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69th IFIP WG 10.4 Meeting Dependability & IoT

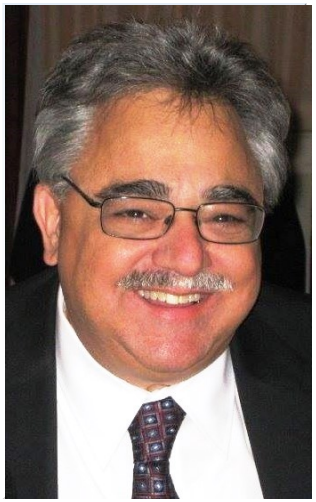
Systems of Systems (SoS)
RMA&D Requirements Decomposition

Aspen / Snowmass, Co

Jan 11-15, 2016

John Perazza
Lockheed Martin Fellow

Biography



John Perazza

LM Fellow
Reliability Engineering / Product Qualification

LM Space Systems Company
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Professional Summary

26 Years service with Lockheed Martin (LM) Space Systems Company and 15 Years with the US Government Naval Air Development Center. Many career technical achievements in Systems Engineering and Specialty Engineering in support of commercial, military and civil programs and proposals. Technical Leadership / Management achievements in Specialty Engineering, Product Qualification and Operations Research. Currently provide LM Fellow consulting to all LM Lines of Business, all LM Corp Business Units, and LM Corporate.

Knowledge & Expertise Areas

Affordability Analysis, Reliability, Maintainability, Availability & Dependability (RMA&D) Analysis; HW / SW Component, Element Product Qualification / Certification for flight; Test Planning and Data Analysis; Operations Analysis; Operations Research; Simulation; BA Applied Mathematics

Agenda

- RMA&D Reqm't Process Needs
- Objective
- LM Business Area RMA&D Activity
- Example SoS for Missile Warning / Defense
- Notional IoT SoS for Intelligent Traffic Control & Autonomous Cars
- Key Design Feature Profile
- "Space Element" RMA&D Decomposition
- "SV or USER Ground Control Element" RMA&D Decomposition
- "User Element" RMA&D Decomposition
- Notional IoT SoS RMA&D Decomposition Summary
- Key Design Feature Verification
- Summary
- Acronym List
- Questions ?

RMA&D Reqm't Process Needs

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- **Reliability, maintainability, availability & dependability (RMA&D) requirements are common to most Programs**
- **Customers / Programs specify RMA&D at high level:**
  - **SoS, System / Mission, Segment or Element**
- **RMA&D requirements traditionally drive program mission / system Architecture / Affordability Baseline and Trades**
- **Programs ensure that RMA&D requirements are decomposed to Element level**
- **Programs further allocate Element RMA&D requirements to HW / SW Components**

IoT RM&D Reqm't Process "Needs" can be Identified / Decomposed / Allocated / Specified

Objective

- **Examine SoS RMA&D requirements decomposition process**
  - **Among System / Mission , Segments and Elements**
- **Highlight where "key design features" are implemented**
  - **Element Fault restoration, Fault tolerance, Fail Safe, Fault management**
- **Examine "key design feature" verification techniques**

LM Business Area Selected Profile

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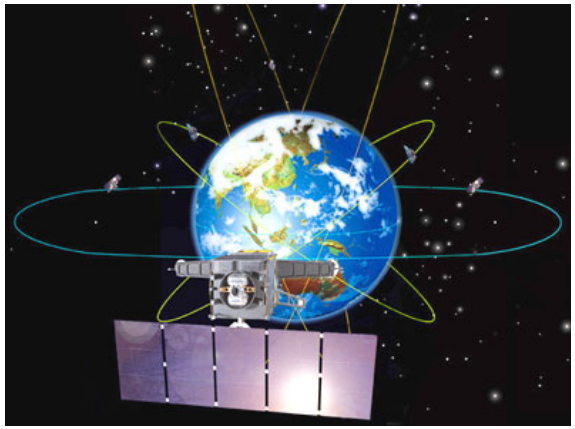
Business Area	SoS Examples	Segments	Elements	Maintained System ?	Recovery During Mission ?	Manned ?
LM Aero	5th Gen Fighter Aircraft	Land	CTOL Aircraft	Yes	Limited	Yes
		CVN	CV Aircraft	Yes	Limited	Yes
		LHA	STOVL Aircraft	Yes	Limited	Yes
LM MFC	Tactical	Ground	Terrestrial Vehicles	Yes	Limited	Yes
	Strike / Defense	Airborne	Missiles	Yes	No	No
		Ground	Missiles	Yes	No	No
LM MST	Situational Awareness	Airborne	UAVs	Yes	Limited	No
	Missile Defense	Ground	Radars	Yes	Yes	Yes
	Missile Defense	Ship	Radars	Yes	Yes	Yes
	Littoral Combat	Undersea	Sensors	Yes	Limited	No
LM SSC	COMM, NAV, Remote Sensing, Weather, etc	Space	Space Vehicles	No	Yes	No
		Ground	Fixed / Mobile	Yes	Yes	Yes
		User	Terminals, Interceptors, etc	Yes	No	No

