Model Based Spacecraft Operations and Anomaly Resolution

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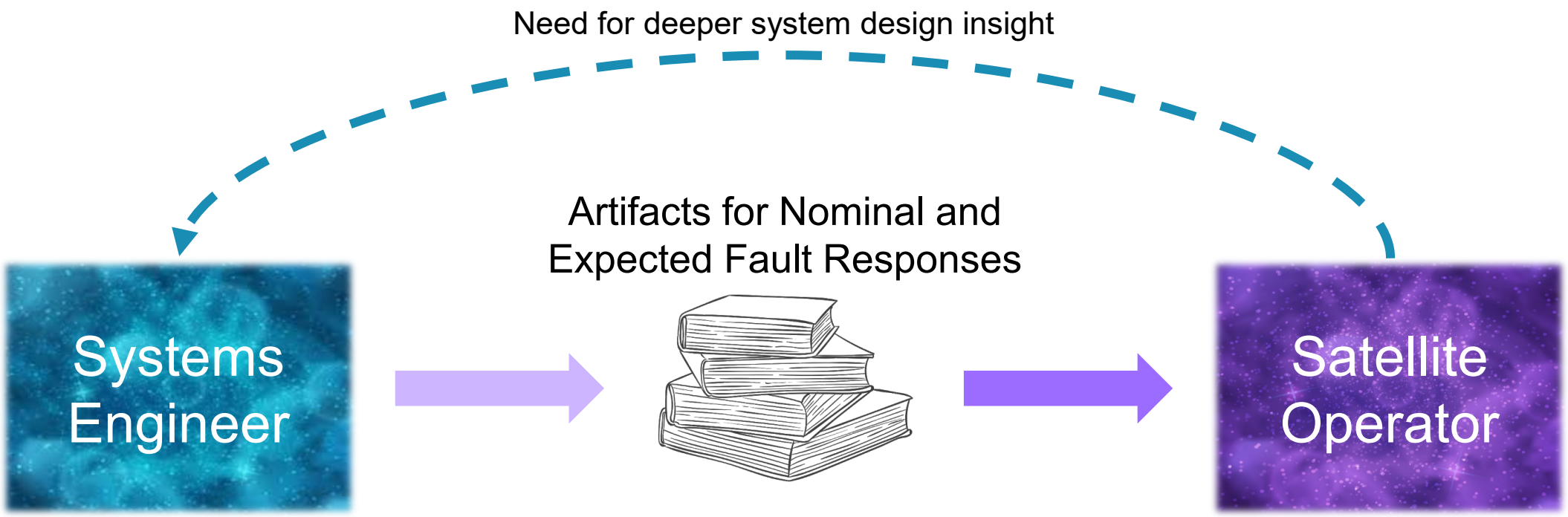
Background

Setting the Stage



Finding accurate system design information in a timely manner is a challenge that could result in mission delays and limitations on operational resilience.

Purpose of Effort

Investigate whether early investment in MBSE could be reused to support operations community

Program Experience
STPSat-5
Significant amount of time digging up anomaly information and reliance on specific individuals

↓

FY20: MBOAR Survey
Investigate whether MBSE can be used to facilitate information access/transfer to operators

↓

FY21: MBOAR Prototype
Refine a prototype capability to isolate anomalies based on telemetry feeds

Scope:

- *Moment of information hand-off between developers and operators*
- *Day-to-day activities of operators*
  - *Anomaly Resolution, etc.*

Perform a minimum of the following:

1. *General interest and perceptions of MBSE from past operators*
2. *Use Cases of interest to the operator community*
3. *Limits of using an MBSE tool (Cameo)*

Agenda

1. Description of Investigation Results
2. Description of Aerospace Implementation
3. Limitations and Lessons Learned

Traditional systems engineering artifacts are not produced with spacecraft operators in mind, so significant effort is required to produce additional documentation to facilitate operations.

Investigation Results

Perceptions, Concerns, and Use Cases of using System Models for Operations

Perception:

- *Interested to Skeptical*

Concerns:

- *Scale of program*
- *User Experience (Human-Machine interaction)*
- *Trust in the tool and suggested responses*

Use Cases:

- *Access historical anomalies/information*
- *Provide physical or functional context for an anomaly*
- *What-If scenarios for commands*
- *Synchronize Operator Handbook (mitigations) to model (i.e. changes to model are propagated to handbook)*

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2	6-svCust	SV Owner/Customer	See a dashboard of operational capability (e.g. during	I can follow the transition from I&T to operations without learning a new	0-Neutral	2-Medium
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17	6-svCust	SV Owner/Customer	Perform what if scenearios if a failure happens.	I can determine the impact to the system if a particular failure occurs or a capability is lost.		

