Brake Groan Simulation for a MacPherson Strut Type Suspension

Dave Riesland
Brian Cheung
MSC.Software Corp.

Mark Donley
MTS System Corp.

Contents

Brake Groan Phenomenon

- **Noise from gradual release of brake from a stopped position**
- **Instability phenomenon comes from difference between static and dynamic friction.**
- **Series of noise bursts**
  - **Repetition rate 20 - 100 Hz**
  - **Dominant spectral content   50 - 300 Hz**

Integrated analytical physical virtual Simulation

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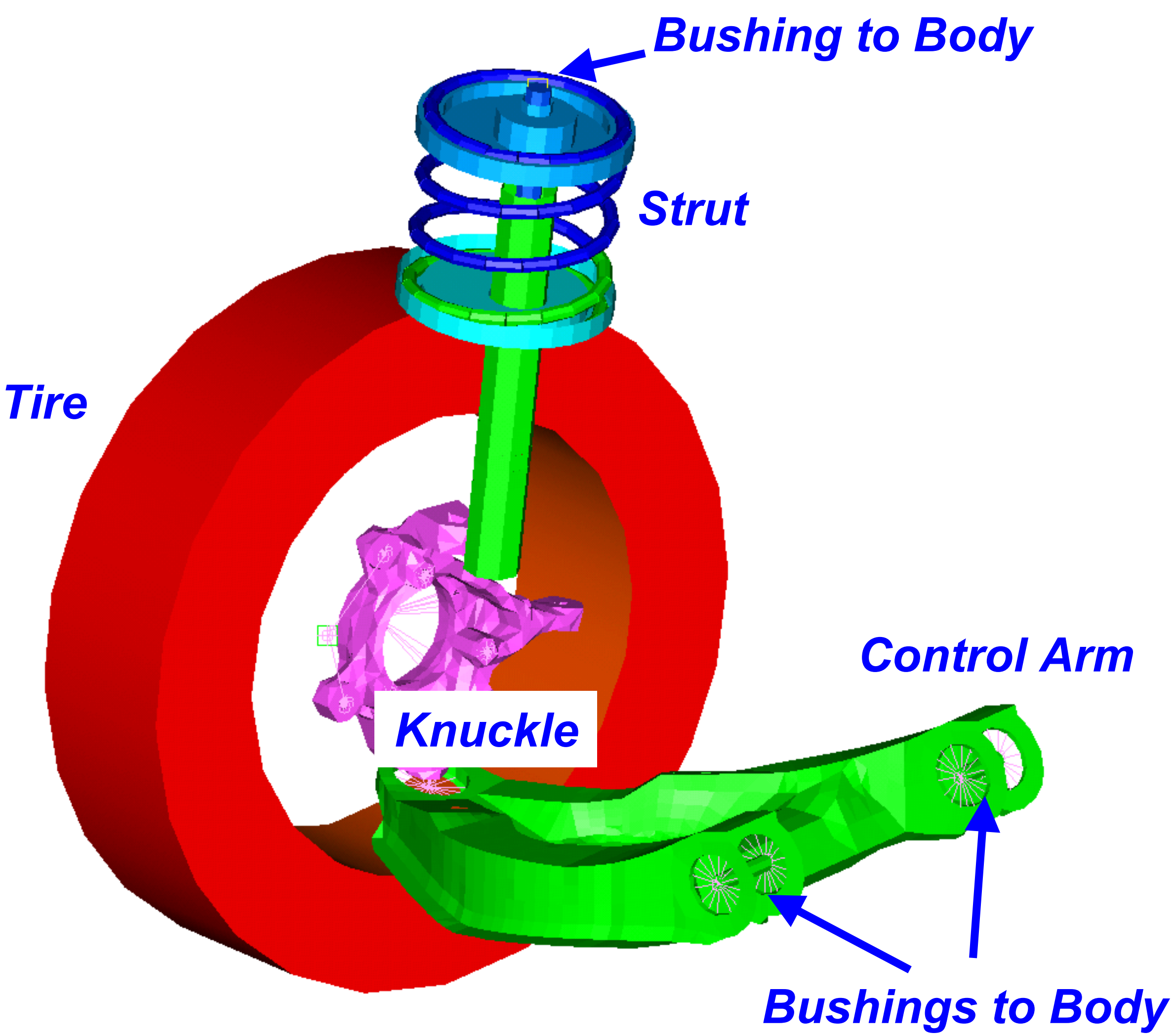
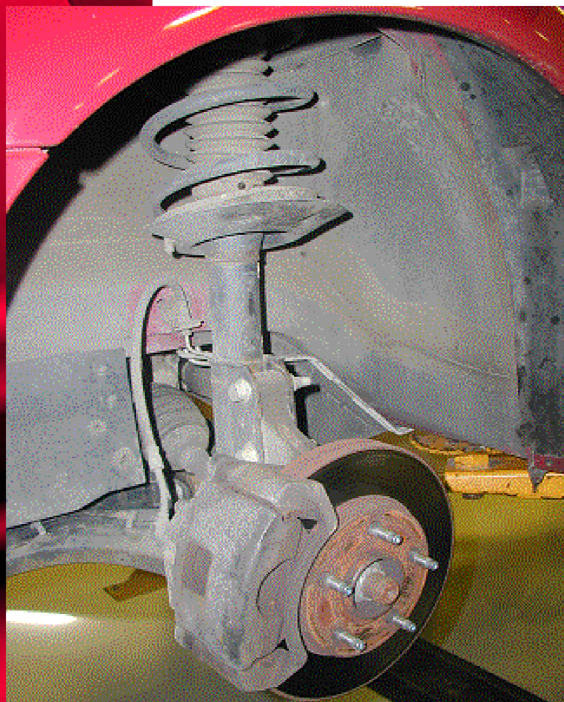
MacPherson Strut Suspension

