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Utilization of Goal Function Trees for Robust Requirements Definition

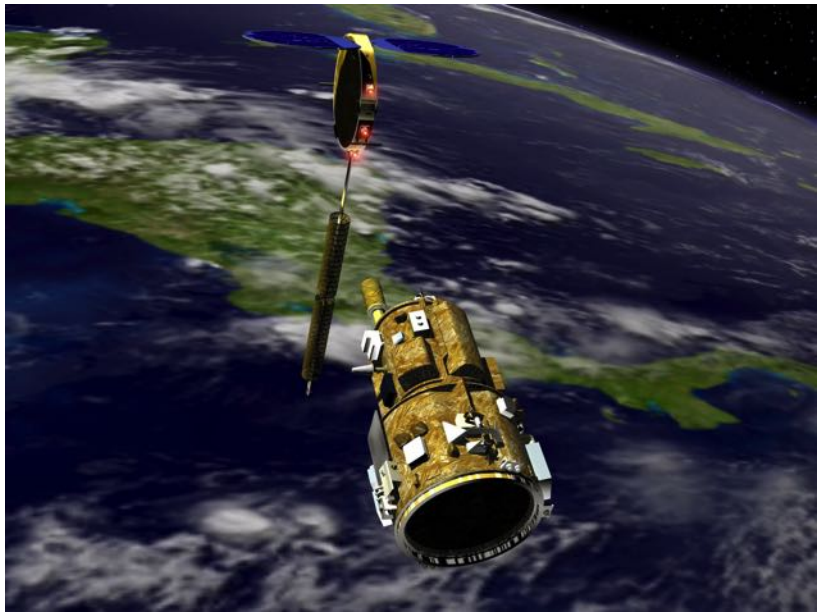
Robust systems

- Robust systems are characterized as “systems that have acceptable behavior over a larger class of situations than was anticipated by their designers”[1]
- Traditional requirements often fail to consider conditional and scenario requirements due lack of knowledge of how to organize the requirements[2]

System requirements are frequently inconsistent with or inadequate for system utilization.

Failure Cases DART

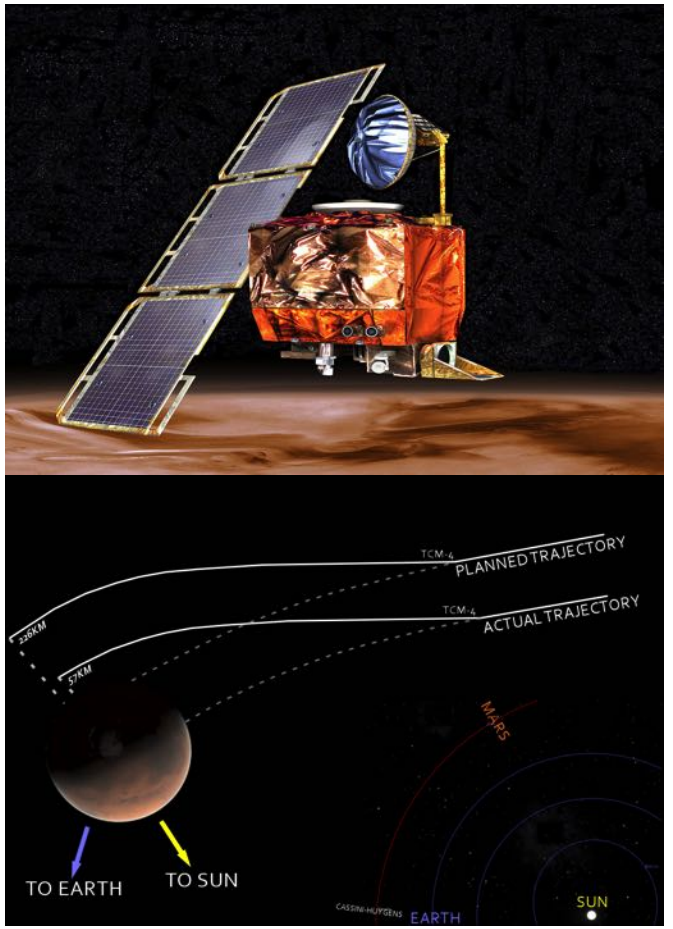
- Demonstration of Autonomous Rendezvous Technology (DART) was an autonomous satellite that had a mission of meeting up with another satellite but instead collided[3]



System lacking off nominal state for a creditable off nominal event.

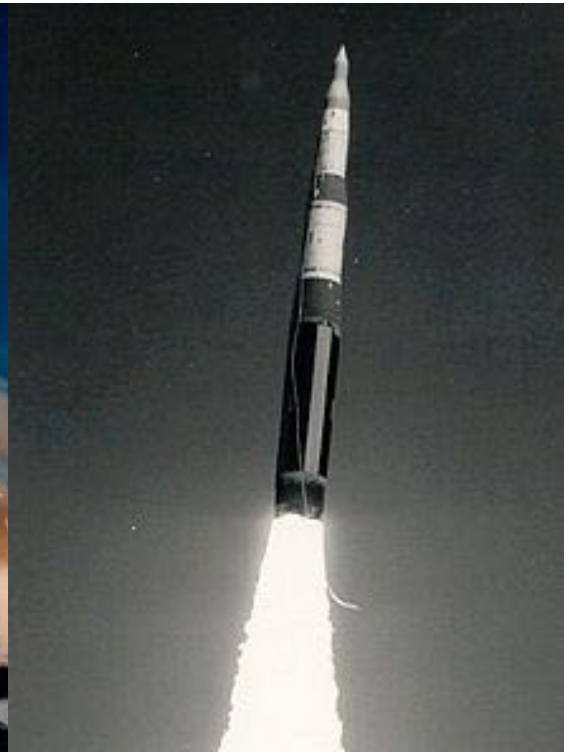
Failure Case MCO

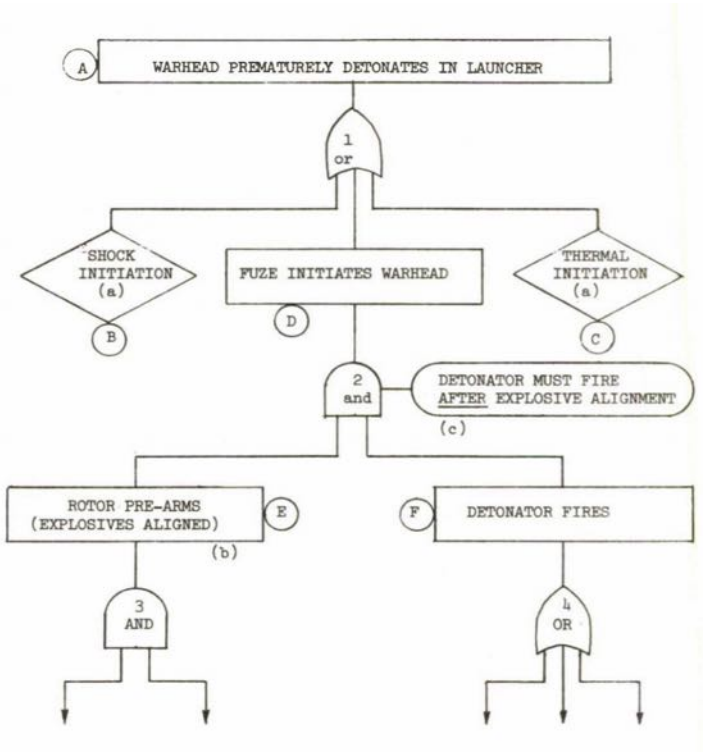
- Mars Climate Orbiter failed upon entering Mars' orbit with a trajectory of 170 kilometers below the planned insertion point[4]



Failure to prepare and understand the off nominal state.

Fault Trees

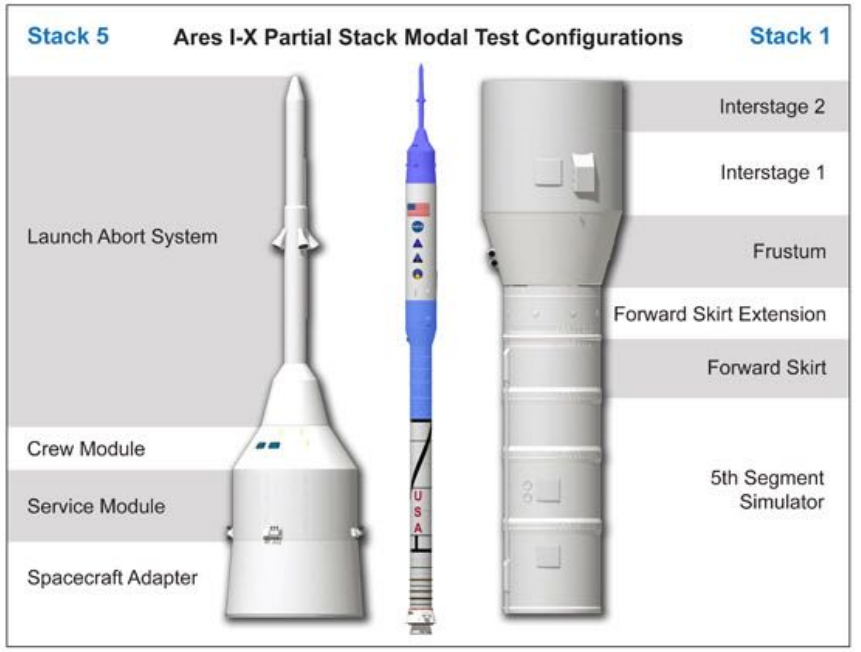




- Bell Laboratories created this method to study the Minuteman 1 Launch Control System[5]
- Hierarchical decomposition method of determining points of failure
- Resource straining task to cover all possible points of failure

GFT Origins

- Derived complications from defining abort conditions for the Ares I[6]
- Fault Trees, Event Sequence Diagrams, and Failure Modes and Effects Analysis entered a classification process to generate the Abort Condition List[6]
- Monitored Vs. Non-monitored condition[6]



New methodology required to capture downstream system events.

