Fatigue Life Predictions of Additively Manufactured Components for Satellite Structures

Research Objective

Objective

- Develop a method to predict critical defect sizes
- Develop a method to predict potential failure locations

Approach

- Identify required input parameters
- Predict critical defect sizes and stresses
- Connect fatigue failure with geometry locations

Application

- Define Minimum Defect Size of Interest
- Define Inspection Locations for AM components

Fatigue Failure Method

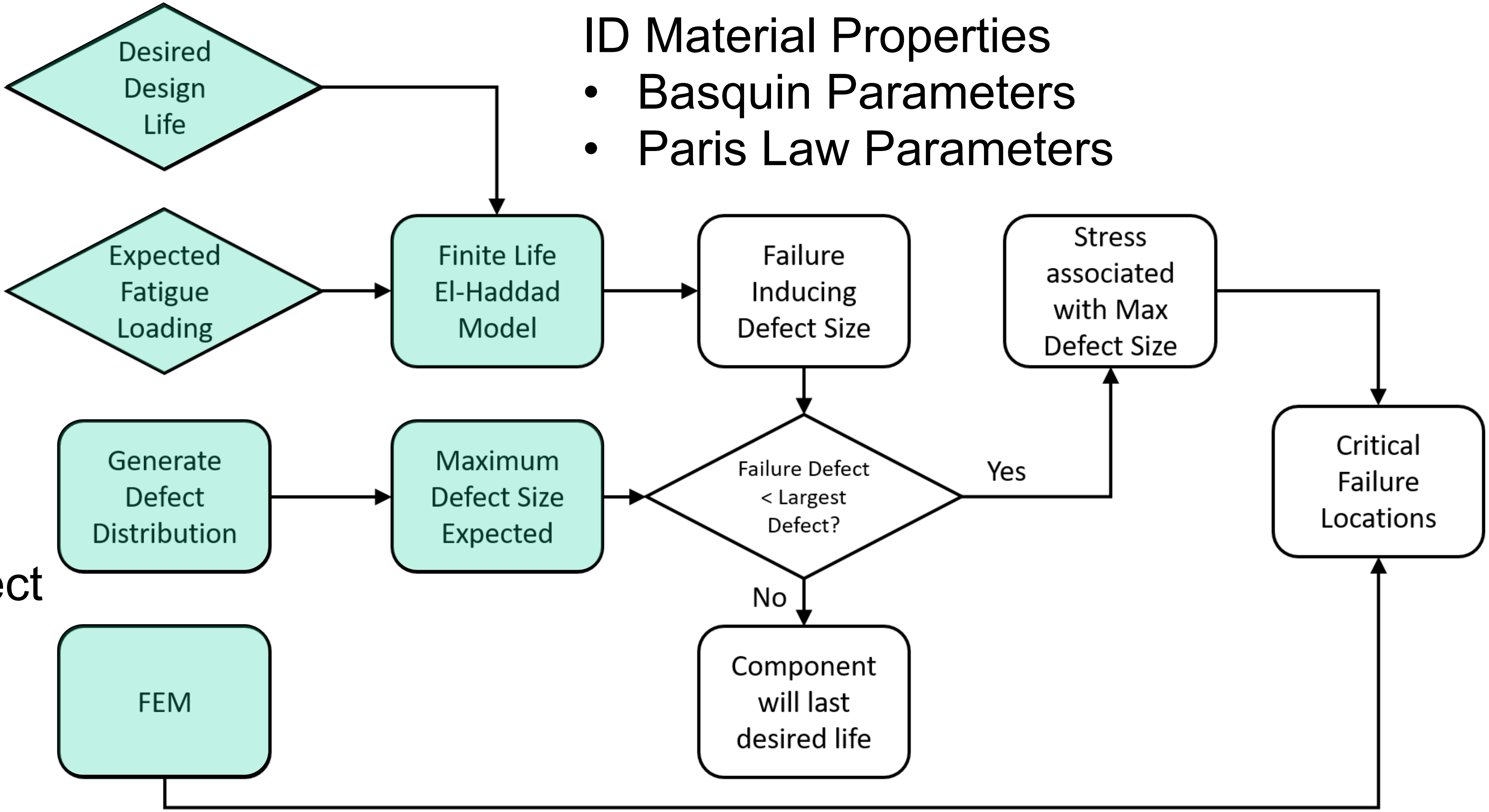
Select the Mission Life

