Uncertainty in the Context of Risk Acceptance Decision-Making at NASA: Thinking Beyond "The Model"

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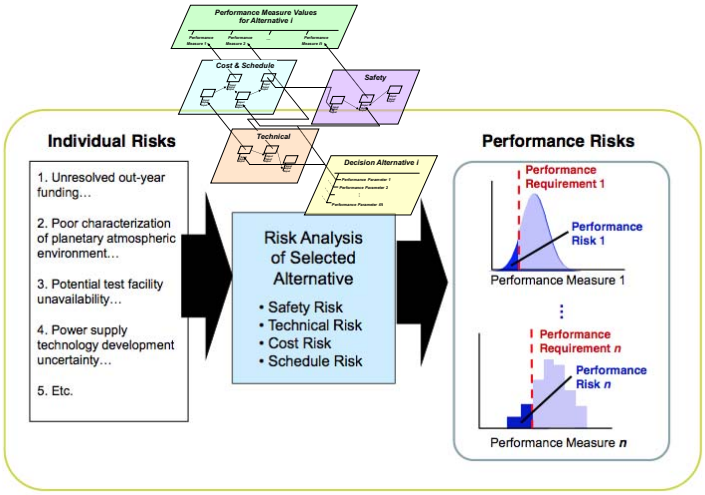
Overview

- In the NASA risk management context, "risk" means "potential for falling short of performance requirements"
  - E.g., a particular value of Probability of Loss of Crew (P(LOC)) might be a safety performance requirement (threshold for maximum acceptable risk)
  - The risk is the probability that the "actual" P(LOC) > the threshold
  - Roughly analogous to MIL-HDBK-189C *consumer risk*: the probability of accepting a system when the true reliability is below the technical requirement
- In a mission context, the scope of performance requirements spans the domains of safety, technical, cost, and schedule
- Specifying acceptable levels of performance for a given system is a question of requirements setting and relates to policy decisions (not a topic of this presentation)
- Uncertainty about what the "actual" performance of a system is, or will be, relates to epistemic uncertainty, and *is* a topic of this presentation
- At issue is the need to make sure that the decision maker (DM) is adequately apprised of *all* the relevant uncertainty when making risk acceptance decisions
  - For the above example, in order to justify a risk acceptance decision, DM needs assurance (enough confidence) that P(LOC) < "threshold"

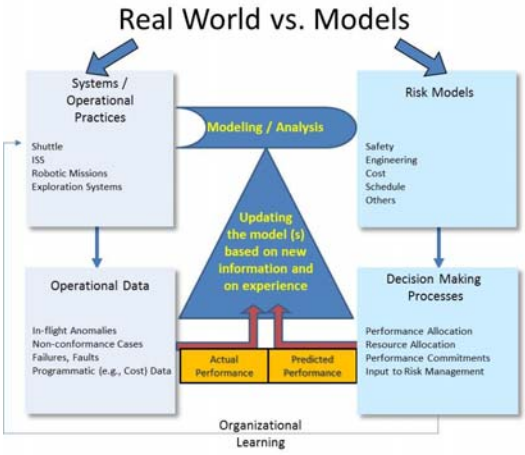
Risk Models

- Risk model development (synthetic analysis) attempts to forecast performance within a probabilistic framework that accounts for known, quantifiable sources of epistemic uncertainty.



Real World vs. Models

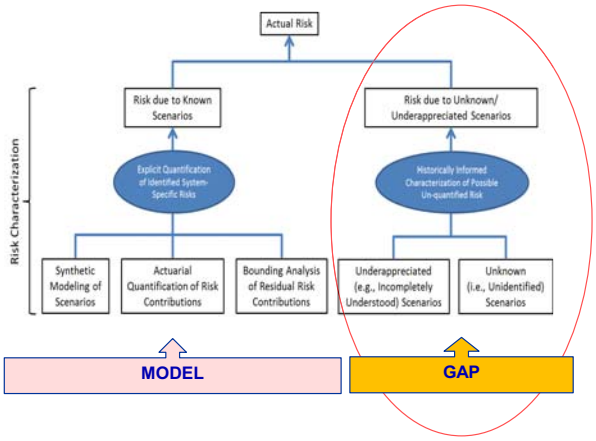
- Risk models must be constantly and critically reexamined for consistency with system configuration/ operation, and updated with relevant information (e.g., accident precursor analysis…) to ensure the closest correlation and fastest convergence between the "real world" and the "risk model"