The Approach: Goal Function Tree

- Hierarchical decomposition of system goals and functions which integrates together to form the GFT[7]
- Traceability for the system's goals and requirements
- Nominal and Off Nominal Goals

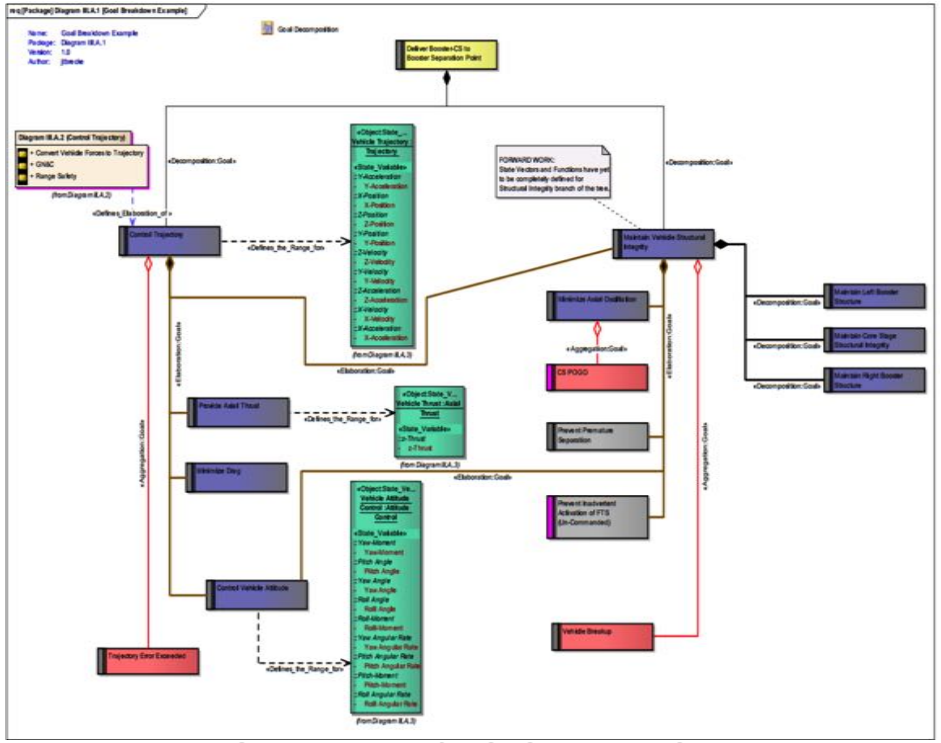
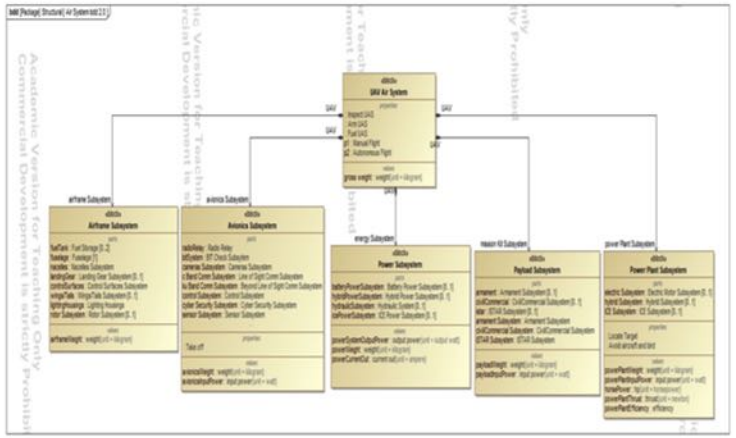


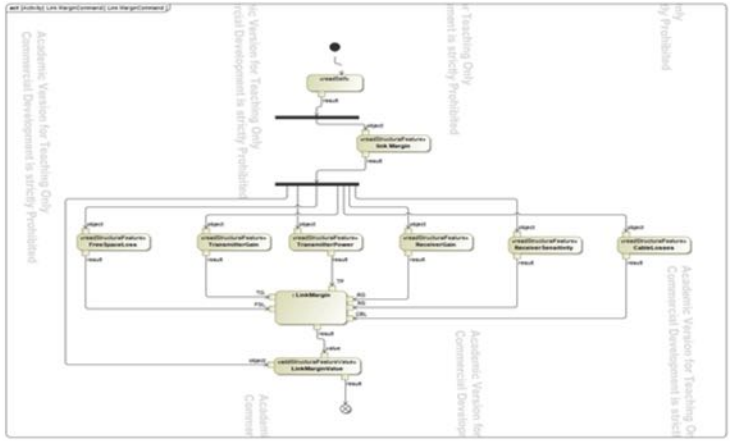
Figure: Goal Diagram for SLS Booster Separation Point

Engineers must understand the transition to the off nominal state and actions in such state.

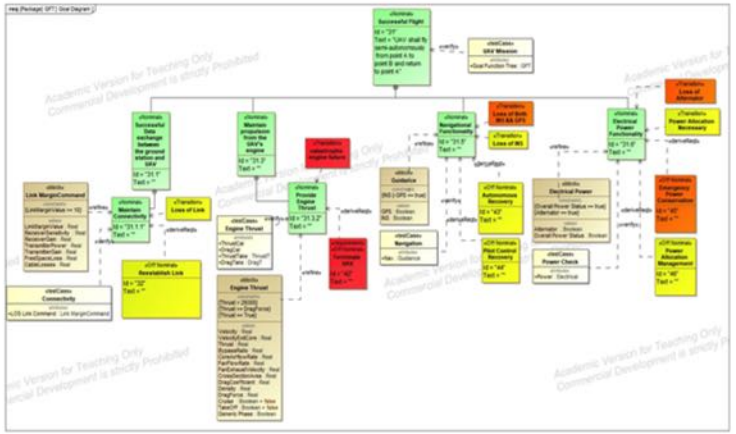
Model Based System Engineering



Structure



Behavior



Requirements

bandwidth : Bandwidth {B...	A5 : Bandwidth@19d96093
engine Thrust : Engine Th...	A2 : Engine ThrustT@623508e8
engine ThrustC : Engine T...	: Engine ThrustC@76852891
fuel to Air Ratio : Fuel to ...	A1 : Fuel to Air Ratio@17141592
link Margin : Link MarginC...	A3 : Link MarginCommand@3fc7080a
CableLosses : Real	27.0000
FreeSpaceLoss : Real	130.0000
LinkMarginValue : Real	14.6000
ReceiverGain : Real	18.0000
ReceiverSensitivity : R...	88.3000
TransmitterGain : Real	28.3000
TransmitterPower : Real	37.0000
link MarginRecieve : Link ...	Link MarginRecieve@31568de9

Simulation

GFT Illustration

Mission :

- UAV semiautonomous flight

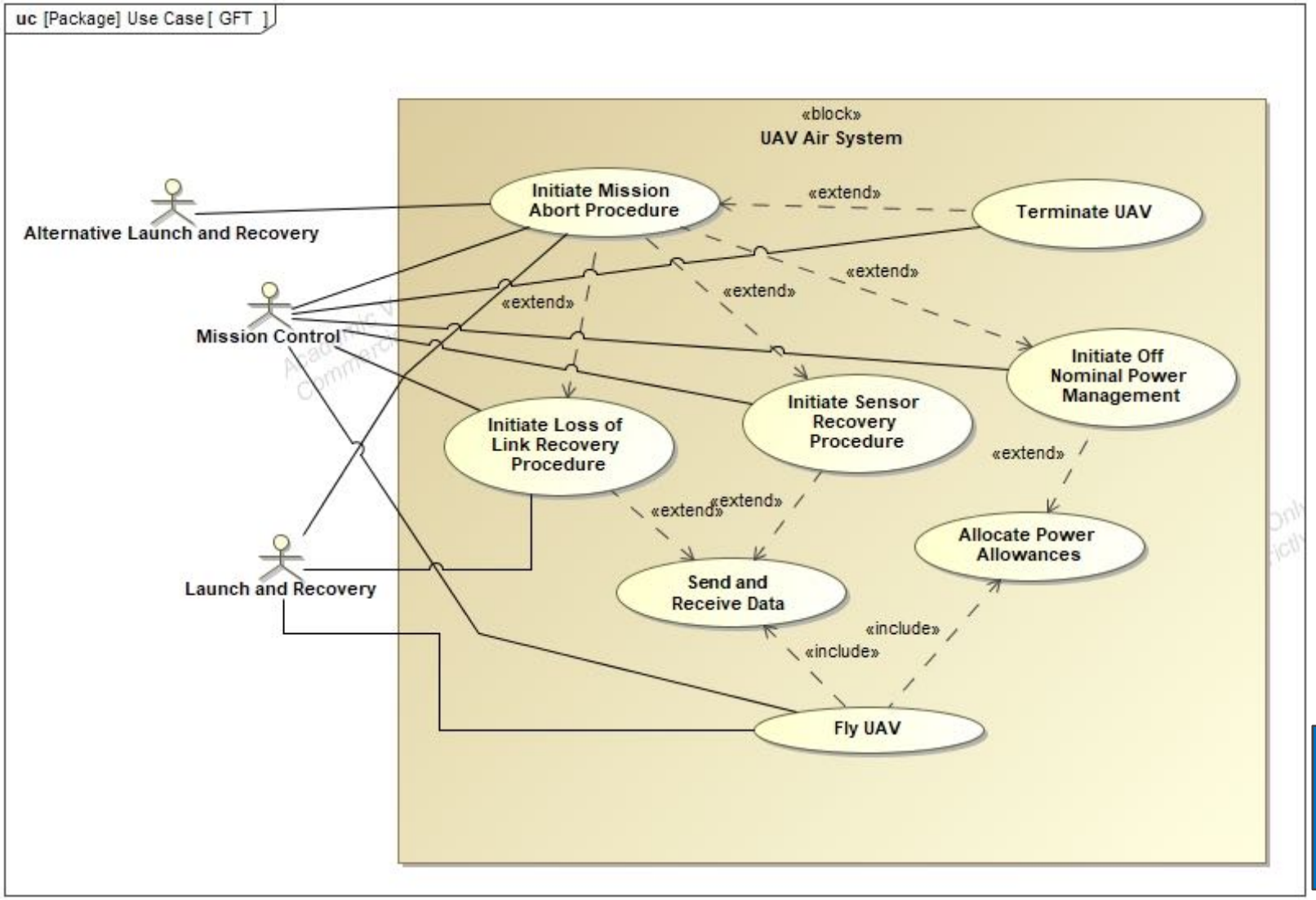
Goal:

- Take off from point A and fly to point B back to point A

Secondary Goals:

- Successful data exchange between ground and UAV
- Maintain propulsion from UAV's engine
- Navigational Functionality
- Electrical Power Functionality

Use Case Diagram

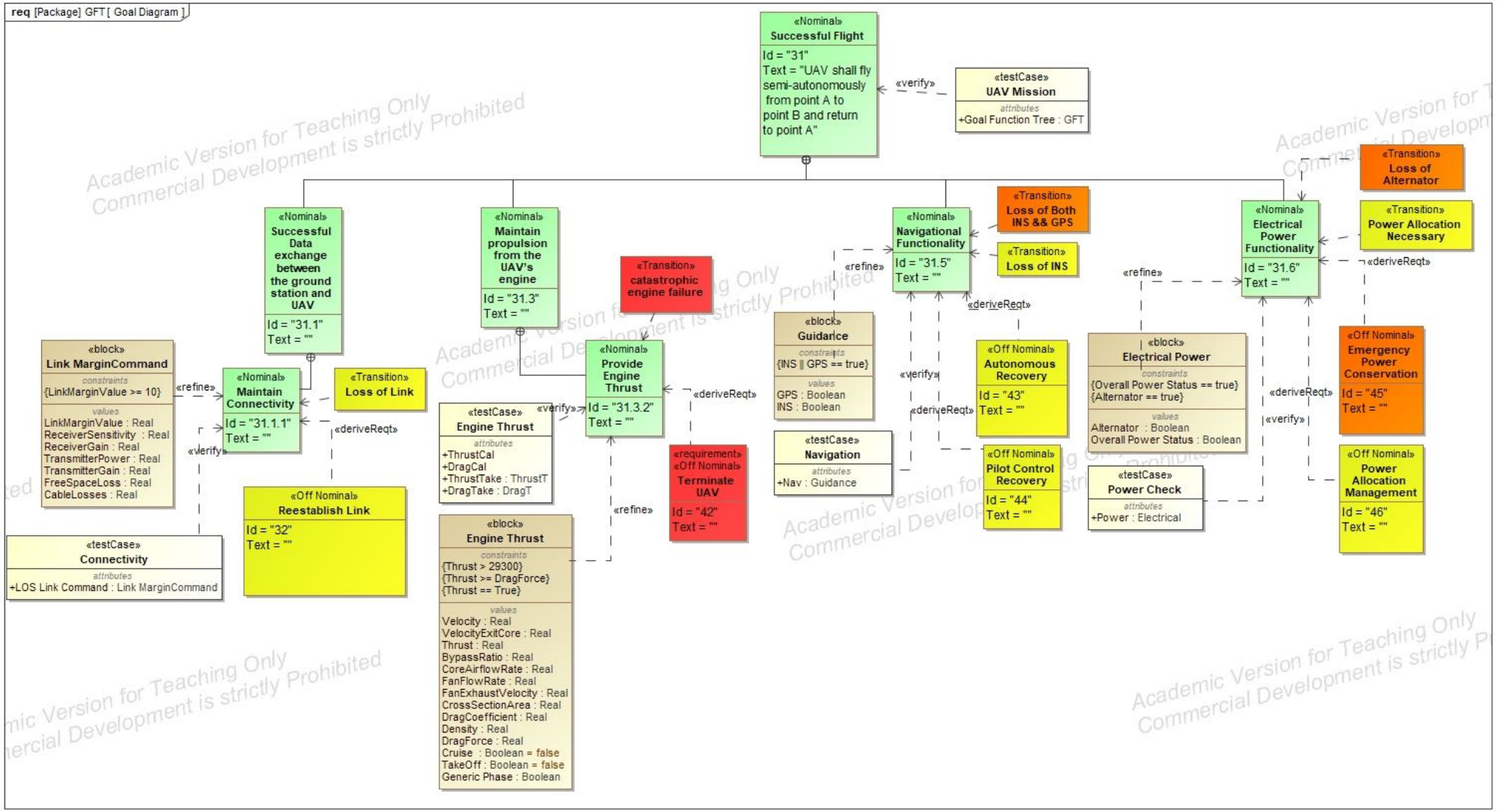


System operation during mission phase.

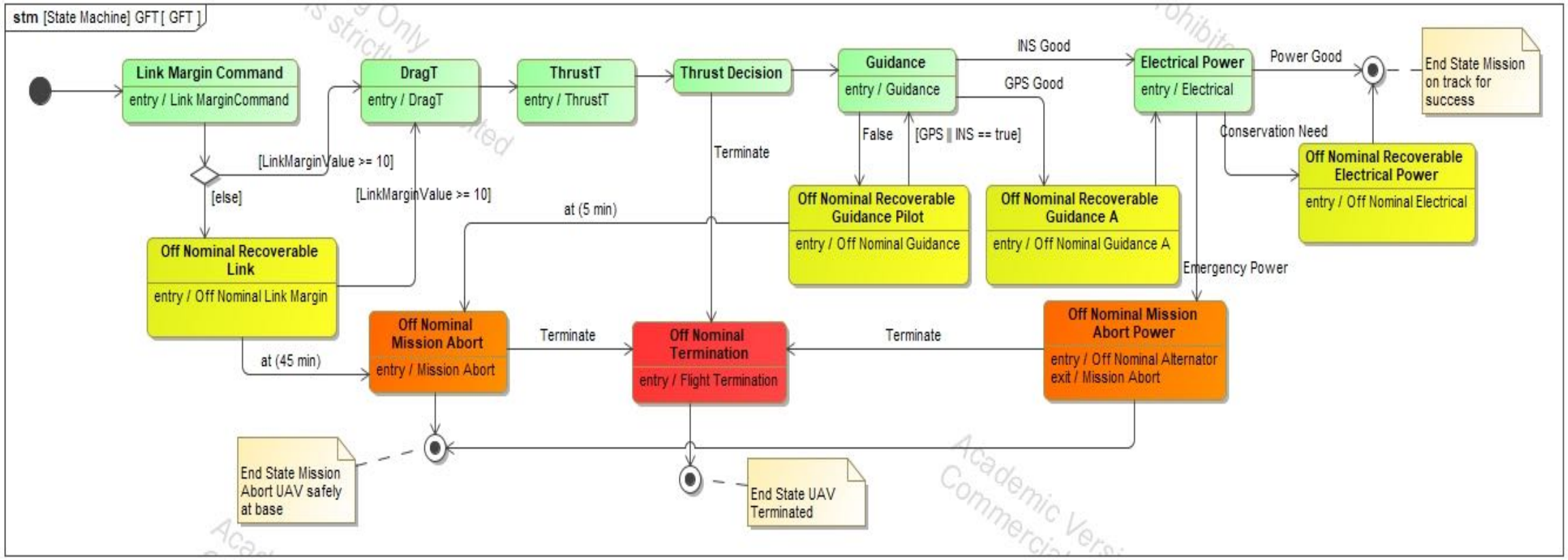
Off Nominal Functions

- Off Nominal Recoverable
  - Activate management of subsystem with the new goal of mitigating off nominal event
- Off Nominal Mission Abort
  - Non common mission critical components goes off nominal causing new goals of aborting the mission and returning to base.
- Off Nominal Termination
  - Flight computer or operator triggers the new goal of a forced crash in an ideal location on the way back to base

