Hybrid FE-SEA model reduction method to obtain detailed responses in complex structures

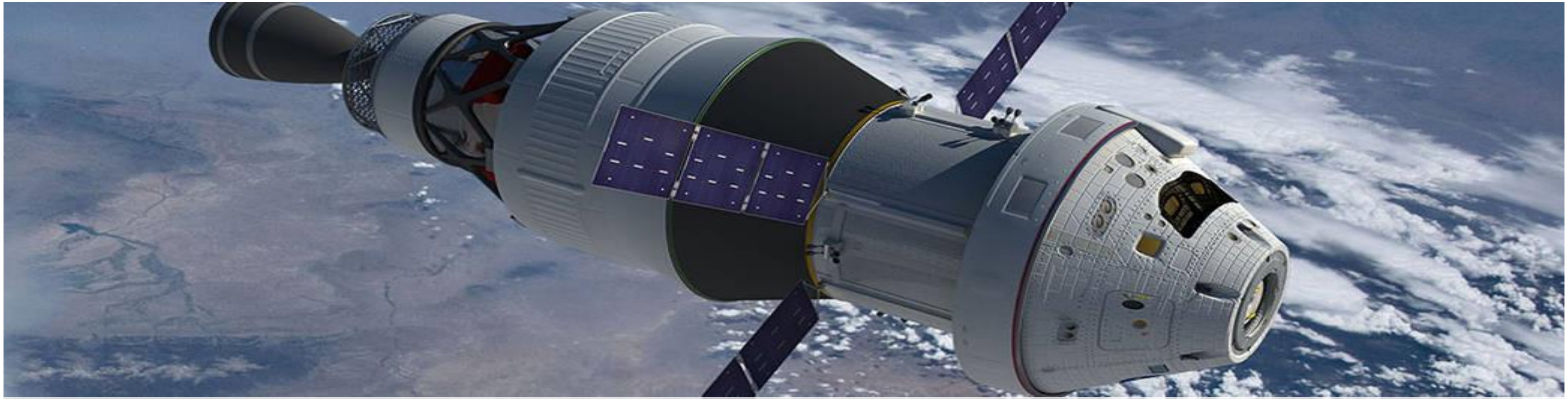

Image credit: Nasa.gov

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Agenda

- Introduction/Motivation
- Hybrid system models needs and requirements
- Reduced hybrid model concept
- Example
  - Hybrid system model
  - Pure SEA model
  - Reduced model
- Results and correlation
- Conclusions

Introduction, context and motivations

- Method developed as Part of an Engineering Services Project. ULA contracted ESI to create a system model of the SLS
- Goal was to create a system model with a detailed response on the structure of the intertank on the ICPS.
  - ICPS model was created from FE
- SEA model of stages not designed by ULA like the Orion MPCV were provided by supplier.

Elements present in model

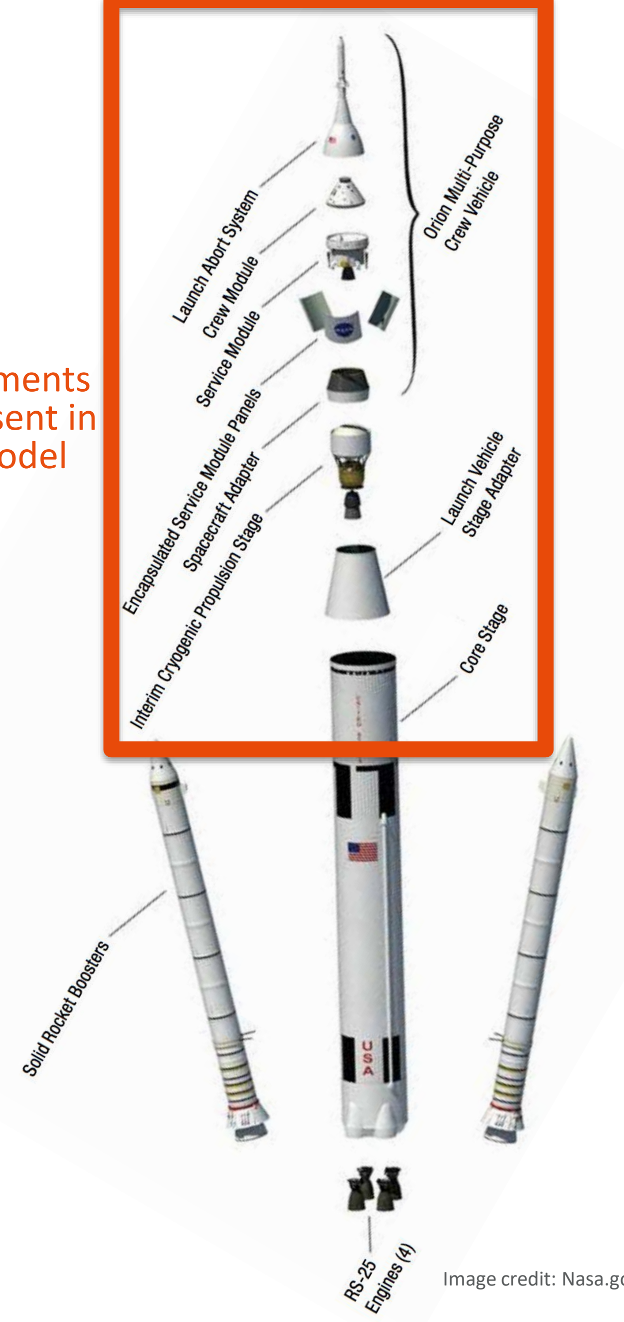


Image credit: Nasa.gov

Reduced hybrid model need on ICPS

- Critical panels are attached between the intertank X-frame
- Detailed response is needed to evaluate panels' response during launch phase.
- X-Frame (intertank) is stiff and therefore a Hybrid model is required for this section.

