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Richard G. Lugar Center for Renewable Energy

Purveyors of
Space Solar Power

# Overcoming the GEO WPT Show-Stopper

presented by

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to the Judges of the
International Space Solar Power Student Competition
International Space Development Conference 2019

# Introduction

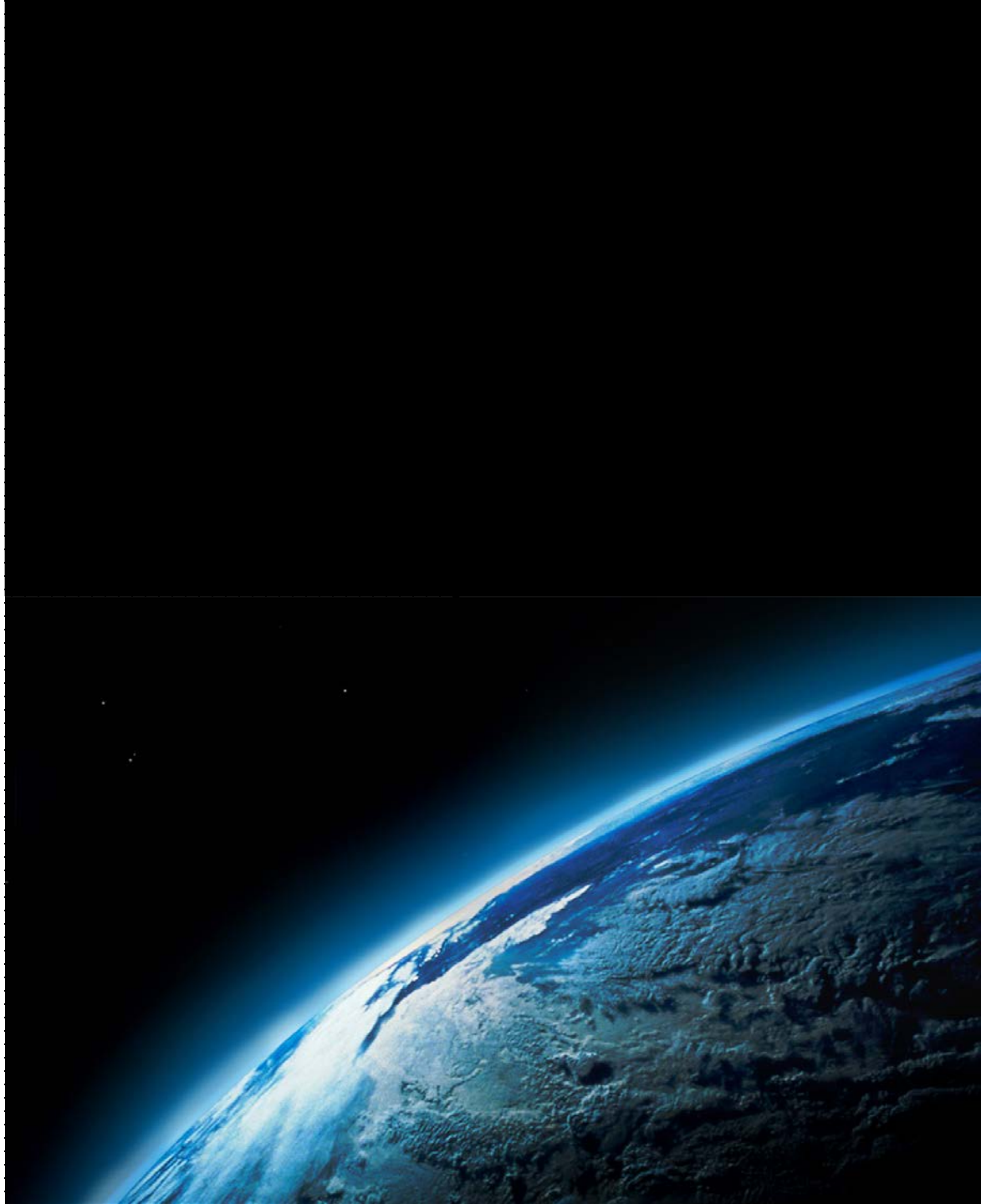
*Areas of Focus:*

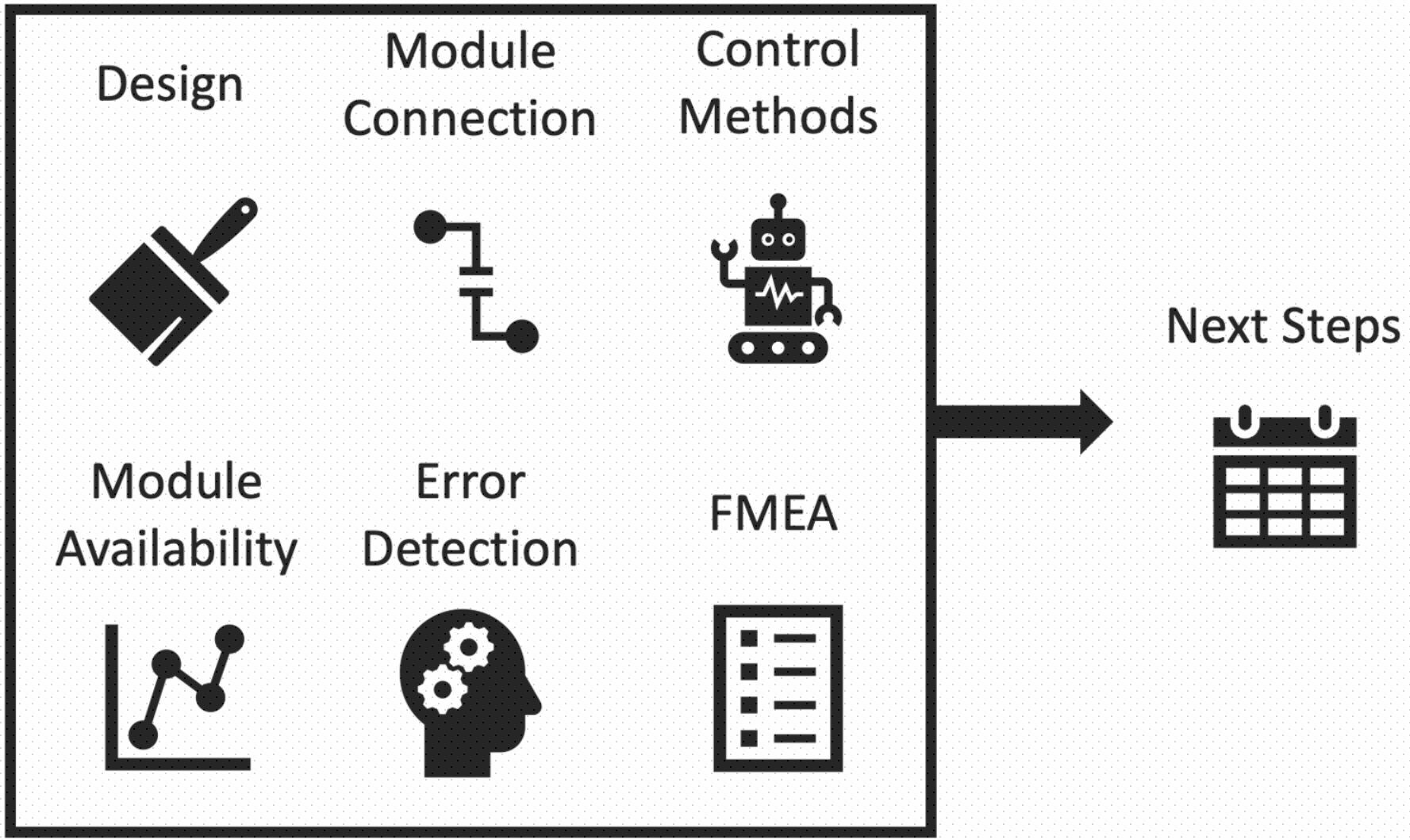
1. Layout & Spacing of Spacetenna Design
2. Error Detection and Repair
3. Minimization of Askew Angles Between Adjacent Sandwich Modules

