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# Functional Fault Model Development Process to Support Design Analysis and Operational Assessment

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# Presentation Outline

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  - Purpose
  - Motivation
  - What is a Functional Fault Model
- FFM Development Process

  Phase 1: Knowledge Acquisition

  Phase 2: Conceptual Design

  Phase 3: Implementation & Verification

  Phase 4: Application
- Concluding Remarks

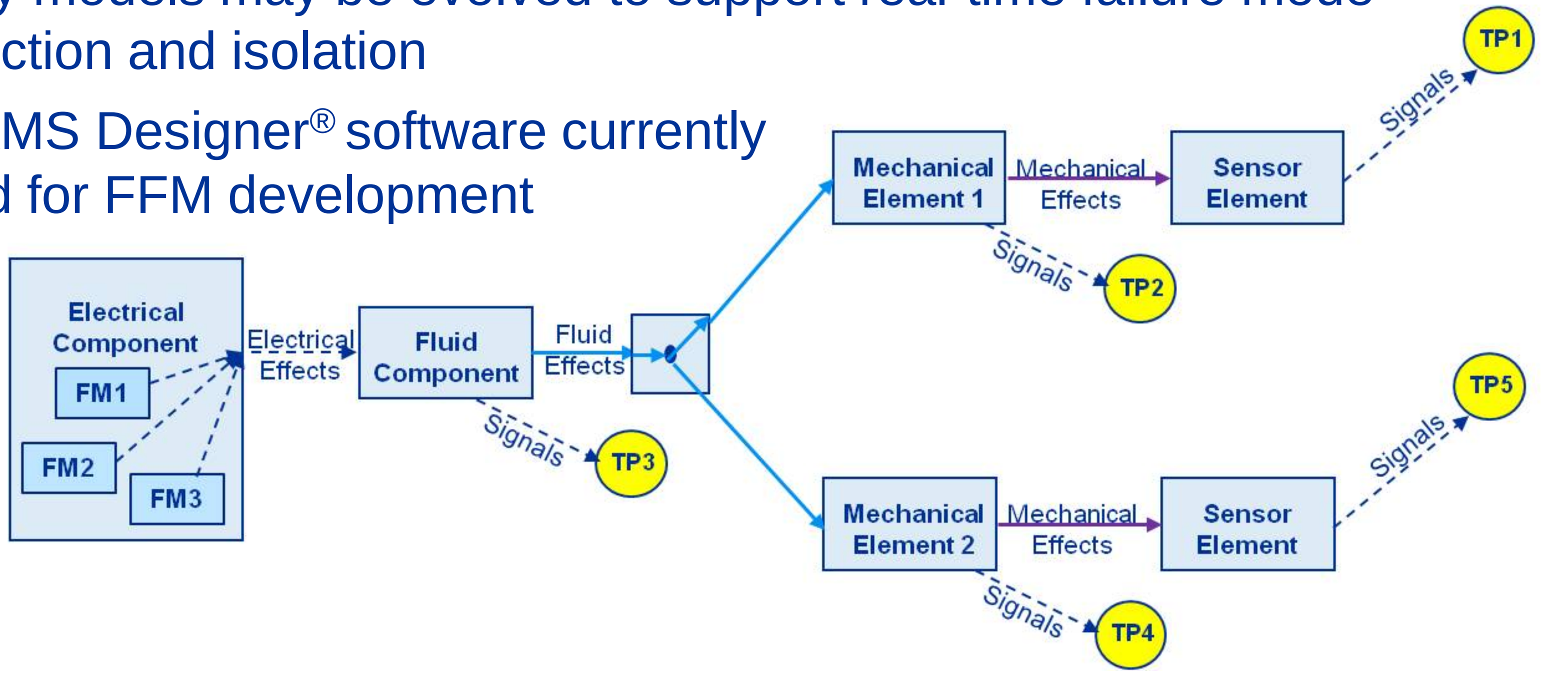
# Introduction

- Purpose of paper
  - To characterize and document the current process used by NASA to develop functional fault models (FFMs)
  - To identify new technologies and capabilities that contribute to an improved process.
- Motivation for the paper
  - Process has evolved over past 10 years with push to support development of new NASA human-rated space systems
  - Modeling guidelines, best practices, and software tools have been developed to substantially improve:
    - The efficiency of the FFM development and verification process
    - The utility and impact of FFM applications
  - Benchmark for future FFM development efforts as the process continues to evolve

