Developing an Error Budget for GOMAP Studies

Marie Levine[1]

w/ inputs from IM Planning Group:

Jason Derleth[2], Alice Liu[2], Rhonda Morgan[1], Gary Mosier[2], Keith Warfield[1]

[1] Jet Propulsion Laboratory, California Institute of Technology

[2] NASA Goddard Space Flight Center

8/10/2023

Starlight Suppression for HWO Workshop,
Pasadena CA Aug 8-10, 2023

The NASA Systems Engineering Engine (NPR 7123.1)

Reqs Definition

Reqs Management

Requirements Flow Down from Level above

Realized Products to Level above

Technical Management Processes

System Design Processes

Requirements Definition Processes
1. Stakeholders Expectations Definition
2. Technical Requirements Definition

Technical Solution Definition Processes
3. Logical Decomposition
4. Design Solution Definition

Cross-cutting

Technical Control Processes
11. Requirement Management
12. Interface Management
13. Technical Risk Management
14. Configuration Management
15. Technical Data Management

Technical Assessment Processes
16. Technical Assessment

Technical Decision Analysis Process
17. Decision Analysis

Cross-cutting

Product Realization Processes

Product Transition Processes
9. Product Transition

Evaluation Processes
8. Product Validation
7. Product Verification

Design Realization Processes
6. Product Integration
5. Product Implementation

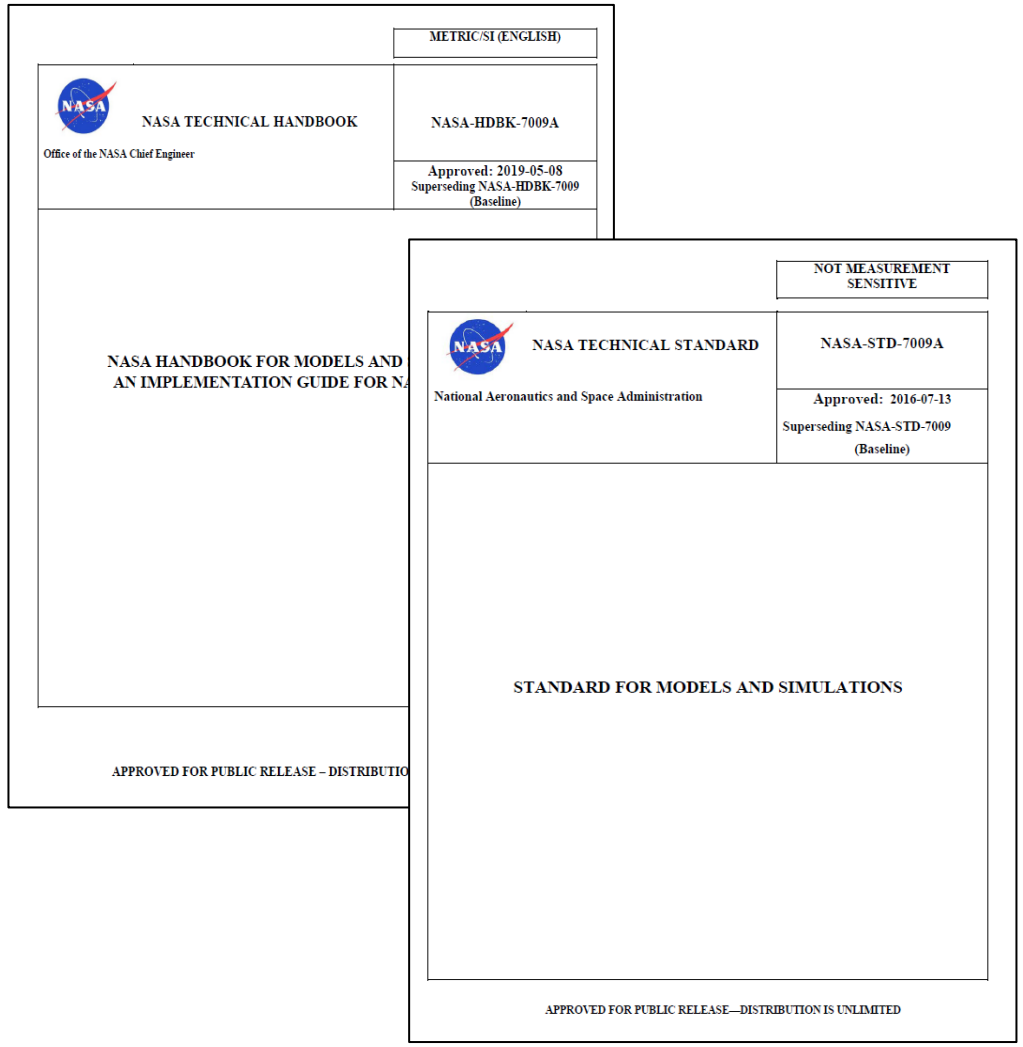
Requirements Flow Down To Level below

System Design Processes applied to each product layer down through system structure

