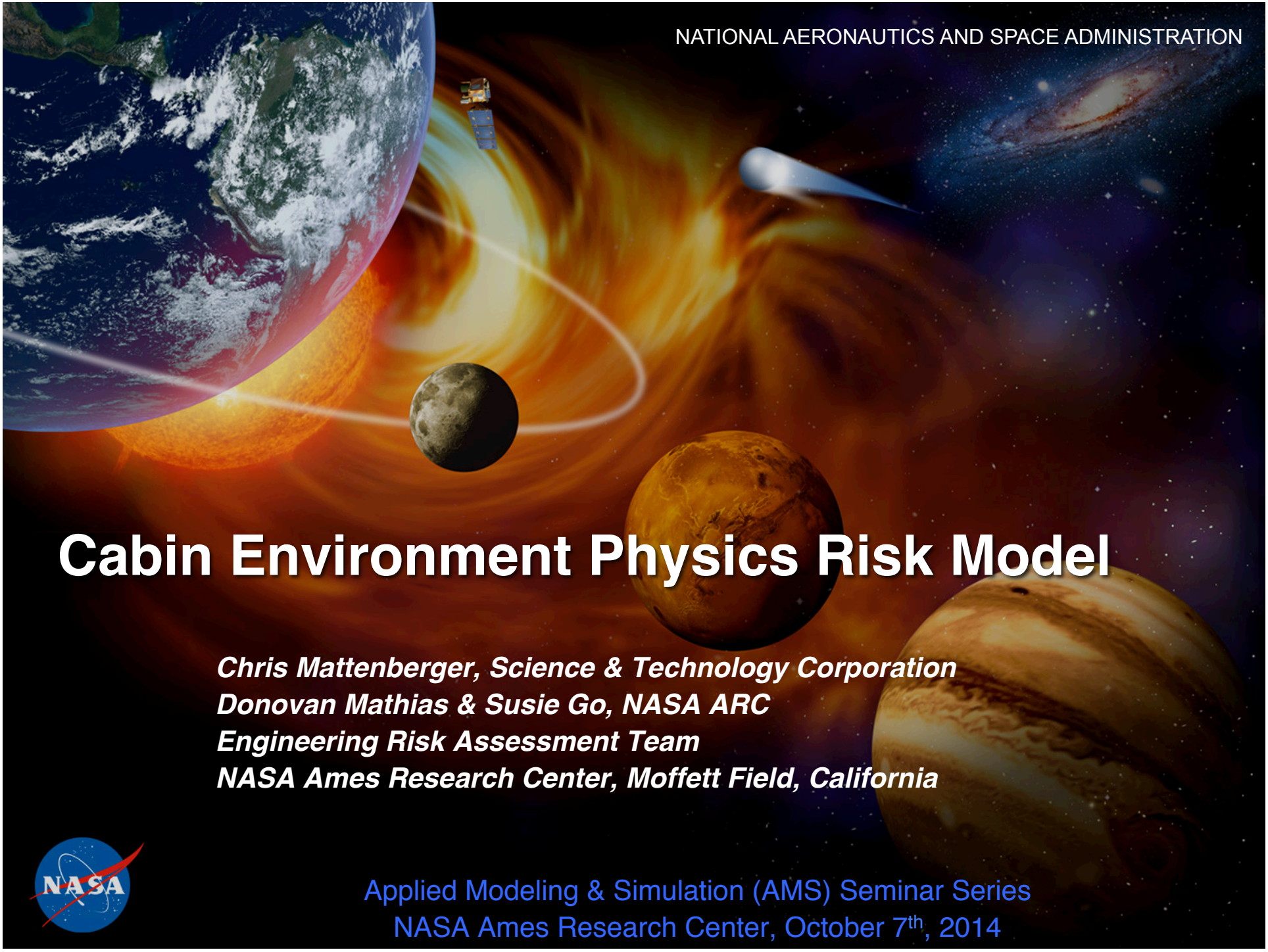
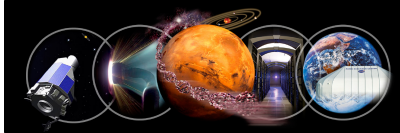


Cabin Environment Physics Risk Model

Chris Mattenberger, Science & Technology Corporation
Donovan Mathias & Susie Go, NASA ARC
Engineering Risk Assessment Team
NASA Ames Research Center, Moffett Field, California

Applied Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, October 7th, 2014

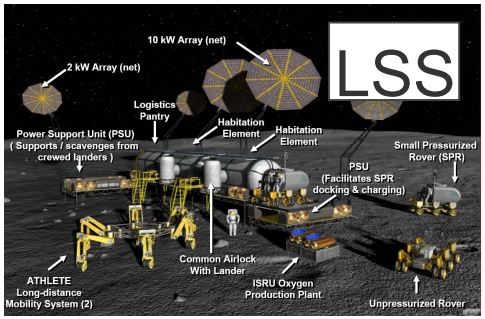


Overview

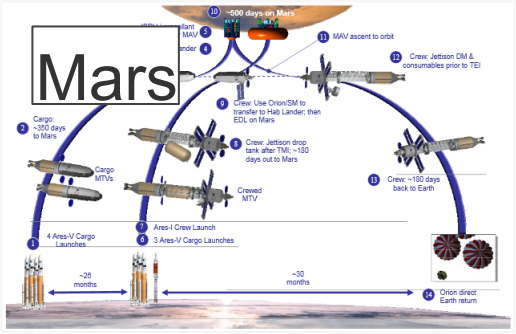
- Engineering Risk Assessment Team Introduction
- Probabilistic Risk Assessment Methodology
- Cabin Environment Physics Risk (CEPR) Model
- Application of CEPR Model to Generic ISS Mission Architecture
- "Blow and Bleed" Sensitivity Study
- "Feed the Leak" Sensitivity Study
- Risk-Informed Design Examples
- Summary and Conclusions

ERA Programs & Projects

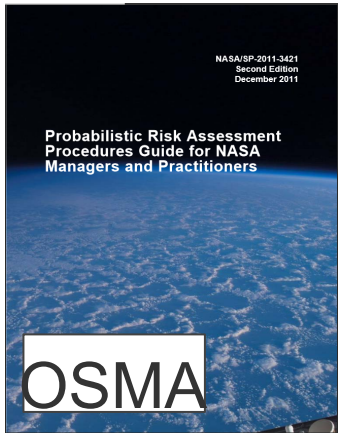
- Blast overpressure, debris, fireball physics modeling
- Ascent abort effectiveness assessment



- Campaign analysis, long-term operations and repair
- LOM/LOC and availability estimates



- Campaign analysis



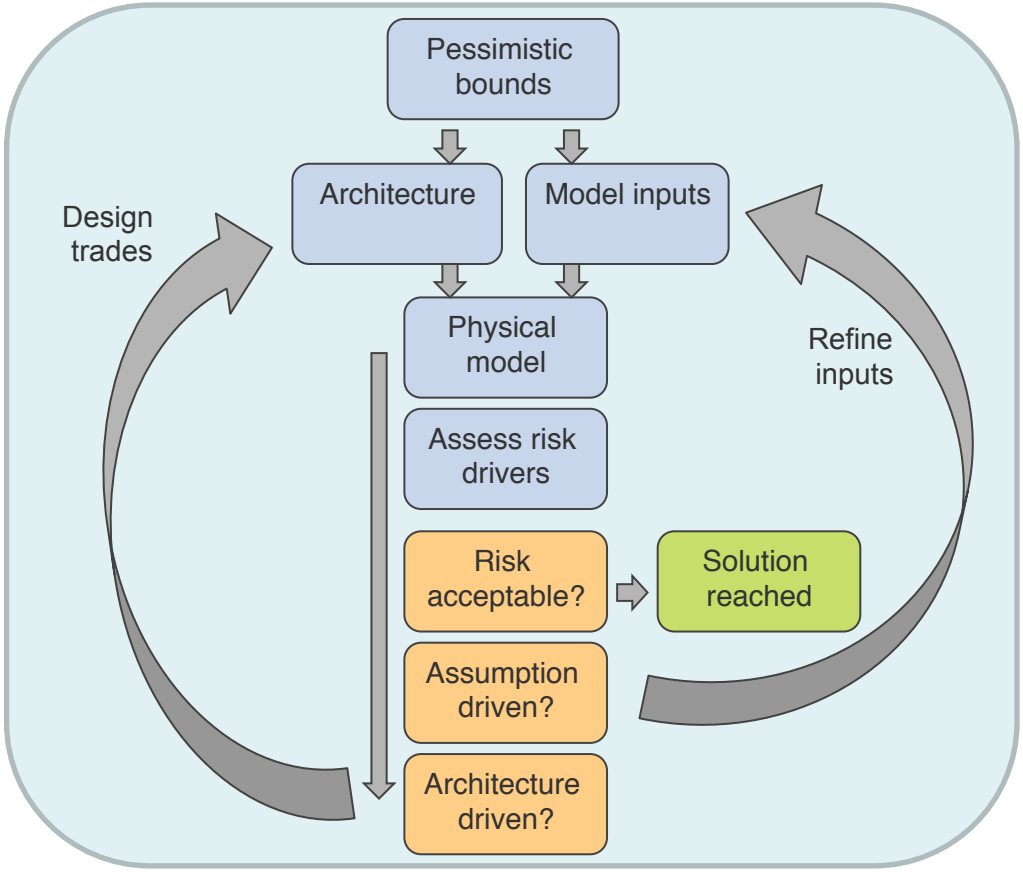
- 7th and 8th Workshops on Probabilistic Risk Assessment Methods (PRAM)
- PRA Handbook
- Simulation-based modeling techniques and their application to PRA

