INFORMATION INTEGRATION FOR STOCKPILE SURVEILLANCE

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Science-Based Stockpile Stewardship

In the absence of full-system testing, how do we understand the stockpile and integrate various sources of information to get a quantitative estimate, with uncertainties, of system reliability and performance?

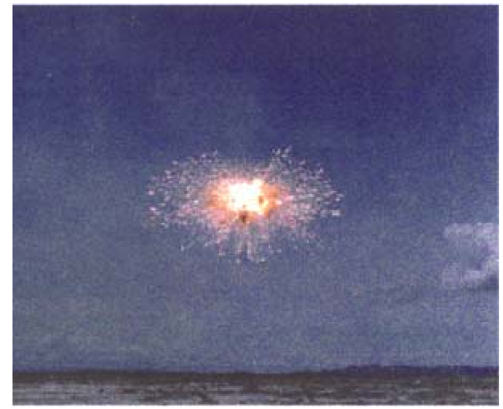
Surveillance

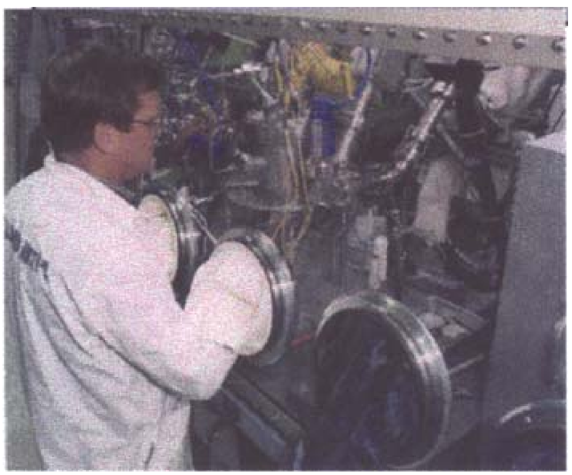
Continuous monitoring of "X" to ensure the health of "Y"

Detect and respond through:

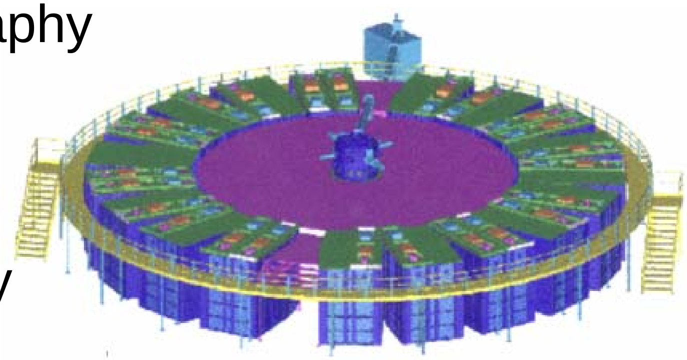
- Planned "***data***" collection
  - Simulation, experimental, field, database, text, images, expert judgment, …
- Maintenance
  - Life extension programs, special investigations, …

Science-Based Stockpile Stewardship





- Large Scale Computing
- Advanced Radiography
- Materials Science
  - Pu
  - High explosives
- High-energy density experiments
- Advanced manufacturing
- Information integration



Outline

- These two problems started off feeling like a reliability assessment or a PRA, but ended up somewhere rather different.
- Model development, Bayesian network
- Can we do better than “x/n”?
- Both have relevance back to LANL stockpile surveillance

