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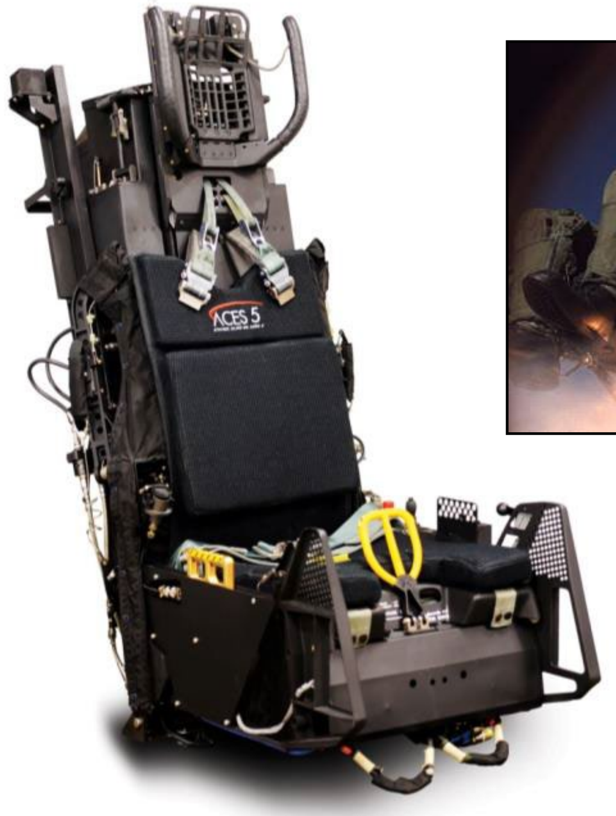


ACES 5

ACES II

EJECTION SYSTEM CAD/PAD OPTIMIZATION USING MODEL BASED SYSTEMS ENGINEERING PRINCIPALS AND MONTE-CARLO SIMULATION TECHNIQUES

CAD/PAD TEW 2024

Carson, Kassidy; Discipline Chief Engineer — Ejection & Propulsion System Design, Collins Aerospace, Colorado, USA

INTRODUCTION

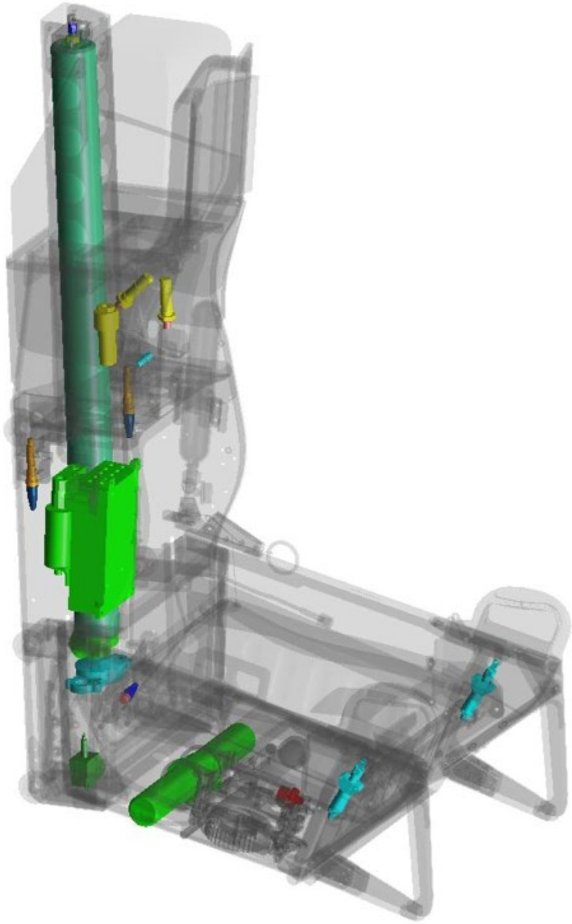
Ejection System CAD/PAD Optimization using MBSE Principals and Monte-Carlo Simulation Techniques

EJECTION SYSTEM CAD/PAD OPTIMIZATION

INTRODUCTION

- The development of ejection systems and integration of CAD/PAD devices involves complex interactions between mechanical, electronic, and energetic sub-systems.

- Optimization of the system architecture, design, and integration to the aircraft requires the use of sophisticated techniques including a system of systems approach and multi-physics simulation across the product lifecycle.



CAD/PAD optimization requires modeling & testing system interactions across the product lifecycle

METHODS

Ejection System CAD/PAD Optimization using MBSE Principals and Monte-Carlo Simulation Techniques

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS

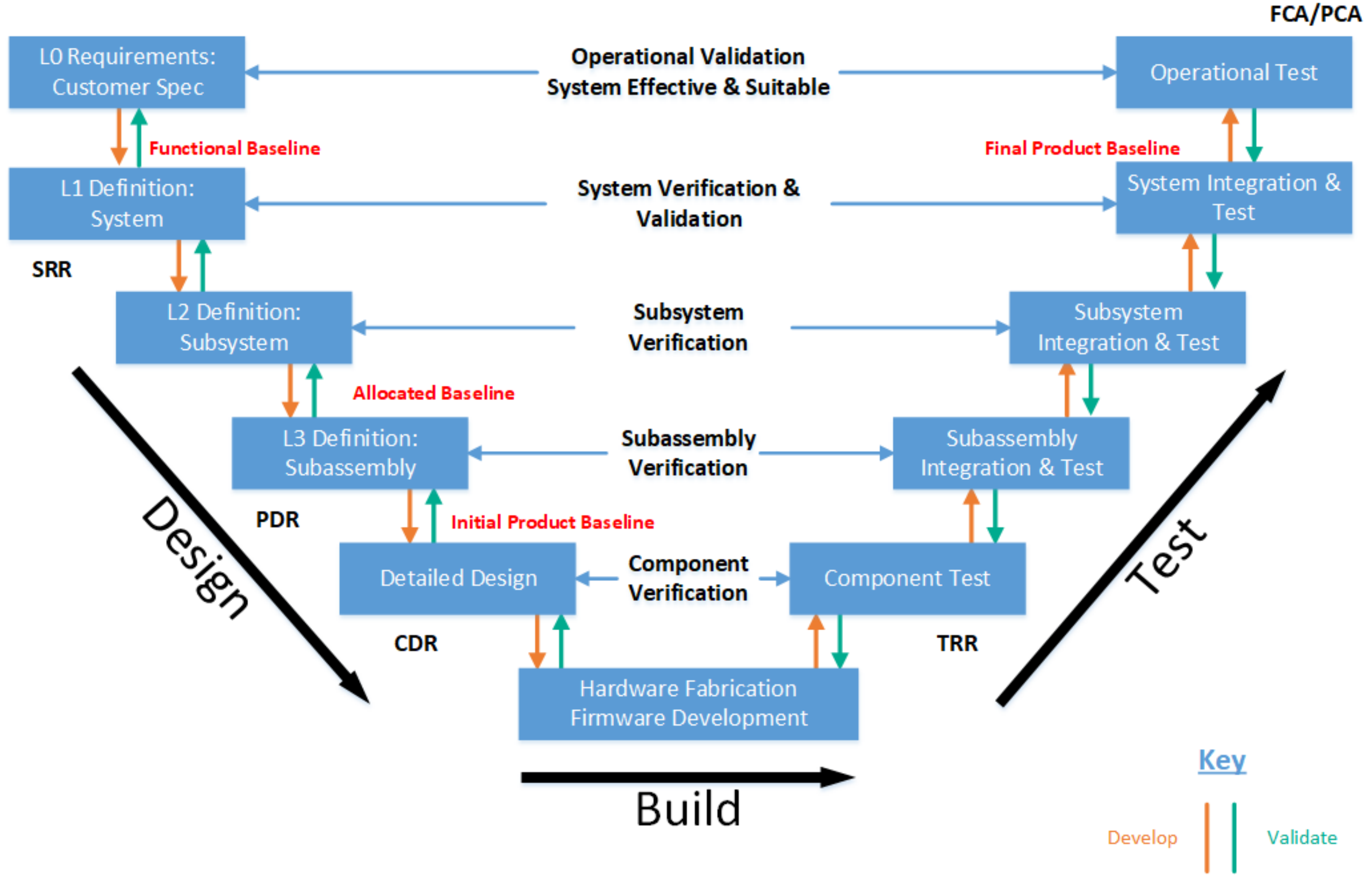
- Implementation of the “V-diagram” product development lifecycle model, Model Based Systems Engineering (MBSE) principals, and system of systems modeling practices are used in ejection system development, CAD/PAD device integration, and aircraft escape system compatibility verification.

- Multi-physics model construction and simulation validation are used, including the use of Monte-Carlo techniques.

MBSE combines the strengths of analytical and empirical methods to drive efficiency & optimization

EJECTION SYSTEM CAD/PAD OPTIMIZATION

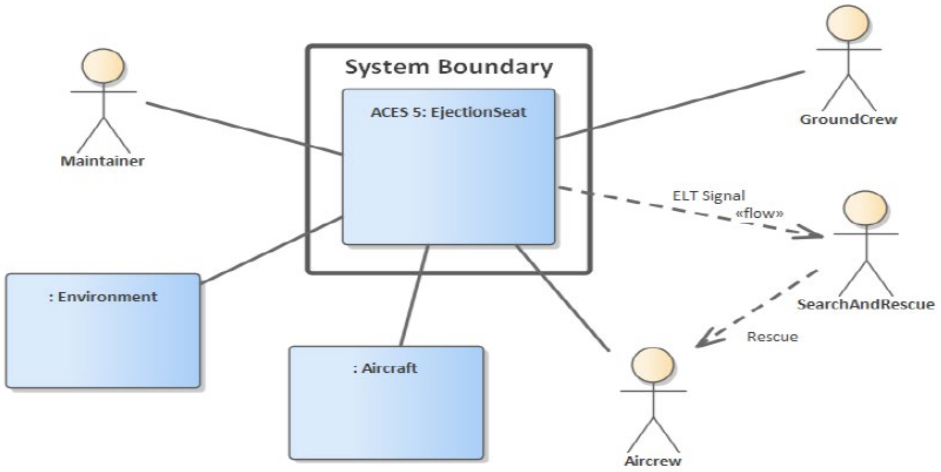
METHODS – OVERALL APPROACH



“V-diagram” approach is used to rapidly develop and validate solutions with progressive maturity