Image credit: ULA

Introduction, context and motivations

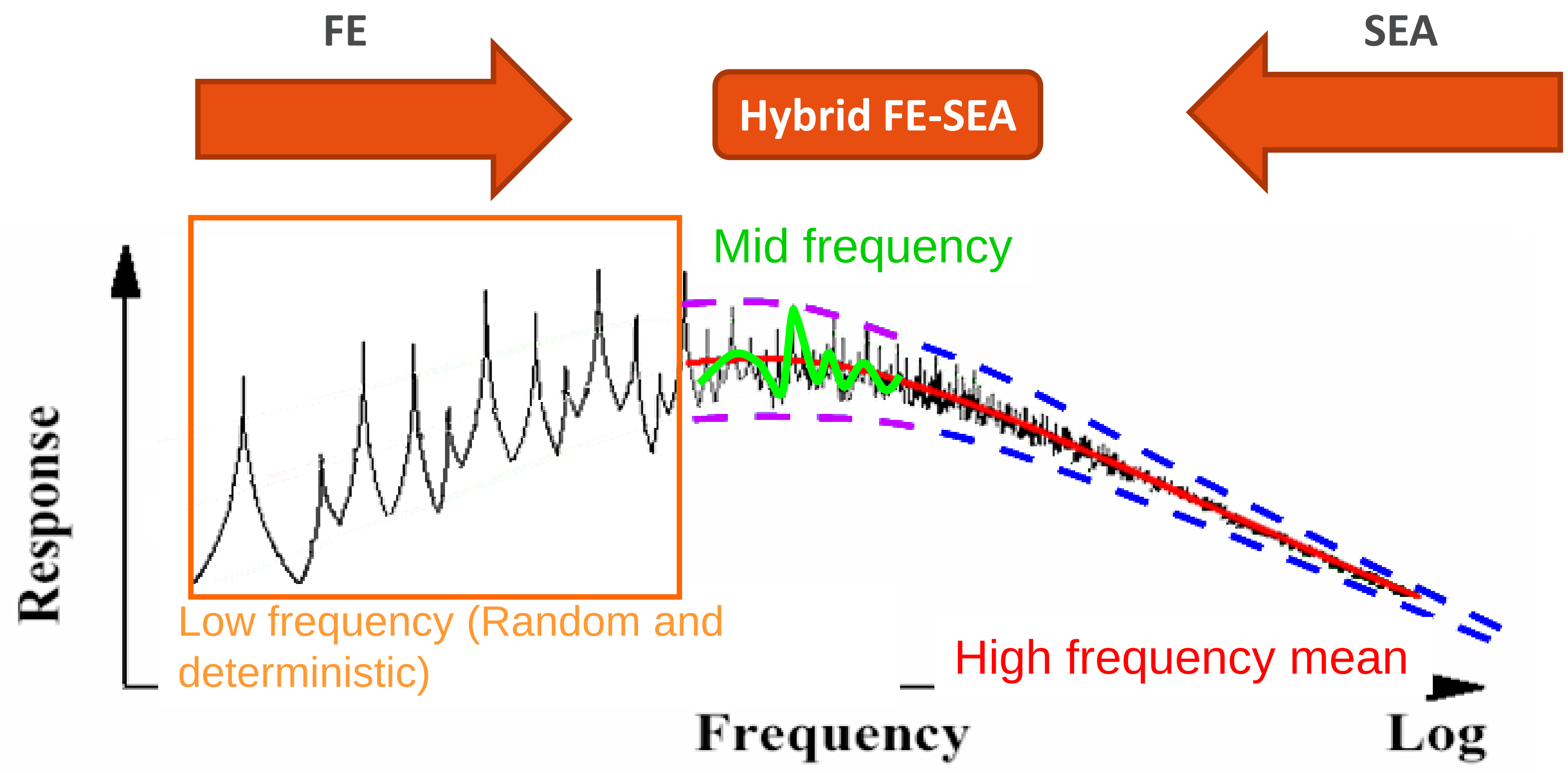
- A large hybrid model is required
  - High number of SEA subsystems
  - Large number of modes present at the intertank for targeted frequency range
  - Detailed response at the intertank is required.