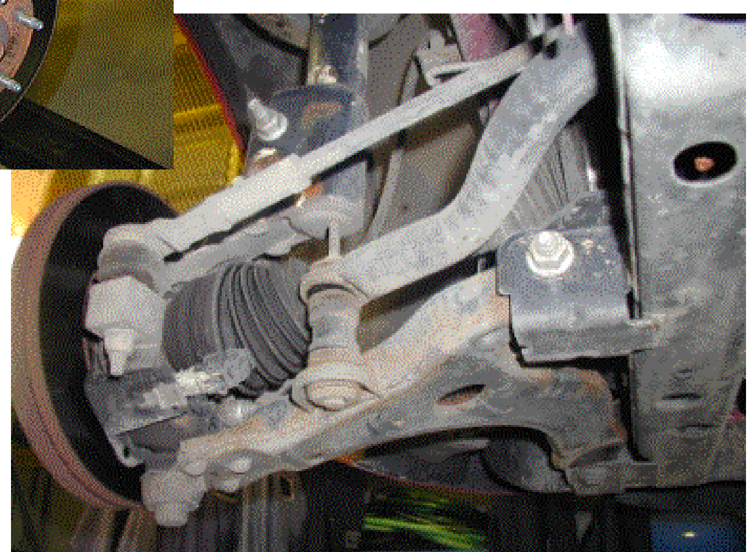


Project Outline

•*Test Analysis*	*Laboratory*
Mini-Van Vehicle	
Hypothetical Vehicle	
•*Dynamics Simulation*	*ADAMS*
•*Groan Behavior Study* *With FRF's and Modal Analysis*	*ADAMS/Vibration* *NASTRAN* *IDEAS*
•*Groan Design Studies*	*ADAMS*