*Goal:*

- Side Lobe Levels (SLL) less than **-112 dBm / -82 dB**
- Good for Bluetooth, IEEE 802.11, IEEE 802.15.4, and radios

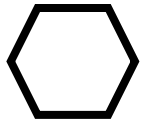
per McSpadden, IEEE Wireless Power Transfer Conference 2015




Design
Module Connection
Control Methods
Module Availability
Error Detection
FMEA
Next Steps

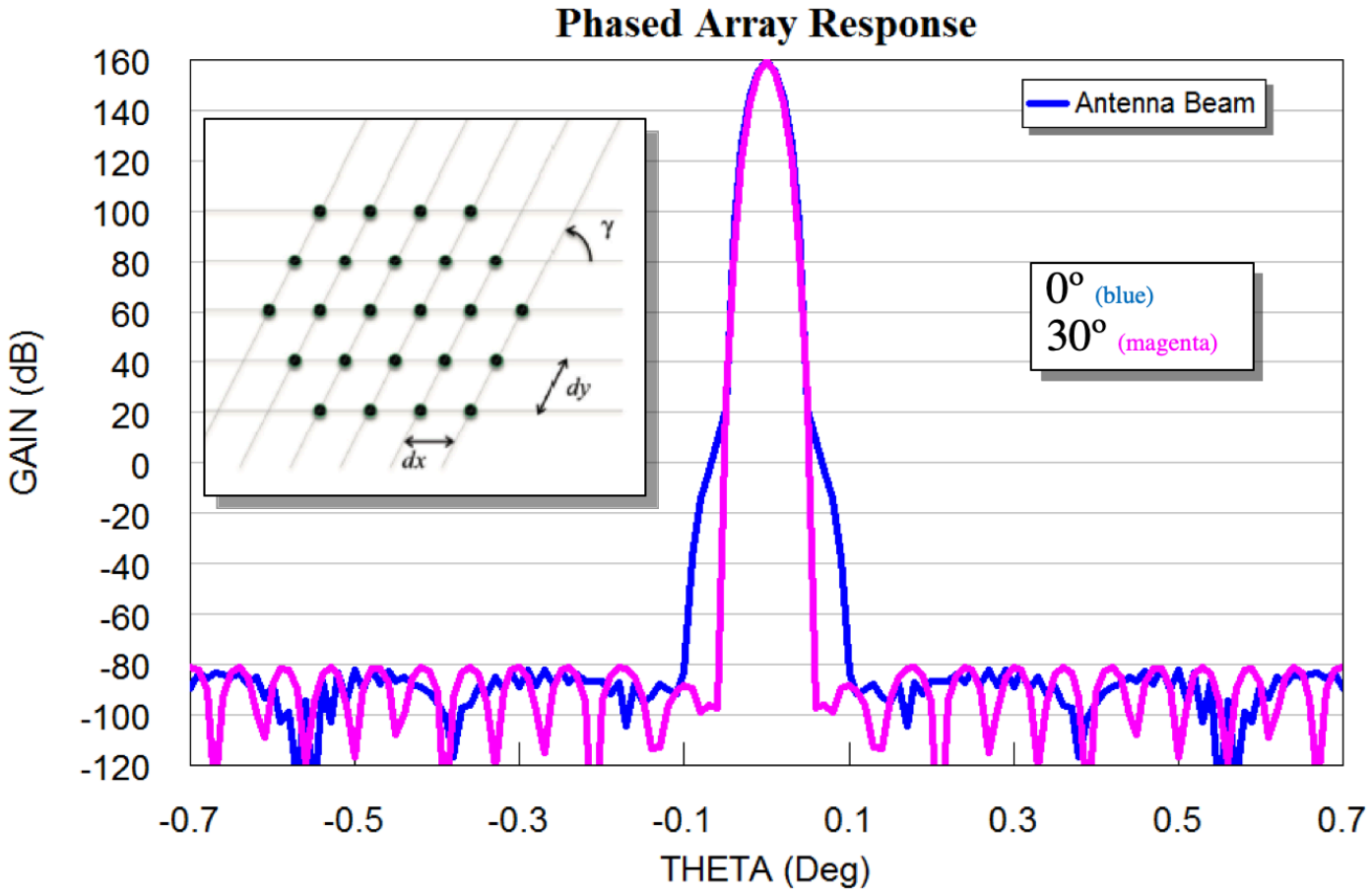
# SLL Breakthrough

Hexagonal perimeter



Symmetry every 60º

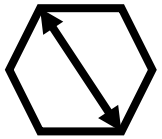
Many Components




Schubert, P., “SIDELOBE REDUCTION FOR GEO TO EARTH WIRELESS POWER TRANSFER”, paper **IAC-16.C3.2.3**, International Astronautical Conference 2016. Guadalajara, MX.