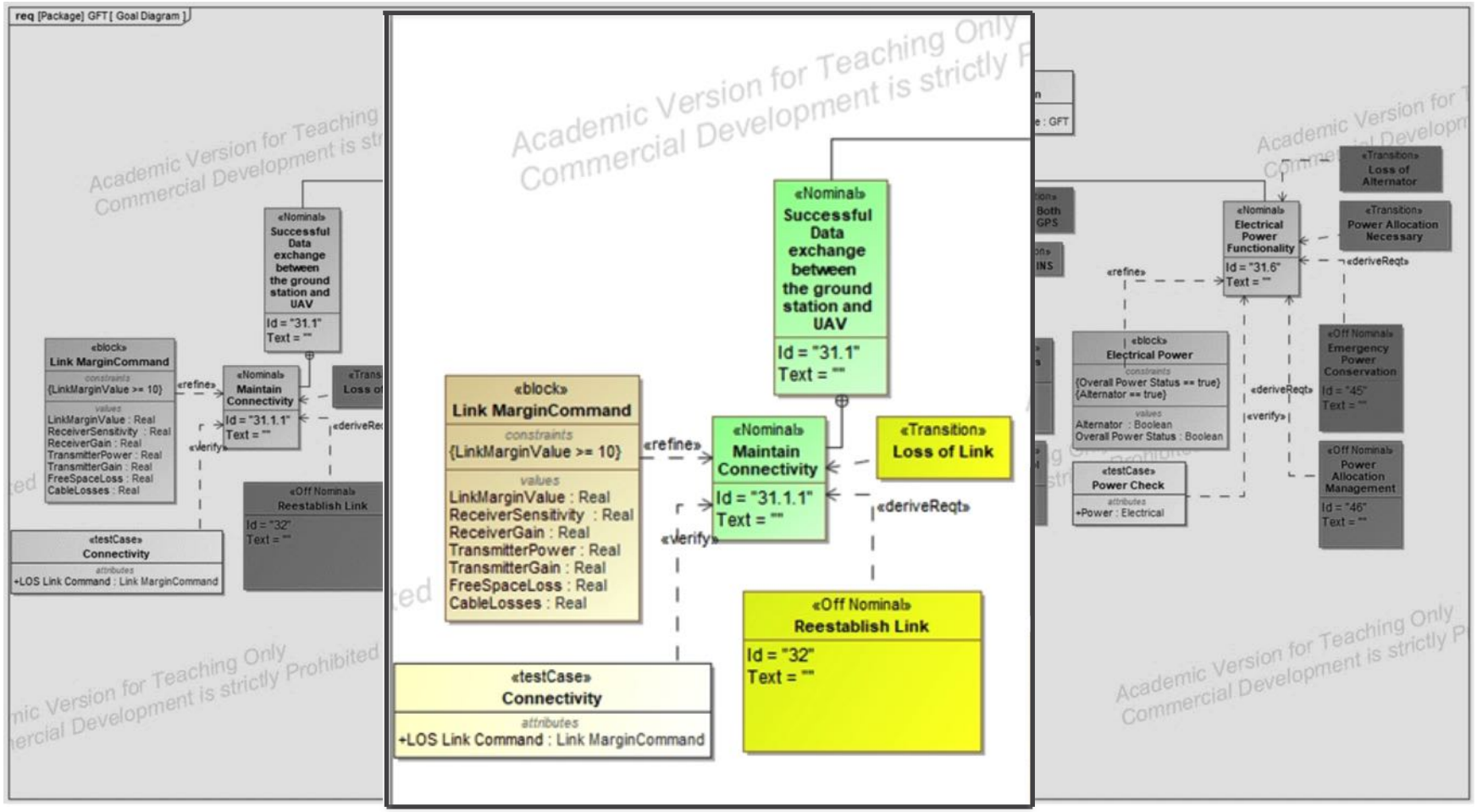
Goal Diagram



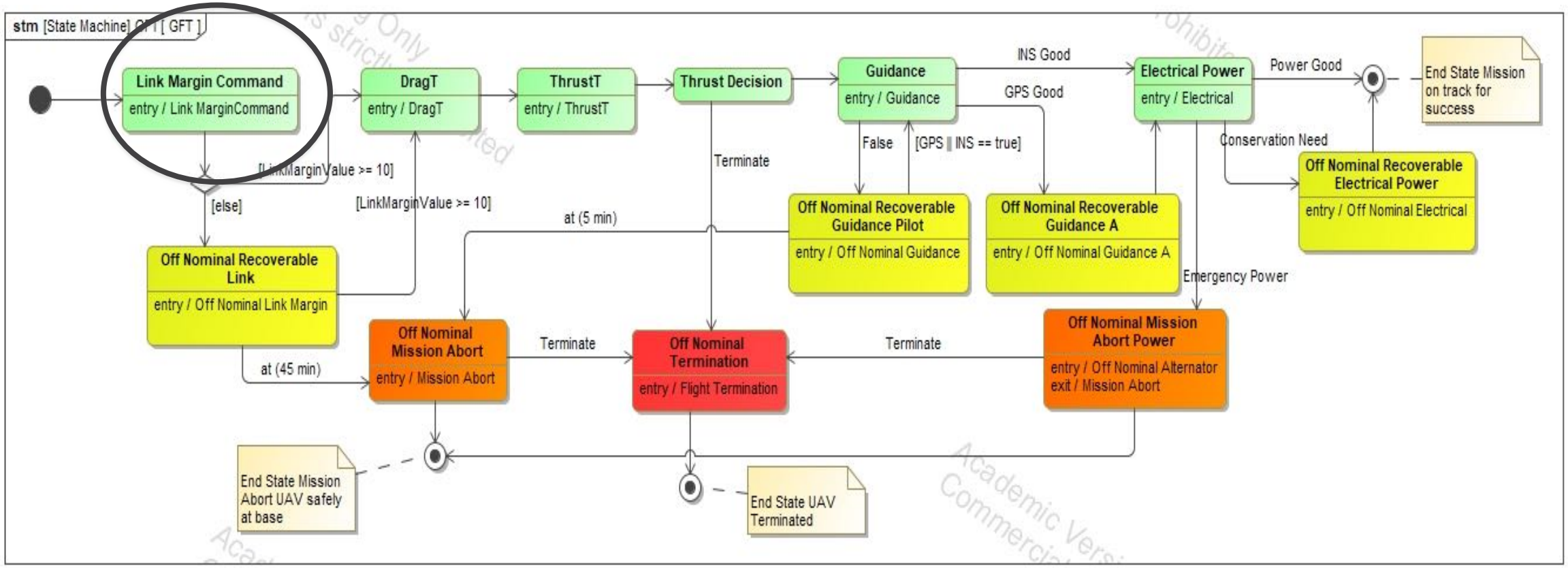
Functions Diagram



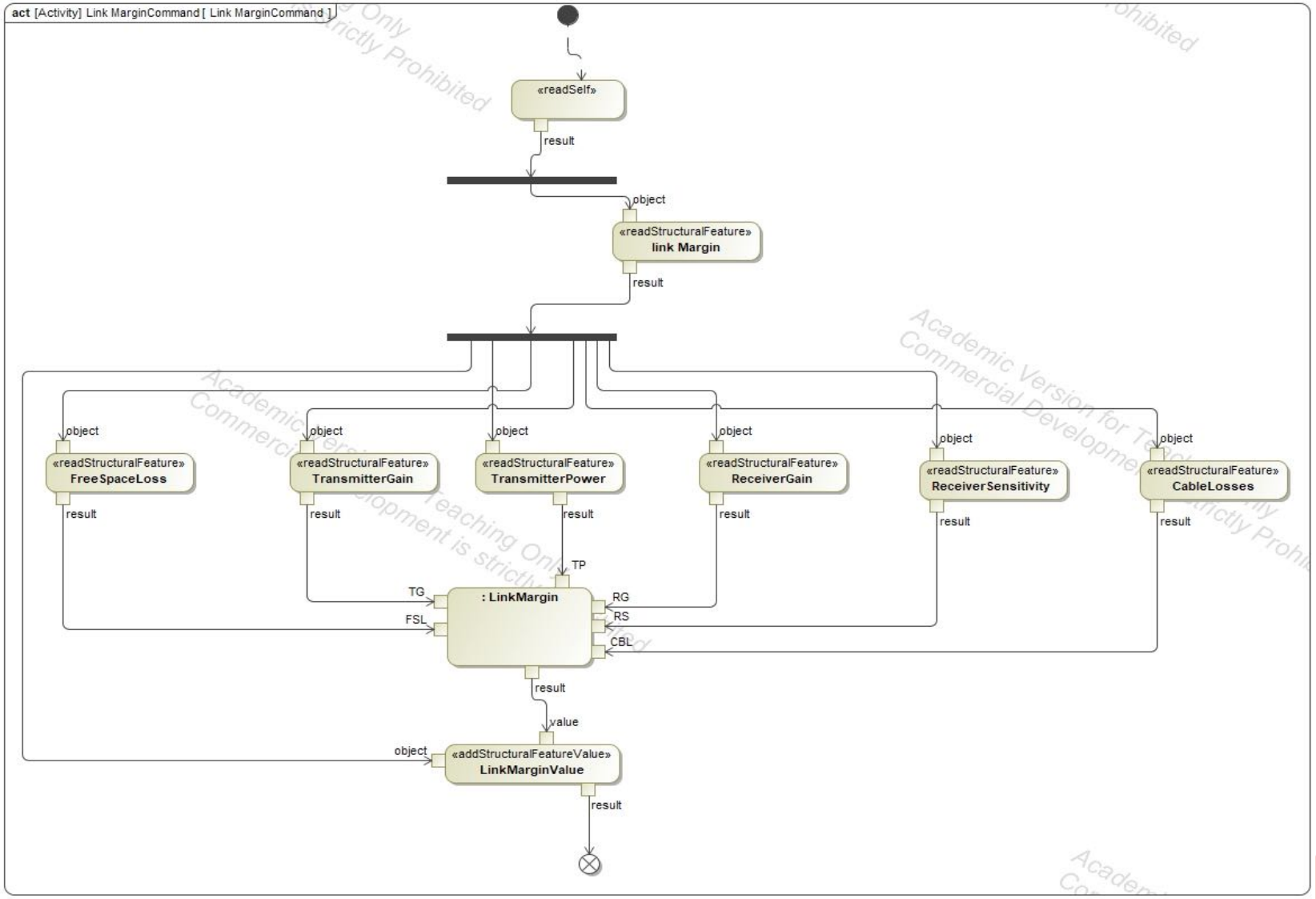
