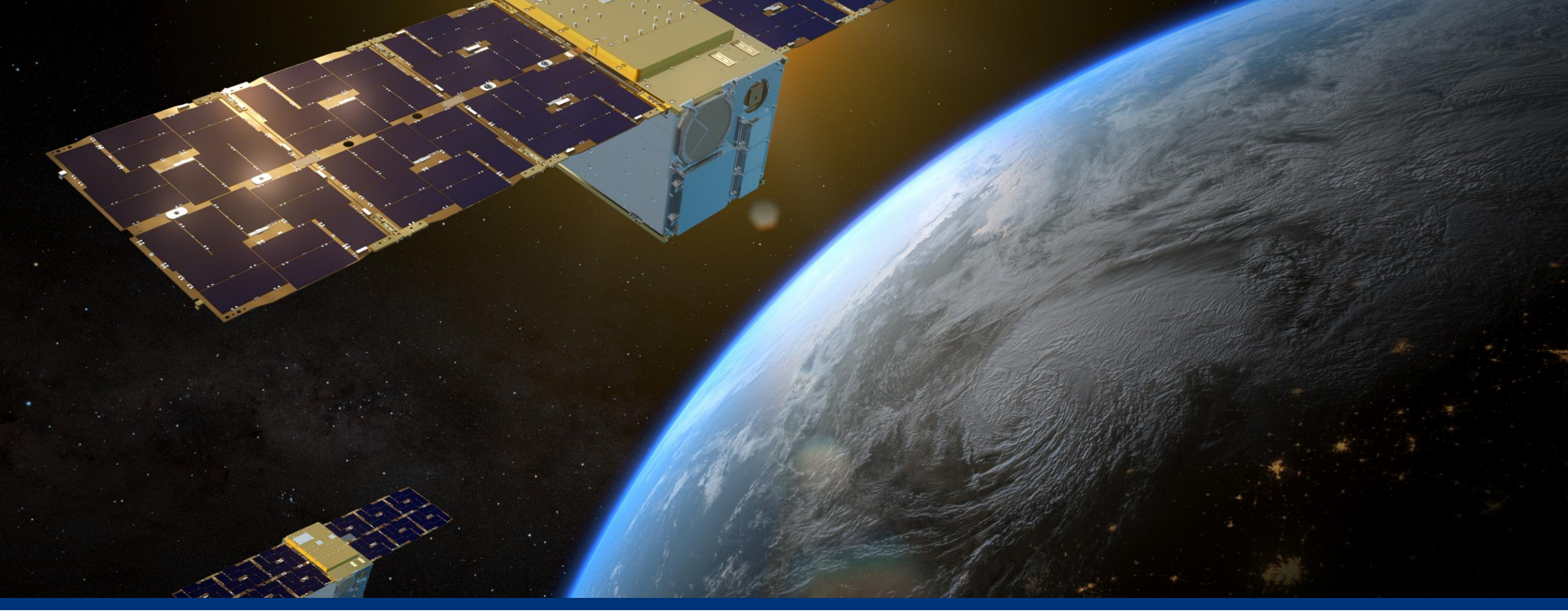

Vehicle-Level Environmental Acceptance Testing in Full Rate Production

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Dr. Ryan Rairigh, Lockheed Martin Fellow

What is Full Rate Production (FRP) and why do we care?

- Highest level of manufacturing maturity *(for a product line)*
  - Low-Rate Initial Production (LRIP) achieved (MRL 9, test-centric production line)
  - Engineering or design changes are few and limited
  - All aspects of system meet requirements
  - All aspects of test and production in place and meet requirements
  - Rate production of system meets cost goals and is funded
  - Continuous improvement ongoing (process control-centric production line) → achieve MRL 10

MRL 10 – Desired end state for all products that will be ***produced at scale*** (i.e., many per month)

- FRP is a key enabler for proliferated systems and building reserve capability (why we care)
- Historically, few space systems achieved FRP and produced at scale
  - Lockheed Martin Space history – Iridium (10 SV/month peak)
  - Near term candidates – Space Development Agency (SDA) programs
- All other aerospace sectors that produce at scale have FRP product lines
  - Within Lockheed Martin examples include Missiles (Hellfire, PAC-3), Airframes (F-35), etc.
  - <u>Key feature: none use 100% environmental test to screen workmanship as part of FRP</u>
  - We need to adapt and develop FRP for space systems