Example 1: Missile Defense Agency

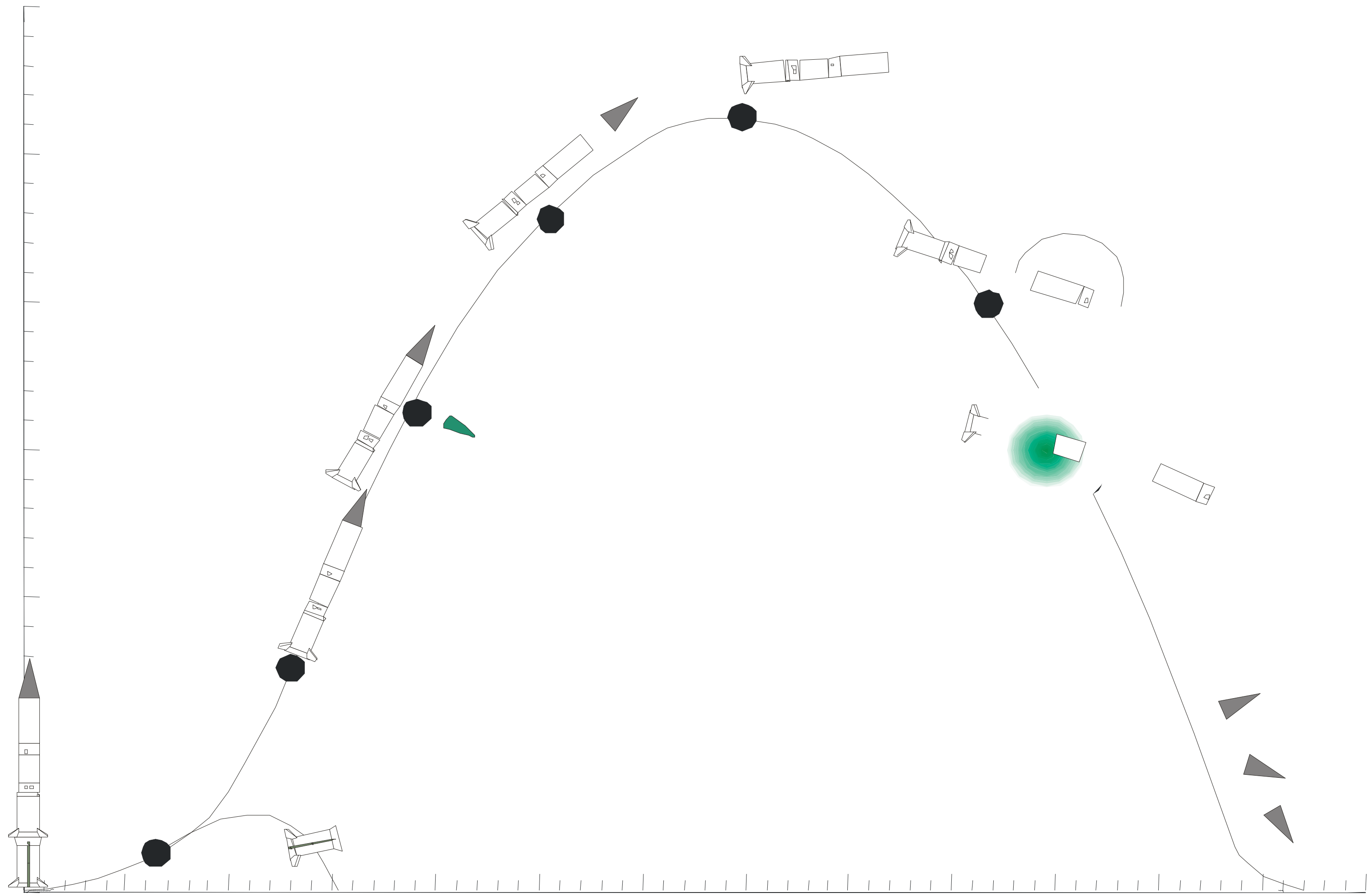
PROGRAM: Fly a high-fidelity, threat-representative missile system for Theater Missile Defense data collection and interoperability exercise

GOAL: "Quantify the probability of mission success" and identify "areas of unacceptable risk" to the program

ISSUES:

- Multiple partners and contractors
- High reliability demanded
- Full system testing not an option
- System requirements dynamic
- Diverse data sources