- <u>How can we minimize the computational requirements of a hybrid system model?</u>

- <u>Can we extend the hybrid model frequency range by minimizing its size?</u>

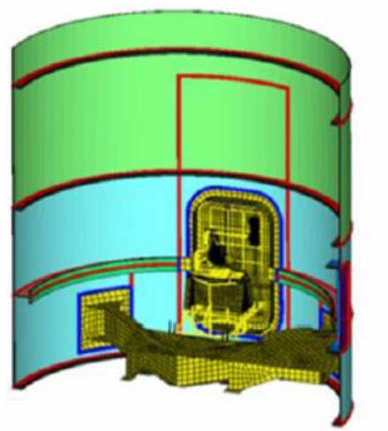
Simulation Methods for Vibro-Acoustics

- Dense modal frequencies cannot be accurately predicted by deterministic methods
- SEA predicts the ensemble average

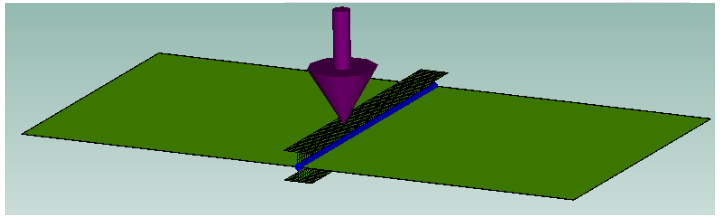


Hybrid system models needs and requirements

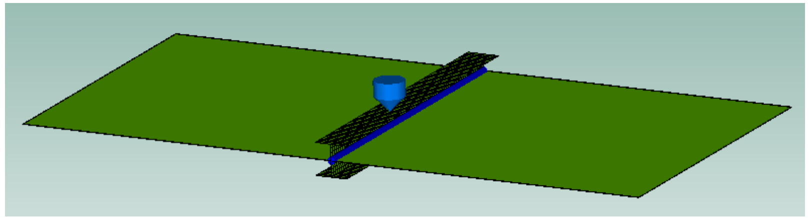
- Hybrid FE-SEA models are typically used for 3 main reasons:
  - Need to model the behavior of stiff elements that can't be accounted for in pure SEA since their modal density is too low.



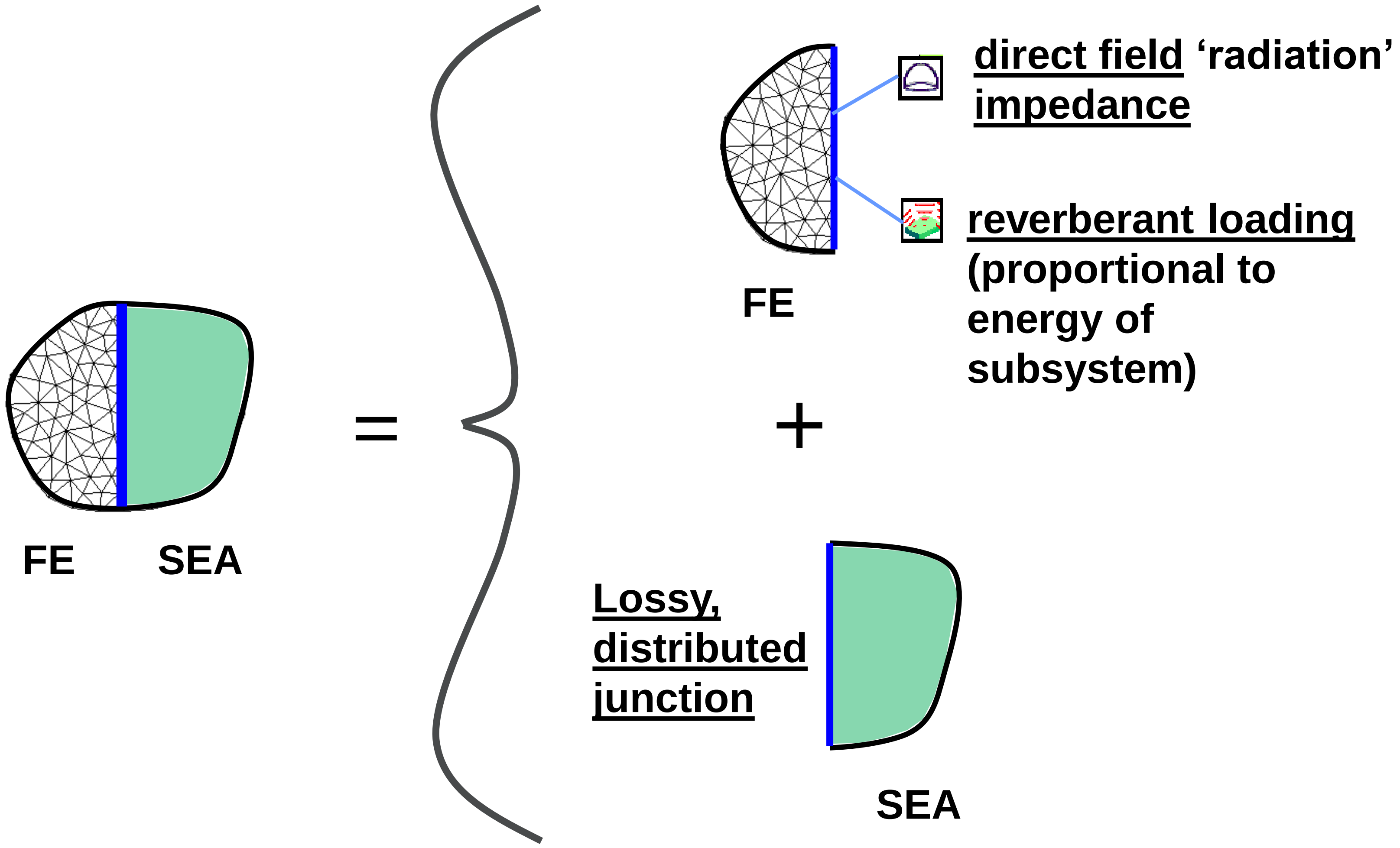
  - Need to apply a detailed structural load on the model.



