

# Virtual NVH Process with ADAMS/Vibration



Gabriele Ferrarotti Sr. Industry Manager 2001 MDI Japan Users Conference







- Integrating vibration investigation in the development process
- Accessing continuous product development







# **Tacoma Narrows Bridge**



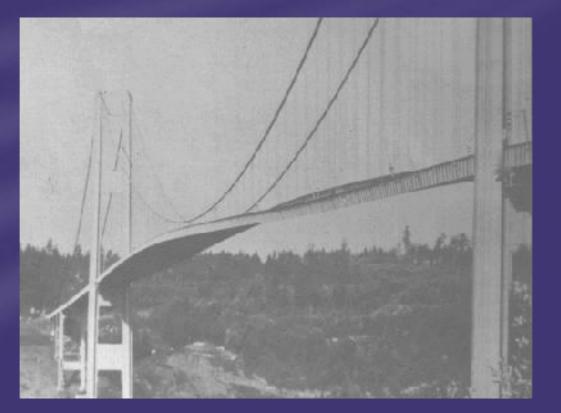
















# New Tacoma Narrows Bridge









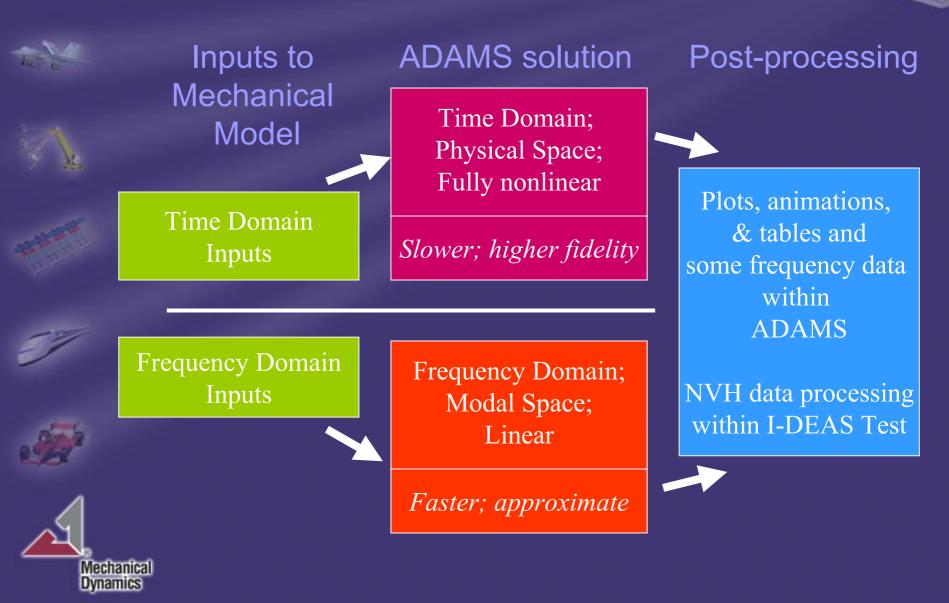








### **The Virtual NVH Process**





### The Time Domain Approach



Inputs to Mechanical Model

Time Domain Inputs **ADAMS** solution

Time Domain; Physical Space; Fully nonlinear

Slower; higher fidelity

Post-processing

Plots, animations, & tables and some frequency data within ADAMS

NVH data processing within I-DEAS Test





### The Time Domain Approach



- Independent from physical testing
- System-level approach (opposed to FE-like component approach)
- ADAMS/Solver enables to take into account non linearity effects
- CPU time increases proportionally with the required frequency resolution





### **Case Study: Ford Motor Company**

**Business:** Major automotive manufacturer

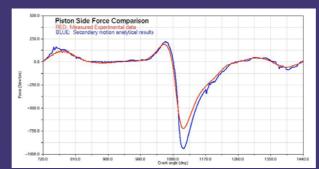
Challenge: Estimate radiated block noise (strong customer dissatisfier) caused by side thrust forces

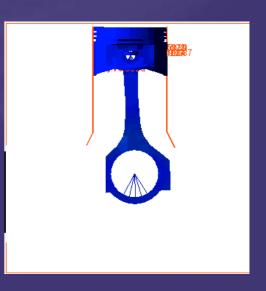
**Solution:** FFT of piston side forces from an ADAMS detailed model are used as input for the NVH analysis in the FE tool to predict sound power level and correlate it with measurements