There are Numerous Opportunities to apply RMA&D Decomposition

Example SoS for Missile Warning / Defense



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Missile Warning

Space Segment (SV Elements)

- Constellation of SVs
- Each SV has Sensors
- Multi-Mission Payloads
- Autonomous Control

Ground Segment Control

- Ground Control Stations
- Space Vehicle (SV) TT&C
- SV Anomaly Recovery
- Mission Planning
- Mission Processing

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Missile Defense

Ground Segment Control

- Ground Stations
- Mission Planning
- Mission Processing
- User Element Cmd & Control

User Segment (User Elements)

- User Elements (e.g. Missile Batteries)

Notional IoT SoS for Intelligent Traffic Control & Autonomous Cars

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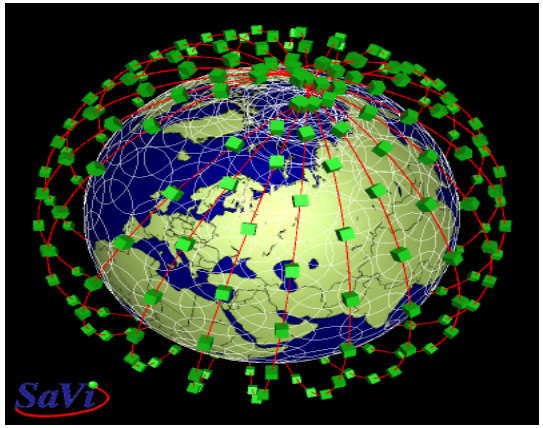

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SV Constellation Detailed Traffic Sensing (DTS)

Space Segment (SV Elements)

- LEO MicroSat Constellation
- LEO MSAT Collect Traffic data
- Data sent to GEO SV Hubs
- GEO SV Hubs send Traffic Data to Ground Hubs

Ground Segment Control

- Ground Control Stations
- Space Vehicle (SV) TT&C
- SV Anomaly Recovery
- Mission Planning
- Mission Processing
- Ground Hubs Process / Distribute Data

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Intelligent Traffic Control

User Ground Control

- Ground Control Stations
- "Course " traffic data compiled
- DTS ("Fine") data received
- Course / Fine data integrated / distributed to terrestrial COMM links to User Elements

User Segment (User Elements)

- User Element (**Autonomous Cars**)

Technical Approach
Example RMA&D Decomposition

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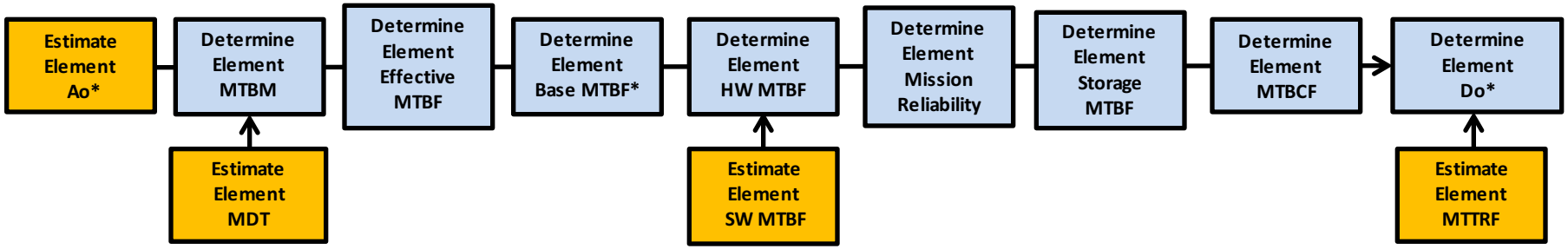
- **Decompose IoT SoS Ao to Segments, Elements:**
  - Decompose SoS Ao to Segment level uniformly or base on Apriori information
  - Decompose Segment Ao to Element Ao level uniformly or based on Apriori information