  - Need a detailed response at a given location on stiff elements on the structure.



Coupling FE with SEA



Hybrid theory exerpt

$$[\mathbf{D}_0]\{\mathbf{x}\} = \{\mathbf{f}\}$$

Dynamic stiffness of deterministic subsystems

= [K-ω^2 M]

"Modes" of FE subsystems used as basis functions

$$\left[\mathbf{D}_0 + \sum_i \mathbf{D}_{i,dir}\right]\{\mathbf{x}\} = \{\mathbf{f}\}$$

Dynamic stiffness of SEA subsystem direct fields

$\mathbf{D}_\mathrm{i}$ is of size

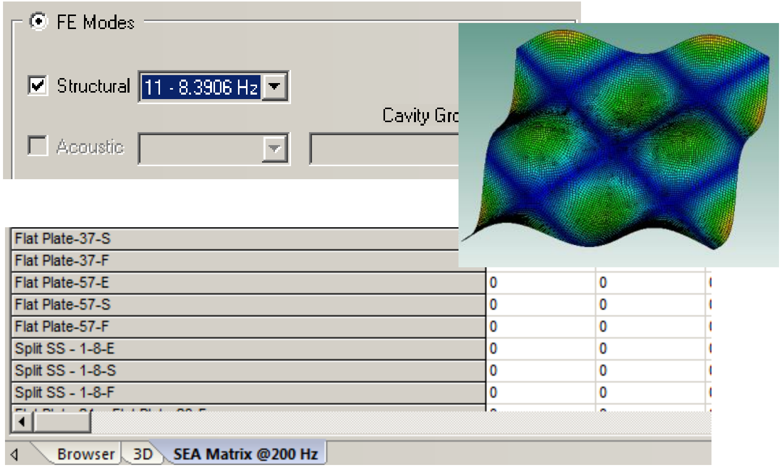
n modes x n wavefield.

$$\mathbf{S}_{xx} = \mathbf{x}\mathbf{x}^H = \mathbf{R}\mathbf{S}_{ff}\mathbf{R}^H$$

$$\mathbf{R} = \left[\mathbf{D}_0 + \sum_i \mathbf{D}_{i,dir}\right]^{-1}$$

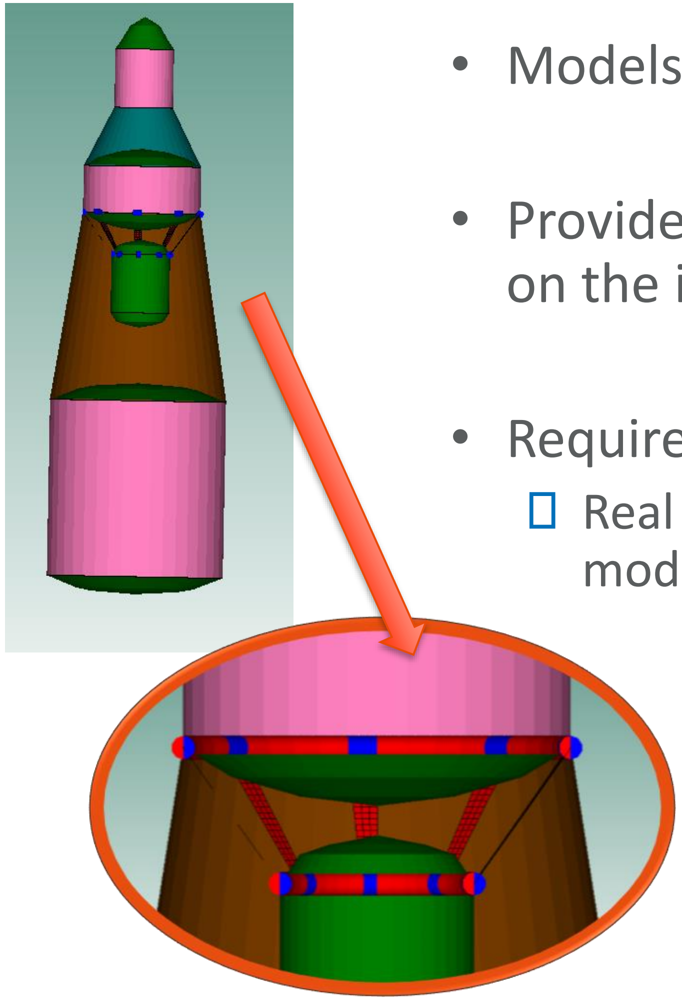
Hybrid system models needs and requirements

