Risk-Based Design Overview

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Outline

- **Risk-Based Design programmatic background**
- **Summary of ASCAC contributions to RBD**

Risk-Based Design History

- **LaRC MDO Industry Tour in 1994 identified design under uncertainty as a major industry interest**
- **1996 MDOB Peer Review echoed this**
- **ACMB/SMC initiated structural reliability-based design under the ASCoT Project in 1998**
- **MDOB initiated aerodynamics robust design work under the Morphing Project in 1999**
- **Gilbert tells Zang in early 2000 that ASCAC's greatest methods need is for system risk assessment at the conceptual design stage**
- **These activities formed the core of the ASCoT Risk-Based Design Focus Area initiated in 2001**
  - **AirSC stochastic controls work started in 2001**
  - **ASCAC system risk assessment work started in 2001**
  - **AAAC CFD uncertainty quantification work started in 2002**
- **Risk-Based Design "White Paper" was circulated for comments in late 2001**

ASCoT Project (1998-2002)

(Aerospace Systems Concept to Test)

Project Vision

Physics-based modeling and simulation with sufficient speed and accuracy for validation and certification of advanced aerospace vehicle design in less than 1 year

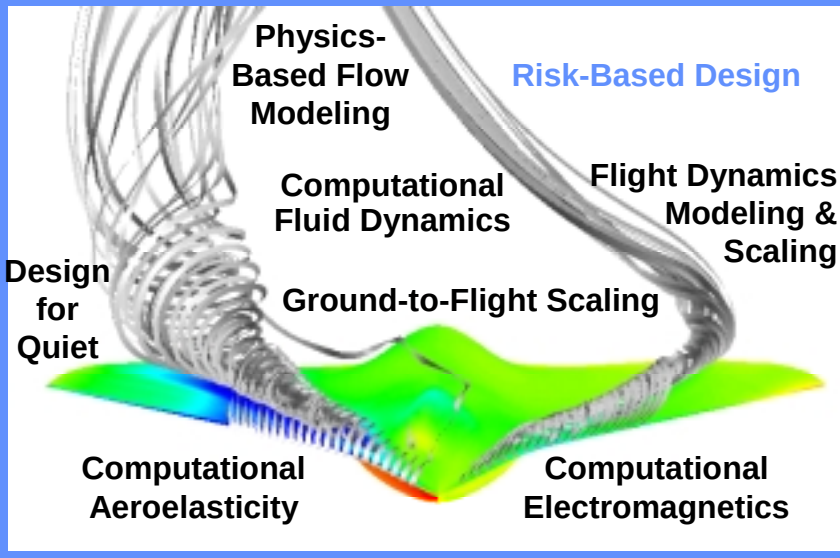
Project Goal

- **Provide next-generation analysis & design tools to increase confidence and reduce development time in aerospace vehicle designs**

Objective

- Develop **fast, accurate, and reliable** analysis and design tools via fundamental technological advances in:
  - Physics-Based Flow Modeling
  - Fast, Adaptive, Aerospace Tools (CFD)
  - Ground-to-Flight Scaling
  - Time-Dependent Methods
  - Design for Quiet
  - Risk-Based Design

