netica	Norsys	N	WUM	W	G	W	Y	N	Y	$	D	jtree	-
Bayes net learner	Moore, Wong (CMU)	N	N	W,U	D	N	Y	Y	N	0	D	SL	optimal reinsertion algorithm

Reference: Murphy, Kevin, “Software Packages for Graphical Models / Bayesian Networks,” http://www.cs.ubc.ca/~murphyk/Software/bnsoft.html

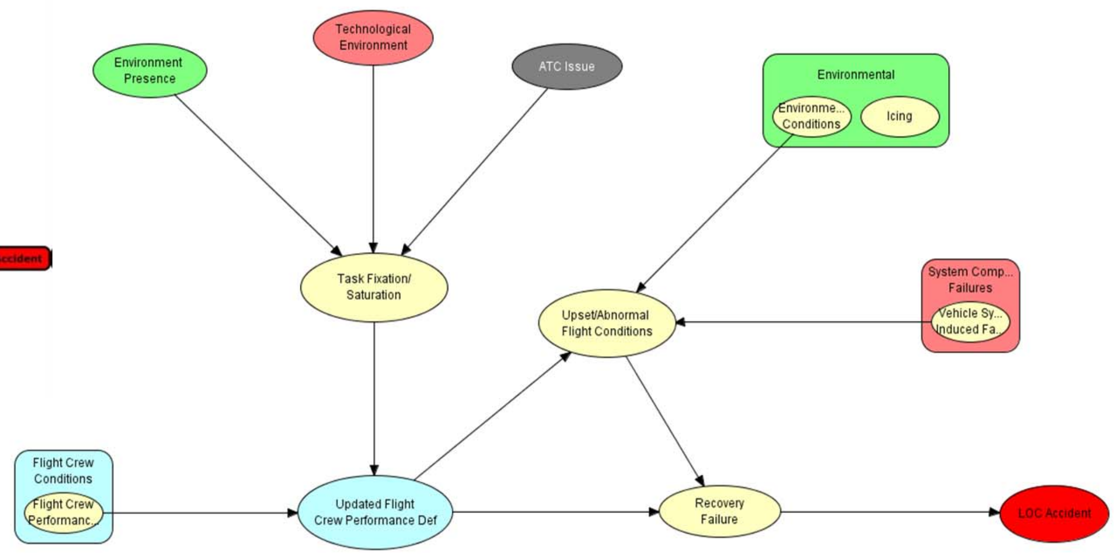
Loss of Control Accident Framework

Conversion to Integrated Systems Model

LOCAF



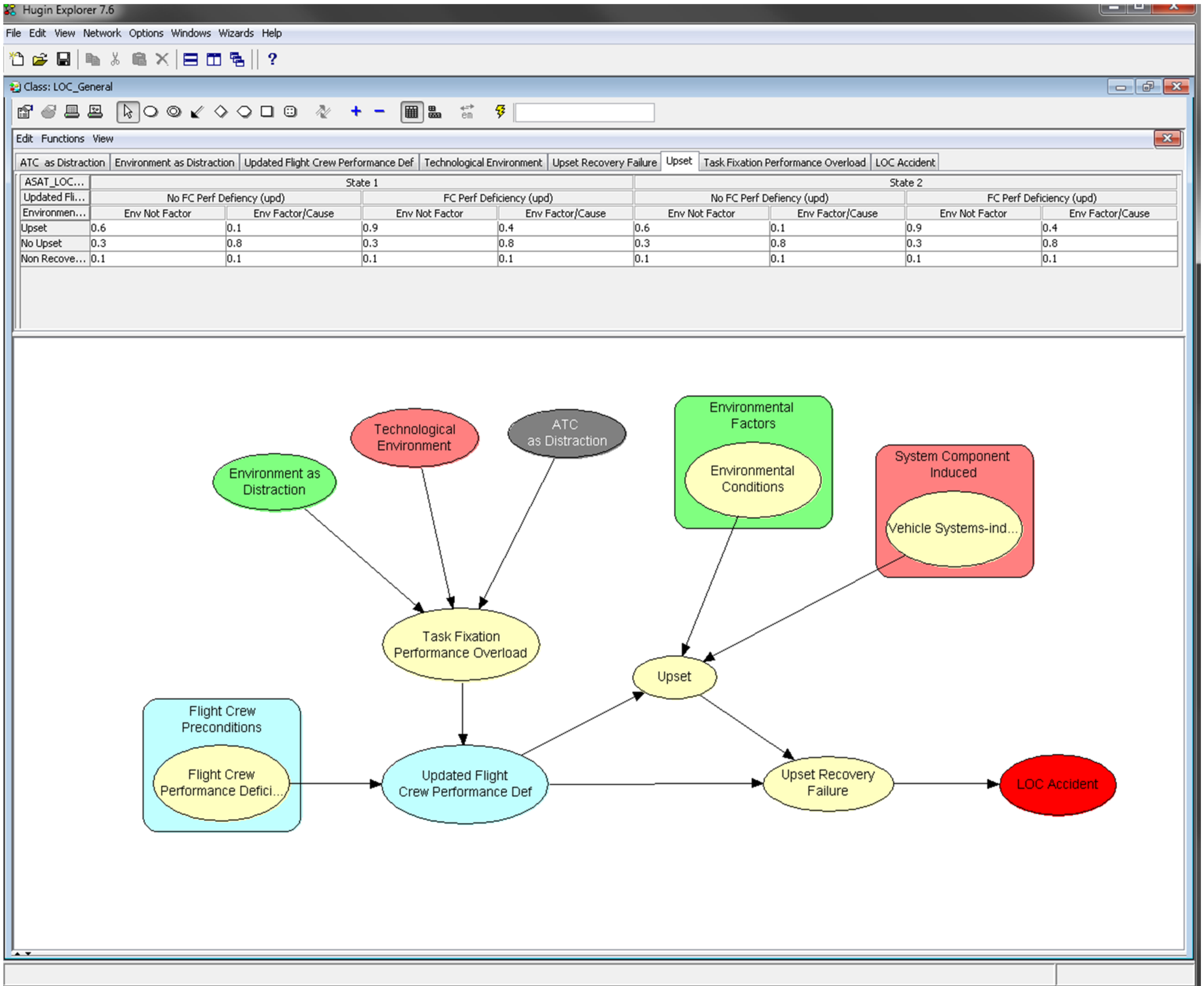
Systems Model of LOCAF



Publication: Ancel, E., Shih, A.T., 2012, The analysis of the contribution of human factors to the in-flight loss of control accidents. Proceedings of the 12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, Indianapolis, IN, Sept 17-19*.*