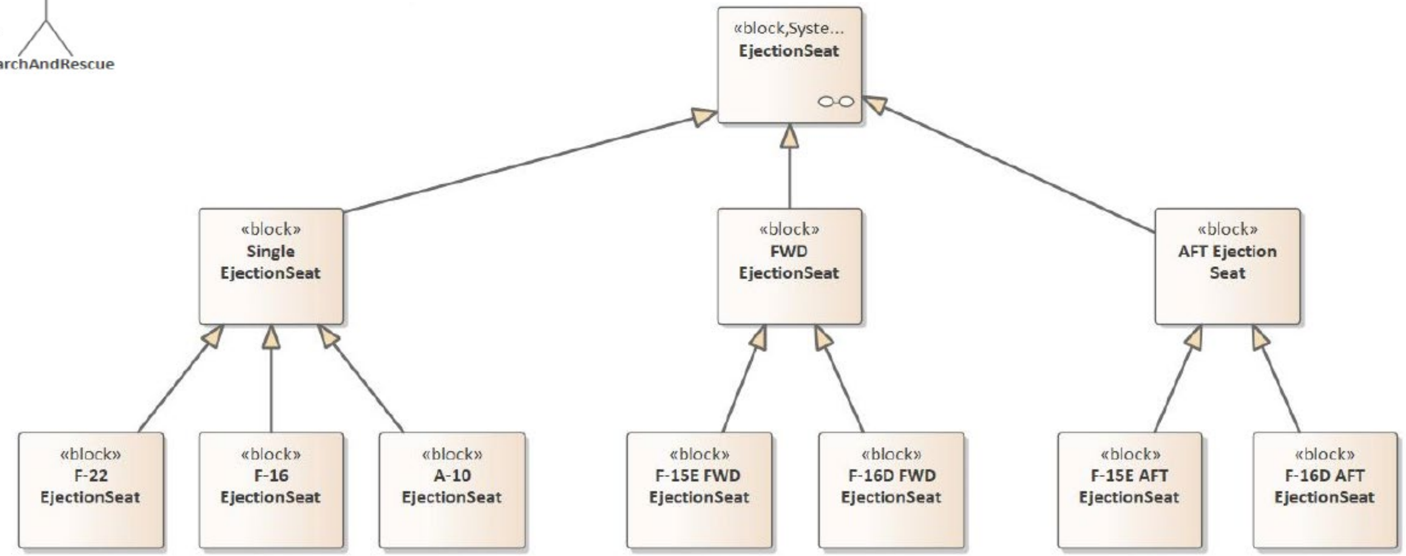
EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ARCHITECTURE



System Boundaries & Actors

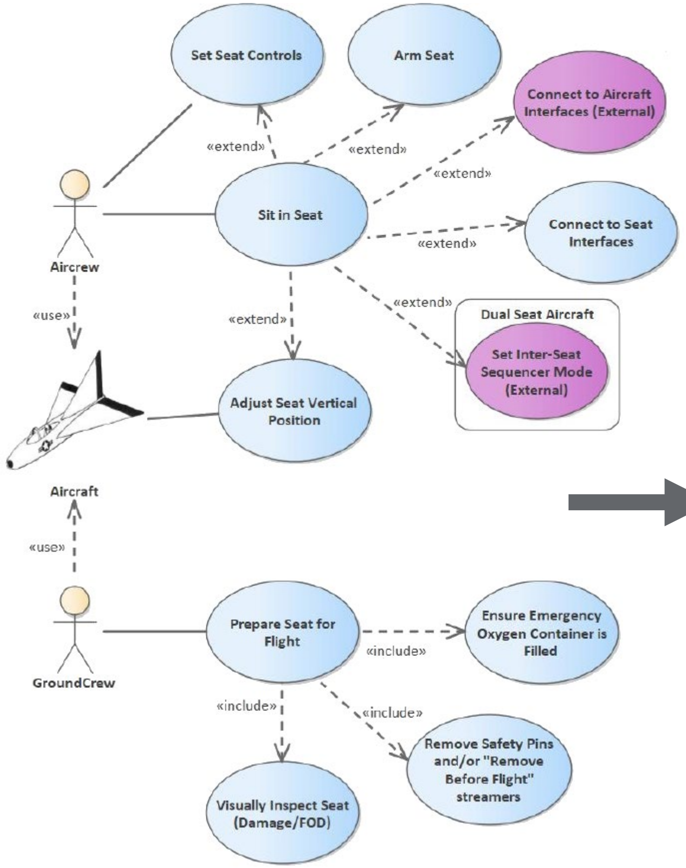
System / Aircraft Platform Variants



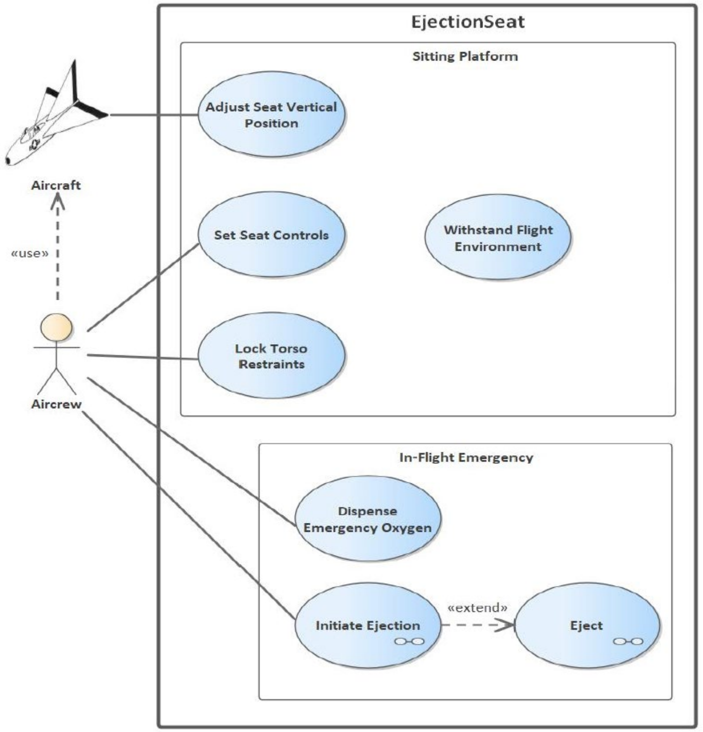
System boundaries, actors, interactions, & platform variants are modeled

EJECTION SYSTEM CAD/PAD OPTIMIZATION

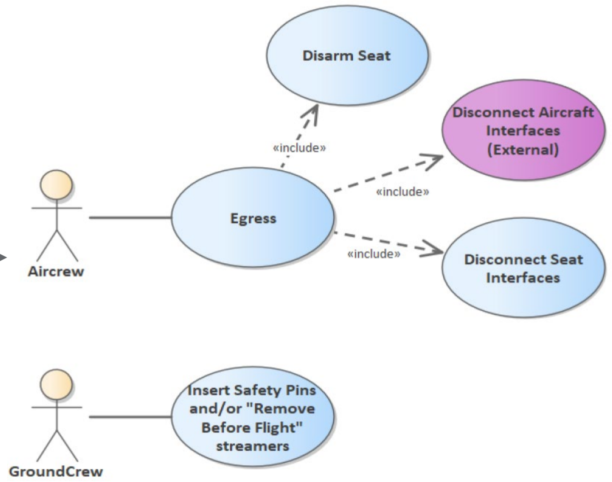
METHODS – ARCHITECTURE



Pre-Flight



Flight



Post-Flight

Functional architecture of mission pre-flight, flight, & post-flight use cases are modeled

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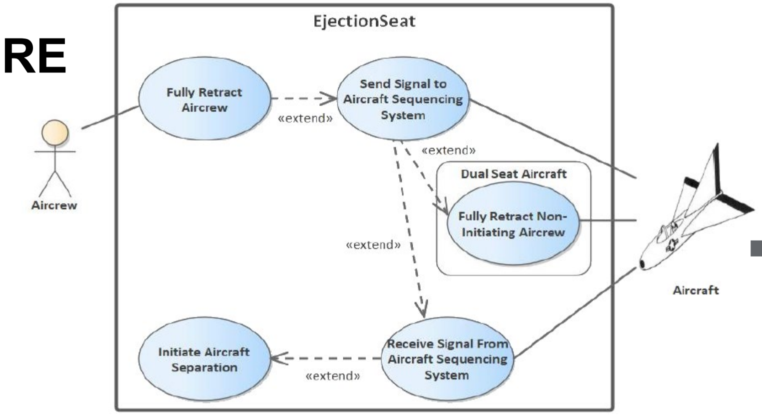
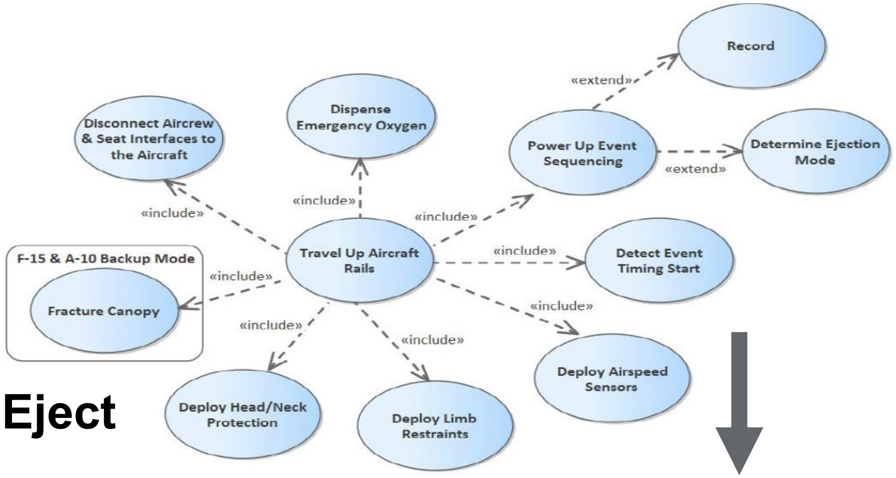
EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ARCHITECTURE