Set Load Case
- Pull the Max Stress

Define defect population
- Pull largest expected defect

Generate a map to relate stress to location

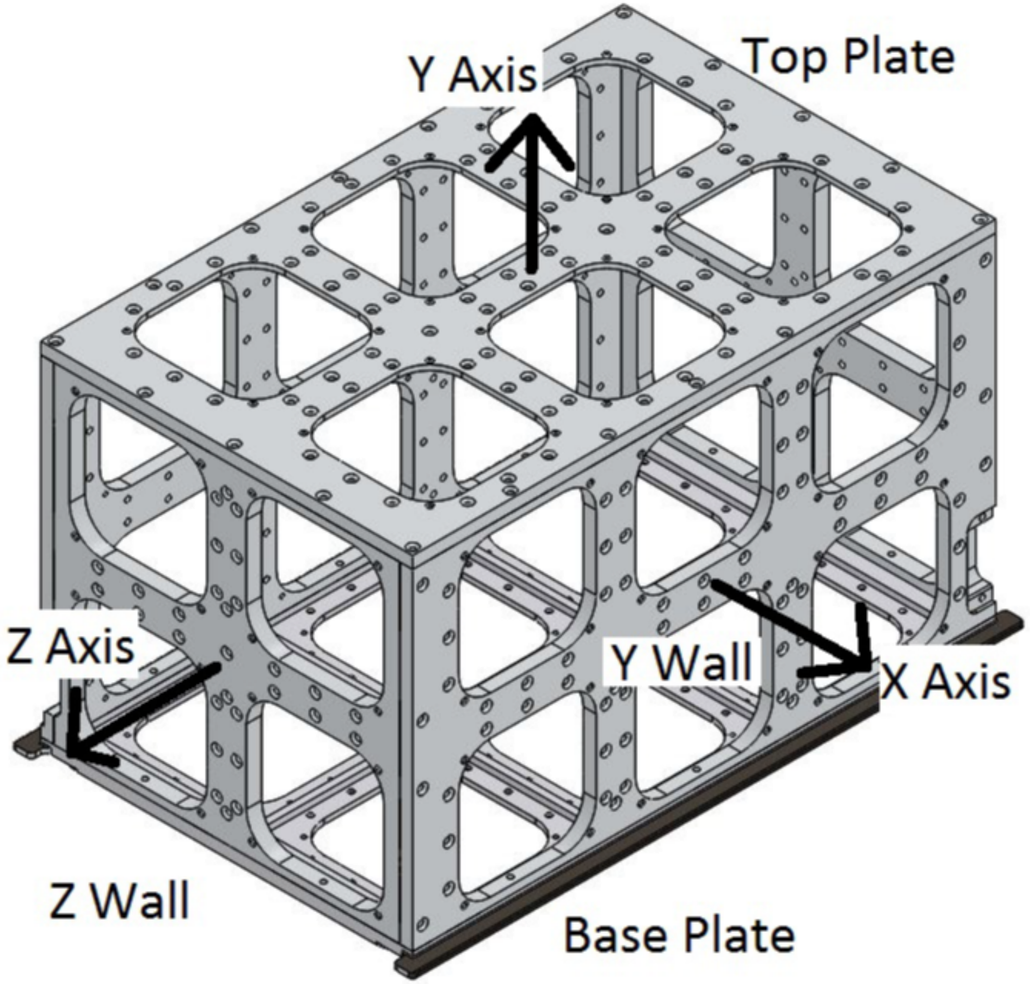
ID Material Properties
- Basquin Parameters
- Paris Law Parameters

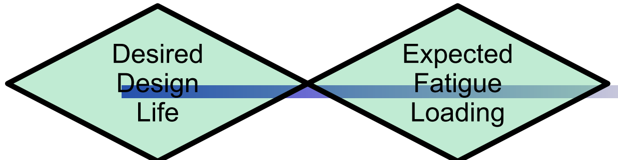


Use Case

- Demonstrating the application with a 12U CubeSat
- Design Life: $3x10^5$ Cycles
- Loading: NASA GEVS vibration profile
- Material: Aluminum

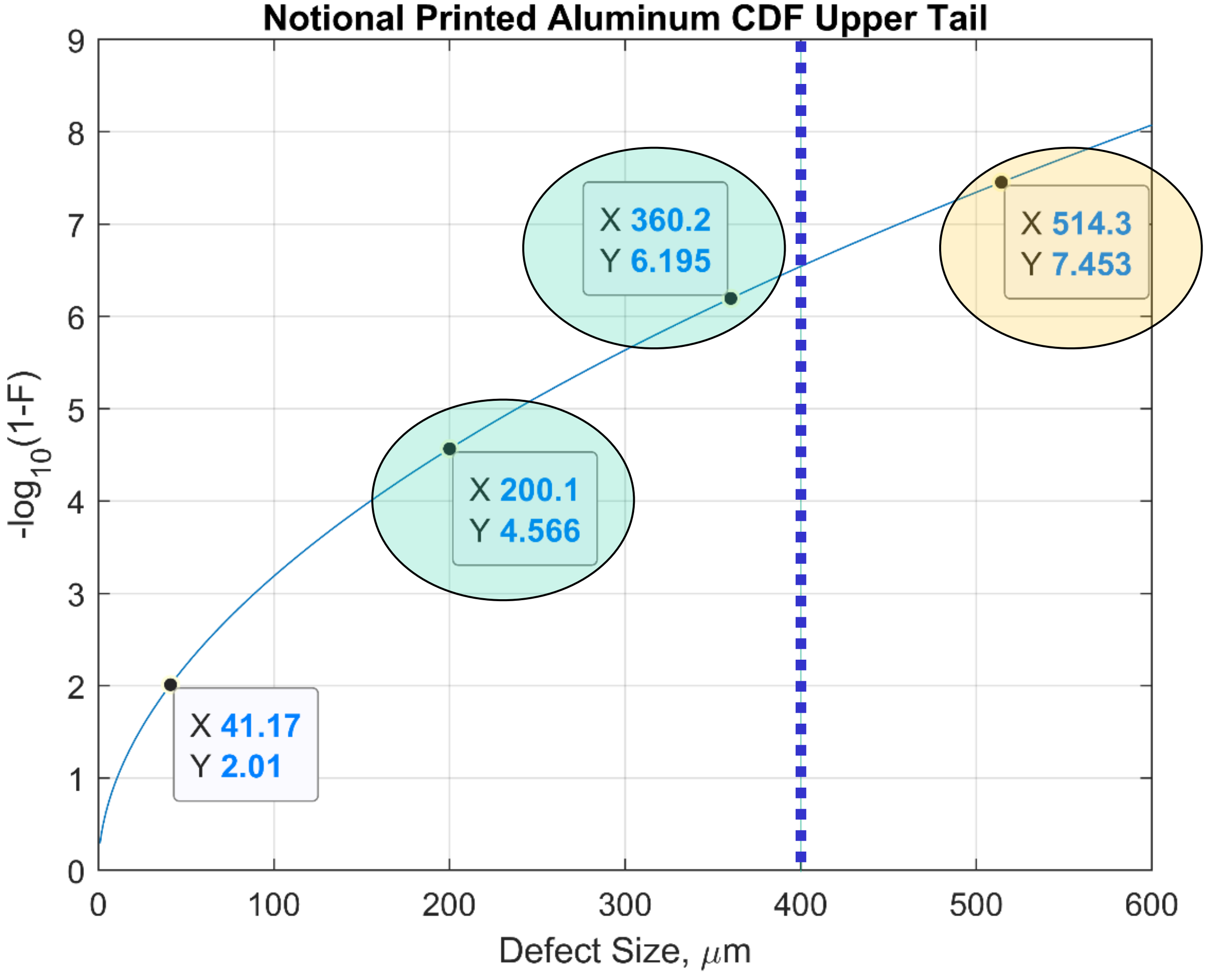
- Configurations:
  - Empty Chassis
  - 12 mass stacks for 24Kg total mass