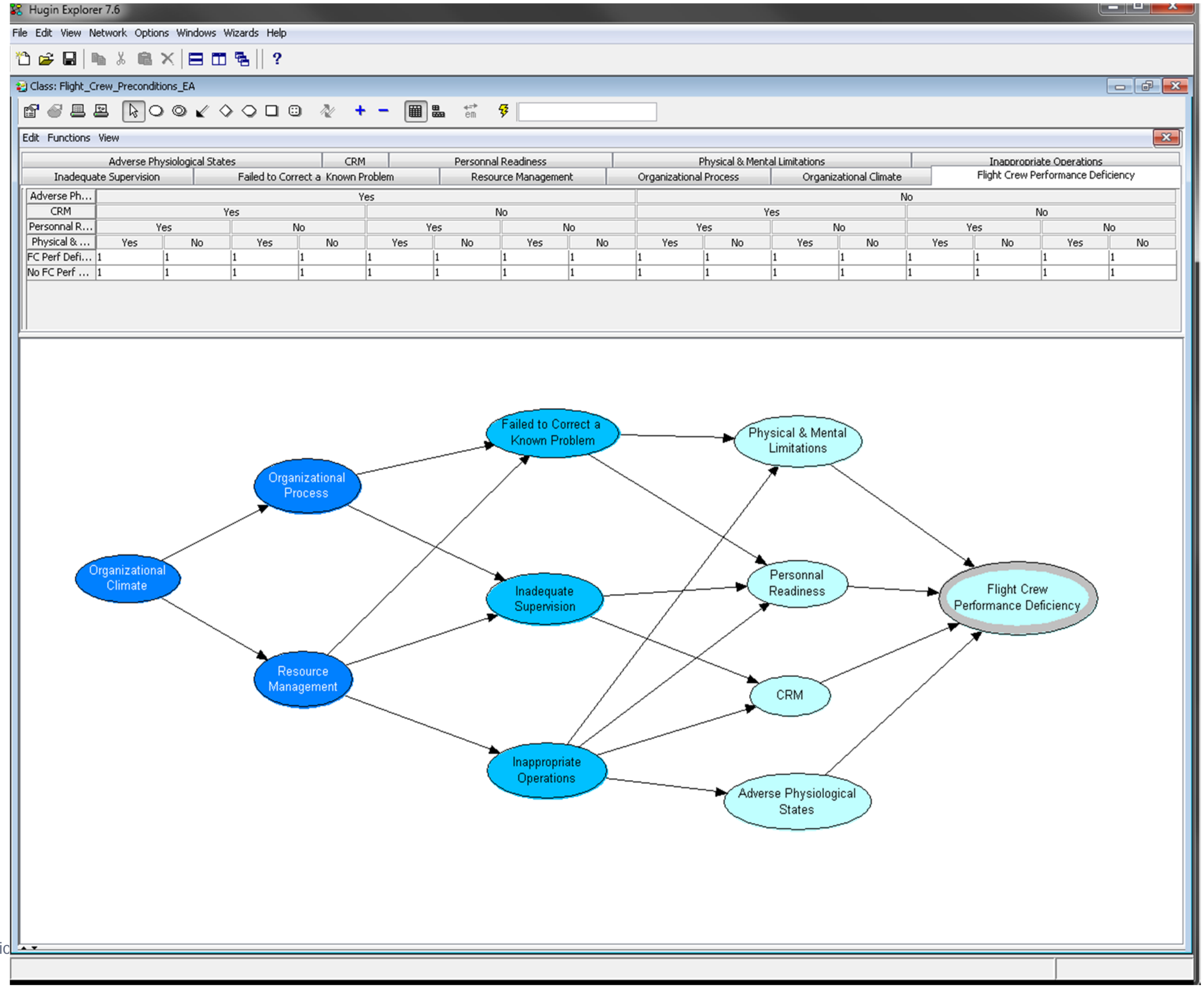
Loss of Control Accident Framework

Top-level Baseline LOCAF Model in Hugin®



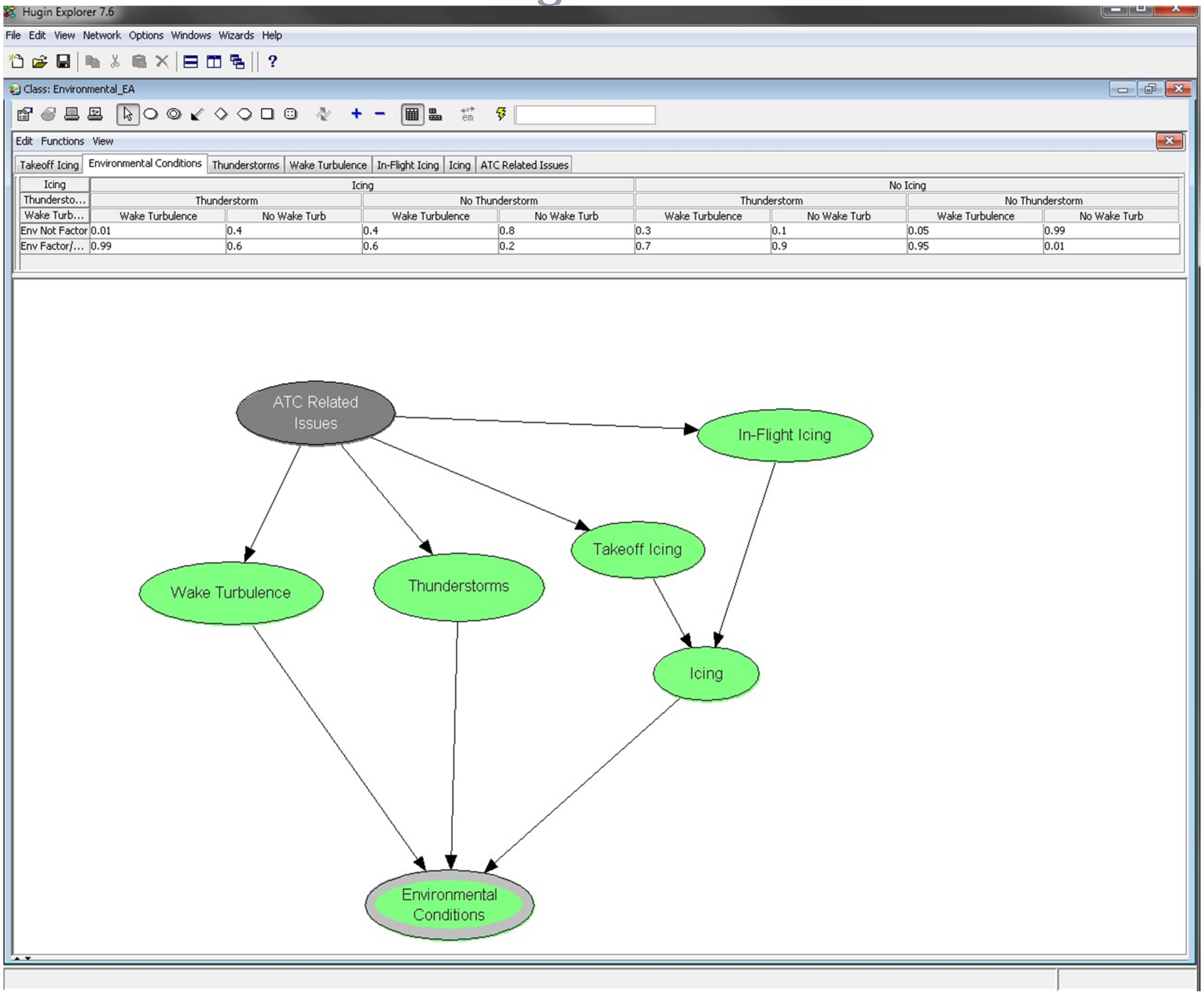
Loss of Control Accident Framework

Flight Crew Performance Subnet in Hugin®



Loss of Control Accident Framework

Environment Subnet in Hugin®



Loss of Control Accident Framework
Knowledge Elicitation Sessions*

Knowledge Elicitation Sessions for:

