# Multiconfiguration Loads Analysis for Missions with an Uncertain Rideshare Manifest

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# Overview

- The traditional coupled loads analysis (CLA) process makes it difficult to change rideshare manifests
- Multiconfiguration loads analysis (MLA) defines a range of rideshare properties to proactively characterize the impact of manifest changes and reduce the CLA-related difficulties with late swaps and manifest flexibility
- MLA can inform more robust structural and mission designs
- MLA can provide design guidance for small satellite builders to improve rideshare availability

*Image credit: U.S. Air Force*

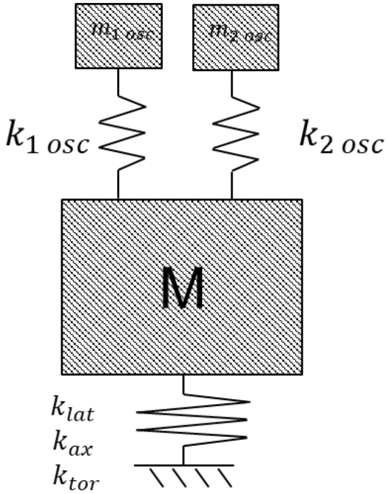
# *Coupled Loads Background*

- The structural verification of spacecraft, launch vehicles, and all elements of a launch system is accomplished, in part, through coupled loads analysis (CLA)
- CLA uses mathematical models of the launch vehicle and all its payloads to predict launch and flight loads
- The structural loads that occur during launch and flight drive the primary structural design of both the launch vehicle and the payloads
- The structural dynamic response of the coupled launch system is **greater than the sum of its parts**
  - *The dynamic properties of the individual parts of the system – the launch vehicle and each spacecraft – interact with each other in complex ways*
  - *Structural changes in any part of the system can cause changes in the dynamics and the loads for all spacecraft and the launch vehicle*
  - *Modelling deficiencies can cause erroneous loads predictions in other parts of the system*

***Making last-minute changes to multi-payload manifests is risky and time-consuming***

# *What is Multiconfiguration Loads Analysis?*

- Multiconfiguration loads analysis (MLA) involves running CLA for hundreds or thousands of potential launch configurations and calculating **an envelope of structural responses**
- **Dynamic simulator models** (instead of mission specific models) are used for spacecraft with uncertain designs or hardware that might be swapped
- Dynamic properties of simulator models are varied to bound the expected flight hardware, and **structural responses are calculated for all configurations**
- The range of dynamic properties of the simulator models define **a dynamic properties envelope** for potential rideshare spacecraft
  - *Spacecraft with properties within the envelope can be swapped without increasing loads beyond those already calculated*



Notional Diagram of generalized Payload Model

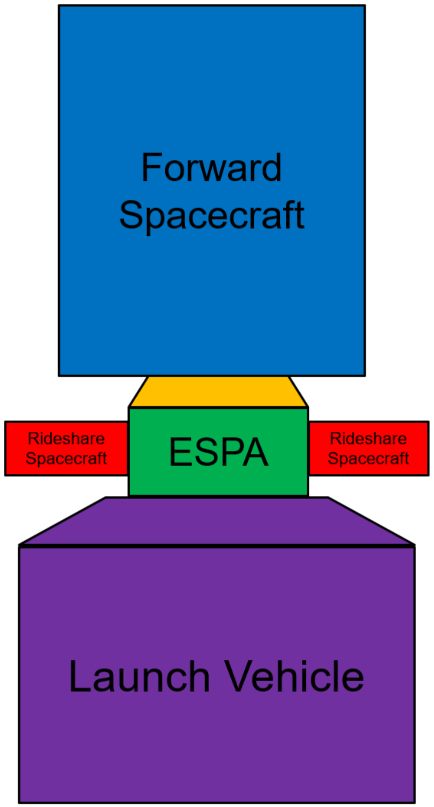
***MLA reduces risk that a late-swap or rideshare configuration change will negatively affect the structural viability of the system***

# MLA Example

- Demonstration of the MLA process completed used Aerospace's Coupled Loads Analysis Sensitivity Program (CLASP) to calculate bounding loads
- Example used:
  - *EELV-class launch vehicle*
  - *Propulsive ESPA adapter rideshare spacecraft on all six ports*
  - *5,000 lb forward spacecraft with over 400 modes below 150 Hz*
- Rideshare spacecraft represented by simulator models with a broad dynamic properties envelope

| Mass (lb) | Center of Mass (in) | Fundamental Frequency (Hz) |
|---|---|---|
| 4-750 | 5-25 | 15-100 |

