Analysis of the Nonlinear Dynamics of an F-16 Aircraft Using the NI2D Toolbox

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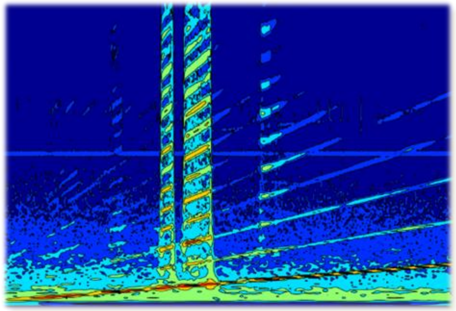
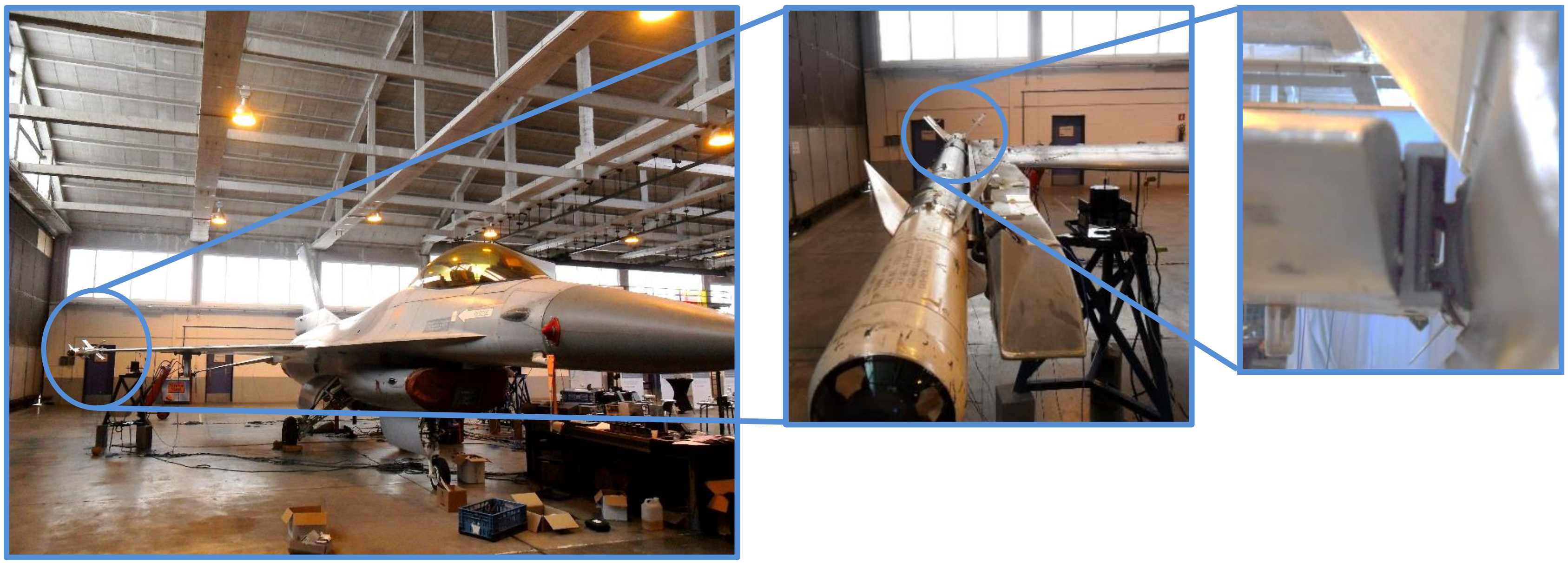


Our Test Case: the F-16 Fighter Aircraft

F-16 fighter aircraft

Wing-to-missile mounting interface

Nonlinear connection?

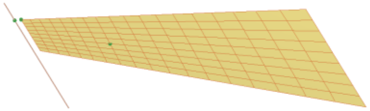


Saffraanberg, Belgium.

