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?

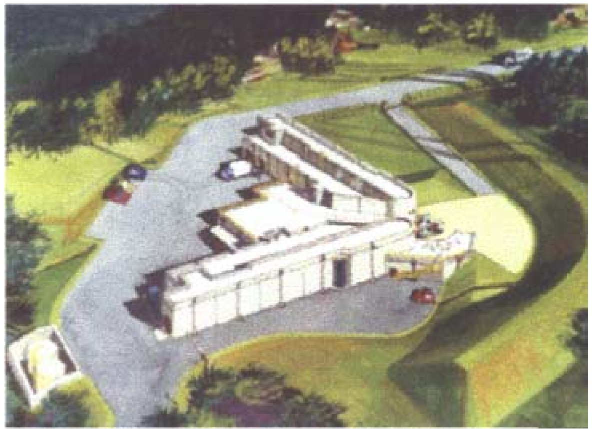
Surveillance

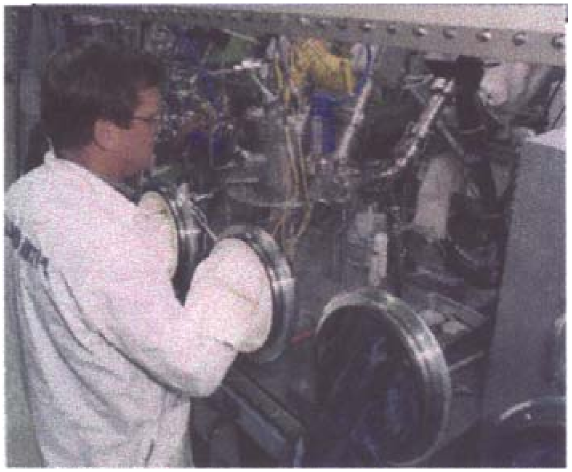
Continuous monitoring of "X" to ensure the health of "Y"

Detect and respond through:

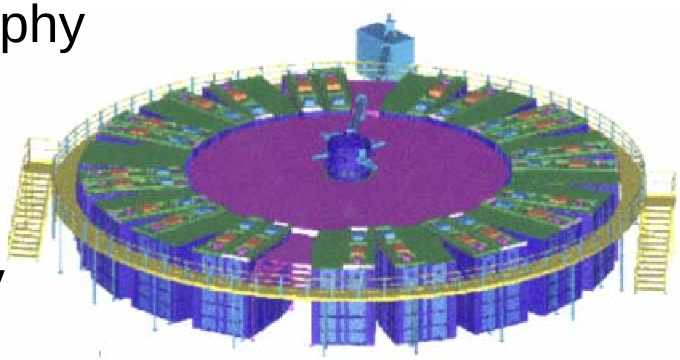
- Planned "***data***" collection
  - Simulation, experimental, field, database, text, images, expert judgment, …
- Maintenance
  - Life extension programs, special investigations, …

Science-Based Stockpile Stewardship





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



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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