Realized Products From Level below

Product Realization Processes applied to each product layer up through system structure

NASA M&S Standards & Handbook 7009



- Requirements and criteria with which models and simulations (M&S) may be developed, accepted, and used in support of NASA activities.
- Addresses M&S management, uncertainty quantification, verification and validation, etc …
- Rigor and formality of processes are functions of project life-cycle phase
- Objective is to reduce risks with M&S-influenced decisions by emphasizing credibility of results and transparency of methods and processes.

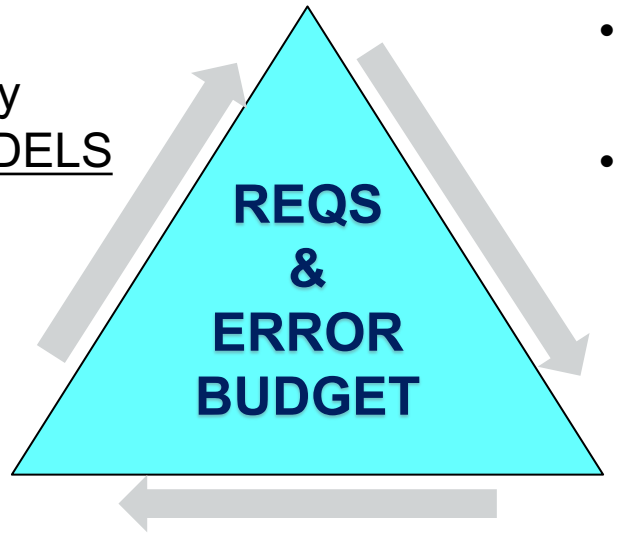
The Error Budget is the Backbone of the GOMAP Studies

SCIENCE
- Objective

- Derive Science Metrics into Engineering Performance Metrics.
- Define Concept of Operations for Simulations and Capabilities (LV, Data Handling, Efficiency …)

TECHNOLOGY
- Maturation

- Demonstrate H/W S/W Maturity
- All reqs must be verifiable by test or by ANALYSIS w/ TEST-VALIDATED MODELS
- Validate Model & Uncertainties
- Apply Validated Models to Flight



DESIGN
- Implementation

- Predict Design Performance & Identify Trades
- Compute Performance Sensitivities and Rank Drivers
- Establish SOA and Tech Maturity
- Define Performance Goals for Demonstration

Models and analyses tie the process

Generalized Requirements / Error Budget Structure

Concept of Operation / Observing Scenario

Level 1 Mission	**Mission Functional** • Orbit, LV, Mass, Data **Science Performance** • GA: • Exo: # Stars, …	
Level 2 Observatory	GA: Strehl, EE Stab, .. Exo: Flux Noise Ratio	
Level 3 System	GA: WFE, LOS, … Exo: Contrast,..	
Level 4 + > Elements	OTA, Coro, Spacecraft… Interfaces	

Modeling & Analysis Domains

Science & Yield Modeling

Engineering Modeling & Analysis:

Coronagraph Starlight Suppression

WFSC: Coro + OTA

Stability: Jitter, Drift

….

Tech Demo Model Validation V&V ….

Process for Defining EB for General Astrophysics is generally well understood (HST, JWST, RST)