Design Cycle of Nonlinear Engineering Structures

MEASURE

IDENTIFY



MODEL

UNDERSTD
UNCOVER

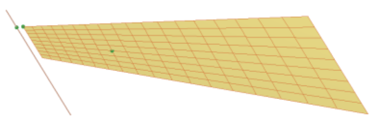
DESIGN

Mature experimental and numerical techniques

Outline

MEASURE

IDENTIFY



MODEL

UNDERSTD
UNCOVER

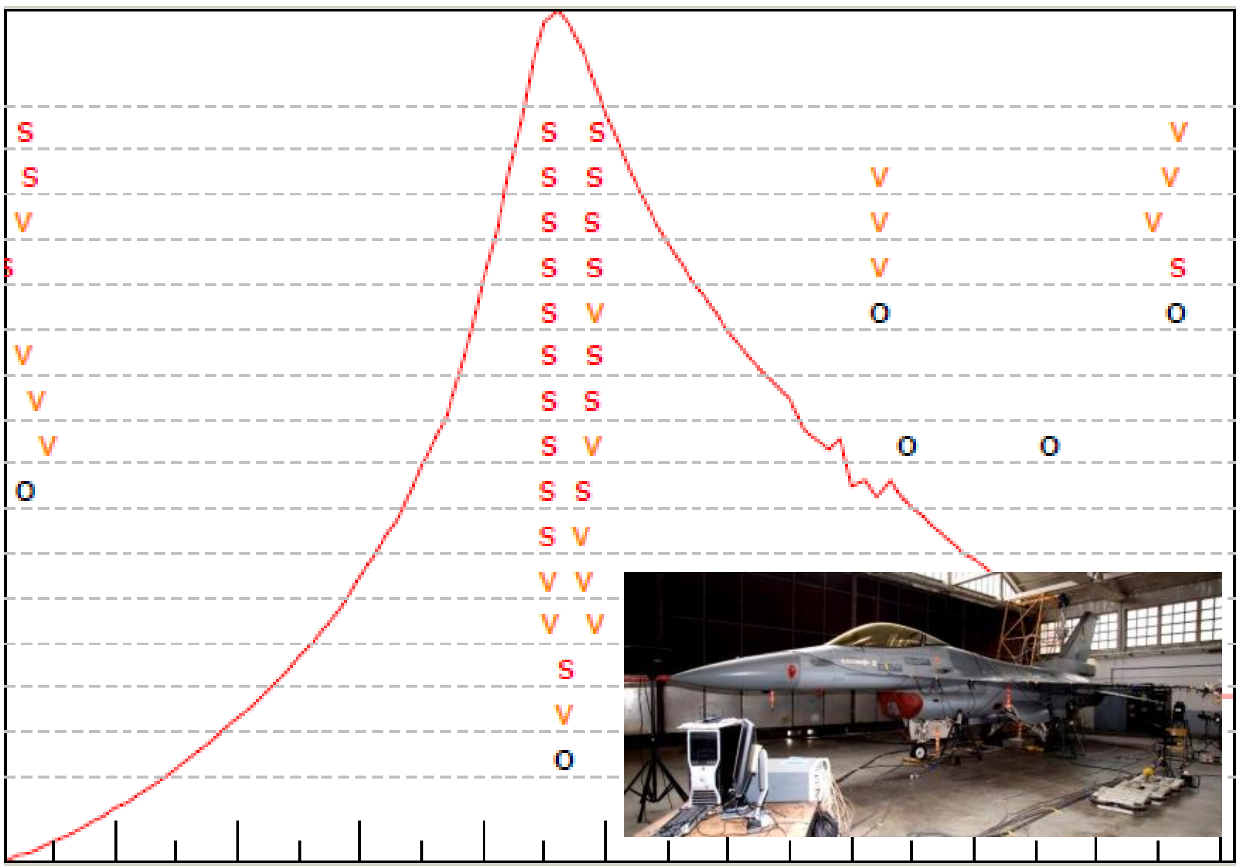
DESIGN

IN THIS PRESENTATION

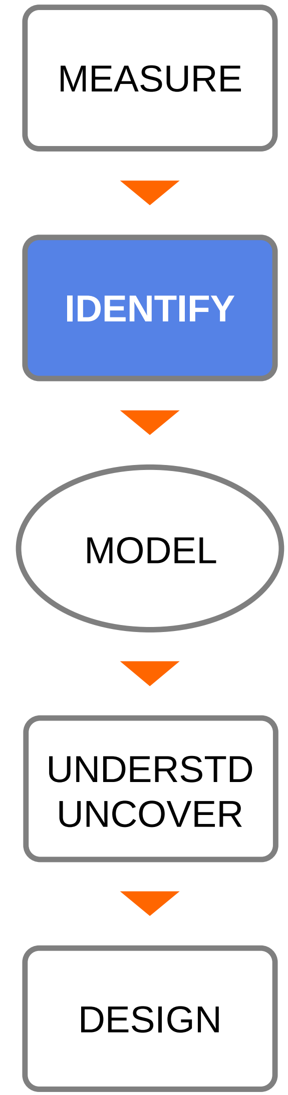
Classical Linear Tools May Fail or Give Wrong Results

[B. Peeters et al., IMAC 2011]

Model order



Frequency (Hz)



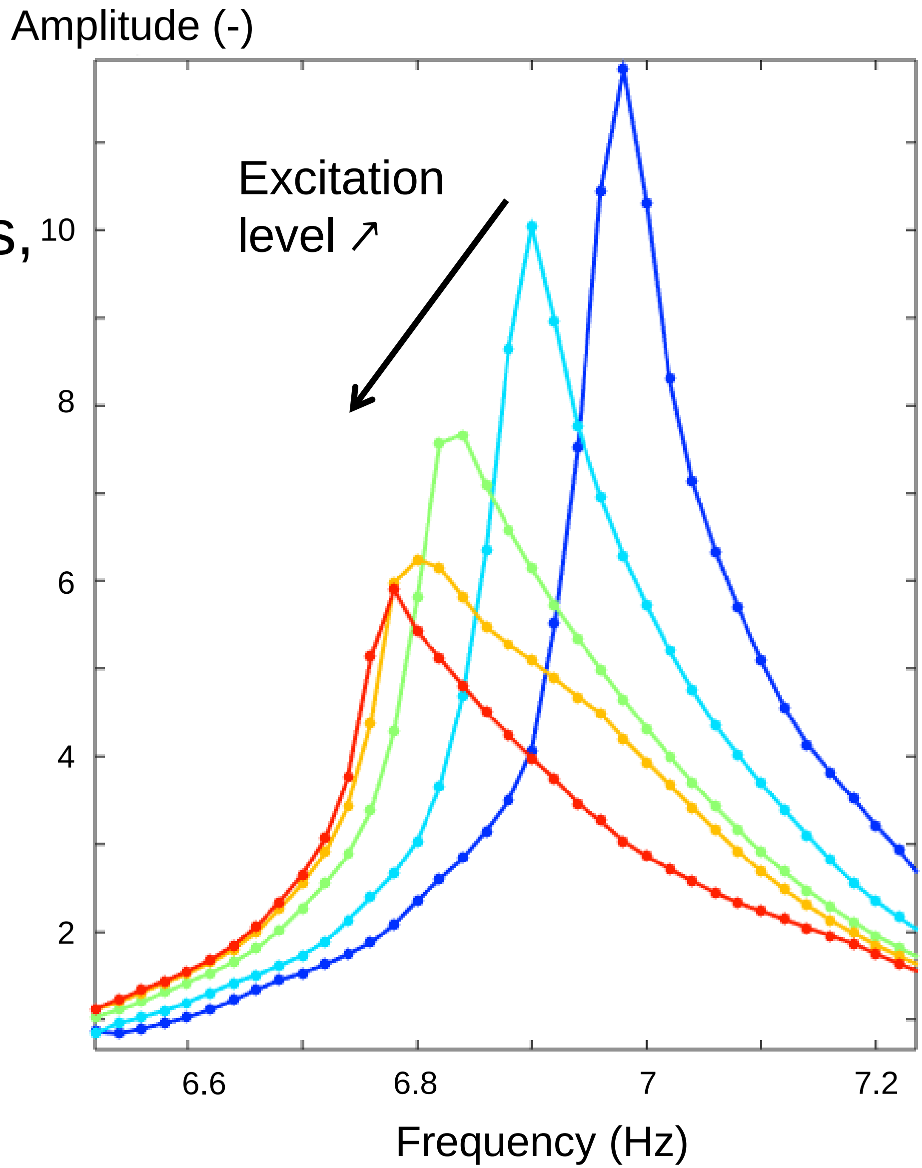
Evidencing Nonlinearity Is Fairly Straightforward

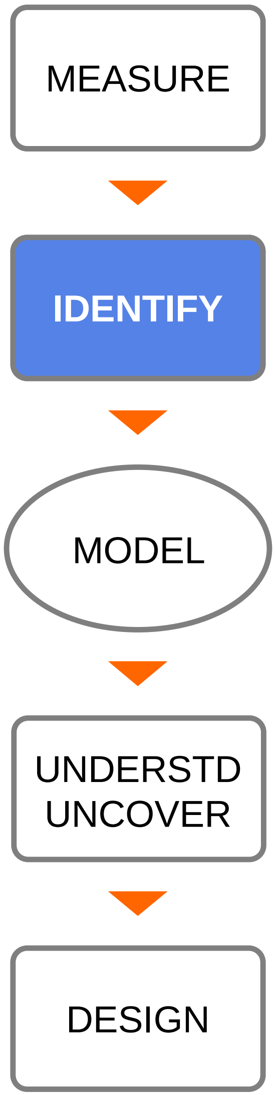
Single FRF:

Distortion (skewness, nonsmoothness, …) of the resonance peak.
→ usually not appliable with random excitation.