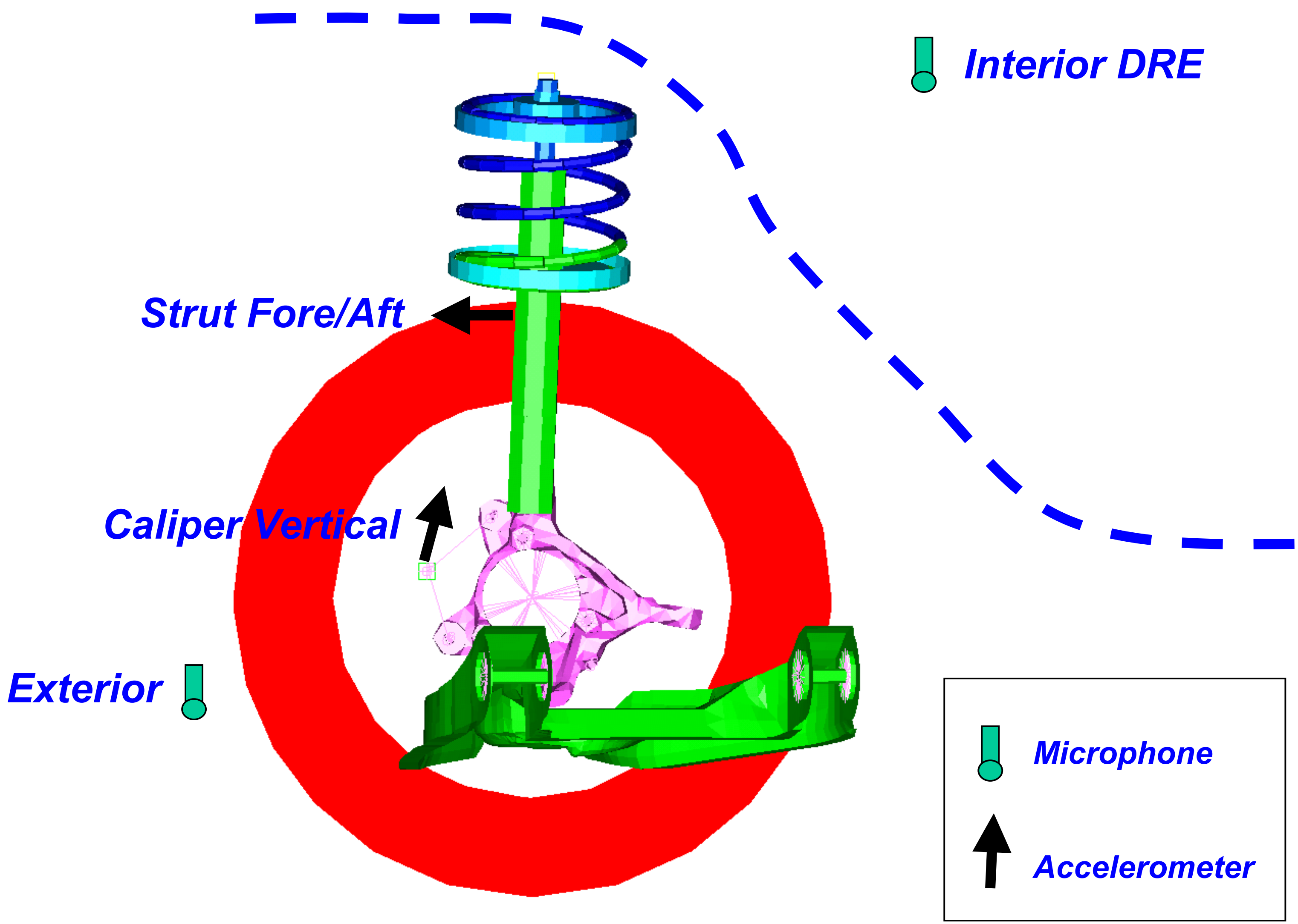
Groan Operating Test



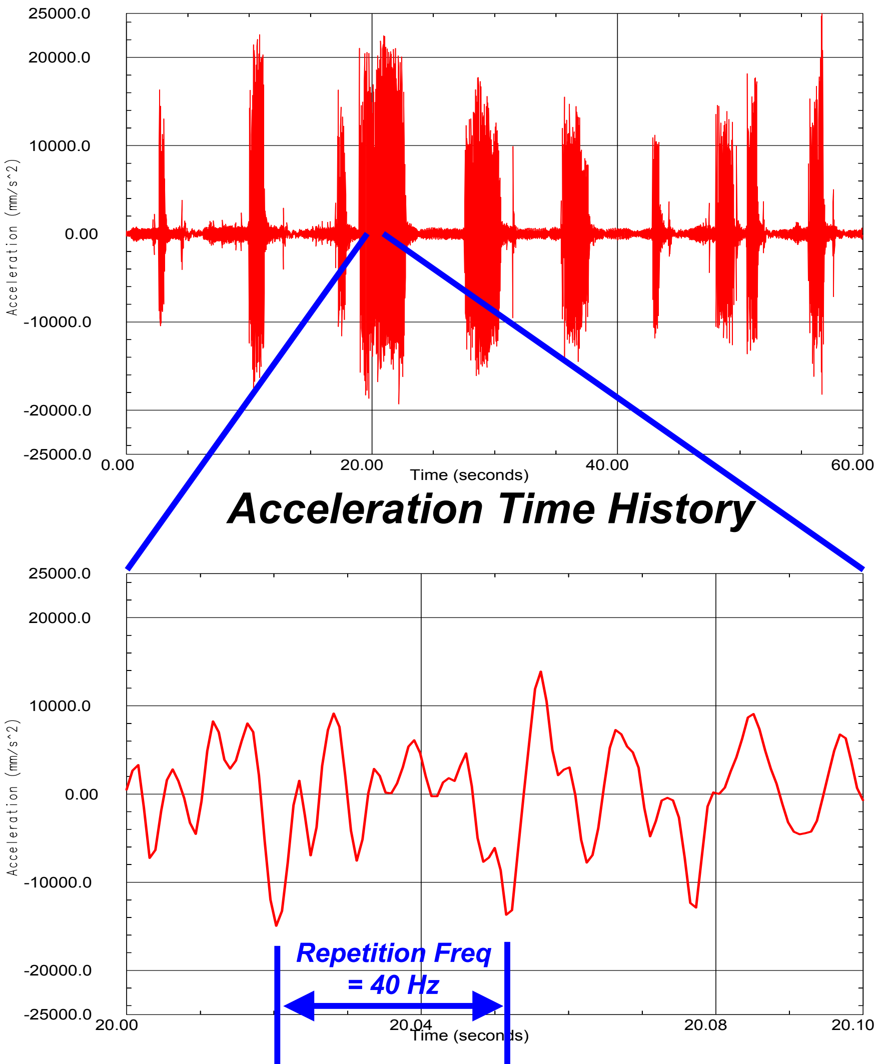


- **Operating test conducted on mini-van vehicle.**
- **Test performed on chassis roll dynamometer.**

