

Focal Length Perturbation Analysis: Digital Twin Uncertainty Propagation\nThermal Effects → Optical Changes → Attitude Performance Degradation

Focal Length Variations\n(Thermal Effects)

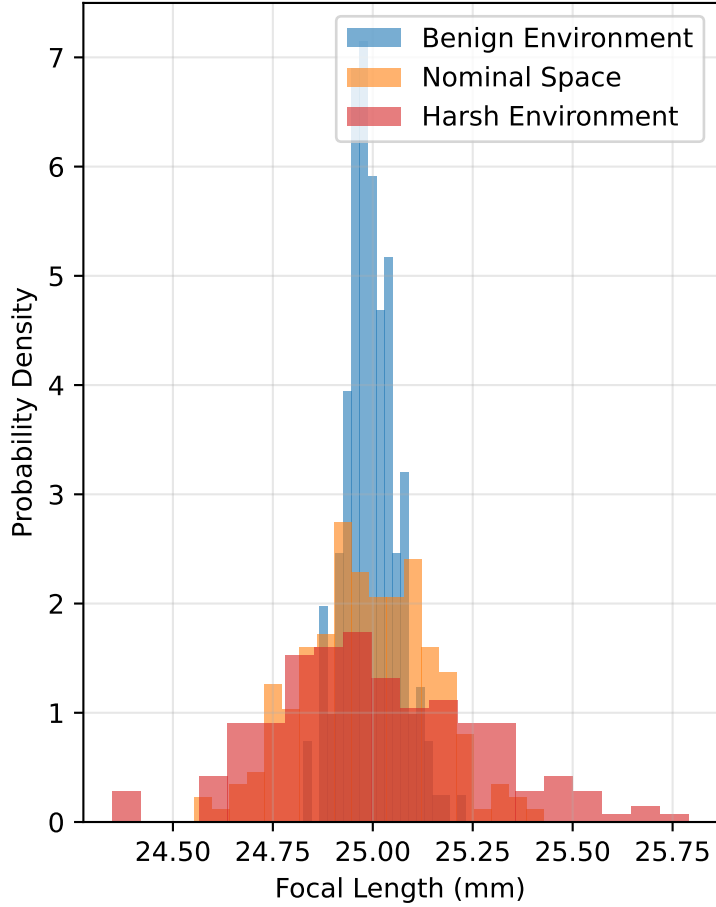
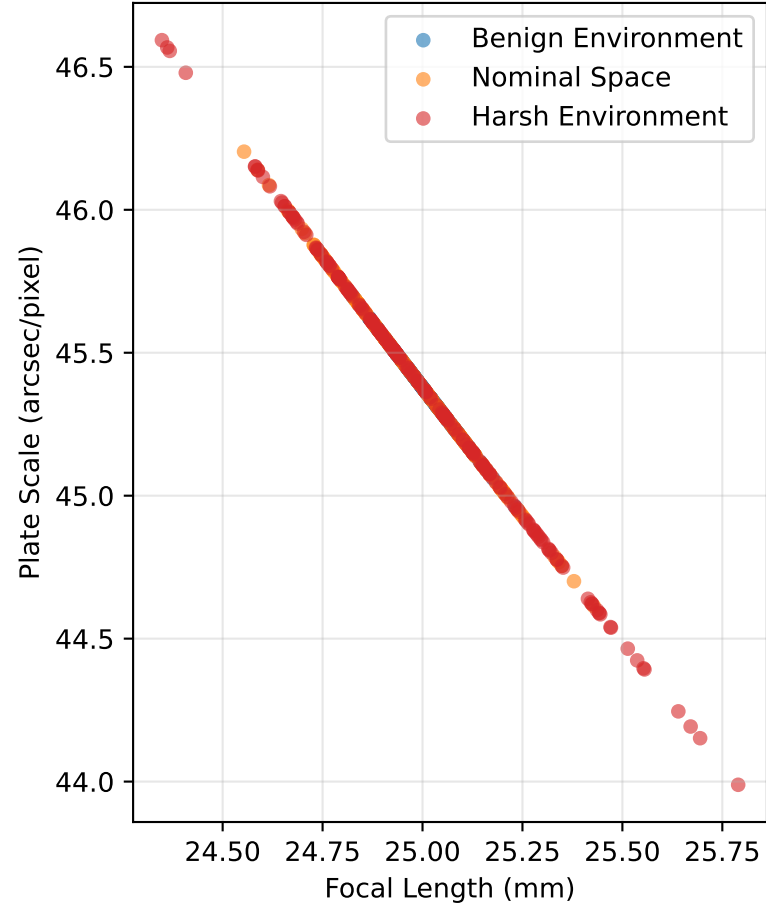
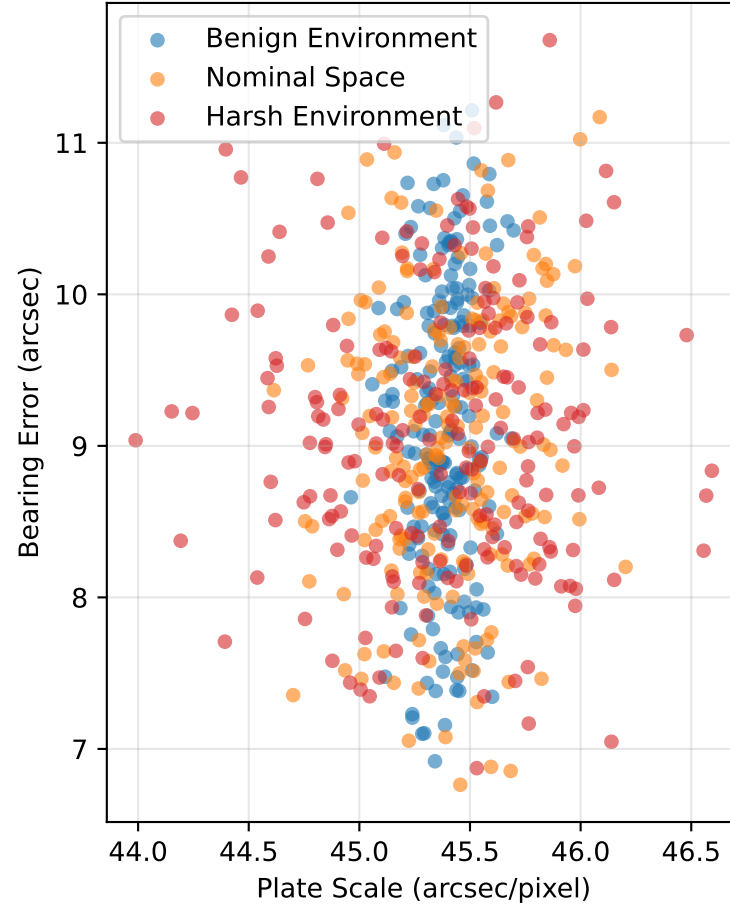