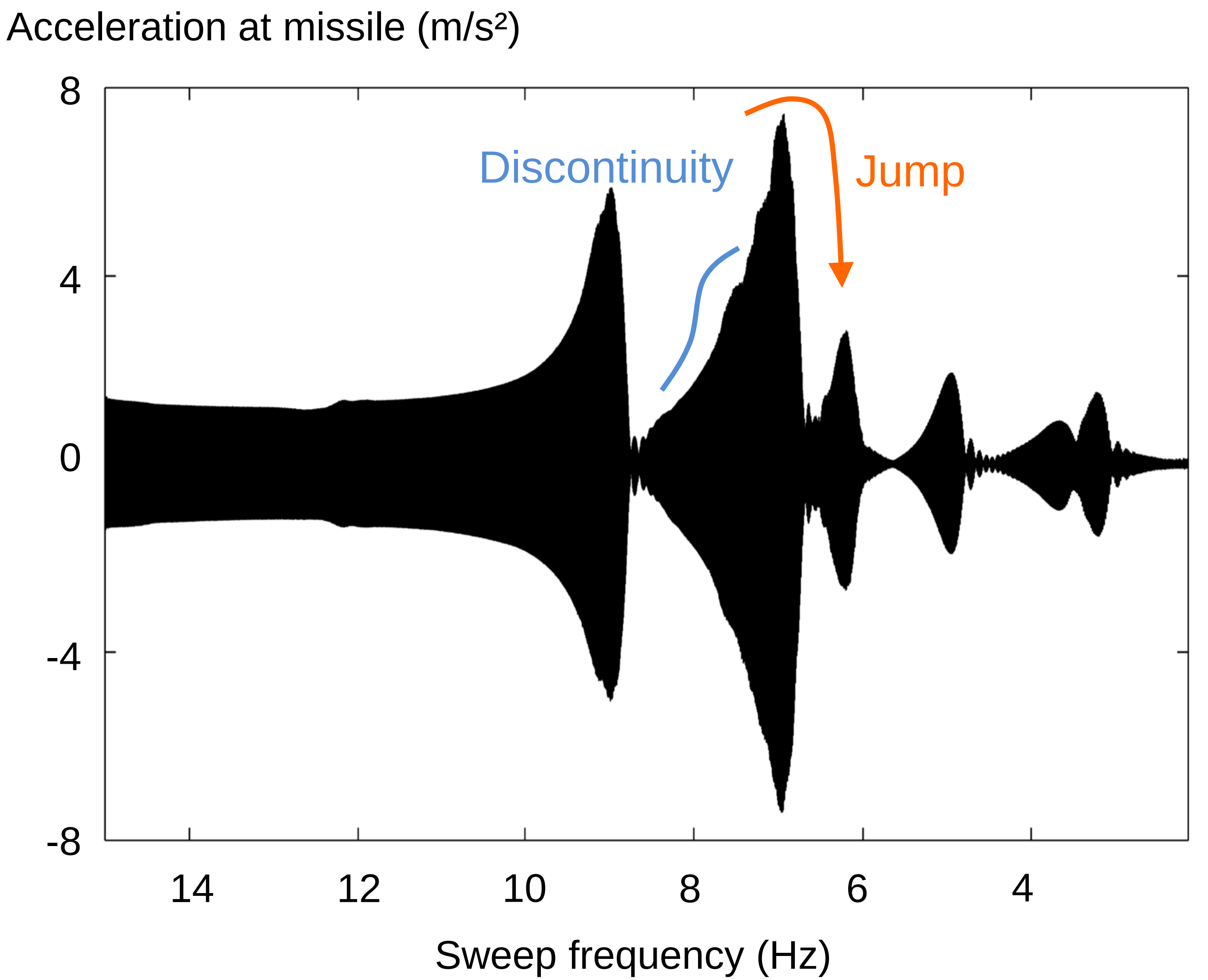
Several levels:

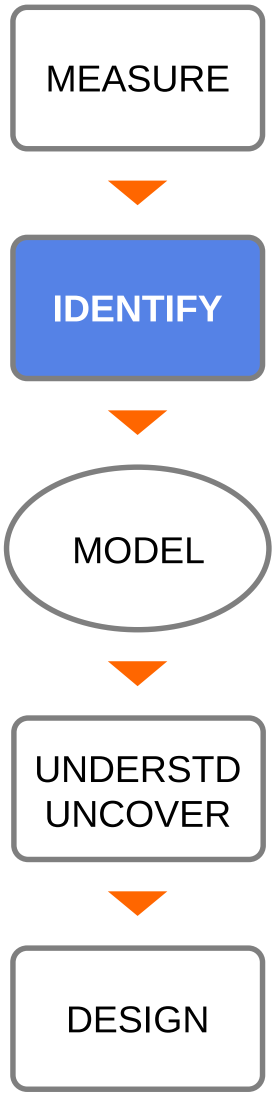
Homogeneity principle can be checked.