Key Difference from LRIP: Shift from test-centric production to a process control-centric production line

Proposed implementation of FRP at Lockheed Martin Space

- FRP shifts focus to process monitoring and control *rather than* product testing
  - Product testing must provide insight into process and design stability
  - Need a mathematically supportable sampling approach to prove that process monitoring is sufficient
- Candidate production lines and associated programs will need to meet “yes, if” criteria for FRP
  - MRL 9 achieved (design qualified and meets objectives, LRIP complete)
    - LRIP affirmed the design is producible, method of integration controlled and repeatable, and minimal nonconformances
    - Functional test program defined for each asset and data is tracked and trended
  - Relevant processes are in control
    - Identification of “Key Manufacturing Processes” (those that “create or substantially affect a key characteristic of a product”)
    - Completion of Process FMEAs on KMPs (see SAE J1739)
    - Identify, monitor, and react to Process Capability Indices, C_{pk}, P_{pk}, etc., (see SAE AS9145)
  - Risk and value assessment complete to show acceptable mission assurance can be achieved in FRP
    - For example, factor the cost of an on-orbit failure against the savings achieved by omitting tests
  - Determine the optimal sampling plan for adequate surveillance of product performance in environments

Criteria defined to support implementation of FRP and Lockheed Martin Space is moving forward

Sampling Problem Statement

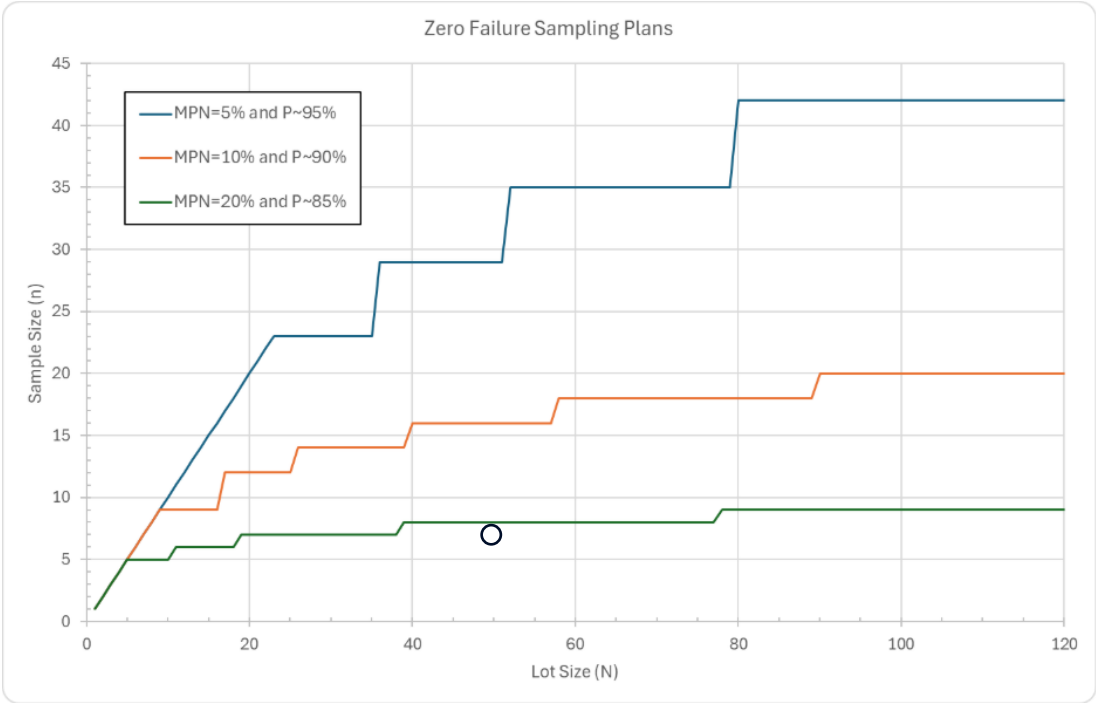
- Sample-based environmental acceptance test (EATP) is independent proof of process control
  - Historically, EATP is proof of workmanship, consistent with staying at MRL 9 (LRIP)
- For N SVs (i.e. a lot of N):
  - How many do I need to test to ensure less than ‘x’ escapes? (more on next chart)
    - We developed an approach using hypergeometric statistics (sampling without replacement)
    - Approach is targeted at high reliability and “small” lots sizes (small relative to other FRP products like automobiles)
  - And how must I choose which units to test? (more on next chart)
    - Developed a selection approach that is both random and can be planned into a schedule
  - And how does that relate to mission-impacting issues?
    - For MRL 10, by definition, design is qualified and successfully achieved LRIP with minimal nonconformance
    - Nonconformance found in FRP should not impact mission (e.g., out of family perf., minor degraded performance)
    - Remember, these would only be discovery in environments. Still functionally testing every asset!
  - And what do I do if there are failures?
    - Nonconformance discovered in a sample is a big deal; it could indicate process breakdown
    - Need root cause and corrective action (RCCA) to isolate issue and determine what penalty the lot will face
      - Unverified failures will require separate focused scrutiny by the technical authority