**Full list of Use Cases from Operator Interviews can be found in Back-Up Slides*

Ground Operator

I want to…

See the source of telemetry measurands on a functional view diagram

So that…

I can quickly make sense of a telemetry signature

System Engineer

I want to…

Generate a fishbone diagram that accurately portrays the design of my system at various levels

So that…

I can organize and focus anomaly resolution efforts without re-creating design schematics

Focused Use Case implementation on visualizing anomalies for operators given a model provided by a different set of engineers and designers.

Operator Use Case Workflow

Leverage design engineer models to support Operators when addressing an anomaly

Telemetry Readings
(Analysis Triggers)
1

Telemetry Selection

Radio Buttons
- Sensor 1
- Sensor 2
- Sensor 3
- Sensor 4

Button
Generate Mitigation Strategies

2

System Model
(Database of Objects and Relationships)

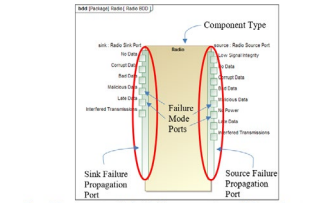


Figure 2 Component type block with failure propagation and failure mode ports

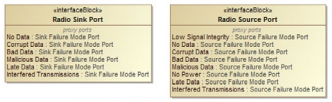
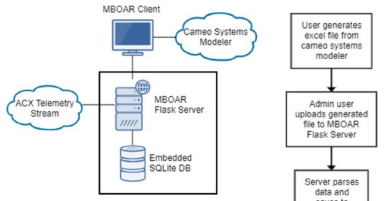


Figure 3 Interface blocks type the source and sink ports

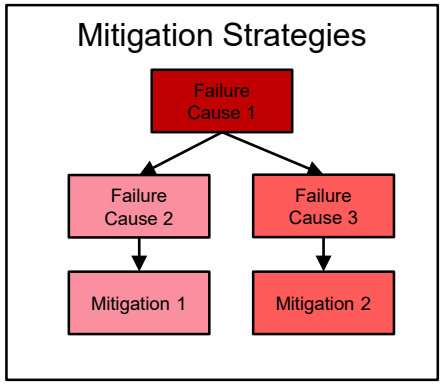
3

Failure Propagation Analysis
(Analysis)
4



5

Structured Diagram
(Visualization)
6



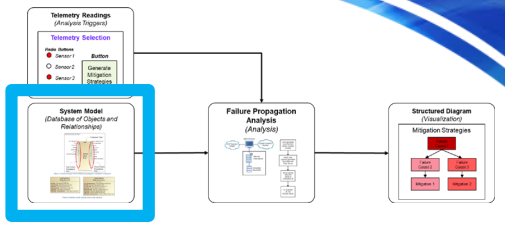
Description of Steps:

1. *Anomalous telemetry identified*
2. *Anomalous telemetry initiates analysis process*
3. *System failure modes provided by System Model*
4. *Synthesis of telemetry and failure modes*
5. *Failure propagation paths visualized for operator*
6. *Human-Machine interactions for mitigation options*

The System Model is leveraged as a relational database of failure modes and propagation paths that an external tool can access for a more holistic understanding of an on-orbit event.

Aerospace Implementation – 1 of 5

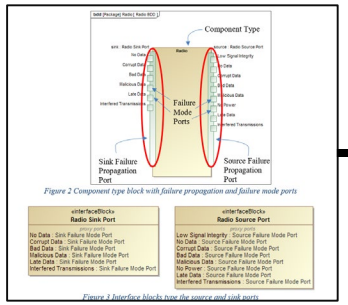
System Model Data Preparation



NoMagic: Cameo System Modeler (CSM)