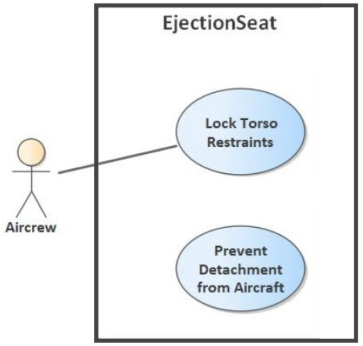


Initiate Ejection

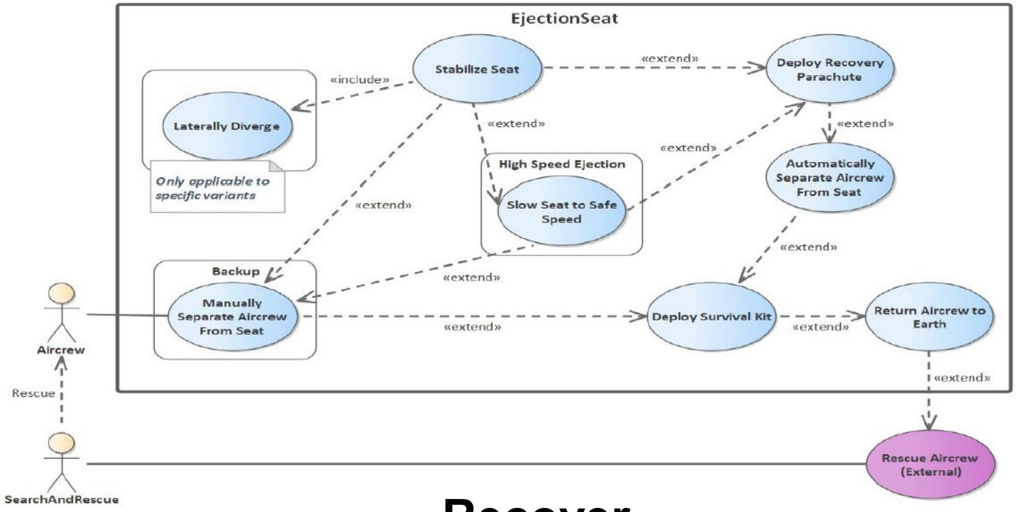
(or)



Eject



Crash Safety

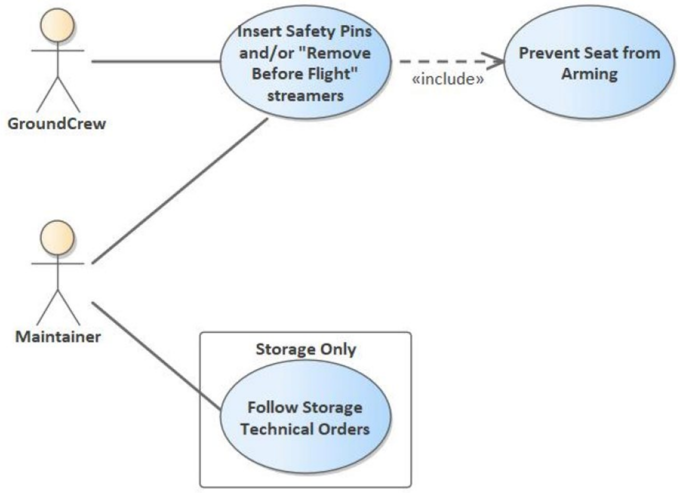


Recover

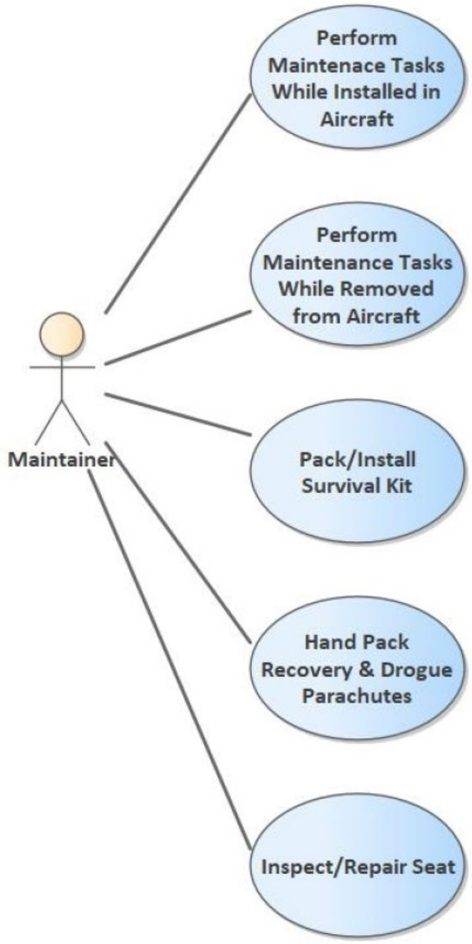
Functional architecture of mishap initiation, ejection, recovery, & crash safety use cases are modeled

EJECTION SYSTEM CAD/PAD OPTIMIZATION

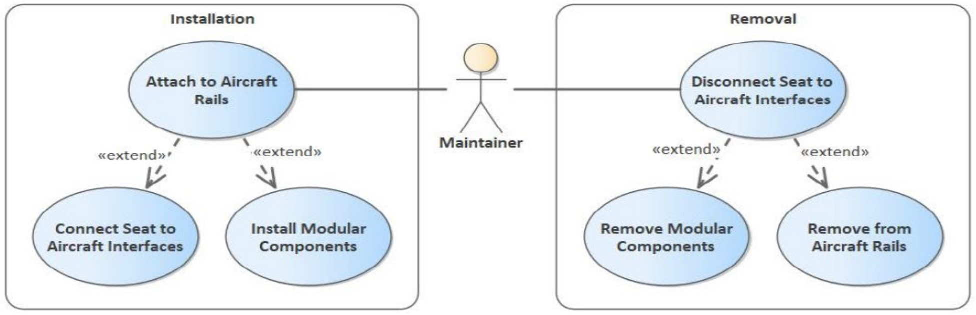
METHODS – ARCHITECTURE



Storage & Display



Maintenance

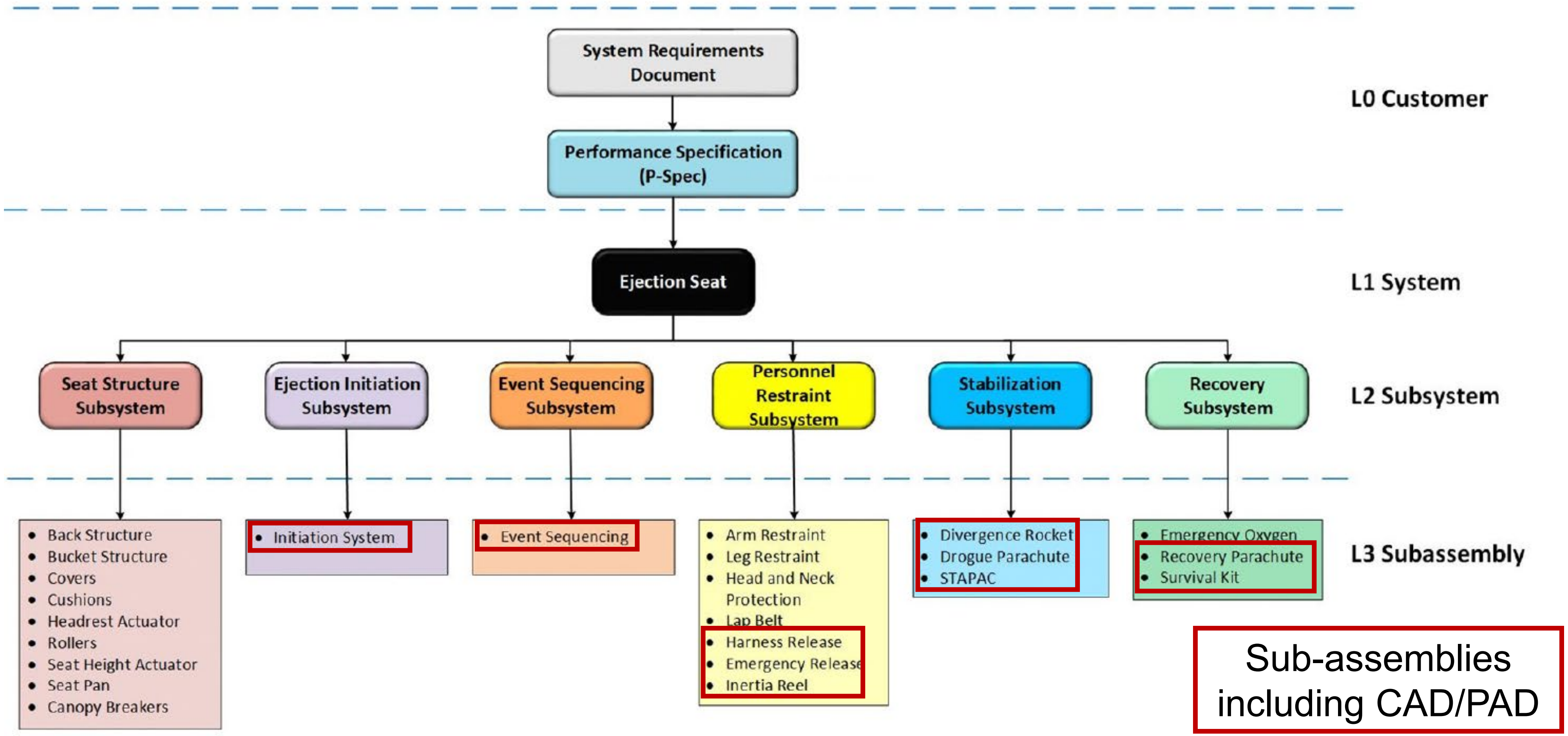


Installation & Removal

Functional architecture of storage, display, maintenance, install & removal use cases are modeled