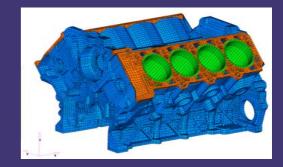
Value:

Piston slap noise in different engine configurations can be virtually predicted earlier in the design process





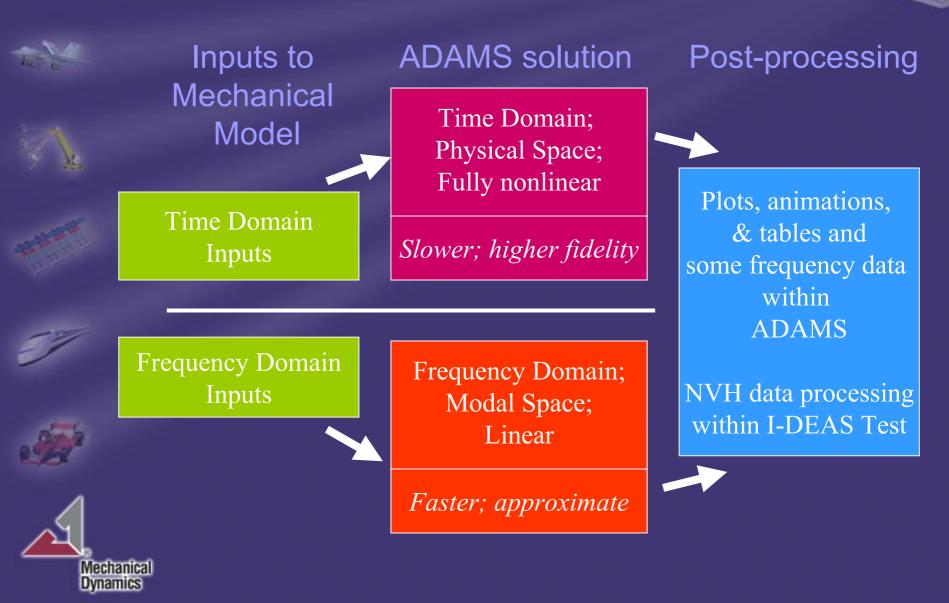








### **The Virtual NVH Process**





#### The Frequency Domain Approach



#### Inputs to Mechanical Model

ADAMS solution

Post-processing

Plots, animations, & tables and some frequency data within ADAMS

Frequency Domain Inputs

Frequency Domain; Modal Space; Linear

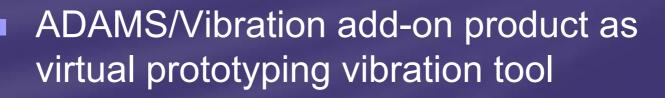
*Faster; approximate* 

NVH data processing within I-DEAS Test





### The Frequency Domain Approach



- Allows to take your system to different operating points to analyze the vibratory behavior (without having to create new models!)
- Allows various evaluations in modal space, including forced response in the frequency domain, FRF and mode shape analysis, modal participation factors
- Validity within the limits imposed by linearization approach

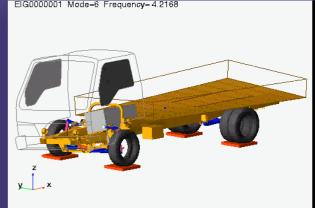


#### **Case Study: Isuzu**

**Business:** Major truck manufacturer

Challenge: Create vehicle natural frequency map to investigate vibration problems bypassing the expensive, time consuming typical experimental approach

**Solution:** Development of customized ADAMS environment able to allow to review frequency data with the help of a web tool



Value:

Mechanical Dynamics Accurate evaluation of vehicle vibrations over 50Hz helps to shorten development time and to cut cost









- Integrating vibration investigation in the development process
- Accessing continuous product development