ERA also supports analysis of satellites, sample return missions and asteroid defense

ERA Team Philosophy

- **Risk-informed decision support**
  - Requirement verification
  - Risk-informed design support
  - Part selection/procurement
- **Probabilistic risk assessment is informative, not predictive**
  - Provides quantitative answers to specific questions
  - Always driven by specific application
  - Based on traditional methods and extended as appropriate

Iterative/responsive modeling approach

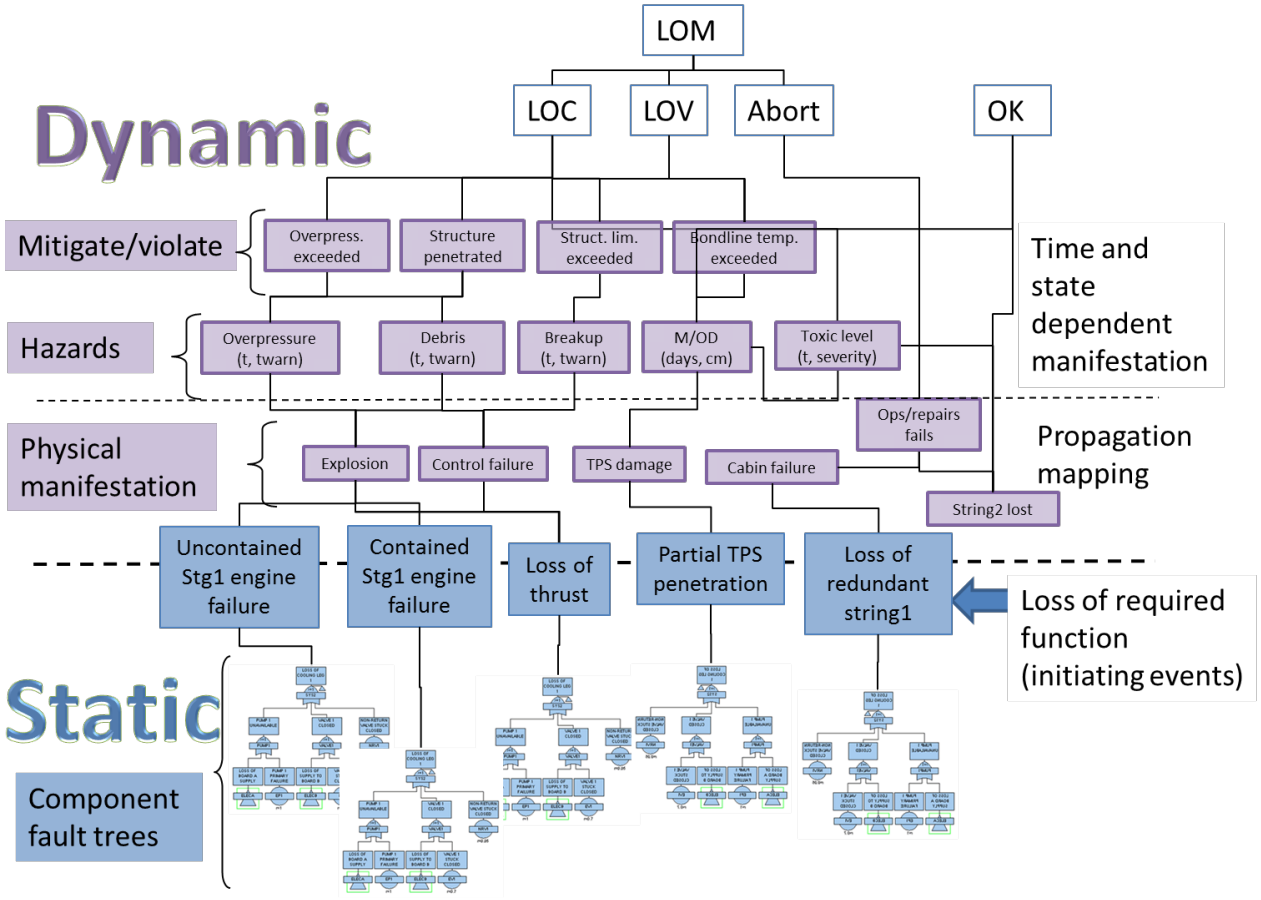


Risk model maturity tracks design maturity and engages engineers early in the design process, rather than a post facto analysis

ERA Team Methodology

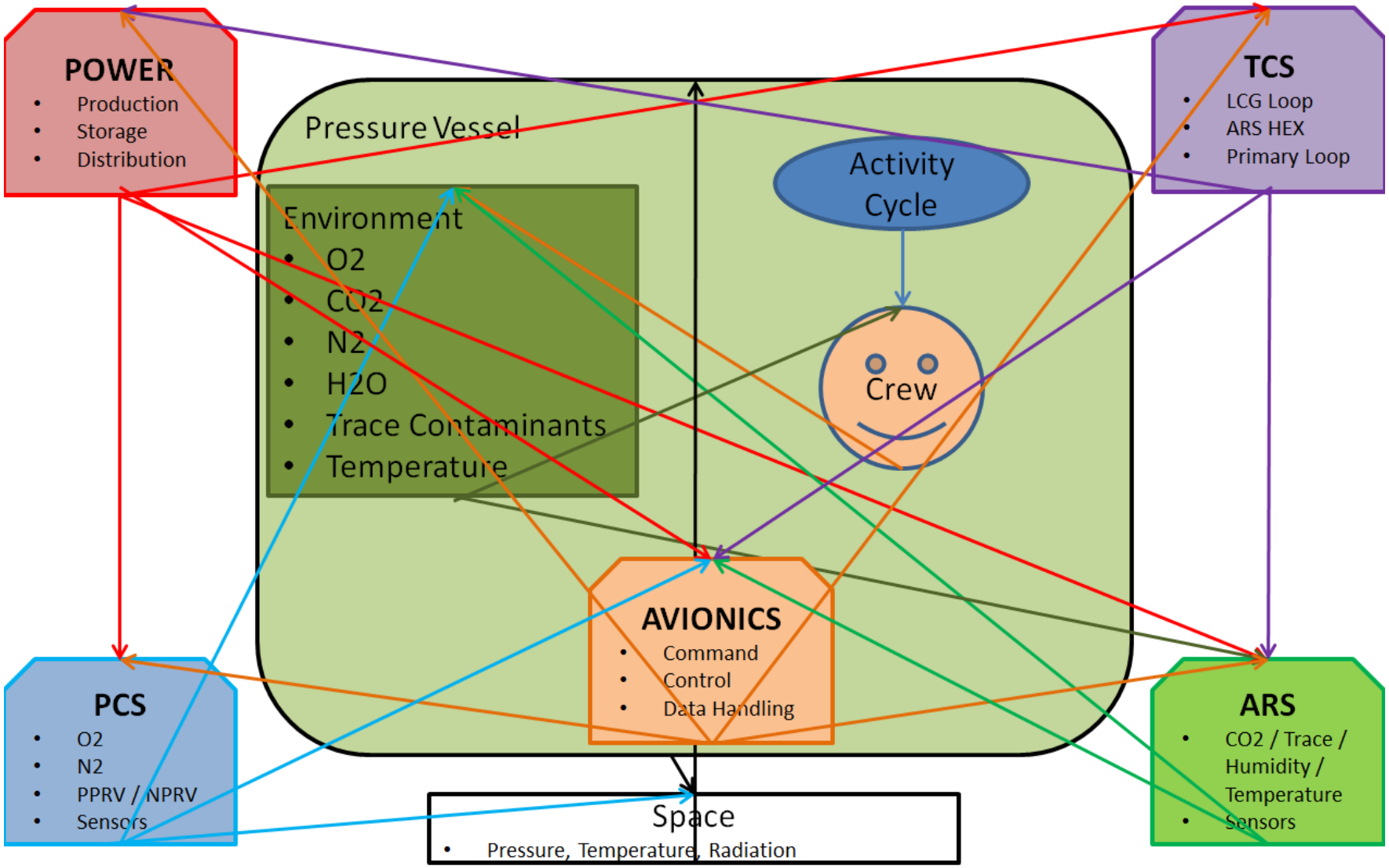
- Dynamic nature of failures
  - Time dependence
  - State dependence
  - Partial & interactive failures
- Physics-based analysis
  - External hazards
  - Failure evolution
- Traditional static models
  - Lower part levels
  - Typically reliability based