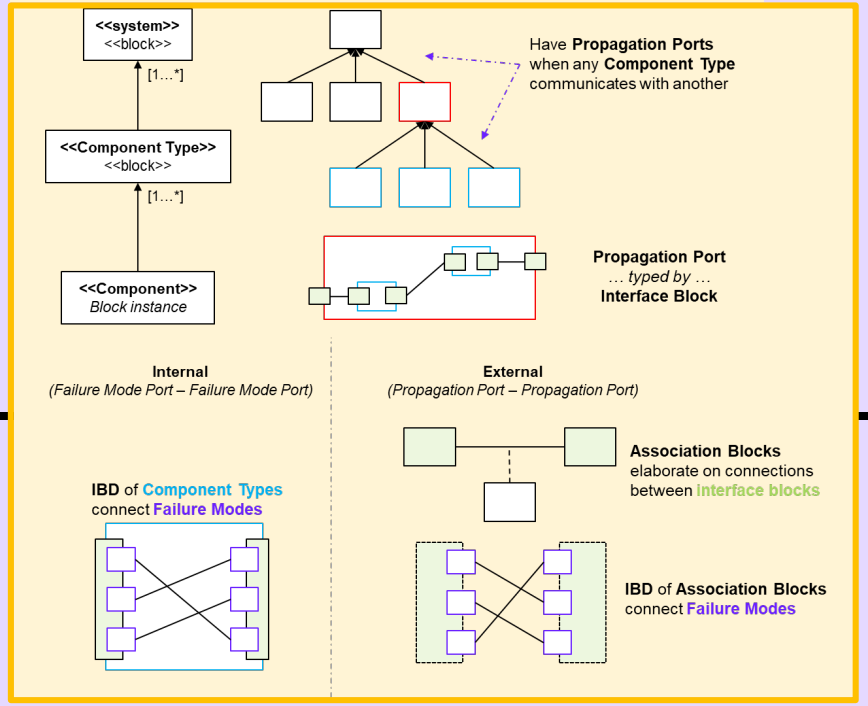
ACX was an available CSM model that Aerospace had full data access to.

AeroCube 10 (ACX)
Leverages draft CubeSat System Reference Model (CSRM)



The System Model provides a rigorous self-consistent documentation of elements and relationships

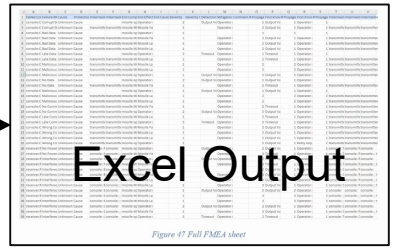
FMEA Plugin (Myron Hecht & Aaron Chuidian)



Identifies and Enumerates all Failure Propagation Paths

FMEA plug-in was developed to a releasable state and its developers were readily available to us.

Automated FMEA Plug-in
Built for CSM. Leverages a custom SysML profile to prepare a model for analysis.

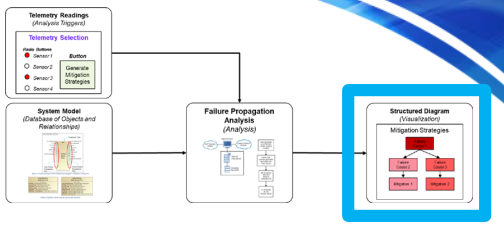


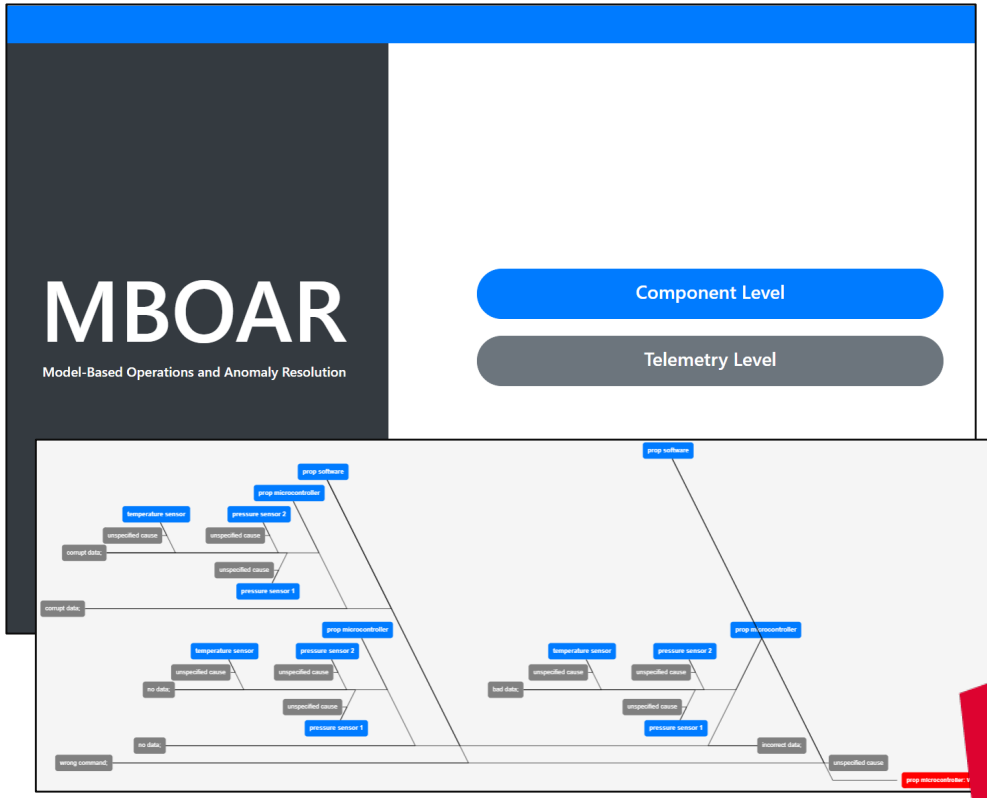
The output provides structured data for enumerated failure propagation paths while reducing all unnecessary data from a full System Model

