System Architecting: Defining Optical and Mechanical Tolerances from an Error Budget

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Objectives

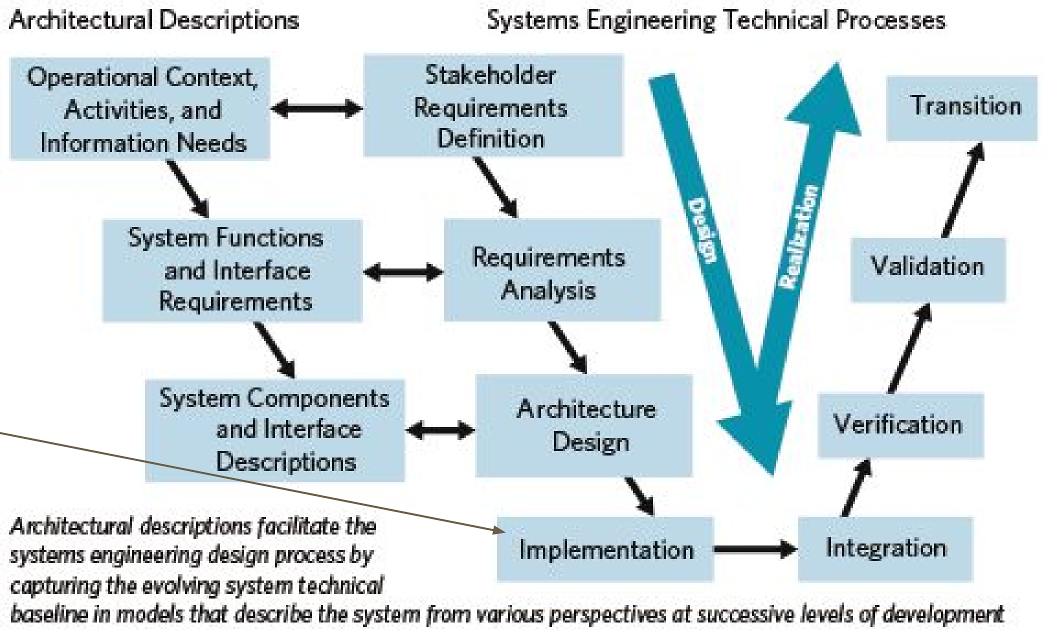
- Deciphering customer requests to requirements
- Insight to requirements flow down
- Insight to Top Level system development
- Understand origin of Optical and Mechanical Tolerance allocations
- Understand importance of engineers role in meeting their allocations

What is System Architecting?

System Architecting is the practice of developing a “conceptual model to define the structure, behavior and other critical elements of a system. An Architecture description is a formal description and representation of system, organized in a way that supports reasoning about the structures and behaviors of the system”. ~Wikipedia

Image: www.mita.lt

Understanding Project Development



Optical, Mechanical, Thermal, etc Engineers

Image courtesy of “Big ‘A’ Systems Architecture From Strategy to Design: Systems Architecting in DoD”

Case Study: View Jupiter's Great Red Spot

REQUEST:

A customer requests a space based telescope to look at Jupiter's Great Red Spot. The telescope must:

- Continuously resolve the spot
- Image in visible wavelengths (400-900 nm)
- Ready to launch in 12 months
- Cost $10,000.00