- **Decompose Ao to Reliability, Maintainability & Do to element level via following process**



  - **Characterize decomposition process inputs, resultant RMA&D allocations**

  - **Highlight Fault restoration, Fault tolerance, Fail Safe, Fault Management Implementation**

- **Summarize Element RMA&D to SoS "system mission" level**

***Notes:**
- Operational Availability (Ao) = MTBM / (MTBM + MDT)
- Base MTBF = 1/Lambda E = 1/(DC*Lambda B+ (1-DC)*Df*Lambda B)
- Operational Dependability (Do) = MTBCF / (MTBCF + MTTRF)

Color Code Legend:
- Blue: MOEs to be determined
- Orange: Estimated driving MOEs

Key Design Feature (Highlighted)

Design Feature	Descriptions	Definition
Fault Restoration	MDT	Mean Down Time
	MTTR	Mean Time to Repair
	MTTRF	Mean Time to Restore Function
Fault Tolerance	Internal redundancy / margin	Within Element Components
	External redundancy / margin	Among Element Components
	Grace Period	Not a critical failure if recovered within accepted time unit
Fail Safe	Safe Mode	Defined by CONOPS, ADR / FMS
Fault Management	BIT	Built In Test
Operational Dependability	Do	Availability during the mission, does not include catastrophic failures

"Space Element" RMA&D Decomposition

Non-Maintained / Limited Mission Recovery / Un-Manned

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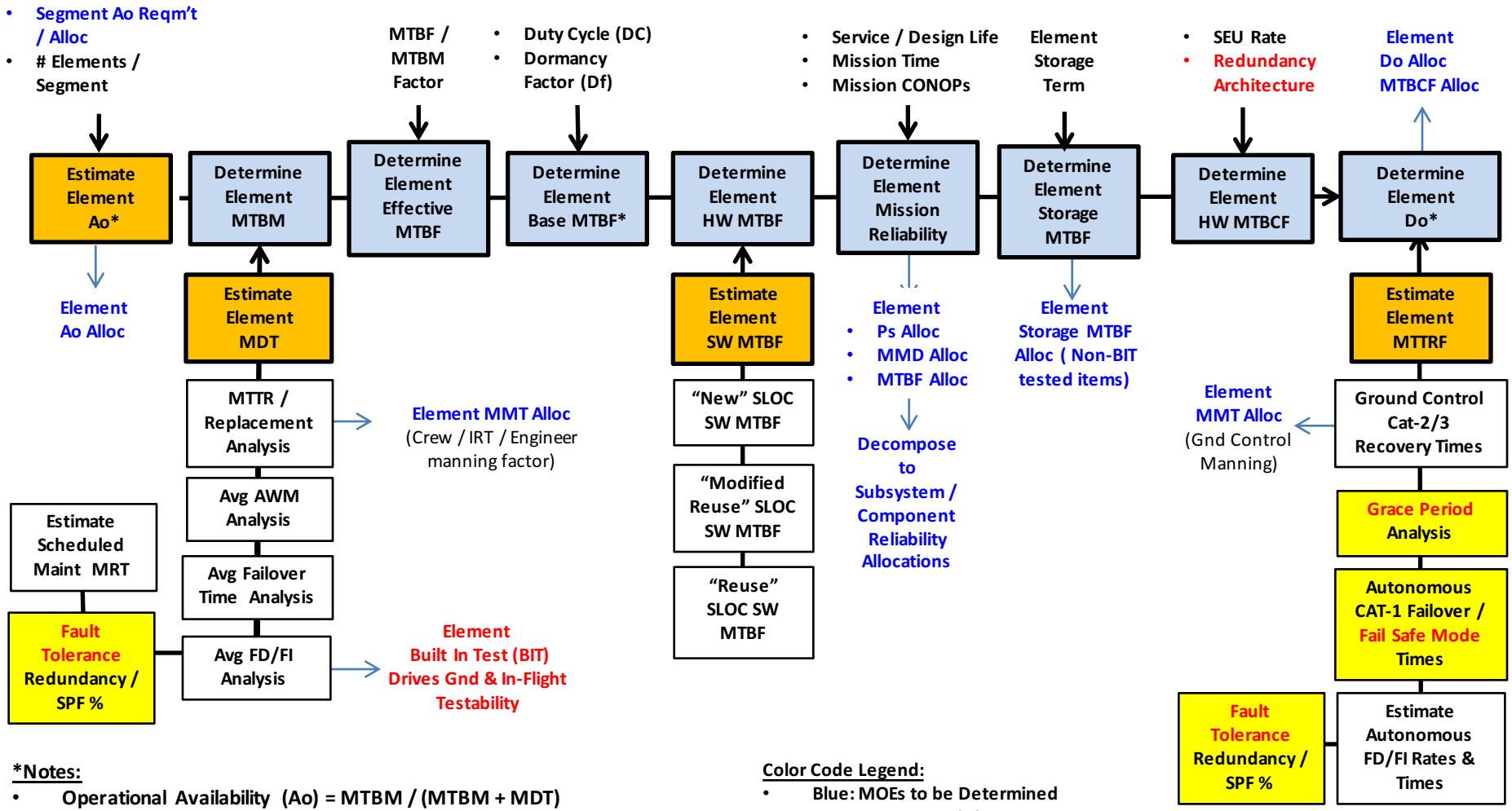