The System Model captures point-to-point relationships, but struggles to enumerate threads or paths in a digestible manner. The two tools were combined to process the threads and simplify accessible data.

Aerospace Implementation – 2 of 5

MBOAR Web Application for Structured Diagramming





Operators do not need to or want to operate in the System Model, but there is value in the visualizations that are possible.

We can use the model as a data-set and perform the analysis external to the tool.

The Web Application provides operators a method of understanding the context around anomalies to better inform mitigation solutions with the added benefit of maintaining synchronization with design (system) models.

Aerospace Implementation – 3 of 5

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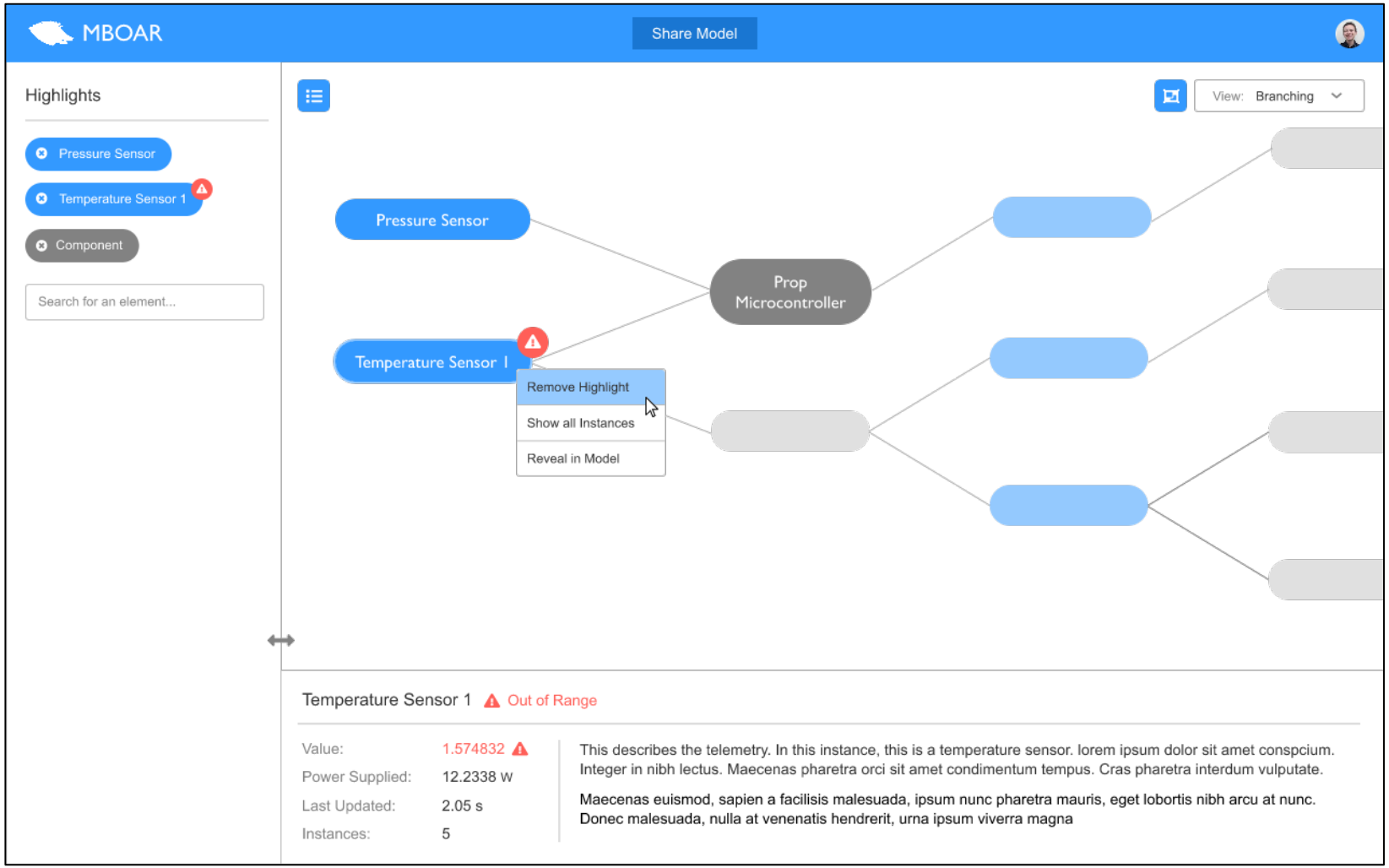
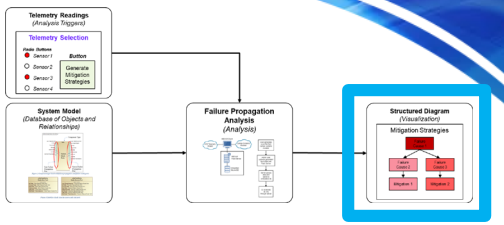