- Reviewing the baseline model structures (ontology and terminology) – Nodes and links in LOCAF model
- Eliciting the conditional probabilities (CP) from LOC accident perspective (not overall aviation accident perspective) in the National Air Space (NAS) for time frame 1990 to 2010
- Inserting AvSP safety technology products from AEST, SSAT, and VSST projects into the LOCAF model for portfolio assessment
- Updating the CPs with the presence of AvSP products in the model
- Reviewing the LOCAF model structures with products inserted

* Publication: Luxhoj, J. T., Shih, A. T., Jones, S. M., Ancel, E. and Reveley, M. S., "Safety Risk Knowledge Elicitation in Support of Aeronautical R&D Portfolio Management: A Case Study," *Proceedings of the American Society for Engineering Management (ASEM) 33rd International Annual Conference*, Virginia Beach, VA, October 17-20, 2012

Loss of Control Accident Framework

Knowledge Elicitation and Subject Matter Expert Review Sessions

Knowledge Elicitation (KE) Sessions

The five elicitation stages of motivating, structuring, conditioning, encoding and verifying were followed.

Session 1.0
Baseline Model
May 8-9, 2012
Hampton, VA
Operational SMEs (3)
- Pilot
- ATC
- Accident Investigator

Session 2.0
Product Insertions
July 31 - August 1, 2012
Hampton, VA
Operational SMEs (3)
- Pilot
- ATC
- Accident Investigator

Session 4.0
Product Insertions Review
June 19-20, 2013
Hampton, VA
Operational SMEs (3)
- Pilot
- ATC
- Accident Investigator

Session 1.5
July 19, 2012
Product SMEs
- Researcher/Academia
- Aero Industry
- Airline/End User

** Product SMEs only reviewed the model's structure and identified any missing causal factors.*

Session 3.0
External Review
September 12, 2012
Washington, DC
External SMEs (3)
- FAA
- FAA/NTSB
- LOC Specialist

AvSP Projects
Feb.-April 2013
WebEx Meetings
Project Personnel
Product Leads or POCs
** Product leads provided feedback comments on products insertion.*

Loss of Control Accident Framework

Degree of Belief (DOB) Approach

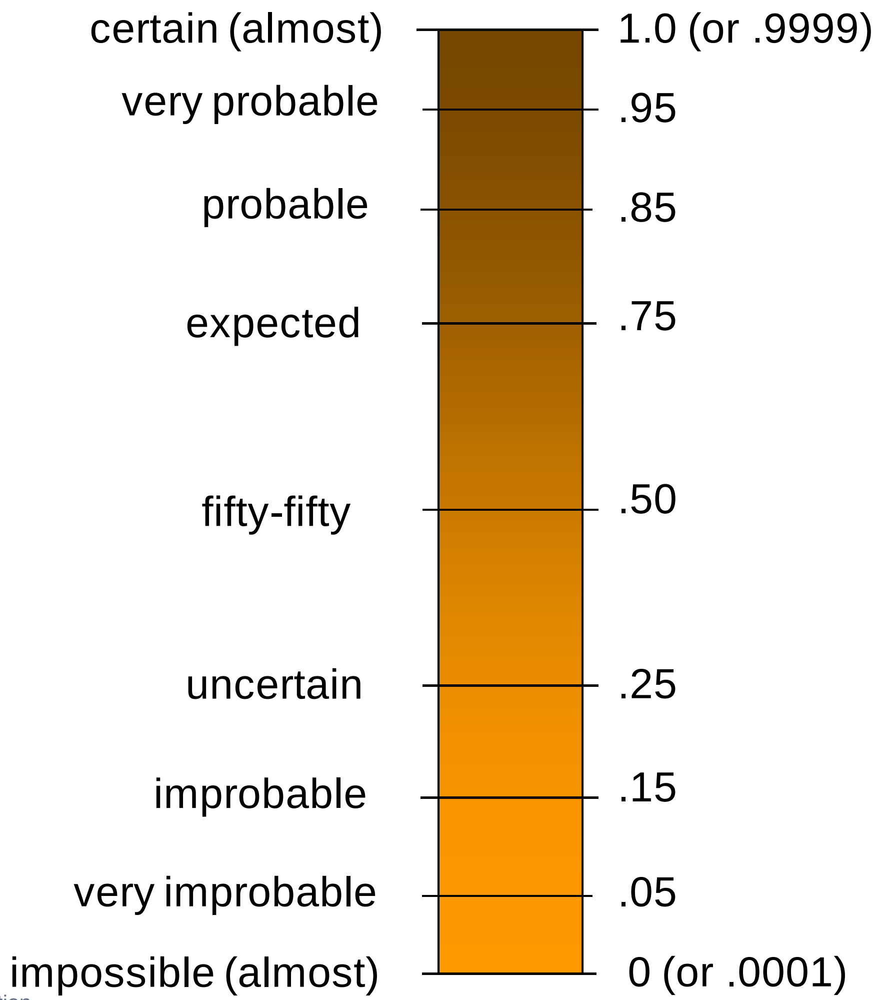
Renooij & Witteman (1999) Verbal Descriptor	Probability	Ang & Buttery (1997) Verbal Descriptor
(almost) certain	1	
	0.9999	extremely likely (i.e., almost certain)
	0.9	very likely
probable	0.85	
expected	0.75	
	0.7	likely
fifty-fifty	0.5	indeterminate
uncertain	0.25	
improbable	0.15	
	0.1	probable (i.e., credible)
	0.01	unlikely
	0.001	very unlikely
	0.0001	extremely unlikely
(almost) impossible	0	

Loss of Control Accident Framework

KE Probability Scale – Verbal/Numerical Equivalents

"The purpose of computing is insight, not numbers."