$$R(t) = e^{-\lambda t}$$



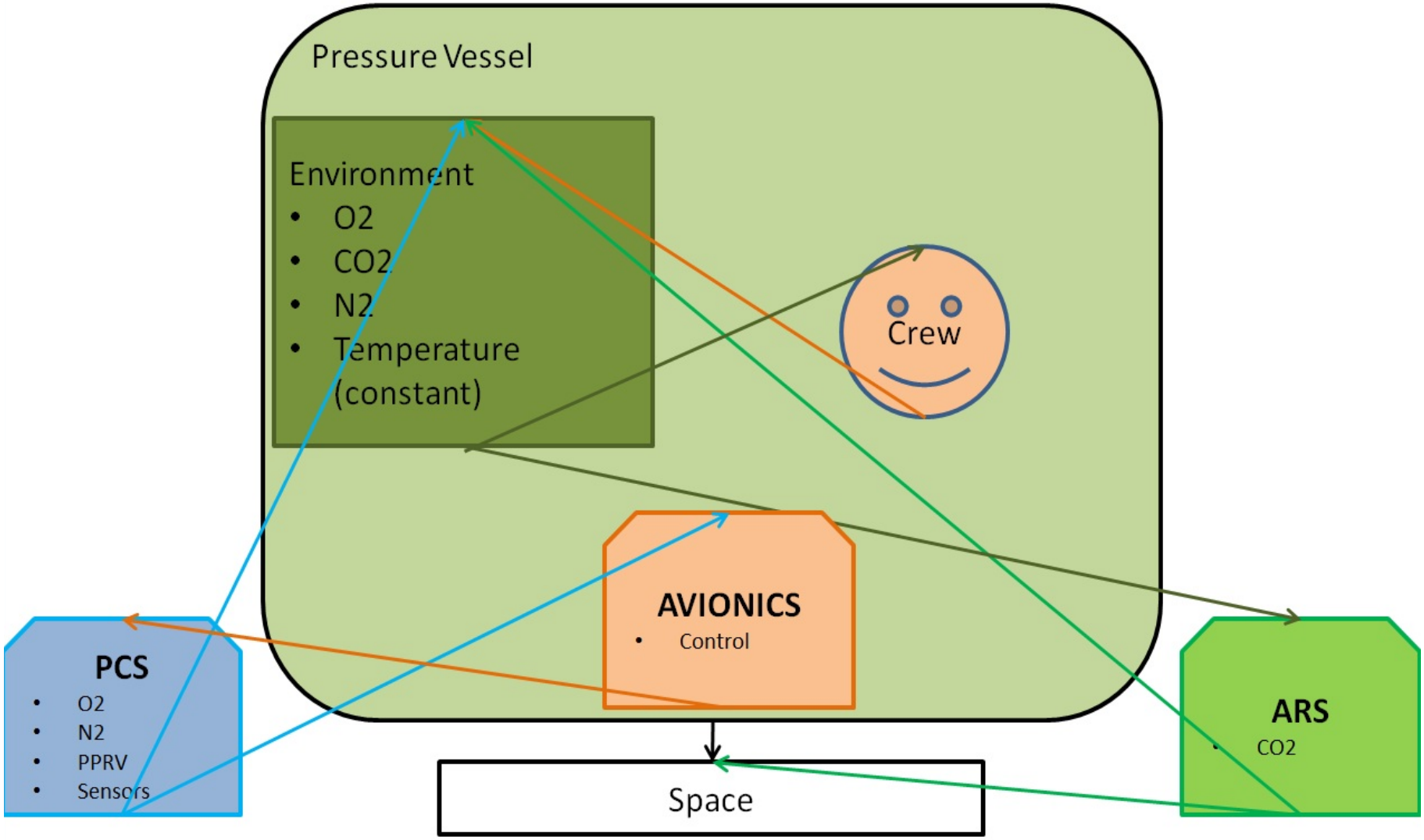
Combines traditional PRA methods with dynamic methods for increased accuracy of representation of system risk

Cabin Environment Influence Diagram



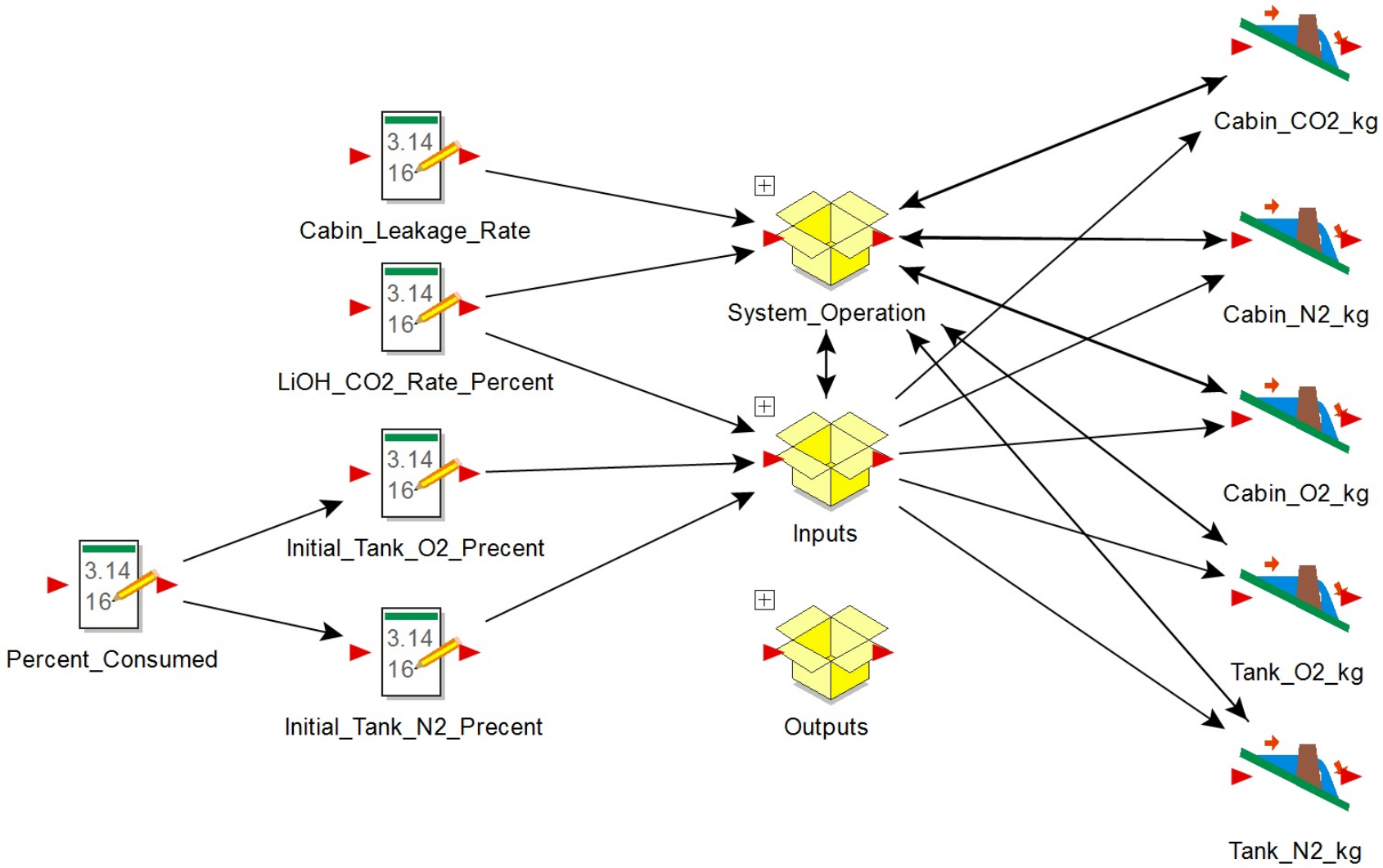
Cabin environment is impacted by many traditional spacecraft subsystems

Cabin Environment Physics Risk (CEPR) Model



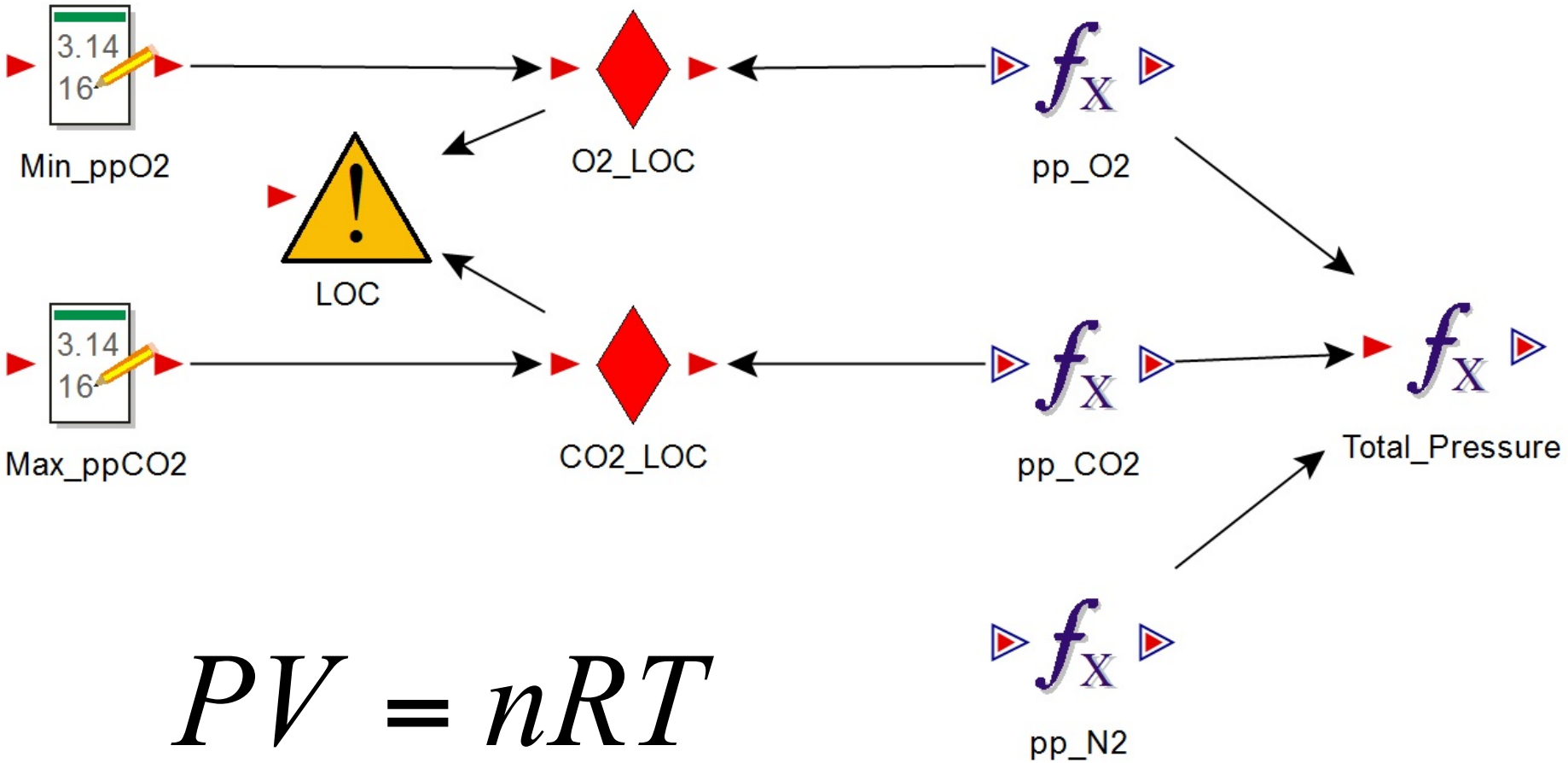
Estimates time from loss of functionality to onset of hazardous environment