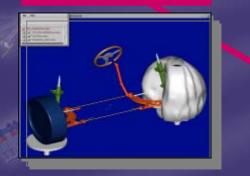




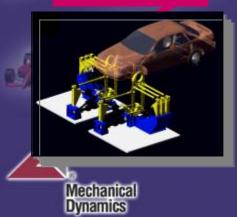


## Integrated NVH in the Functional digital Prototype

#### Packaging



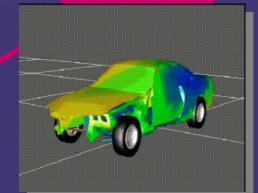
#### Durabilitv



#### **Virtual Prototype**



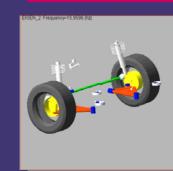
#### Handling

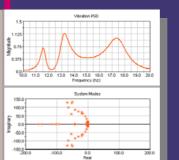


#### Controls



NVH





#### Typical Automotive System-Level Scenario

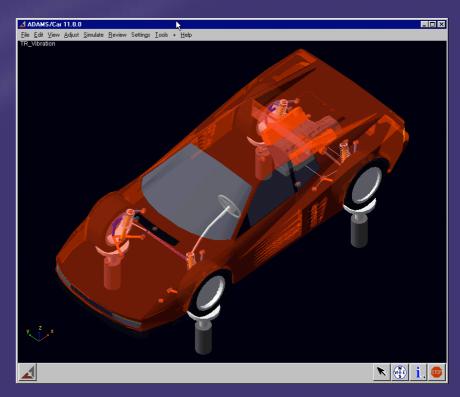
#### Engine-Mount Manufacturer's Sensitivity Test

- Input (to front wheels):
  - In-phase sine sweep
  - ◆ 0.8 40.0 Hz
  - 2mm peak-to-peak displacement

Measure: acceleration at 3DOF on both sides of all engine mounts. Also at selected points on body.

**Graph**: response vs frequency, with phase.

Mechanical Dynamics



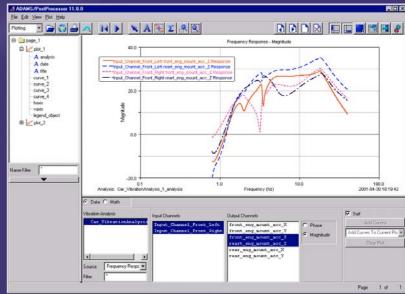
Mechanical Dynamics



#### Typical Automotive System-Level Scenario

#### In modal space with ADAMS/Vibration:

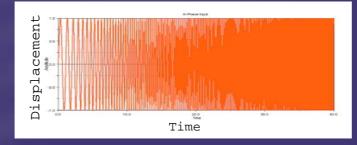
- Instantaneous calculation of FRFs between any input and any output to quickly understand vehicle dynamics
- Forced vibration animation
- Modal contribution map for selected input channel and frequency



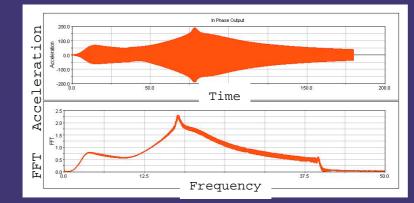
### Typical Automotive System-Level Scenario

#### In physical space with ADAMS/Solver:

- Input specified in time domain (frequency sweep)
- Solution in time domain, using  $\Delta t = 0.002$ ,  $t_f = 180$ sec
- Output in time domain (acceleration requests in the engine mounts)









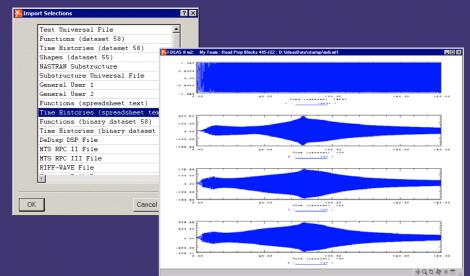
#### Typical Automotive System-Level Scenario