EJECTION SYSTEM CAD/PAD OPTIMIZATION

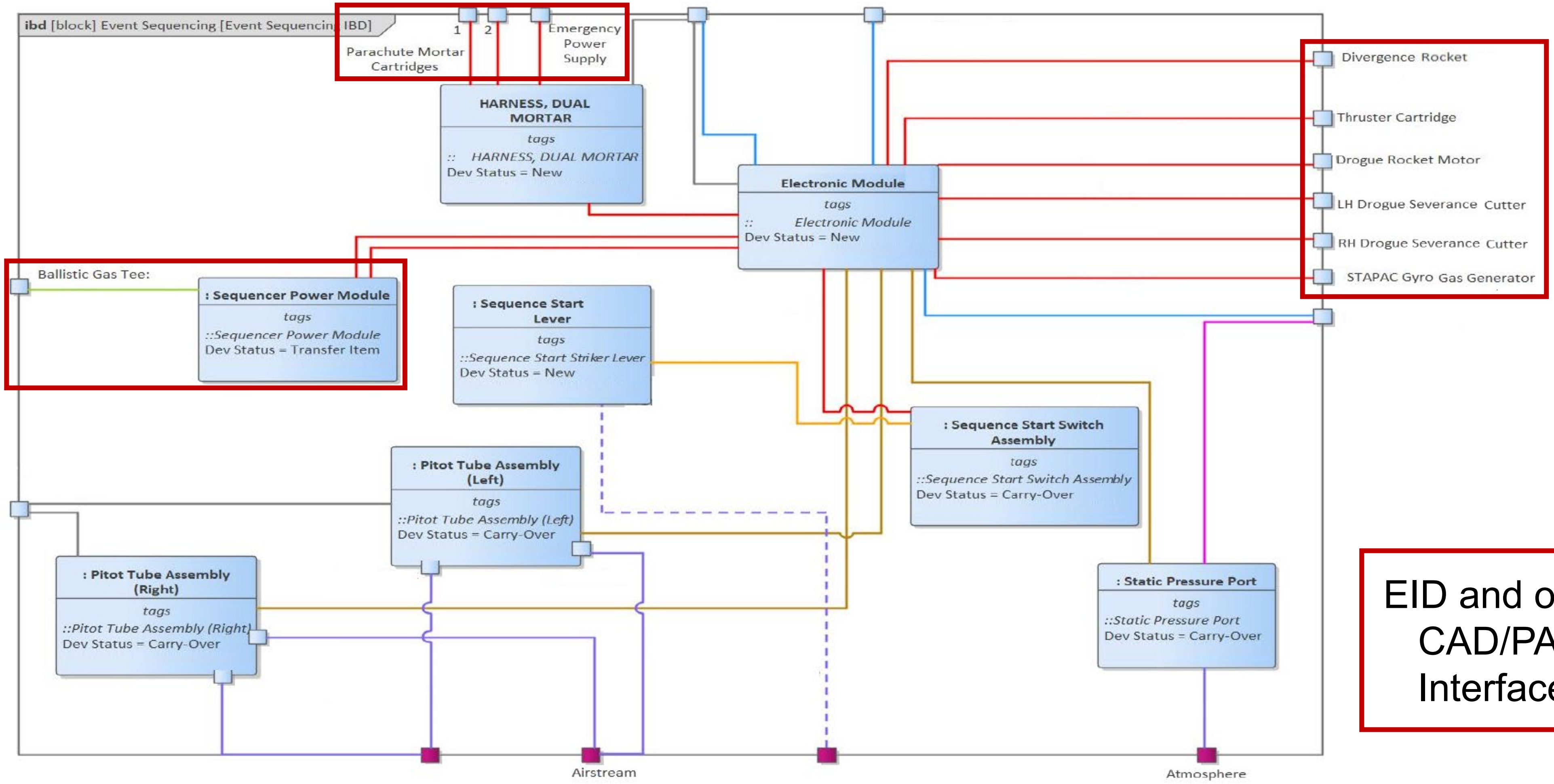
METHODS – ARCHITECTURE



Requirements decomposition and derivation informs the system CAD/PAD hierarchy development

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ARCHITECTURE

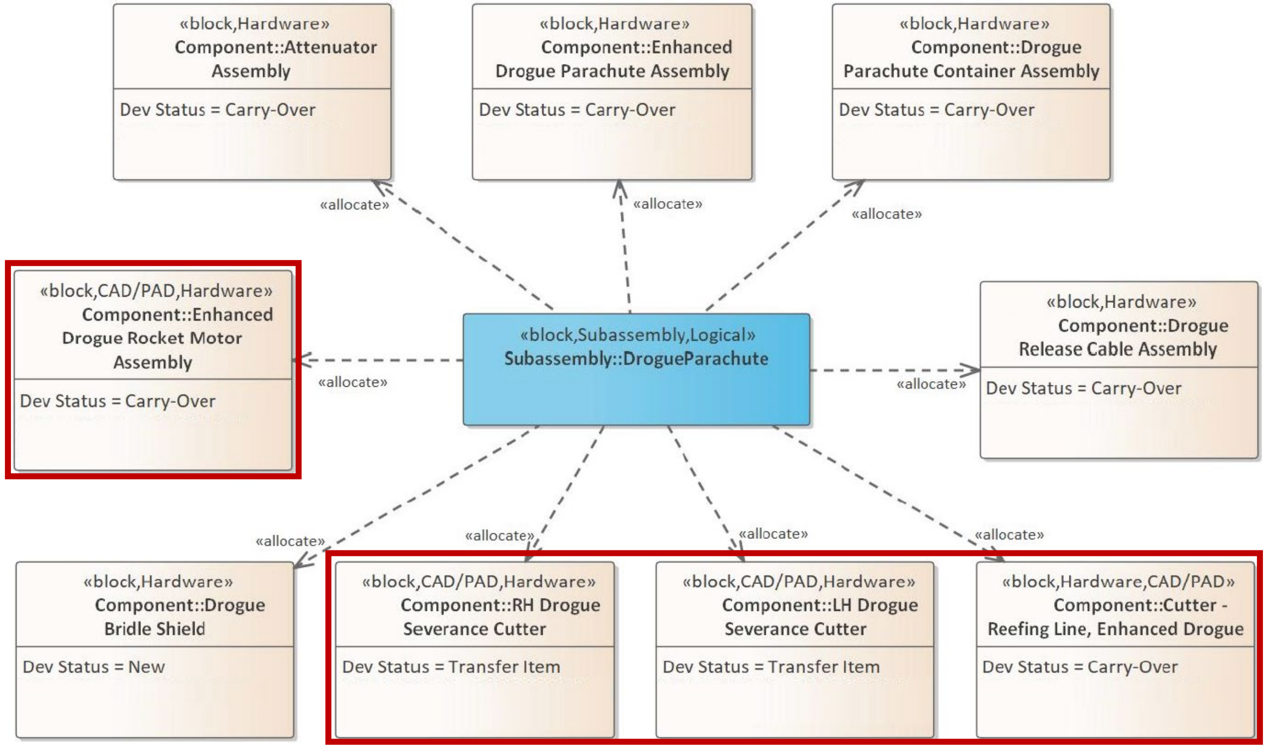


EID and other CAD/PAD Interfaces

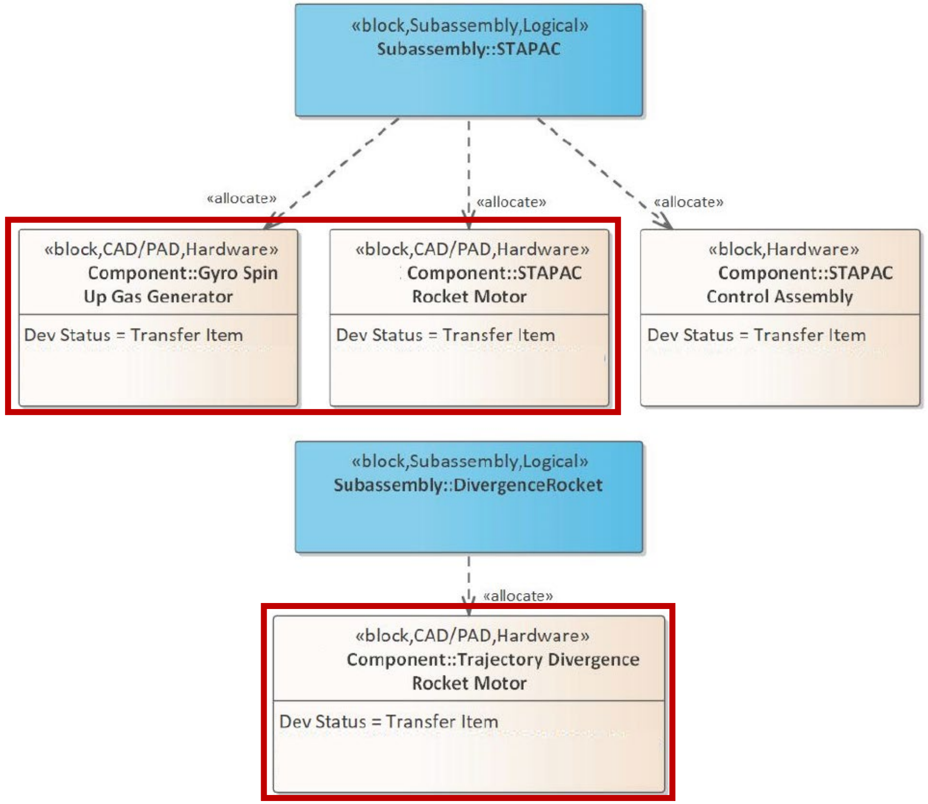
Internal Block Diagrams (IBDs) are used to model EID and other CAD/PAD device interfaces

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ARCHITECTURE



Drogue Deployment Rocket & Severance Cutters



STAPAC Vernier, Gyro GG, & TDRM

CAD/PAD Devices within Stabilization Sub-Systems

Sub-assembly physical architecture of the stabilization sub-system includes key CAD/PAD devices