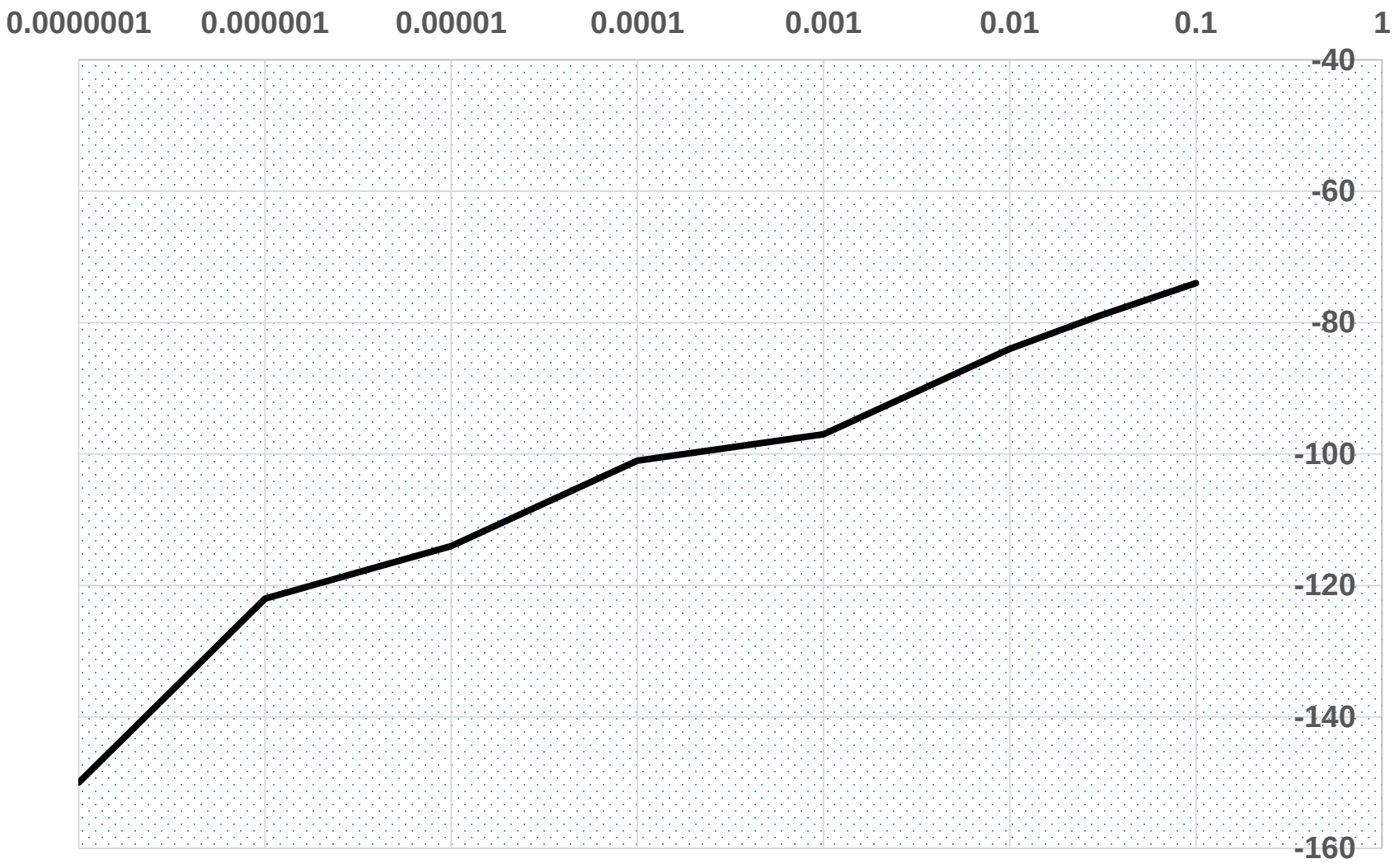
# Side Lobe Level vs Element Error Fraction