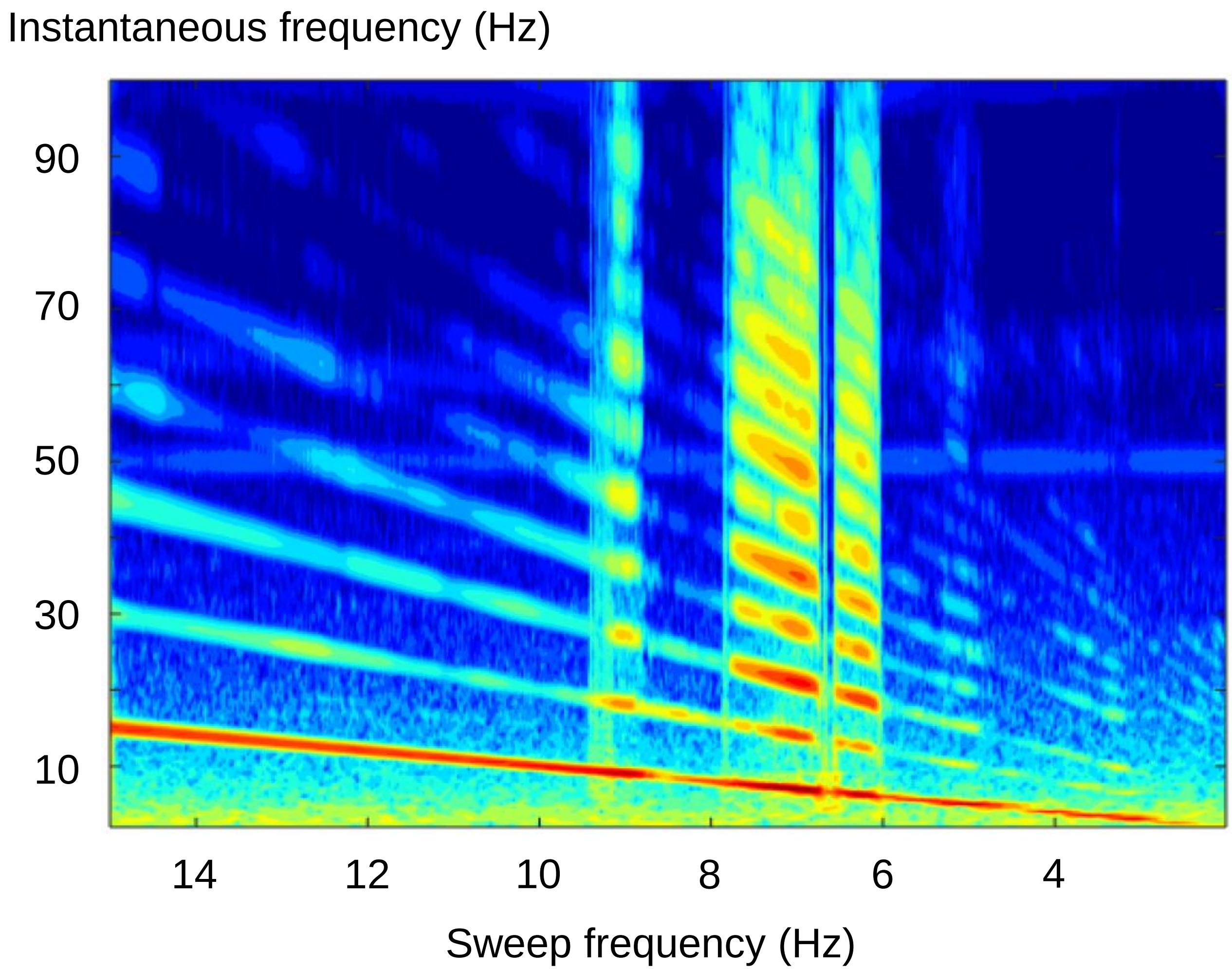


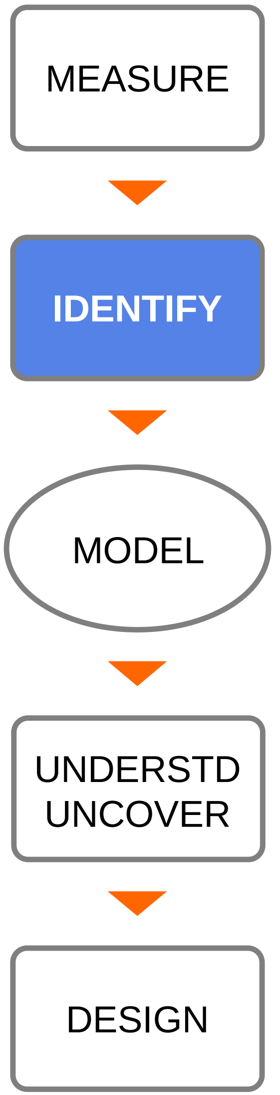
Evidencing Nonlinearity Is Fairly Straightforward





Inferring a NL Model from Time-Frequency Analysis



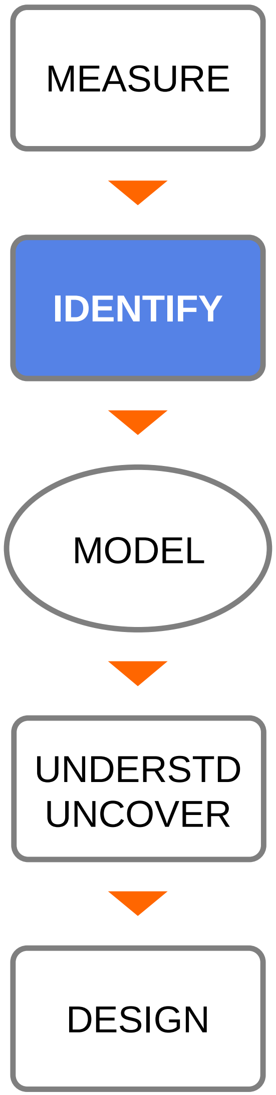


The RFS Method: An Underutilized Approach

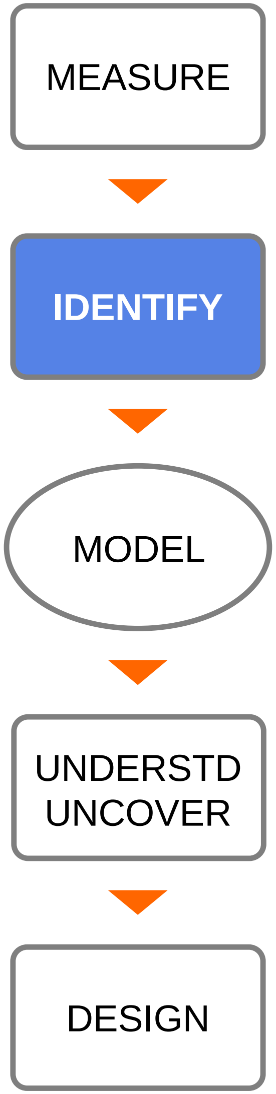
Introduced by Masri and Caughey (1979, ASME JAM) as a nonlinear parameter estimation technique.

Very popular in structural dynamics because of its simplicity.

Rigorously applicable to low-dimensional systems, but can be exploited qualitatively for visualising nonlinearity.



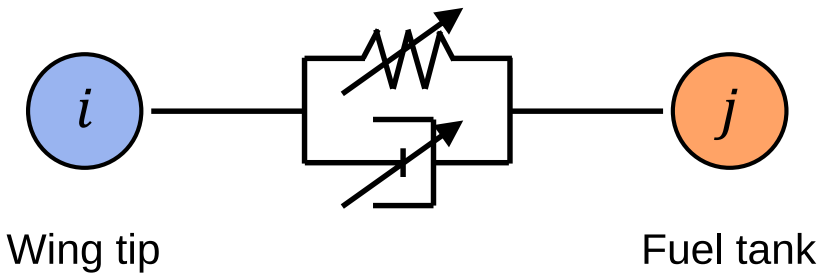
How Can We Visualize the NL Behavior of this Connection?