Technology Areas



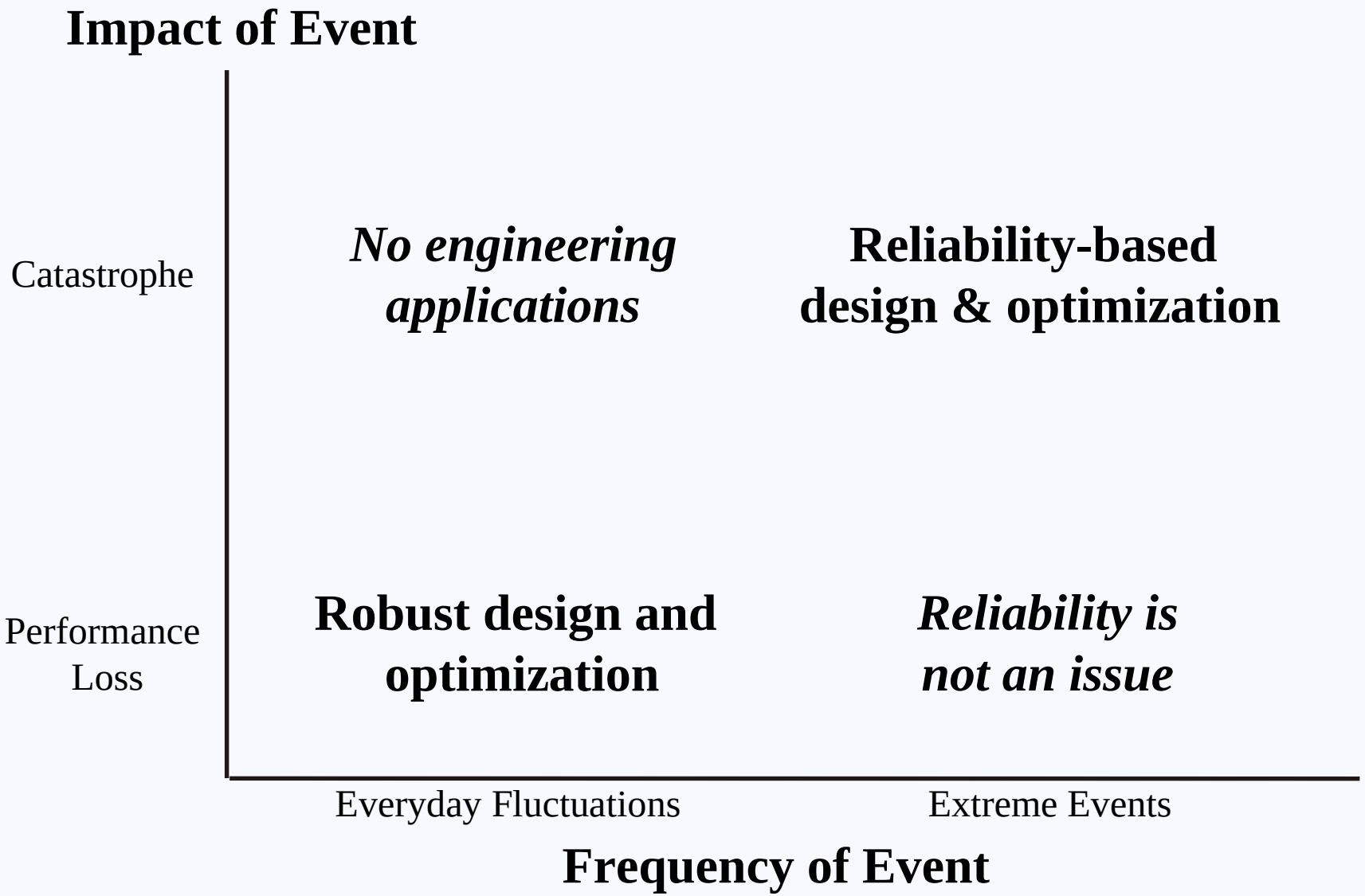
Benefit

- **Increased Design Confidence**
- Reduced Development Time

Proposed LaRC Niche in RBD

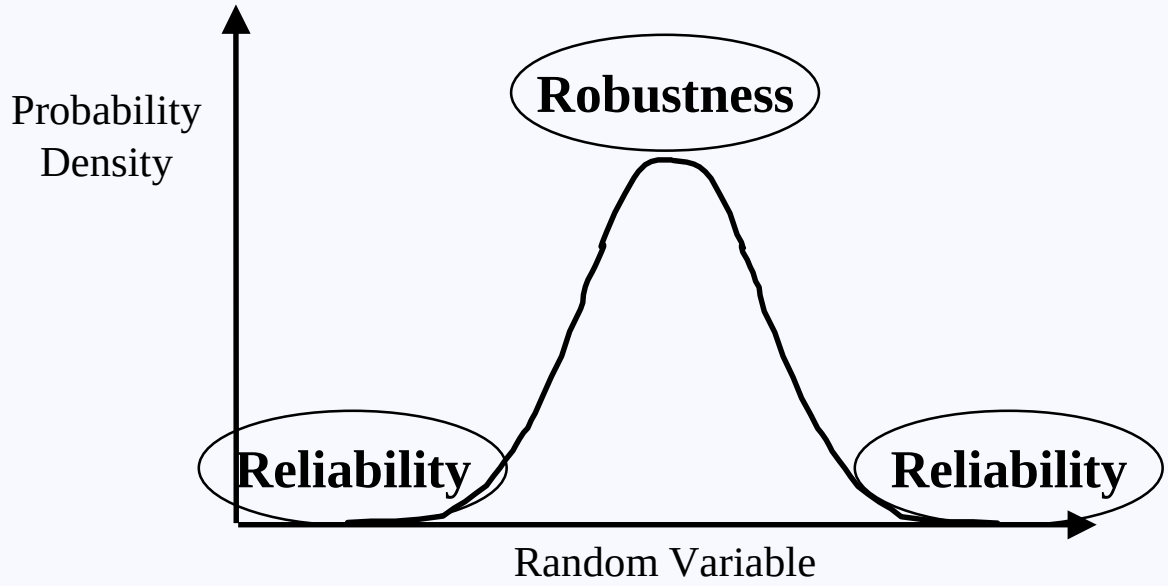
- **Evaluate and improve methods for control of risk with applications to multidisciplinary airframe design by**
  - **Developing and validating strategies, algorithms, tools and data for**
    - characterizing and controlling the uncertainties from the individual airframe design disciplines, esp. aerodynamics, structures and controls, based on the best available experimental and computational results
    - characterizing the norm and distribution of the resulting uncertainties in system metrics
    - accounting for uncertainties in the design of airframes at the conceptual through the detailed design stages

