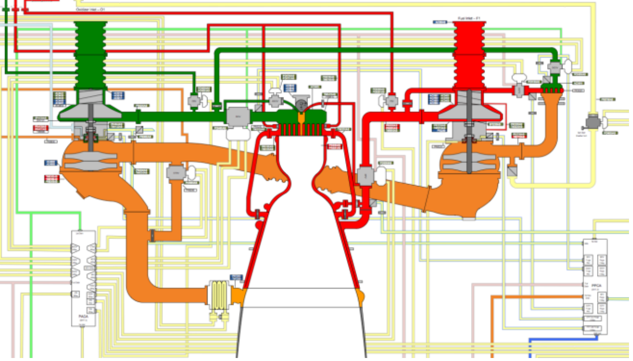
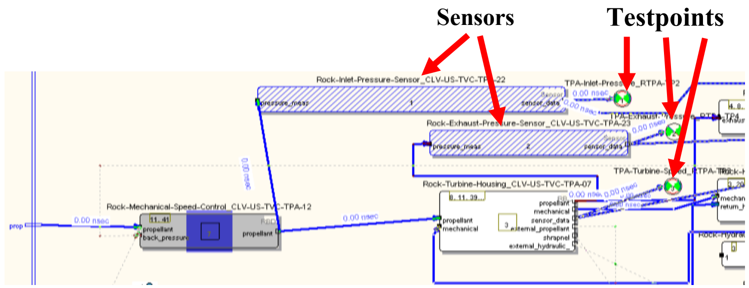
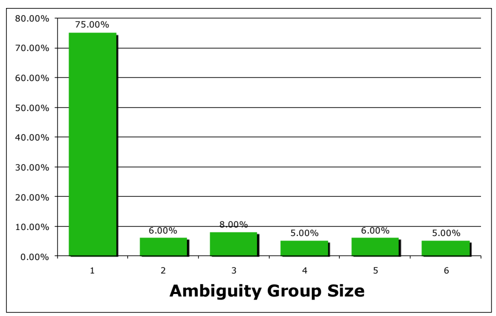


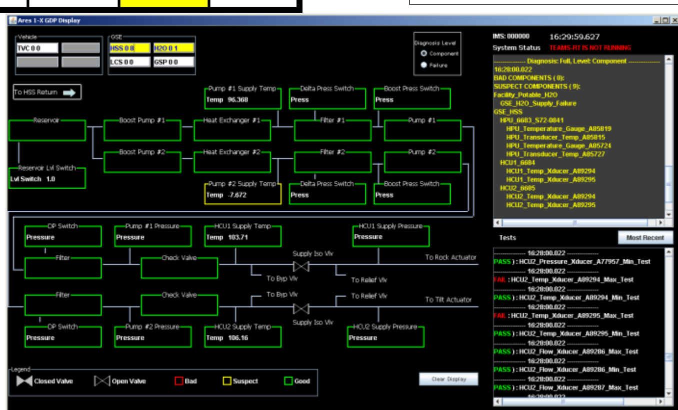
Launch Vehicle Ground-Based (LVGB) Diagnostics



April 27, 2010

	T1	T2	T3	T4
FM1	1			
FM2	1	1		
FM3		1		
FM4		1	1	
FM5			1	
FM6			1	
FM7				1
FM8			1	





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Agenda

Launch Vehicle Ground Based Diagnostics (LVGBD) is a ground application that analyzes health & status of launch vehicle systems and ground support equipment (GSE) to isolate and diagnose failures

- **Requirements and Drivers**
- **Complexities**
- **TEAMS Model Use**
  - Diagnostic Model Real-time Output
  - Testability Analysis
- **Architectural Approach & Considerations**
- **Benefits**
  - LRU ambiguity example
  - Summary
- **Fleet Supportabilty**
- **Shuttle History**

Launch Vehicle Ground-Based Diagnostics (GBD) Requirement Drivers

- **Based on the Functional Fault Analysis (FFA) Vehicle Diagnostic Model (VDM)**
  - Directed graph representation of failure effect propagation paths within the vehicle architecture
  - A ***fundamental representation*** of the system's failure space behavior
  - Extension and formalization of FMEAs (and potentially, Fault Trees) into a model of the vehicle architecture
  - Built from schematics, IPCL, FMEAs, LRU list, and ICDs