Introduction

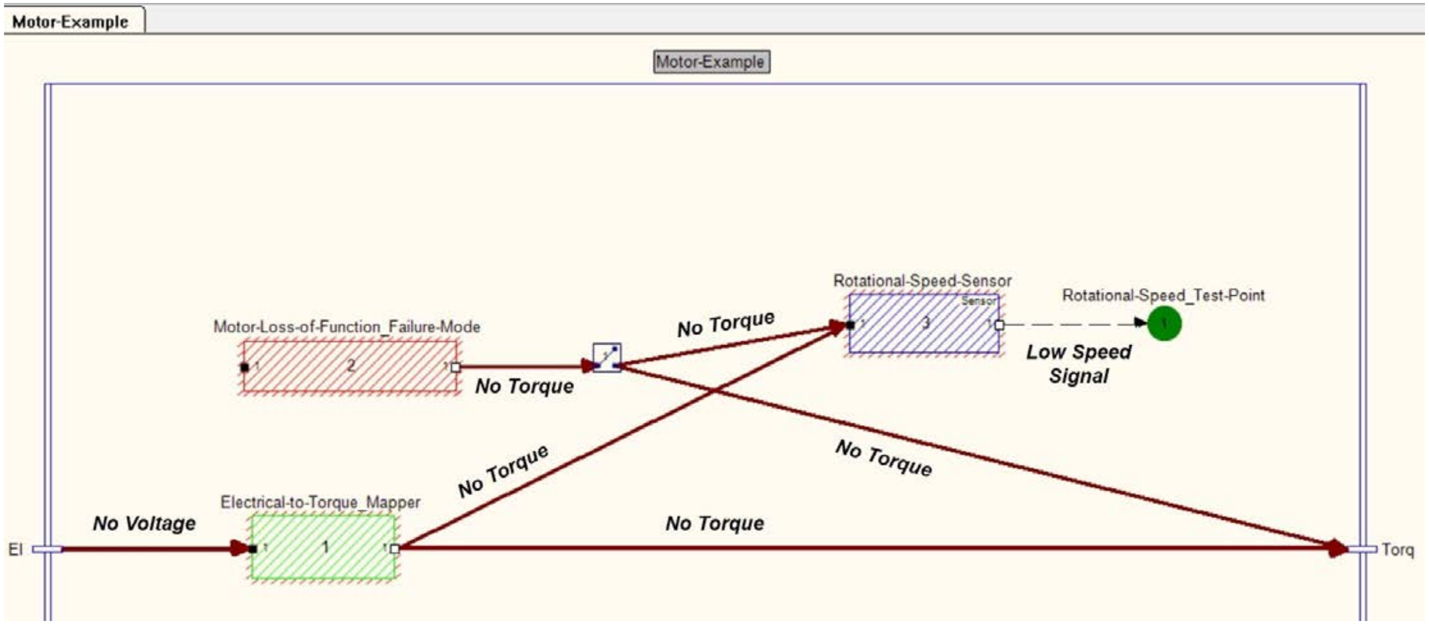
# What is a Functional Fault Model?

- Directed graph representation of failure effect propagation paths within the system architecture
- Developed to address limitations of traditional methods
- Initial models can be qualitative supporting requirements verification early in system design process
- Early models may be evolved to support real-time failure mode detection and isolation
- TEAMS Designer® software currently used for FFM development