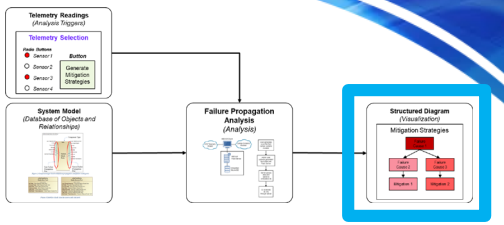


Phase 2 Functionality

- Navigate model using "highlights" to focus on certain components
- Mark out-of-bounds telemetry
- Provide component information

Aerospace Implementation – 4 of 5

MBOAR Web Application for Structured Diagramming



MBOAR

MBOAR

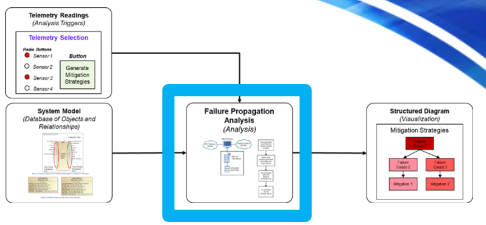
Model-Based Operations and Anomaly Resolution

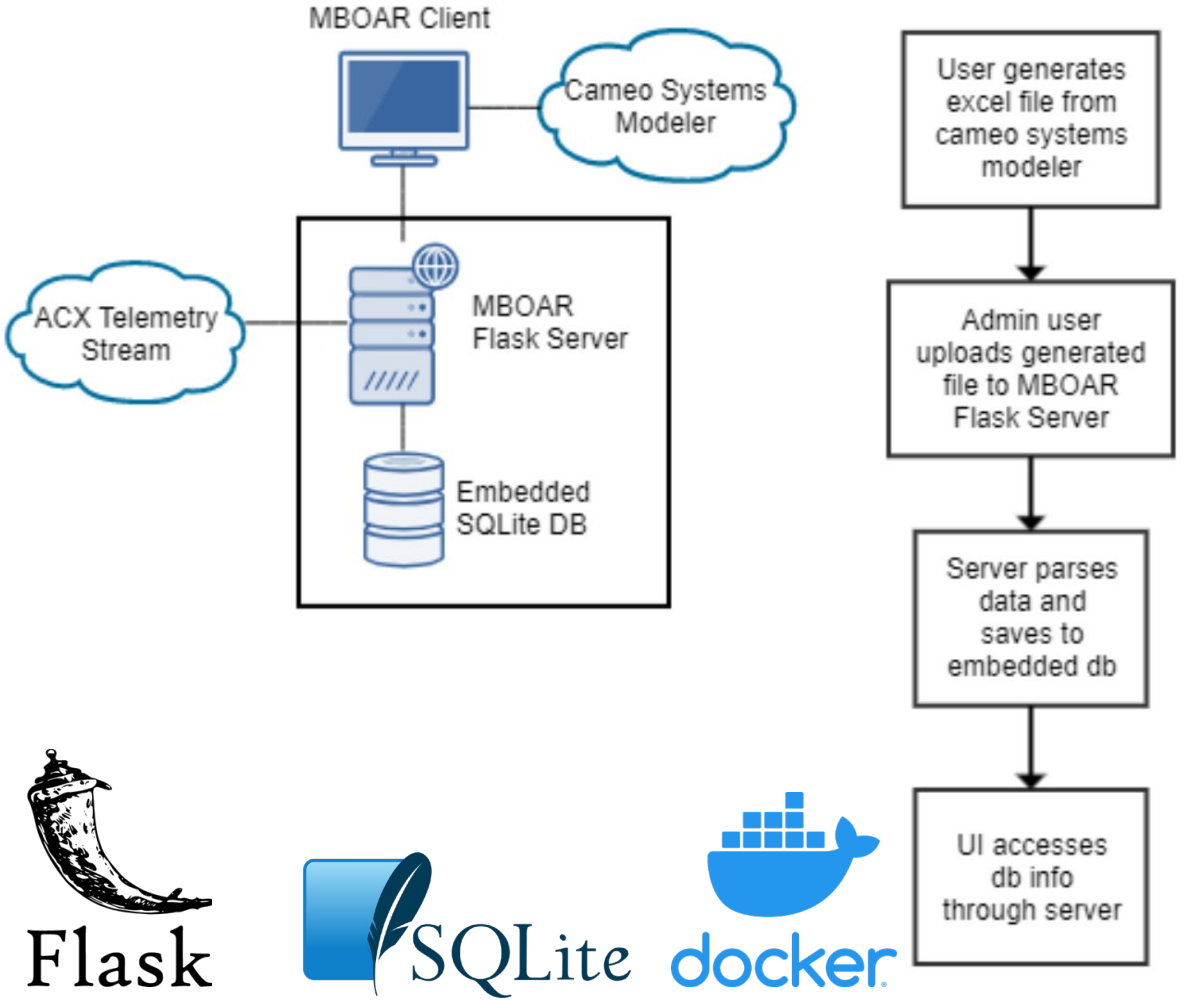
Component Level

Telemetry Level

Aerospace Implementation – 5 of 5

MBOAR Server Ecosystem for Data Management and Hosting





- MBOAR Flask Service performs a variety of functions supporting the UI and model visualizations
- Serves model data to clients
- Stores model data in embedded database and allows write access to admins
- Will process and ingest FMEA excel output
- Connects to ACXB Propulsion Telemetry

The Server Ecosystem acts as the mitigator between the System Model and Web Application to manage data configurations, store rules for data access, process telemetry streams, and more.

Lessons Learned

Thoughts for the Future

- **Semantic mapping is key for scaled modeling**
  - *Significant time used to Perform Failure Analysis, Translate to profile acceptable elements/relationships, Model the Failures*
  - *Pre-existing System Models may be harder to adapt, but possible if modeled consistently.*
  - ***Ideal:** Perform Failure Analysis ONCE, not each time it needs to be translated*

- **Every user does not need all the information. Find a way to selectively query the model for critical information**