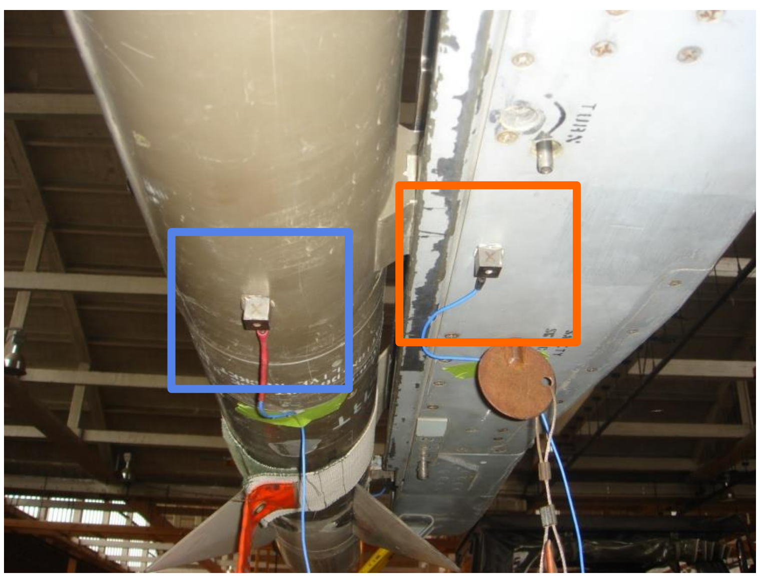


Slide connection involving complex dynamics.

Physical insight is key to parametric modelling.

Macroscopic Idealization as Lumped Spring and Dashpot





Potential nonlinear connections must be instrumented on both sides.

MEASURE

IDENTIFY

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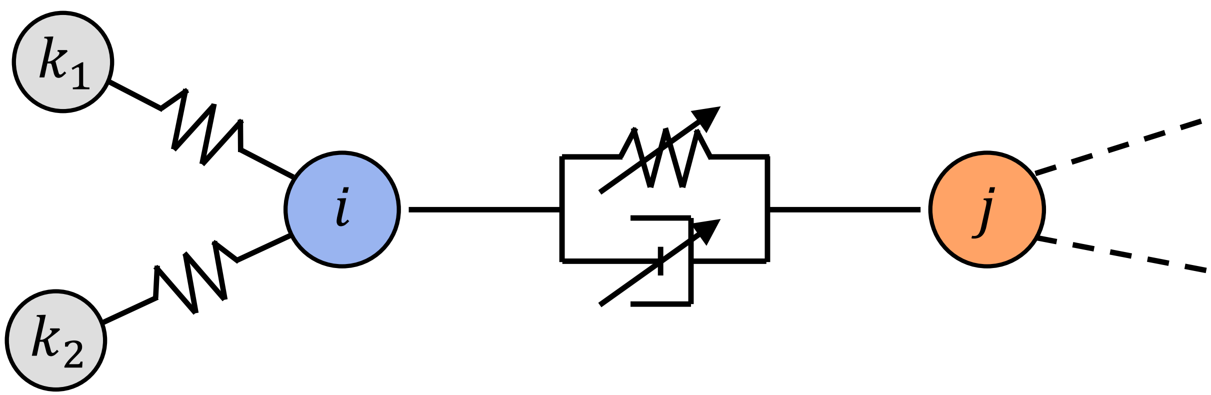
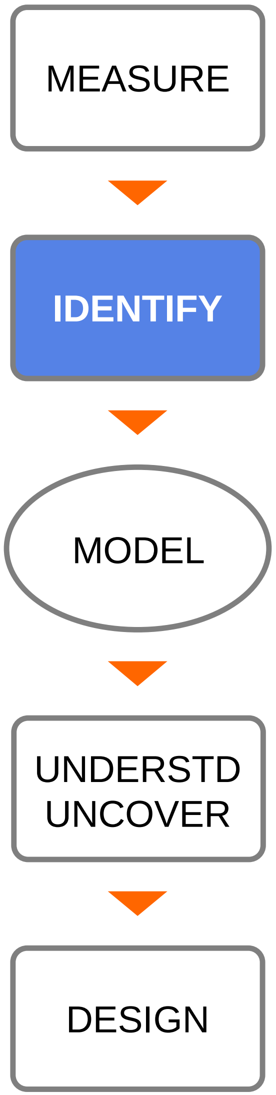
Newton's Second Law Written at Degree of Freedom "i"

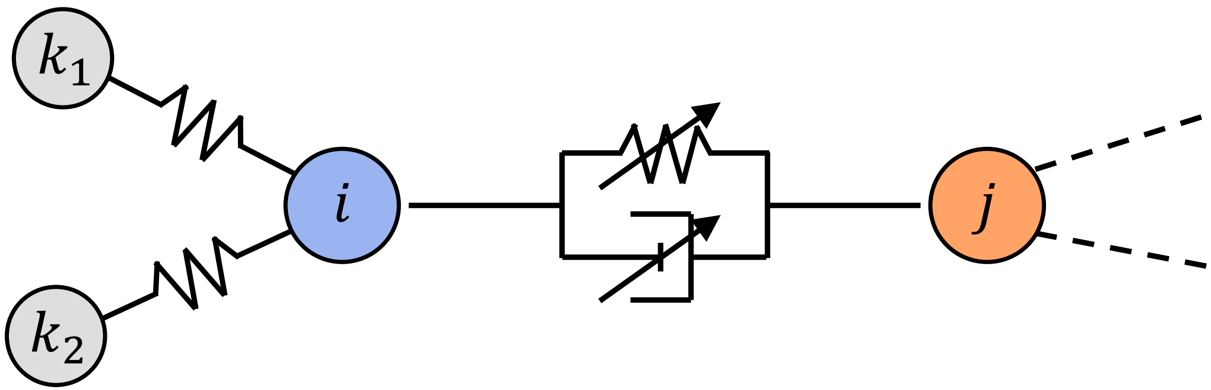


Linear connections
to neighbouring DOFs
(*e.g.*, bending stiffnesses in a wing)

$$\sum_k m_{i,k}\,\ddot{q}_k + g_i(q,\dot{q}) = p_i$$



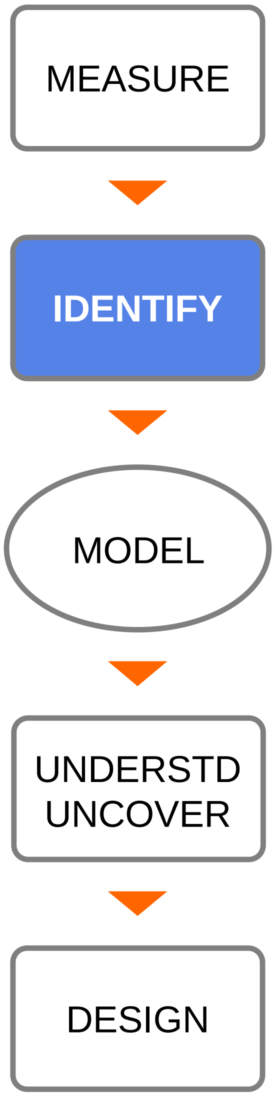
Discard all Terms not Related to the Nonlinear Connection