Defect Populations

- Generate a defect distribution for the material of choice
- Potential methods to ID the largest expected defect
  - Statistical expectation
  - Historical data
- Set largest expected defect to 400μm
  - ~1 of 5 million defects
  - Larger than documented internal defects



(Maskery et al.,2016), (Beretta and Romano, 2017), (Wu et al., 2021), (Gumpinger et al., 2020)

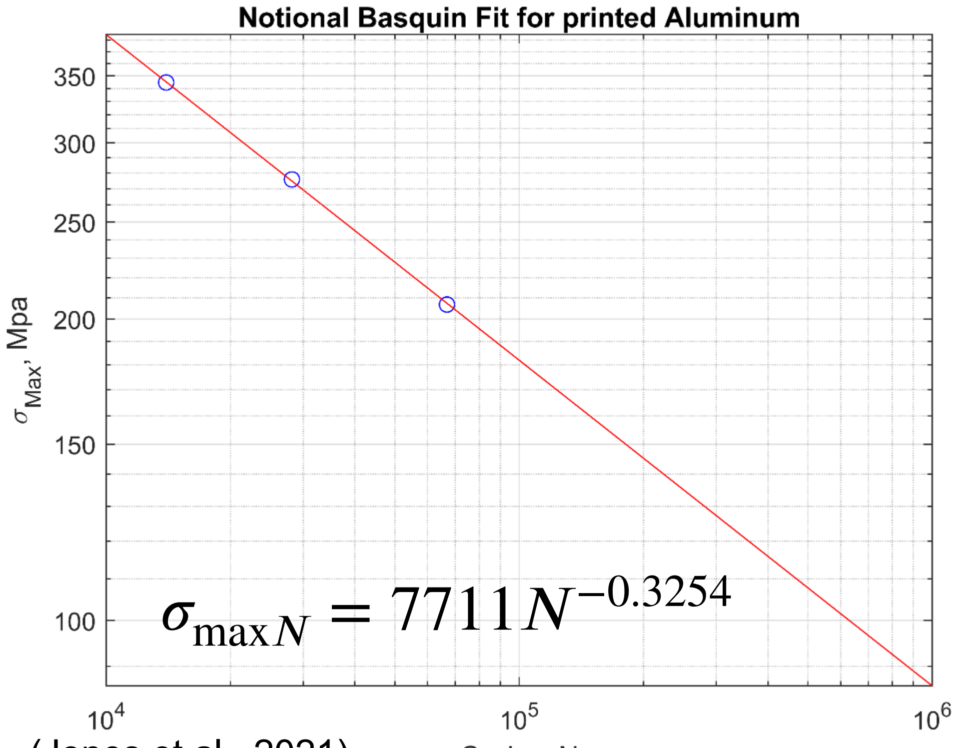
Maximum Defect Size Expected

Generate Defect Distributio n

Material Properties

- Basquin Law:

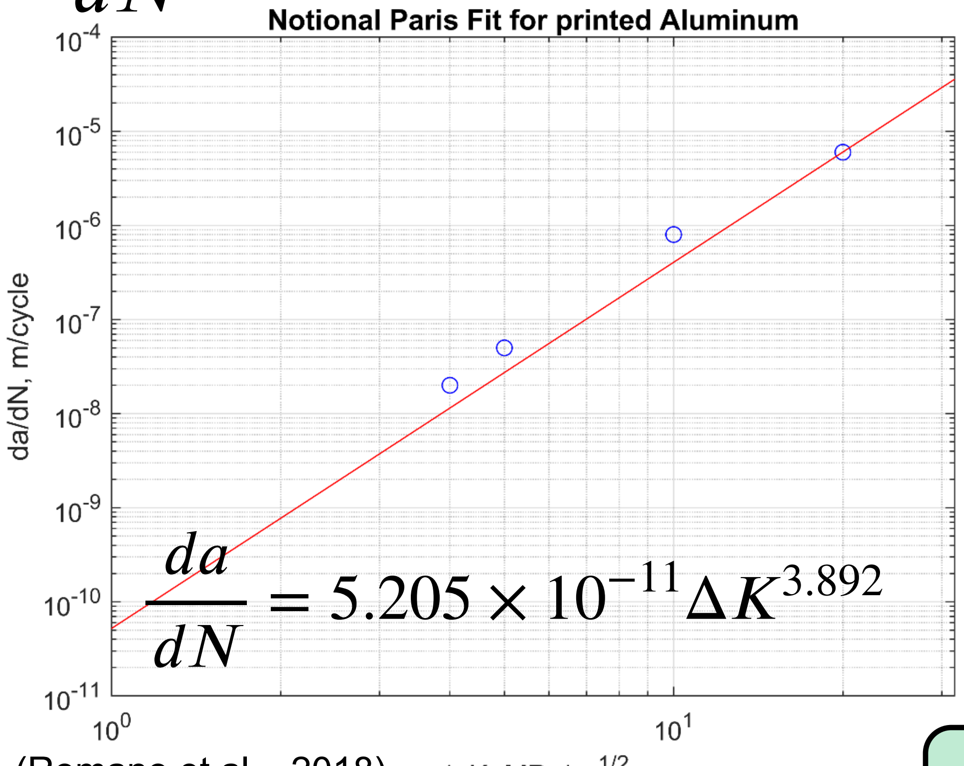
$$\sigma_{max_N} = (A)N^b$$



(Jones et al., 2021)

- Paris Law:

$$\frac{da}{dN} = C\,\Delta\,K^n$$



(Romano et al., 2018)

Finite Life El-Haddad Model

Finite Fatigue Life Model

The AFIT of Today is the Air Force of Tomorrow.