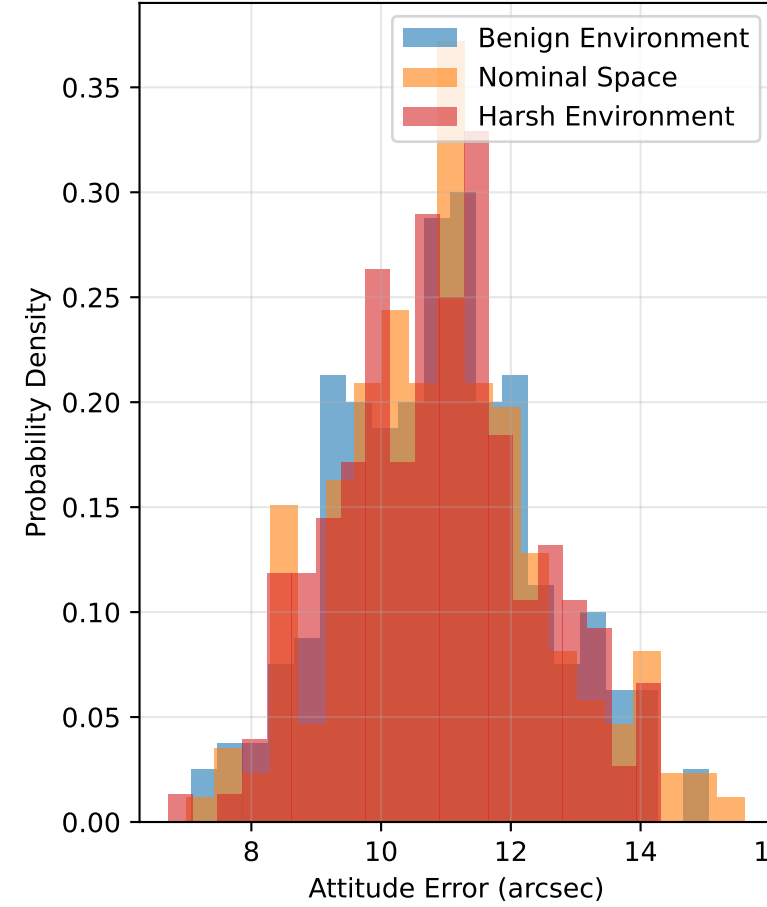
Plate Scale vs Focal Length\n(Fundamental Relationship)