Notional Trajectory



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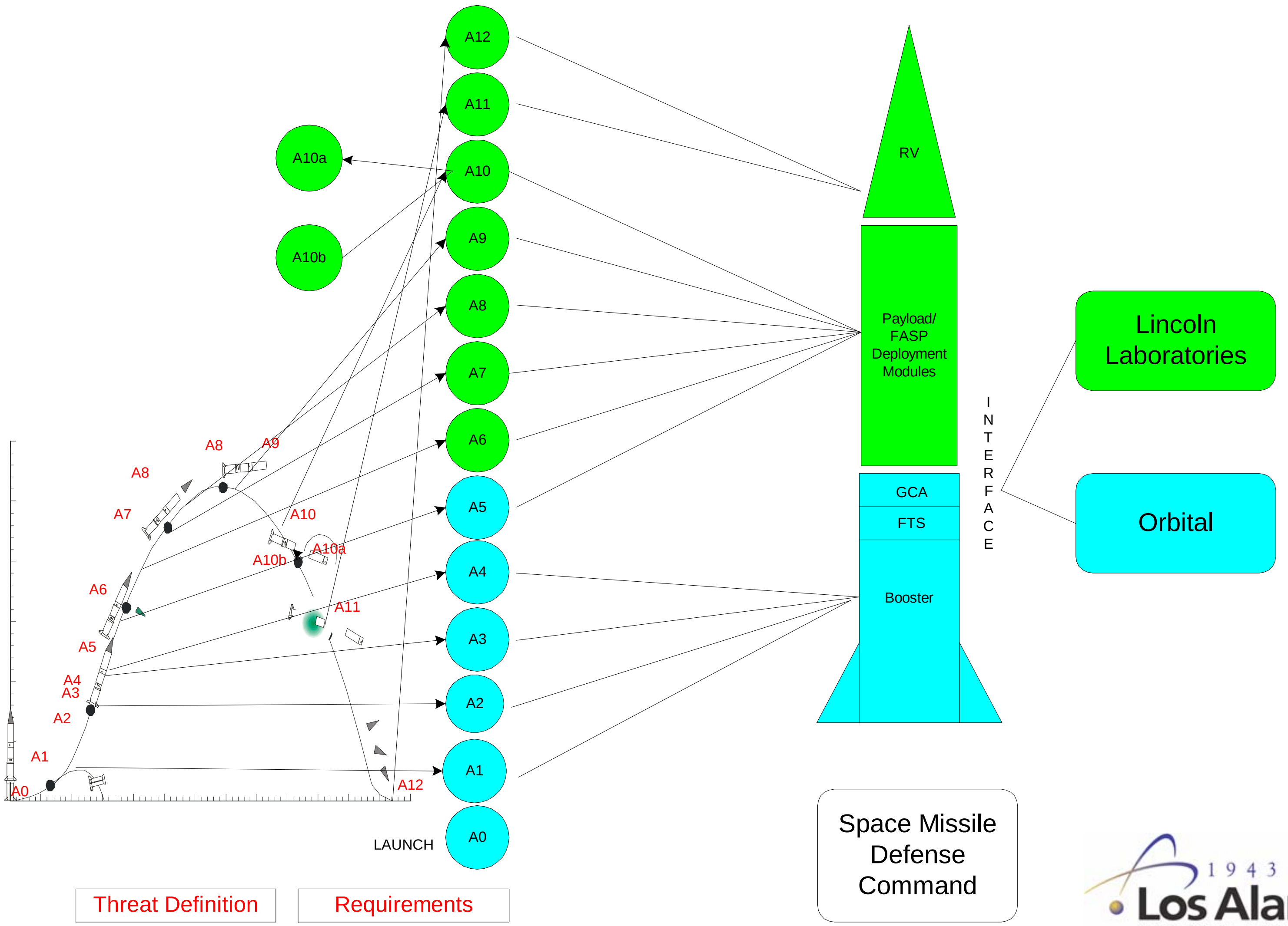
Ideas That Change the World