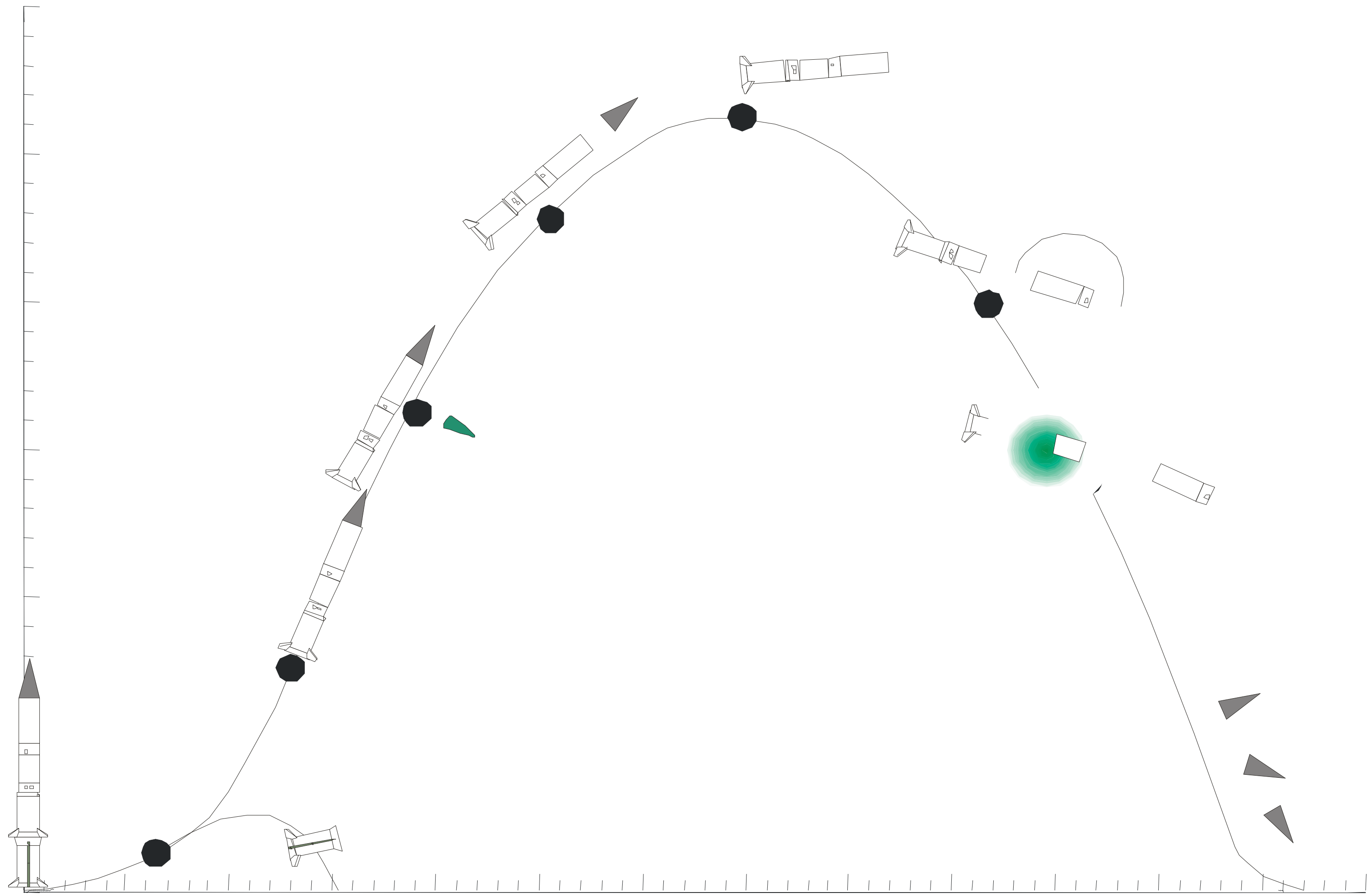
PROGRAM: Fly a high-fidelity, threat-representative missile system for Theater Missile Defense data collection and interoperability exercise