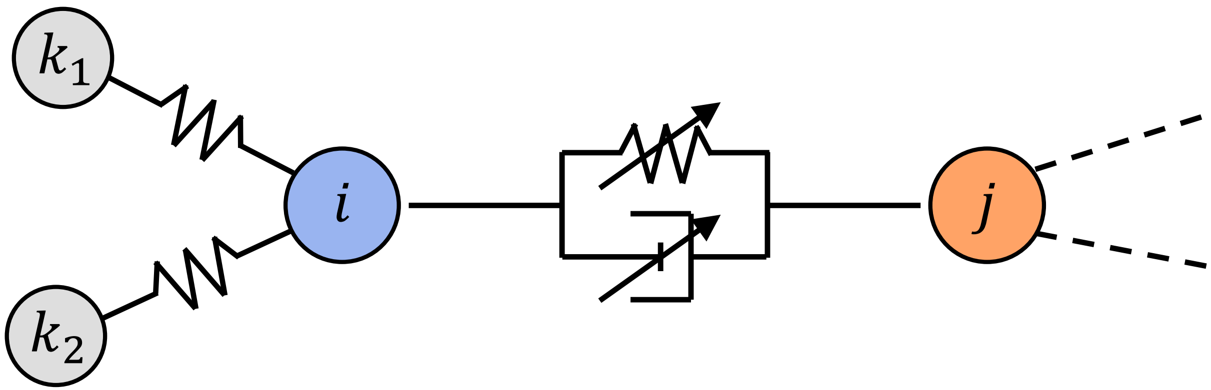
Linear connections
to neighbouring DOFs
(*e.g.*, bending stiffnesses in a wing)

$$\sum_k m_{i,k} \; \ddot{q}_k + g_i(q, \dot{q}) \; = p_i$$

$$m_{i,i} \; \ddot{q}_i + g_i(q_i - q_j, \dot{q}_i - \dot{q}_j) \cong p_i$$



Assume no Forcing Term and Drop the Mass Constant

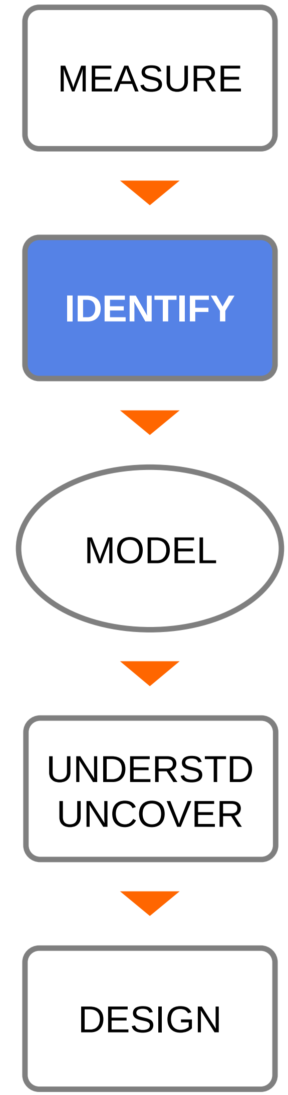


Linear connections
to neighbouring DOFs
(*e.g.*, bending stiffnesses in a wing)

$$\sum_k m_{i,k}\,\ddot{q}_k + g_i(q,\dot{q}) = p_i$$

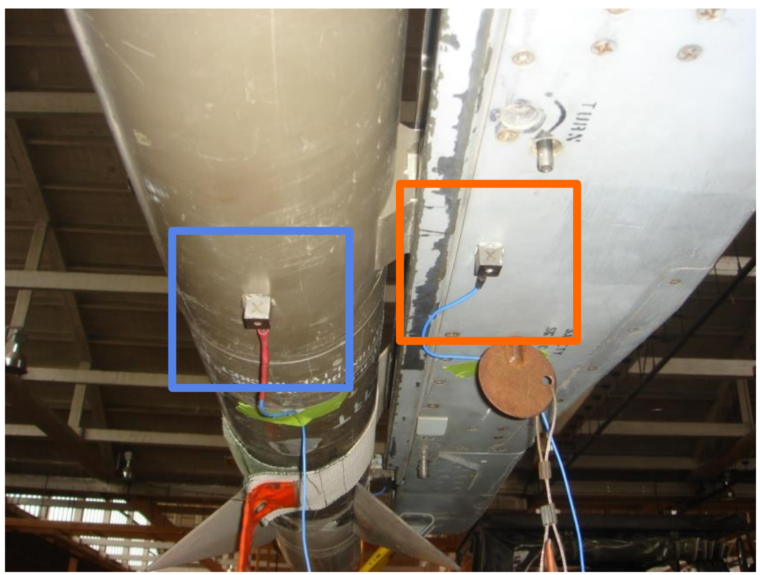
NL can be visualized!