- Model size if proportional to:
  - Number of modes
  - Number of SEA wave fields



- This has a direct impact on:
  - Solve time/CPU requirements
  - Memory usage
    - Proportional to:
      - Number of wave fields
      - Number of modes^2

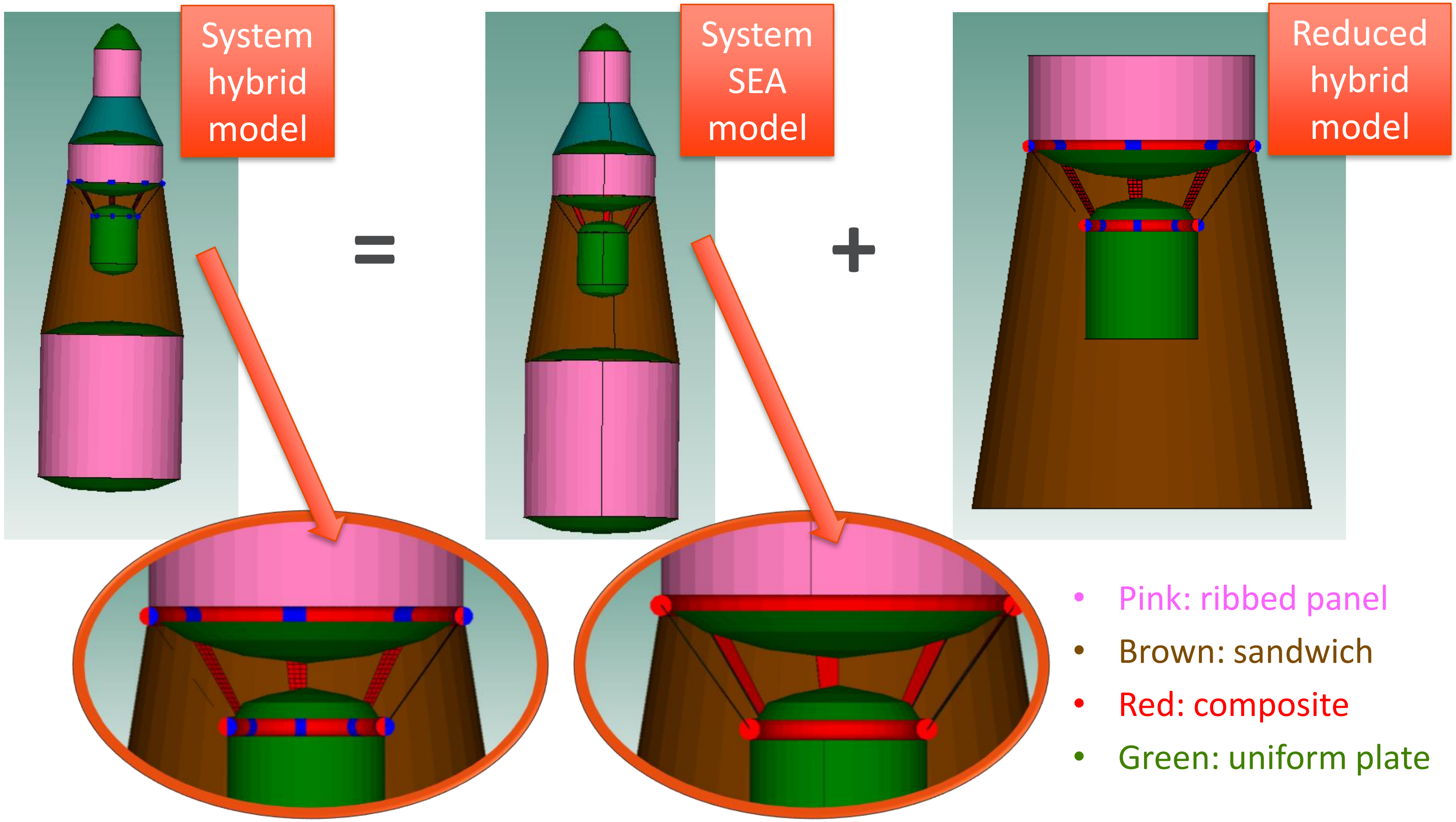
Hybrid model for SLS



- Models intertank in detail with FE
- Provides detailed response at the panels placed on the intertank.
- Requires large computational capabilities
  - Real model has approx. 2200 wave fields and 6000 modes