Events to System

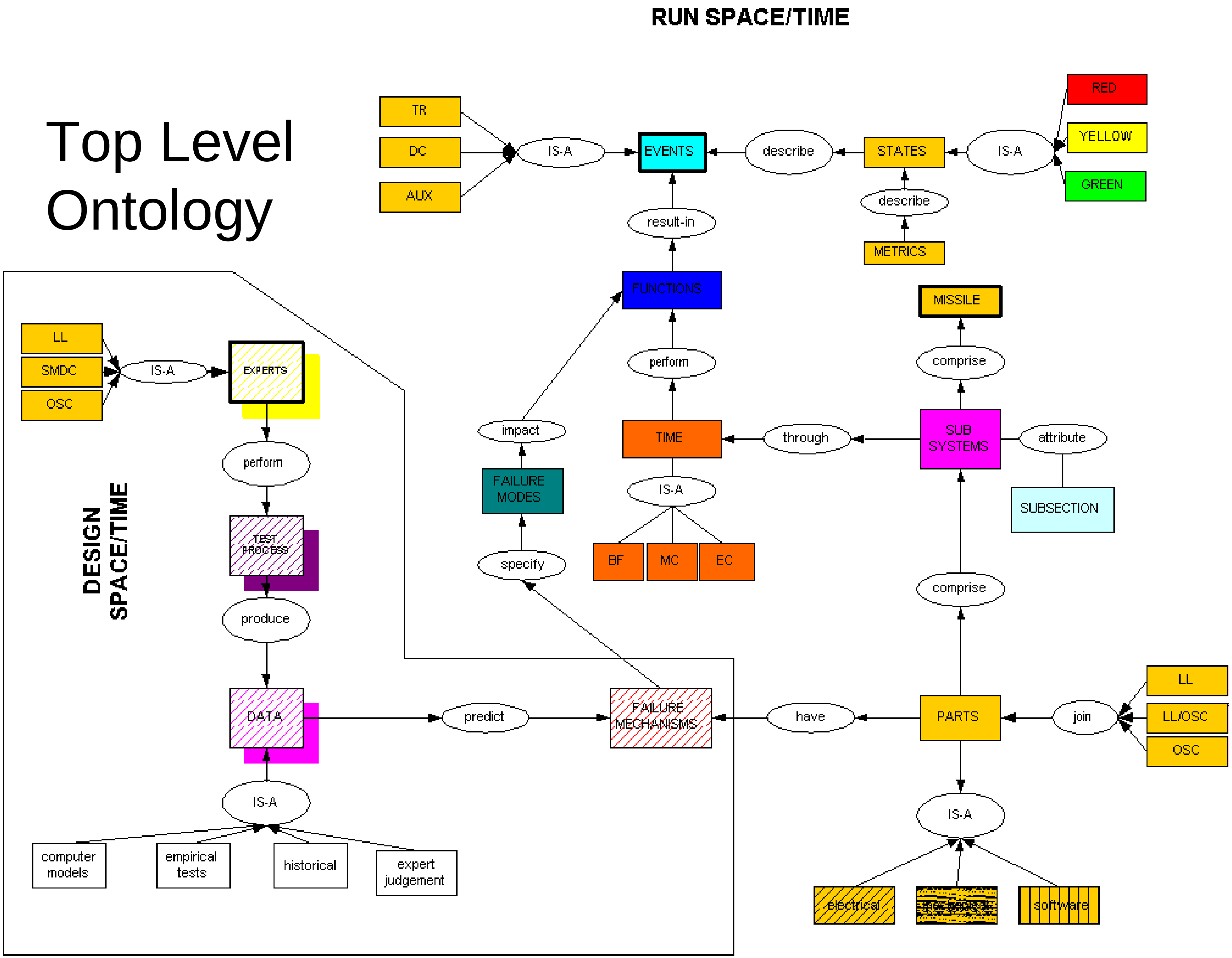
EVENTS IN SCENARIO



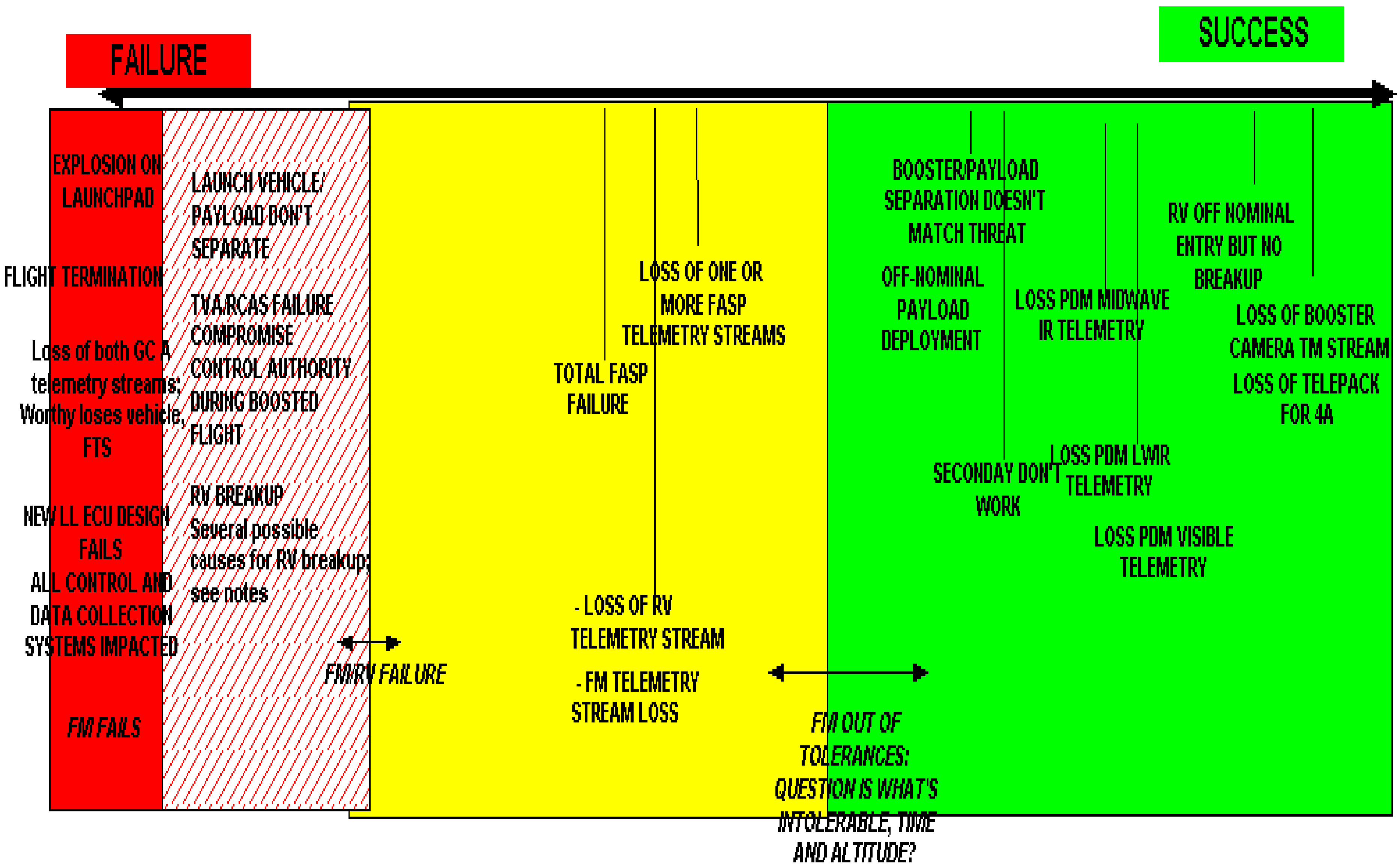
Threat Definition

Requirements

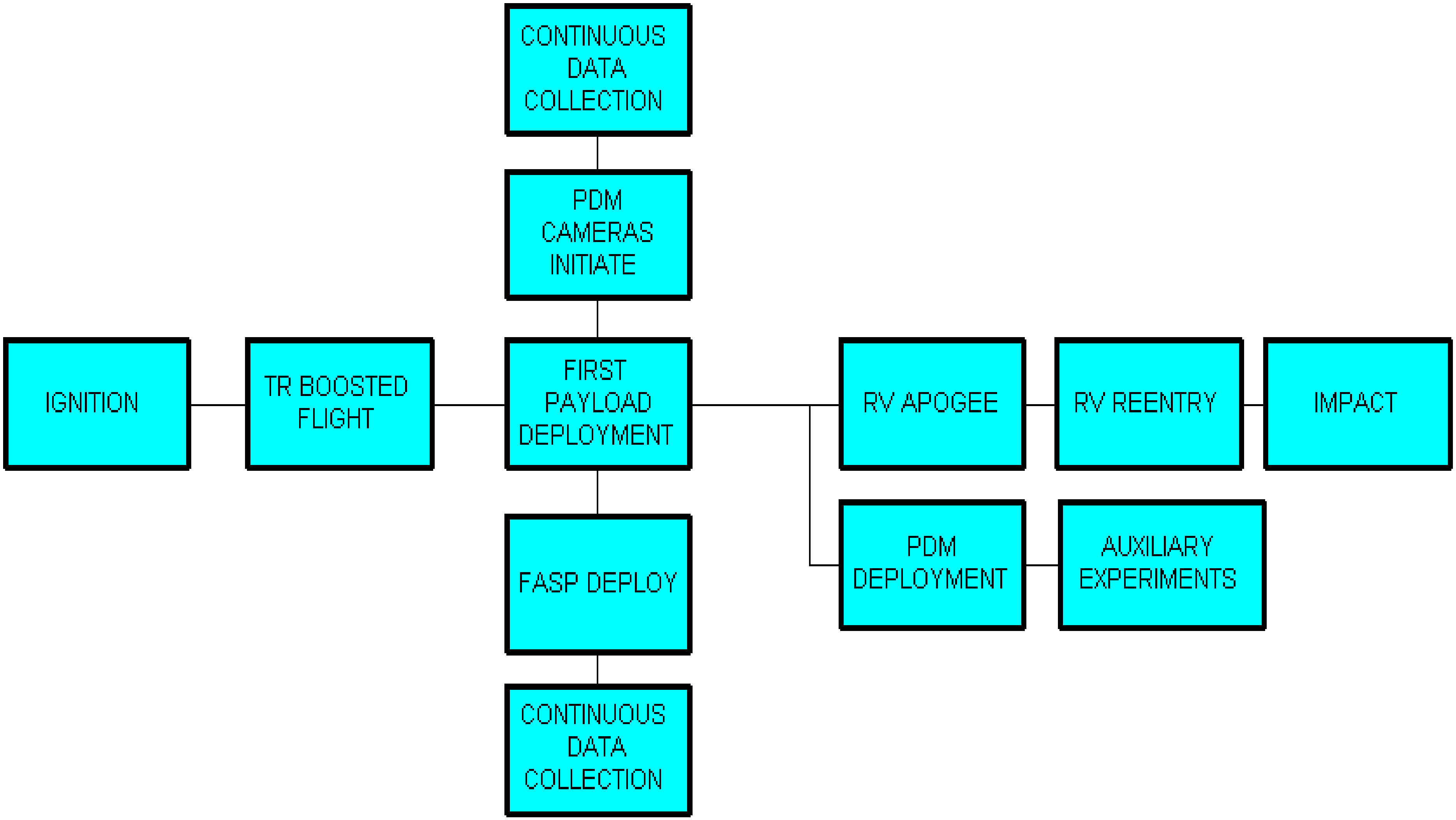
Top Level Ontology



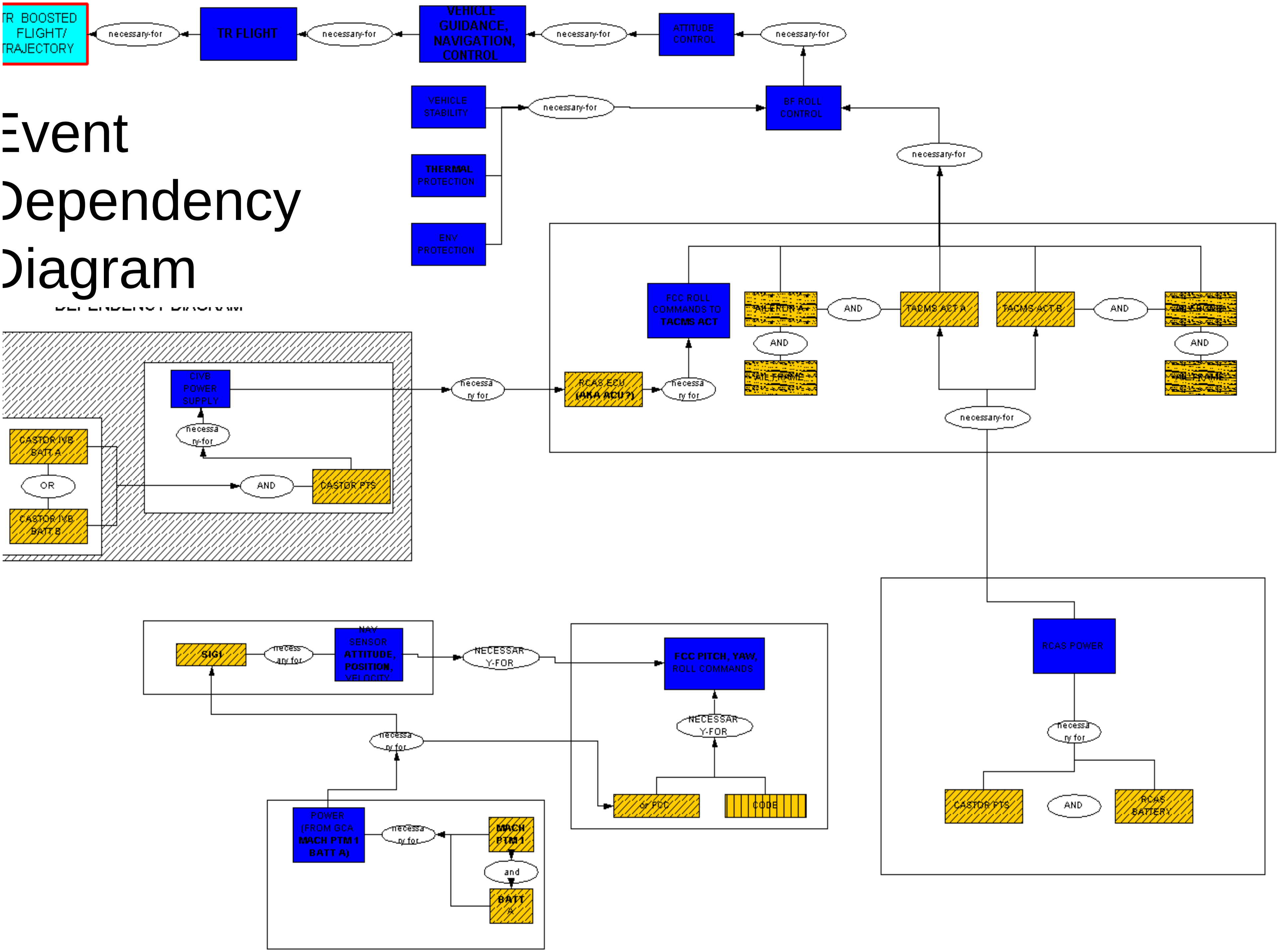
Mission Success



Event Diagram

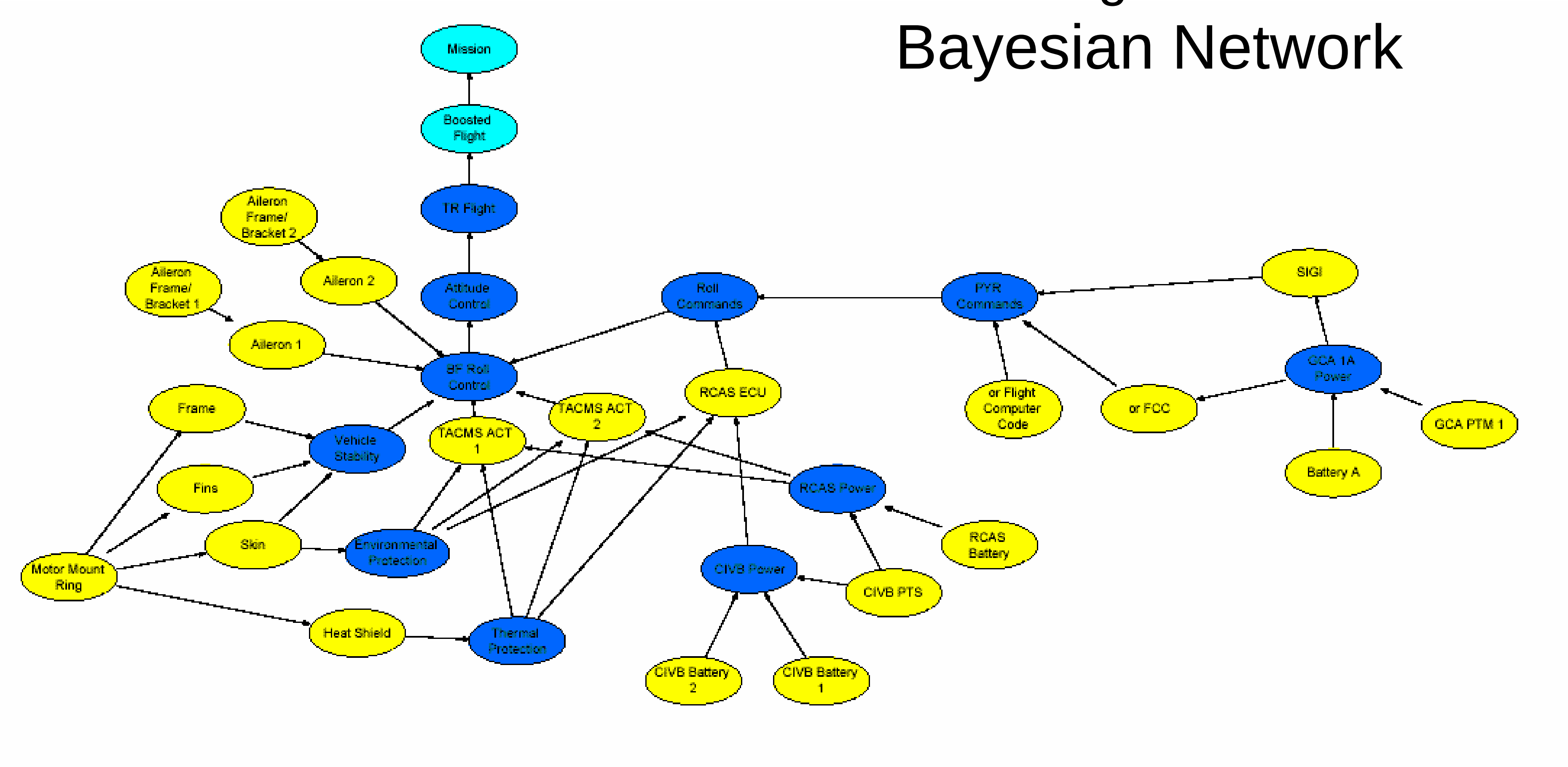


Event Dependency Diagram



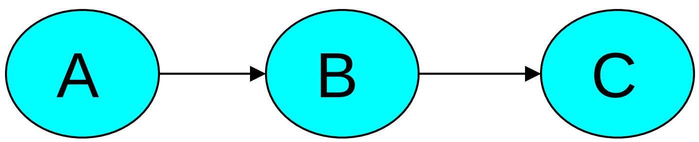
Statistical Model Representation

Boosted Flight Roll Control Bayesian Network

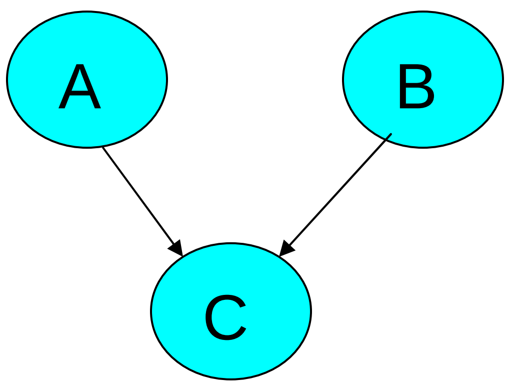


Bayesian Network Calculation

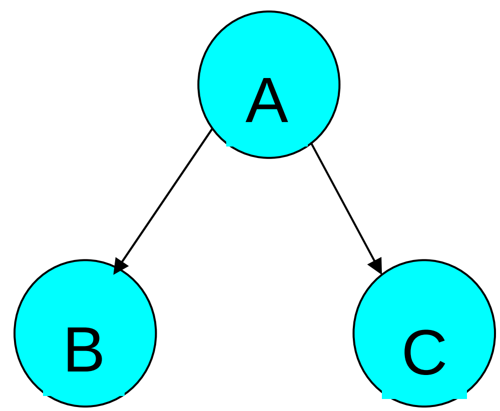
- Local conditional structure (like the elicited data)