## Introduction

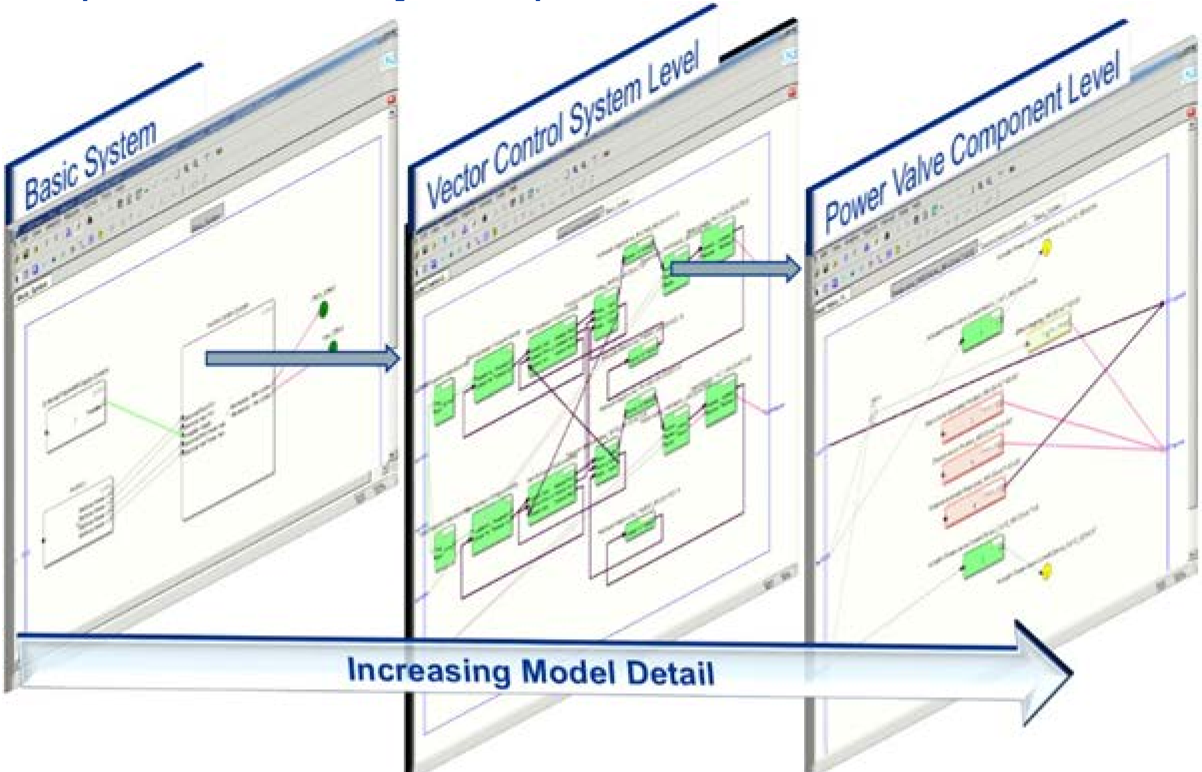
# Functional Fault Models in TEAMS



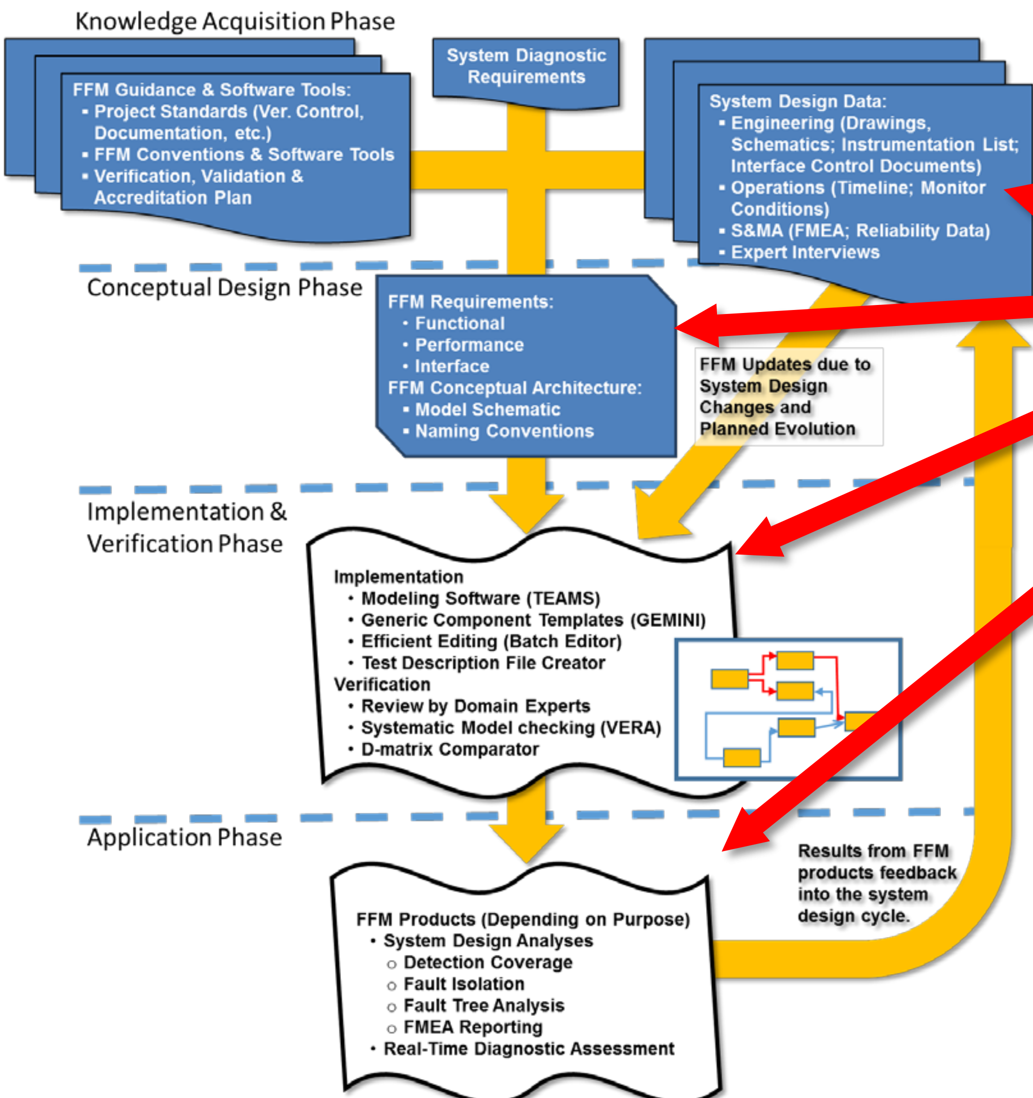

- Modules – represent systems, assemblies, components
- Failure Mode Modules – contain the qualitative failure information
- Mapper Modules – represent the nominal transition of the failure effects being propagated
- Test-Points – represent the observation points of the system (typically associated with sensors)
- Tests – detect specific failure effects

# Introduction
# Functional Fault Models in TEAMS

- Hierarchical modeling capability:
  - Supports a model structure that reflects a hierarchical decomposition of system hardware & software
  - Facilitates portioning of large complex models into smaller models for implementation by multiple individual modelers