 ADAMS time domain results provided to NVH analyst in TXT - RPC format

> Can be imported into I-DEAS Test from MTS

🔯 Inbox - Microsoft Out			
Ele Edt Yew Favgrite			
33 New - 🚭 🖓 🗡	Reply Reply to Al	Forward 🛃 Send/Regeive 🌚 Find 🖉 Organize 🔛	- 3.
Inbox			·
Telder Luts >> >> >> >> >> >> >> >>	<ul> <li>bel Curre 0 Good Selevy 0 Bood Selev</li></ul>	Your all has been kind on Tecking.com (model) RE: Universential noise regs PPT Residual Letter RE: Spreadheet dampli stapp RE: Index (Hendel Swinghon, com RE: Swinghon, Gene National Swinghon, Com National Swinghon, Com National Swinghon, Com	umn, which ngrui. I need e working with 18 produced as produced as, the 4 I propose

to put it together and provide it for the conference CD. I'll work on the



NH subut DOP neuro subut ODP neuro PE dat	<ol> <li>front_sweep_fourpost_out_phase_front_sweep_fourpost_out_phase_accel_reat_es</li> <li>front_sweep_fourpost_out_phase_front_sweep_fourpost_out_phase_accel_reat_es</li> <li>front_sweep_fourpost_out_phase_front_sweep_fourpost_out_phase_accel_reat_es</li> <li>front_sweep_fourpost_out_phase_front_sweep_fourpost_out_phase_accel_reat_es</li> </ol>	gine_mount_left m
Image         Image           MVG Observed         Image           V1 = 0         Image		

Mechanical

**Dynamics** 

Mechanical Dynamics

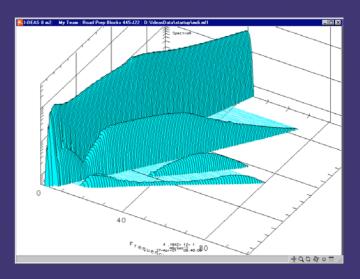
### Typical Automotive System-Level Scenario

- Observations:
- Harmonics are due to nonlinear components in the model (bushings, mounts, suspension dampers)

#### Conclusions:

- "Modal space analysis" with linearized model provides fast qualitative NVH information
- "Physical space analysis" with complete non-linear model provides higher fidelity NVH information







### Typical Automotive System-Level Scenario

#### Wheel Out Of Balance (OOB) Analysis

#### Input:

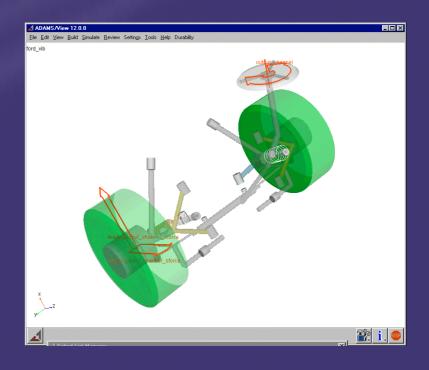
 Unbalanced masses (leading and lagging) on right wheel (5 g, 2 cm)

#### Measure:

- local rotational velocity at steering wheel
- Graph:

Mechanical Dynamics

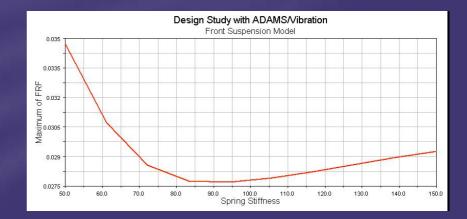
- Frequency responses
- Sensitivity study to spring stiffness values



ADAN

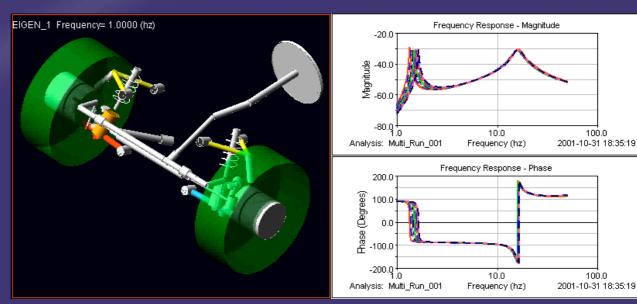
#### **Typical Automotive System-Level Scenario**

Investigate the steering wheel resonance shift due to change in spring stiffnesses



100.0

100.0









#### Additional Automotive System-Level Scenarios

#### Random Road Profile Analysis Observe the PSD response of vehicle components to PSD inputs at the contact patch

#### Powertrain Out Of Balance (OOB) Analysis

 Observe the frequency response of vehicle components to out of balance inputs acting on powertrain components (i.e. driveline vibration analysis)









- Integrating vibration investigation in the development process
- Accessing continuous product development