The Gap

- However, in NASA contexts there is typically a gap between the real world and the model that is initially dominating and does not converge until long after most major decisions have been made
  - Executing first-of-a-kind missions with first-of-a-kind hardware
  - Employing systems that operate at the edge of engineering capability
- This gap is the domain of so-called Unknown and/or Underappreciated (UU) risks
- UU risks live outside the model due to:
  - Model incompleteness
  - Being outside the scope of the model
  - Violating the model assumptions
  - Remaining latent in the system until revealed by operational failures, precursor analysis, etc.
  - Tending to be most significant early in the system life cycle
  - Disproportionally reflecting complex intra-system and environmental interactions

How Significant is the Gap?



UU scenarios have historically represented a significant fraction of actual risk, especially for new systems

Launch System Reliability Trends

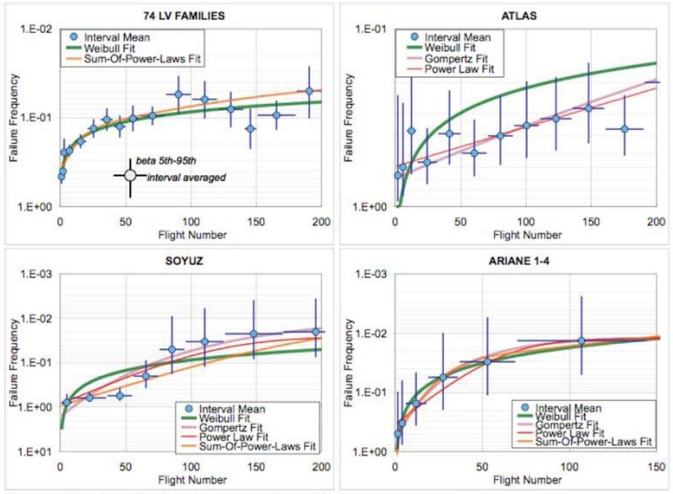
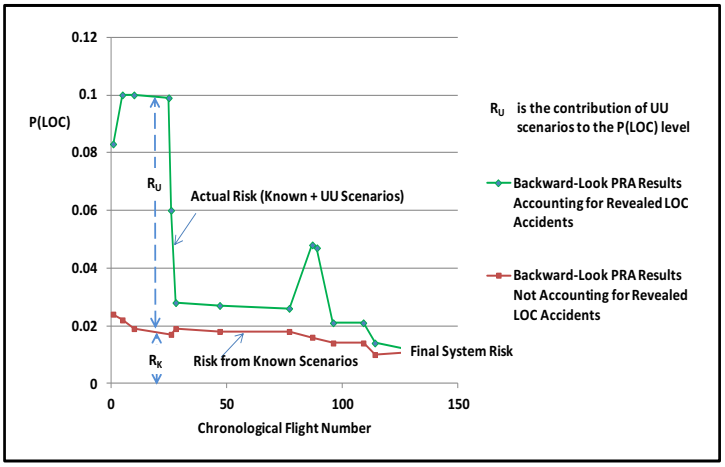


Figure 3. Model matches to selected examples of historical growth curves

Source: *Morse et al., "Modeling Launch Vehicle Reliability Growth as Defect Elimination," AIAA Space Conference and Exhibition (2010).*

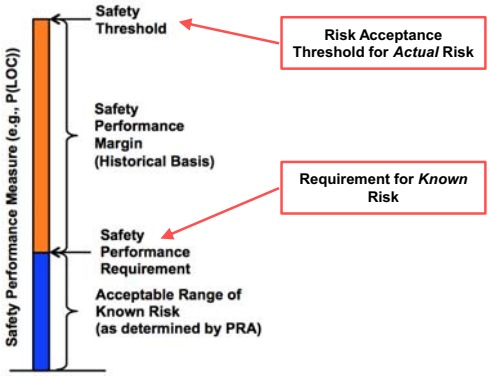
Results of Retrospective Analysis on Shuttle Risk