- **System Requirements**
  - Fault Isolation
  - Availability
  - Maintainability (MTTR)
  - Launch Probability

- **Ground-based approach drivers for launch vehicles**
  - Volume of measurements and test criteria
  - Cadre-based control
  - Limited response time & possibilities
  - Deployable at test and integration sites during staged vehicle build-up
  - Potential for test, integration & launch site GSE model integration

Complexities

- **Input complexity**
  - LV Health & Status
  - Command Logs
  - BIT results
  - GSE inputs
  - Results of procedural diagnostics
  - Other User Inputs
  - Fidelity of vehicle state definition and notification
- **Complexity drivers**
  - Model test criteria
  - Model function mapping
  - Integration of GSE with LV models
  - Integrity of test criteria (data integrity and design accreditation)

TEAMS
Testability Engineering and Maintenance System

- **TEAMS tool suite**

- **Develop Launch Vehicle Diagnostic Model (LVDM) using the TEAMS-Designer tool**
  - TEAMS-Designer provides ability to perform analyses of
    - Fault detection
    - Fault isolation
    - Failure effect propagation paths and times
    - Reliability (currently not used for this purpose)
  - Output of TEAMS-Designer is the “Dependency Matrix” exported to TEAMS-RDS (Remote Diagnostic Server) / -RT (Real-Time)

- **TEAMS-RDS operates TEAMS-RT, which provides the capability for GBD to use the LVDM to perform operational diagnostics**
  - Diagnostics = fault isolation + fault diagnosis
  - Fault isolation = possible locations of faults that could cause the observed failure behavior, to a specified level (LRU, for example)
  - Fault diagnosis = which failure modes are possible causes of observed failure behavior (the FMEA identifiers)

Real-time Diagnostic Model Output

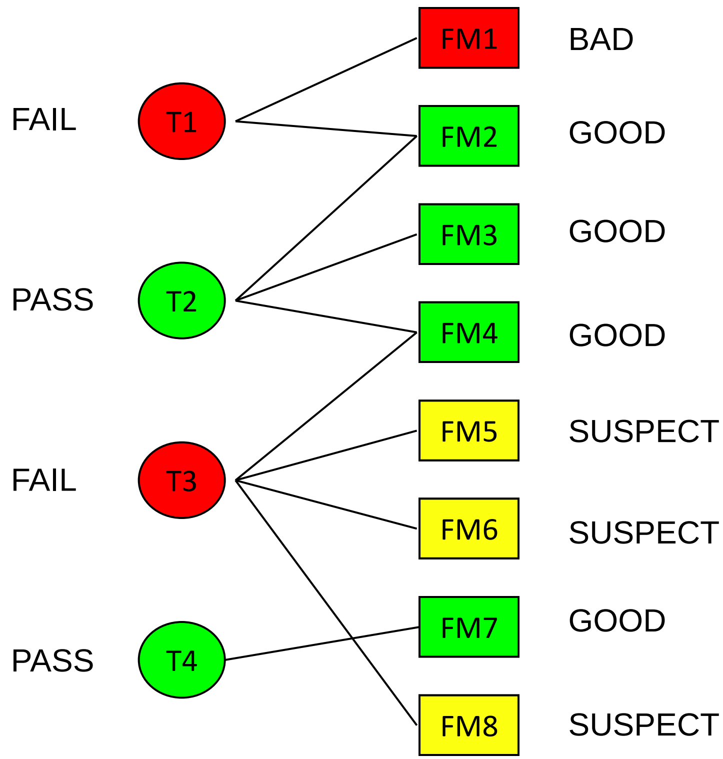
D-matrix

Observable points
(TEAMS "tests")

Failure
Modes
(causes)

	T1	T2	T3	T4
FM1	1			
FM2	1	1		
FM3		1		
FM4		1	1	
FM5			1	
FM6			1	
FM7				1
FM8			1	

1 = observable point can detect failure mode (from failure effects passing by observable location)



Compute *GOOD* failure modes: Every failure mode connected to a *PASS* test is *GOOD*.