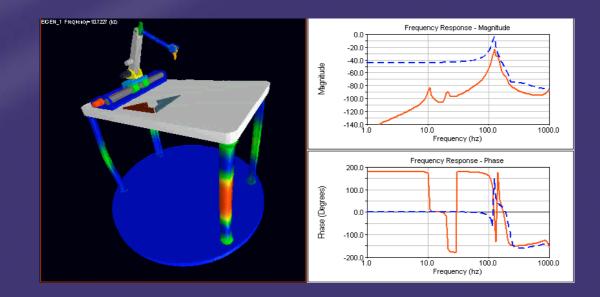






ADAMS/Vibration 11.0 offers:

- Frequency domain input forcing functions
- Frequency response function calculations
- Modal participation tables
- Forced vibration animation









PSD

# Step 1: Create input channels, output channels, and actuators

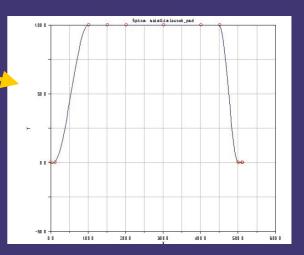
1
-
T

Mechanical

**Dynamics** 

Create Vibration	table.input_table.input_C	hannel 2		<u>×</u>				
Input Channel Name		nonnor_z						
Input Marker	МК34							
Translational O Rotational								
Force Direction	🔿 Local	ΟX						
	<ul> <li>Global</li> </ul>	ΟY						
		ΘZ						
Actuator Parameters								
C Swept Sine								
C Rotating Mass								
	Mass Spline Name SPLINE_1							
- · · · ·	Interpolation Type	- Lina						
O User								
		<u>o</u> k	Apply	<u>C</u> ancel				
				0				
				Spl				

🔏 Create Vibration Output Channel 🛛 🛛 🔀									
Output Channel Name	.table.Output_Channel_Y								
Output Function Type	Predefined								
Output Marker	Output Marker laser_tip								
Global Component									
Displacement  C X  O Z O Mag									
	<u>O</u> K <u>A</u> pply	<u>C</u> ancel							



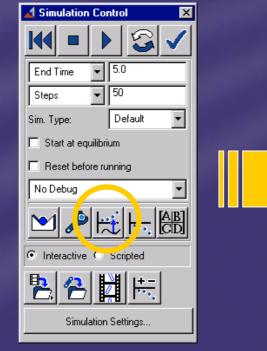




#### Step 2: Run Analysis







A Perform Vibration Analysis	×
Vibration Analysis 💽 Vibra	ationAnalysis_mhagx
Operating Point 💽 S	itatic O Assembly O Script
Import Settings From E	xisting Vibration Analysis
Forced Vibration Analysis C Norma	al Mode Analysis
Input Channels	Output Channels
Input_Channel_mhagx	.h.Output_Channel_dz_hiravl .h.Output_Channel_dz_hiravr .h.Output_Channel_dz_hirahl .h.Output_Channel_dz_hirahr
Frequency Range (hz)	Logarithmic Spacing of Steps
Begin 1.0	
End 100.0	
Steps 200	
Reuse Existing State Matrix	Modal Energy Computation
	OK <u>Apply</u> Cancel

Define inputs/outputs to be used, operating point, frequency range, and steps



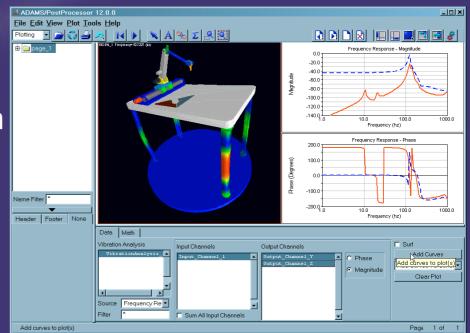


Mechanical Dynamics

# **The ADAMS/Vibration Solution**



- System Modes
- Frequency Response Functions
- Power Spectral Density
- Modal Participation Tables
- Normal Mode
   Animation
- Forced Vibration Animation





ADAMS/Vibration 12.0 offers:

Integration with vertical products

 Same look and functionalities for ADAMS/Standalone and ADAMS/Vertical Product

Create Vibratio	n Input Channel				Vibration Analysis 🔹	VibrationAnalysis_mhagx	
Input Channel Name	.h.Input_Cha	nnel_1			Operating Point	● Static ○ Assembly ○ Script	
Input Marker							
Translational C	Rotational				Impert Cattings	From Evisting Vikestian Australia	
Force Direction	Cocal	Θ×	1		Import Settings From Existing Vibration Analysis  Forced Vibration Analysis  Normal Mode Analysis		
	🔿 Global	ΟY			Input Channels	Output Channels	
	I	ΟZ			Input_Channel_mhagx	.h.Output_Channel_dz_hiravl .h.Output Channel dz hiravr	
Actuator Parameters			🖌 Create Vibration Outpu	t Channel		.h.Output_Channel_dz_hirahl .h.Output_Channel_dz_hirahr	
Swept Sine	Force Magnitude		Output Channel Name	.h.Output_Channel_1			
C Rotating Mass	Phase Angle (deg)		Output Function Type	Predefined			
O PSD		,	Output Marker		[] []		
O User			Global Component		Frequency Range (hz) Begin 1.0	Logarithmic Spacing of Steps	
			Displacement	<ul> <li>• Х О Ү О Z О Мад</li> </ul>	End 100.0		
1		~	: 1		Steps 200		
		<u>0</u> K		<u>OK</u> <u>Apply</u> <u>Cancel</u>	Reuse Existing State Matrix	Modal Energy Computation	
hanical							
amics							



Mechanical Dynamics

### **The ADAMS/Vibration Solution**

ADAMS/Vibration 12.0 offers:

- Integration with ADAMS/Insight
  - Dedicated dialog box to create objective macros for DOE - A/Insight

Create Vibration D	esign Objective Macro	×
Macro Name		
Return Value Variable		
Target Vibration Data	Frequency Response: 1 Input , 1 Output	•
Input Channel		1
Output Channel		
Value Type	⊙ Minimum O Maximum	
Frequency Range	All Frequencies C Specific Range	
	OK Apply Cancel	

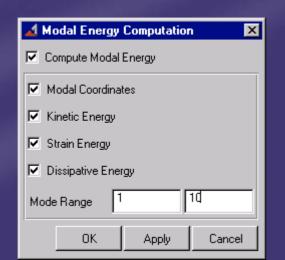


Mechanical Dynamics

# **The ADAMS/Vibration Solution**

ADAMS/Vibration 12.0 offers:

- Modal energy computation
  - Energy contribution of each model element in
    - HTML format



🛃 Modal Informa	ition									>
🔿 Modal Coordinates 🔿 Modal Participation 💿 Modal Energy										
Modal Energy Table for Analysis = VibrationAnalysis_mhagx_analysis Mode = 1									×	
	Header									
	Undamped Natural Damping Generalized Generalized Kinetic Frequency Ratio Mass Stiffness Energy									meae
35.4222 hz			0.0222564	1191.52 kg		0.0139252 newton/mm			0 newton-mm	
· · · · · · · · · · · · · · · · · · ·			Norma	alized Coordin	ates					
Name	X		Y	Z		RX		RY		RZ
hira	1	-0.0	0.0202775 0.0252359		-0.000103903 -0		-0.00	-0.000604037		0.00069695
hag_qt	-0.0836765	-0.0	0.0137778 -0.012442 7.114				884e-C	105	-6.98827e-C	
hag	-0.0805146	-0.0	0445398	-0.00352767	7.114	e-005	4.26	6884e-005 -6.98827		-6.98827e-C
hag_haldex	-0.0852386	0.00	0961762	0.00025908	7.114	e-005	4.26	4.26884e-005		-6.98827e-C
hag_st	-0.0852704	0.0	170063	0.00474011	7.114e-005 4.26884e-0			05	-6.98827e-C	
		Per	centane D	istrihution of S	train	Fnerav				 ▶
Mode 4					•	1				
File Format HTML  Display Phase Values Write Table To File										
Asse Font Size 10  Close										

Conclusions

 ADAMS provides two approaches for system-level vibration analysis allow complete NVH insight early in the design process



- ADAMS allows to balance competing requirements for optimum NVH by integrating the vibration investigation in the development process
- ADAMS continuous product development guarantees a steadily improving solution for your NVH
   process

Mechanical Dynamics