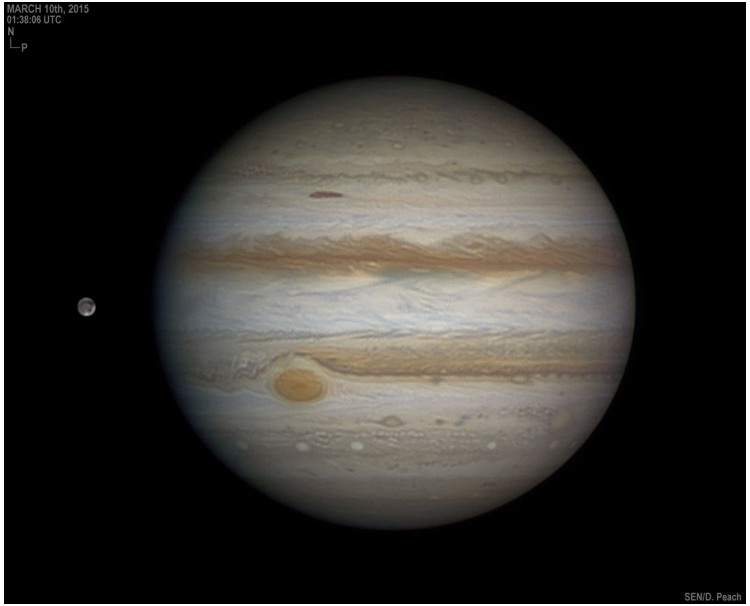
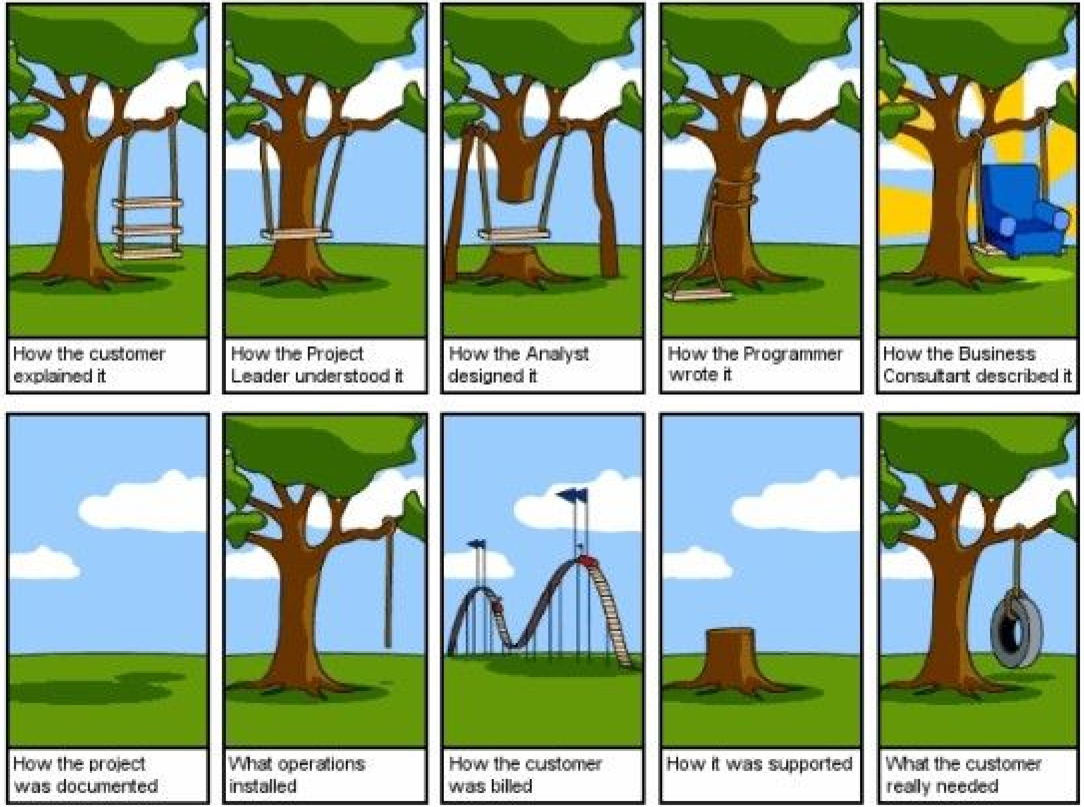


Image Courtesy of NASA

Assess Customer Request

- 12 month lead time is tight but achievable
- Technology is available to build telescope to meet technical requirements
- $10,000.00 budget is unrealistic