Sample-based environmental test approach is a key feature of FRP

Sample-based Environmental Acceptance Testing (EATP)

- Inputs into model, as follows:
  - Lot Size
  - Max. Possible Nonconformance (MPN)
    - Think of MPN as “what can you tolerate” in the lot
  - Required Sensitivity (test power) (P)
    - Probability of correctly detecting a defective lot
    - Set at 85% minimum for our approach
- Output = Sample Size

Program must select sampling plan based on risk and value assessment (i.e., what is acceptable)



Example – A Class C mission with a 40 SV constellation will be delivered, and mission could tolerate 8 SVs with degraded performance. What sampling plan do they choose?

- Lot Size = 40 SV
- MPN = 8 (this corresponds to 20% (8/40 = 0.2))
- Sensitivity = 85%
- Output = 8 SVs should receive EATP
- Test cadence determined by 1) defining sub-lots: 42/8 = 5.25 (rounded to 5). 2) Randomly select first SV for test. 3) Then test every 5th SV until 8 are tested.
- Impact: If EATP costs $0.5M per SV then total cost savings is $16M. Also, significant schedule and capital benefit.

Sample-based EATP produces significant reduction in test scope while meeting mission need

Summary and Next Steps

- In summary, Lockheed Martin Space has developed an approach to FRP to implement across the enterprise
  - Leverages process control, sampling and robust functional test to reliably accept space systems
  - Includes a risk and value assessment to ensure the FRP approach delivers acceptable mission assurance

Next Steps

- Request feedback from the community on this approach to FRP

- Lockheed Martin Space is working to define and allocate roles and responsibilities for process control
  - Ensure that we can support and execute the requisite process control program

Lockheed Martin believes the industry needs to adopt risk-appropriate MRL 10 imperatives to enable FRP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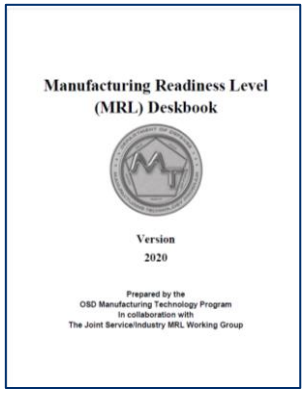
Back Up

Not an abstraction, MRL is associated with a specific product!

Component design(s) exist in early/immature or conceptual state

Basic manufacturing implications, concepts, and proof of concept established

TRL/MRL 1→3: typically, the domain of academia, VC, or focused IRAD



MRL4 Capability to produce prototype component in a lab environment demonstrated (TRL4)

MRL5 Capability to produce prototype component in a production-relevant environment demonstrated (TRL5)

DoD MRL Deskbook defines 9 "threads":

A. Technology and Industrial Base
B. Product Design
C. Cost and Funding
D. Materials (includes Supply Chain Mgmt)
E. Process Capability and Control
F. Quality
G. Manufacturing Personnel (Mfg, Engineering and Production)
H. Facilities
I. Manufacturing Management (MRP)

Process Control - Highlighted as a major focus shift from traditional test-centric approach

PDR

CDR

Design Qualified

MRL6 Capability to produce prototype system/subsystem in a production-relevant environment demonstrated (TRL6)

MRL7 Capability to produce all HW in a production-relevant environment demonstrated (TRL6)

MRL8 Pilot line capability demonstrated; ready to begin LRIP (TRL7/8)

MRL9 LRIP demonstrated; ready to begin FRP (TRL8/9)

MRL10 FRP demonstrated; lean practices in place

MRL 10 – Desired end state for all products that will be ***produced at scale*** (i.e. many per month)

Full Rate Production requires achieving MRL 10; MRL 10 enables production at scale

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