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Color Code Legend:

- Blue: MOEs to be Determined
- Orange: Estimated driving MOEs
- Yellow / Red: Key Design Features
- White: Supporting analyses to estimate driving MOEs

"Space or USER Ground Control Element" RMA&D Decomposition

Maintained / Recoverable during Mission / Manned

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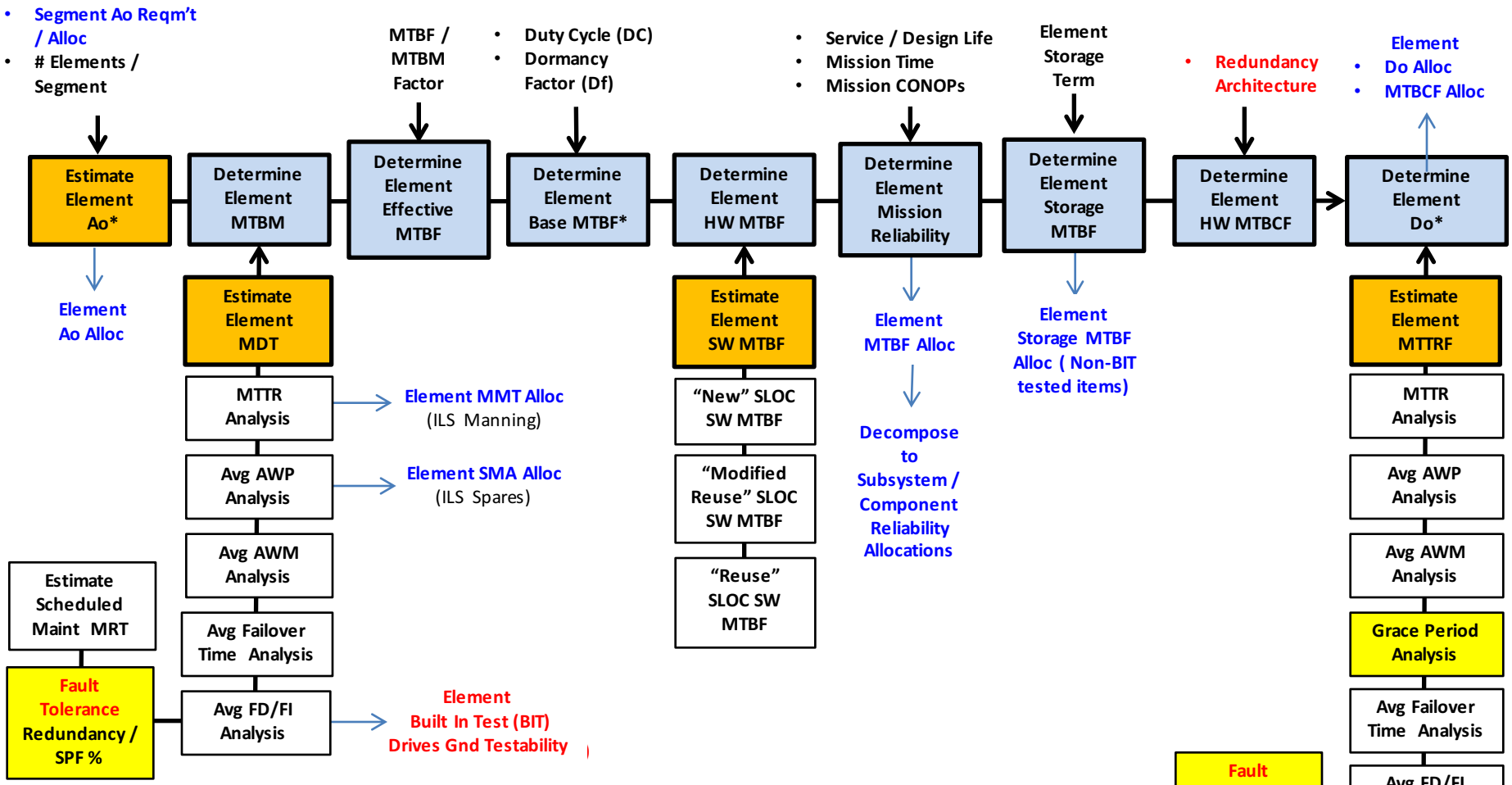