- Forward spacecraft responses calculated for 1582 rideshare configurations
  - *Simulator models randomly assigned for 1500 configurations*
  - *All six ports populated with identical, rigid simulator models for other 82 configurations to capture "edge cases"*



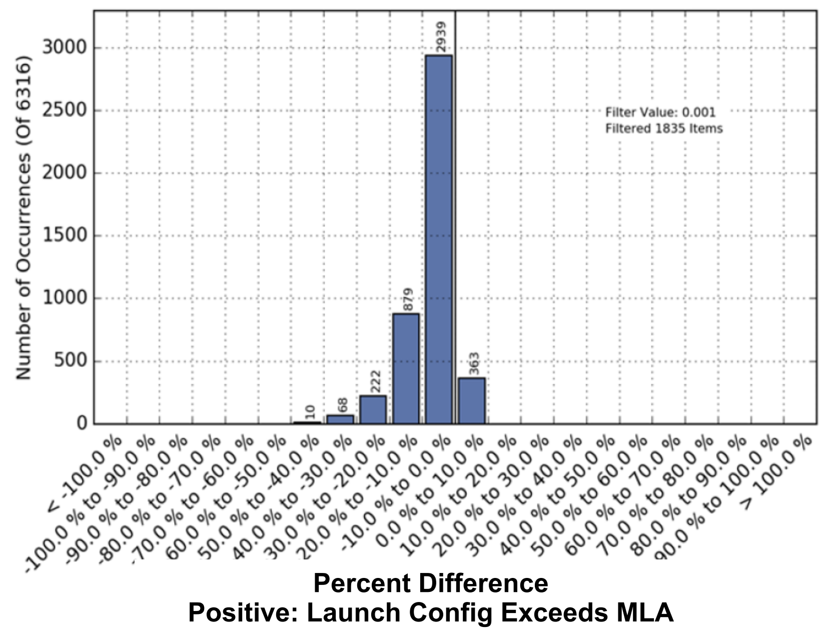
# MLA Example (cont.)

- A second set of loads were calculated using same launch vehicle, forward spacecraft, and propulsive ESPA with six detailed models of actual rideshare spacecraft

| | Mass (lb) | Center of Mass (in) | Fundamental Frequency (Hz) |
|---|---|---|---|
| Rideshare 1 | 617 | 19.9 | 47.4 |
| Rideshare 2 | 125 | 11.4 | 39.8 |
| Rideshare 3 | 317 | 12.0 | 46.5 |
| Rideshare 4 | 10 | 2.7 | 129.6 |
| Rideshare 5 | 381 | 21.2 | 27.4 |
| Rideshare 6 | 142 | 9.4 | 23.6 |

- Responses calculated for 156 potential launch configurations
  - *Rideshare spacecraft randomly assigned for 150 configurations*
  - *Identical spacecraft on all ports for six configurations*

**Forward Spacecraft Loads: Launch Config vs. MLA Envelope**




- Forward spacecraft loads did not exceed the MLA envelope by more than 10% for any of the 156 potential launch configurations

- Other examples exist / are in work

***MLA generated set of forward spacecraft loads that envelope the loads expected for an actual launch configuration <u>without</u> detailed models of the rideshare spacecraft***

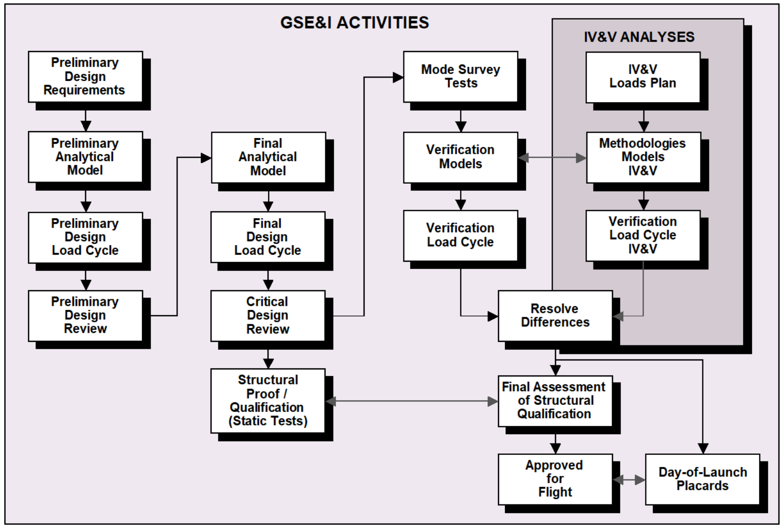
# *Summary*

- The multiconfiguration loads analysis (MLA) process increases mission manifest flexibility by allowing payload changes or swaps without requiring coupled loads analysis (CLA) updates
- MLA can be used to characterize the impact of manifest changes on loads for forward spacecraft, rideshare spacecraft, and the launch vehicle
- On a mission-specific basis, a dynamic properties envelope can be defined that will allow rideshare spacecraft that “fit” within the envelope to be swapped
- MLA is most effective when it is used early in the mission design and integration process
- MLA is being used on a limited basis to reduce mission risk and ensure compatibility of the final mission manifest
- Aerospace expects MLA to become more common as multi-manifest missions and the need for responsiveness and manifest flexibility increase