$$\Delta\sigma = \Delta\sigma_{0,N}\sqrt{\frac{a_{0,N}}{a + a_{0,N}}}$$

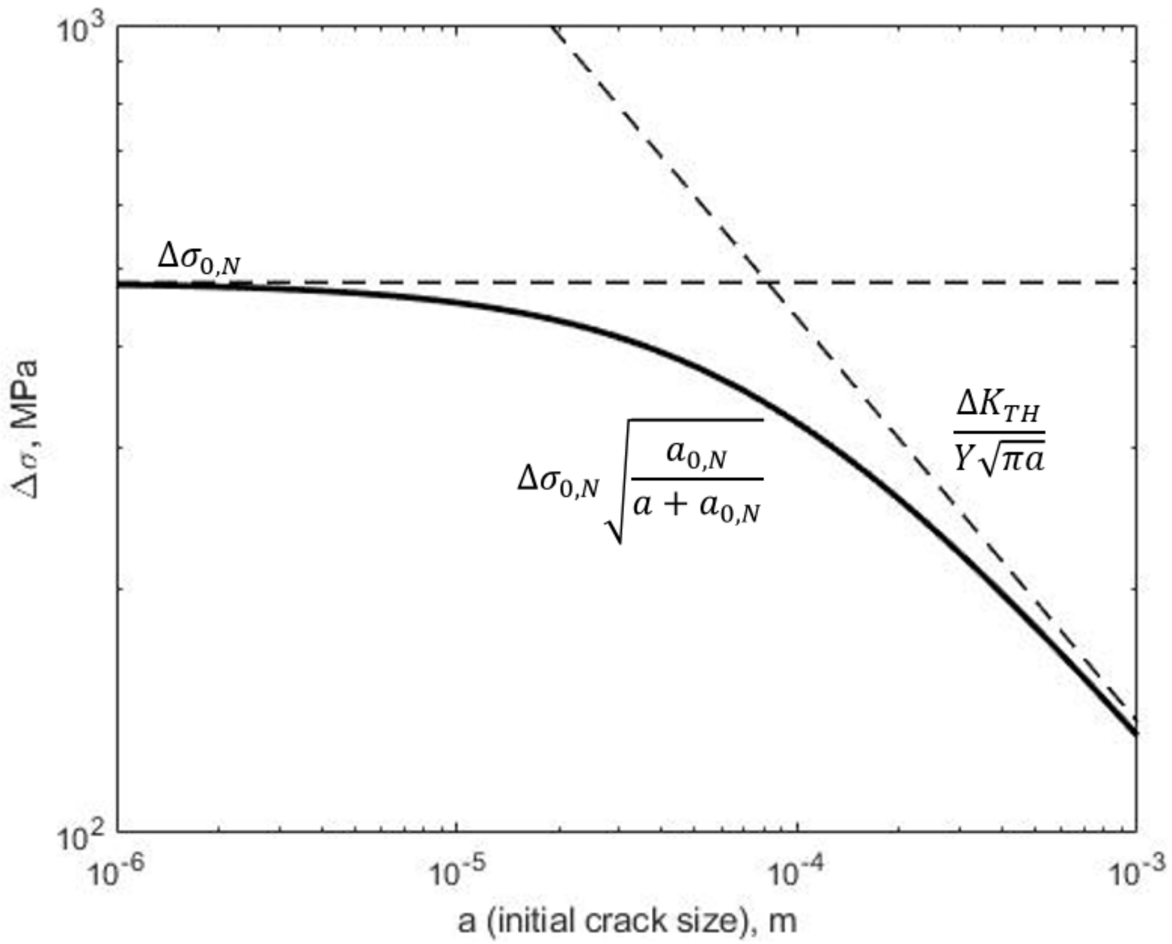
$$\Delta\sigma_{0,N} = A(1-R)N^{b}$$

$$a_{0,N} = \left(a_c^{1-\frac{n}{2}} - N\left(1-\frac{n}{2}\right)C_0\left(Y\Delta\sigma_{0,N}\sqrt{\pi}\right)^{n}\right)^{\frac{1}{1-\frac{n}{2}}}$$

Design Variables:

- Applied Stress Range - $\Delta\sigma$
- Defect of interest - a
- Design Life – N

