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INTES

DYNAMIC SIMULATION WITH NON-LINEAR DAMPING DEVICES

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PERMAS
Users' Conference
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OBJECTIVES FOR ARIANE GROUP

- **Payloads comfort is a crucial point for an efficient launcher**
- **Strong commercial argument in the increasing competitive market of the space access**
- **Needs to reduce/damp vibrations at low frequencies (5-100Hz)**
- **Two potential concepts :**
  - Dedicated isolation function via a passive damping device (add-on solution) : **Focus of this presentation**
  - Components with integrated damping as "damping structure" (add-in solution)
- **To reach higher levels of damping → needs to deal with non-linearities (friction, material, viscoelasticity)**
- **How to incorporate such non-linear devices in the launcher simulation frame ?**

INCAS R&D PROJECT

- **INCAS : INnovation de Concepts AttenuateurS** – *inovation of damping designs*
- **Vibration mastering for the comfort of sub-structures sensitive to low frequency vibrations**
  - Significant deformation rate,
  - Difficulties in predicting dynamic behavior,
  - Dynamic improvement for more sensitive equipment.
- **Objectives :**
  - Develop technological solutions to reduce vibratory environments of embedded equipment by isolation and/or damping
  - Develop software tools to predict the dynamic behavior of the system taking into account nonlinearities.

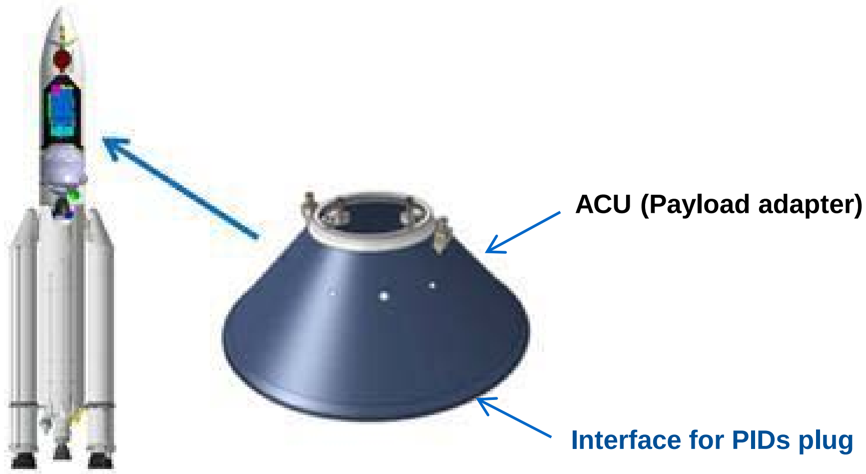
LAUNCHER APPLICATION

Improve the vibratory low frequency environments of satellites on launcher (PID) :

- 2 to 4-fold reduction of vibratory environments at the payload level

Willingness to :

- ➢ Develop passive damping devices (PID) for the upper part of the launcher in the short term.
    - ✓ Plug-in between the ACU (Payload adapter) and the lower component.
- ➢ Remove longer-term vibration isolation systems and use a new class of damping materials.



LAUNCHER APPLICATION (2)

Two damping concepts for PID will be review

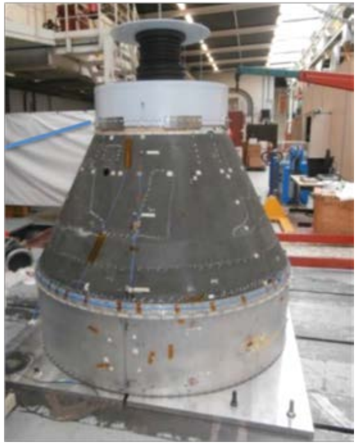
- Friction damping based (via cables)
- Material damping based (via elastomer)