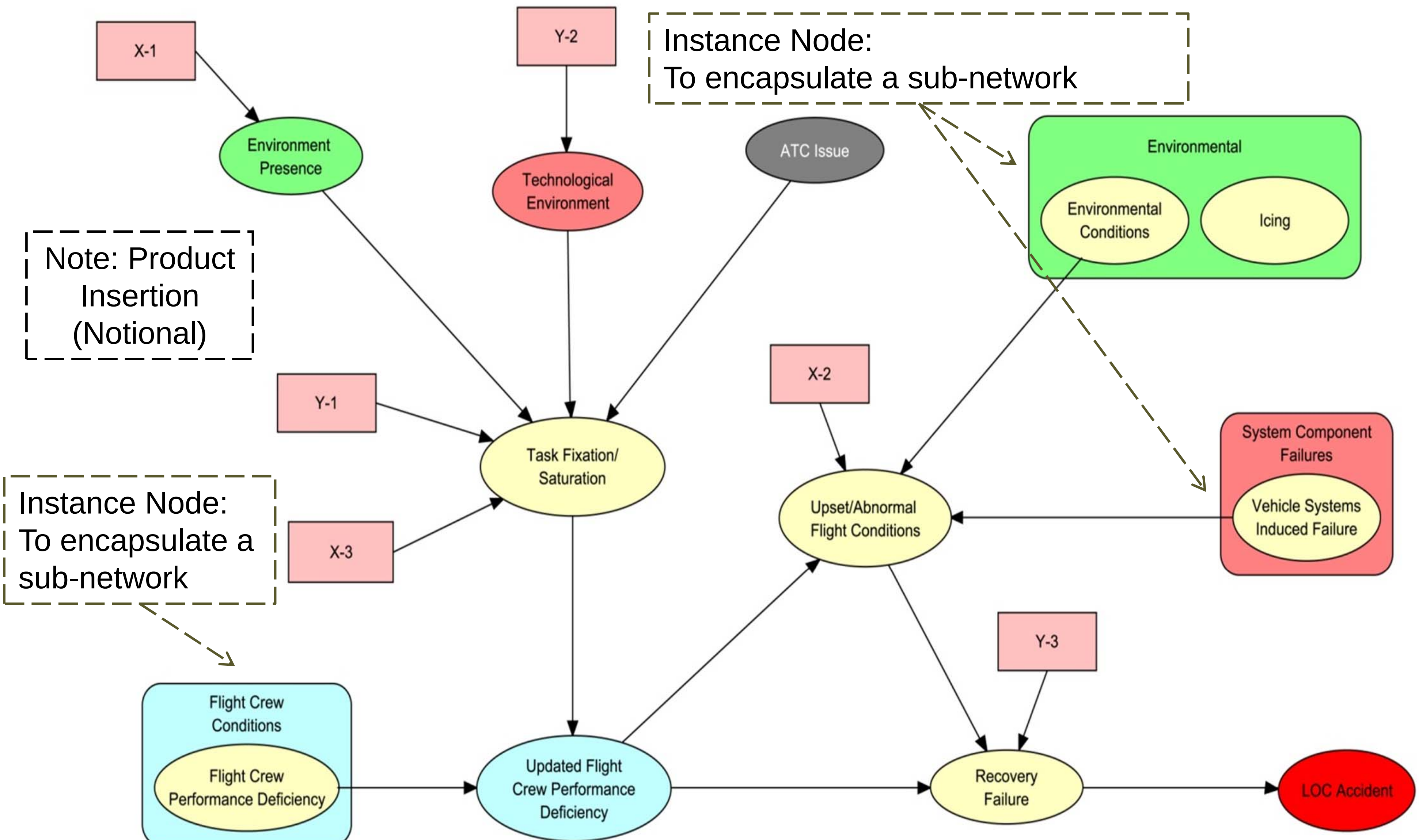
-Richard Wesley Hamming



Adapted from Druzdel and van der Gaag, 2000; Renooij and Witteman, 1999

Loss of Control Accident Framework

Top Level LOCAF Model



Aviation Safety Program Portfolio

(as of the summer of 2012)

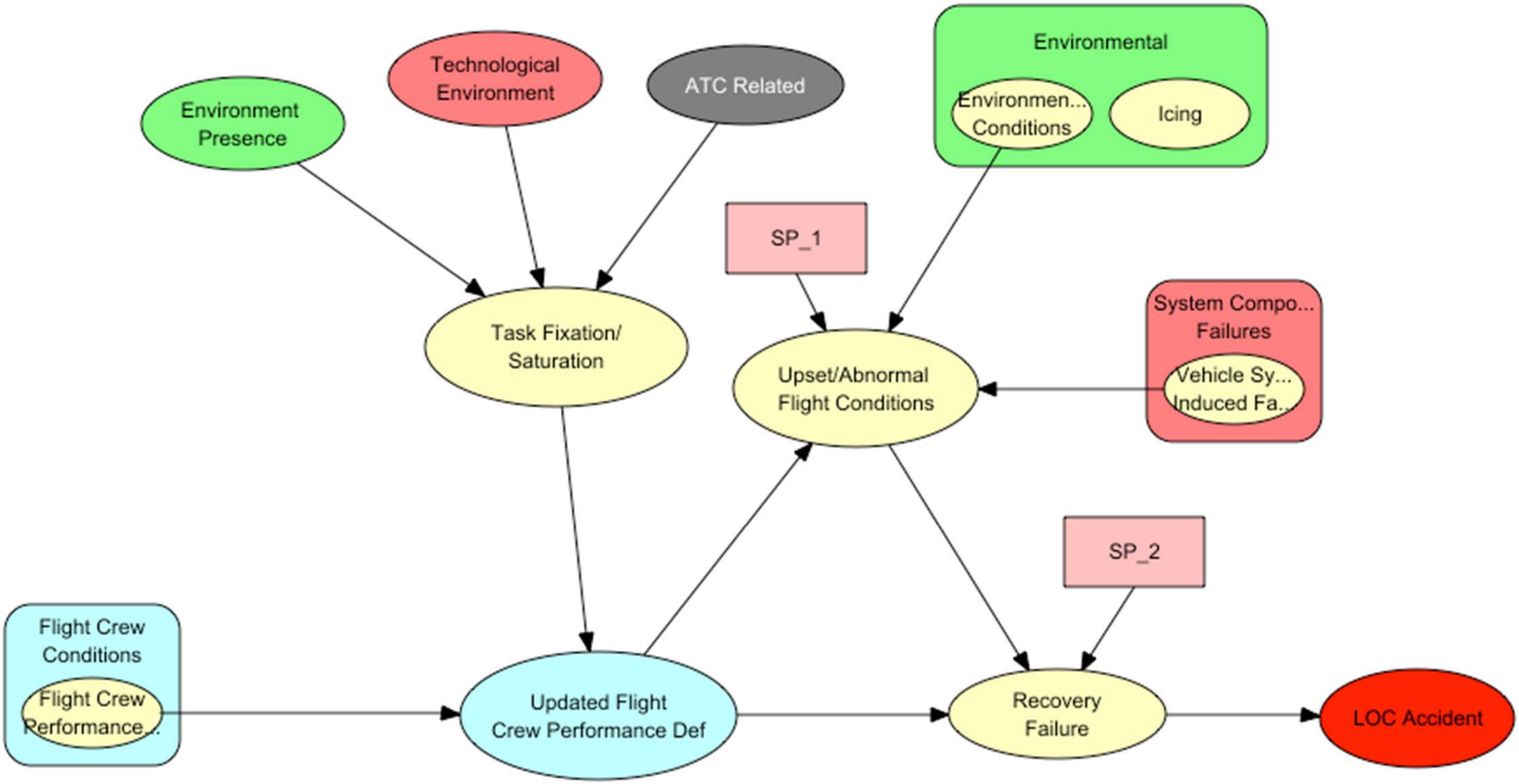
SSAT PRODUCTS	
ASSURANCE OF FLIGHT CRITICAL SYSTEMS (AFCS)	
AFCS-1	Models of Integrated Distibuted Systems for Vehicles and Airspace Problems
AFCS-2	Early Life Cycle Software Verification Methods and Techniques
AFCS-3	Tools and Methods for Ensuring Authority and Autonomy
AFCS-4	Argument-Based Safety Assessment and Assurance Methods
DISCOVERY OF PRECURSORS TO SAFETY INCIDENTS (DPSI)	
DPSI-1	Vehicle Level Reasoning System
DPSI-2	Anomaly Detection Algorithms
DPSI-3	Causal Factor Identification Algorithms
DPSI-4	Adverse Event Prediction Algorithms
ASSURING SAFE HUMAN SYSTEMS INTEGRATION (ASHSI)	
ASHSI-1	Tools, Models and Design Guidelines for Human/Automation Interaction
ASHSI-2	Human Performance Assessment
ASHSI-3	In situ Human Performance Characterization
ASHSI-4	Training and Procedure Development
ASHSI-5	Operational Complexity Methods and Tools
PROGNOSTIC ALGORITHM DESIGN FOR SAFETY ASSURANCE (PDSA)	
PDSA-1	Tools and Techniques for Remaining Life Estimation
PDSA-2	Prognostic Decision Making Methods
PDSA-3	Assurance Process for Prognostic Health Management (PHM) Algorithms