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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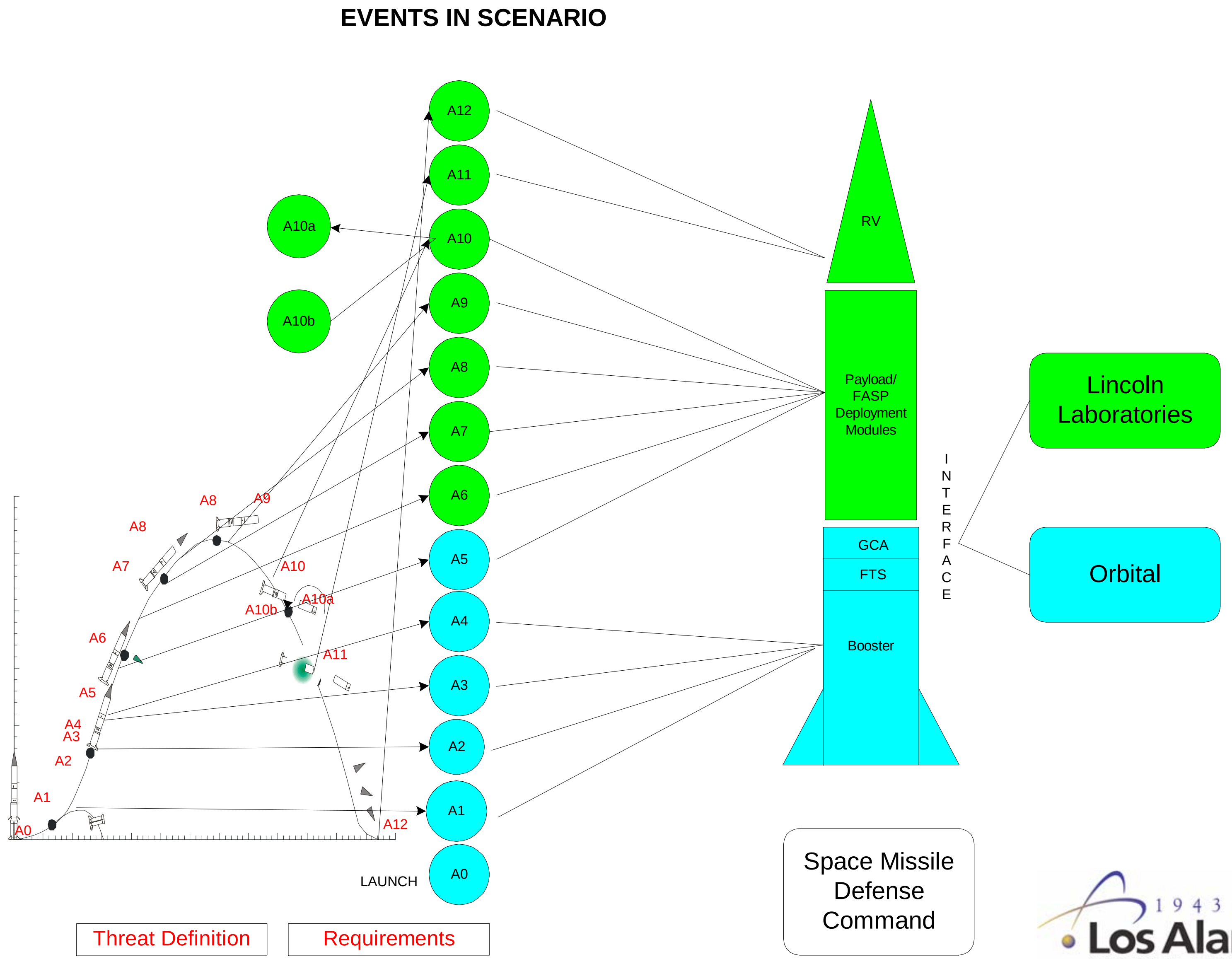
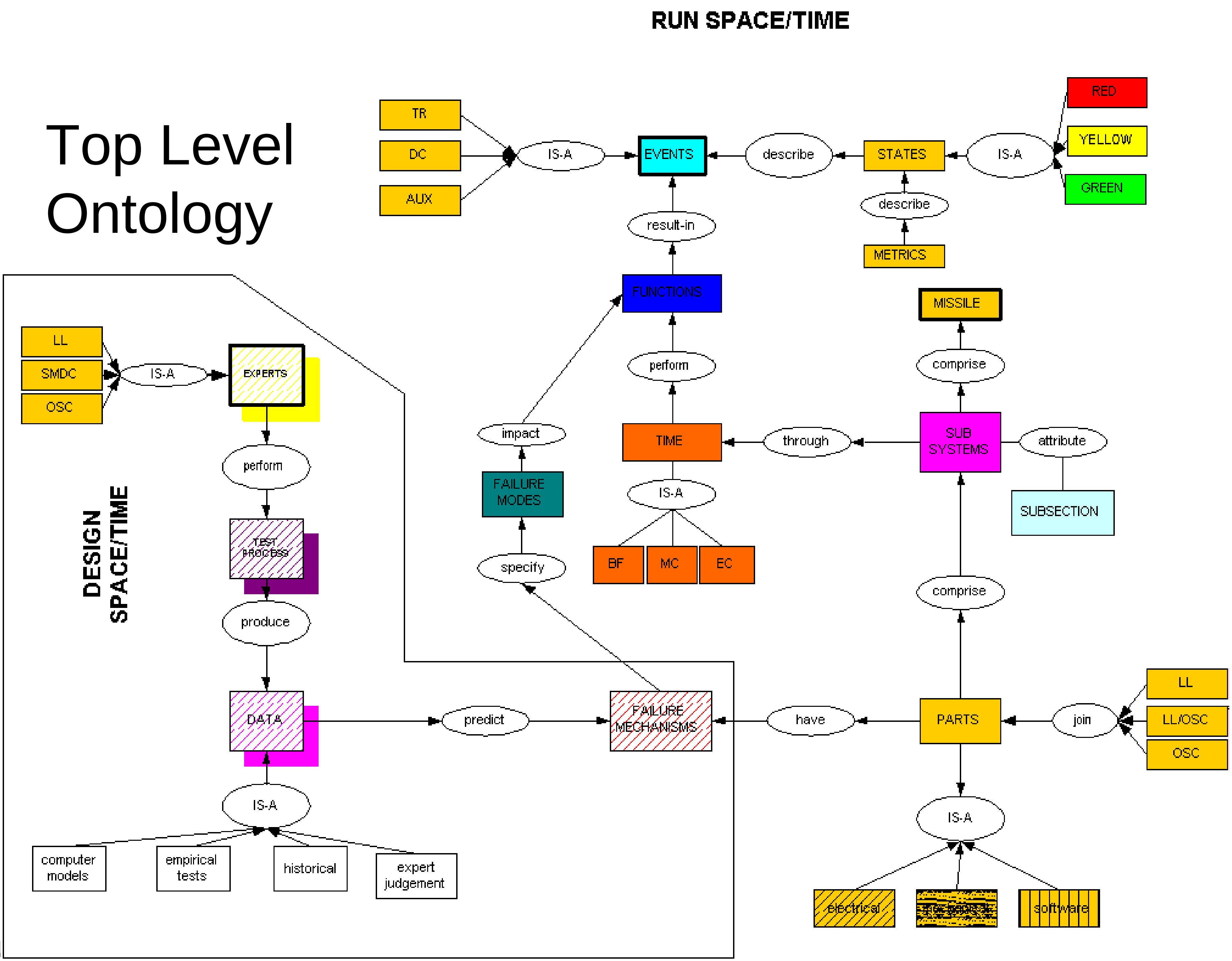
Events to System