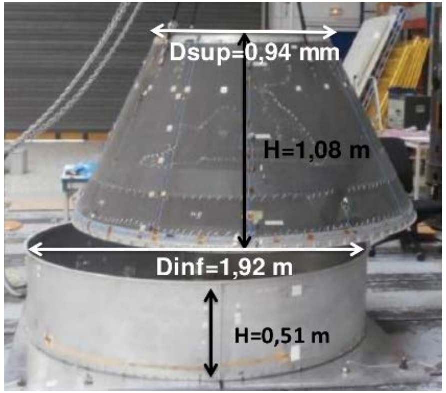
Elastomer devices

Friction devices

To be validated with **experimental tests** (unit level and full assembly level) and by **numerical simulations**

Experimental structure





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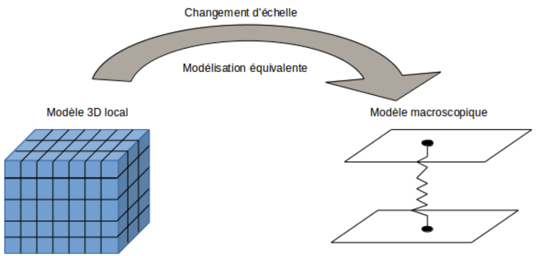
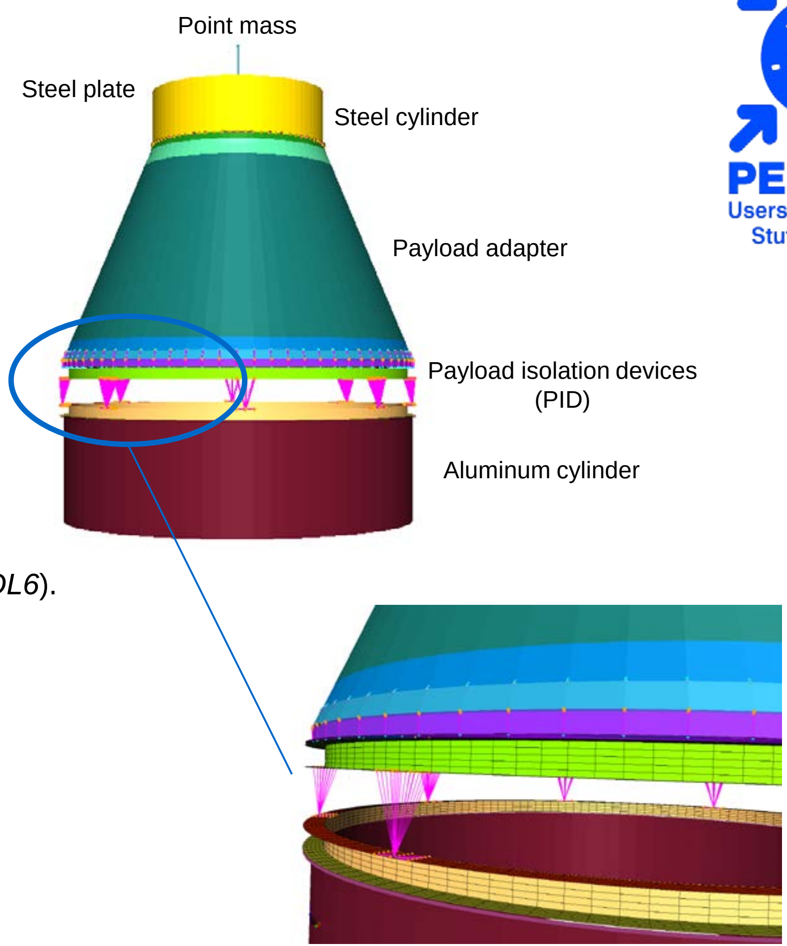
MODELLING STEP

- **F.E. model for the numerical benchmark**
  - Around 300 000 elements, 400 000 nodes
  - Involving shell and solid elements,
  - Laminate material for the Payload adapter

- **Two levels of idealization for the non-linear device**
  - Local 3D (detailled) model,
  - Equivalent model with a 2 nodes structural element (*CONTROL6*).