VSST PRODUCTS	
IMPROVE CREW DECISION-MAKING AND RESPONSE IN COMPLEX SITUATIONS (CDMR)	
CDM-1	Advanced Displays for Terminal Area and Surface Operations
CDM-2	Flight Deck Countermeasures for Spatial Disorientation and Loss-of-Energy State Awareness
CDM-3	Robust Interfaces to Trajectory Automation (RITA)
CDM-4	Flight Deck Information Management Systems for Integrity and Awareness
CDM-5	Revised Pilot Proficiency Standards for Manual Handling and Automation Interactions
MAINTAIN VEHICLE SAFETY BETWEEN MAJOR INSPECTIONS (MVS)	
MVS-1.1	Dynamic Assessment of Aircraft Structural Health (DAASH)
MVS-1.2	Physics-Based Models and Algorithms for Wiring Fault Detection
MVS-1.3	Vehicle-Level Diagnostics
MVS-2.1	Propulsion System Diagnostics
MVS-2.2	Smart High Temperature Sensor Systems
MVS-3.1	Integrated Sensing and Healing System (ISHS)
MVS-3.2	Bonded Joints and Repairs
MVS-3.3	Emerging Disks and Composite Materials
ASSURE SAFE AND EFFECTIVE AIRCRAFT CONTROL UNDER HAZARDOUS CONDITIONS (ASC)	
ASC-1	Enhanced Vehicle Dynamics Models
ASC-2	Upset Onset Detection and LOC Prevention Methods
ASC-3	Maneuverability Estimation and Upset Prevention Methods
ASC-4	Multiple Hazards Mitigation and Upset Recovery Methods

AEST PRODUCTS	
ENGINE ICING (EI)	
EI-1	Ice-crystal Icing Environment Characterization
EI-2	Engine Icing Performance Simulation Tool
EI-3	Engine Icing Accretion Simulation Tools
EI-4	Altitude Engine Ice Particle Test Capability (facility & particle scaling)
AIRFRAME ICING (AI)	
AI-1	Swept Wing Ice Accretion Simulation Tools
AI-2	SLD Ice Accretion Simulation Tools
AI-3	3-D Ice Scanning Tools and Methods
AI-4	Ice Protection System Modeling
ATMOSPHERIC HAZARD SENSORS AND MITIGATION (AHSM)	
AHSM-1	Icing Weather Systems
AHSM-2	Advanced Radar Enhancements
AHSM-3	Airworthy LIDAR
AHSM-4	Pattern Recognition Engine for Enhanced Vision System
AHSM-5	Lightning Protection and Detection Systems for Composite Aircraft