Test Measurement Locations



Strut Fore/Aft Acceleration

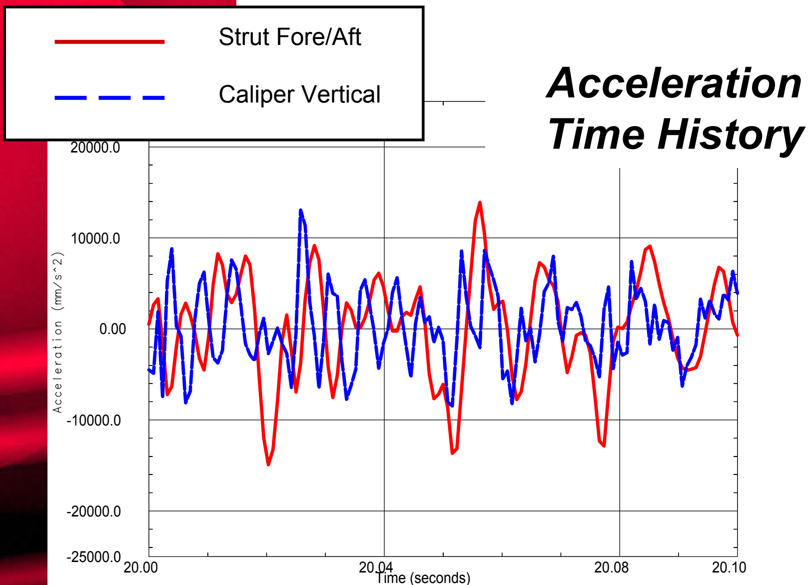


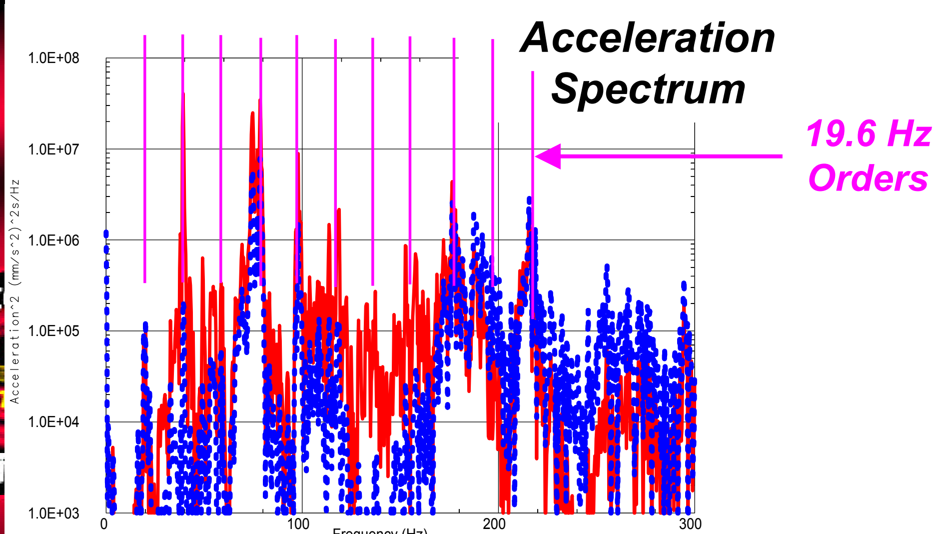
Acceleration Time History

Acceleration Time History

- **Groan occurs in bursts of 1 to 5 seconds.**
- **Each burst has repetition frequency around 40 Hz.**
- **Later show analytically that repetition frequency corresponds to stick-slip frequency.**

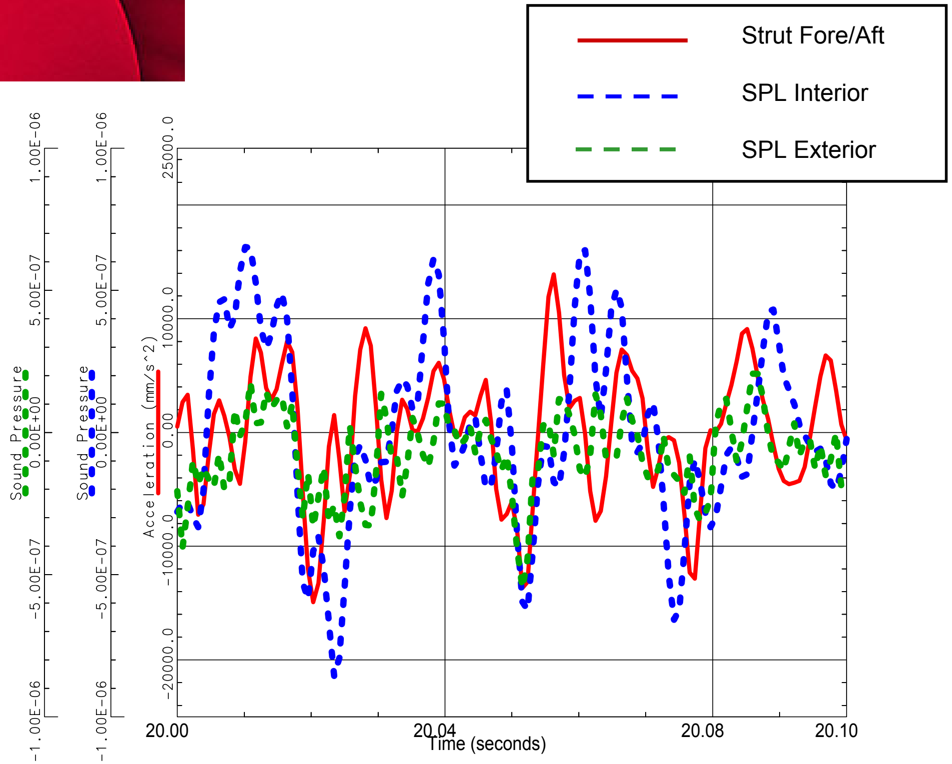
Strut and Caliper Correlation





- **Strut fore/aft and caliper vertical acceleration have similar dynamic content.**
- **Response occurs at orders of 19.6 Hz.**
- **Peak caliper response at 4th order (78.4 Hz).**