# Backup

# The Load Cycle Process

- Coupled loads analysis is performed as part of the Load Cycle Process prescribed in SMC-S-004
- CLA is mission-specific for the planned launch configuration with little accommodation for manifest uncertainty
- Process is iterative with discrete "cycles" required to account for normal changes that occur during the mission design process
- Typically, the entire mission is finalized 8-12 months prior to launch to support the last load cycle (Verification Load Cycle or VLC)
  – *Correlated models of all hardware are needed at this time*
- Late swaps are costly, time-consuming, risky, and may require a rerun of VLC

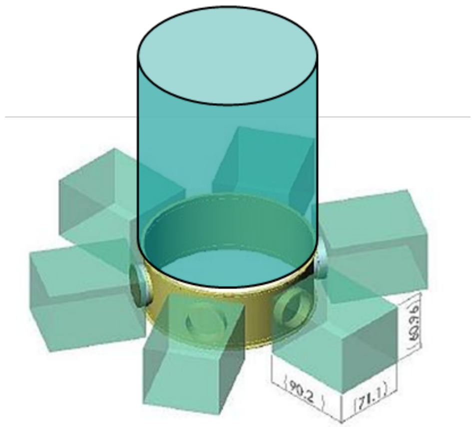



***To support late integration capability, the current Load Cycle Process can be supplemented with multiconfiguration loads analysis.***

# *The MLA Process*

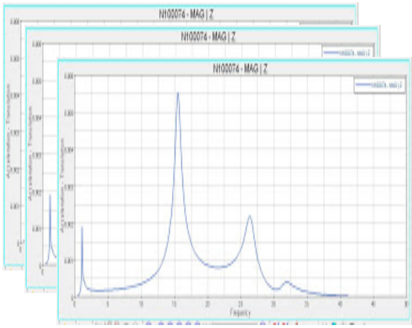
- The process defined here is applicable to missions with a large forward spacecraft on top of an ESPA-like adapter where the launch vehicle has been defined, but can be applied to other mission types

- Process is most effective when applied early in the mission integration cycle and continued through subsequent load cycles




1. Define initial dynamic properties envelope by setting ranges for mass, center-of-mass location, and fundamental frequencies (first bending in each plane, first axial, first torsion) of rideshare spacecraft

2. Enveloping set of loads calculated via MLA. Dynamic properties of the simulator models are varied to cover the envelope.



3. Forward spacecraft, launch vehicle, and rideshare spacecraft evaluate the loads from the MLA, identify any incompatible hardware, and update their design / qual plans
   – *If response limits are provided along with spacecraft models, this evaluation can be performed as part of the MLA*

# *The MLA Process (cont.)*

4. If design updates are not feasible, problematic configurations are identified and the dynamic properties envelope is reduced to exclude these configurations
5. Mission integration team advises rideshare providers on updates to the dynamic properties envelope. Rideshare spacecraft with properties within the envelope can be added or swapped without impacting the loads envelope.
6. The process is repeated for each load cycle. Simulator spacecraft models are replaced with detailed spacecraft models as the manifest is defined.
7. For the Verification Load Cycle (VLC) test verified models of all hardware are used. MLA is used with simulator models for any remaining uncertainty (including rideshare spacecraft that may not be ready for launch).
8. When the final flight manifest is known, an assessment is made to confirm the configuration is within the VLC MLA limits.

***By bounding loads, MLA "envelopes" the final launch configuration, as long as rideshare spacecraft properties are within the envelope***

# *Spacecraft Margin Incorporation*

- Incorporating spacecraft structural limits and margin calculations in the MLA process enable rapid mission design iterations by incorporating knowledge of how response changes affect the spacecraft structure

- Loads that change significantly with rideshare configuration changes may have no impact on spacecraft structural design if sufficient margin exists

- Top plot shows variation in a spacecraft shear load over 500 rideshare configurations
  - *One configuration results in an increase of >20% above the baseline configuration*

- Bottom plot shows the same data with the spacecraft structural capability included
  - *20% increase in shear load is well within the capability of the hardware*