Top Level Ontology



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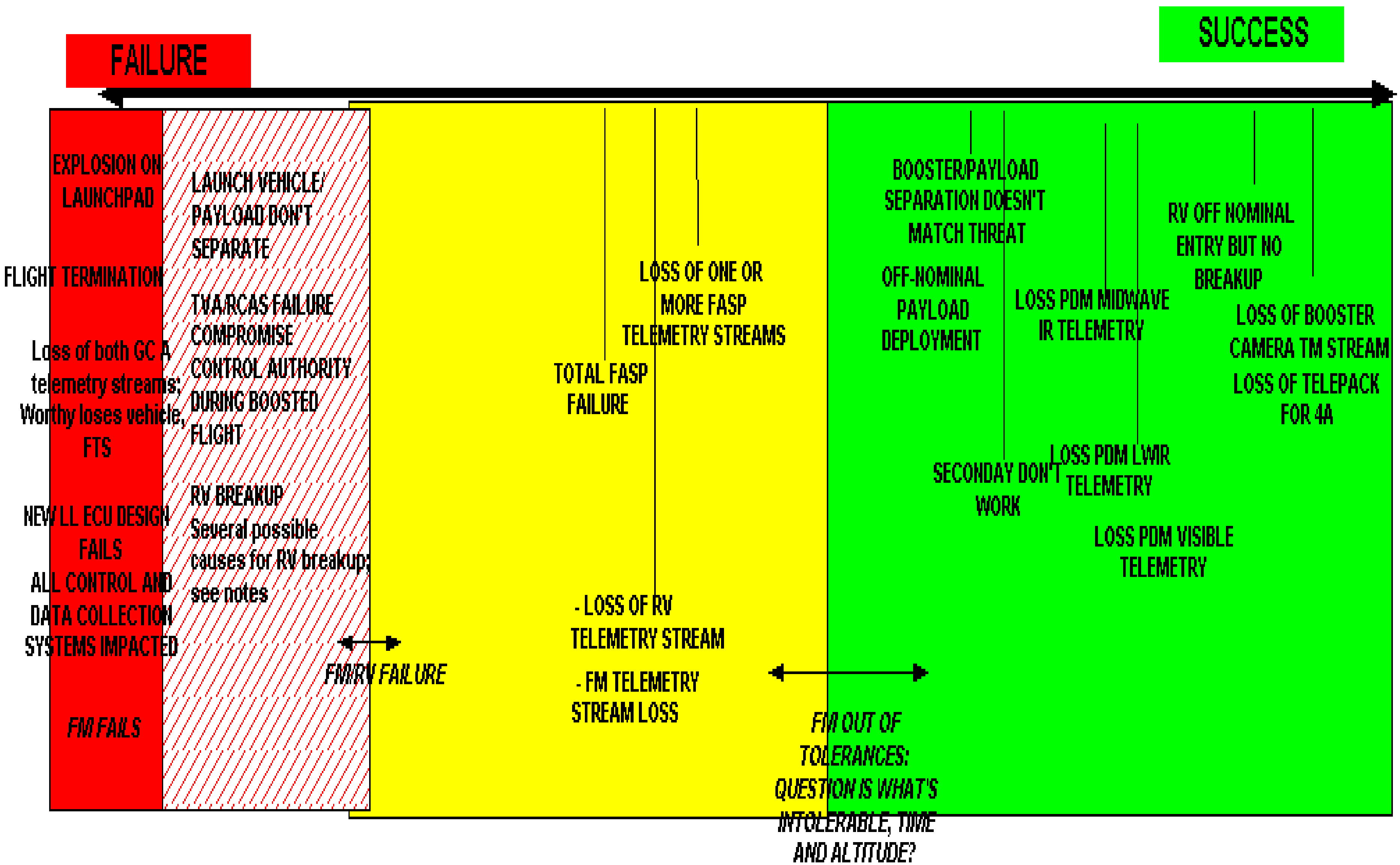
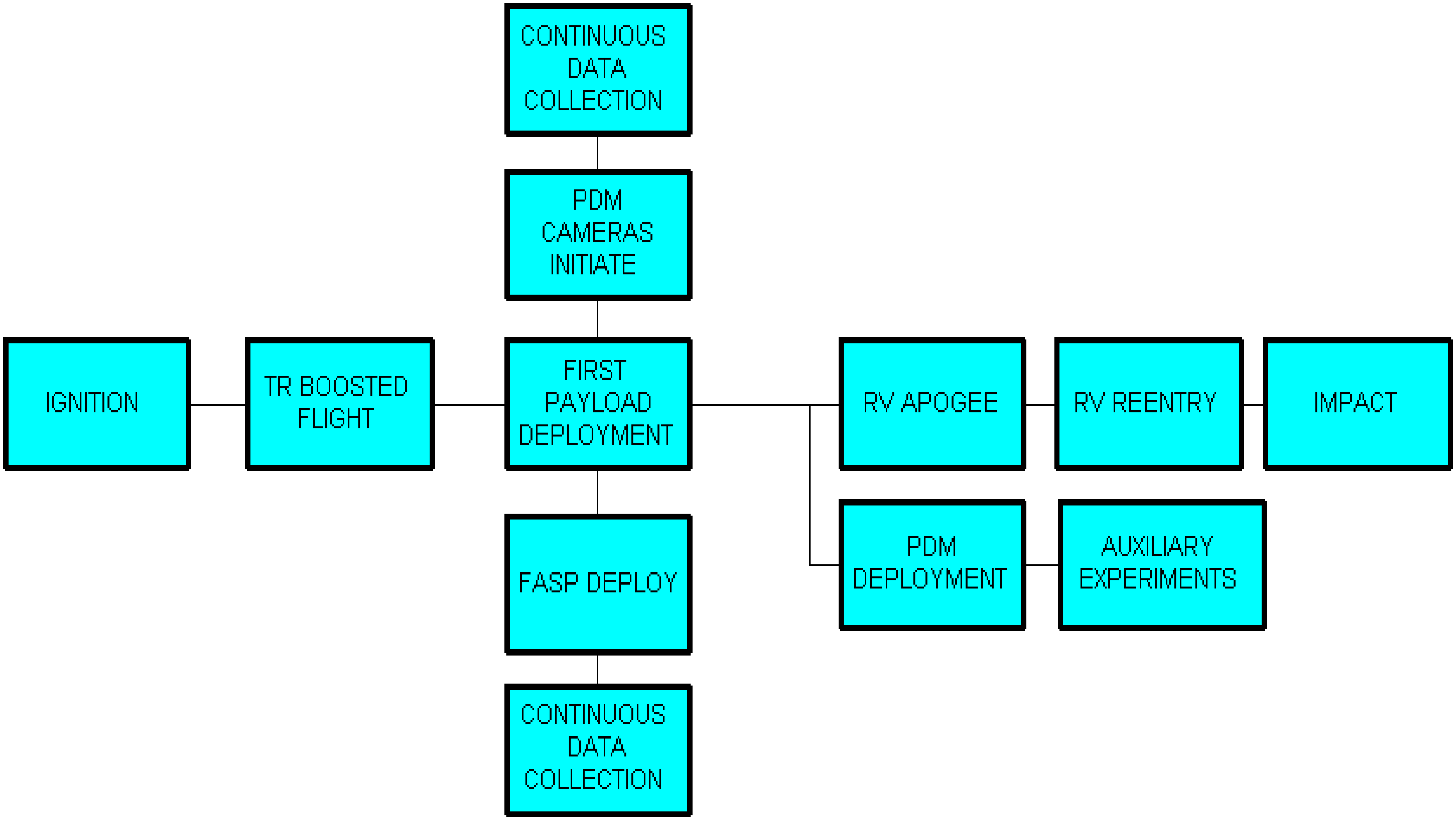