  - *Operators need to save the satellite NOW and going through a complex (all-encompassing) system model would not be helpful*
  - *The visualizations we made after selectively querying information was more helpful than the diagrams actually in the model*
  - *Multiple views utilizing the same structure can allow for different ways to consume the model*

- **Understanding all of the components and their functions is integral for seamless integration and resulting in expected functionality**
  - *Data sources: Model excel data, ACX Telemetry Stream*
  - *Components: UI, Flask Server, Embedded Database*

The MBOAR implementation only addresses two Use Cases. There is plenty of room for additional research and development.

Thank you!

Questions?

Back-Up Slides

Back-Up: References

- M. Hecht, A. Chuidian, T. Tanaka and R. Raymond, "Automated Generation of FMEAs using SysML for Reliability, Safety, and Cybersecurity," *2020 Annual Reliability and Maintainability Symposium (RAMS)*, Palm Springs, CA, USA, 2020, pp. 1-7, doi: 10.1109/RAMS48030.2020.9153708.

- D. Kaslow, B. Ayres, P. T. Cahill, L. Hart, A. G. Levi and C. Croney, "Developing an MBSE CubeSat Reference Model — Interim status #4," *2018 AIAA SPACE and Astronautics Forum and Exposition*, Orlando, FL, 2018, AIAA 2018-5328, doi: 10.2514/6.2018-5328.

Back-Up: Full List of Use Cases

1 of 2

ID	As a …	<Role>	I want to …	So that …	Priority	Estimated Effort
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