Link Traceability



Nominal Link Function

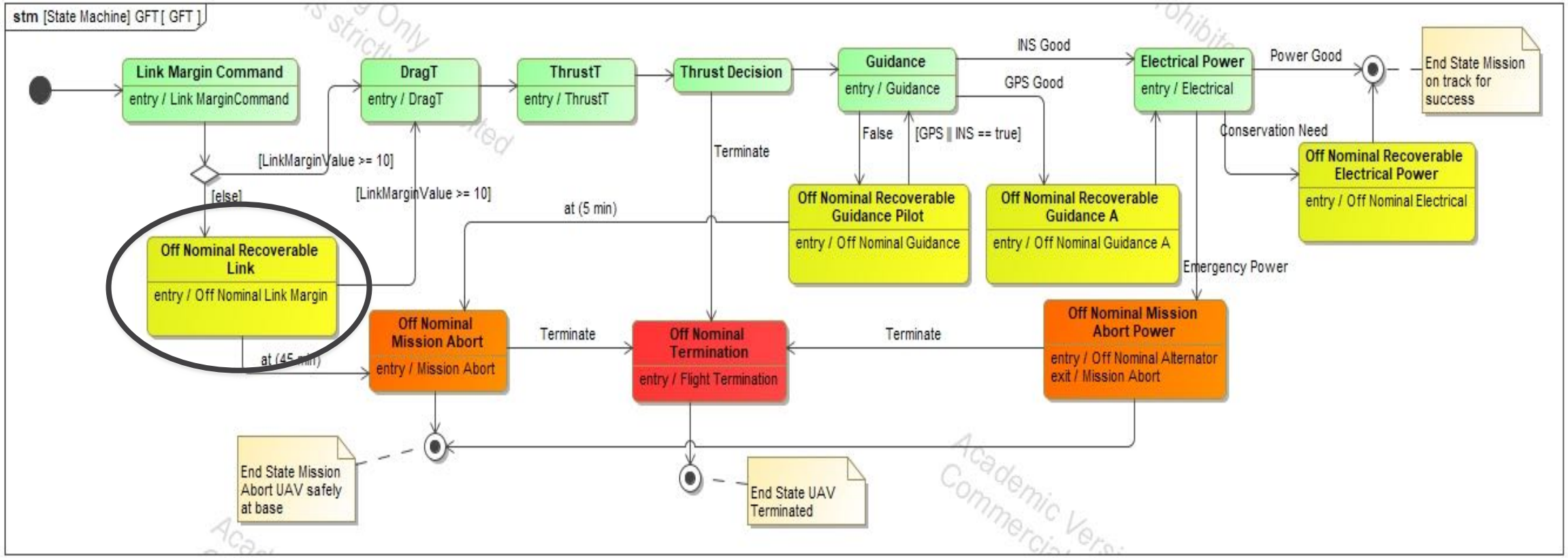


Nominal Link

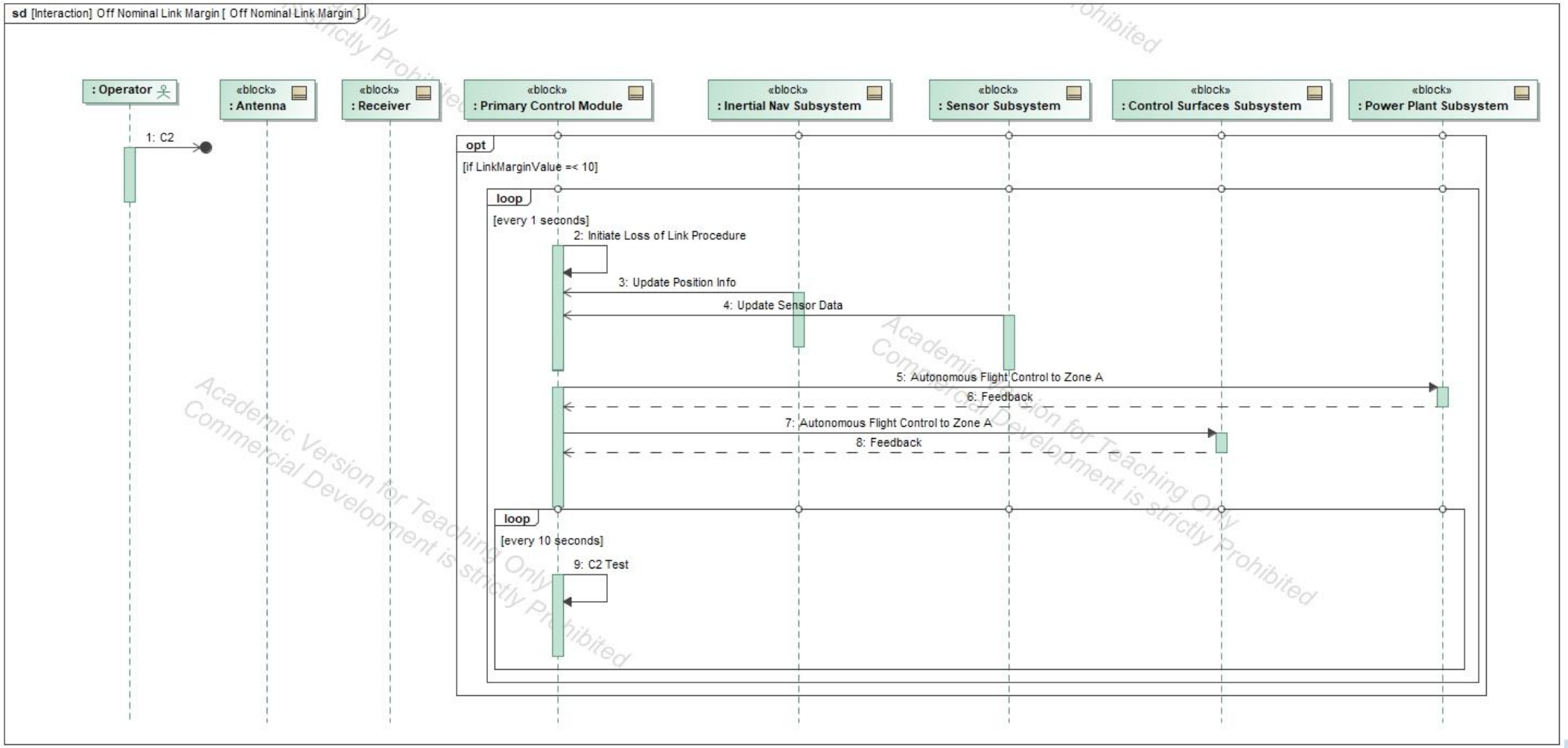


Calculation of link value.