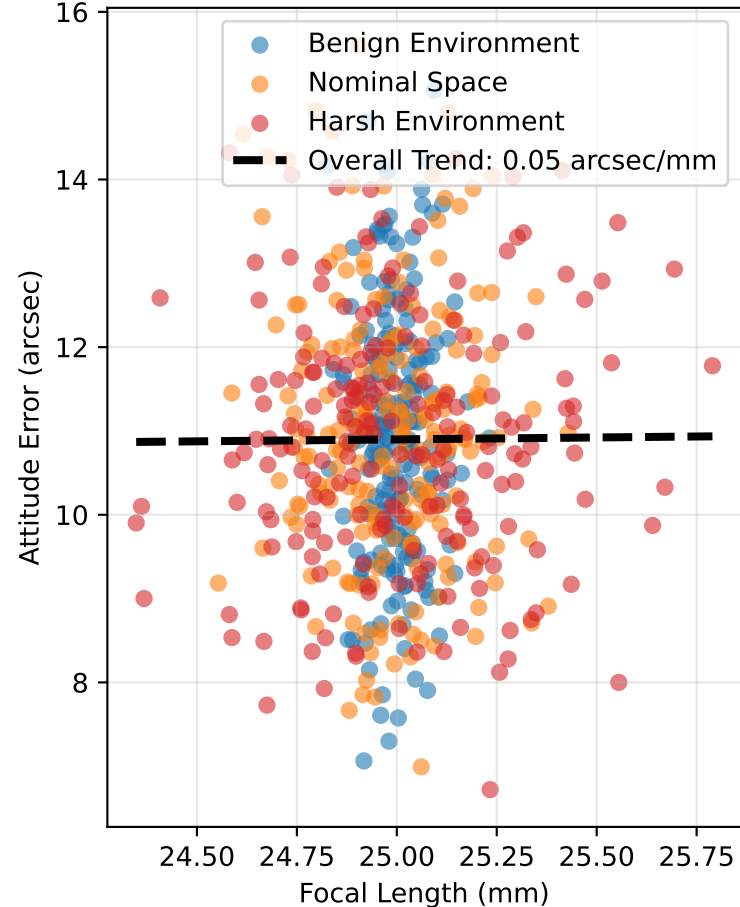
Bearing Error Propagation\n(via Plate Scale)