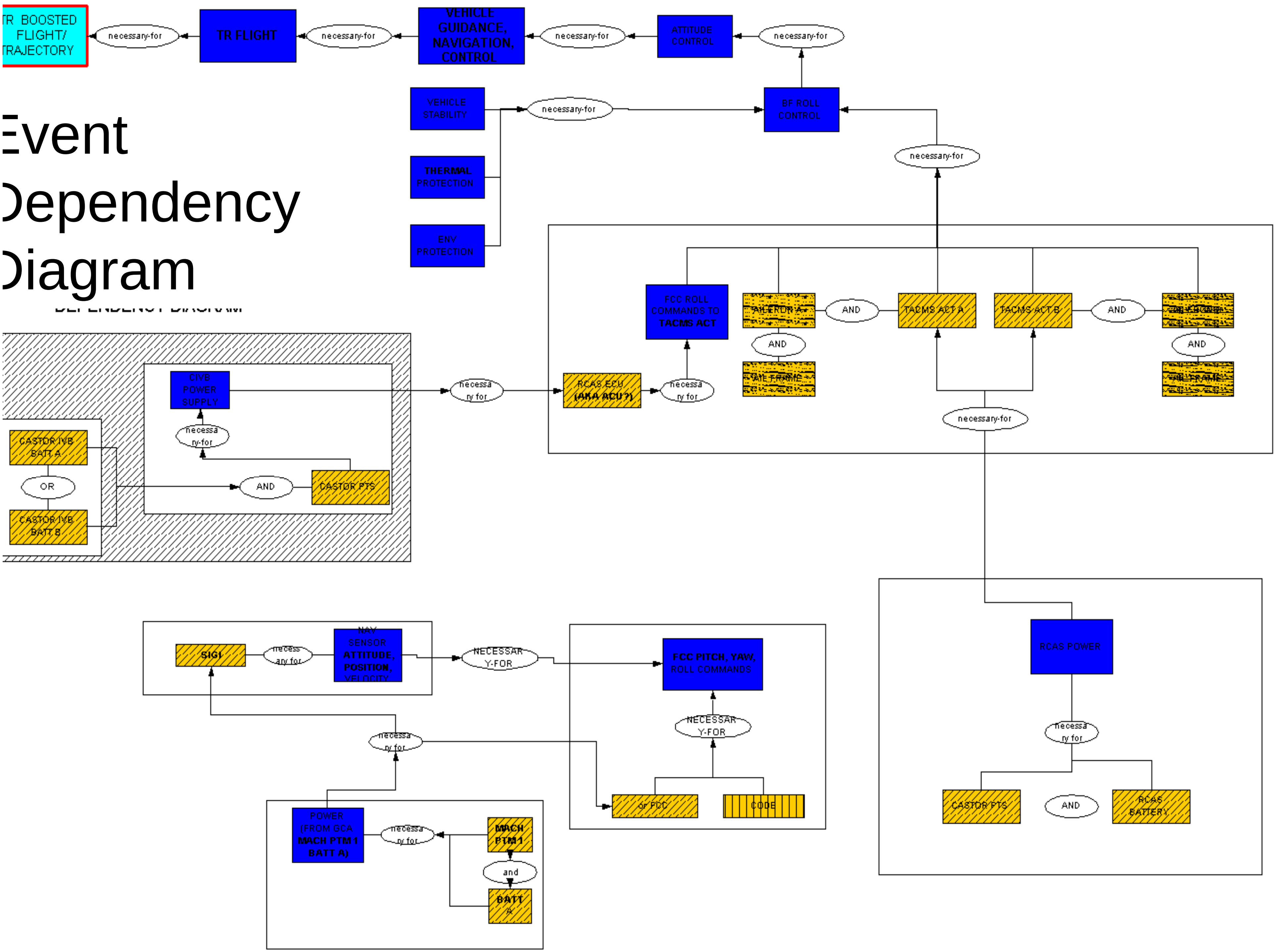
Mission Success



