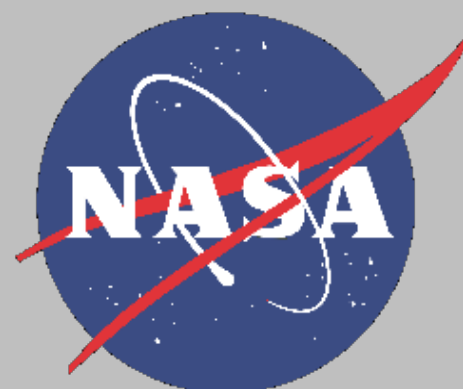


Loads Generation Process for Multi-Commercial Supplier Space Station

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Objective:

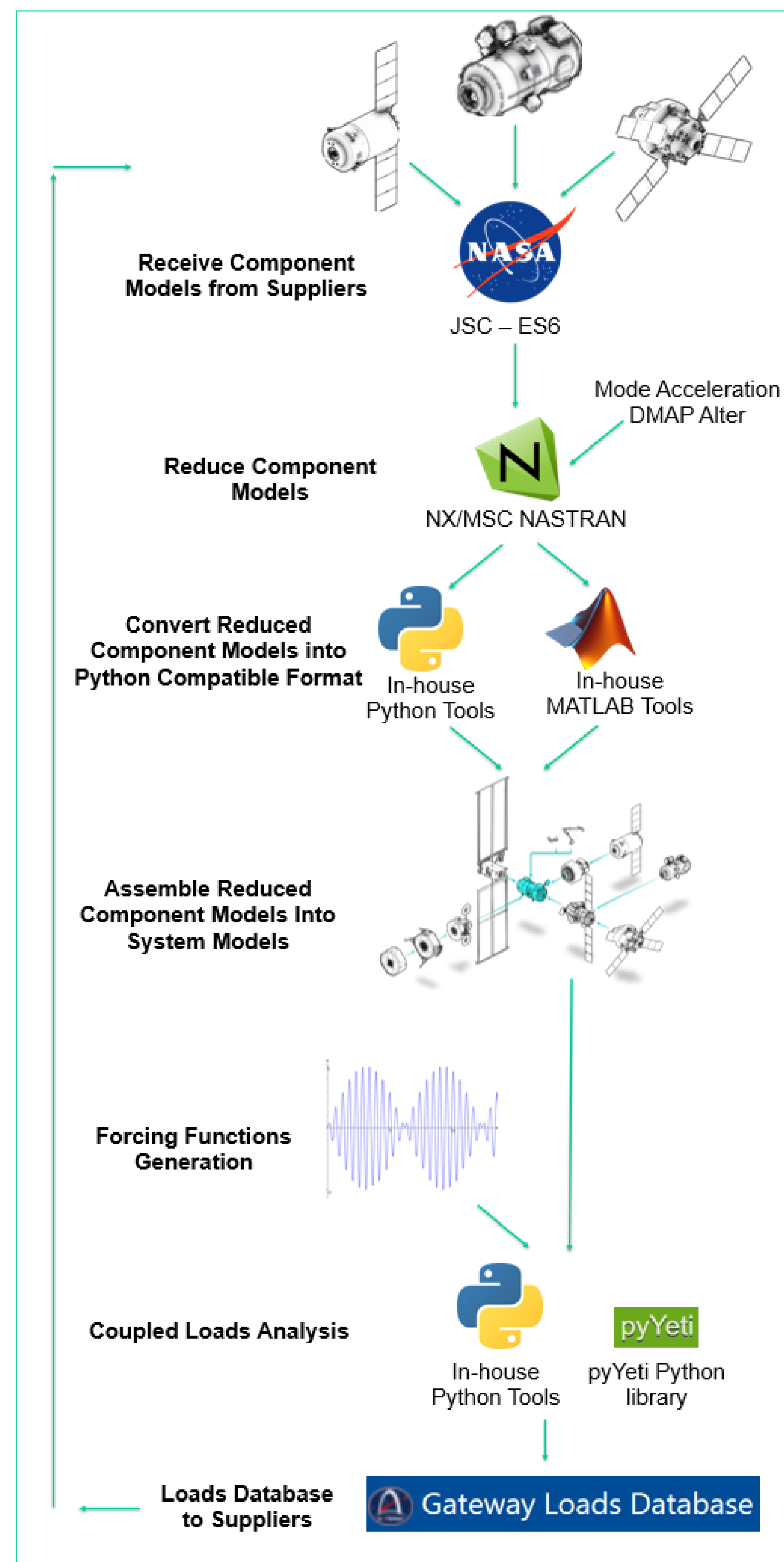
Create a standardized process to accurately and consistently generate loads from evolving/maturing models, forcing functions, and configuration manifests.