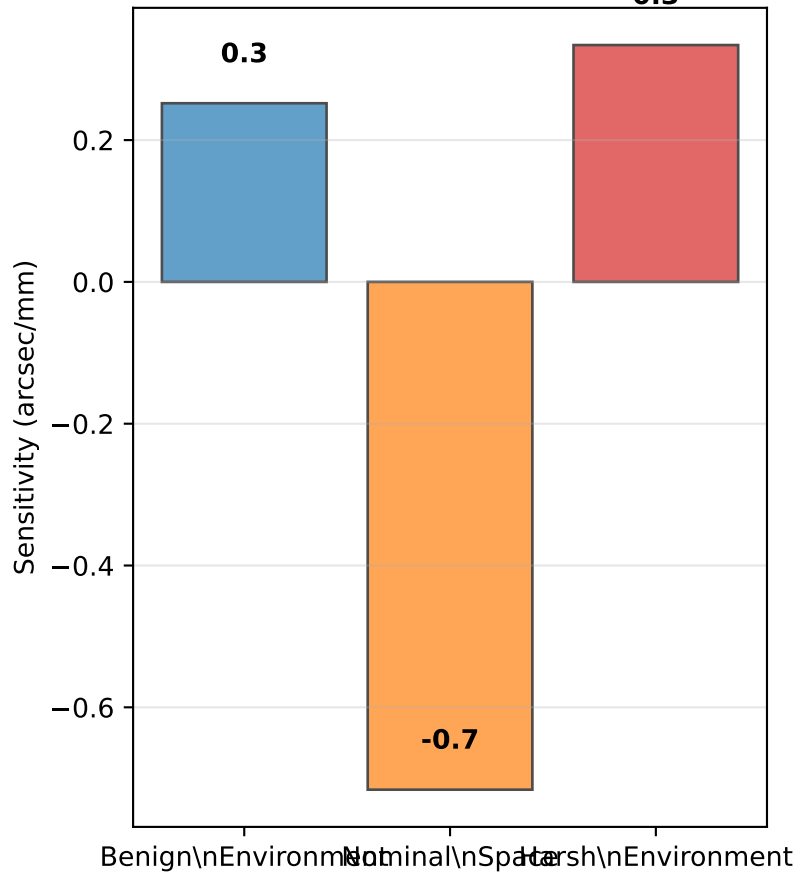
Final Attitude Error\n(System Output)



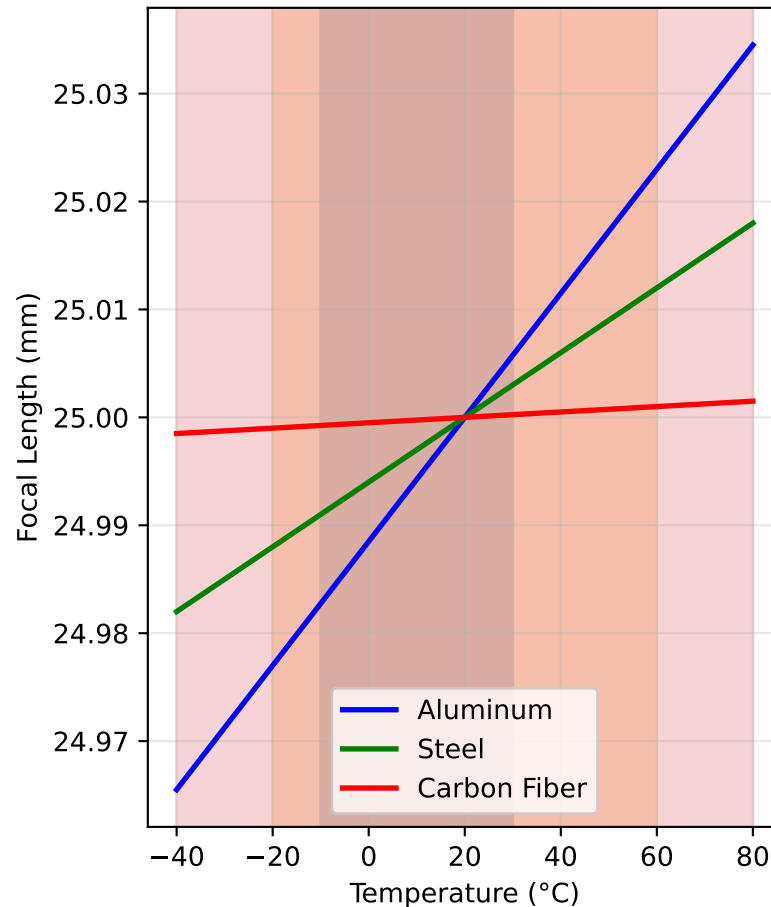
Direct Impact Relationship\n(Key Engineering Insight)