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"User Element" RMA&D Decomposition

Maintained / Limited Recovery during Mission / Un-Manned

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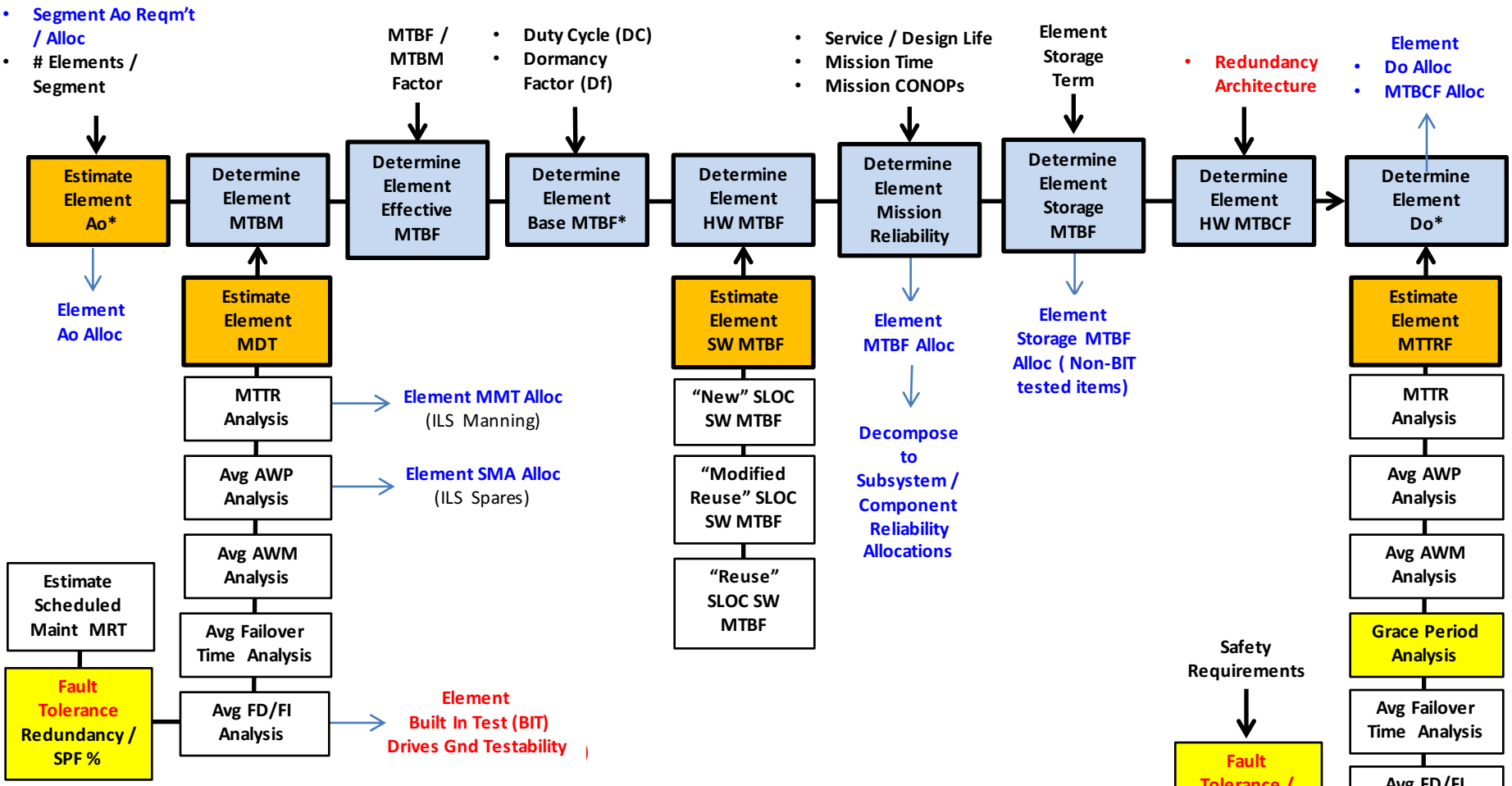