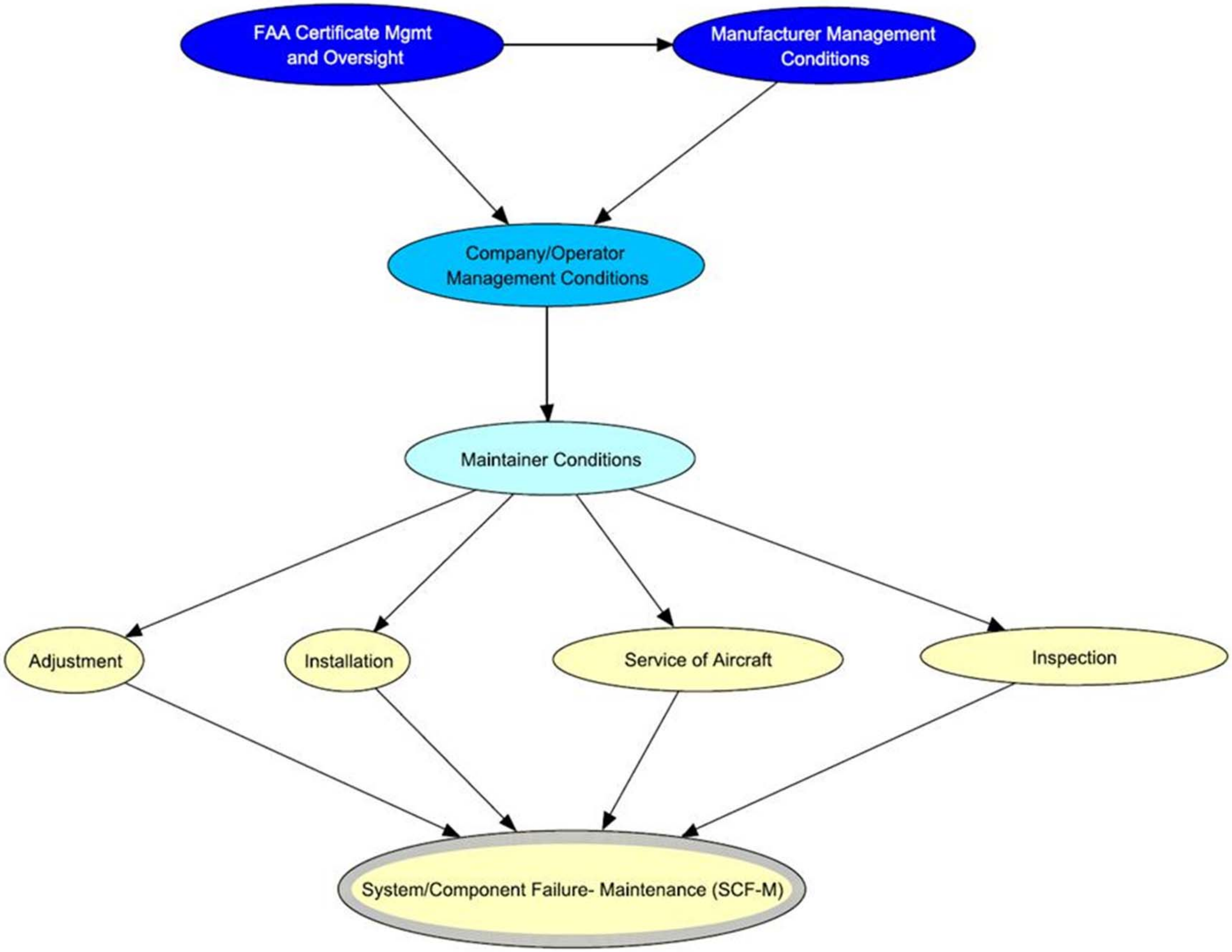
Loss of Control Accident Framework

Top-level Baseline LOCAF Model in Hugin®



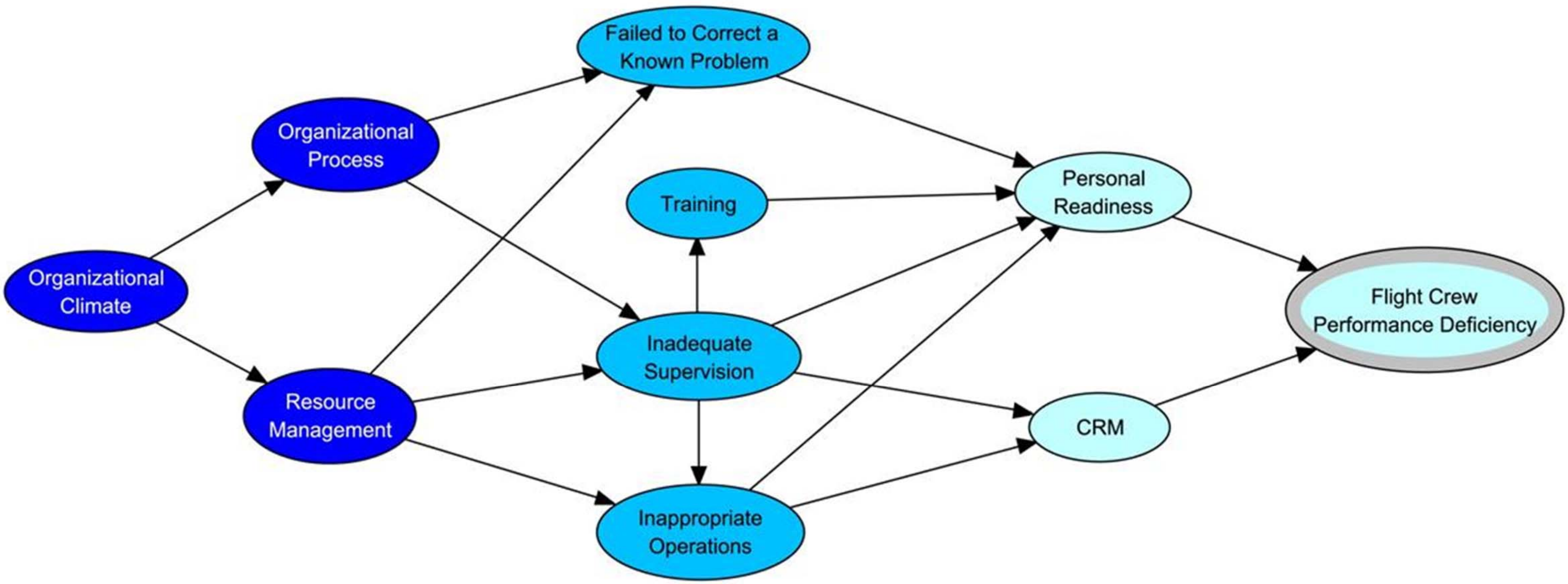
Loss of Control Accident Framework

System/Component Failure-Maintenance (SCF-M) Sub-Network



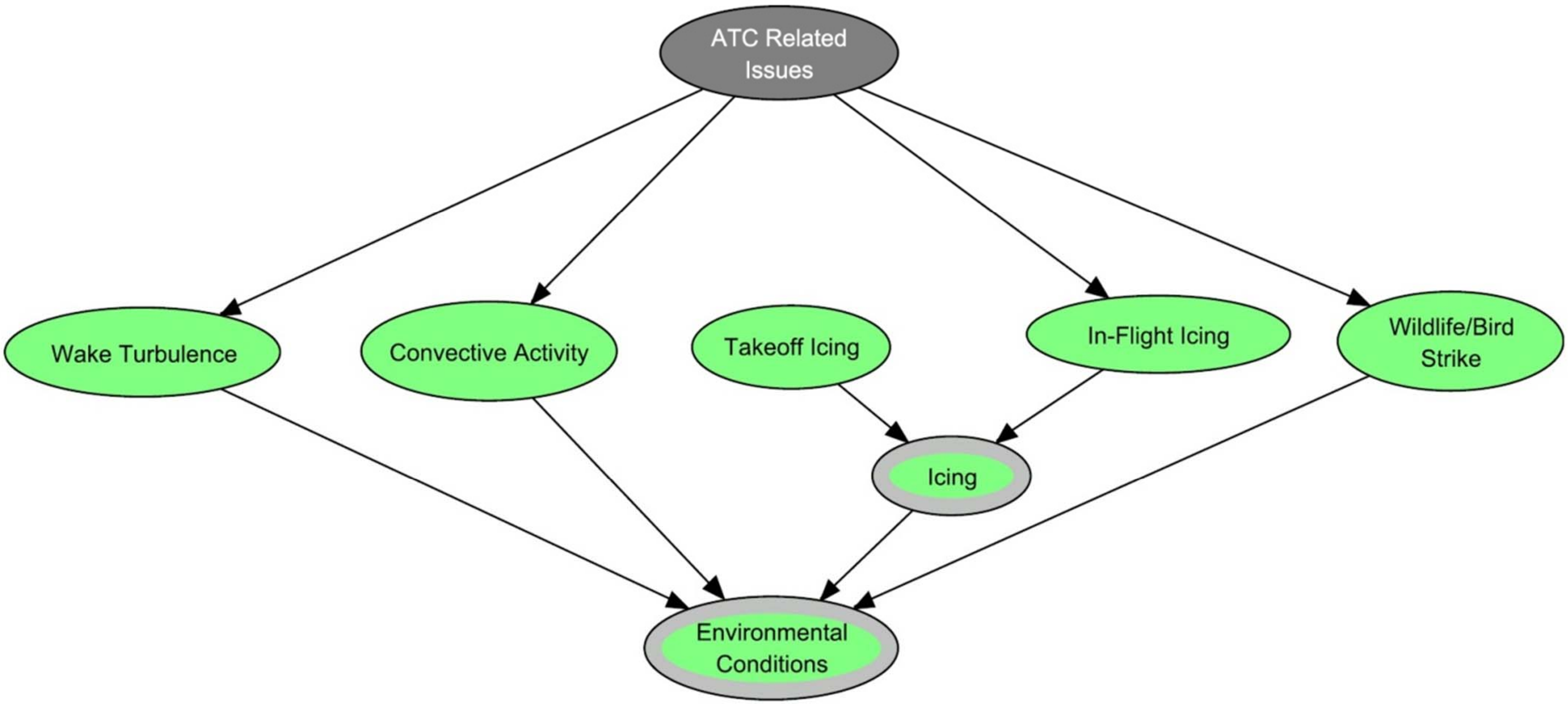
Loss of Control Accident Framework

Flight Crew Performance Sub-Network



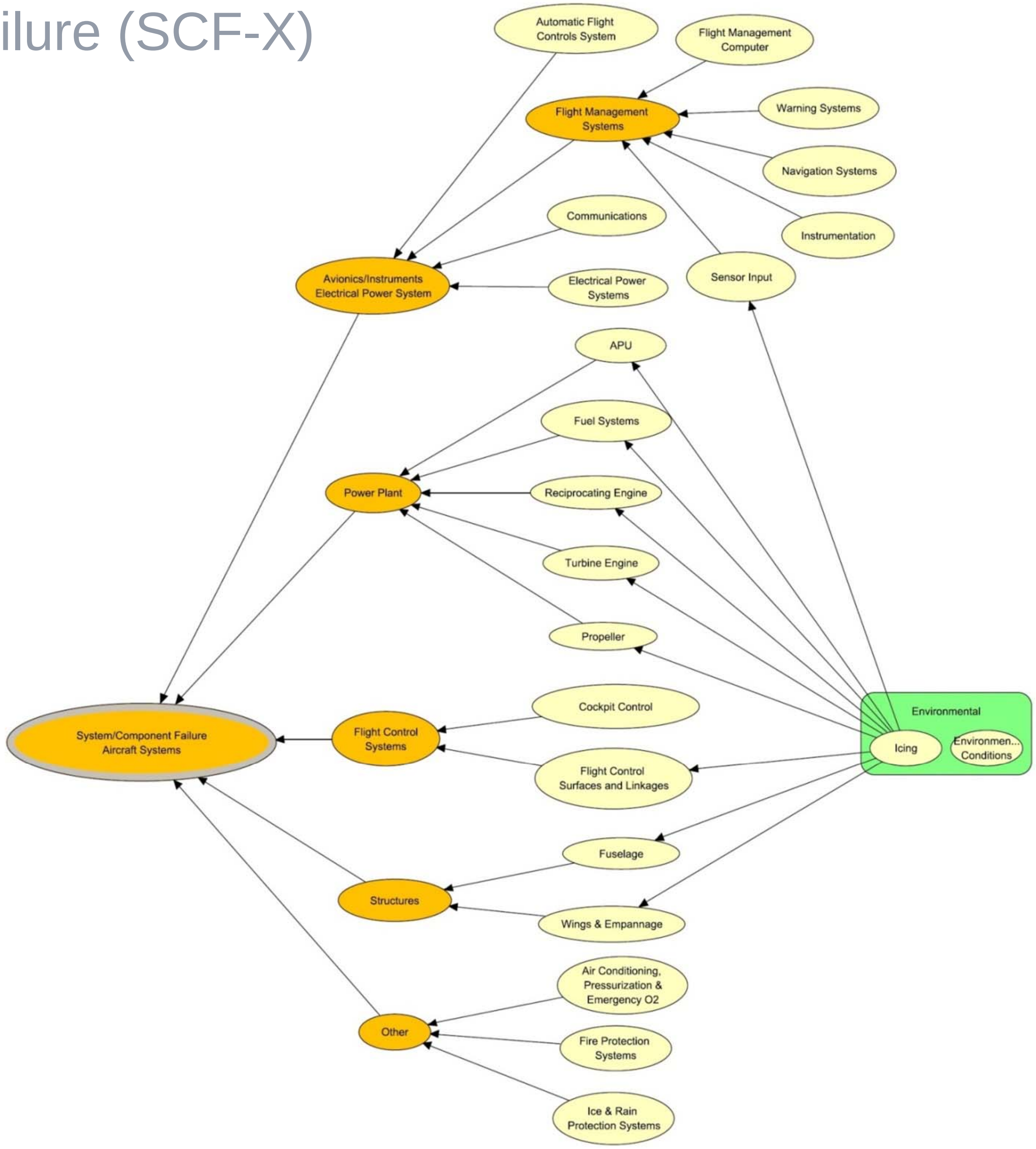
Loss of Control Accident Framework

Environment (ENV) Sub-Network



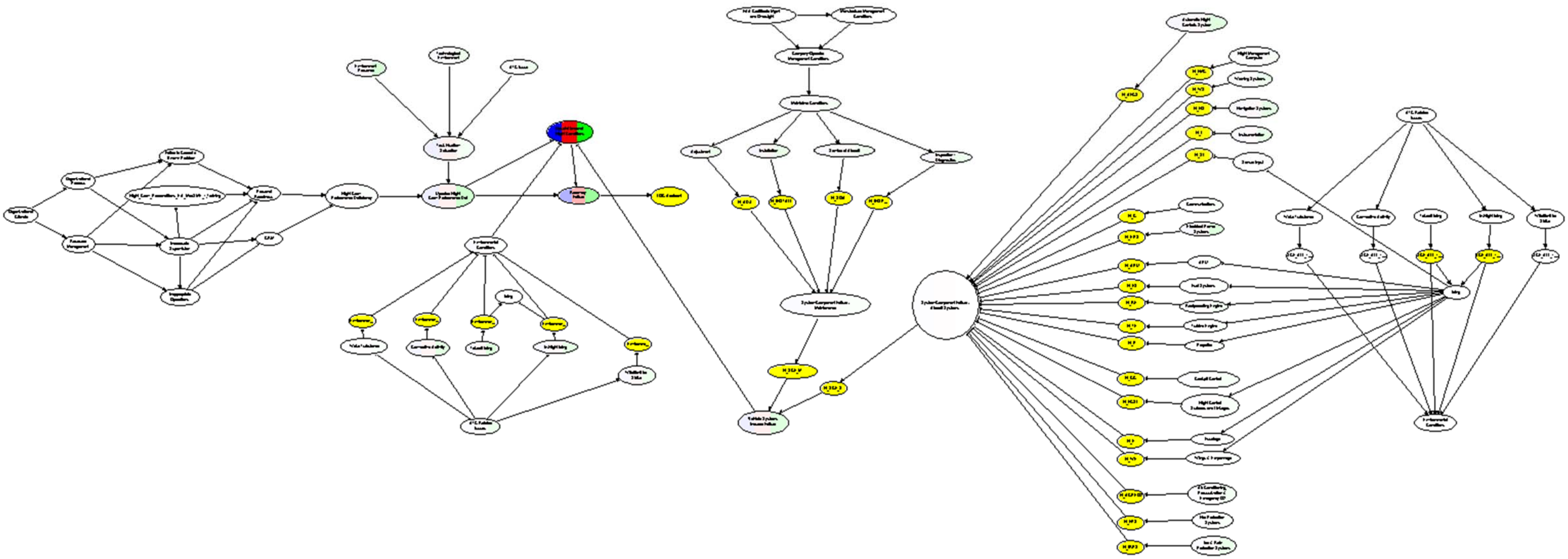
Loss of Control Accident Framework

System/Component Failure (SCF-X) Sub-Network



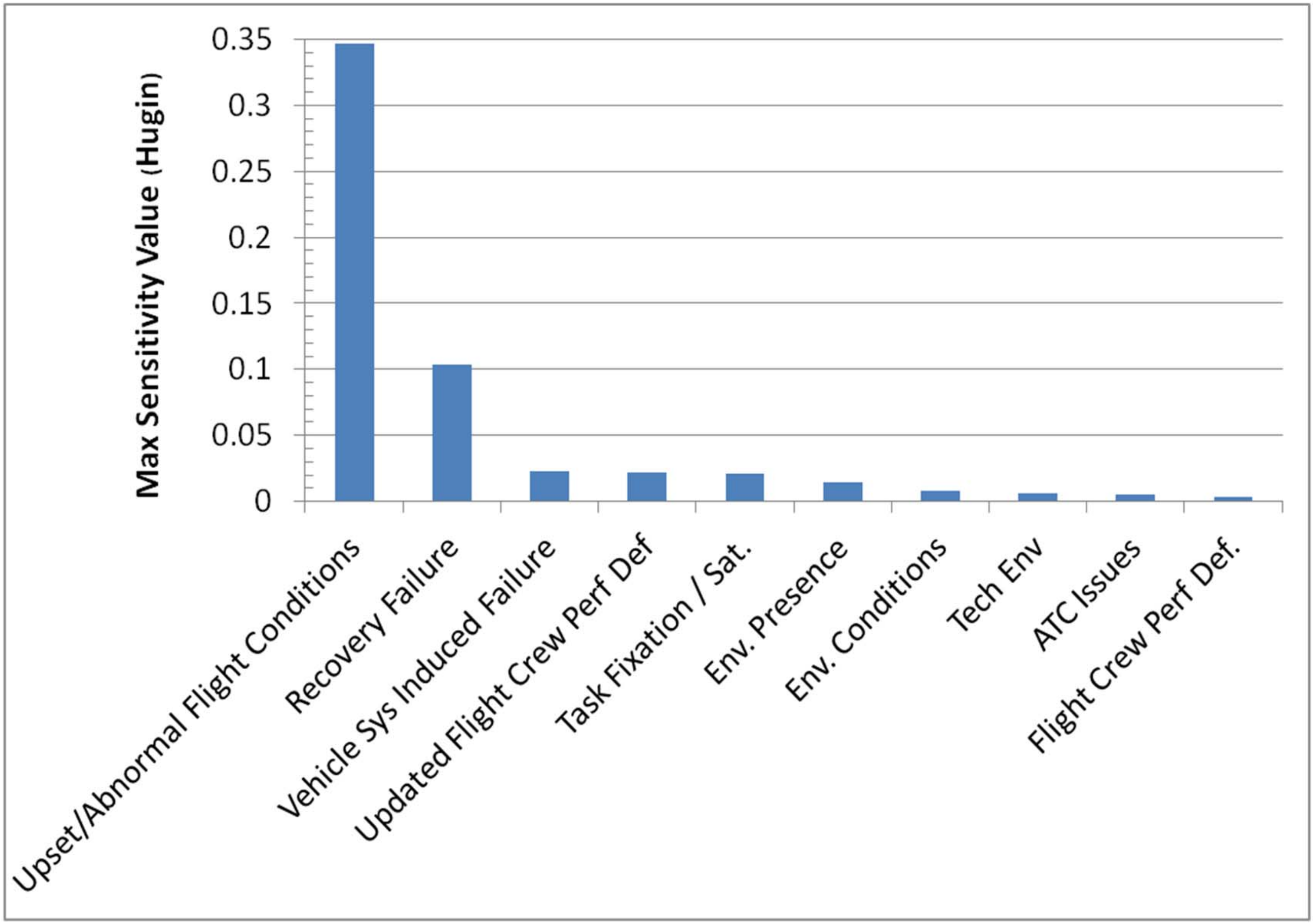
Loss of Control Accident Framework

