A Simulation Assisted Risk Assessment Approach for Space Launch Systems

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Susie Go
NASA Ames Research Center
Introduction

• Goal
  • Design a safer space transportation system
  • Assess the risk to the crew
  • Improve understanding of mission risk through richer simulation modeling
  • Focus work on the things that matter
    – Identify risk drivers
    – Support trade studies
    – Identify sensitivities

• Approach
  • Top-down integrated system analysis approach
  • Define risk scenarios involving complex interactions
  • Include failure probabilities that depend on time or operational state “topology” changes due to evolving scenarios
  • Assess mitigation strategies – abort effectiveness
Simulation-based approach

- Represent dynamic interactions
  - Space launch systems tend to fail more through complex interactions, not random part failures
  - Interactions are function of the physical environment and relationships between “systems”
- Faithful representation of scenarios
  - Track multiple metrics within a single simulation
  - Richer description of data and dependencies (state and environmental)
    - Failure probabilities
    - Failure responses
- “Natural” (less abstract) model construction
  - Models defined through “atomic” elements
  - Scenarios dynamically evolve
  - Un-anticipated scenarios can be self-generated
  - Allows easier communication with discipline experts
- Provides insight into system behavior and sensitivities
Crew Launch Vehicle (Ares I)

- Two-stage vehicle
  - First stage: augmented Shuttle SRB
  - Upper stage: advanced J-2 engine
- Payload is the CEV
- Launch abort system (LAS) provides mitigation during first stage ascent and the first part of the upper stage ascent
- Results to output
  - Probability of Loss of Mission (LOM)
  - Probability of Loss of Crew (LOC)
CLV Ascent Phase

- Launch
- Liftoff
- SRB Separation
- Maximum Dynamic Pressure
- Main Engine Start
- MECO
- Maximum Axial Acceleration
- LAS Jettison
- Payload Separation
Mission Simulation Schematic

Create model representation of mission
Consequences of failure

Time- and state-dependent component failure rates along mission segments

Event-specific failure probabilities

Graph representation opens vast failure scenario space (relative to static tree)

Failure consequences information supplemented using modeling and simulation

Failure initiator information provided by program/experts

AbortManeuver

Launch

MidStage

Staging

OrbitInsertion

AscentFailure

UpperStageAscent

FirstStageAscentEarly

FirstStageAscentLate

Control

Breakup

Explosion

ControlPrecursor

BreakupPrecursor

ExplosionPrecursor

BeginAbort
Physics-based data supplied to GoldSim

Physics based failure simulations
(computationally expensive)

Overpressure propagation

Structural dynamics

Debris trajectory

Time and state dependent failure probabilities

Design limits

CBM_OverPressure_Table

Side_Breach_Table

Fragment_Table
Representation with GoldSim elements
Integrated Mission Risk Model

CEV/LAS Design

Warning Time

Reliability Data (Initiator Likelihoods)

Dynamic Risk Simulation

Failure Environments, Risks

Design Reference Mission Timeline

Crew, Mission Risk and Sensitivities
Integrated Mission Risk Analysis Outputs

LOC failure distribution as a function of mission elapsed time, with 5th and 95th percentiles.

Risk to the crew during ascent

Warning time sensitivity study

Mean Mission Count Between LOC

Available Warning Time

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Conclusions

• NASA is beginning to use more simulation analyses in PRA
  • Time-variation of initiators
  • Complex interactions
  • State-dependent aborts
  • Traditional PRA methods are not optimal
    – Require significant effort when changes are made
    – Difficult to represent dynamic, phased mission problems
• GoldSim provides a convenient framework for dynamic simulation modeling
  • Natural representation of phased mission problems
  • Conditionally triggered events and interrupt events
  • Lookup tables
  • Tracking of multiple system states or figures of merit
  • Larger user community than in-house tool
  • Commercially managed software
• Initial GoldSim usage for CLV launch abort risk assessment well-received
Reference Lunar Sortie Mission

LSAM Performs LOI

Earth Departure Stage Expended

Ascent Stage Expended

100 km Low Lunar Orbit

Low Earth Orbit

EDS, LSAM

CEV

Direct Entry

Land Landing

Service Module Expended