Reduced hybrid model concept

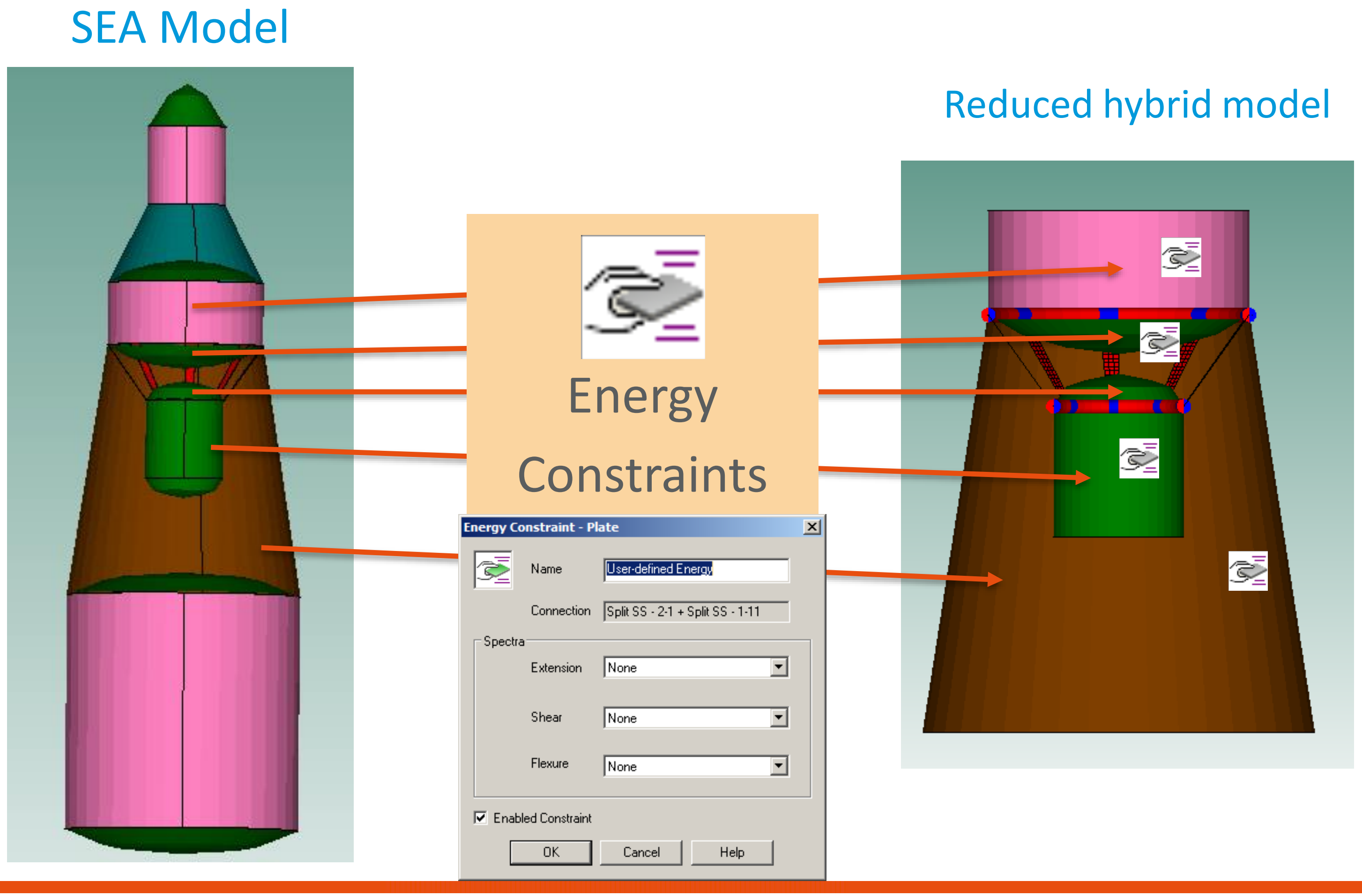
How to limit memory requirements



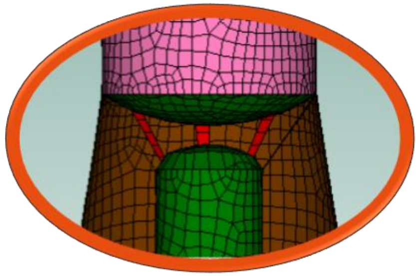
- Pink: ribbed panel
- Brown: sandwich
- Red: composite
- Green: uniform plate

Reduced hybrid model concept

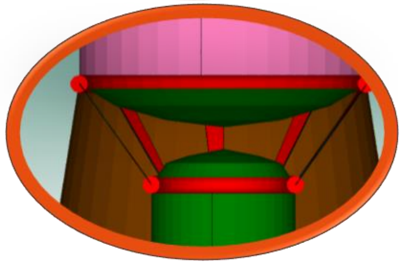
Responses from SEA model are used to constrain all SEA Wavefield in Hybrid model



Model creation process

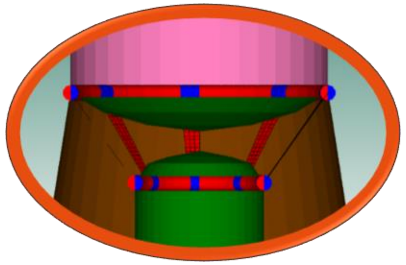


Source FE model



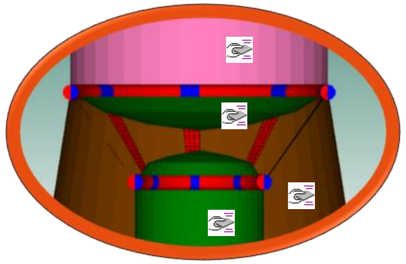
Create SEA system model

Created from FE models



Create hybrid system model

Used for correlation on limited frequency range and reduced hybrid model creation