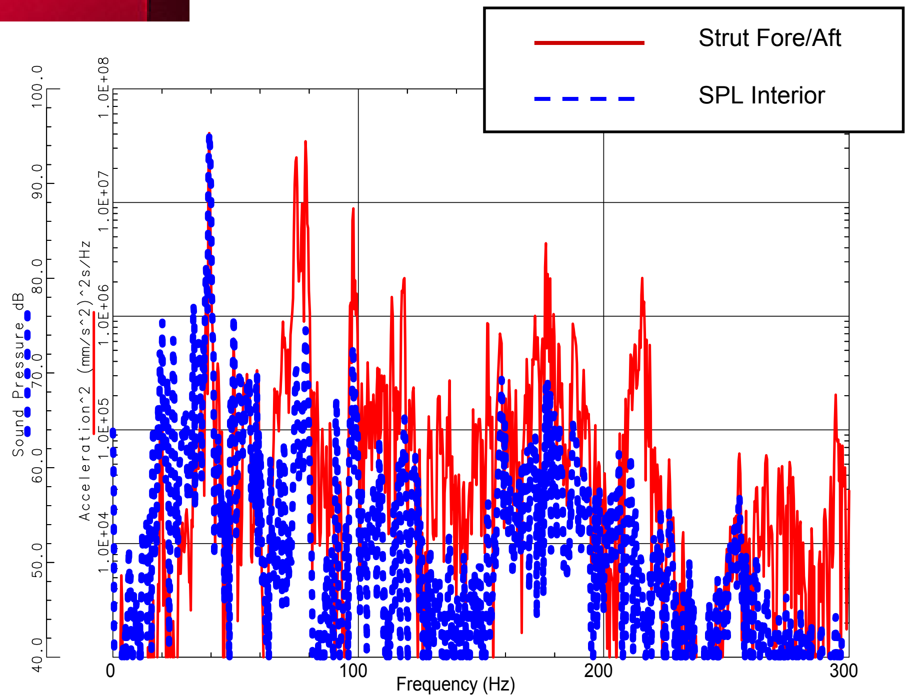
Strut and SPL Correlation



Acceleration and SPL Time History

- **Interior Sound Pressure Level (SPL) greater than exterior SPL. Indicates that groan is primarily structure borne.**
- **Interior SPL closely correlates with strut acceleration. Indicates that strut is main noise path.**

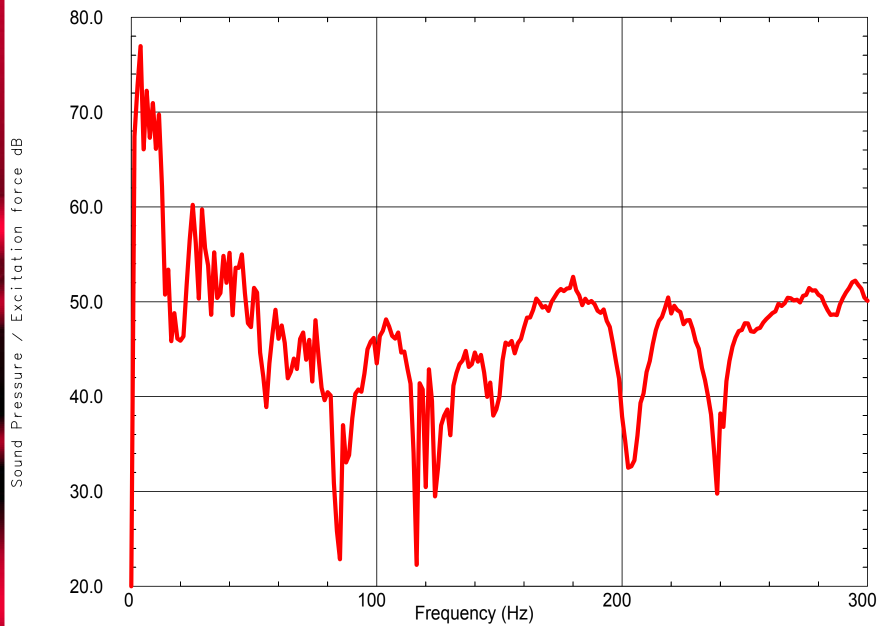
Strut and SPL Correlation



Acceleration and SPL Spectrum

- **Spectral content of SPL and strut fore/aft acceleration is similar.**
- **Transmissibility (TR) higher at lower frequencies. TR = SPL/A**
- **Highest SPL peak is at 39.2 Hz. This would be perceived groan noise.**

Strut to Driver's Right Ear P/F



P/F, DRE SPL from Strut Mount

- **P/F (SPL due to force at mount location) can be measured directly and is similar to transmissibility.**
- **Content of P/F shows why transmissibility is highest near 40 Hz.**
- **1st acoustic fore/aft cavity mode typically around 50 Hz.**
- **2nd acoustic fore/aft cavity mode typically around 100 Hz.**
- **Possible design approach: tune strut groan response away from peaks in P/F**

Pressure and Mount Force Relationship:

$$P_{sp} = F_{mf}\left(P/F\right)$$

P = operating sound pressure

F = operating mount force

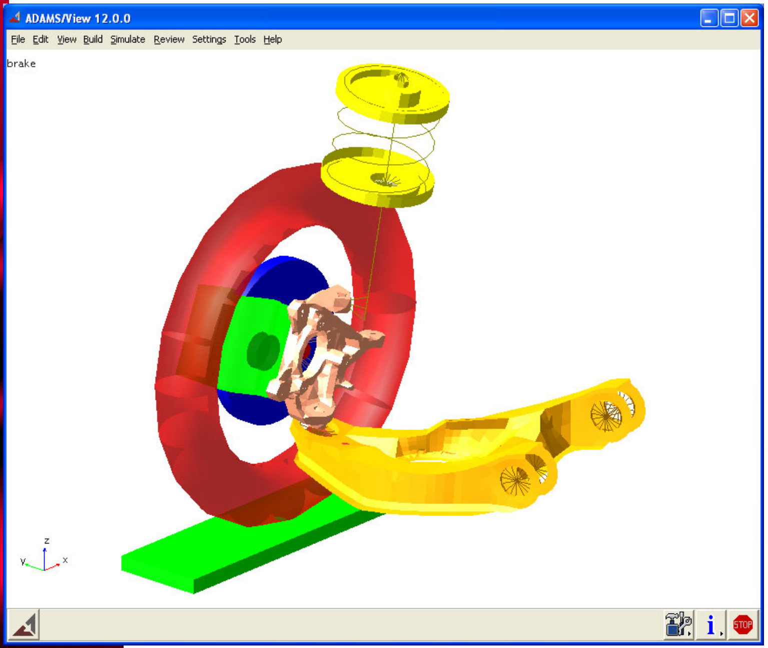
P/F = pressure/force transfer function

Quiet Groan Design Approach

- **Probably not possible to completely eliminate stick-slip of rotor and pad.**
- **Instead design/tune suspension so peak orders fall at less sensitive regions of P/F functions.**
- **Analytical simulation is ideal approach to study and tune suspension.**

ADAMS Model

Quarter Suspension Model



Note: Model is for hypothetical vehicle and does not correspond to vehicle of test measurement.