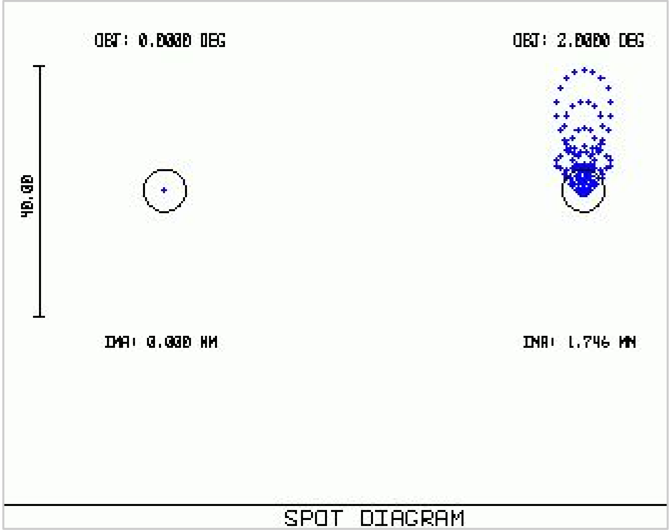
For purpose of this case study, team is given green light to allocate requirements and build. **HIGHLY ITERATIVE!**



Define Performance Metrics

Team is waiting on directives. Requirements flowdown is typically in terms of performance metrics to the lead engineers. Some or even all metrics can include:

- RMS WFE: Root Mean Square Wavefront Error
- MTF: Modulation Transfer Equation
- Distortion
- Fractional Encircled Energy
- Beam Divergence
- Geometric RMS Image size
- Dimensional Limits
- Boresight
- Throughput



Error Budget Development

You decide the appropriate metric is RMS WFE. Resolving typically means a strehl ratio > 0.8.

$$SR \approx e^{-(2\pi W_{RMS}/\lambda)^2} \approx 1 - (2\pi W_{RMS}/\lambda)^2$$

So we convert strehl to RMS WFE, using 500 nm for evaluation wavelength:

$$W_{RMS} = \frac{\lambda\sqrt{1-SR}}{2\pi} = 35\ nm$$

Top level performance = 35 nm

System Error Budget

Level	1	2	3	4	Description
Total Performance	27				Requirement = 35 nm
Nominal Design Residual		15			Design residual inherent to design, assume on-axis
Static Image Quality		21			Image quality under static conditions
1g offload			4		Result of aligning on Earth and releasing in space
dryout			4		Result of materials shrinking as they outgas & lose moisture
Static Thermal offset			7		Result of aligning in lab at 22C and having +5 degrees
Manufacturing			18		Ability/Allocation for how well the optics must be made
Primary				10	How well the Primary Mirror is made and mounted
Secondary				15	How well the Secondary Mirror is made and mounted
Alignment			4		How well the System can be aligned
Primary to Secondary				4	How well the Primary and secondary can be initially aligned
Telescope to sensor				2	How well the Telescope can be aligned to the sensor
Non-Static Image Quality		10			Changes faster than your thermal control
Thermal Gradients			10		Gradients across optics and system that impact performance

All terms are initially allocated and RSS'd to the next higher level. **The process of allocating is highly iterative as design maturity increases.**

Optical and Mechanical Tolerances

Team has allocation of:

- 10 nm for mounted primary
- 15 nm for mounted secondary

Your team goes through the same process of allocating terms which will RSS to the 10 and 15 nm.

Team builds opto-mechanical design and evaluates using Finite Element Analysis (FEM). The FEM shows the design is influencing up to 7 nm of WFE. You decide this is sufficient and begin evaluating the other terms in the System Error Budget.

Summary

- Deciphering customer requests to requirements
    - Build a telescope to view Jupiter’s Red Sport
- Insight to requirements flow down
    - Translate customer request to RMS WFE
- Insight to Top Level system development
    - Allocation of 35 nm and flowed down to system influences
- Understand importance of engineers role in meeting their allocations