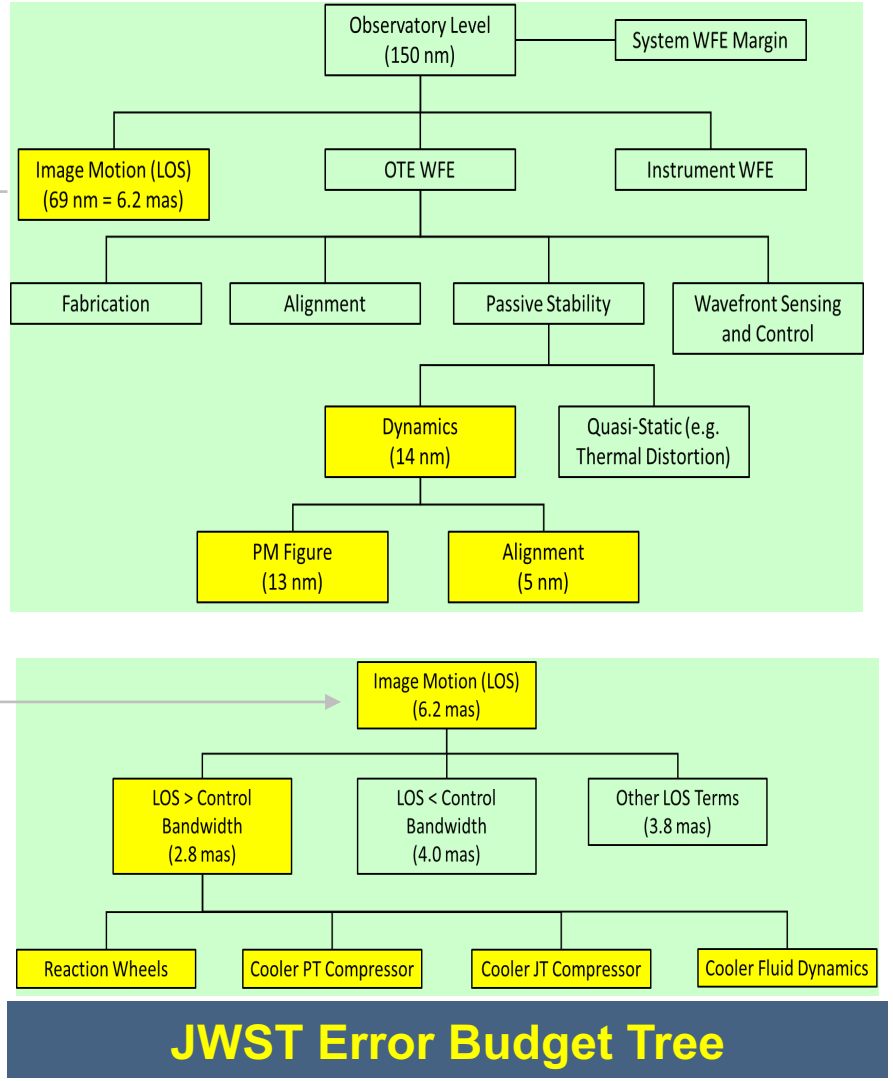
- GA Science → Image Quality Reqs
  - Strehl Ratio → WFE

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

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

  - Encircled Energy Stability →
    - WFE Spatial Frequencies and Pointing Stability