- $P(A_1, \ldots, A_{599}) = \prod_{A_i} P(A_i|\text{parents})$
- Three structures: serial, converging, diverging



$P(A, B, C) = P(C|B)*P(B|A)*P(A)$



$P(A, B, C) = P(C|A,B)*P(A)*P(B)$



$P(A, B, C) = P(B|A)*P(C|A)*P(A)$

Data

Engineering Judgment

- The probability of the motor mount ring failing catastrophically is under 1%.
- If the motor mount ring fails catastrophically, then the fins and frame fall off the vehicle.
- There is somewhere between a 5% and 10% chance that the skin will peel back.
- If the fins or frame are missing, then the vehicle is unstable.
- If the skin peels back, then the vehicle is unstable.
- If the fins warp, then vehicle stability is compromised.

Experimental Data

- There is about a ten percent chance that the fins will warp during flight.
- The frame will not fail if loads do not exceed 5000 psi.

Computer Model

- Our simulations indicate that there is a 15% chance that flight loads exceed 5000 psi.

Notional Mission Success

Estimates of mission success (full distributions available)

- Mission yellow is most likely (50% ± 10%)
- Mission **red** is second (35% ± 5%)
- Mission **green** is third (15% ± 5%)

Decompose these estimates into parts, subsystems, and functions that contribute to size and variability of estimates.

Munitions Example

Two sets of test data:

(Z = success/failure, X = covariates)

(S = spec measurement, X = covariates)

Measuring success/failure is expensive, so it would be useful to figure out how to use the spec data as a surrogate for measuring success/failure.

The ultimate aim is to predict reliability as a function of age, P(Z = 1|age).

Assumptions

- For this example, the probability of success increases (monotonically) with the (unobserved) spec measurement.
  - We do not have data that lets us verify this.
  - We generally choose the functional form using engineering judgment.
  - No restriction on the functional form

- For this example, the spec measurements relate to the covariates through a linear regression.
  - Nick Hengartner has developed a nice way to do the estimation semi-parametrically that does not require the specification of this functional form
  - Accelerated testing

Munitions Example

$$Z_i \sim \text{Bernoulli}\left(\Phi\left(\frac{S_i - \theta}{\sigma}\right)\right)$$ ("surrogacy assumption")

$S_k \sim N(X\alpha, \gamma^2 I)$

Can integrate out the unobserved S_i and get

$$Z_i \sim \text{Bernoulli}\left(\Phi\left(\frac{X\beta - \theta}{\sqrt{\gamma^2 + \sigma^2}}\right)\right)$$

Munitions Example