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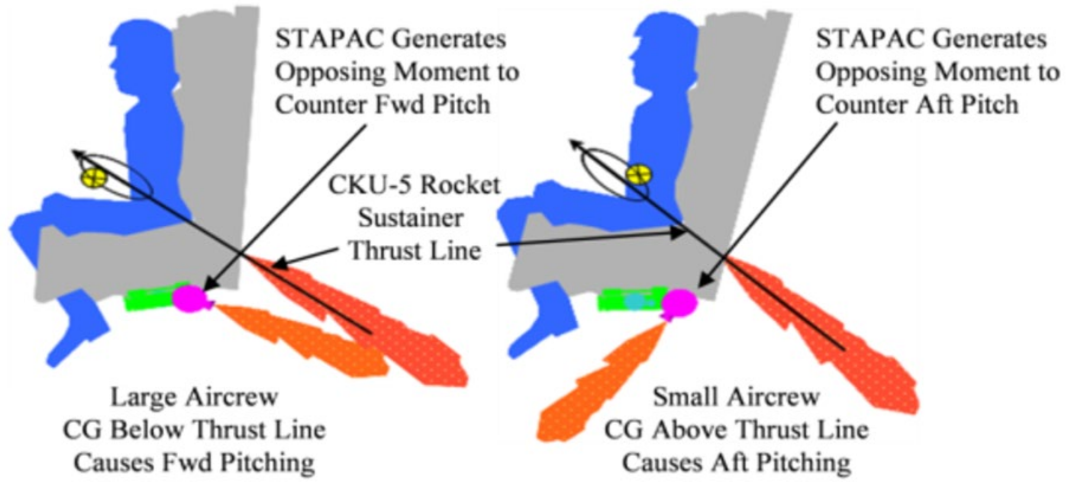
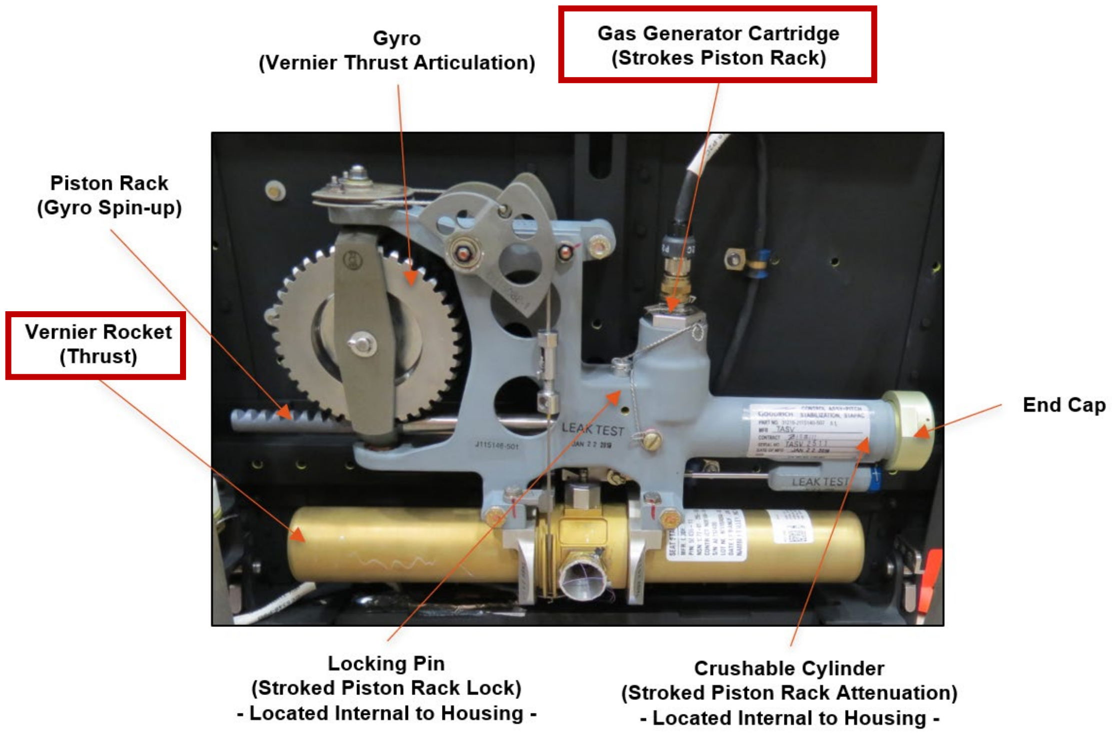
EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – EMPERICAL

ACES Stabilization Package (STAPAC) Function



Vernier Rocket (PAD) & Gyro Gas Generator (CAD)



CAD/PAD devices are essential to ejection seat propulsion, stabilization, and other critical functions

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EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – EMPERICAL

STAPAC Vernier Rocket

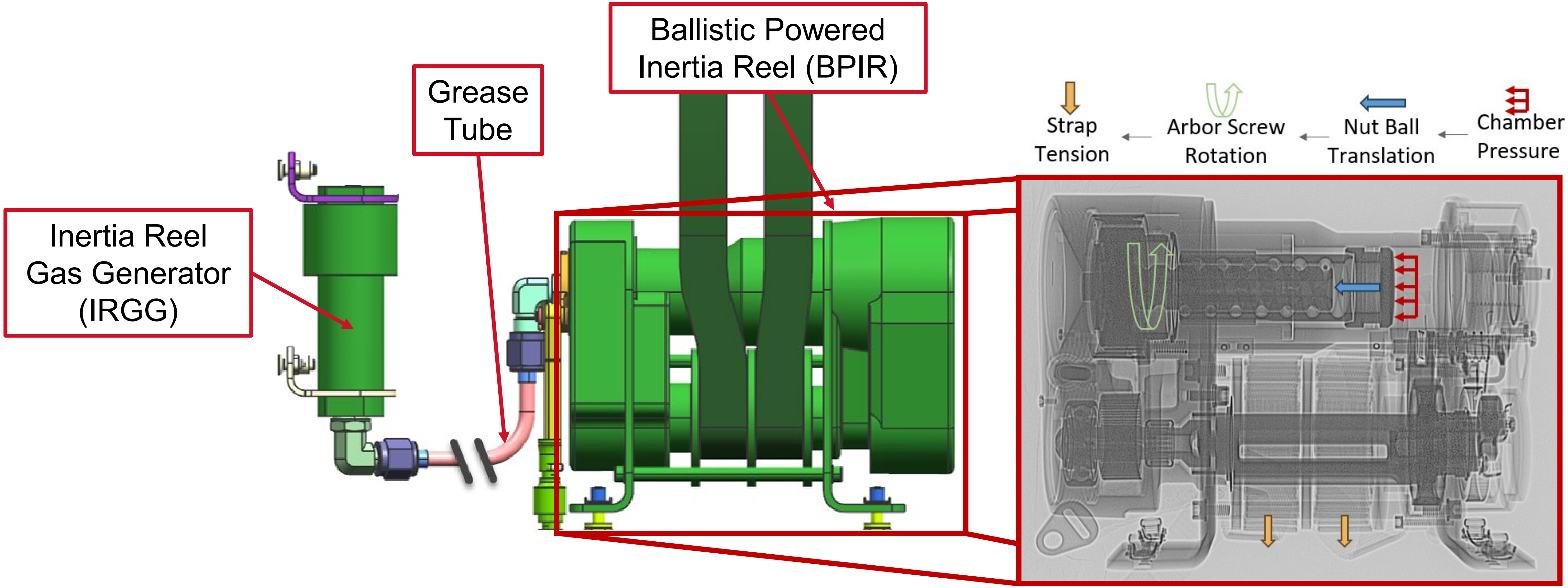
Trajectory Divergence Rocket Motor (TDRM)

CKU (RoCat) Sustainer Rocket

The seat propulsion (CKU), divergence (TDRM), and stabilization (Vernier) CAD/PAD all must work in harmony

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – EMPERICAL



CADs interface mechanically with complex Gas Operated Devices (GODs) such as the Inertia Reel

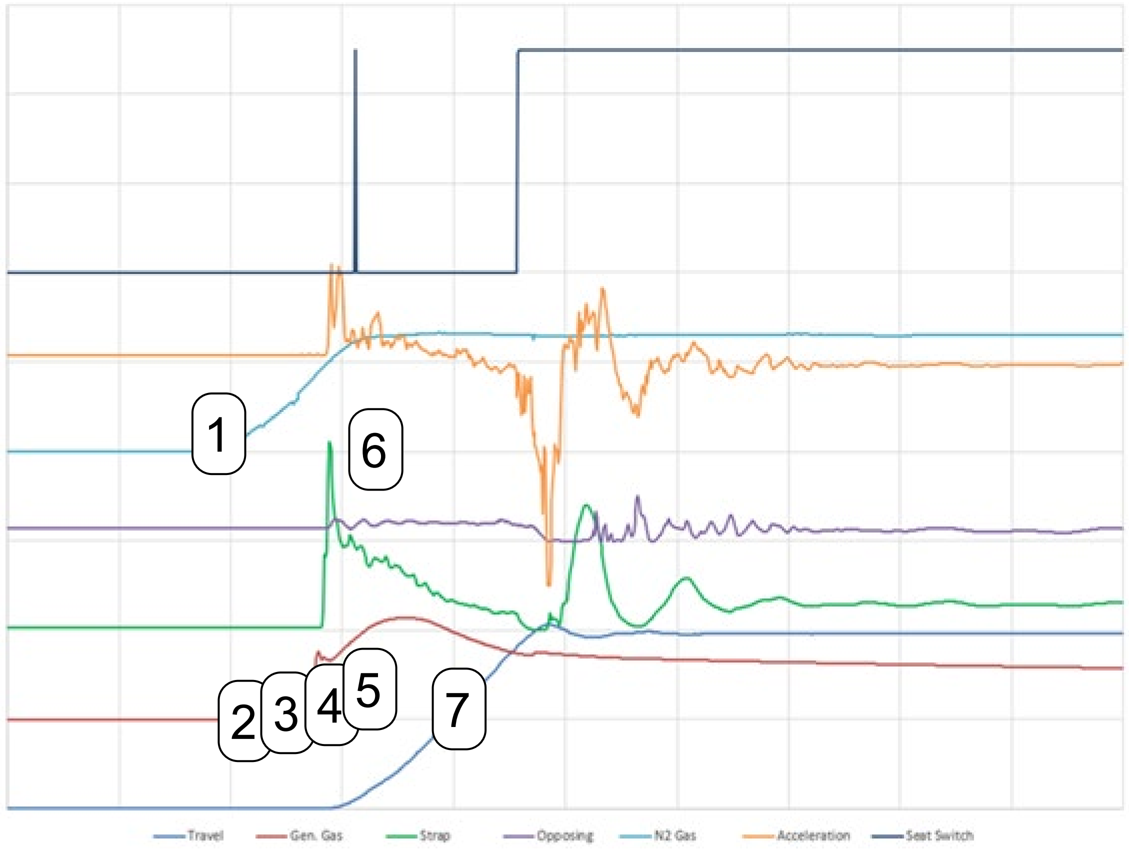
EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – EMPERICAL

BPIR Ballistic Haulback Functional Overview

1. Ballistic gas initiates percussion primers on IRGG
2. Propellants ignite in IRGG creating hot, high-pressure gas
3. High-pressure gas forces liquified grease through the grease tube
4. Liquified grease acts on a piston in the IR, pressurizing an oil damping fluid
5. A rupture disk opens, allowing the oil to flow out and the IR to begin function
6. The piston drives a ball nut over a ball screw, causing the ball screw to rotate, creating torque
7. The rotation of the ball screw hauls back the straps via gear train and accelerates the torso

BPIR Test Data (LAT histogram - not to scale)