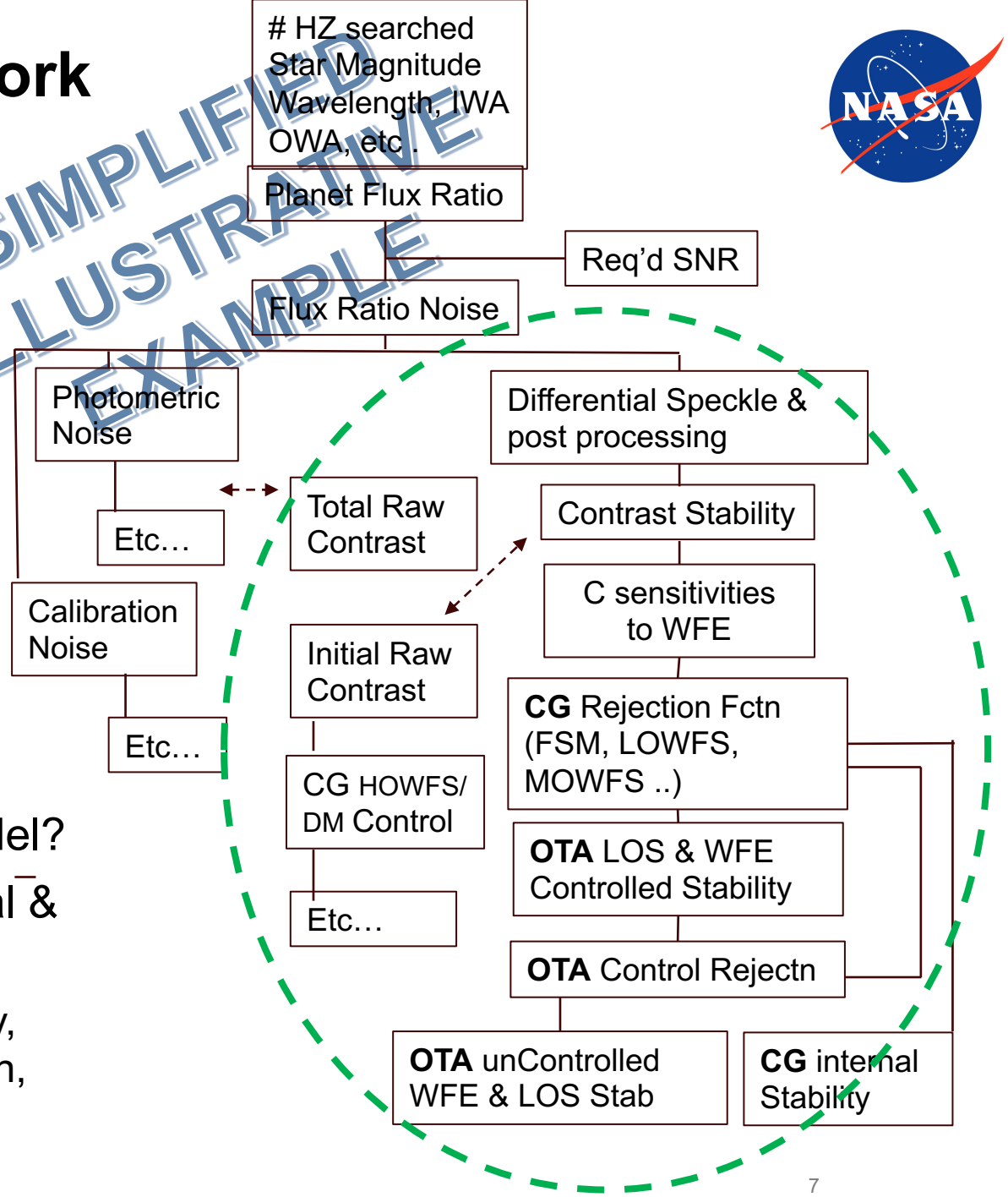
- EB verification and validation for GA anchored through launch & commissioning