Compute *BAD* failure modes: Every "test" that is *FAIL* has **at least one** failure mode that is *BAD*.

If there is more than one failure mode that leads to a *FAIL* "test", then all failure modes not labeled as *GOOD* are labeled as *SUSPECT*.

All remaining failure modes are labeled *UNKNOWN*: they are connected to "tests" for which we have no test information.

Notional Testability Analysis Summary

Ambiguity Group: The smallest set of components to which a fault can be isolated, or the smallest set of failure modes that could have caused a detected failure.

Ambiguity Analysis Conditions:

Measurements: OFI
Failure Modes: Crit-1R2, Crit-1S, Crit-1R3, Crit-1, Crit-1R, Crit-2, Crit-2R, Crit-3
Operational Mode: Mainstage
Portion of Model: Engine
Analysis Level: LRU

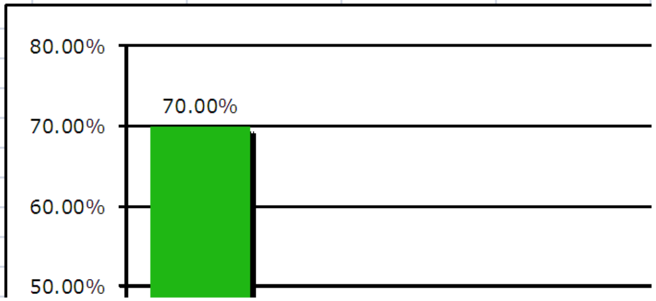
Ambiguity Analysis Results:

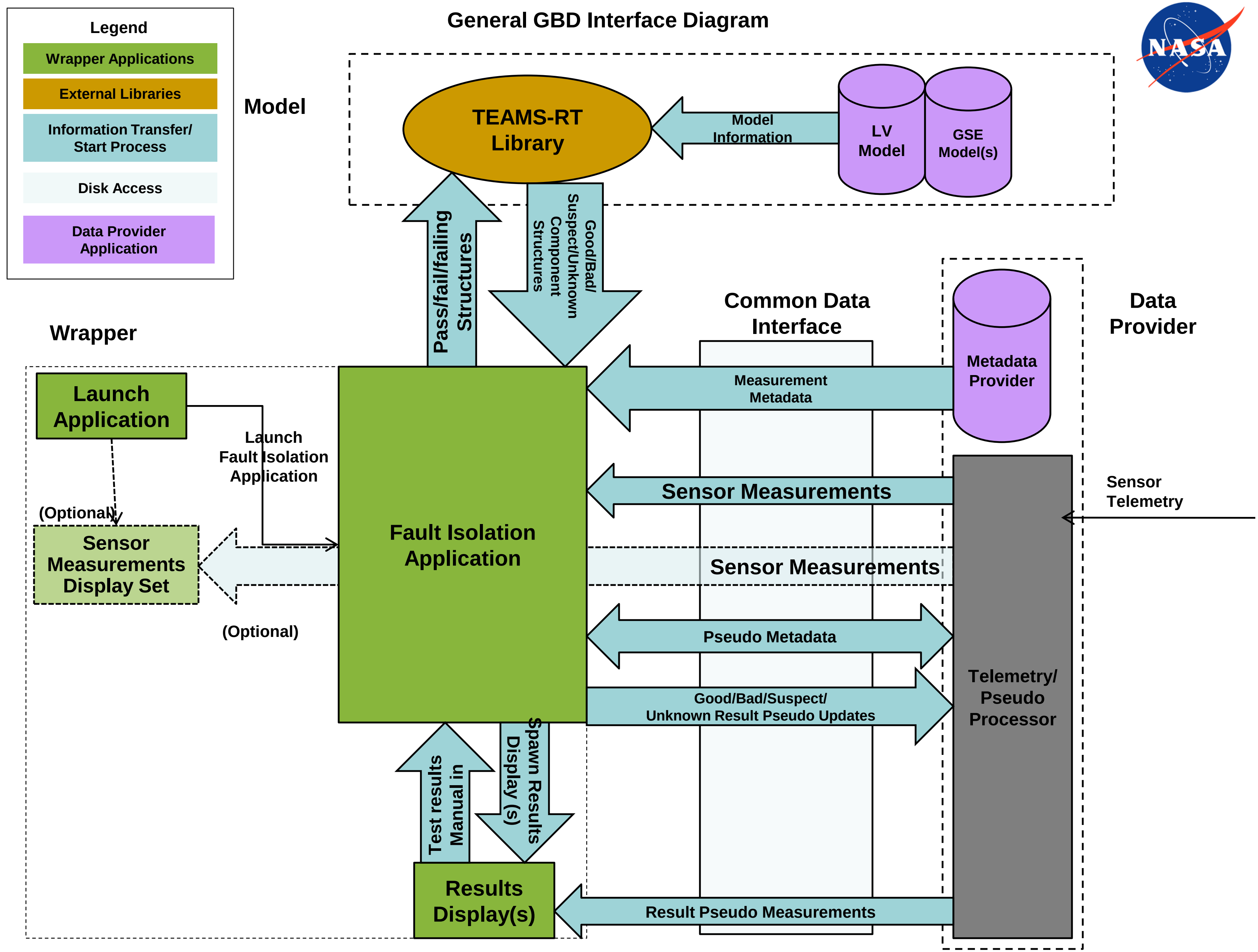
Number of Ambiguity Groups ……………….126
Number of Active Failure Modes ……………759
Number of Active LRUs ………………………51