950m diameter spacetenna



Randomized failures

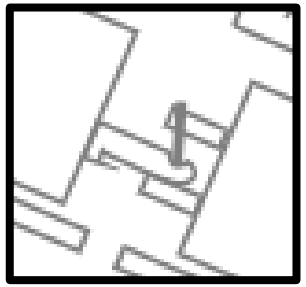
NI VSS Tool



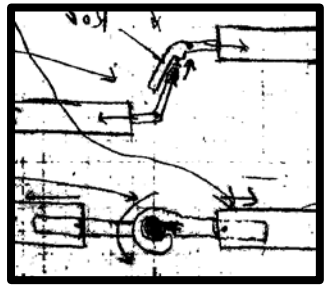

** All errors at this level or lower are -240 dB*

# Module Connection

## Railroad Coupling

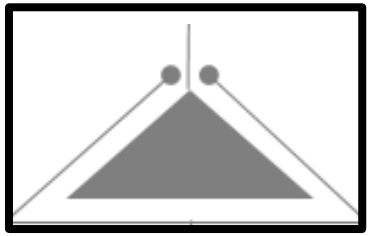


## Mechanical hand

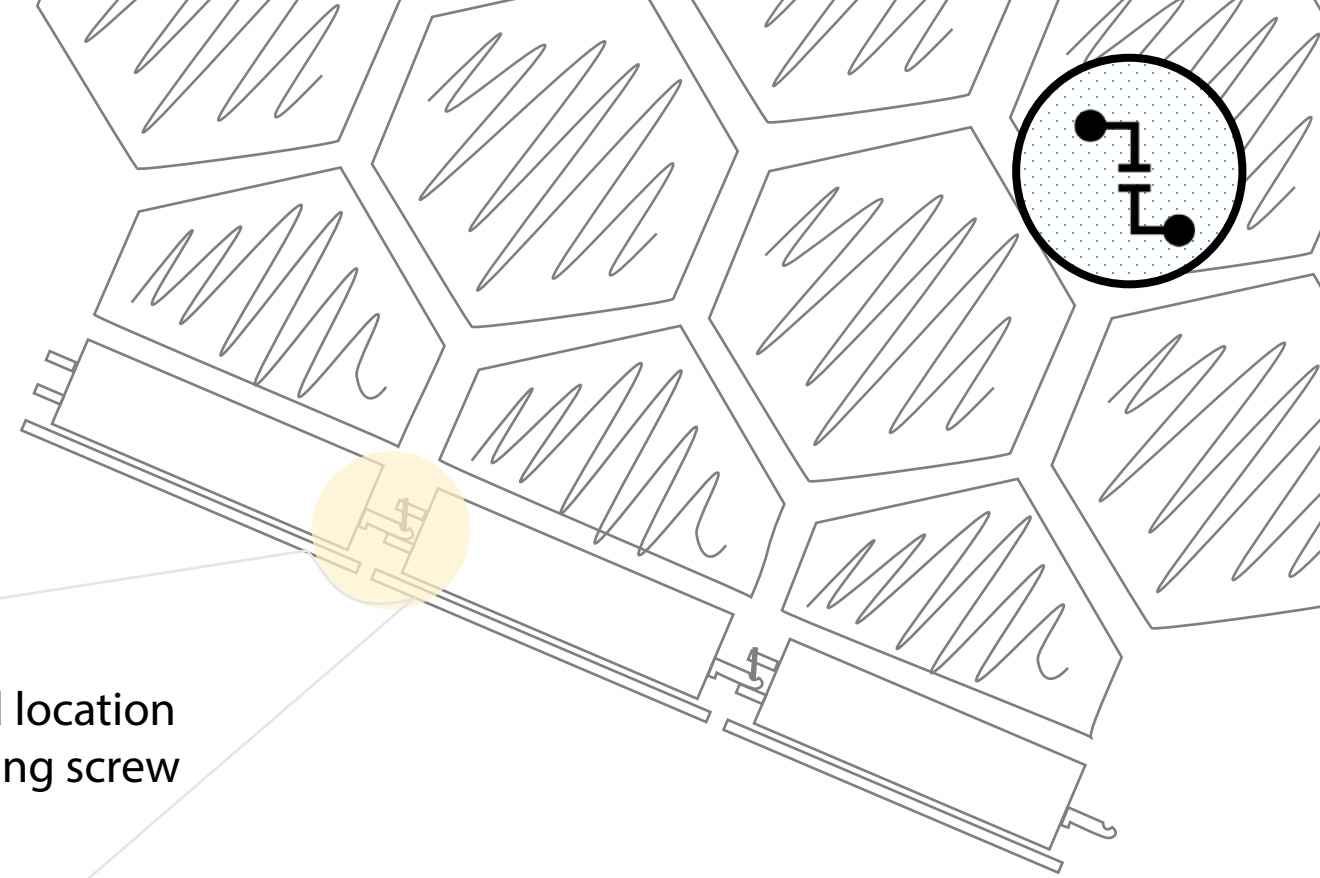


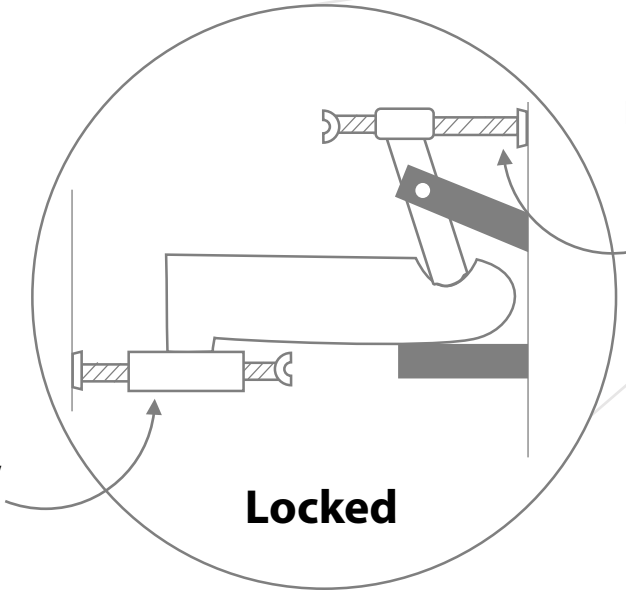
## Flying tab

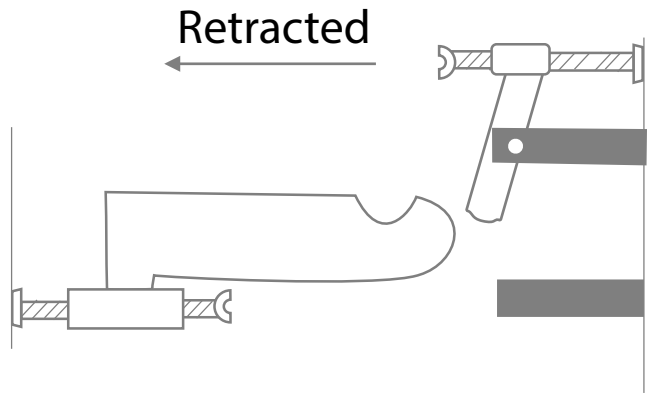
## Binder clip



# Railroad Inspired Coupling Design

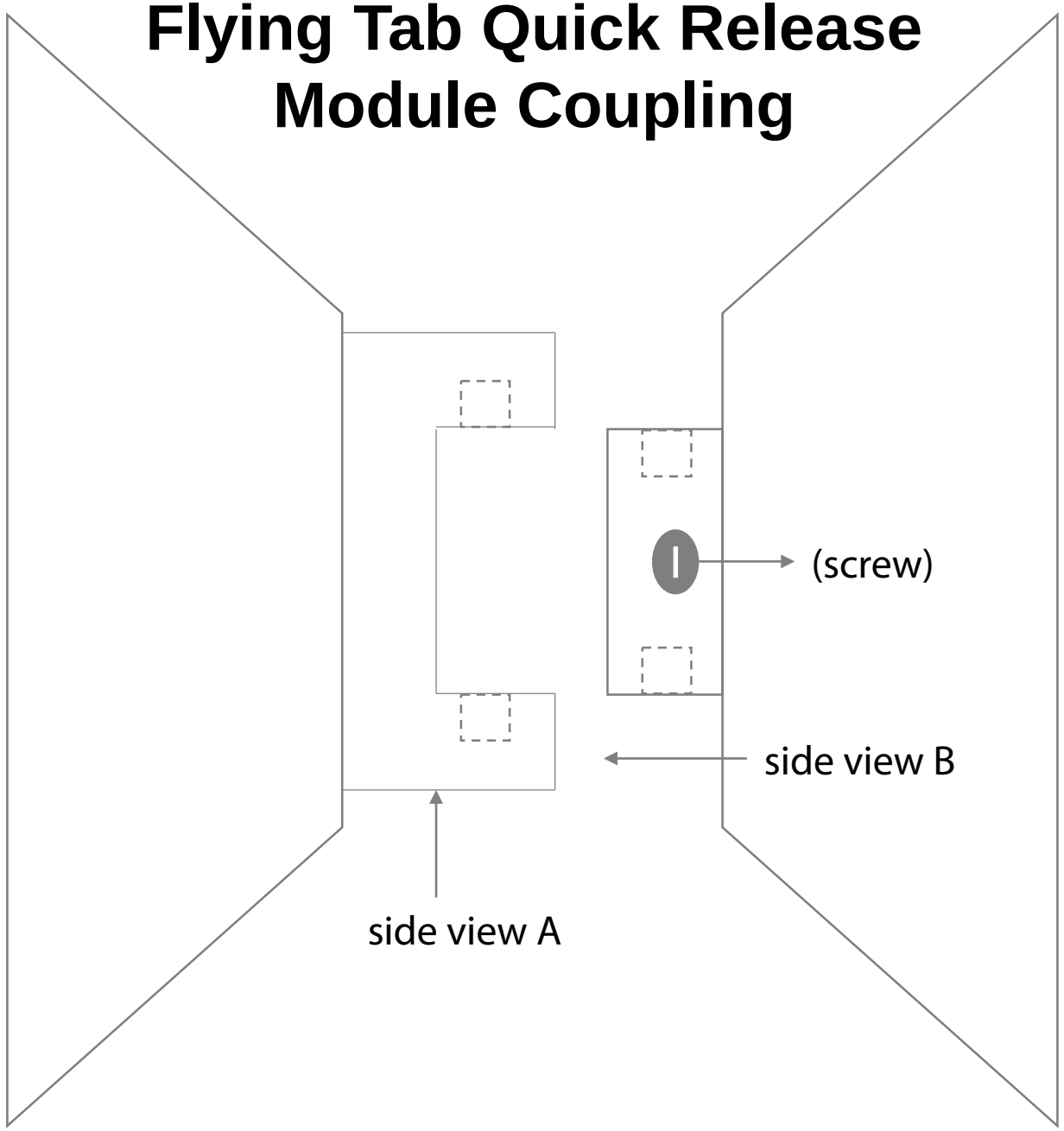




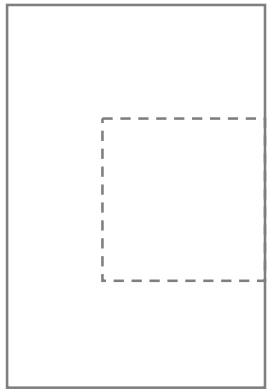

**Unlocked**

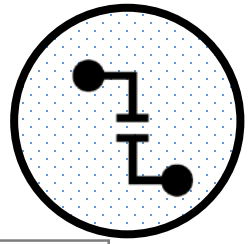
# Flying Tab Quick Release Module Coupling