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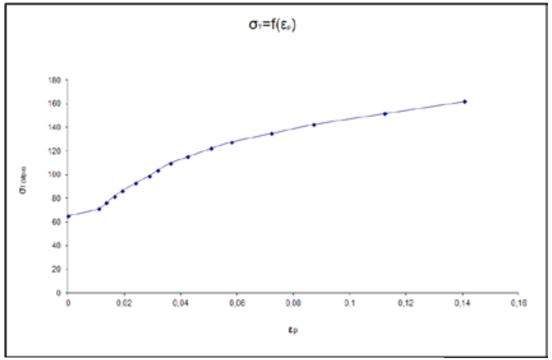
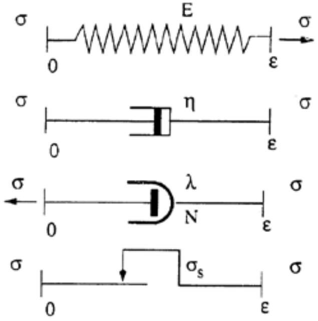
MODELLING STEP (2)

From experimental tests, or theoretical datas, and numerical simulations with local 3D models, the laws of behavior (non-linearity and/or visco-elasticity) have to be derived for the equivalent model. It can be done using two ways :

- **“Point-by-point” definition**
  - Could be a long and a low accurate process,
  - Difficulties to obtain the complete set of data,
  - Valid only in a particular context.



- **Rheological series**
  - More robust, but need an identifaction process,
  - Better flexibility facing a modification of the law of behavior,
  - Need the building of a library of non-linear rheological series in PERMAS (via USER FUNCTIONs)
  - Underlines the causal link,
  - Better numerical stability.



$\sigma = E\,\varepsilon$	*Spring*
$\sigma = \eta\,\dot{\varepsilon}$	*Damper*
$\sigma = \lambda\,\dot{\varepsilon}^{1/N}$	*Non-linear damper*
$-\sigma_s < \sigma < \sigma_s$	*Friction damper*

SIMULATION METHODS

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In the frame of dynamic launcher analysis, the modal methods with linear (FS) models are mainly used :

Real Eigenmodes
[FSCoupled] VIBration ANalysis

Transient loads
(Lift off…)

Time history solution
Modal [FSCoupled] TIMEhistory

Periodic loads
(Pressure oscillation…)

Harmonic solution
Modal [FSCoupled] FREQuency

Random loads
(Aerodynamics…)

Random response
Modal [FSCoupled] RANDOM

SIMULATION METHODS (2)

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Extension of the previous methods with non-linear devices

Real Eigenmodes
[FSCoupled] VIBration ANalysis

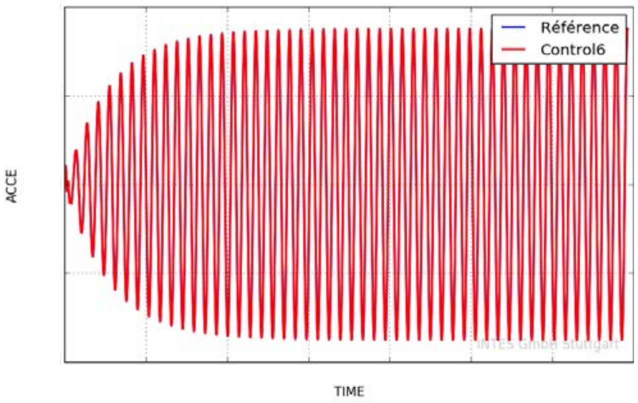
- Transient loads (Lift off…) → Time history solution with non-linear discrete elements — Modal [FSCoupled] TIMEhistory
- Periodic loads (Pressure oscillation…) → Harmonic Balance Method with non-linear discrete elements (APC solution)
- Random loads (Aerodynamics…) → Under investigation !