CEPR Model Implementation in GoldSim



GoldSim provides a graphical representation of data flow within model

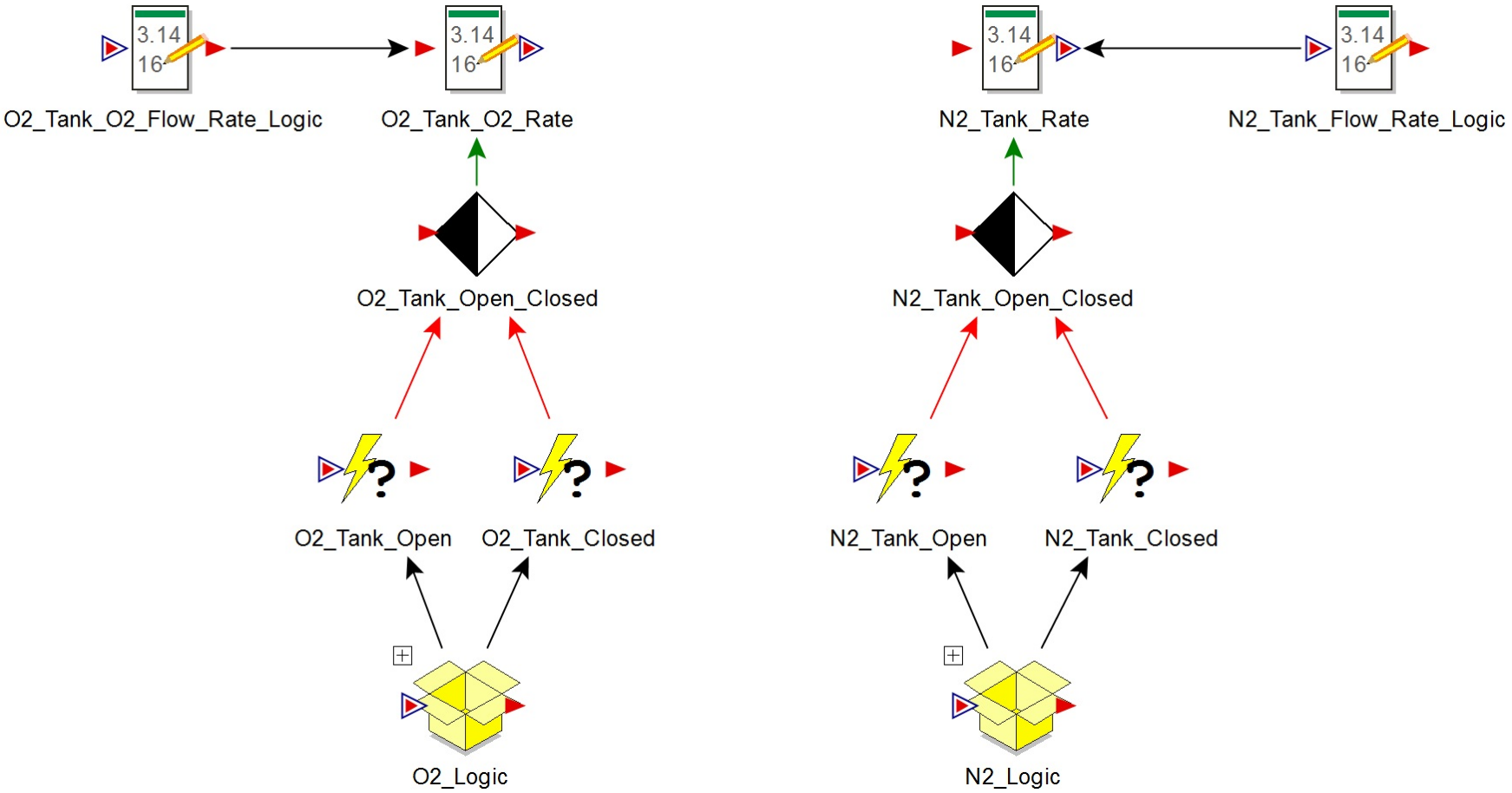
Loss-of-Crew Threshold Tracking



$$PV = nRT$$

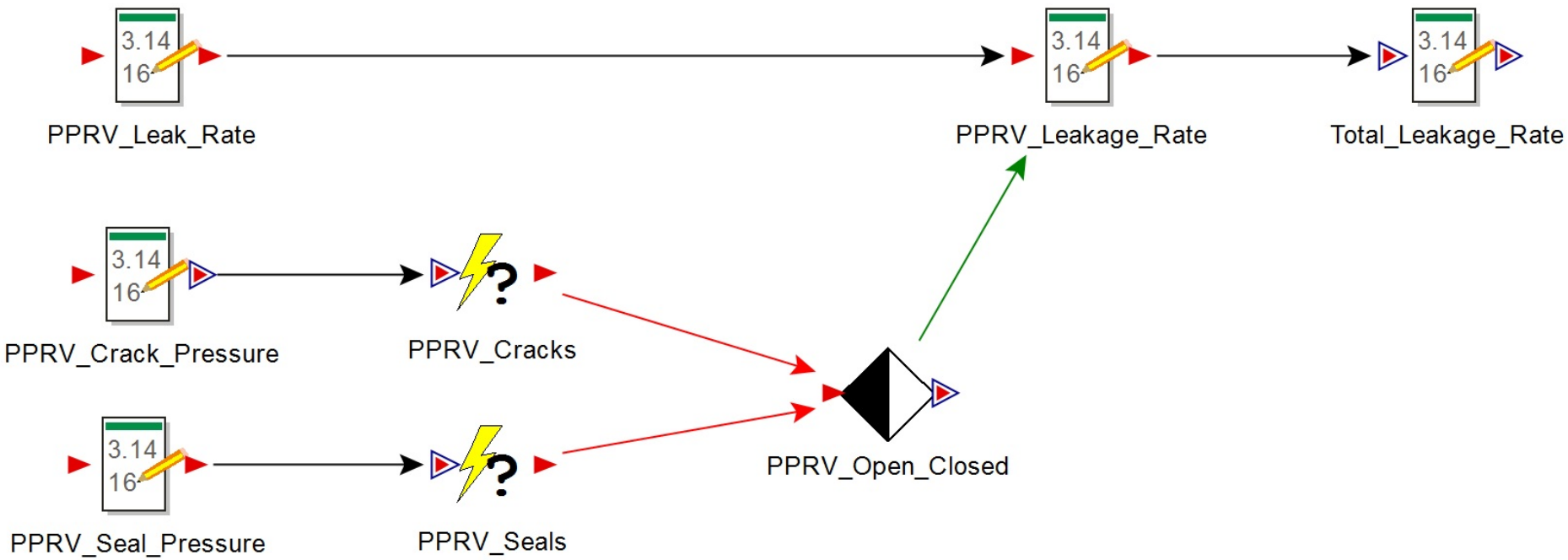
CEPR tracks partial pressures of key cabin atmospheric constituents