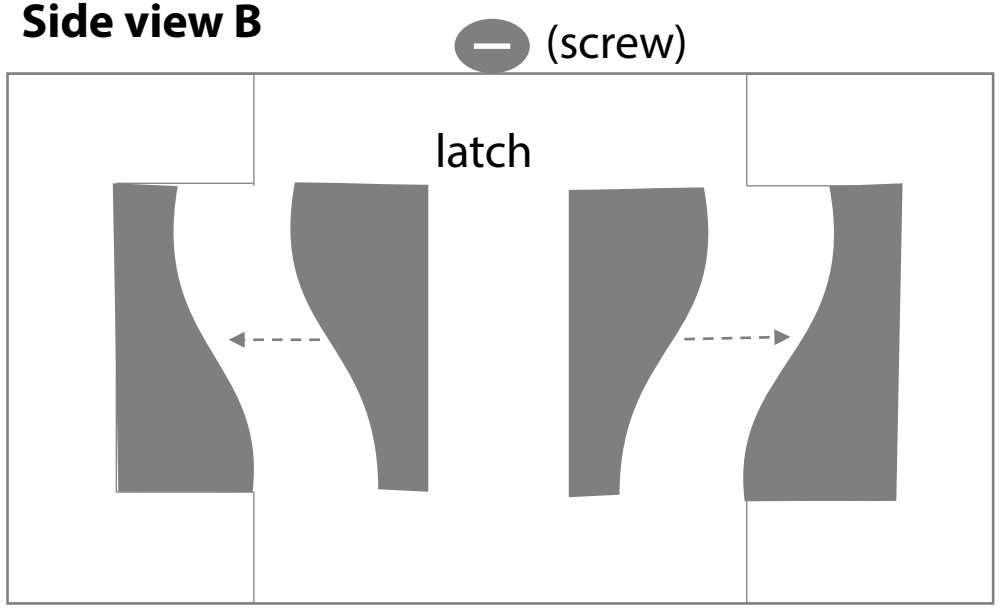

**Lock System**

**Side view A**



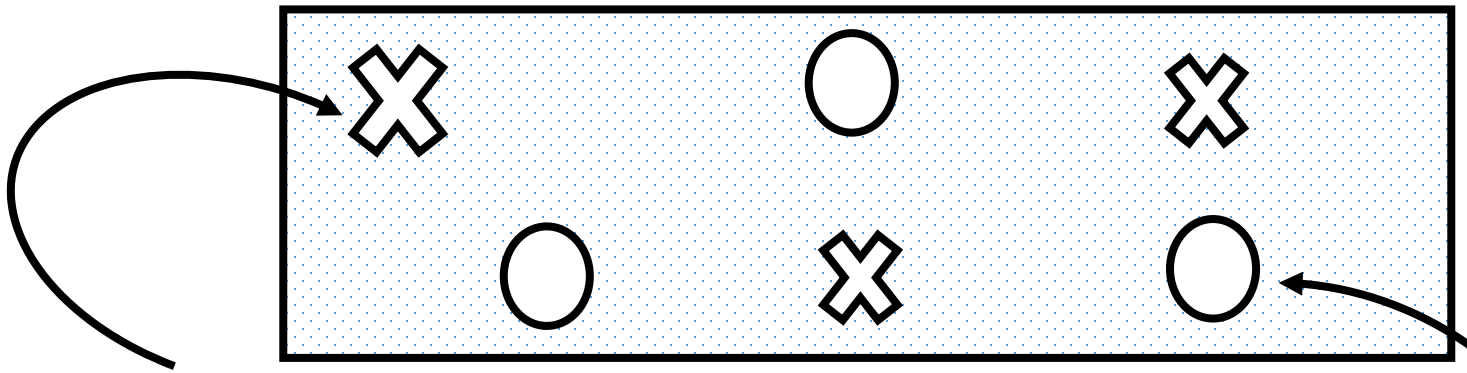


**Side view B**

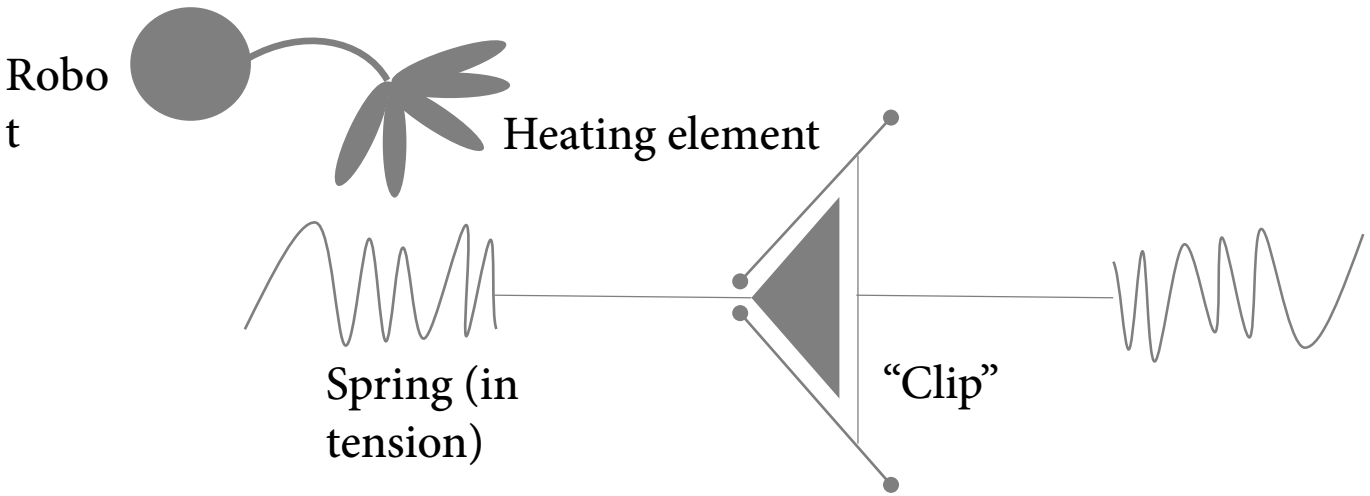


# Binder Clip Inspired Coupling

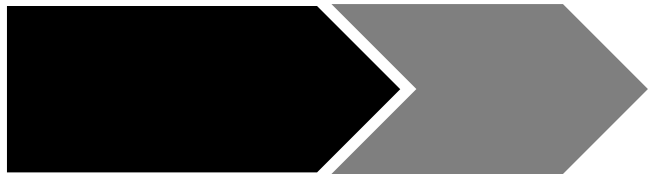
**Cross section of hexagon side**



**“Clip” Connections**

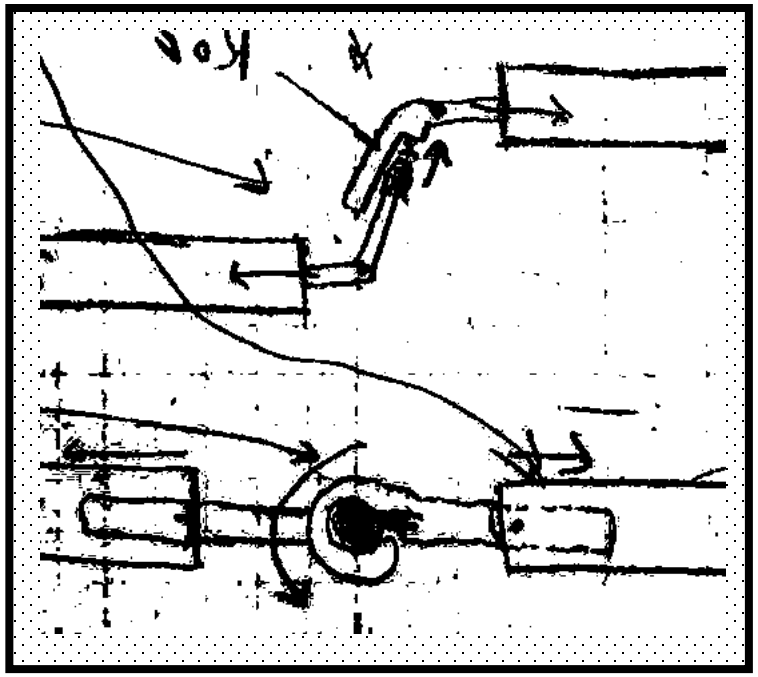



“Wire” Connections