- Sufficient to model groan for MacPherson strut type suspensions with quarter vehicle suspension model.
- Component Modeling Approach
  - Control Arm – FEM
  - Knuckle – FEM
  - Strut – FEM
  - Tire – Lumped parameter or test based modal
  - Rotor, caliper assembly – lumped parameter

Integrated analytical physical virtual Simulation

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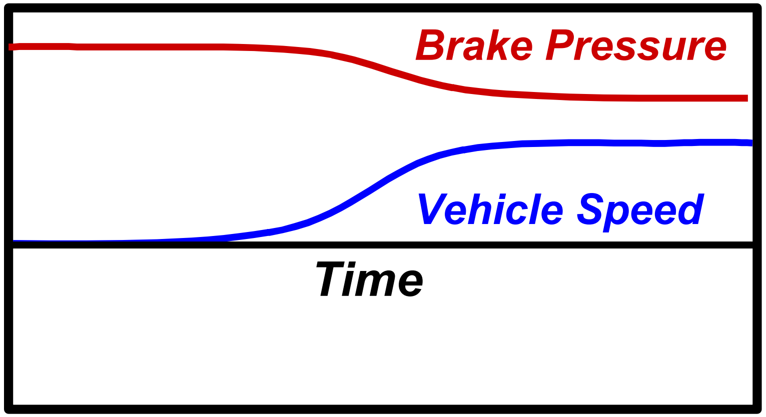
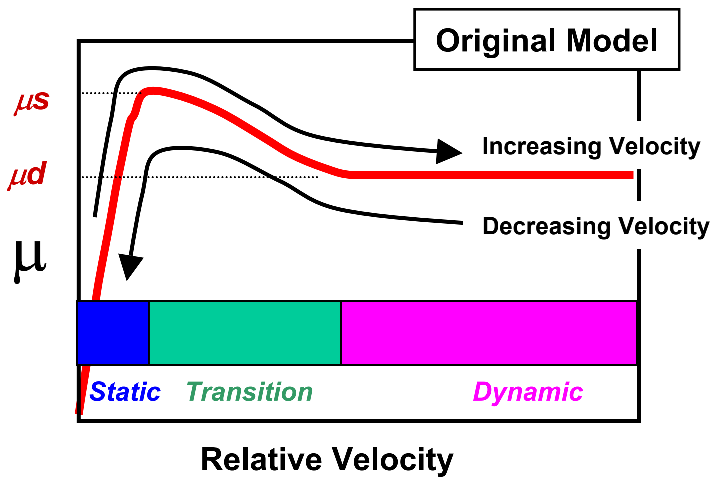
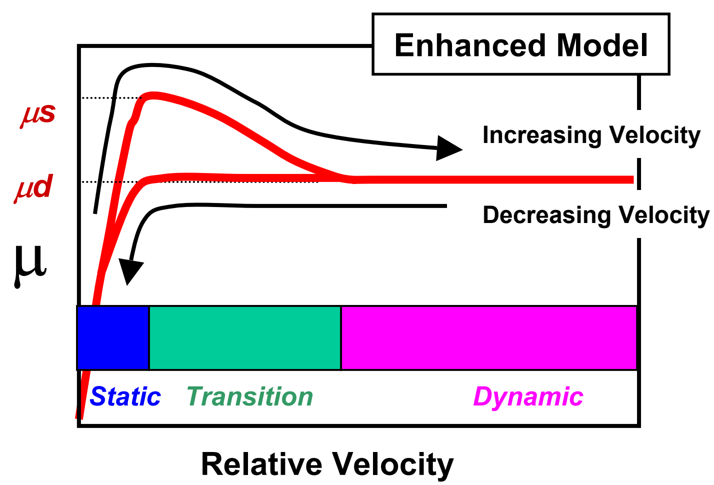
Boundary Conditions



- Brake pressure gradually released.
- Vehicle speed gradually increased.
- Combination of vehicle speed with brake friction creates brake torque load.