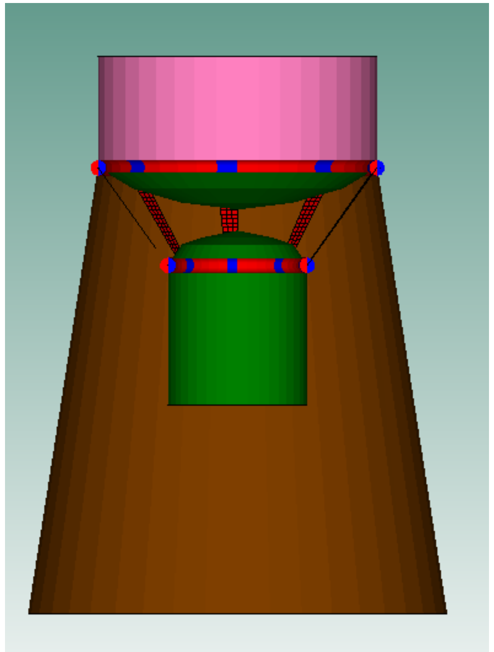


Create reduced hybrid model

Created by removing unnecessary SEA subsystems from hybrid system model and adding energy constraints.

Memory requirements

- Example System hybrid model
  - has 66 wavefields, FE intertank has 208 modes
- Example Reduced hybrid model
  - Has 15 wavefields and the same 208 modes
- Memory requirements and solve time scale with # of wavefields.



- On the services project related to this model, using this technique allowed to obtain results in the whole desired frequency range limiting computational resources to a workstation.
  - System hybrid model had ~2200 wavefields
  - Reduced hybrid model has 25 wavefields.

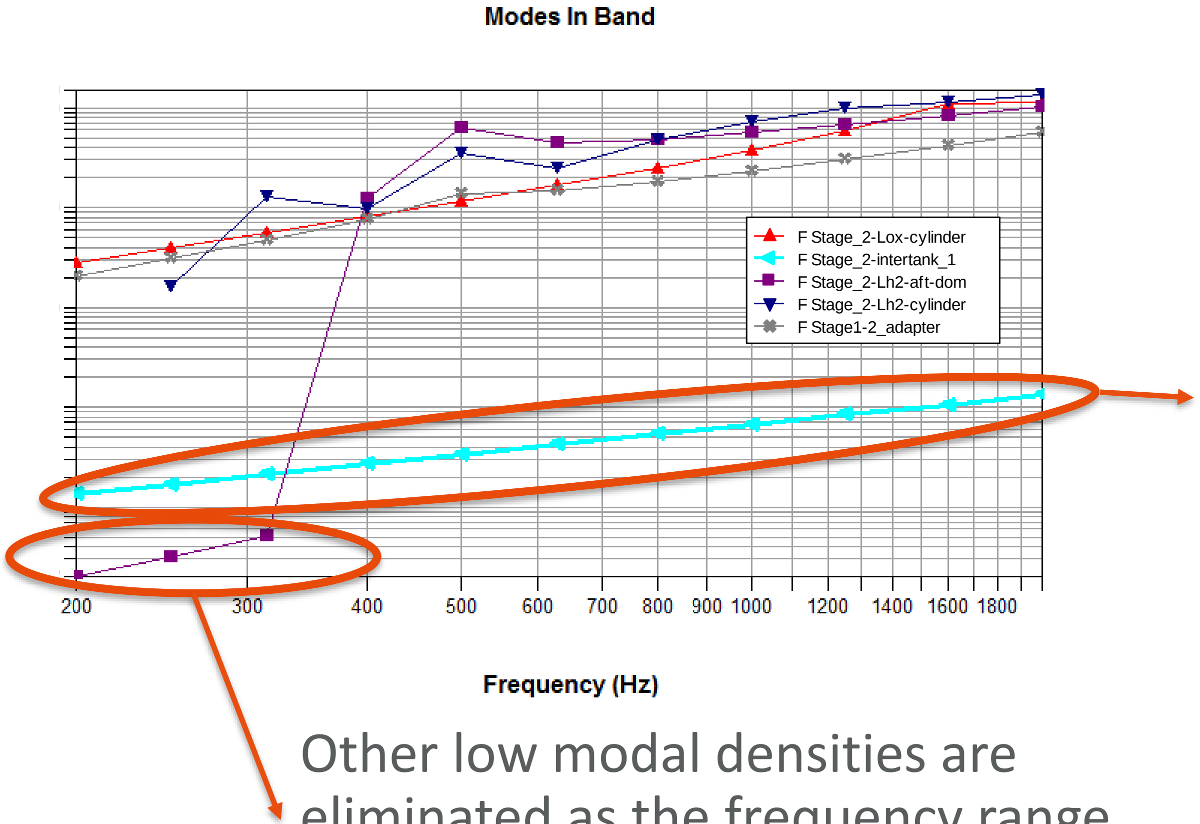
Potential limits to the method

- Low modal density SEA have to be watched for.
  - At least 3 modes in band are recommended for SEA subsystems