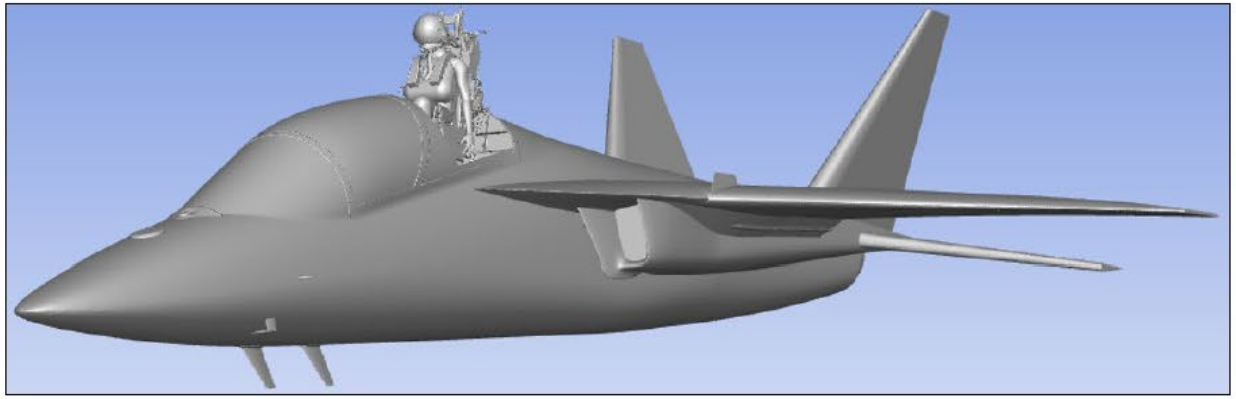


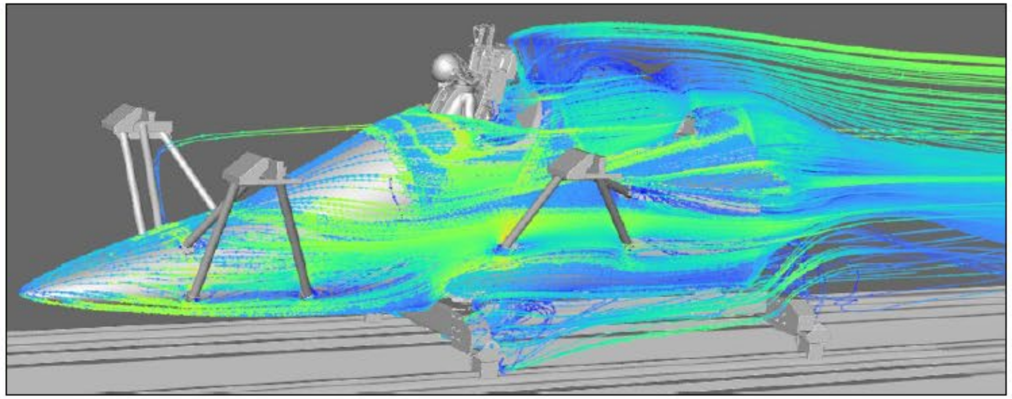
Inertia Reel ballistic haulback is achieved through complex interaction between mechanical & CAD

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ANALYTICAL

- Computational Fluid Dynamics (CFD) simulations are useful for characterizing potential differences between sled test and aircraft environments upon emergence into airstream.
  - Removal of camera booms and ground/track effects
  - Addition of aero surfaces not present on sled
- Fluid Structure Interaction (FSI) modeling combines aerodynamic and structural



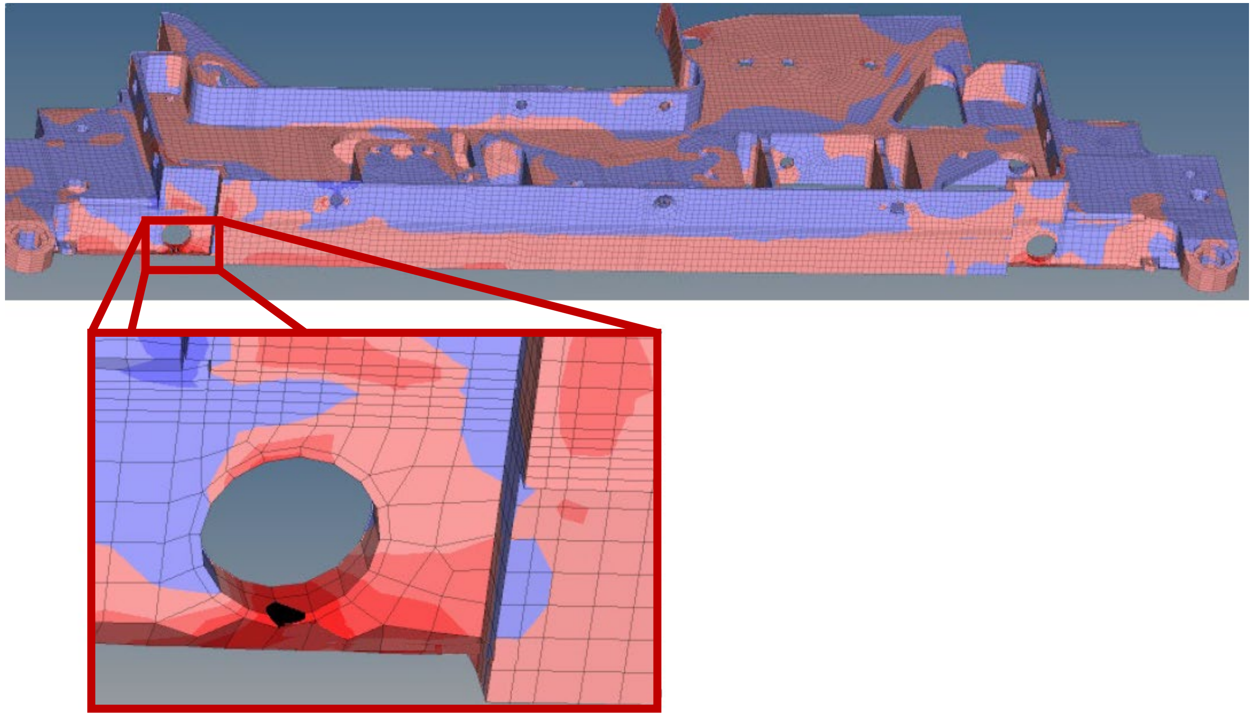


Sophisticated multi-physics models may be used to solve problems where high fidelity is needed

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ANALYTICAL

- Non-linear Finite Element Analysis (FEA) modeling enables structural interface optimization for one-time use load cases (e.g., strength, stiffness, deflections)
  - Used in quasi-static and dynamic analyses

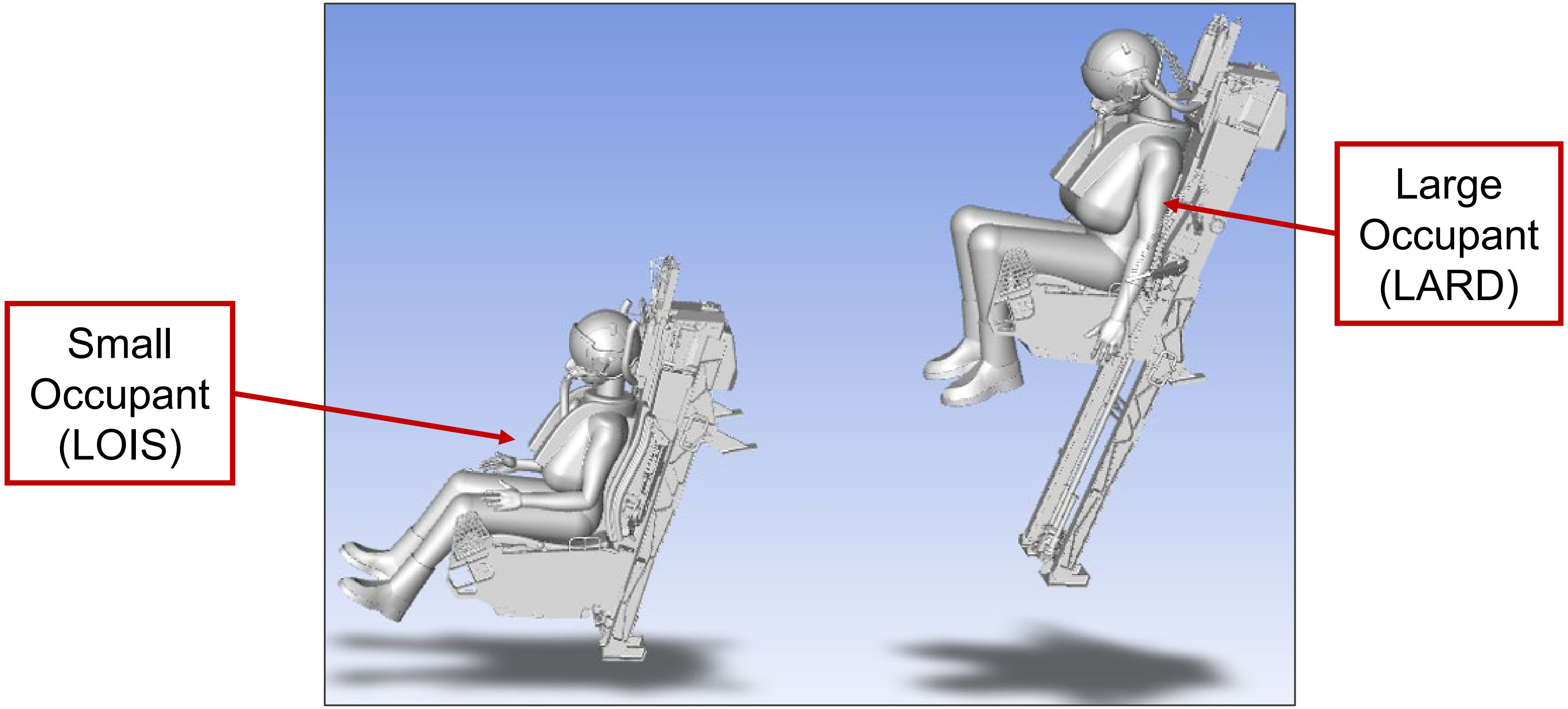


Non-linear structural FEA is used to optimize interfaces for one-time ejection or crash load use cases

EJECTION SYSTEM CAD/PAD OPTIMIZATION

METHODS – ANALYTICAL

Pre-Ejection (Fwd Cockpit – Left) vs Post-Catapult Stroke (Aft Cockpit – Right)



Defeatured 3D models are useful in numerous computational modeling methodologies

RESULTS & DISCUSSION

Ejection System CAD/PAD Optimization using MBSE Principals and Monte-Carlo Simulation Techniques

EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION

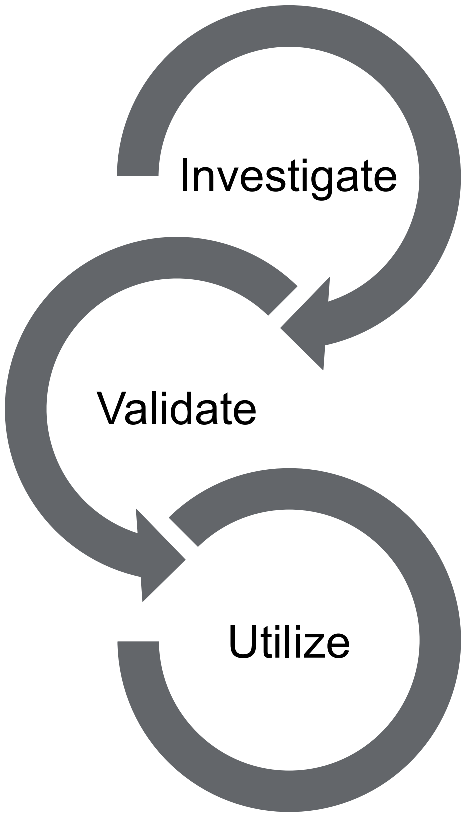
- Ejection system rigid body six-degree-of-freedom (6-DOF) simulation is constructed in the Collins Aerospace proprietary Dynamic Escape System Simulator (DESS) software using simple sub-system models with low computational cost.