Probabilistic Problem Classification



Probabilistic Design Categories

- **Robust Design**
  - **a design is sought that is relatively insensitive to small changes in the uncertain quantities**
- **Reliability-Based Design**
  - **a design is sought that has a probability of failure that is less than some acceptable (invariably small) value**



RBD Disciplinary Foci at LaRC

- **Aerodynamics**
  - **Uncertainty quantification for CFD**
    - Moment methods (in ASCAC)
    - Statistical Quality Control for CFD (in AAAC)
    - Polynomial chaos (in AAAC)
  - **Robust design for performance (in ASCAC)**
  - **Reliability-based design for controllability (in ASCAC)**
- **Structures**
  - **Reliability-based structural design using possibilistic methods (in SMC)**
- **Controls**
  - **Stochastic control laws (in AirSC)**
- **Systems**
  - **System reliability predictions at the conceptual design stage (in ASCAC)**
  - **Multidisciplinary aero-structural reliability-based design and robust design (in ASCAC & SMC)**

RBD-related Work at LaRC

- **Wind Tunnel Enterprise**
  - **Modern Design of Experiments is being applied to large-scale wind tunnel testing [Richard DeLoach]**
  - **Statistical Quality Control principles are used to measure data quality [Michael Hemsch]**
- **Reliability-Based Structural Design**
  - **Twenty-first Century Aircraft Technology Program supports significant experimental and computational work in SMC**
  - **2nd Generation RLV supports some also**
- **System Uncertainty Quantification**
  - **2nd Generation RLV supports uncertainty analysis/sensitivity analysis for launch vehicle design (in ASCAC)**

ASCAC Role in RBD

- **Level 3 management of RBD**

- **Moment methods for aerodynamics uncertainty propagation (*see Newman presentation*)**
- **Robust aerodynamics design algorithms (*see Padula presentation*)**
- **Multidisciplinary aero-structural robust and reliability-based design (with SMC) (*see Newman presentation*)**
- **Develop tutorial on uncertainty methods for CFD (*at ICASE by Bob Walters of VPI&SU*)**
- **Reliability-based design applications for controllability**
- **System risk assessment at conceptual design stage**

CFD Uncertainty Tutorial: Methods
(ones in *blue italics* were implemented by Walters)

- **Non-Probabilistic**
  - ***Interval Analysis (IA)***
  - ***Sensitivity derivatives w. propagation***
  - **Possibilistic**
    - Fuzzy Sets
- **Probabilistic**
  - ***Monte Carlo (MC)***
    - *Crude*
    - Importance Sampling
    - Latin Hypercube
  - ***Moment Methods***
    - *First-Order, Second Moment (FOSM)*
    - *Second-Order, Second Moment (SOSM)*
  - ***Polynomial Chaos (PC)***

CFD Uncertainty Tutorial: Examples

- **Generalized Burgers equation**
  - **IA, FOSM, SOSM, MC, PC**
  - **Exact deterministic and stochastic solutions**
  - **Random variables and random fields**
- **Heat equation w. internal conduction**
  - **IA, PC: examine PC convergence**
- **Model PDE for reacting flow**
  - **IA, MC, FOSM**
- **Supersonic, inviscid flow**
  - **Wedges, expansions, airfoil**
  - **Exact results from shock expansion theory**
  - **MC, FOSM using CFD w. sensitivity derivatives**
  - **Random variables and correlations**
- **2-D laminar, boundary-layer flow**
  - **MC, FOSM, SOSM**

System Risk Assessment & Allocation
Vanderbilt-NASA LaRC Cooperative Agreement

- **NASA supplies launch vehicle conceptual design problem to Vanderbilt**
- **Vanderbilt (S. Mahadevan) applies advanced risk technologies to this design problem**
- **NASA evaluates Vanderbilt results**
- **If results are promising, NASA will sponsor development of production software by a third party**

Risk-Based Design References

- **Michael J. Hemsch, Mark W. Hilburger, Sean P. Kenny, James M. Luckring, Peiman Maghami, Sharon L. Padula, W. Jefferson Stroud and Thomas A. Zang, "Needs and Opportunities for Risk-Based Multidisciplinary Design Technologies for Aerospace Vehicles", NASA TM, to appear in 2002**
- **Robert W. Walters, "Uncertainty Analysis for Fluid Mechanics with Applications", ICASE Report, in press**
- **Luc Huyse and Robert W. Walters, "Random Field Solutions Including Boundary Condition Uncertainty for the Steady-state Generalized Burgers Equation", ICASE Report No. 2001-35, October, 2001.**