- SEA system model has to represent correct energy flow
  - SEA model results can be compared to system hybrid model for a limited frequency range
  - In Engineering Services project, this comparison showed satisfying results

- In presented example, we notice a difference of levels on stage 2 Lox tank cylinder

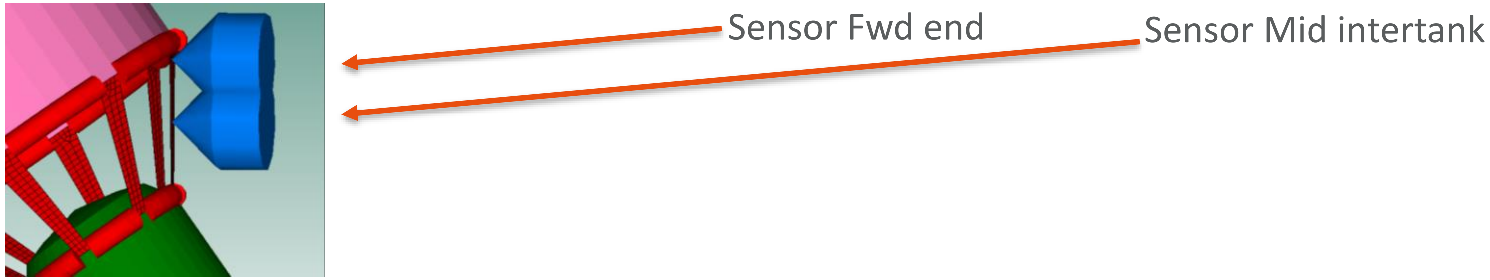
Modal densities

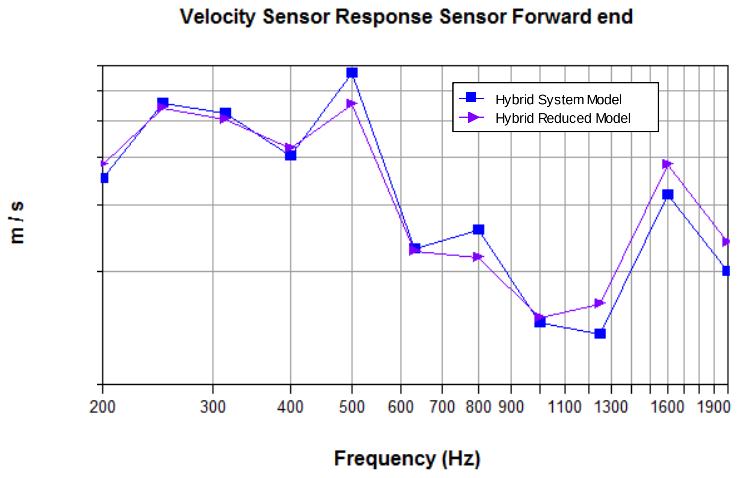


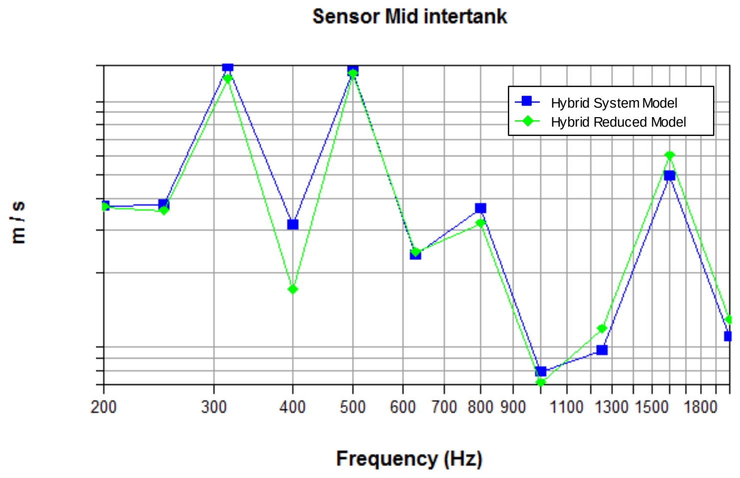
Modal density on intertank is too low for SEA.

Other low modal densities are eliminated as the frequency range increases or are not part of the energy dominant path.

Results comparison between full and reduced hybrid







Correlation between the two models is very good.

Conclusions

How can we minimize the computational requirements of a hybrid system model?

Can we extend the hybrid model frequency range by minimizing its size?

- Reduced hybrid model allows
  - minimization of the memory requirements
  - reduced computation time
  - therefore allowing their potential frequency range.

- For this Engineering Services project
  - Technique allowed the calculation of a detailed response on a stiff structure at specific locations
  - effectively doubling the initial frequency range of the system hybrid model (for the same machine)

Thank you!

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