***Notes:**

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- Base MTBF = 1/Lambda E = 1/(DC*Lambda B+ (1-DC)*Df*Lambda B)
- Operational Dependability (Do) = MTBCF / (MTBCF + MTTRF) and does not include catastrophic failure modes

Color Code Legend:

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- Orange: Estimated driving MOEs
- Yellow / Red: Key Design Features
- White: Supporting analyses to estimate driving MOEs

Notional IoT SoS RMA&D

Decomposition Summary

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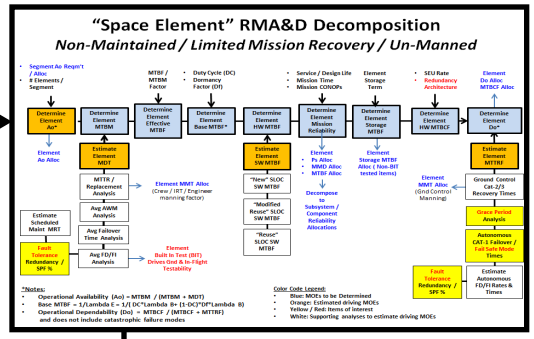
Space Segment: # Space Elements

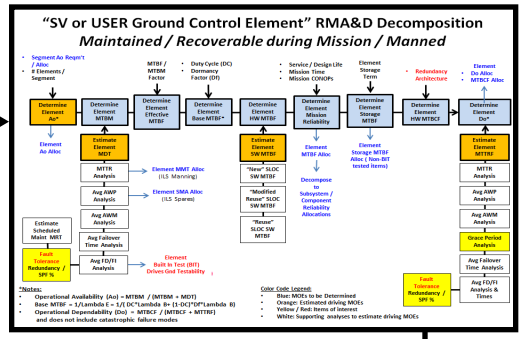
Space Segment Ao



- Assumptions
- Ao%
- Do%
- MTBCF
- MTTRF
- MaxTTRF
- Mission Ps
- MMD
- MMT
- MTBM