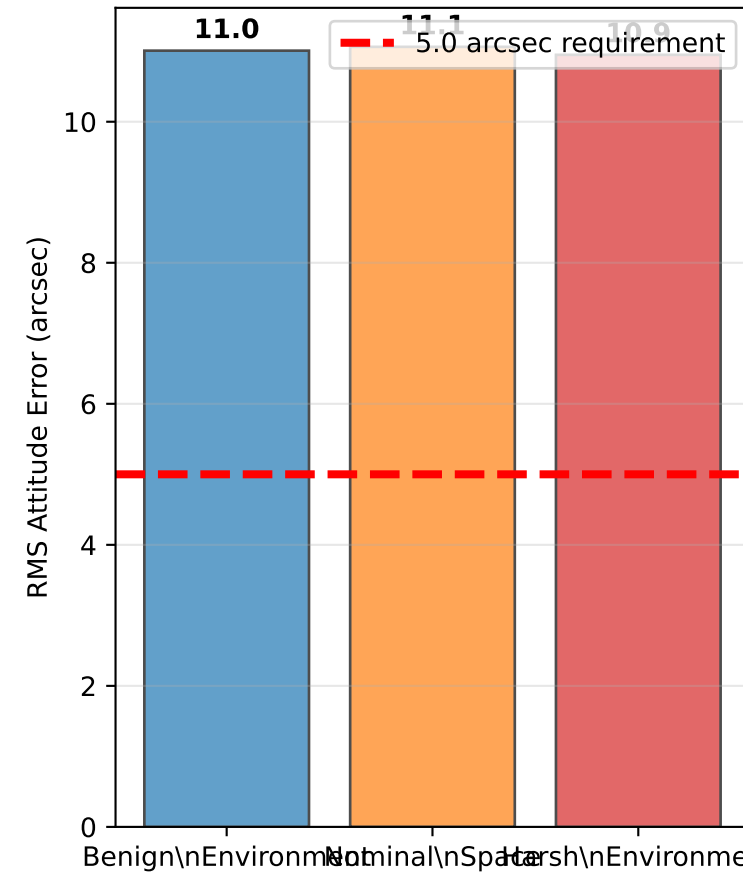
Sensitivity Analysis\n(Impact per unit change)



Material Thermal Expansion\n(Root Cause)



Performance vs Requirements\n(Design Verification)



KEY ENGINEERING INSIGHTS:

QUANTITATIVE RELATIONSHIPS:

- Sensitivity:  $\sim -0.0$  arcsec/mm focal length
- Requirement margin: 0.5x safety factor
- Thermal control benefit: 1.0x improvement