Avionics & PCS Implementation



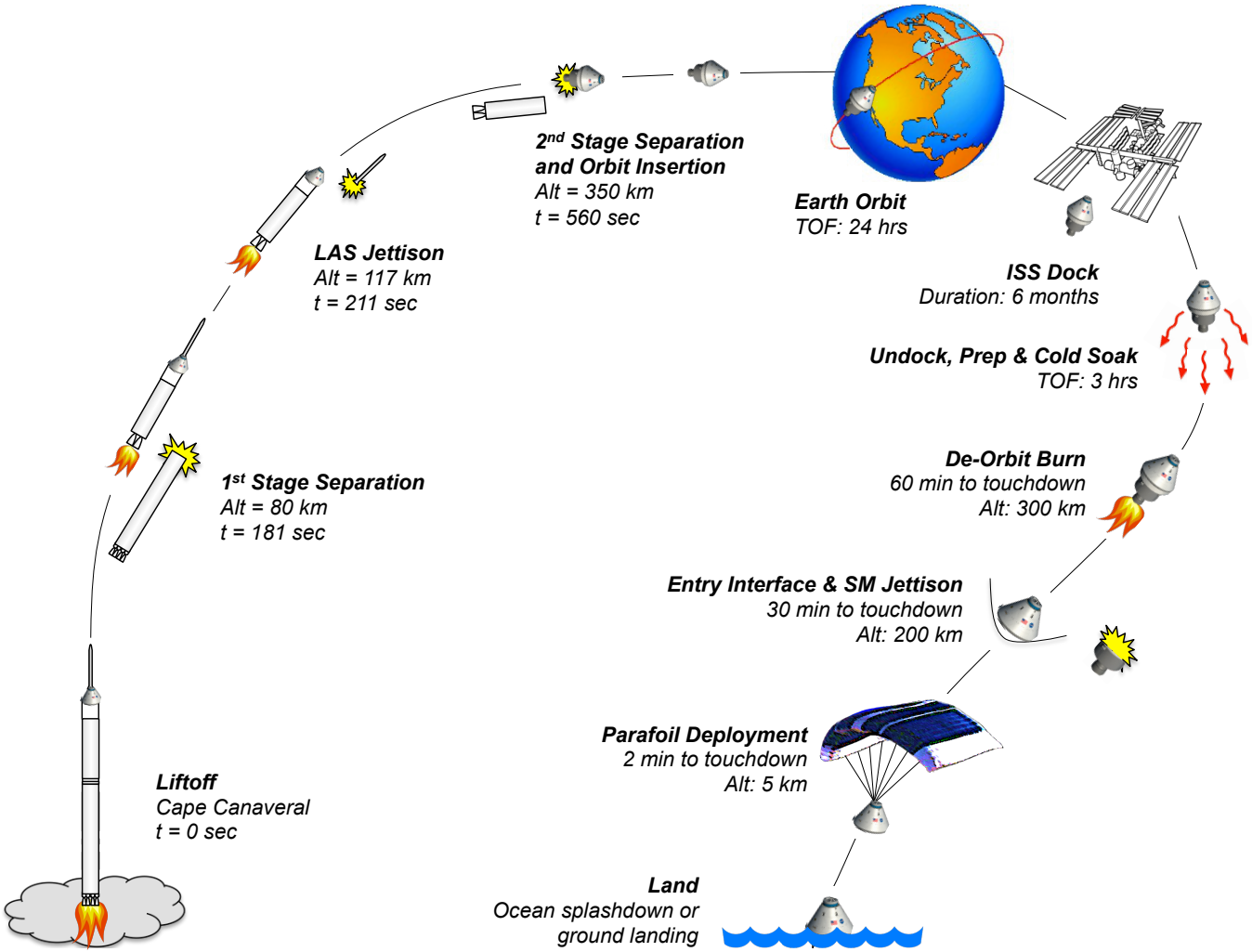
CEPR model captures dynamic interaction of spacecraft subsystems

PPRV Implementation



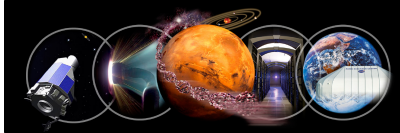
CEPR model captures physics-based impacts of component functionality

ERA Generic Launch Vehicle & Spacecraft



Conceptual Launch Vehicle and Spacecraft Design for Risk Assessment, NASA/TM-2014-218366

Mission concept of operations used to demonstrate CEPR model implementation

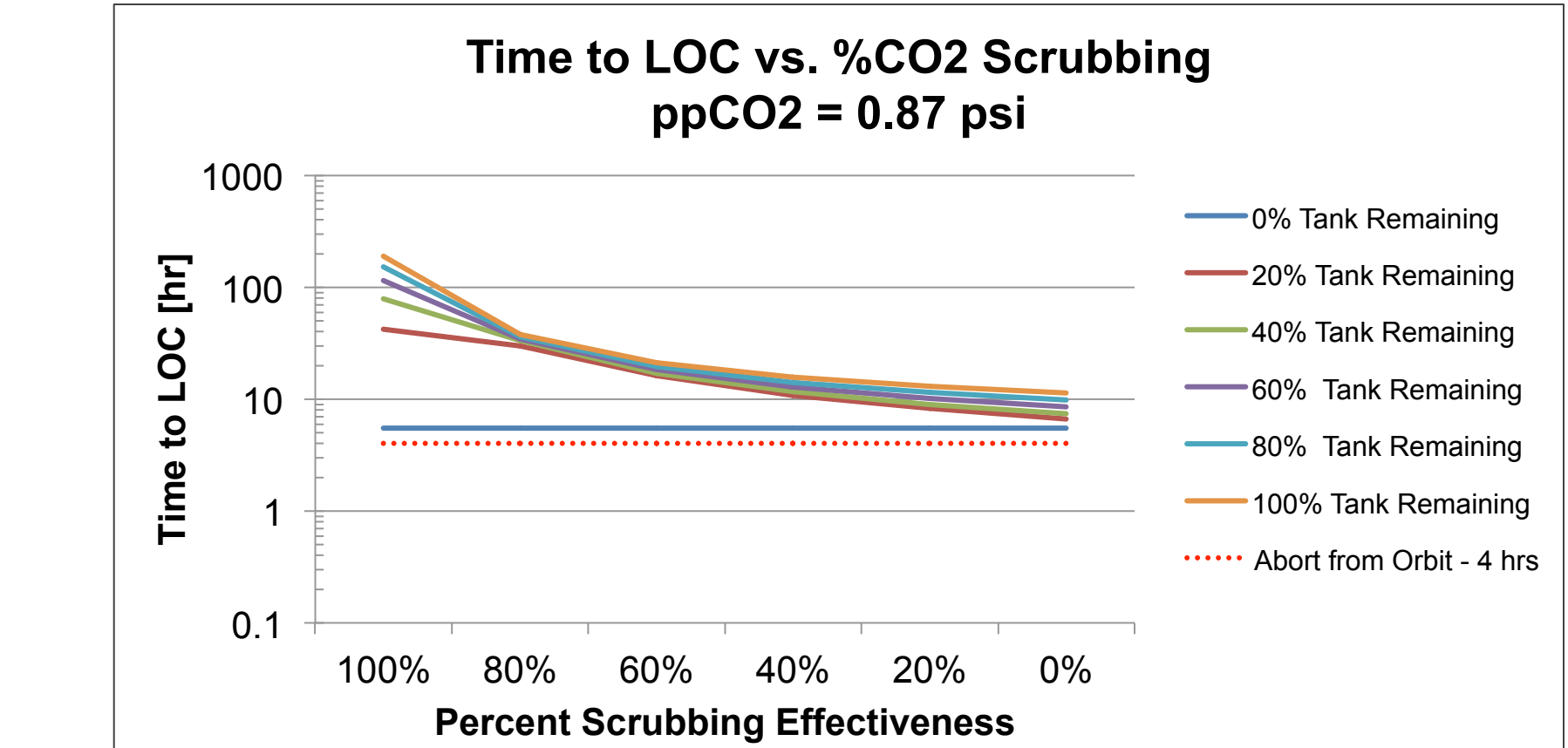


Assumptions

- Cabin Properties
  - 16 m^3 air volume
  - Leakage rate of 0.036 lbm/day
  - 297 K constant temperature
  - Perfectly controllable O_2 mass flow rate and O_2 sensors
  - Perfect pressure vessel
  - Perfect Mixing
  - Ideal Gas
- Initial Nominal Cabin State
  - 3.234 psi ppO_2
  - 0.058 psi $ppCO_2$
  - 11.408 psi ppN_2
- Crew
  - 4 Crew
  - Consume 0.2434 kg/hr of O_2
  - Produce 0.2554 kg/hr of CO_2
- Consumables
  - 44.7 kg of O_2 at 100% Full
  - 167 kg of N_2 at 100% Full
  - 297 K constant temperature
- LiOH Canisters
  - Removes 0.2554 kg/hr of CO_2 at 100% effectiveness level
- LOC Thresholds & Return Time
  - Minimum ppO_2 is 2.3 psi
  - Maximum $ppCO_2$ is 0.87 psi
  - Return Time is 4 Hours

Green indicates Simplifying Assumption / Blue indicates Uncertain Assumption / Black indicates Uncertain Design Requirement

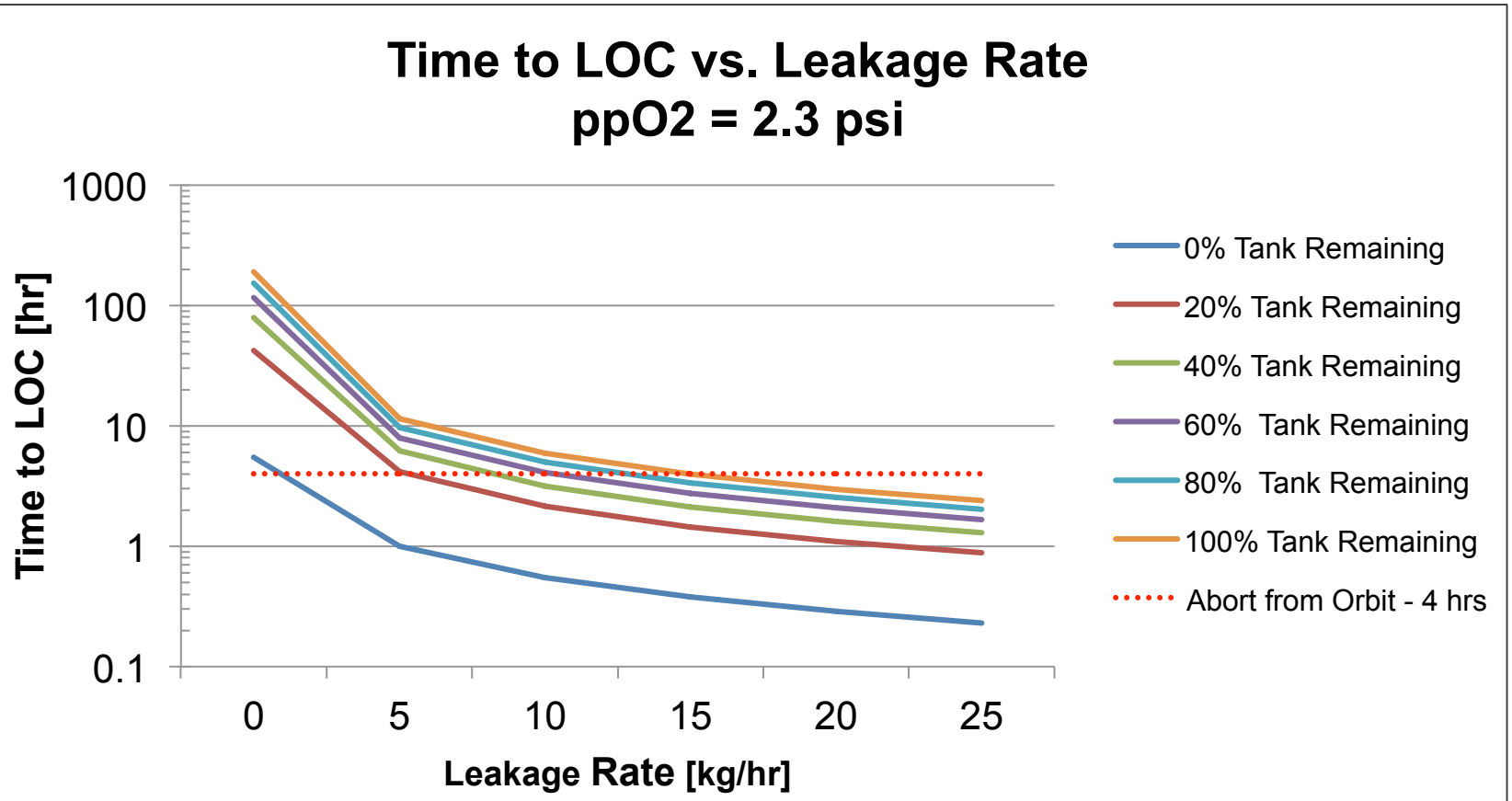
Design Insights for Risk-Informed Decisions: "Blow and Bleed" Sensitivity Study