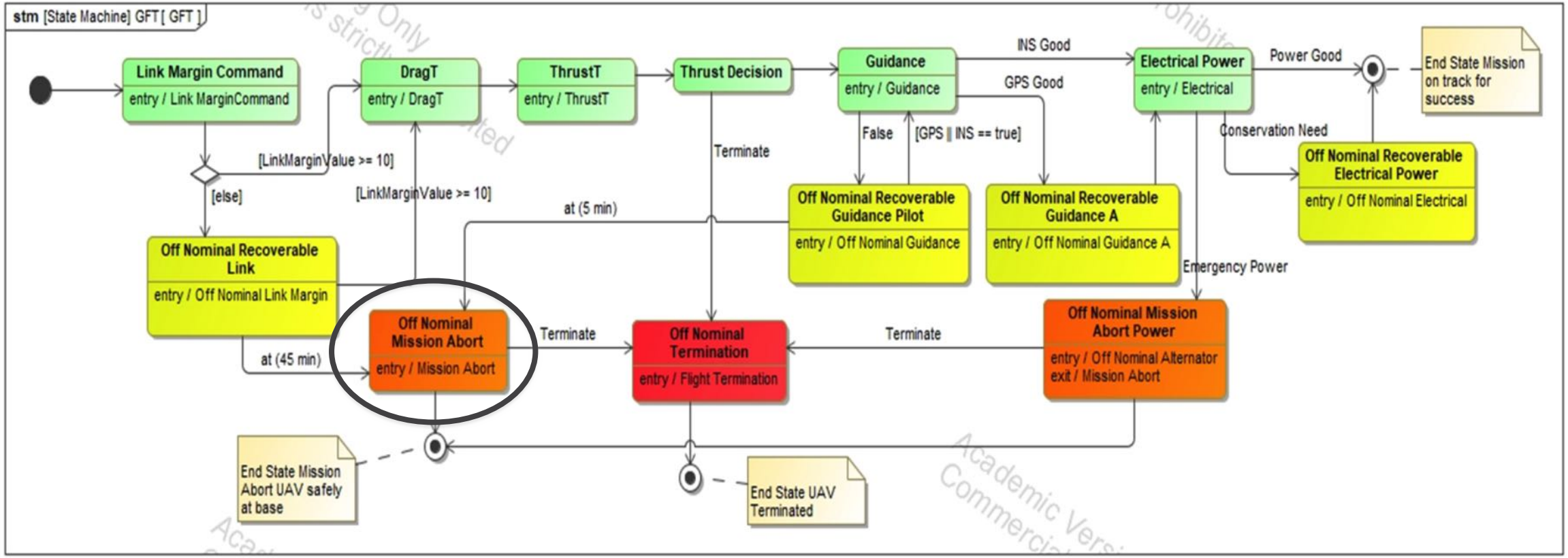
Off Nominal Recoverable Link



Off Nominal Recoverable Link



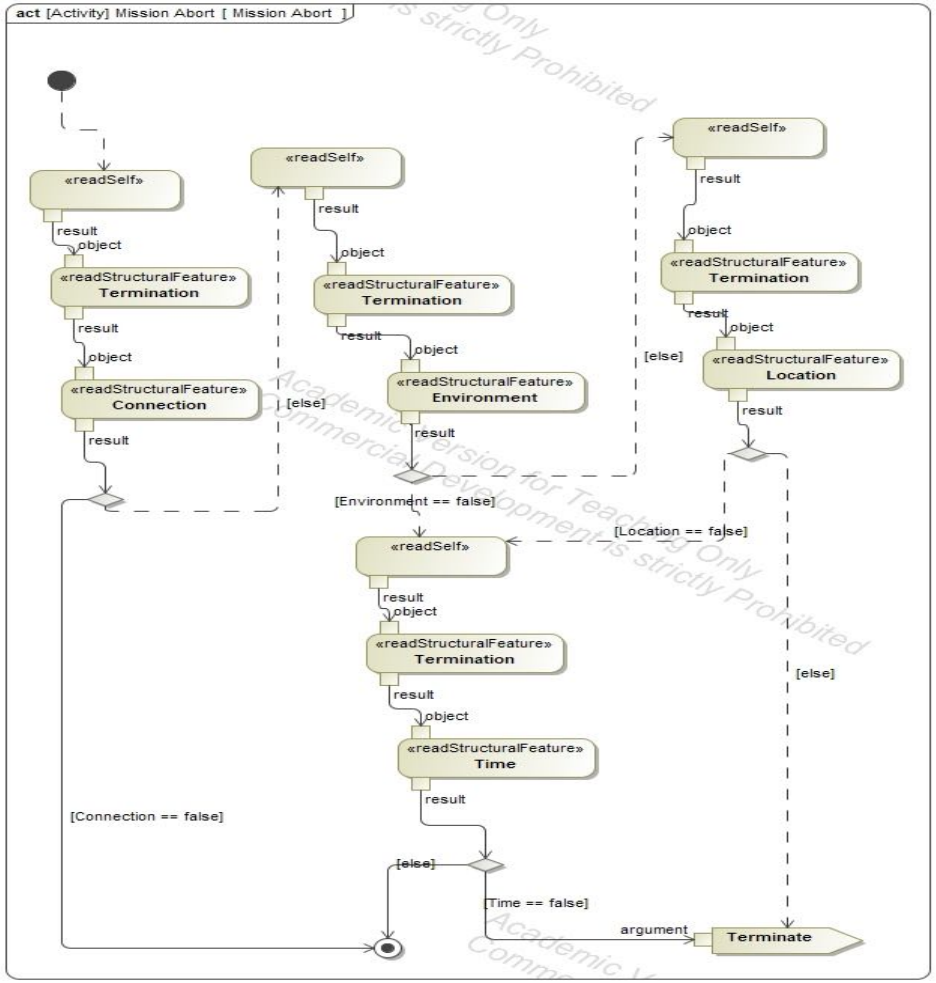
Off Nominal Mission Abort



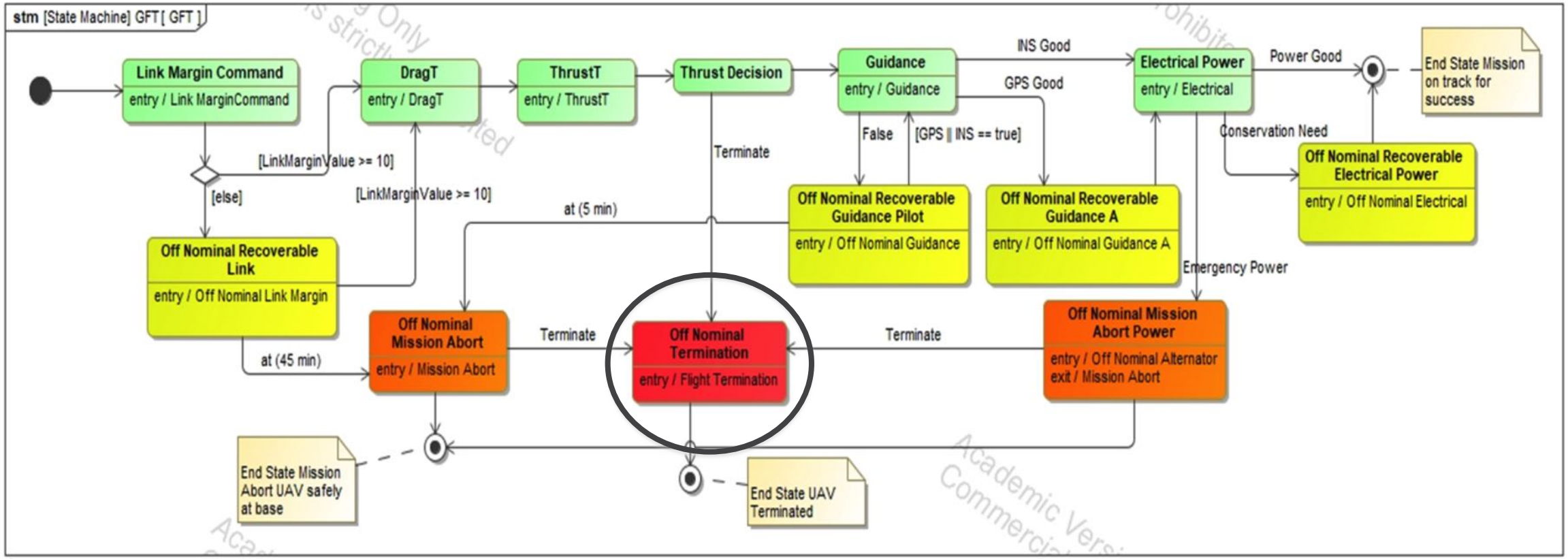
Off Nominal Mission Abort

Termination Criteria

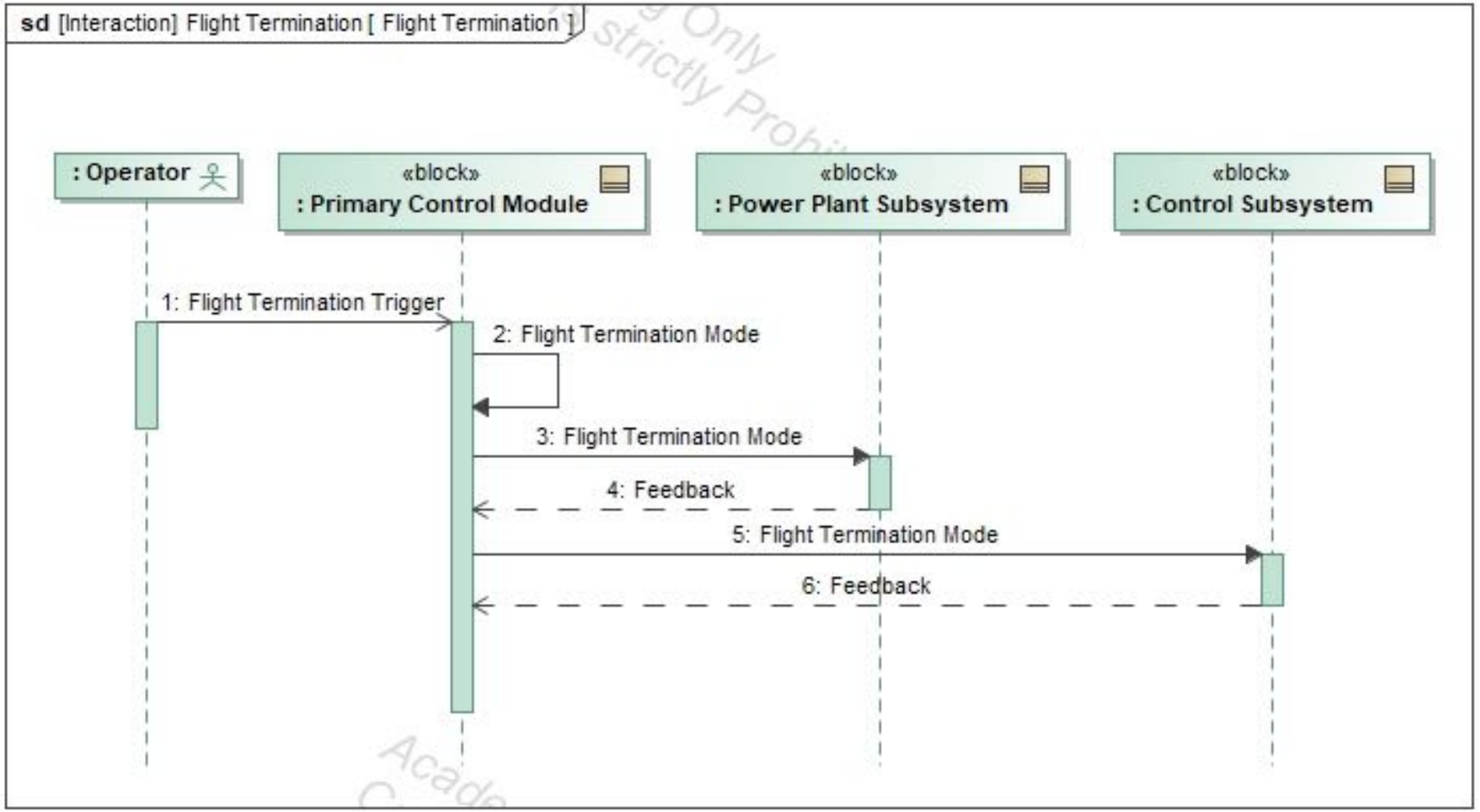
- Connectivity
- Environment
- Location