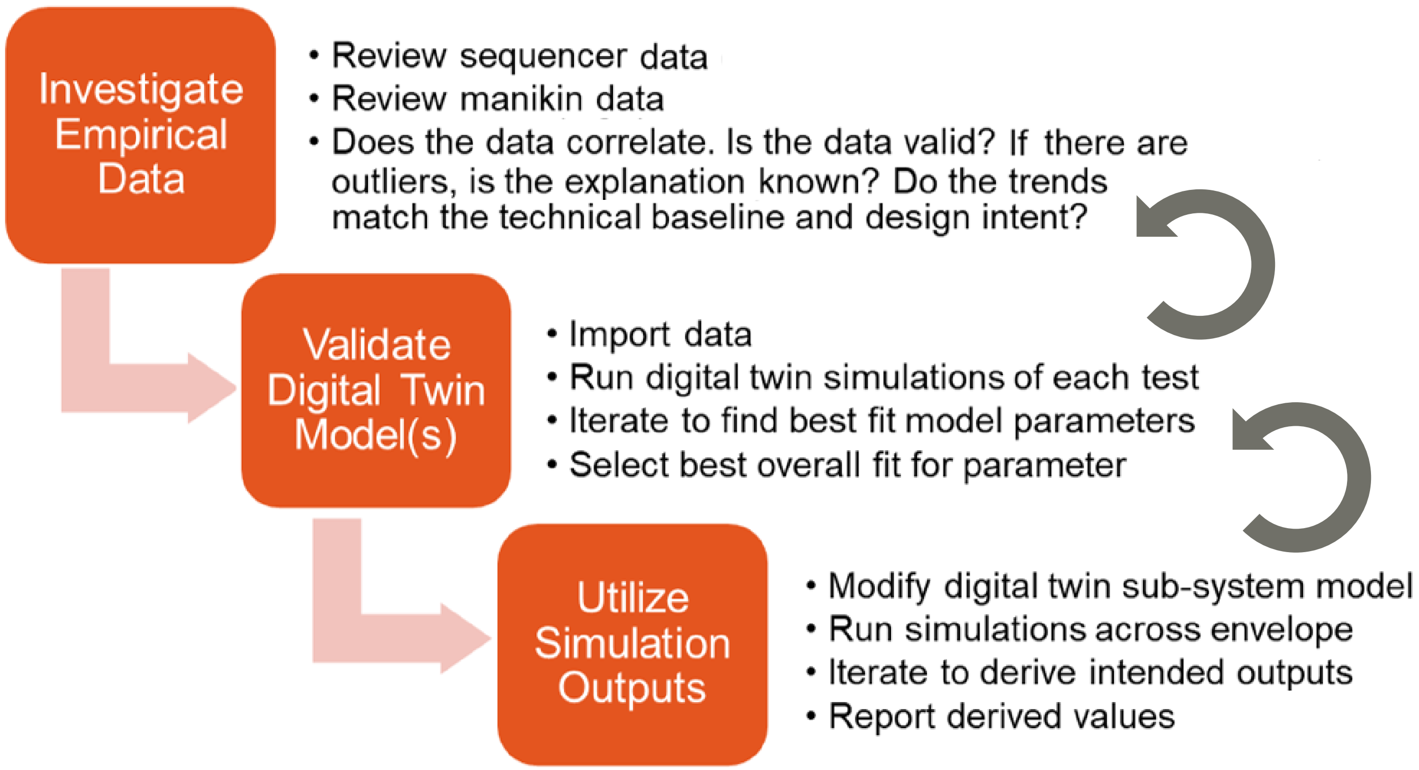
- Empirical data from sub-system testing, sled testing, and wind tunnel testing is augmented with other higher computational cost simulations such FEA (e.g., stiffness) and CFD (i.e., aero) and used in the validation of high-fidelity sub-system models.

High fidelity sub-system models are validated with extensive empirical & analytical data

EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION





Multi-physics 6-DOF model validation requires extensive interrogation of all available data

EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION

- The resulting digital-twin model is run iteratively with the randomization of variables for the evaluation of statistical variation, variable sensitivity studies, design trade studies, and to inform verification approaches.

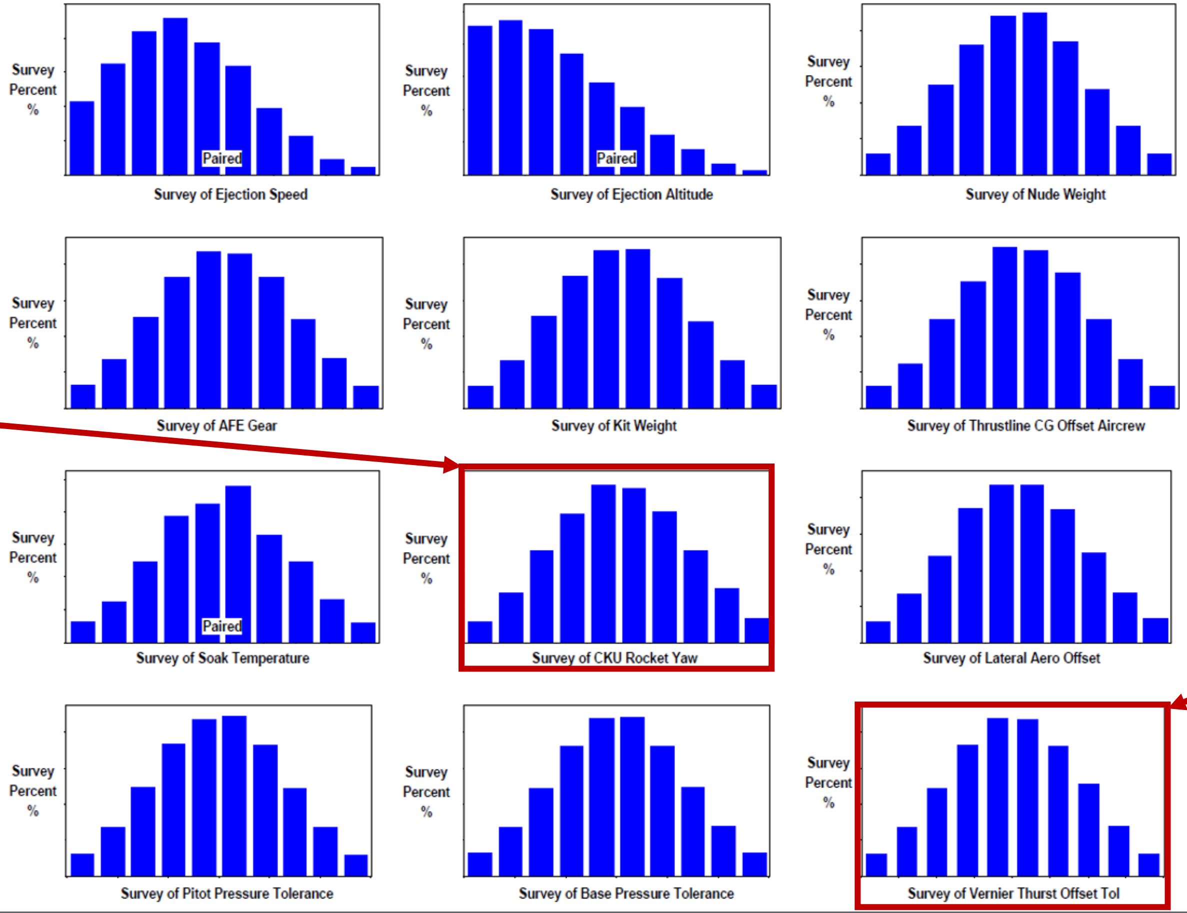
- Design parameters, specification control limits, and functional algorithms are modulated to establish optimized CAD/PAD (e.g., location, orientation, tolerances), sub-system designs, and overall system performance, while balancing this with verification testing considerations.