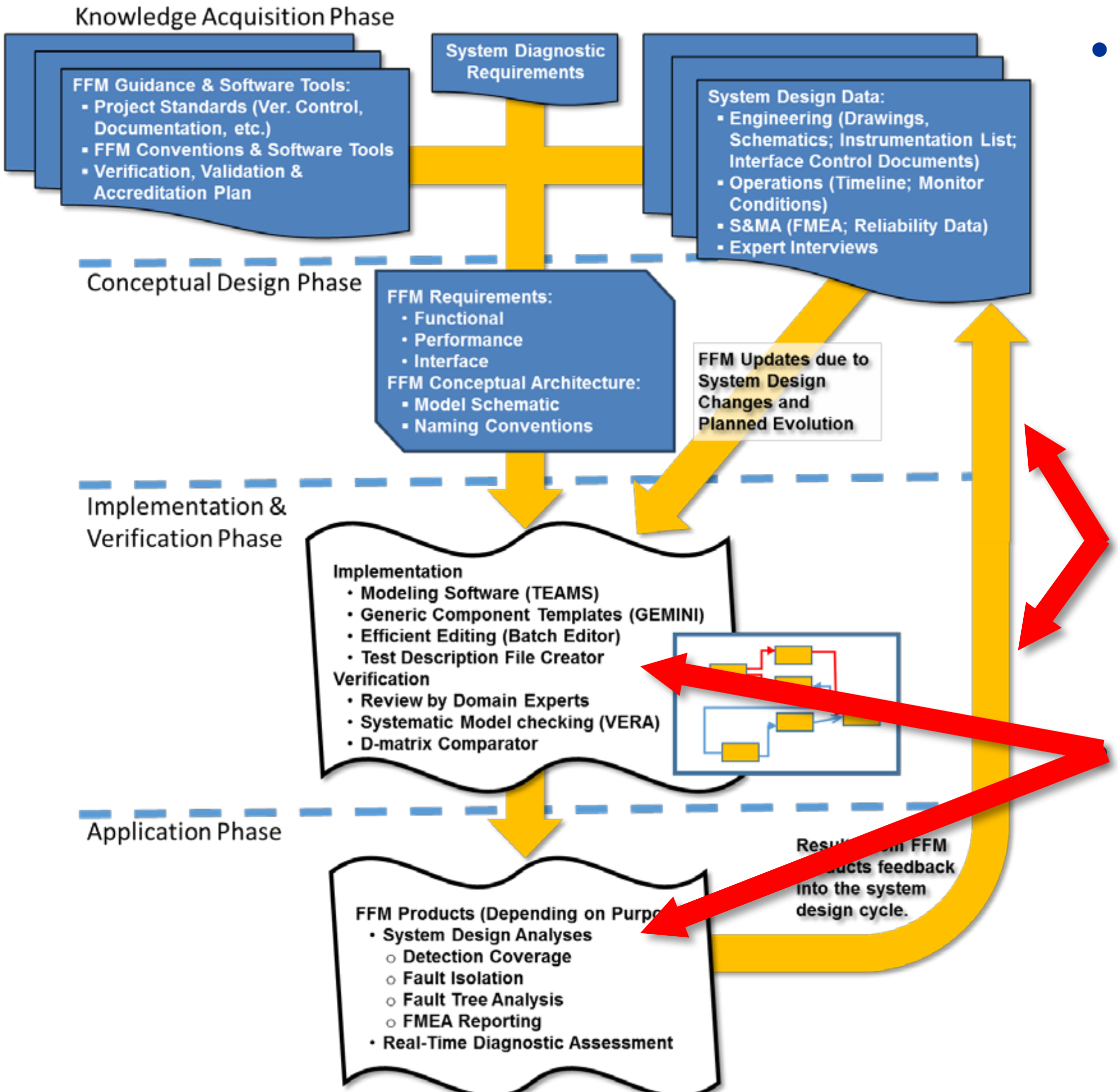


# FFM Development Process: Overview




- High-level traditional modeling process with four (4) phases:
  1. Knowledge Acquisition
  2. Conceptual Design
  3. Implementation and Verification
  4. Application