In compression

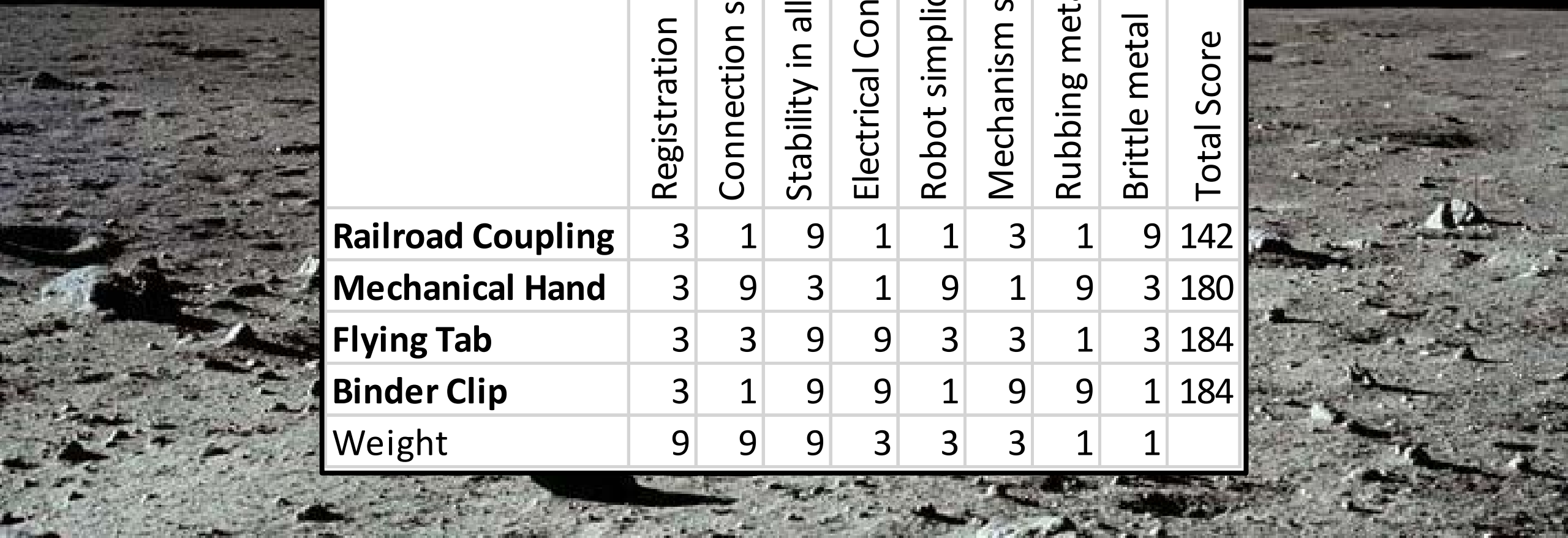
# Mechanical hand inspired coupling



Side view of two sandwich modules connecting

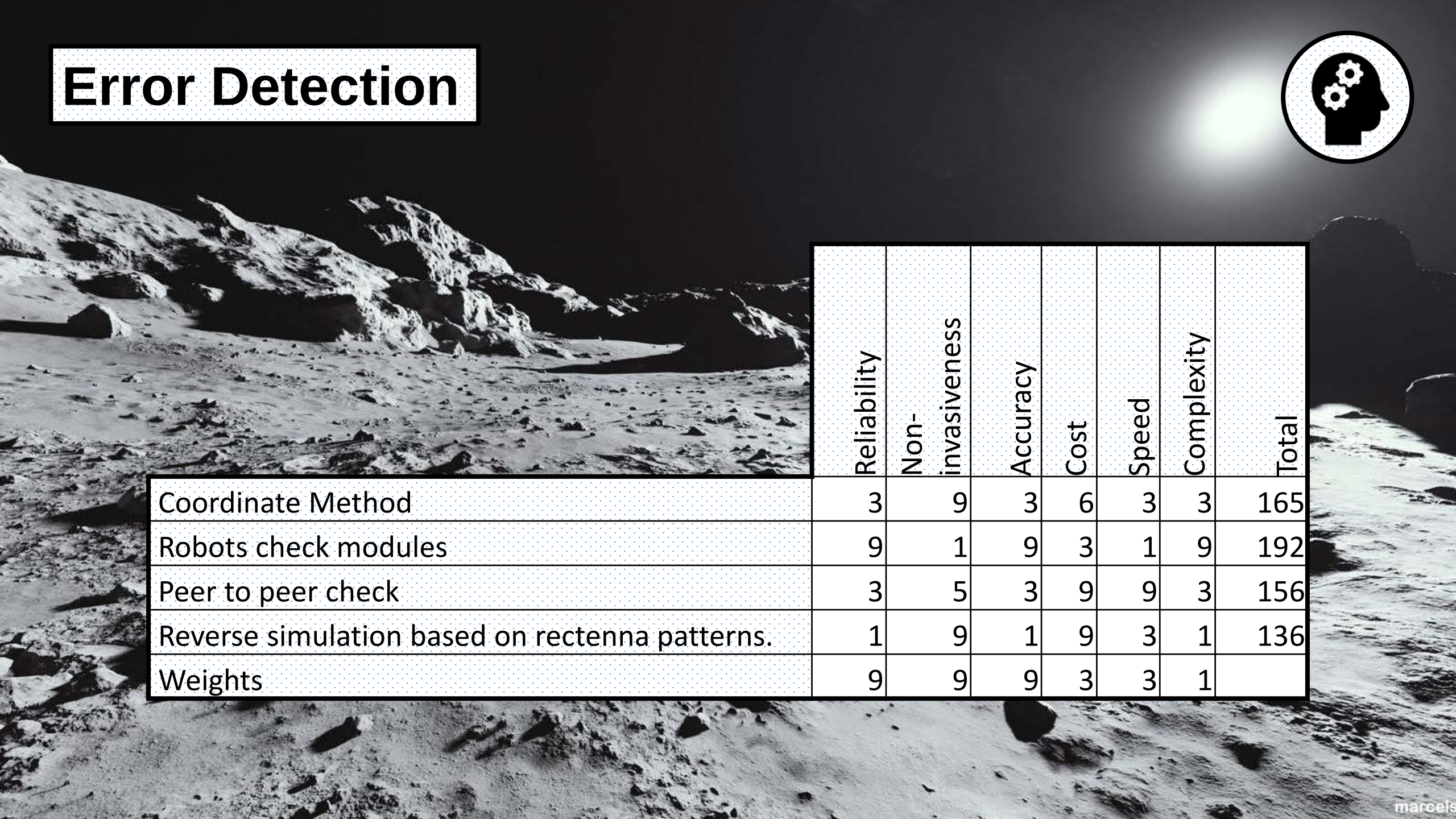
Mechanical analogy

# Connection Analysis Chart



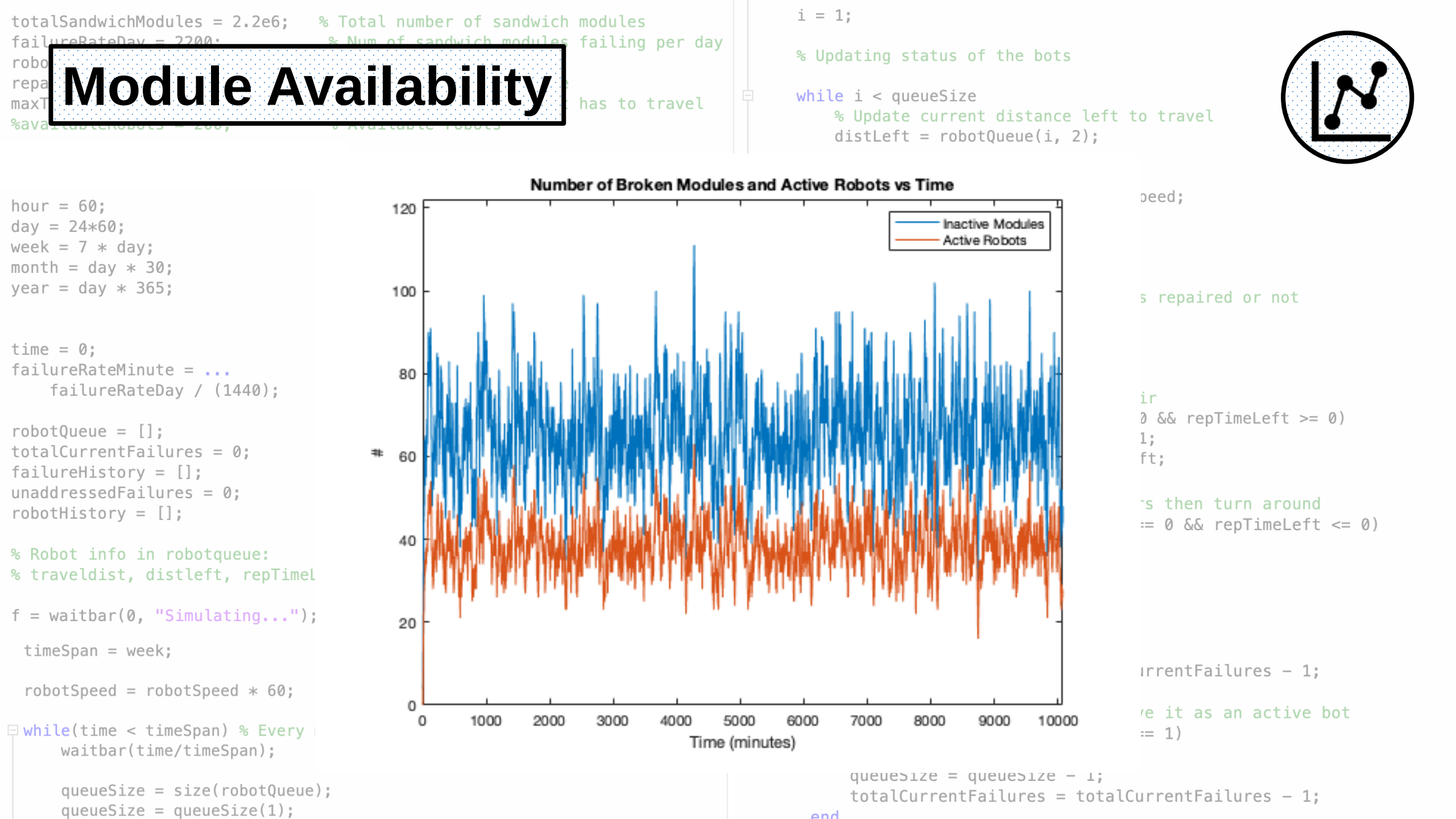
| | Registration | Connection speed | Stability in all axes | Electrical Connection | Robot simplicity | Mechanism simplicity | Rubbing metal | Brittle metal | Total Score |
|---|---|---|---|---|---|---|---|---|---|
| **Railroad Coupling** | 3 | 1 | 9 | 1 | 1 | 3 | 1 | 9 | 142 |
| **Mechanical Hand** | 3 | 9 | 3 | 1 | 9 | 1 | 9 | 3 | 180 |
| **Flying Tab** | 3 | 3 | 9 | 9 | 3 | 3 | 1 | 3 | 184 |
| **Binder Clip** | 3 | 1 | 9 | 9 | 1 | 9 | 9 | 1 | 184 |
| Weight | 9 | 9 | 9 | 3 | 3 | 3 | 1 | 1 | |