$$\dot{m} = CA\sqrt{\gamma\rho P\left(\frac{2}{\gamma+1}\right)^{\frac{(\gamma+1)}{(\gamma-1)}}}$$

CEPR model yields design insights to inform mission rules

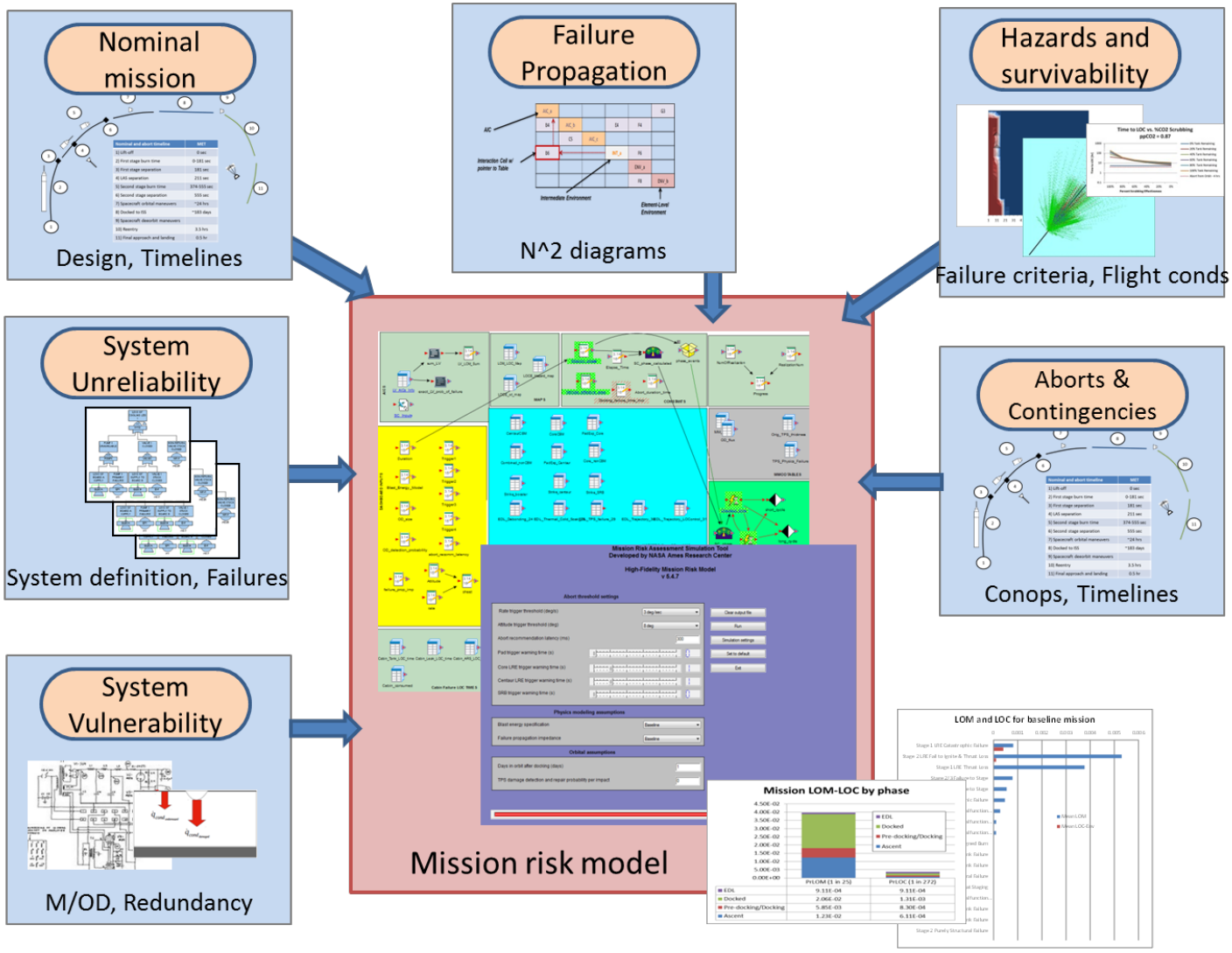
Design Insights for Risk-Informed Decisions: "Feed the Leak" Sensitivity Study



$$\dot{m} = CA\sqrt{\gamma\rho P\left(\frac{2}{\gamma+1}\right)^{\frac{(\gamma+1)}{(\gamma-1)}}}$$

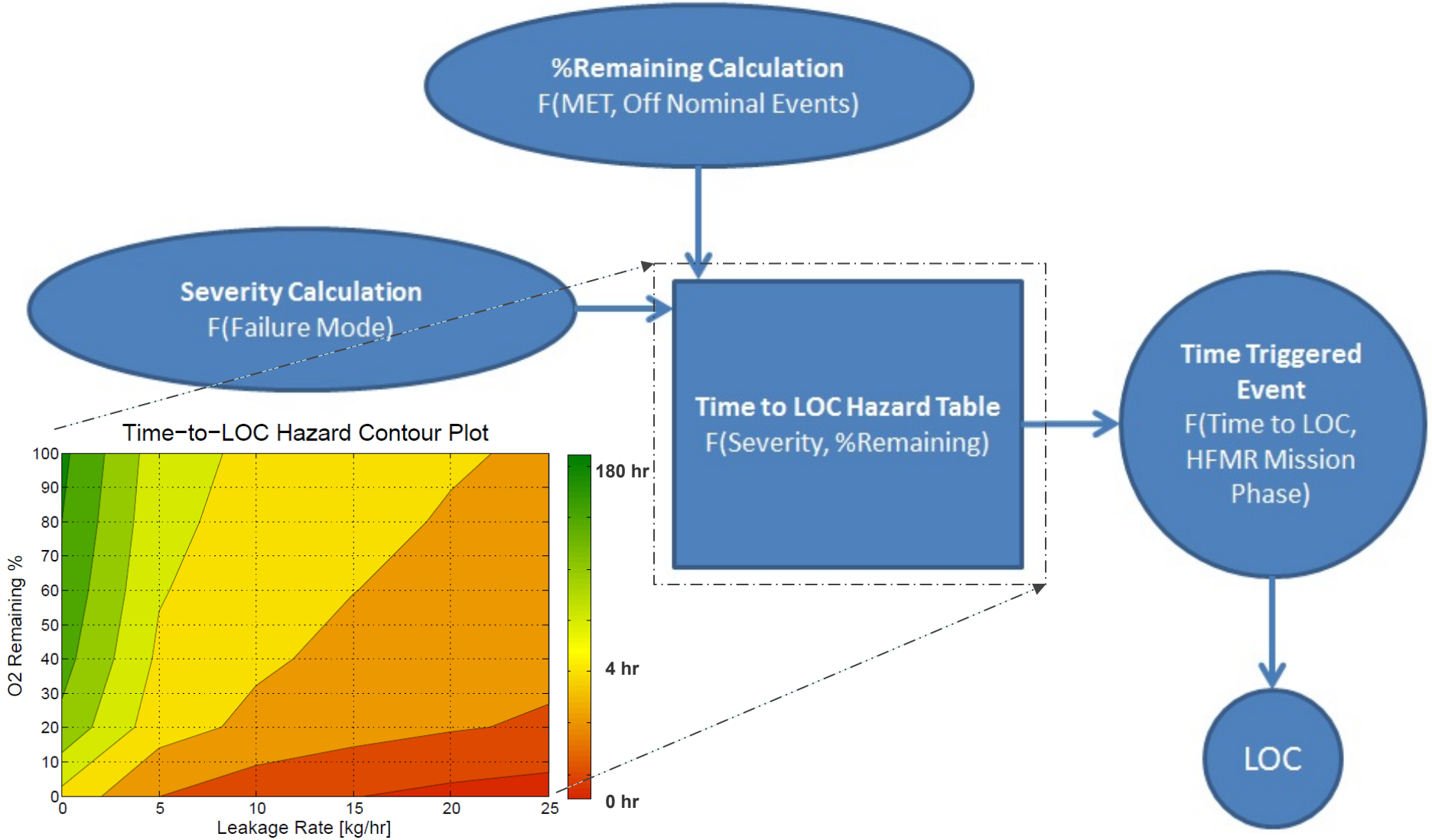
CEPR model yields design insights to aid in risk-informed decision making