Pick 2, solve for the third

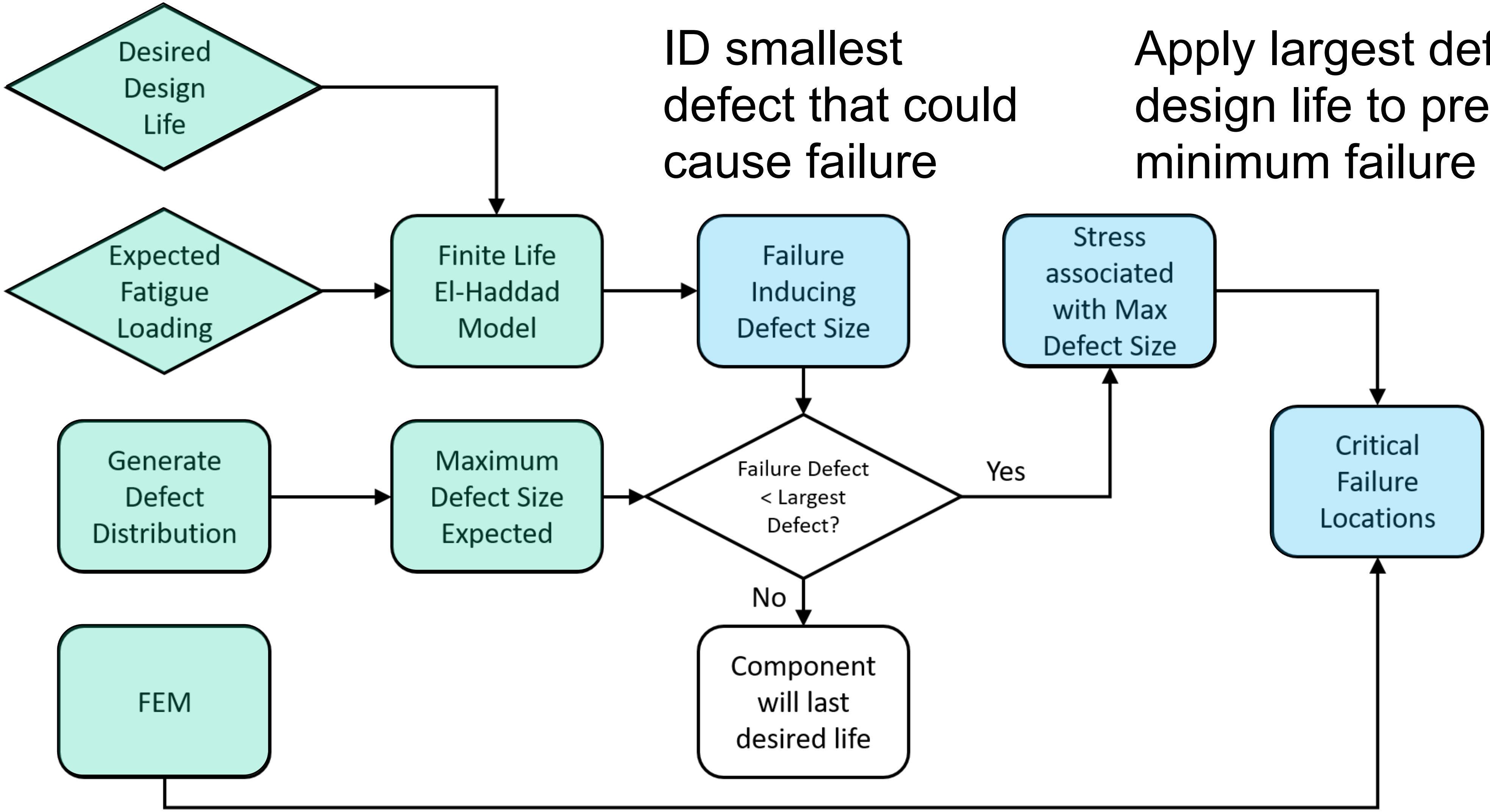


Finite Life El-Haddad Model

Fatigue Failure Method

ID smallest defect that could cause failure

Apply largest defect and design life to predict minimum failure stress



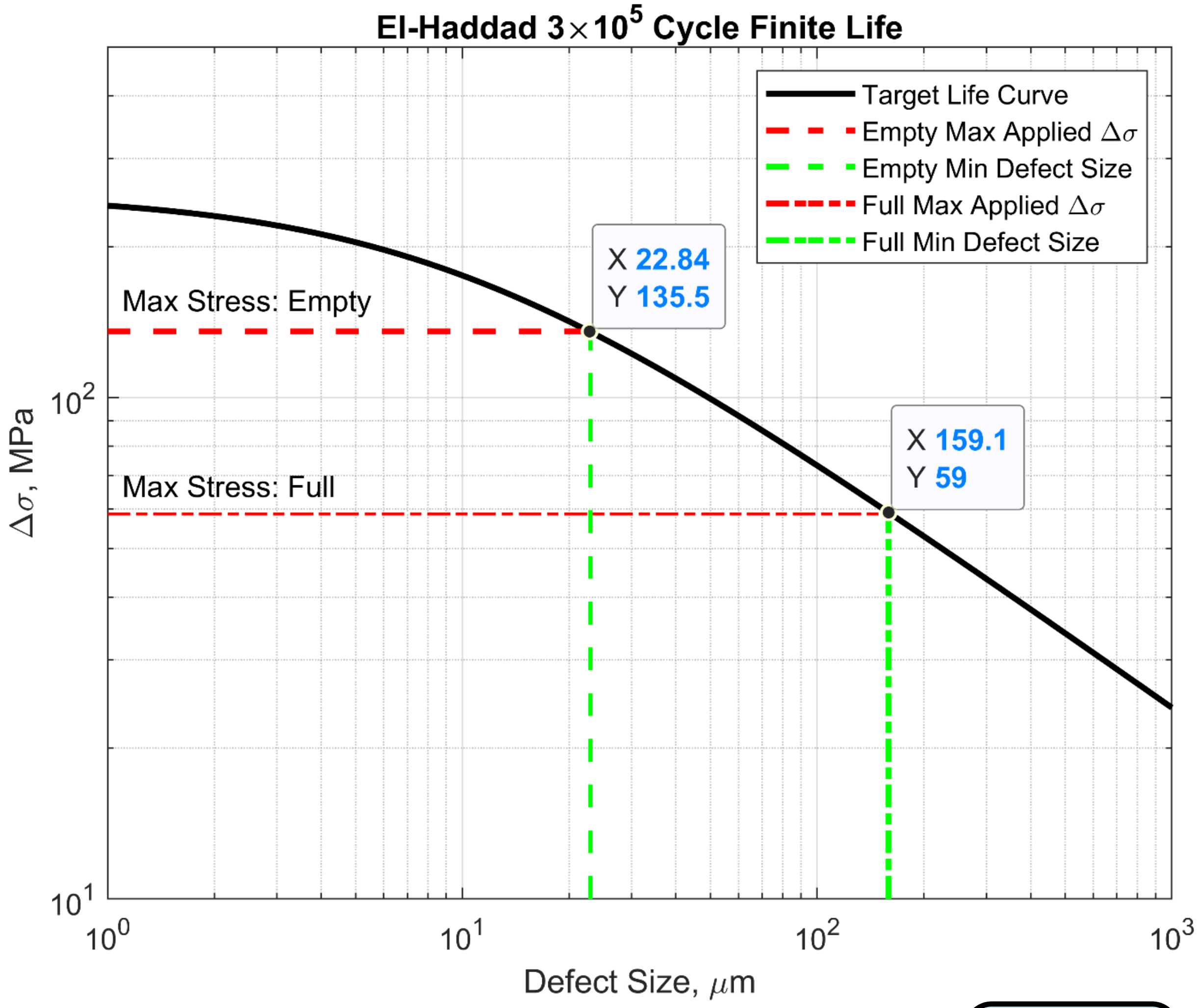
Map stress ranges to FEM

Predict failure locations

Minimum Failure Defect of Interest

- Input
  - Design Life
  - Max Stress
- Output
  - Smallest defect predicted to cause failure