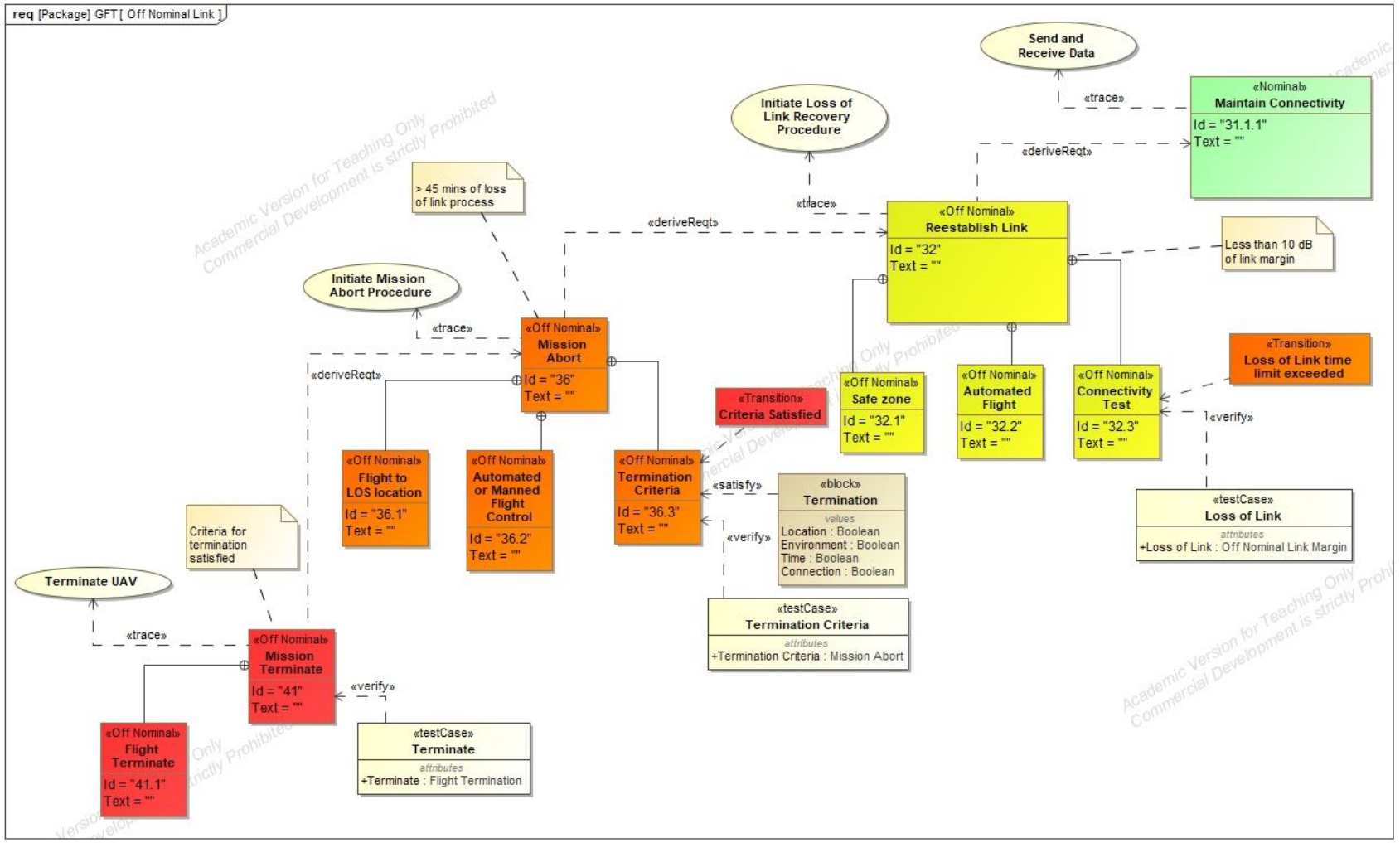
Off Nominal Flight Termination



Off Nominal Flight Termination



Loss of Link Off Nominal



System Development[8]

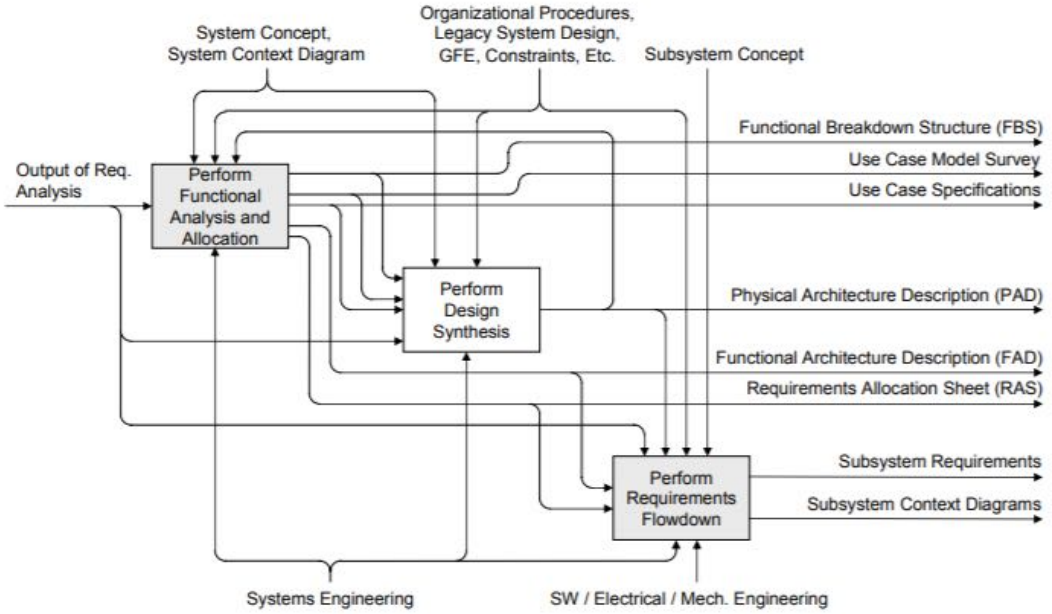
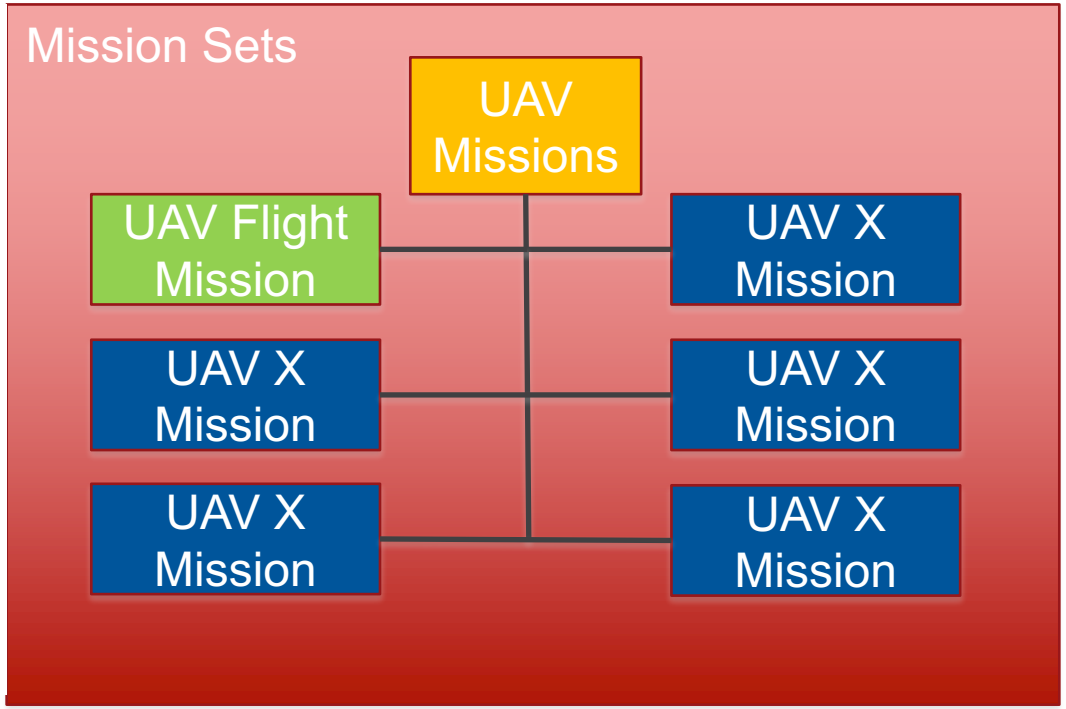


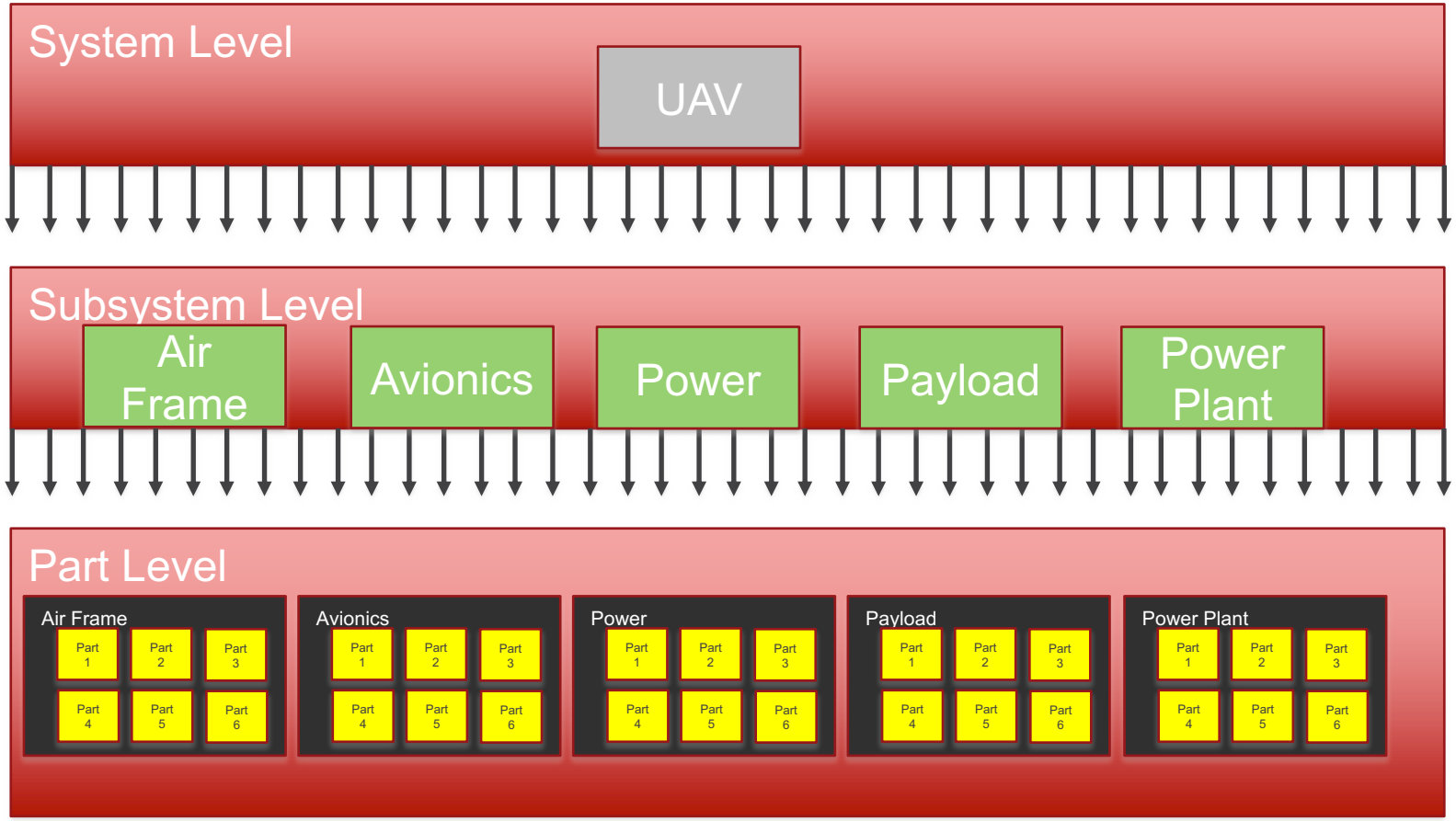
Figure 1. Context diagram for the FAR approach in IDEFØ.