$$g_i\left(q_i - q_j, \dot{q}_i - \dot{q}_j\right) \cong -\ddot{q}_i$$



Demo in NI2D Software

Nonlinear Identification to Design
Software



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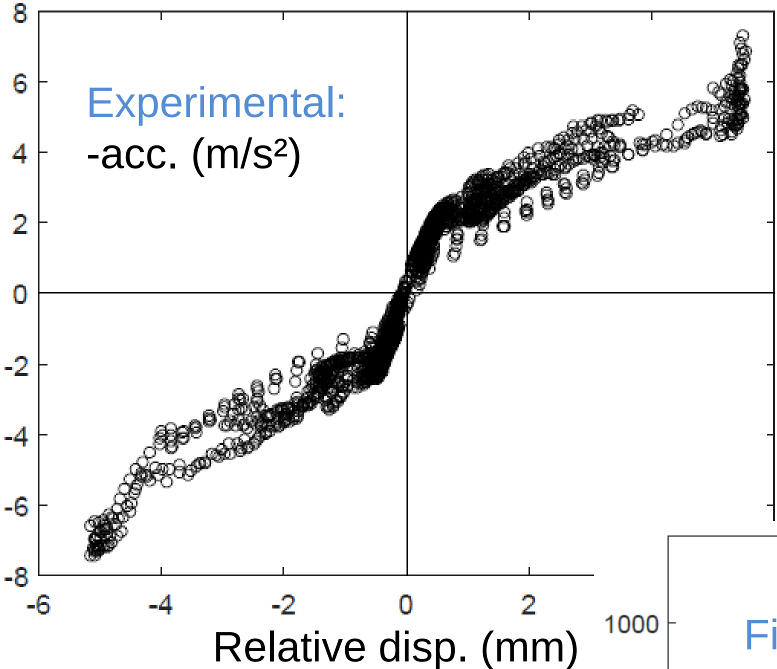
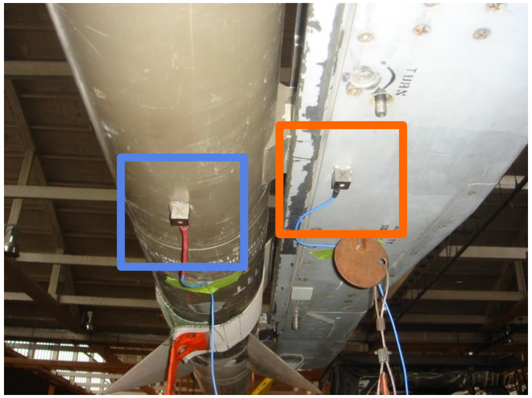
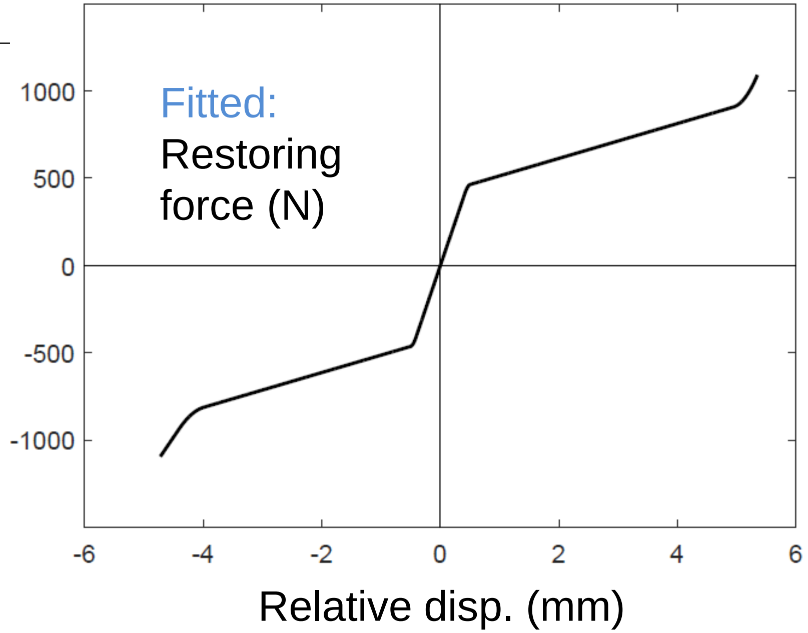
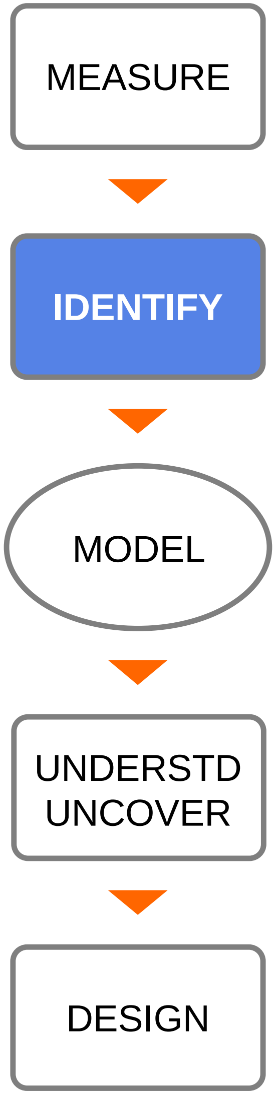
Quantifying the Parameters of the Nonlinearity Model



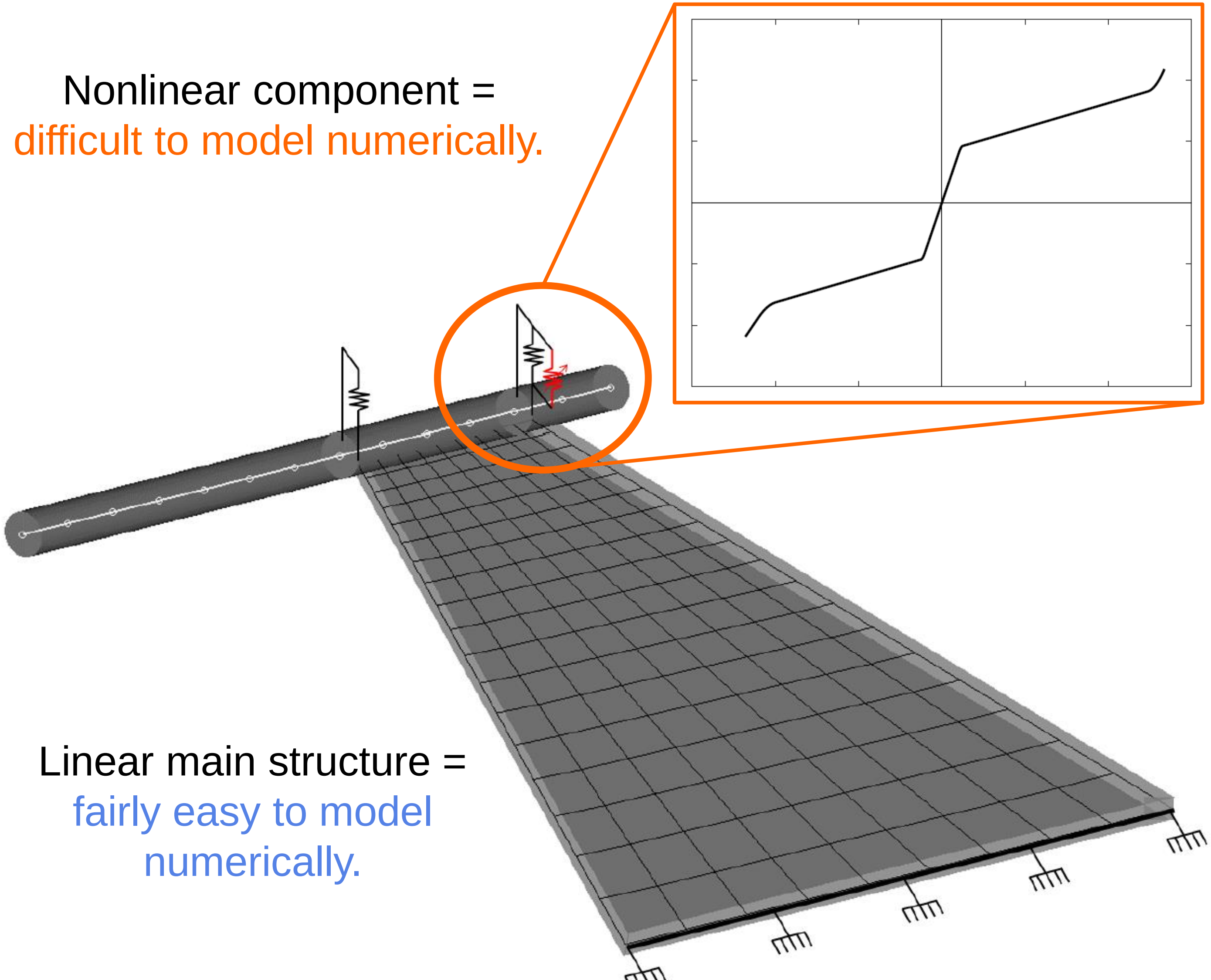






Data-Driven and Computer-Aided Models Are Integrated

Nonlinear component =
difficult to model numerically.