# FFM Development Process: Overview

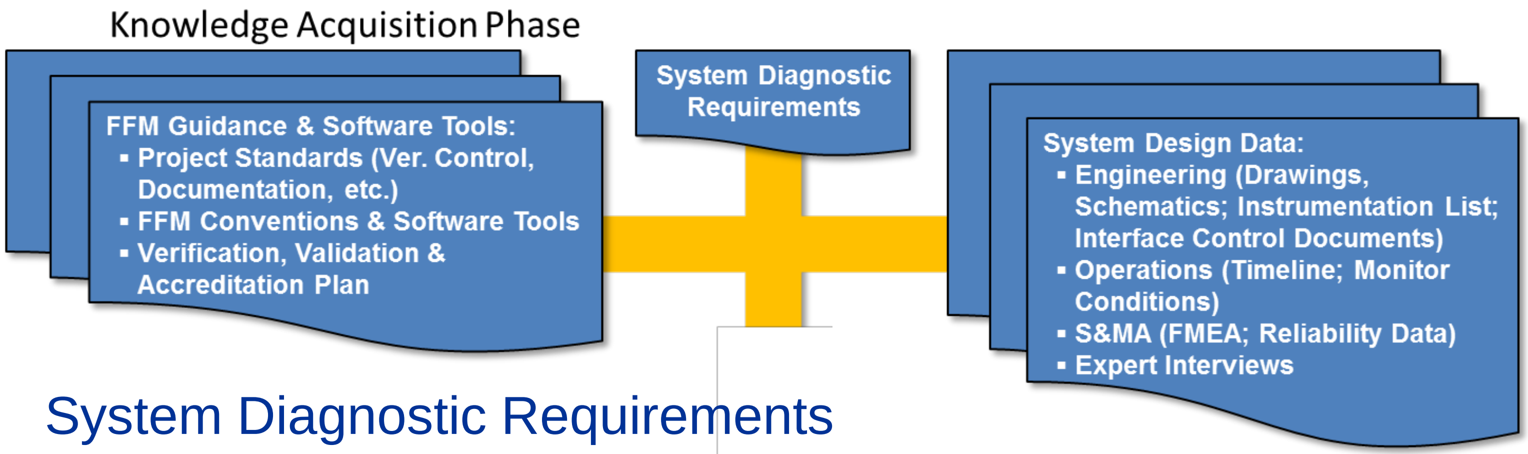



- High-level traditional modeling process with four (4) phases:
  1. Knowledge Acquisition
  2. Conceptual Design
  3. Implementation and Verification
  4. Application

Ideally, analysis results from the *Application Phase* feed back into the system design

Each phase incorporates FFM-specific features

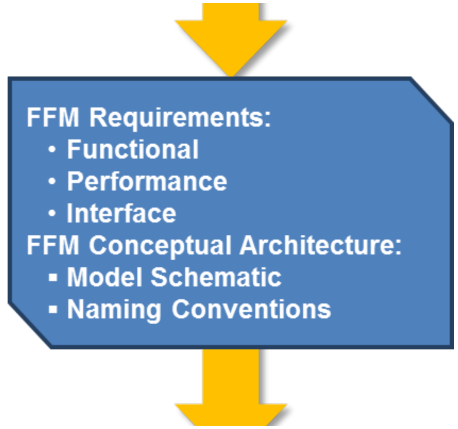
# Phase 1: Knowledge Acquisition




- System Diagnostic Requirements
  - System-level requirements impact all phases of the FFM dev. process
  - Examples: Abort conditions, launch commit criteria, line replaceable units
- System Design Data
  - Information that defines the system design and operation
  - Examples: Engineering drawings and reports, concept of operations, Failure Modes and Effects Analysis (FMEA)
- FFM Guidance & Software Tools
  - Information needed to implement a model that informs the Conceptual Design, Implementation & Verification, and Application phases
  - Examples: modeling conventions, model VV&A plan
- Establish System Breakdown Structure (SRS) & other databases

# Phase 2: FFM Conceptual Design

Conceptual Design Phase




- FFM Requirements
  - Flowed down from system diagnostic requirements, FFM conventions and practices
  - Functional: Failure modes, test points, test logic
  - Performance: Time to detect/isolate failures, False positive/negative rates
  - Interface: FFM-to-FFM, system to FFM to key decision makers on ground or vehicle
- FFM Conceptual Architecture
  - System Operational Profile
  - Model Schematic/Structure
  - Naming Conventions

# Phase 2: Conceptual Design
# FFM Rqmts: Modeling Conventions & Practices

- Approved by NASA's SLS, Orion, and Ground Systems FFM communities.
- Documents FFM best practices of all three communities.
- Benefits:
  - Model elements and sub-models have consistent look and feel
  - Improves human understanding
  - Enables more efficient integration of independently developed FFMs
  - Facilitates development of the interfaces needed for integration of FFMs with real-time systems
  - Improves traceability of model features back to source documents