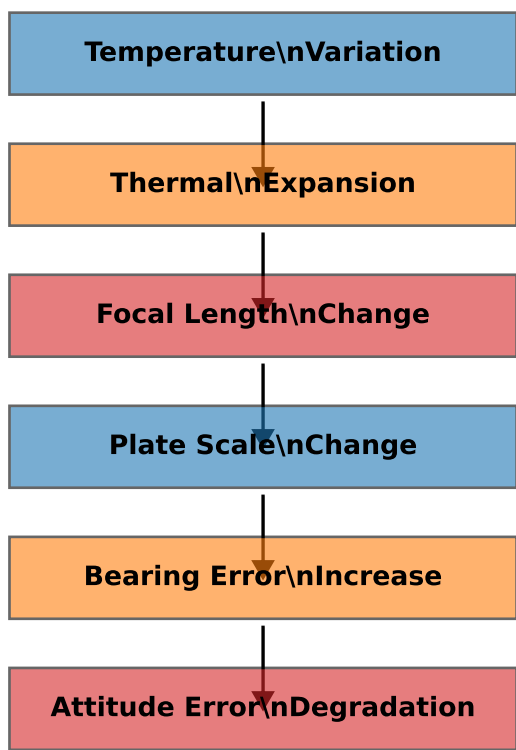
DESIGN IMPLICATIONS:

- 0.5mm focal length change =  $\sim -0.0$ " attitude error
- Thermal stability directly affects performance
- Predictable, linear relationship enables optimization

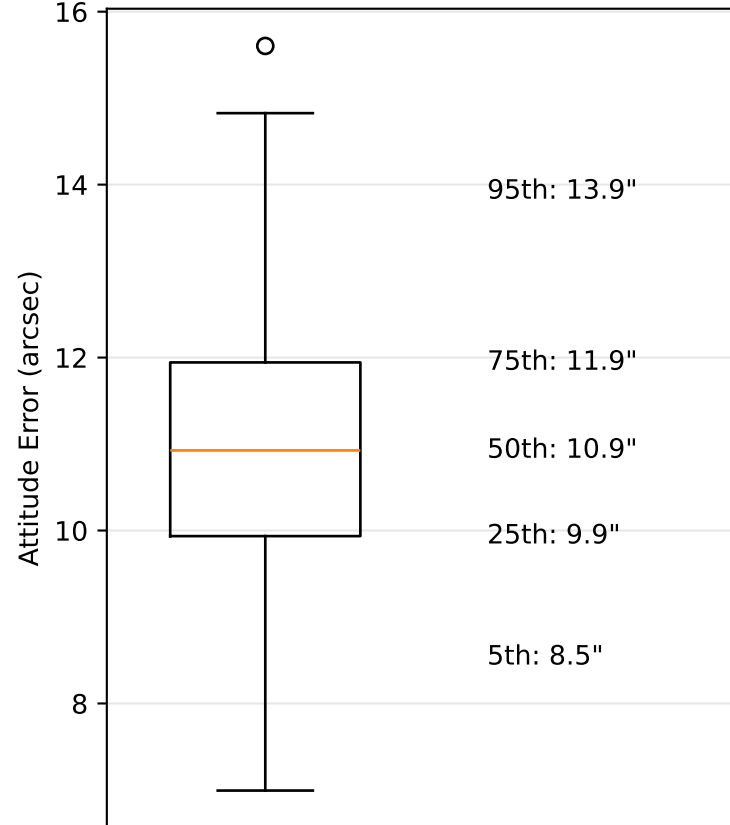
RISK MITIGATION:

- Quantify thermal control requirements
- Validate designs before hardware build
- Optimize performance vs cost trade-offs

Uncertainty Propagation Chain\n(Complete Digital Twin)



Statistical Distribution\n(Nominal Space)



SIMULATION VALUE:

BEFORE THIS ANALYSIS:

- "Thermal effects probably matter"
- "Need some thermal control"
- "Hope it works in testing"

AFTER THIS ANALYSIS:

- $-0.0$  arcsec/mm quantified impact
- 0.5x safety factor calculated
- Thermal specs:  $\pm 10^{\circ}\text{C}$  vs  $\pm 60^{\circ}\text{C}$
- Risk quantified, not guessed

DESIGN CONFIDENCE:

- Predict performance before build
- Optimize thermal vs cost trade-offs
- Validate requirements compliance
- Reduce late-stage surprises