Number of Isolated Groups (LRU) ……………31

Ambiguity Groups Size Distribution

1	70.00%
2	6.00%
3	8.00%
4	5.00%
5	6.00%
6	5.00%




General GBD Interface Diagram
Legend
Wrapper Applications
External Libraries
Information Transfer/ Start Process
Disk Access
Data Provider Application
Model
TEAMS-RT Library
Model Information
LV Model
GSE Model(s)
Pass/fail/failing Structures
Good/Bad/ Suspect/Unknown Component Structures
Common Data Interface
Data Provider
Wrapper
Metadata Provider
Measurement Metadata
Launch Application
Launch Fault Isolation Application
(Optional)
Sensor Measurements Display Set
Fault Isolation Application
Sensor Measurements
Sensor Telemetry
Sensor Measurements
(Optional)
Pseudo Metadata
Good/Bad/Suspect/ Unknown Result Pseudo Updates
Telemetry/ Pseudo Processor
Test results Manual in
Spawn Results Display (s)
Results Display(s)
Result Pseudo Measurements

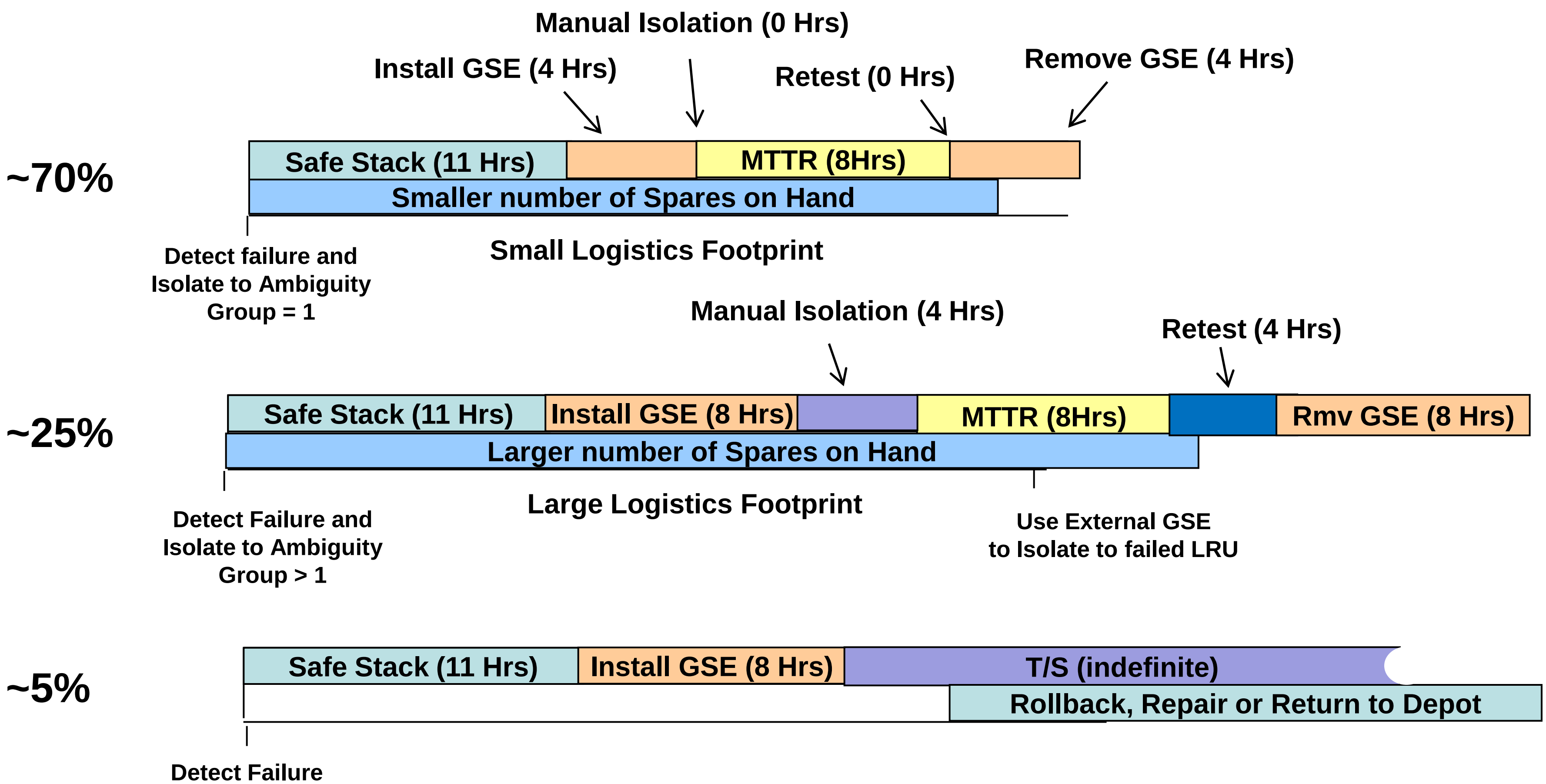
Architecture Considerations

- Recommend interfacing to nominal control center telemetry processing to minimize anomalous results compared to other control center applications.
- Test criteria is an integral part of the vehicle design and model definition and should be controlled as such.
- Verification and validation efficiency is significantly increased using integrated LVGBD application and LVDM.
- Evaluate ‘standardization’ of interfaces to support deployment at multiple vendor/test/integration sites.

LV GBD Benefits

- **Automates fault isolation when failures occur**
  - Possible failure modes