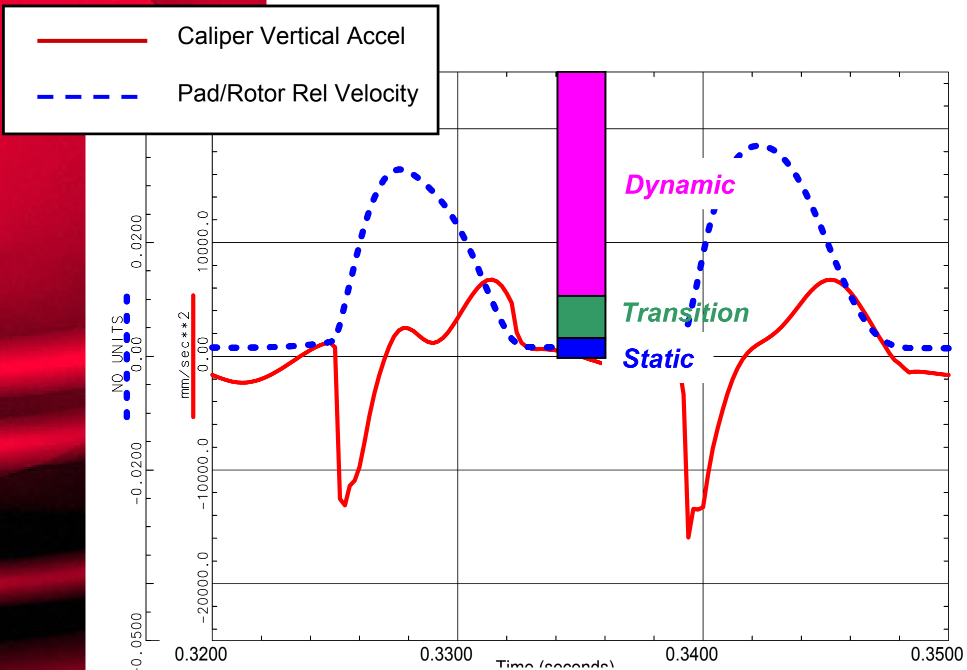
Enhanced Friction Model





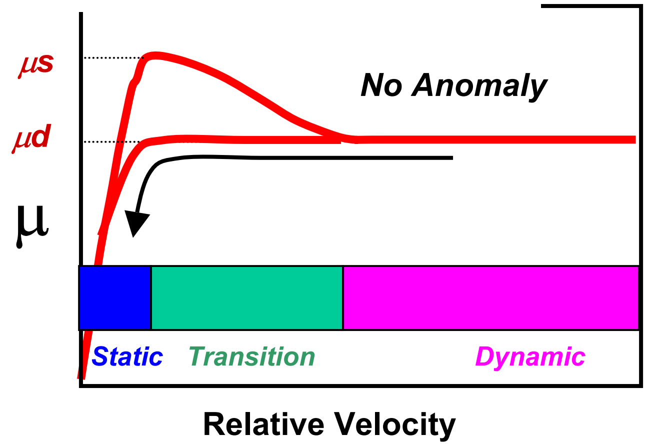
- Original friction model is path independent.
  - Physically reasonable for increasing relative velocity. As relative velocity increases, static friction breaks and reduced dynamic friction occurs.
  - May not be reasonable for decreasing velocity. As relative velocity decreases, friction probably does not increase.
- Enhanced friction model has path dependence.
  - No increase in friction coefficient for decreasing velocity.

Enhanced Friction Curve Effect

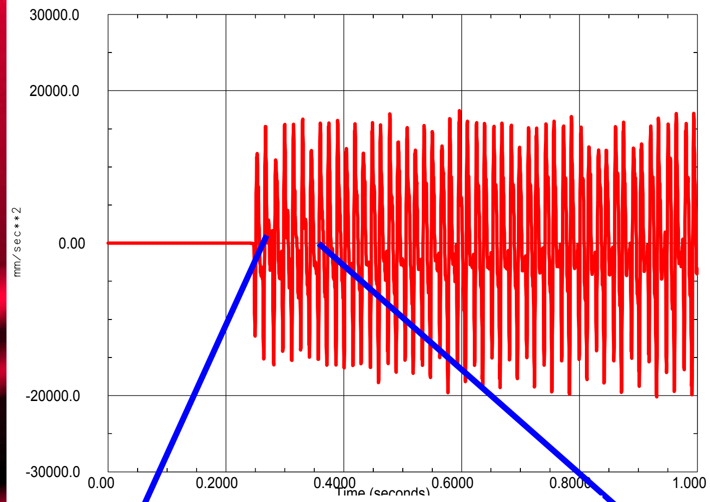


Acceleration and Velocity Time History

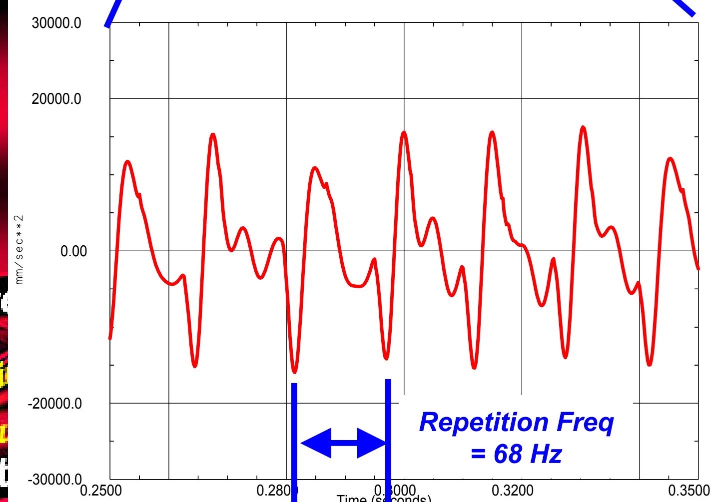
- **Acceleration spike at onset of stick is now gone.**
- **Believed that this is better friction model.**