SIMULATION METHODS (3)

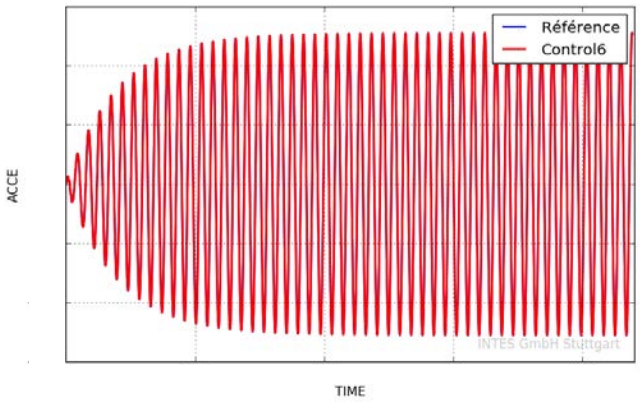
Validation of the results obtained by a modal method by a comparison with results from a direct analysis.

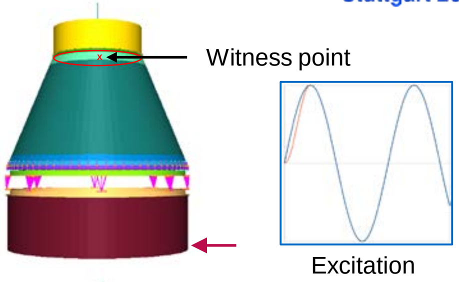
f1 and f2 are respectively the eigenfrequencies related to the first transversal and longitudinal mode.
The excitation is a prescribed acceleration.

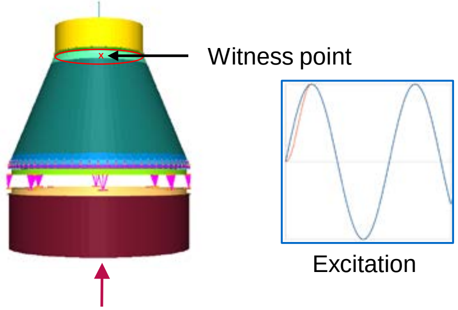
Lateral excitation



Longitudinal excitation







Linear configuration

Many parameters have been checked : additional modes, time step, inner step, number of modes, modes damping, solver type.

SIMULATION METHODS (4)

Validation of the results obtained by a modal method by a comparison with results from a direct analysis.

f1 and f2 are respectively the eigenfrequencies related to the first transversal and longitudinal mode.
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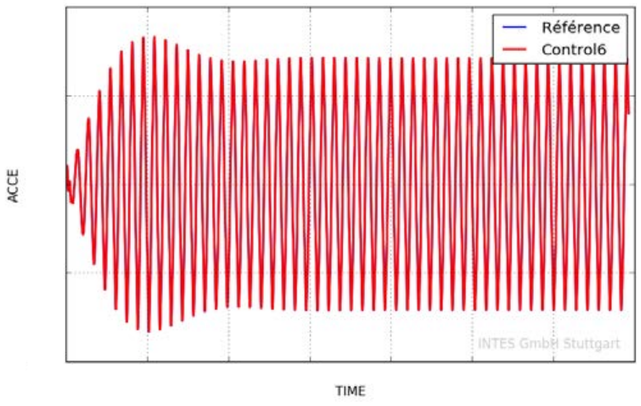
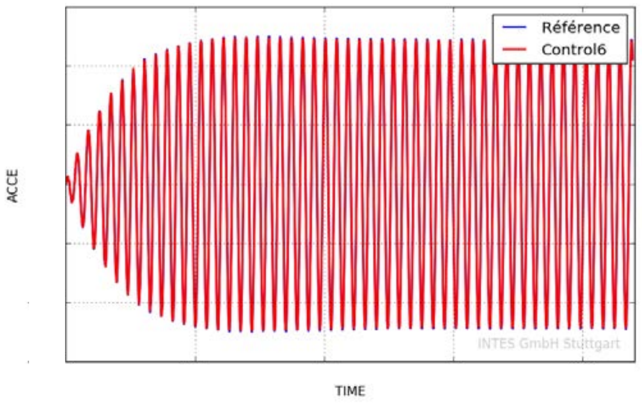
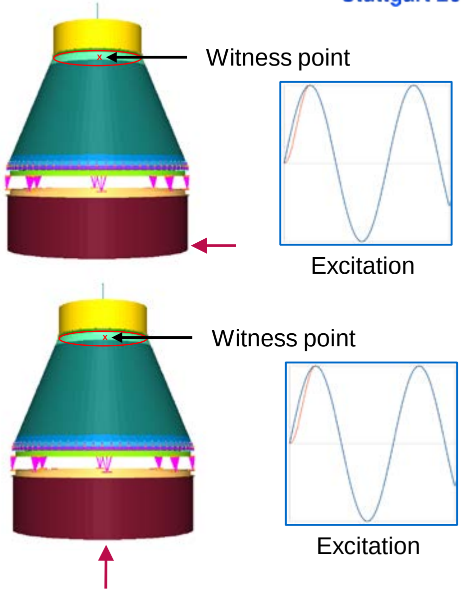
Lateral excitation