SV Gnd Control Segment: # Gnd Elements Elements

Space Gnd Control Segment Ao



- Assumptions
- Ao%
- Do%
- MTBCF
- MTTRF
- MaxTTRF
- MMT
- MTBM

SoS System / Mission RM&D

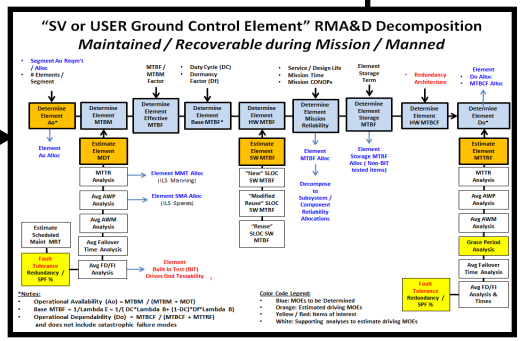
System / Mission

- Op'l Life
- Ao%
- Do%
- MTBCF
- MTTRF
- MaxTTRF
- MMT
- MTBM
- Readiness

- Assumptions
- Ao%
- Do%
- MTBCF
- MTTRF
- MaxTTRF
- MMT
- MTBM

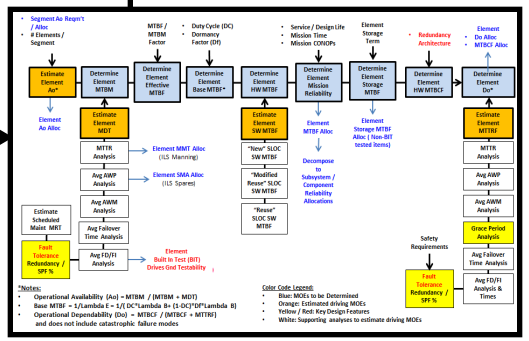
- Assumptions
- Ao%
- Do%
- MTBCF
- MTTRF
- MaxTTRF
- MMT
- MTBM

User Gnd Control Segment Ao



User Segment: # User Gnd Control Elements

User Segment Ao



User Segment: # User Elements

System RMA&D Requirements are Decomposed / Allocated

Key Design Feature Verification

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Item	MOE	Unit Level	Element Level	Segment Level	SoS
Fault Restoration	MTTR	Analysis	Test / Demo	n/a	n/a
Fault Restoration	MDT	Analysis	Test / Demo	n/a	n/a
Fault Restoration	MTTRF	Analysis	Test / Demo	n/a	n/a
Fault Tolerance	Internal Redundancy / Margin	Analysis / Test	Analysis / Test	n/a	n/a
Fault Tolerance	External Redundancy / Margin	Analysis	Analysis / Test	n/a	n/a
Fault Tolerance	Grace period	n/a	Analysis / Test	n/a	n/a
Fail Safe	Safe Mode	n/a	Analysis / Test	n/a	n/a
Fault Mgt	BIT	Analysis	Analysis / Demo	n/a	n/a
Operational Dependability	Do	n/a	Analysis / Demo	Demo	Demo

Key Design Feature Requirements can be Verified

Conclusions

- **SoS RMA&D requirement decomposition process for Segments and Elements ensure that System / Mission requirements are met**

- **“Key design features” can be implemented within Elements**
  - **Fault restoration, Fault tolerance, Fail Safe, Fault Management**

- **“ Key design feature” requirements are verifiable by analysis & test**

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Backup Charts

Acronym List

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Acronym	Definition	Acronym	Definition	Acronym	Definition
Ao	Operational availability	**DTS**	Detailed Traffic Sensing	**MTBM**	Mean time between maintenance
ADR	Anomaly detection and resolution	**FD/FI**	Fault Detection / Fault Isolation	**MTTR**	Mean time to repair
AWM	Awaiting maintenance	**FMS**	Fault management system	**Ps**	Probability of success
AWP	Awaiting parts	**GEO**	Geo- Synchronous	**RMA&D**	Reliability, Maintainability , Availability and Dependability
ATP	Acceptance test procedure	**HW**	Hardware	**SEU**	Single event upset
BIT	Built in test	**IoT**	Internet of Things	**SLOC**	Software lines of code
Cat-X	Category	**LEO**	Low Earth Orbit	**SoS**	System of System
COMM	Communications	**LHA / LHD**	Amphibious assault ships	**SPF**	Single point failure
CONOPs	Concept of Operations	**MaxTTRF**	Max time to restore function	**STVOL**	Short takeoff and vertical landing
CTOL	Carrier take off and landing	**MDT**	Mean down time	**SW**	Software
CV	Carrier Vessel	**MMD**	Mean mission duration	**SV**	Space Vehicle
CVN	CV Nuclear	**MMT**	Mean maintenance time	**TT&C**	Telemetry, Tracking & Control
Dc	Duty cycle	**MOE**	Measure of effectiveness	**UAV**	Un-manned Air vehicle
Df	Dormancy Factor	**MST**	Micro Sat		
Do	Operational dependability	**MTBF**	Mean time between failure		

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