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**ADVANCED GROUND SYSTEMS MAINTENANCE (AGSM) PROJECT**

**NASA GROUND SYSTEMS AND LAUNCH VEHICLES TESTABILITY ENGINEERING AND MAINTENANCE SYSTEM (TEAMS)**

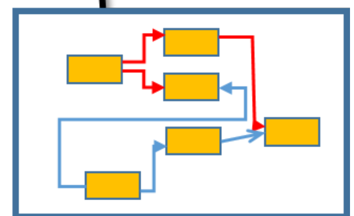
**MODELING CONVENTIONS AND PRACTICES**

# Phase 3: Implementation & Verification

Implementation & Verification Phase

**Implementation**
- Modeling Software (TEAMS)
- Generic Component Templates (GEMINI)
- Efficient Editing (Batch Editor)
- Test Description File Creator

**Verification**
- Review by Domain Experts
- Systematic Model checking (VERA)
- D-matrix Comparator



Start Modeling

## Create/Revise FFM
- TEAMS Designer software
- NASA-developed software tools
  - Batch Editor
  - GEneric Model INstantIator (GEMINI) software
  - Test Description File Creator

## Verify FFM
- Review by domain experts
- NASA-developed software tools
  - VERification Analysis (VERA) Tool
  - D-matrix Comparator

Tightly Coupled Lower-Level Processes

# Phase 3: Implementation & Verification
# NASA-Developed Tools

- Batch Editor
  - Includes model query and update commands to efficiently make broad systematic changes to FFMs (not available in TEAMS)
  - Commands cover a wide variety of TEAMS modules & features
  - Graphical or command line user interfaces
  - Used by several other NASA-developed FFM tools to extract model information
- GEneric Model INstantItation (GEMINI) Tool
  - Supports the use of generic model libraries
  - Generates component-specific FFMs by adding user-provided component data to generic component models
- Test Description File Creator
  - Aligns real-time system data to FFM tests (mode dependent)
  - Defines thresholds–results in quanitative diagnostic assessment

Slide Credit Eric Barszcz, Ames Research Center, Moffett Field, CA.

# Phase 3: Implementation & Verification
# NASA-Developed Tools

- VERification Analysis (VERA) Tool
  - Checks model for adherence to NASA FFM conventions & practices
  - Reads model information into MS Excel Workbook
  - Analyzes model in four areas:
    - Technical
    - Practices & Conventions
    - Cosmetic
    - Informational content
  - Generates detailed reports that identify non-compliant FFM features
  - Provides scores to support accreditation of the model for operational use.
- D-Matrix Comparator
  - Reports differences between D-matrices from two different FFMs
  - Useful for regression testing to ensure minor model checks reflected in results

# Phase 4: Application

Application Phase


## FFM Analysis Products

- Failure Detectability Report
  - Analyzes FFM for detected / undetected failure modes
  - Verifies detection coverage rqmts.
- Test Utilization Report
  - Analyzes FFM for used/not used tests (sensors)
  - Supports sensor selection/buy-in
- Fault Isolation Report
  - Analyzes failure mode uniqueness / ambiguity
  - Verifies rqmts for algorithms used to detect failure effects
- Component Isolation Report
  - Analyzes isolation of failure modes to user-defined components
  - Verifies requirements for line replaceable units
- FMEA Report
  - Uses data embodied in FFM to generate a report containing failure mode description data and detection capabilities from FFM

# Phase 4: Application

Application Phase


## Moving FFM from analytical use to real-time:

- Interface policies & software for generating FFM input from the real-time data
  - Handling dynamic data
  - Loss of data
  - Align FFM tests with software that processes real-time data

## Real-time Diagnostic Assessment:

- Provide a list of failure modes, components, and sensors that align to the latest test detection
- Textual information traceable to design and FFM documentation
- Used by decision makers in flight and on ground.

# Concluding Remarks

- This paper presented an iterative, four (4) phase process to support the development of FFMs.
- Special emphasis was placed on key approaches, capabilities, and tools that are unique to FFMs.
- The process has proved beneficial to recent systems engineering assessments under NASA's Ares I, Space Launch System, and Ground Systems Development and Operations Programs.
- Continued evolution of the process is anticipated as:
  - Current capabilities mature,
  - Additional capabilities are developed,
  - All capabilities are demonstrated in future flight and ground systems.

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