  - Possible fault locations
- **Improves operational responses for failure**
  - Reduces time needed to isolate failures
  - Provides full set of possible failure modes that can cause observed failure symptoms
- **Supports launch integration and test operations**
  - Standardizes fault isolation capabilities across test and operations sites
- **Provides input to flight rationale and rollback decisions**
  - Reduce time to build launch rationale
- **Reduces operator cognitive workload**
  - Standardizes fault detection and isolation
  - Allows for reference material to be linked to failures
- **Vehicle Design Impacts**
  - Assess fault detection and isolation for C&W, FDIR, Aborts
  - Help verify LRU criteria
- **Operations Design & Development**
  - Determines and reduces need for on-site spares
  - Resultant ambiguity group size goals can drive reliability
  - GSE and manual inspection observation points in the model will improve the isolation capability
  - Help determine needed logistic procedures
  - Help identify / generate procedures to isolate faults to smaller ambiguity groups
  - Prioritize procedures to most quickly isolate faults to smaller ambiguity groups
  - Provides educational & training forum
- **Verification**
  - Fault isolation metrics for availability calculation

Notional Fault Isolation Capability Impact on Ground Operations Off-Nominal Timeline



Percentages = proposed fraction of faults (out of all faults that can occur), which are isolated to the level defined for each case.