Event Diagram

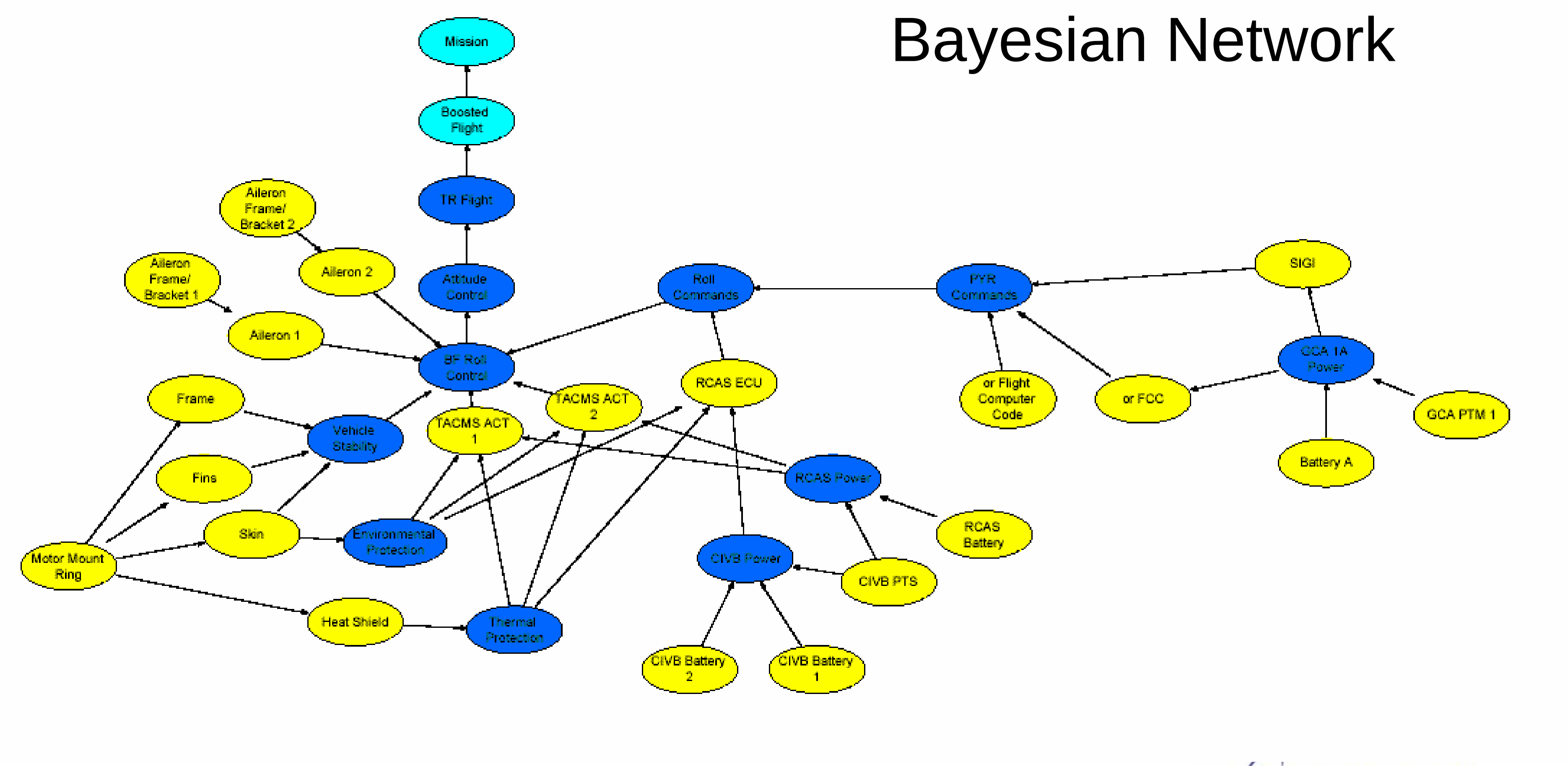


Event Dependency Diagram



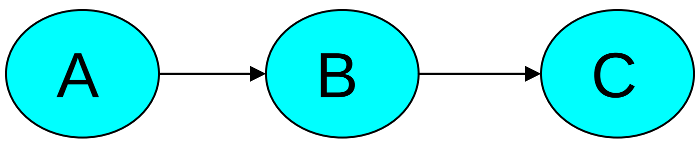
Statistical Model Representation

Boosted Flight Roll Control
Bayesian Network

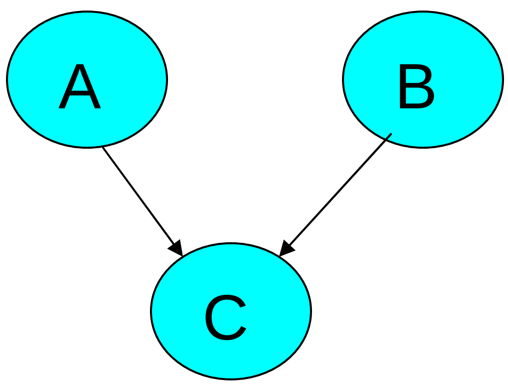


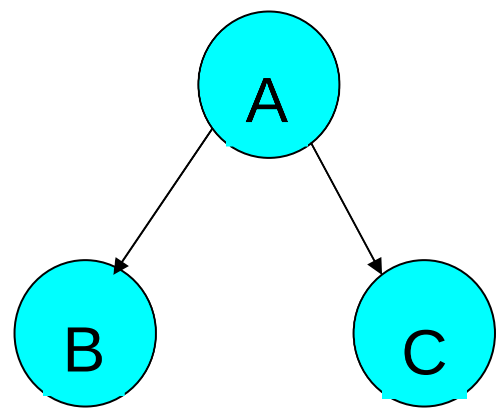
Bayesian Network Calculation

- 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