Background:

The lunar outpost, Gateway (GW), is comprised of multiple commercial elements at different stages of design and production. Integrated Analysis Cycles (IACs) are performed one to two times a year to provide current loads to suppliers to inform design decisions.

Procedure:

- Receive Component Models from Suppliers
 - Gateway Loads Control Plan 10029 Rev. A establish acceptable deliveries of models
 - Specified NASTRAN compatibility, numbering scheme for Coordinate Systems/Grids/Elements
 - Modeling checks: 6 rigid body modes, good frequency separation between rigid body modes and first flexible modes, passing strain energy grounding checks
- Reduce Component Models
 - Component Mode Synthesis to at least 50 Hz for Coupled Loads Analysis (CLA) to be valid up to 25 Hz
 - GW is more interested in on-orbit global modes which occur at low frequencies.
 - NASA-STD-5002: “the finite element model shall be reduced to a cutoff frequency of at least 1.5 times the cutoff frequency of the load analysis”
 - Gateway uses a 2x cutoff frequency
 - Prioritize retaining 90% or more of mass after reduction
 - In-house NASTRAN DMAP alter used to implement Mode Acceleration Method for creation of Output Transformation Matrices for all output requests
 - Creation of Loads Application Matrices
- Convert Reduced Component Models
 - JSC-ES6 Prime CLA Tools prepares models for Coupled Loads Analysis
 - Assumed 1% critical modal damping per NASA-STD-5002 in absence of measured damping data
- Assemble Reduced Component Models into System Mode
 - Configurations are determined by the GW Configuration Analysis Model and Mass Properties team
- Forcing Functions (FFNs) Generation
 - Exercise – developed from human-in-the-loop testing of exercise device
 - Plume Impingement
 - JSC-developed codes: RCSPLUME (ES6) and EMPIRE (EG3)
 - Compute impingement pressures and heating using jet firing histories, GW surface models, visiting vehicle thruster configurations, and plume flow field engineering models
 - Docking – developed by the JSC-ES6 Dynamic Attach Mechanism-Modeling, Simulation, Analysis & Test (DAM-MSAT) Team using Trick simulations of various docking systems



Gateway Coupled Loads Analysis Process

Equation of Motion

$$M\ddot{x}(t) + Kx(t) = F(t)$$

Transform to modal space: $x(t) = \phi q(t)$

$$M\phi\ddot{q}(t) + K\phi q(t) = F(t)$$

$$\phi^T M \phi \ddot{q}(t) + \phi^T K \phi q(t) = \phi^T F(t)$$

$$m\ddot{q}(t) + kq(t) = f(t)$$

Introduce modal damping ζ

$$m\ddot{q}(t) + 2\zeta\omega_n\dot{q}(t) + \omega_n^2q(t) = f(t)$$

M = System Mass K = System Stiffness F = Forcing Function
 ϕ = mode shapes/eigenvectors ζ = Modal damping (as % of critical)

Forward Work:

- Isolated and un-isolated exercise effects on GW fatigue life
- Plume loading effects on GW appendages from visiting vehicles
- Integration of detailed models as contracts are awarded

Lessons Learned:

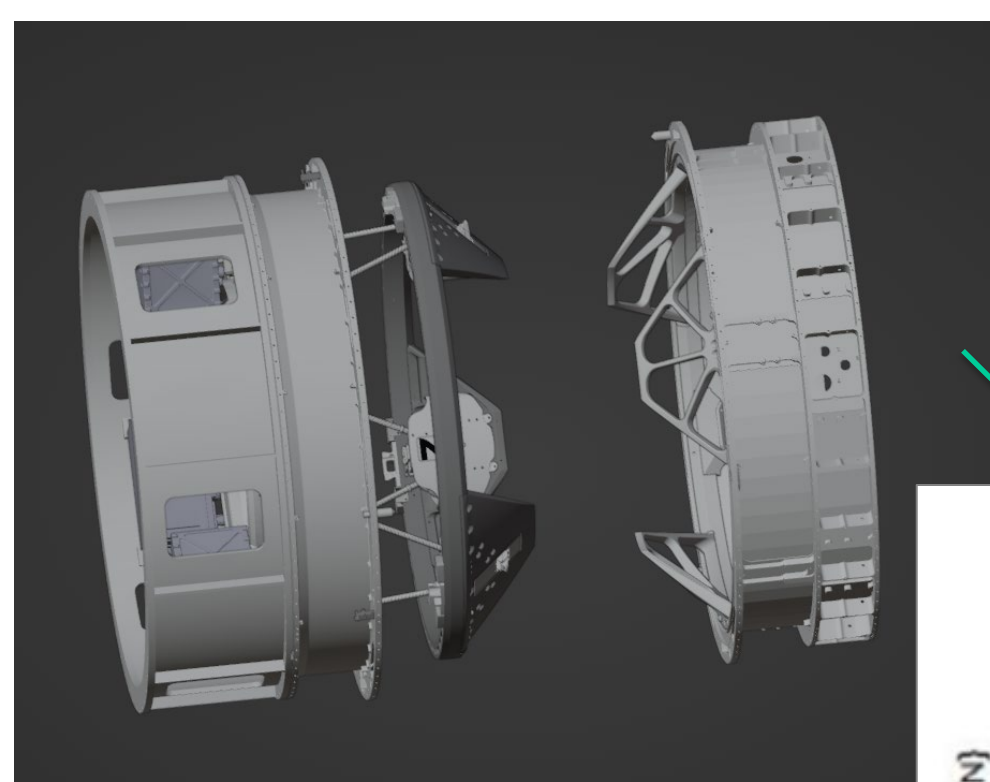
- Importance of enforcing GW LCP for model deliveries to promote ease of integration
- Maintaining conservatism during early design phases
- Residual Vector method was replaced with Mode Acceleration Method
- Creation of Load Application Matrices during model reduction to decrease analysis set size of the reduced component model
- Version controlling code between IACs to track updates