Hugin® Sensitivity Graph at Top Level



Loss of Control Accident Framework

Node Max Sensitivity Values at Top Level



Loss of Control Accident Framework

Baseline LOCAF Model – Preliminary Results

LOC Likelihood Results Comparison:

Data from historical database

54 Cases ('87-'09):

- SCF: 50%
- ENV: 31.5%
- LOC: 13.81%

Historical Data '88-'04:

- SCF: 20.8%
- ENV: 14.37%
- LOC: 12.84%

LOCAF model results

For This Study (54 Cases), '87-'09:

- SCF: 50%
- ENV: 31.5%
- **LOCAF LOC: 15.92% (+2.11%)**

For Historical Data (1962 Cases), '88-'04:

- SCF: 20.8%
- ENV: 14.37%
- **LOCAF LOC: 10.11% (-2.73%)**

Loss of Control Accident Framework

Summary

- Papers describing results of LOCAF development have been presented to several different technical communities
  - Aeronautics (AIAA ATIO)
  - Systems engineering/operations research/engineering management
  - FAA risk analysis personnel
- Results of LOCAF will be used to compute “relative safety risk reduction” metric for September 2013 Aviation Safety Program Portfolio Assessment milestone
- Two additional models are currently in development:
  - Runway Safety Model
  - Increasing Complexity and Reliance on Automation Model
- Current model is based on historical accidents, the next version of LOCAF will reflect future NextGen operating environment