Linear main structure =
fairly easy to model numerically.

MEASURE

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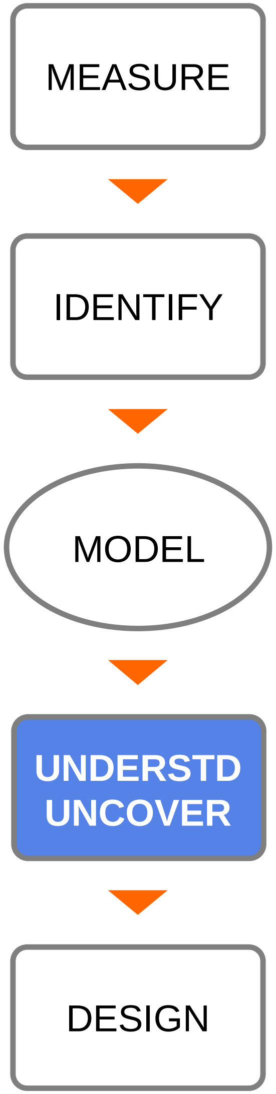
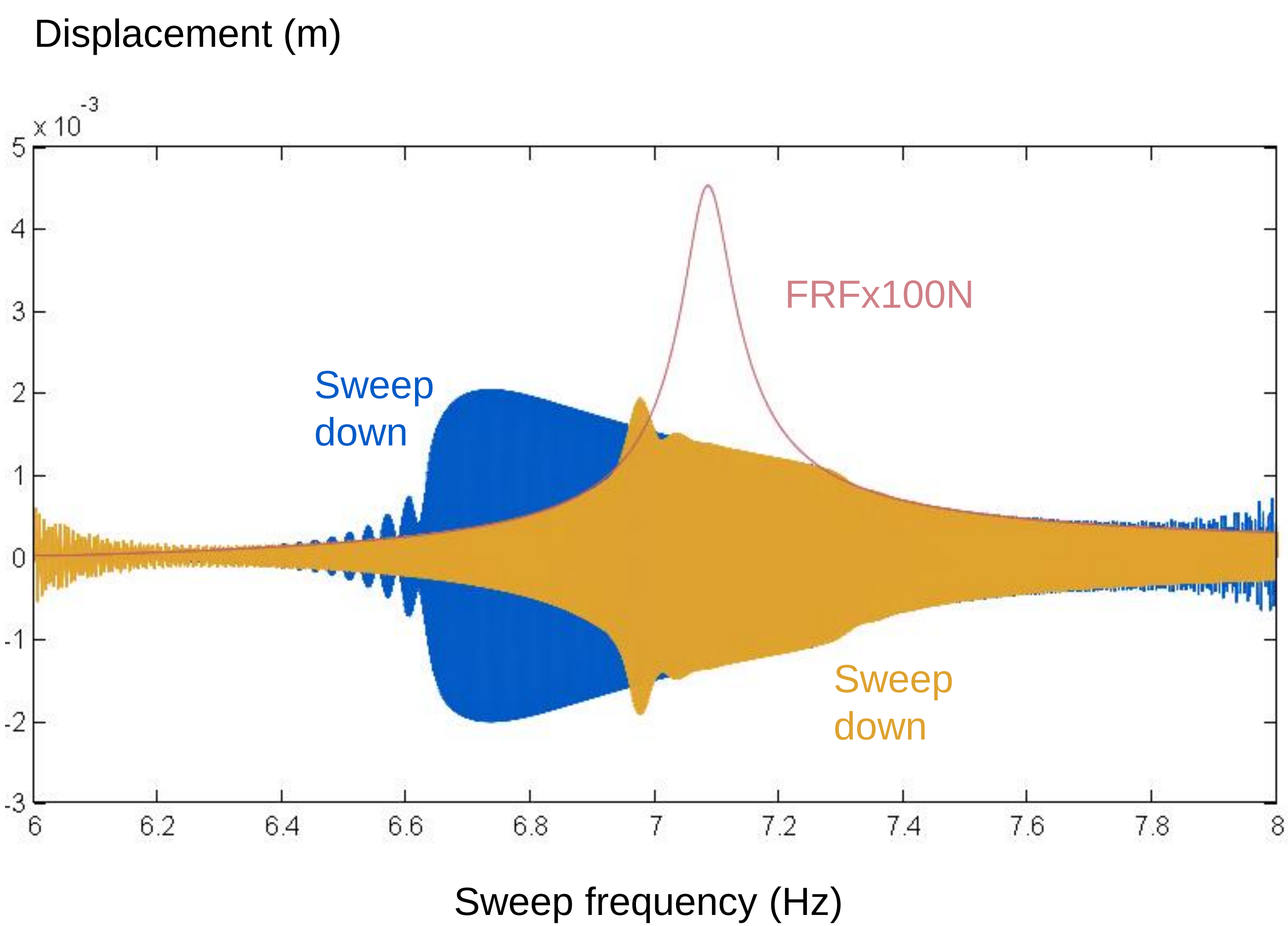
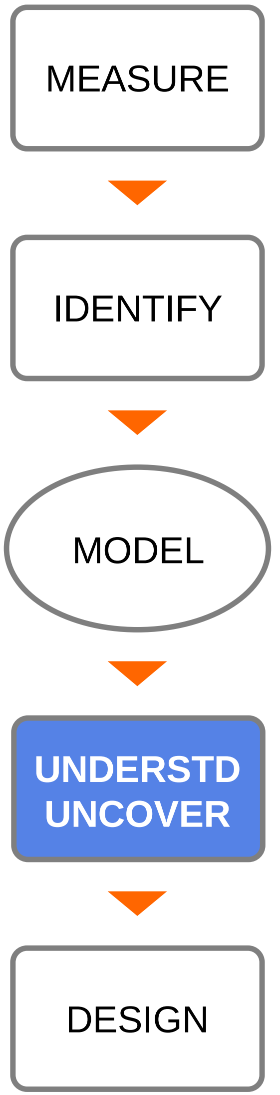
Classical Nonlinear Simulation Tools Can Now Be Employed

NID
Nonlinear Identification to Design
Software



Responses to Swept-Sine Excitations





Concluding Remarks

Data-driven and computer-aided techniques are complementary approaches to model nonlinear structures.

With limited physical insight, a complete design cycle can be studied.

This allows to precisely quantify the impact of nonlinearities, and to undertake design modifications on a sound basis.

Thank you for your attention!

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