Dynamic Mission Risk Model



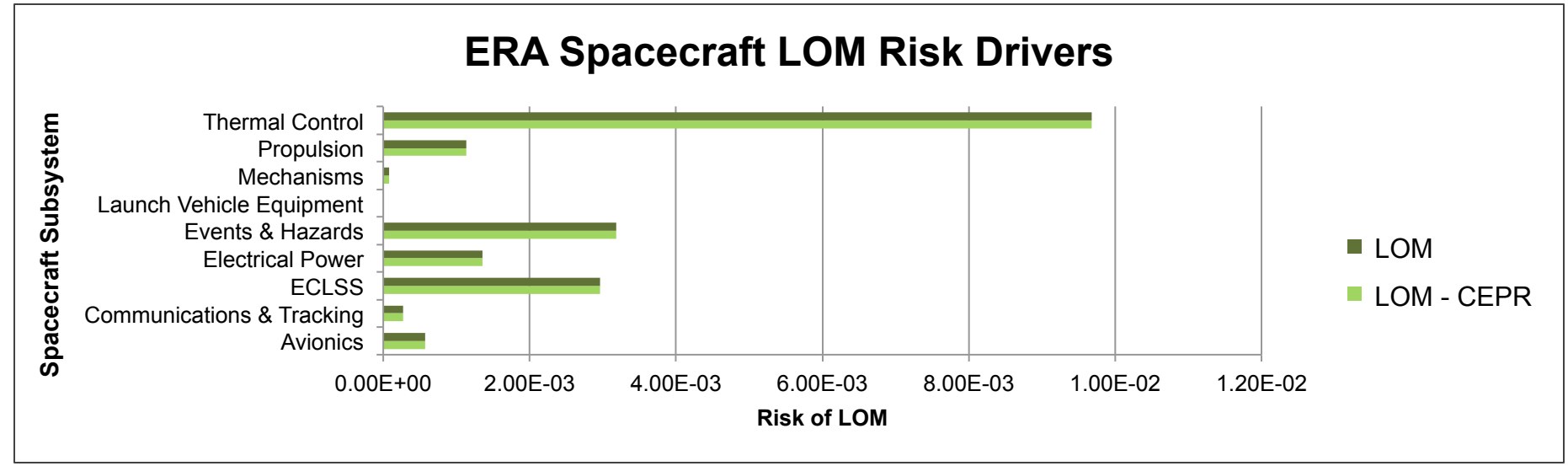
Integrated dynamic risk model captures time- and state- dependent behavior