Changing the structure has a large impact on critical defect sizes

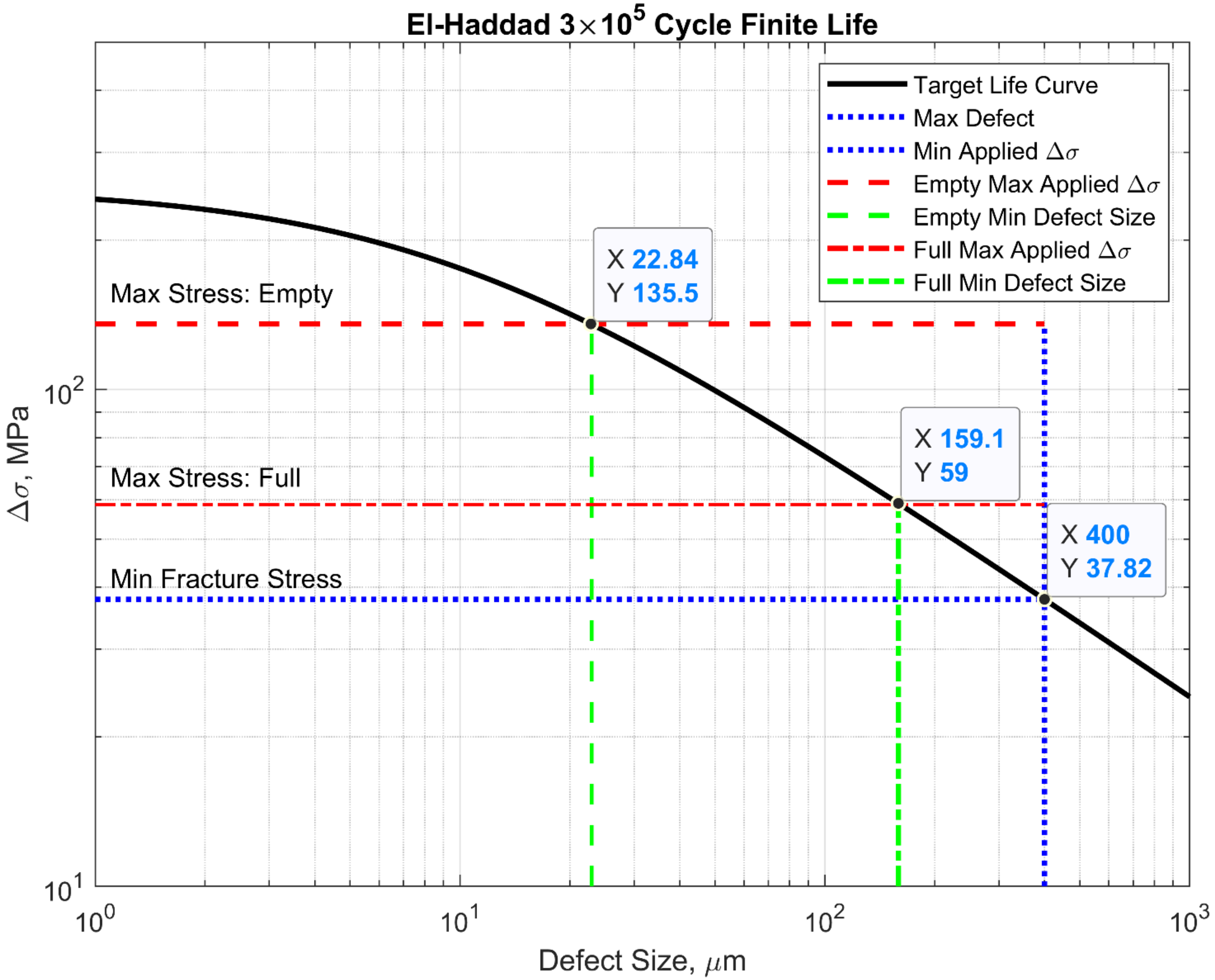


Failure Inducing Defect Size

Minimum Failure Stress of Interest

- Input
  - Design Life
  - Largest Expected Defect
- Output
  - Smallest stress with potential to cause failure

Triangle above the El-Haddad curve predicts defect size and stress combinations that lead to early failure