CAD/PAD device integration can be optimized with visibility to macro-effects of tolerances

EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION

CKU Sustainer Rocket Nozzle Thrust Offset Tolerance



Vernier Rocket Nozzle Thrust Offset Tolerance

Randomized variable distributions, such as PAD nozzle tolerance parameters, are used as the foundation for Monte Carlo digital twin simulations

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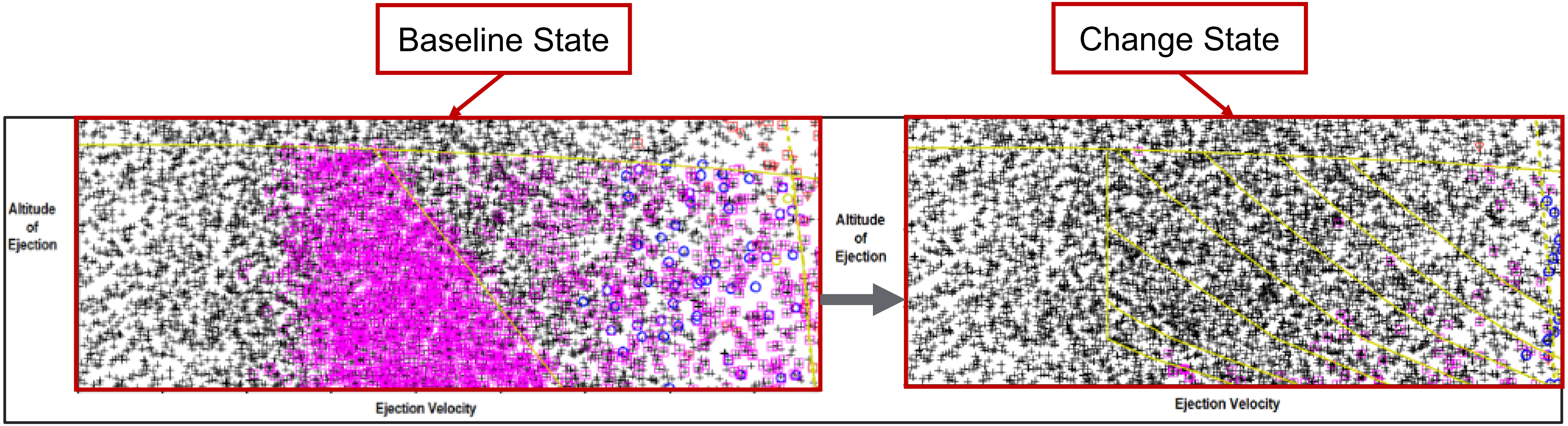
EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION

- Monte Carlo simulations of low computational-cost, high fidelity 6-DOF multi-physics models enable evaluating tens of thousand of ejection scenarios in minutes
  - Allows for rapid iteration of baseline and change state candidates to identify sensitivities & optimums

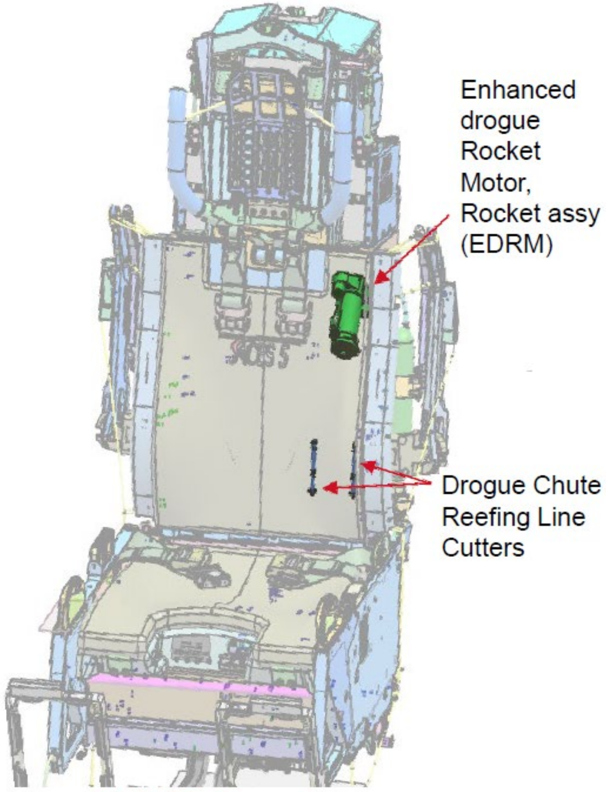


Multi-parameter optimization of candidate change states is enabled by rapid iteration & goal seeking in relation to key figures of merit, such as stability, clearance, and injury risk metrics

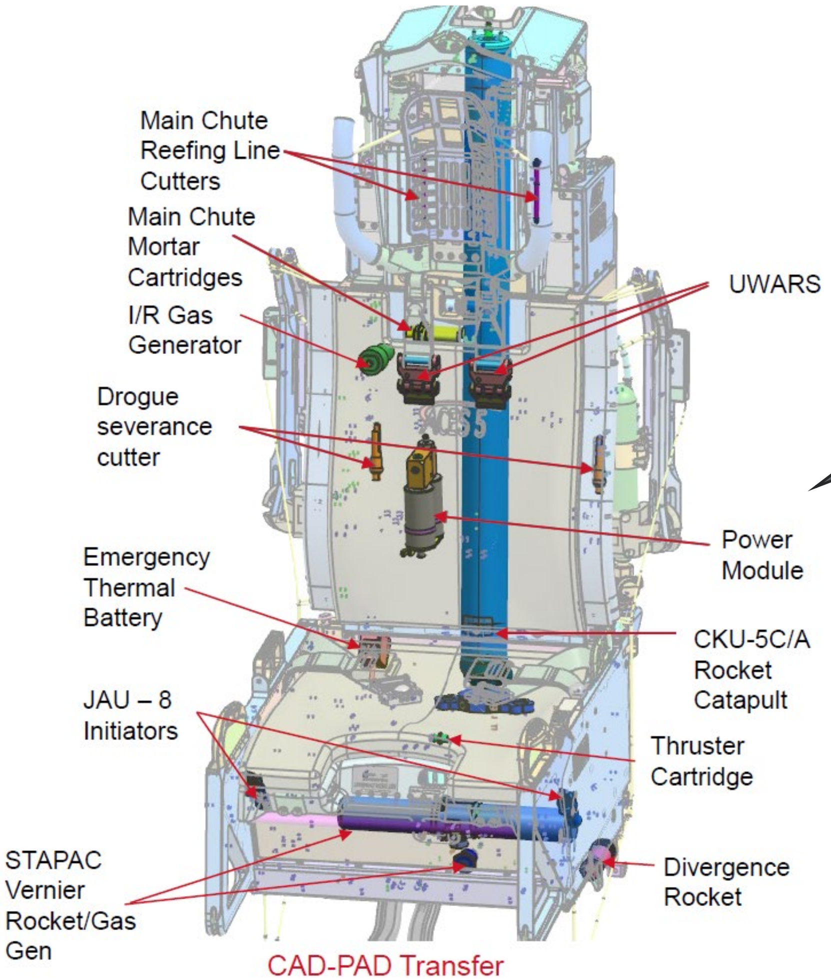
EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION

Retrofit kits require minimal newly manufactured CAD/PAD



CAD-PAD Carry Over



CAD-PAD Transfer

Nothing “new” to see here, maximize your useful life!

MBSE has enabled design optimization on NGES/ACES 5 using all existing qualified and fielded CAD/PAD

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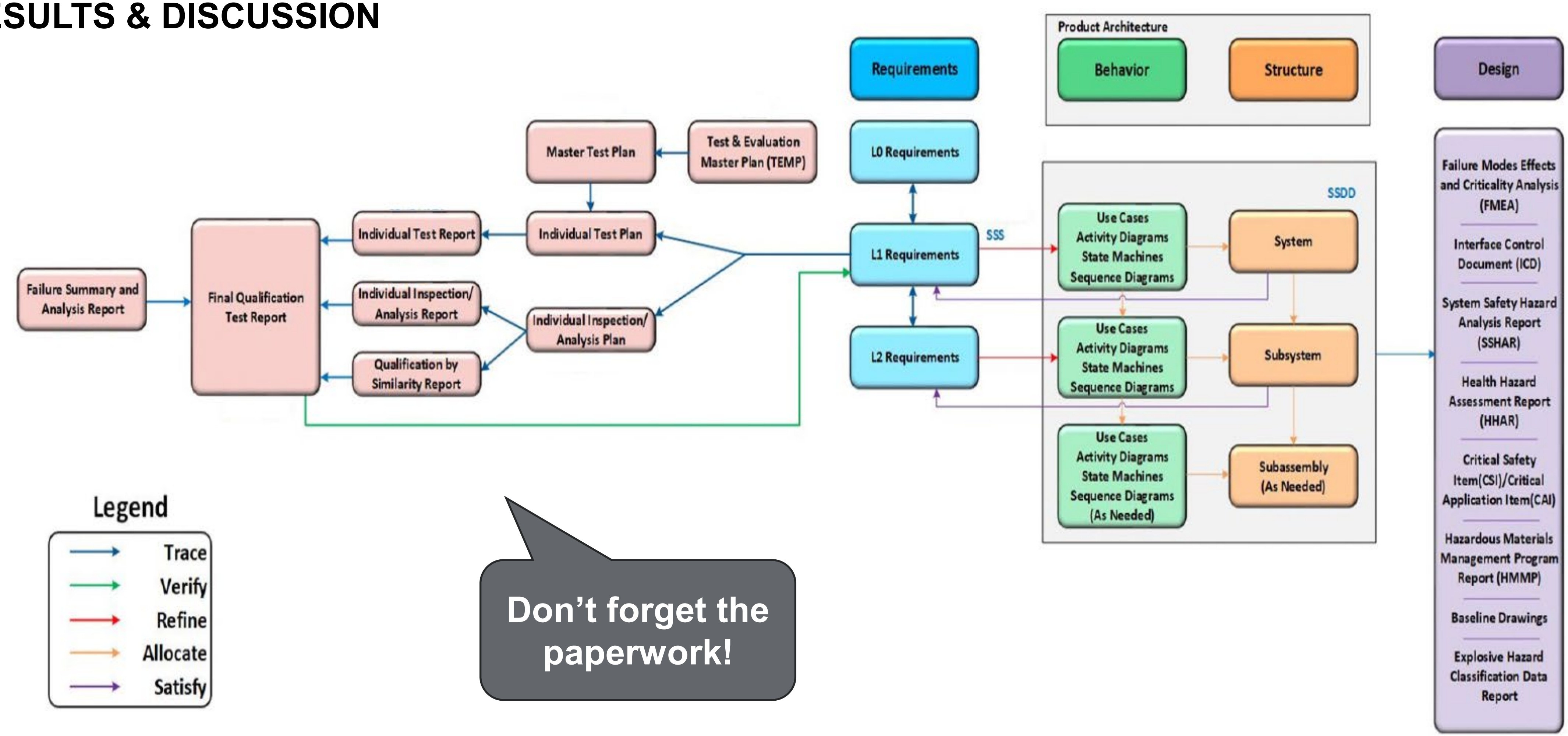
EJECTION SYSTEM CAD/PAD OPTIMIZATION

RESULTS & DISCUSSION



Traceability documentation ensures the design has satisfied all system requirements

ACKNOWLEDGEMENTS

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  - Sr. Technical Fellow — Aircraft Escape Systems, Collins Aerospace, Florida, USA
- **Mastrolia, Brad**; Contributor
  - Principal Engineer — Mechanical Design, Collins Aerospace, Colorado, USA
- **Miller, Brett**; Contributor
  - Principal Engineer — Systems Engineering, Collins Aerospace, Colorado, USA

QUESTIONS

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