# Error Detection

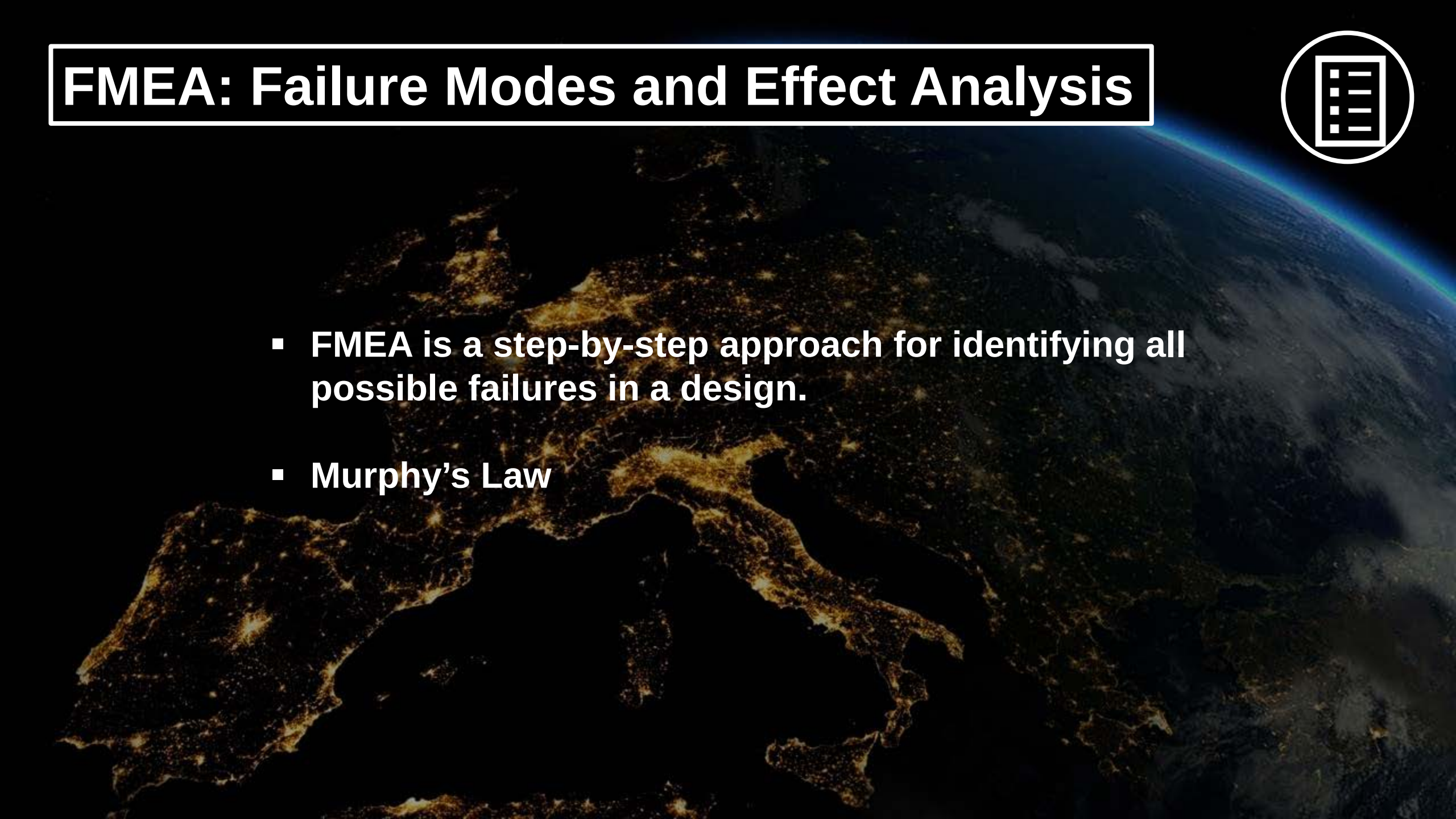


| | Reliability | Non-invasiveness | Accuracy | Cost | Speed | Complexity | Total |
|---|---|---|---|---|---|---|---|
| Coordinate Method | 3 | 9 | 3 | 6 | 3 | 3 | 165 |
| Robots check modules | 9 | 1 | 9 | 3 | 1 | 9 | 192 |
| Peer to peer check | 3 | 5 | 3 | 9 | 9 | 3 | 156 |
| Reverse simulation based on rectenna patterns. | 1 | 9 | 1 | 9 | 3 | 1 | 136 |
| Weights | 9 | 9 | 9 | 3 | 3 | 1 | |

# Module Availability



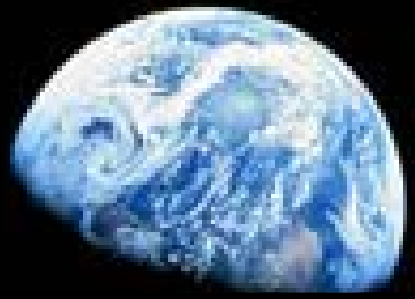
# FMEA: Failure Modes and Effect Analysis



- FMEA is a step-by-step approach for identifying all possible failures in a design.
- Murphy’s Law

| Process Step/Input | Potential Failure Mode | Potential Failure Effects | Potential Causes | Action Recommended | SEVERITY (1 - 10) | OCCURRENCE (1 - 10) | DETECTION (1 - 10) | RPN |
|---|---|---|---|---|---|---|---|---|
| Pilot beam | Loss of Signal | Beam direction off | Loss of power, sabotage, broken parts, interference | Shut off beam | 10 | 4 | 1 | 40 |
| Phase | Phase decoherence | High sidelobe levels (SLL) | Loss of flatness | Shut off beam /or spin the spacetenna | 7 | 5 | 1 | 35 |
| Acts of Nature | Solar Flare | Wipe out electronics | coronal mass ejection | Shut off beam, use rad-hard electronics | 9 | 3 | 1 | 27 |
| Module | Module comes loosed | Debris field | Micrometeorite | Debris avoidance manoeuvre | 3 | 3 | 2 | 18 |
| | | | Failed coupling | Debris avoidance manoeuvre | 3 | 3 | 2 | 18 |
| Acts of War | Large-scale damage | Loss of beam coherence | Missile | Shut off beam | 9 | 2 | 1 | 18 |
| Solar Panel | Connection is loose | Decrease energy captured by the panel | Collision of space debris | Debris avoidance manoeuvre | 2 | 4 | 2 | 16 |
| DC to RF converter | device might burned out | Decrease in efficiency | Manufacturing defect | Replace module | 2 | 4 | 2 | 16 |
| Phase Electronics | Phase shifter broken | Beam decoherence | Manufacturing defect | Replace module, insist on improved quality | 2 | 4 | 2 | 16 |
| | Temperature is too high | Decrease in efficiency | Concentration level is too high | addition of radiator area to the PV panel | 2 | 3 | 2 | 12 |
| Antenna | Multipactor which might damage antenna | Decrease in efficiency | exponential electron multiplication | Replace module, improve design, operate at lower power | 2 | 2 | 2 | 8 |

# Control Methods



| Centralized | Distributed |
| --- | --- |
| **Less equipment on each individual sandwich model, leading to fewer components.** | More equipment on each individual sandwich module, leading to higher component count. |
| **Higher control over control software, allowing for adjustments and updates.** | Phase control is more sophisticated and individualized to each module. |
| **Increased wiring connecting each sandwich module, allowing for connection-based failures and increased connection complexity.** | Fewer wired connections between neighboring sandwich modules, reducing connection-based failures. |
| **Increased potential for delayed controls with large array structure.** | Completely localized control, reducing errors due to communication delay. |
| **Increased communication between modules, allowing for a connection-based error detection system.** | Higher difficulty communicating with neighboring modules, requiring more complex RF communication. |

# Next Steps: Proposed Timeline

**Current Objective: Continued Modeling and Analysis**

- **Array Antenna Arrangement**
- **Failure and Repair Time Analysis**

**7/15:** **Completed list of Specifications**

**8/19:** **Completion of all Modeling and Analysis**

**9/30:** **Completion of Formal Paper**

**10/19:** **Completion of Formal Presentation**

**10/21:** **Presentation of Results at the IAC**