System Development Flow Down

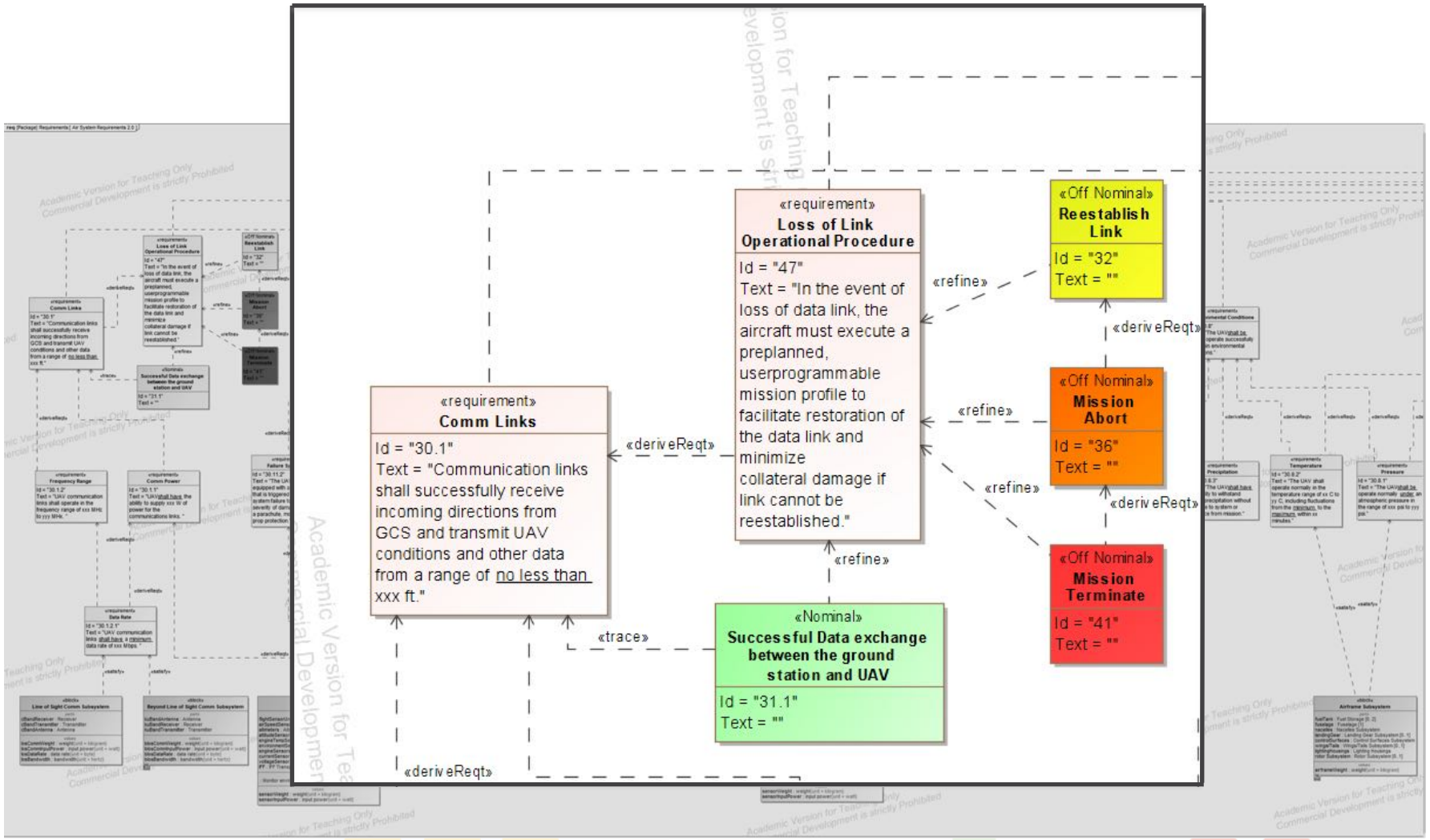


Top Level UAV Goals

Requirements Flowdown

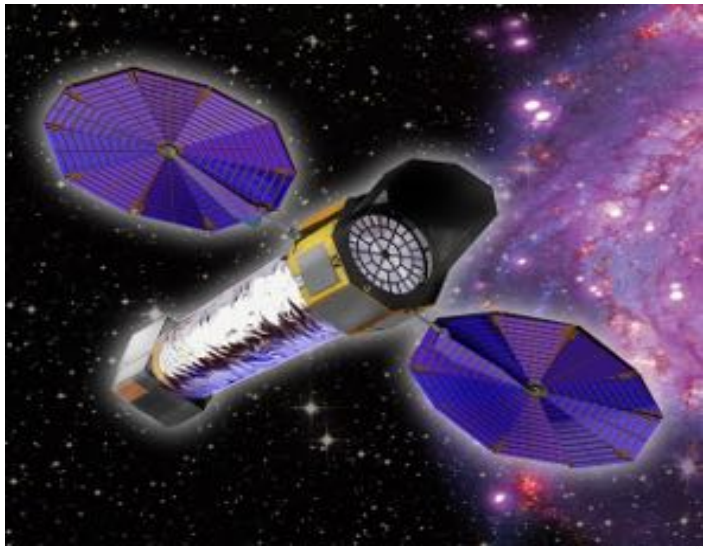


Goals to System Requirements

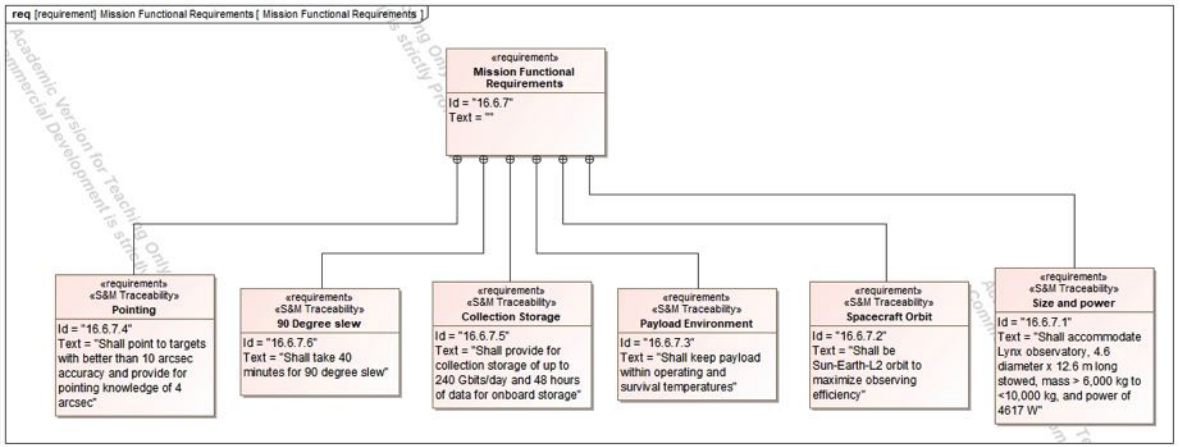


Future Work

- Lynx X-ray Observatory
- Identify nominal and off nominal “day in the life” operations
- Identify the types of requirements the GFT promotes



Capture system behaviors to satisfy existing requirements and identification of new requirements.



Conclusion

- MBSE instrumental in the identification system behaviors
- Application of GFT methodology to identify goals of the system
- Allocation of goals to requirements to identify missing and off nominal requirements

: Constraint(s) {LinkMarginValue > 10} owned by Link MarginCommand failed.
: Requirement Maintain Connectivity is not satisfied.
: Constraint(s) {Thrust > 29300} owned by Engine ThrustT failed.
: Requirement Provide Engine Thrust is not satisfied.
: Constraint(s) {Bandwidth == true} owned by Bandwidth failed.
: Requirement Maintain Connectivity is not satisfied.
: Constraint(s) {LinkMarginValue > 10} owned by Link MarginRecieve failed.
: Requirement Maintain Connectivity is not satisfied.

References

[1] Sussman, Gerald Jay. "Building robust systems an essay." Massachusetts Institute of Technology (2007).

[2] Sage, Andrew. Systems Engineering: Analysis, Design, and Development. Wiley, 2016.

[3] Thomas, Dale. Selected systems engineering process deficiencies and their consequences. ACTA Astronautica, 2007.

[4] Mars Climate Orbiter Mishap Investigation Board Phase I Report. National Aeronautics and Space Administration, 1999.

[5] Larsen, Waldemar F. *Fault Tree Analysis*. p. 80.

[6] Pisanich Greg, Bajwa Anupa, Sanderfer Dwight. The Ares I Abort Failure Detection, Notification, and Response System: An Overview of the Development Process.

Institute of Electrical and Electronics Engineers, 2007.

[7] Johnson, Stephen B. Goal-Function Tree Modeling for Systems Engineering and Fault Management. AIAA, 2013.

[8] Eriksson, Magnus, et al. “7.2.2 Performing Functional Analysis/Allocation and Requirements Flowdown Using Use Case Realizations - An Empirical Evaluation.” *INCOSE International Symposium*, vol. 16, no. 1, July 2006, pp. 965–79.

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CSIL

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ISEEM

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RSESC

Rotorcraft Systems Engineering and Simulation Center