JWST Error Budget Tree

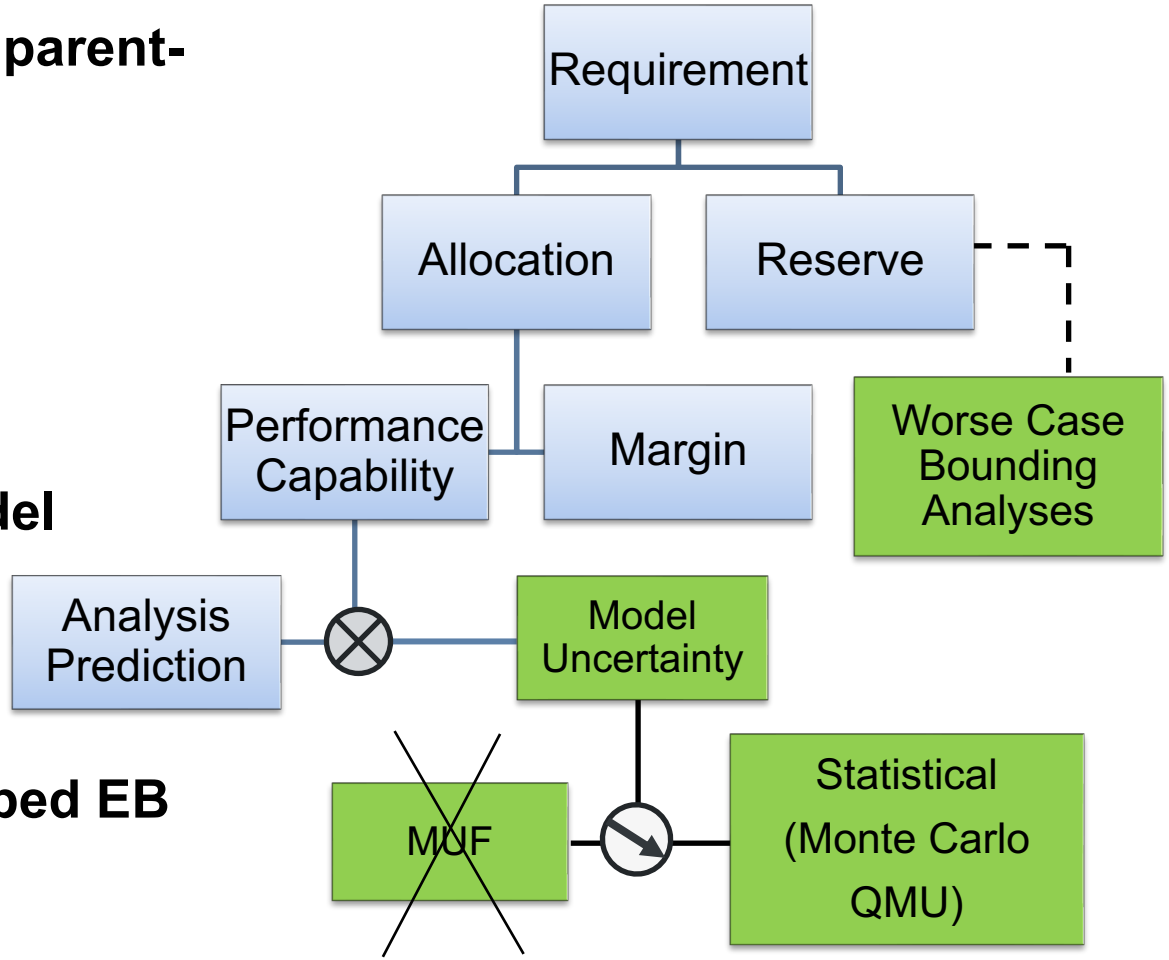
Coronagraph EB Allocation needs work

- Flow from L2 → L3/L4 is the most complex,
- After ~L4/L5 “traditional” metrics (WFE, LOS) flow down is standard
- Build upon existing studies to populate the EB:
  - Analytical approach established by CGI at 10^{-9}
  - USORT WBS’, CRT, SCDA, ….
- Architecture dependent process – will require design specific models & EB analyses
- Clear definition of terms for verification:
  raw contrast, initial, stability, cross terms
- Are all terms verifiable by test or test-validated model?
- Nested control of CG + OTA opens trades (temporal & spatial freqs):
  - OTA control vs CGI Control, Raw Contrast vs stability, minimize sensitivities to mask and observation design, post-processing, psf calibration, ….



Note on “Robust Margins”

- **The EB defines performance allocations for each parent-child derived terms.**
- **The allocation is further subdivided into:**
  - Margin & Reserves
  - Current Best Estimate
  - Model Uncertainty (prediction tolerance)
- **Model Uncertainty allocations define the test-model validation goal for the metric**
  - Risk that model uncertainty (or test errors) exceed performance requirement and break the budget
- **TRL demo MUST include model validation & Testbed EB**
  - Predict performance in test configuration, environment
  - System sensitivities w/ EB traceability flight vs test
  - Model uncertainties vs test measurement errors



Proposed EB Implementation Approach

- **Convene a TAG Error Budget WG to work in coordination w/ START:**
  - Agree on EB structure for 1 or more architectures. E.g. On-axis vs off-axis telescope
  - Establish metrics for each levels (Parent – child relationship) w/ definitions
  - Verify completeness of the EB flowdown sufficient for GOMAP trades & no Orphans
  - Define key analyses for populating the EB values and sensitivities, and readiness of models
  - Identify verification method for each and technology demonstrations as applicable
  - Perform Analyses as Architecture(s) & Concept of Operations are defined
  - Support parallel (non-NASA?) EB development & analyses for cross checks

- **EB will be maintained by NASA**
  - Make available for community collaboration, (Subject to ITAR)
  - Configuration management as upgrades and trades occur,
  - Documentation, tutorials, repository of analysis results & publications

ERROR BUDGET DEVELOPMENT GOALS

- Define a Comprehensive Error Budget framework that brings together the details of the coronagraph and ultrastable observatory for architecture trades, from Level 1 -2 down.

- Bring community to build upon existing work (USORT, CRT, SCDA, …)
  - WBS definitions flow down
  - Starlight Suppression and WFSC analyses

- Define EB terms for consistency across START, TAG, Tech Dev efforts
  - Will be a point of reference for all studies and analyses
  - Report predicted performances w/ common definitions of metrics & assumptions
  - Point to specific technology demos and model validation accomplishments.

- Will establish key models/analyses & technology demos.

Group Discussion