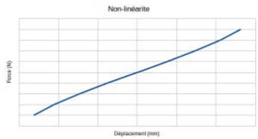


Longitudinal excitation





Extension to the non-linear configuration



Non-linearity profile (20% stiffening)
(relationship between force and displacement)

Many parameters have been checked : additional modes, time step, inner step, number of modes, modes damping, solver type.

SIMULATION METHODS (5)

Some hints :

For modal solutions, non-linear devices are handle as external non-linear loads in PERMAS

- Linearization point of non-linear device is needed for the real eigenmode calculation
- Modal truncation effect
- Non-linear dofs have to represented in the modal basis

Modal methods are well adapted for a moderate number of non-linear dofs :

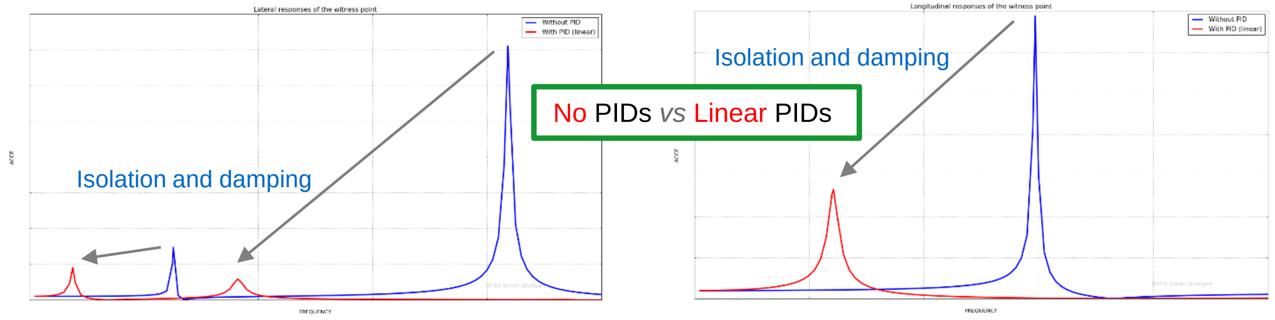
- Linear model with discrete non-linearities modelled by specific elements (NLSTIFF, NLDAMP, CONTROL6)
- Reduced response (PRIMRES = REDUCED) are available which reduces drastically the runtime and the diskspace
- Extension to a coupled fluid structure problem remains avalaible in PERMAS (mandatory for launcher simulation !)

For time history simulations, the current modal integration method is based on a fixe time increment which is not always adapted for strong non-linearities.

The direct solutions would be more efficient in case of large number of modes and/or non-linear-dofs.