Benefit to NASA:

As NASA becomes a more prominent integrator between commercial suppliers, a standardized uniform process is essential to providing design critical loads in a timely manner.

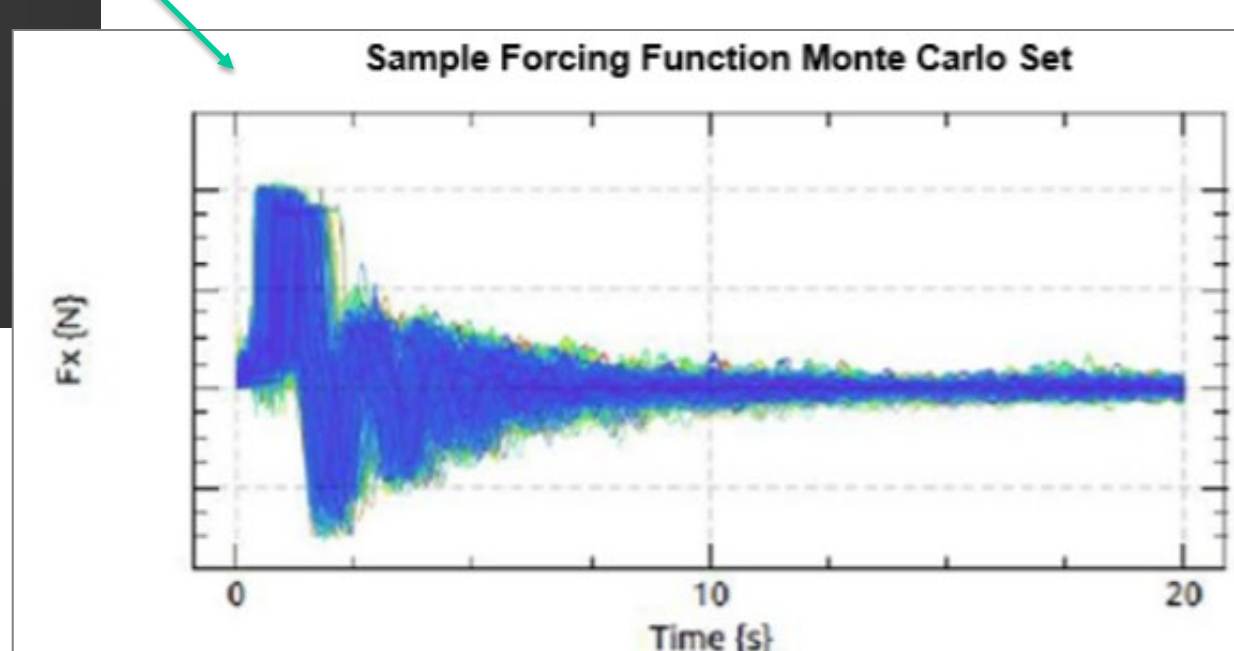
References:

- GP 10029 Rev A
- NASA-STD-5002 Rev A
- “Modal Equations of Motion” Jeremy Priest



NASA Docking System Block I Visualized in Blender

JSC-ES6 DAM-MSAT in-house suite of tools to create Monte Carlo set of forcing functions to simulate docking of various visiting vehicles to GW



- Coupled Loads Analysis (CLA)
 - pyYeti ODE solver
 - JSC-ES6 Prime CLA Tools builds on pyYeti ODE solver
 - Defines a standard format of FFNS, transforms and applies FFNs, post-processing of outputs
 - JSC-ES6 GW CLA Tools builds on Prime CLA Tools to do GW specific post-processing for supplier specific requests
- Loads Database to Suppliers
 - Access controlled website that allows suppliers to retrieve loads while maintaining commercial sensitivity
 - Collect max/min results from multiple FFNs across multiple cases and configurations
 - Calculates load combinations and case consistent loads