Source: *Shuttle Risk Progression: Use of the Shuttle Probabilistic Risk Assessment (PRA) to Show Reliability Growth, Teri L Hamlin et al. (AIAA, 2010) (downloadable from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110004917_2011004008.pdf)*

Accounting for Unknown/Underappreciated Risks

- Aerospace Safety Advisory Panel (ASAP) and others have identified the need to consider the gap between *known* risk and *actual* risk when applying NASA safety thresholds and goals
- We use the concept of safety performance margin to account for UU risks
  - Based on historical discrepancies between initially-calculated and eventually-demonstrated safety performance
  - Provides a rational basis for deriving probabilistic requirements on known risk



The Case for the "Risk-informed Safety Case"

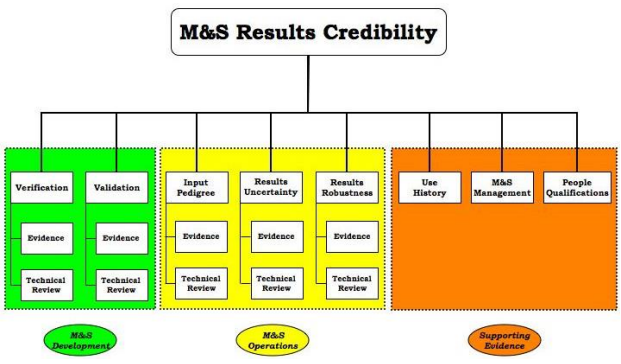
- Informed risk acceptance decision making must go beyond the model to be adequately risk-informed
- The "case" that the system risk is within the safety threshold must be made by a coherently-stated argument with supporting evidence – hence a "Risk-Informed Safety Case (RISC)"
  - Substantiation that UU risks (UU uncertainties) are adequately managed via application of best practices and a defense-in-depth philosophy to:
    - Minimize the presence of UU scenarios (e.g., via margin, programmatic commitments)
    - Maximize discovery of UU hazards (e.g., via testing, liberal instrumentation, monitoring, and trending, anomaly investigation, Precursor Analysis, use of best safety analysis techniques)
    - Provide broad-coverage safety features (e.g., abort capability, safe haven, rescue)
  - Substantiation that the known risk (calculated by PRA) is within the specified safety performance requirement
    - Known risks are managed by applying controls that are designed to mitigate identified adverse scenarios
- The RISC is the totality of the "uncertainty story" about the "actual" safety performance of the system
  - presented and defended by the provider at key decision points
  - provides the DM with a rational basis for identifying assurance deficits (inadequacies in the evidentiary support of the safety claims)
  - involves serious consideration of things that live outside traditional risk models (e.g., organizational and management factors)

Unknown / Underappreciated

Known

The Model as Evidence

- The risk model counts as (major) evidence in the case.
- But how good is it? To what extent can the DM rely on it?
- NASA-STD-7009, Standard for Models and Simulation (M&S) presents a framework for assessing the credibility of models and simulations in the context of the uses to which they are put
- The credibility assessment is presented with the model and model results, as an integral part of the case



Summary

- **In general:**
  - When a system is being acquired or licensed, someone (acquirer, licensing authority) is making a risk-acceptance decision…
    - Potentially affecting a range of stakeholders (public, workers, …) in different ways (safety, performance, cost, schedule …)
  - The decision is informed by some combination of modeling, analysis, *experience with the subject system, experience with related technology, and, in some cases, a sense of the provider's (or the applicant's) capability*
  - The responsible decision-maker has to have a sense of the uncertainties affecting the decision, *including the limitations of the model*
- **At NASA:**
  - The challenge is to execute high-stakes, first-of-a-kind missions that are subject to significant uncertainty in all domains (safety, performance, cost, schedule)
  - As in other complex, high-stakes undertakings, modeling is a vital ingredient in the development process
  - But responsible risk-acceptance decision-making requires the decision-maker to think beyond the model