Summary

- **LVGBD improvements**
  - Reduces operations costs (FTEs & spares)
  - Reduces troubleshooting times
  - Not all benefits are quantified
    - Additional cost savings over life of program will materialize as results of analysis are implemented for improvements
    - Aggressive modeling, analysis and implementation of measures earlier in the design phase will improve design & operability

Launch Vehicle Fleet Supportability

Launch Vehicle Fleet Supportability is an offline ground-based capability to analyze launch site processing and ascent performance for anomalous behaviors trending towards failure

- **Benefits**
  - Model & locate complex failure effect interactions
    - Identify failure modes with multiple failure effect propagation paths
    - Interacting FEPPs point to interacting control center and/or abort algorithms
    - Identify possible Caution & Warning "message storms"
  - Automate fault isolation
    - Pre & Post Flight
    - Rapid provision of possible failure modes & fault locations when failures occur
  - Reduce failure analysis time and resources
  - Offline support of launch site processing and ascent analysis
    - Root Cause Analysis
    - Integrated Vehicle Anomaly assessment
    - Trending across multiple flights

Shuttle Scenarios

- **Launch vehicle safety and operational costs are historically problematic**
  - CAIB and CxP Goals require that we do better than historical precedents
  - Shuttle reliability ~ 1 in 60, launch delays typical

GOP Benefit Scenarios

- **STS-88 12/3/1998**
  - Scenario where additional information could have prevented a 24 hour scrub
    - At T-minus 4 minutes 24 seconds a master alarm in the crew cabin was noted and the countdown clock automatically stopped the clock at a built in hold at the T-minus 4 minute mark. The alarm was due to pressure on Hydraulic System #1 temporarily registering below 2800 psi during its startup transition from low to high.
    - The launch countdown was then held at the T-31 second mark to further assess the situation. *Shuttle system engineers attempted to quickly complete an assessment of the suspect hydraulic system and eventually gave an initial "go" to resume the countdown. With only seconds to respond, launch controllers were unable to resume the countdown clock in time to launch within the allotted remaining window*, which was limited due to liquid oxygen (Lox) drain-back constraints. Managers are discussing the 24-hour launch turn-around plans and are expected to make a final determination later this morning.
  - How would FDIR help in this scenario?
    - Additional information would be provided to the console operators, which components are suspect will reduce the time required to assess the situation and provide a recommendation
    - By capturing the system design knowledge during development, we will be less reliant on variations in personnel experience and skill set.

GOP Benefit Scenarios

- **STS-99 2/9/2000**
  - Scenario where additional information could have provided positive information to hold the launch for a failure
    - On Monday, January 31, 2000, The launch team also investigated a potential problem with the onboard Master Events Controller (MEC) #2 Built In Test Equipment (BITE). The problem did not reoccur during additional testing. At 1:58pm EST, (18:58 UTC) NTD gave the go to pickup the count and countdown to the T-minus 9 minute mark and hold pending weather. At 2:08pm EST, the *call was made to scrub due to weather constraints and enter into at 24 hour scrub turnaround*. The new launch date was tentatively set for Tuesday, February 1, 2000 at 12:44pm.EST. Over the night, engineering teams will evaluate data from the Master Events Controller.
    - On Tuesday, February 1, 2000, mission managers decided to *delay the launch until no earlier than February 9, 2000 to give the launch team time to swap out Endeavour's Enhanced Master Events Controller (EMEC) #2* located in the orbiter's aft compartment
  - How would FDIR help in this scenario?
    - A positive list of failure modes for the detected indication would allow operators to quickly build the case for halting the launch to replace the component (launch was scrubbed for weather)
    - By capturing the design information during development, a reduced set of support personnel are required to be present during launch operations. Today the support personnel are asked to answer design questions in response to anomalies and reconstitute the corporate design knowledge in real-time.