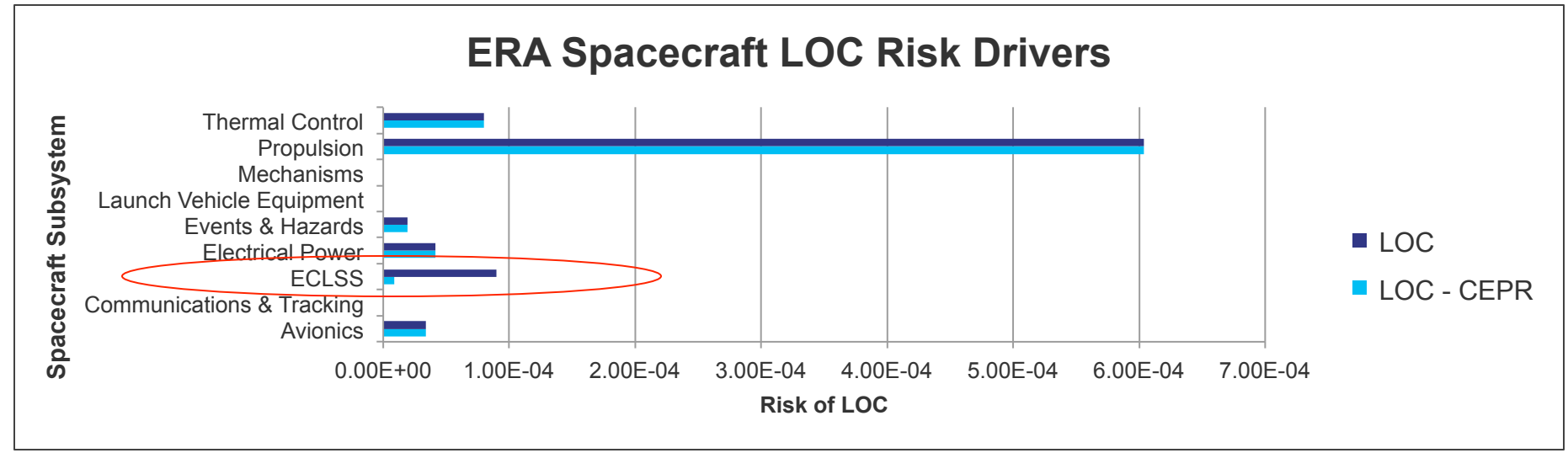
Dynamic Risk Model Integration



Monte Carlo simulation enables CEPR results to impact overall mission risk

Risk-Informed Design Example: Risk Driver Ranking

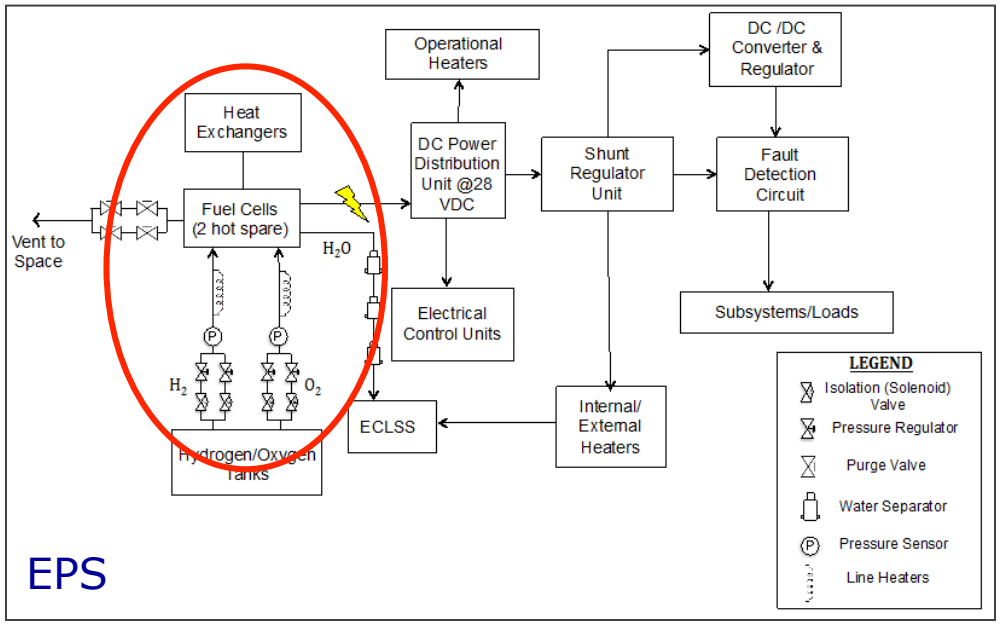


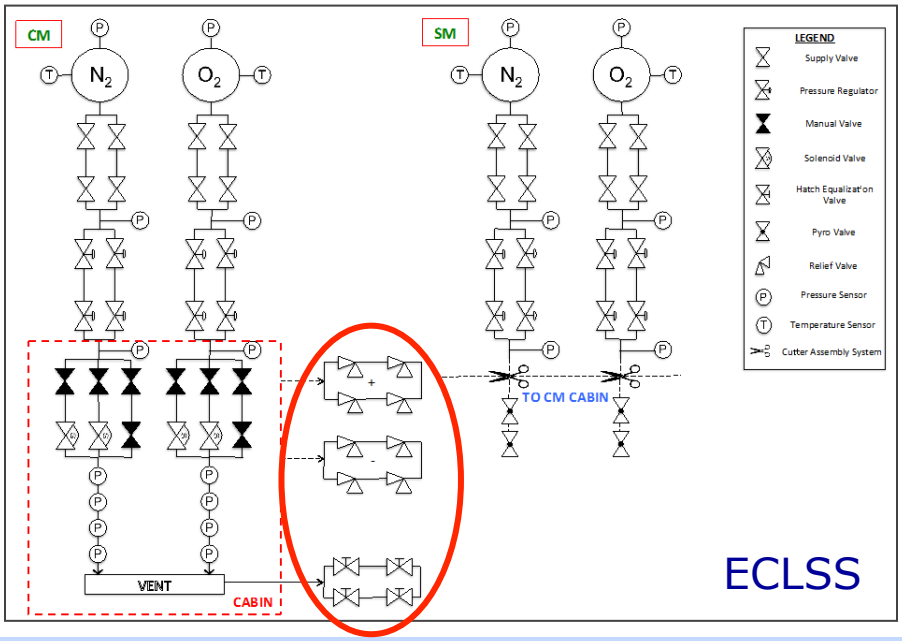


Excessively conservative assumptions can impact relative risk results

Risk-Informed Design Example: Risk Reduction Trade Study

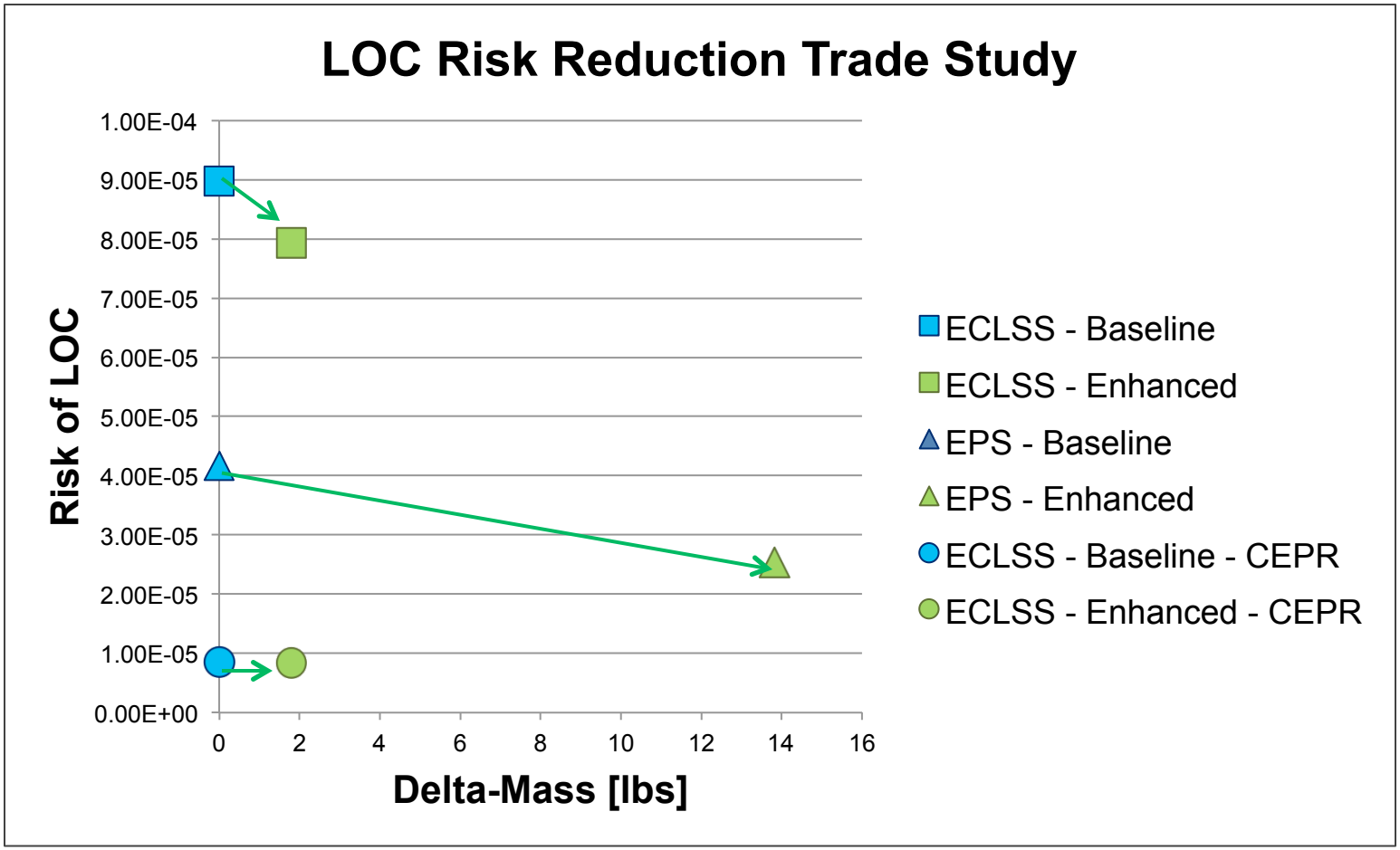
Trade Study Options			
EPS - Enhanced	**Mass [lbs]**	***ECLSS - Enhanced***	**Mass [lbs]**
Fuel Cell Stack	10.7	Manual Valve	0.3
Heater	1	Manual Valve	0.3
Heat Exchanger	0.65	Manual Valve	0.3
Pressure Regulator	0.635	Manual Valve	0.3
Pressure Sensor	0.22	Manual Valve	0.3
Hydrogen Purge Valve	0.1	Manual Valve	0.3
Water Separator	0.5		
Total Mass Delta	13.805	**Total Mass Delta**	1.8



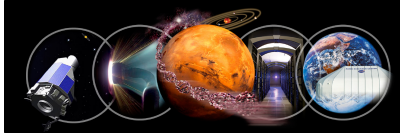


Risk-Informed Design Example: Risk Reduction Trade Study

Risk Reduction Efficiency = ΔRisk / ΔMass



Excessively conservative assumptions can alter trade study results dramatically



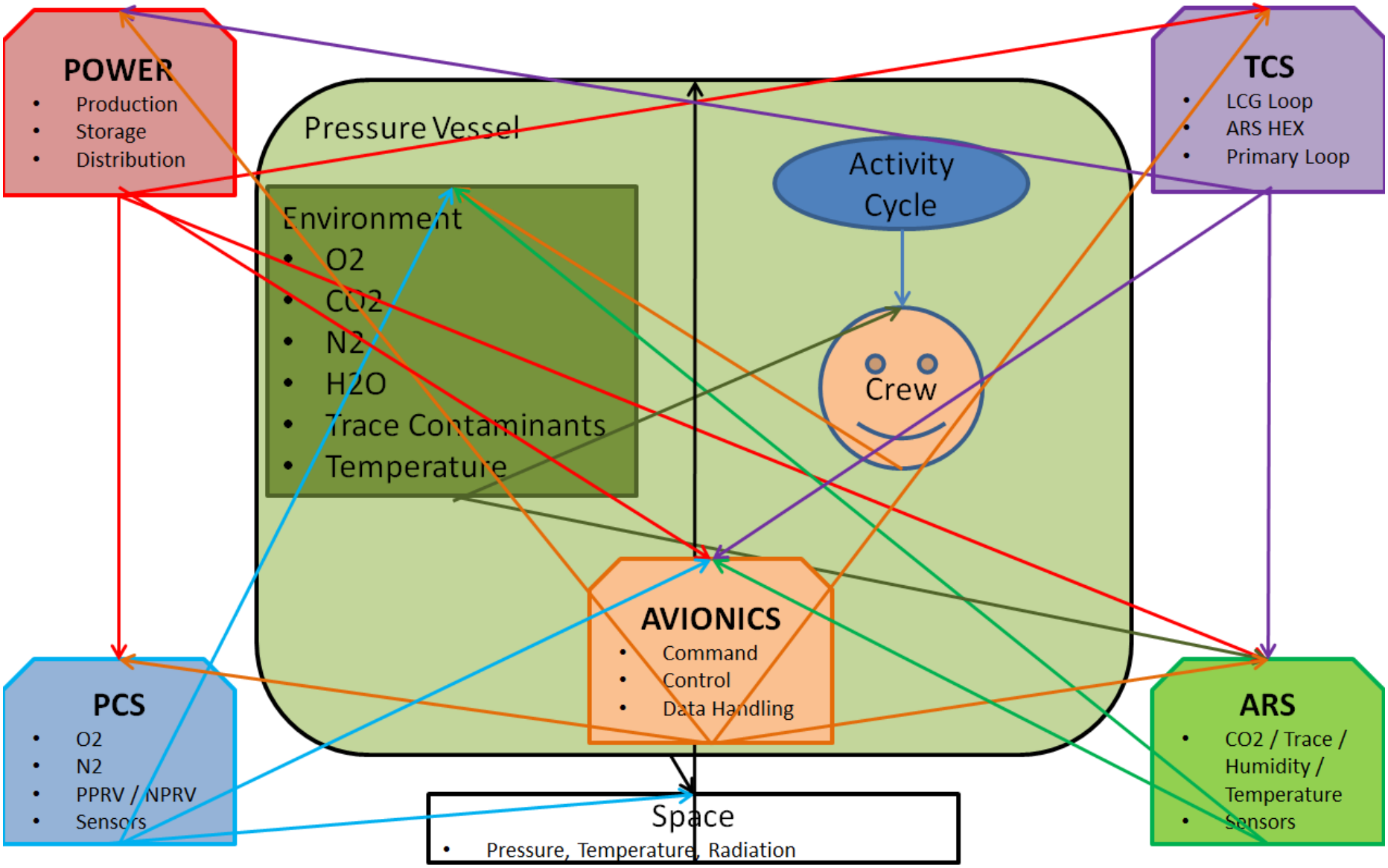
Summary & Conclusions

- **CEPR model is used to predict the time for an initial ECLSS failure to propagate into a hazardous environment and trigger a LOC event**
  - Can be utilized as a stand-alone model to aid in decision-making
  - Allows for integration of model results into dynamic mission risk models
  - Enables the risk analyst to remove the assumption that loss of functionality triggers LOC

- **The assumption that loss of functionality triggers LOC has been shown to be excessively conservative**
  - Impacts overall risk driver ranking
  - Impacts risk reduction trade study results
  - Could lead to a suboptimal design that inherently increases the risk of LOC

- **Incorporating CEPR results yields more accurate design insights**

Future Work


POWER
Production
Storage
Distribution
TCS
LCG Loop
ARS HEX
Primary Loop
Pressure Vessel
Activity Cycle
Environment
O2
CO2
N2
H2O
Trace Contaminants
Temperature
Crew
AVIONICS
Command
Control
Data Handling
PCS
O2
N2
PPRV / NPRV
Sensors
ARS
CO2 / Trace / Humidity / Temperature
Sensors
Space
Pressure, Temperature, Radiation