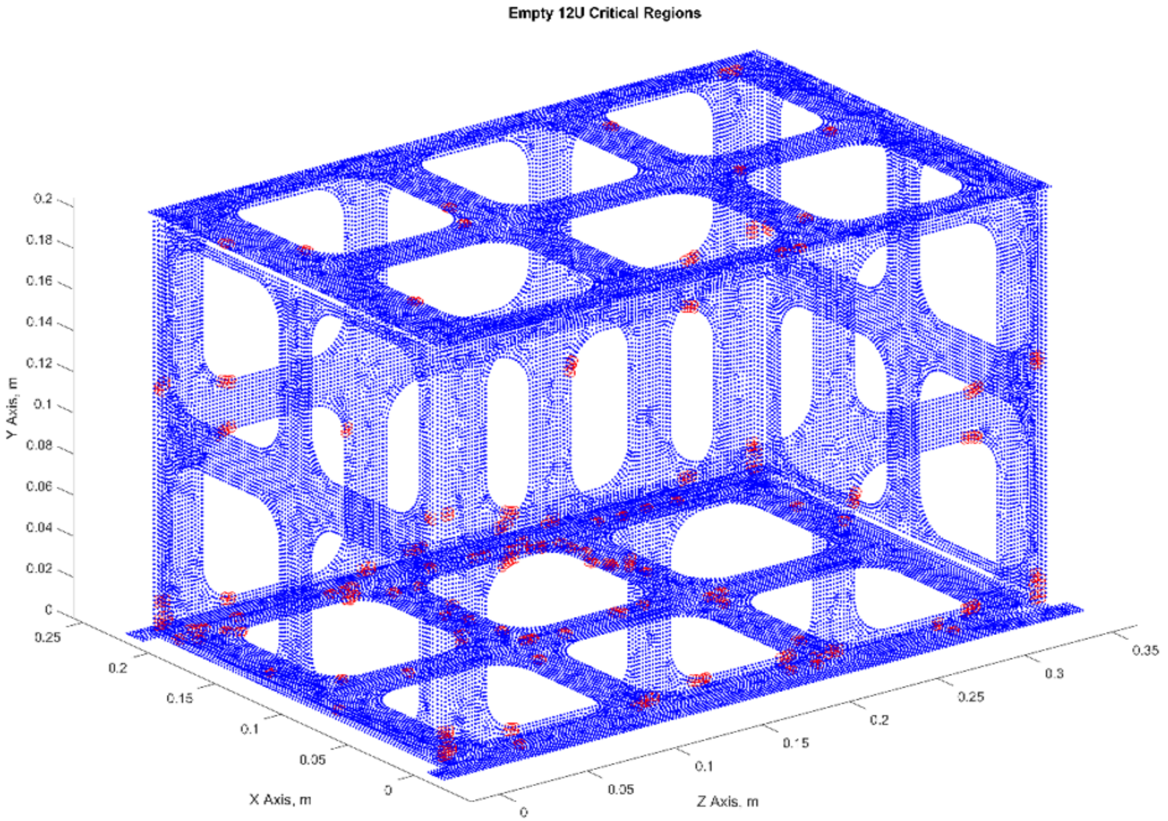


Stress associated with Max Defect Size

CubeSat Critical Failure Areas

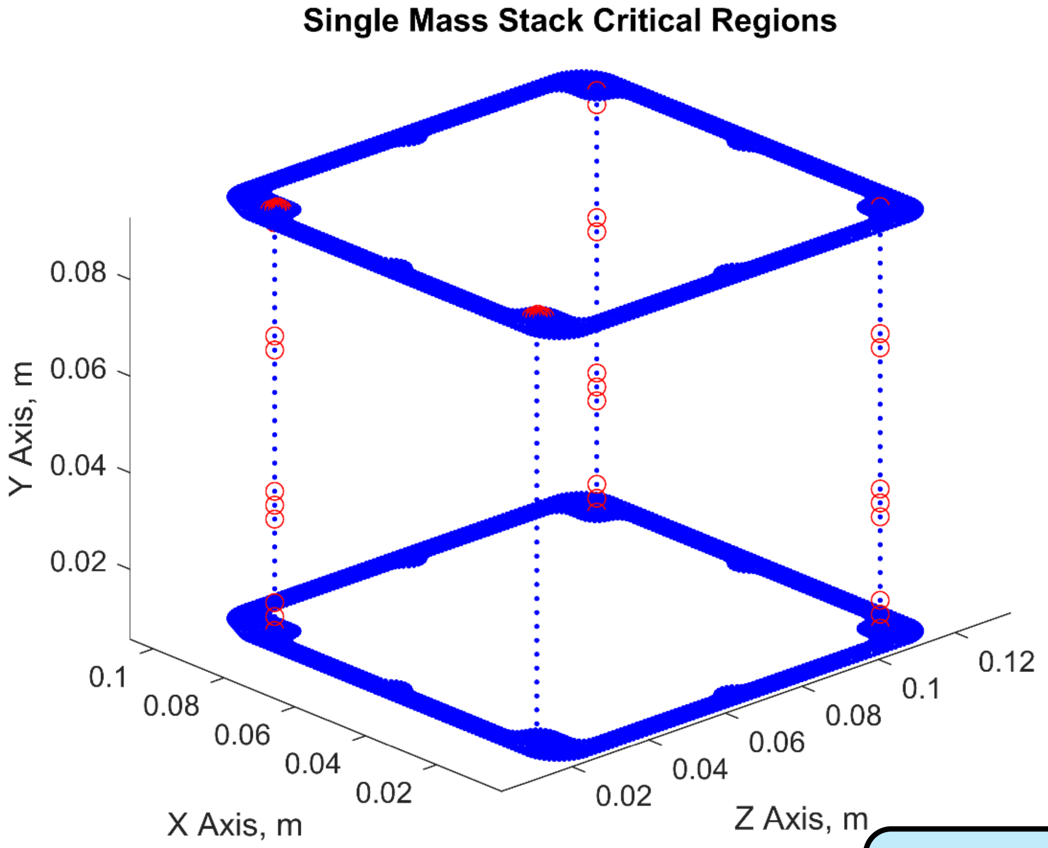
Empty 12U predicted potential failure locations at:

- Screws
- Curve changes
- Thickness transitions



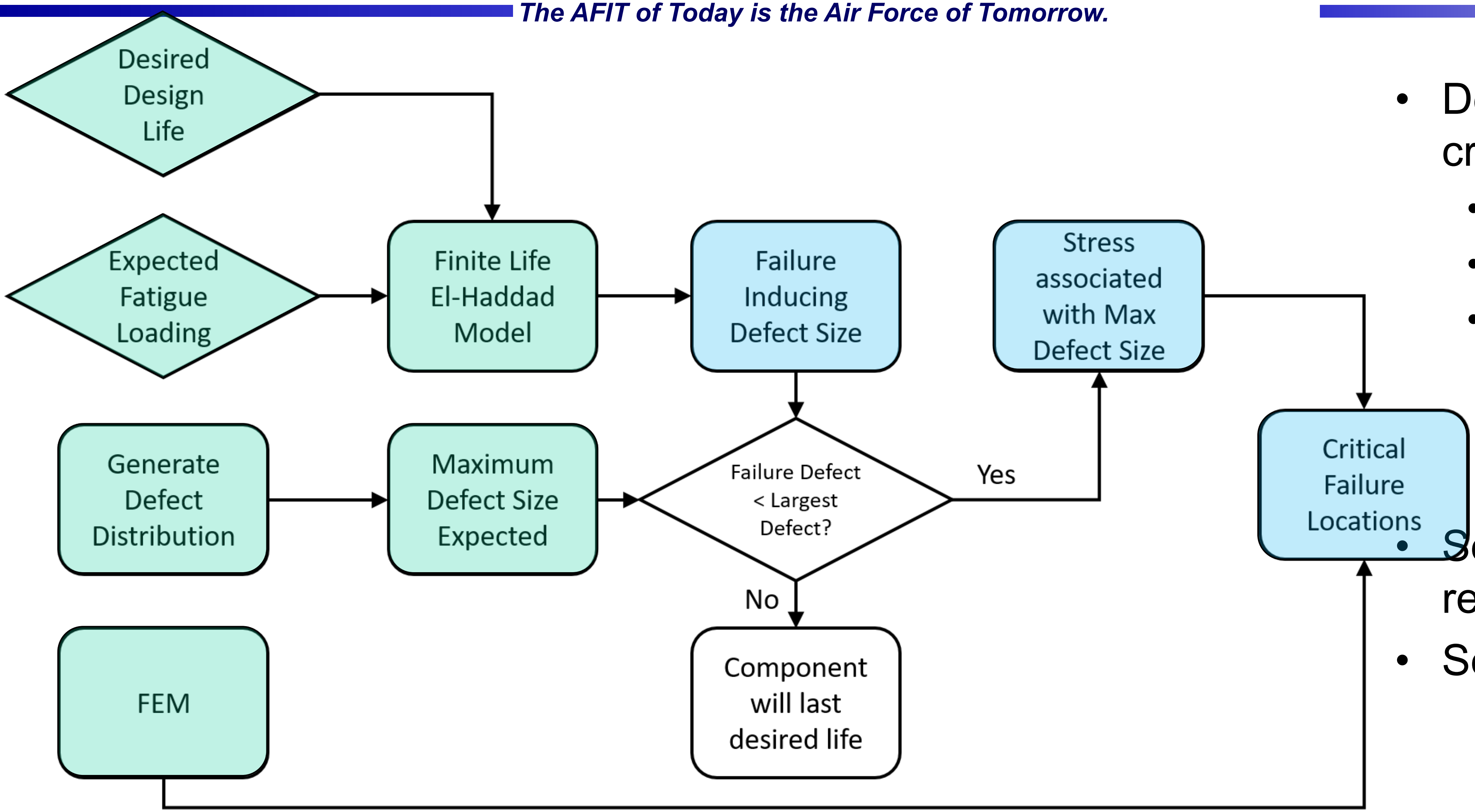
Full 12U predicted potential failure locations at:

- Mass Stacks



Critical Failure Locations

Summary



- Defined inspection criteria based on
  - Geometry
  - Material
  - Mission
- Sets inspection resolution
- Sets regions of interest

Questions?

References

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2) S Romano, A Br¨uckner-Foit, A Brandao, J Gumpinger, T Ghidini, and S Beretta. Fatigue properties of alsi10mg obtained by additive manufacturing: Defect-based modelling and prediction of fatigue strength. Engineering Fracture Mechanics, 187:165–189, 2018.
3) Ian Maskery, NT Aboulkhair, MR Corfield, Christopher Tuck, AT Clare, Richard K Leach, Ricky D Wildman, IA Ashcroft, and Richard JM Hague. Quantification and characterization of porosity in selectively laser melted al-si10-mg using x-ray computed tomography. Materials Characterization, 111:193–204, 2016.
4) S. Beretta and S. Romano. A comparison of fatigue strength sensitivity to defects for materials manufactured by am or traditional processes. International Journal of Fatigue, 94:178–191, 2017. Fatigue and Fracture Behavior of Additive Manufactured Parts.
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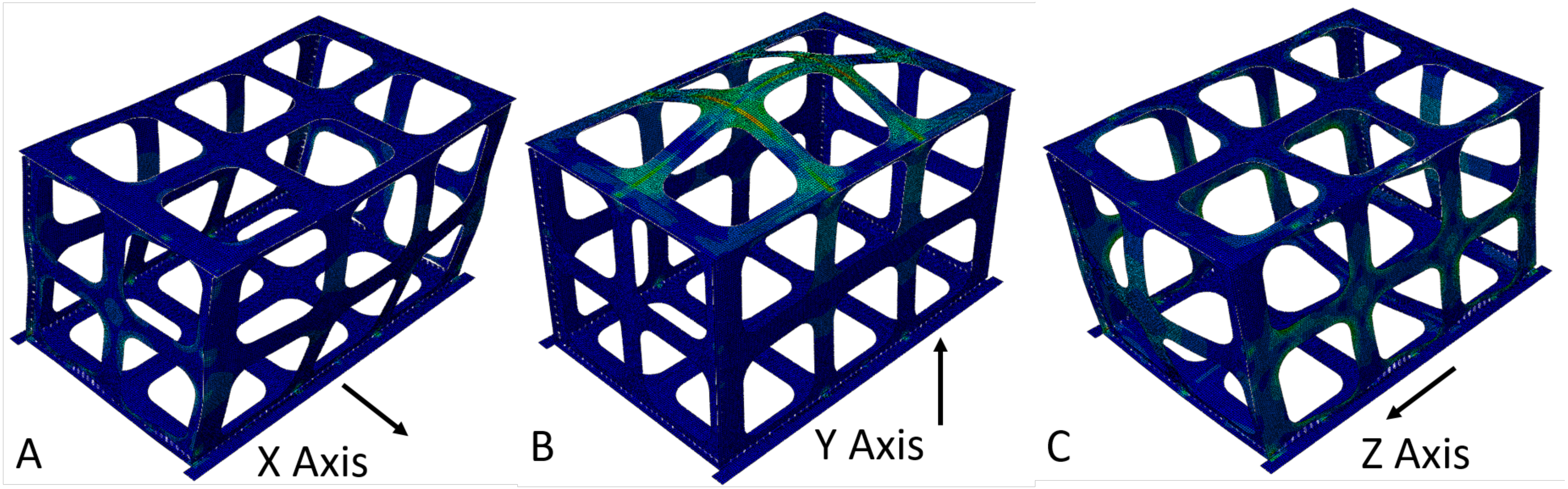
6) Johannes Gumpinger, Ana D Brand˜ao, Emilie Beevers, Thomas Rohr, Tommaso Ghidini, Stefano Beretta, and Simone Romano. Expression of Additive Manufacturing Surface Irregularities Through a Flaw-Based Assessment. ASTM International, 2020.

Stress Map

- Primary axial frequencies from 20-2000 Hz
- Creates the relationship between location and stress



FEM