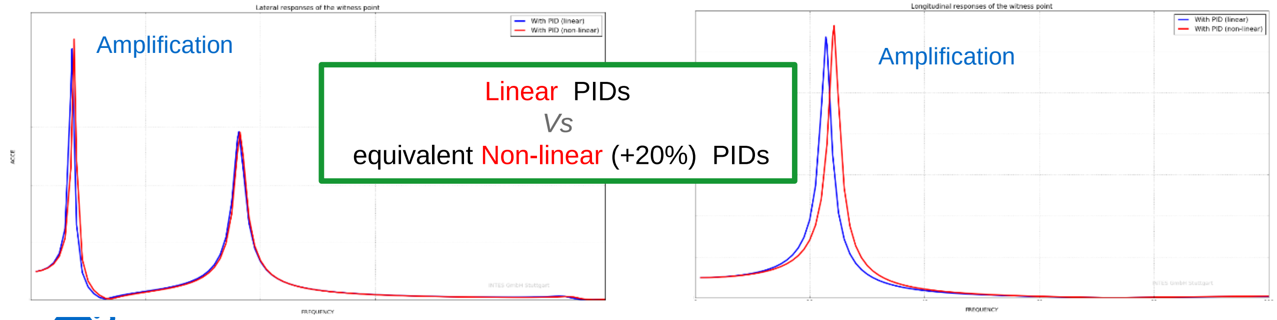
PRACTICAL EXAMPLES

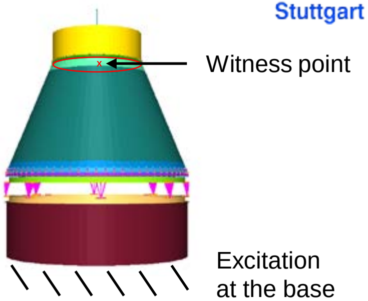
The dynamic responses of the witness point (center of the interface between the payload and the payload adapter) permit to underline the effect of the use of non-linear PID.

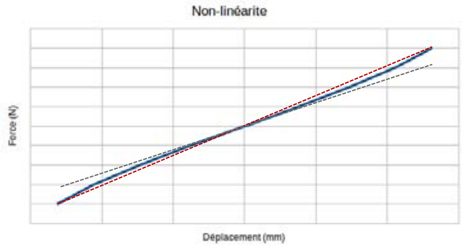


Lateral responses

Longitudinal responses





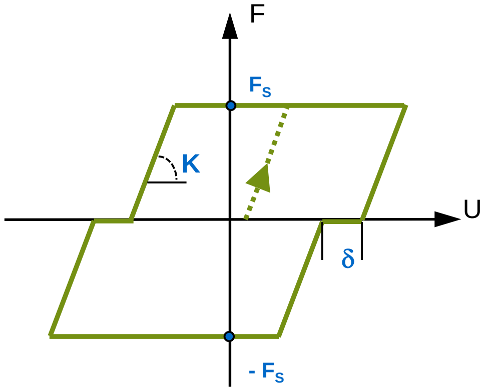


Non-linearity profile (20% stiffening)
(relationship between force and displacement)

PRACTICAL EXAMPLES

On going work : extension to Friction models

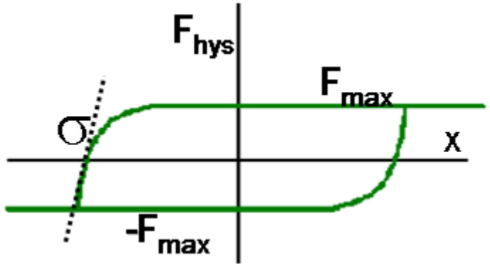
(Discrete) Friction model with gap :



Dahl friction model :

(**Dahl P.R.**, « A solid friction model », The Aerospace Corporation, El-Secundo, California, 19

With σ the initial tangential stiffness, Fc the maximal friction force and x the displacement.



OUTLOOK & CONCLUSION

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- Reducing vibrations is a general topic, interesting for launcher application and other branches of industry as well.
- Dedicated function via discrete damping devices (PID).
- Higher damping effect with the non-linear behavior (elastomer or friction).
- Demonstration and design of such concepts in progress via experimental tests (unit level and full assembly level) and numerical simulations (optimization).
- The analysis of the vehicle dynamic behavior with discrete non-linearities will be the key point in the launcher simulation frame.
- PERMAS provides standard solutions for time history analysis with discrete non-linearities based on modal or direct integrations.
- For frequency responses, the Harmonic Balance Method is currently evaluated via an APC prototype.