Simulated Groan Results with ADAMS



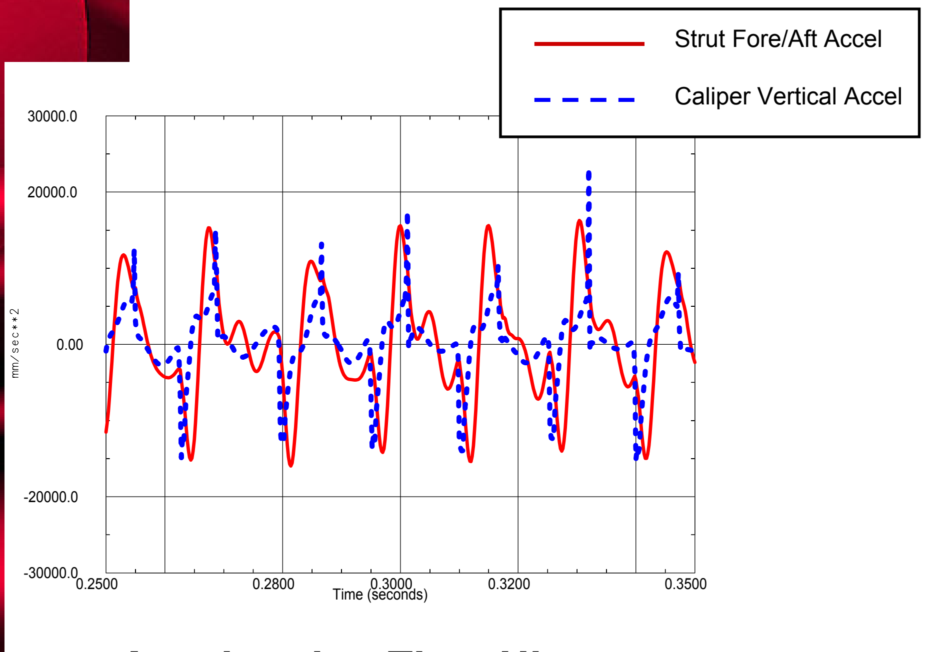
Acceleration Time History



Acceleration Time History

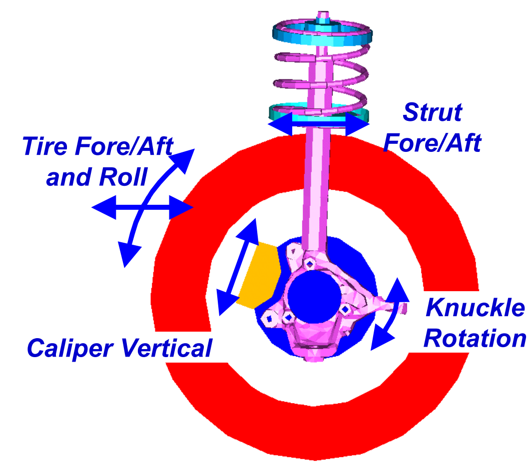
- **Strut has 68 Hz repetition frequency.**
- **Maximum strut acceleration is about 20,000 mm/sec^2 or 2.0 G.**

Simulated Groan Results with ADAMS

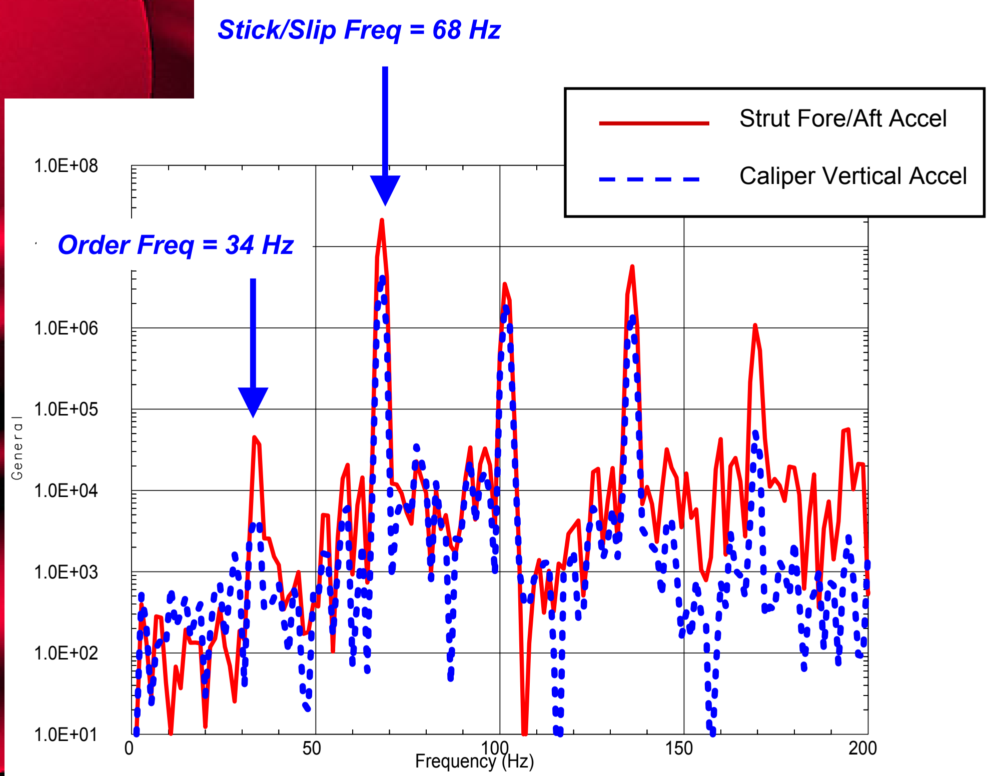


Acceleration Time History

- **Strut fore/aft and caliper vertical acceleration are closely correlated.**
- **Correlation the result of coupling by knuckle rotation from friction force.**



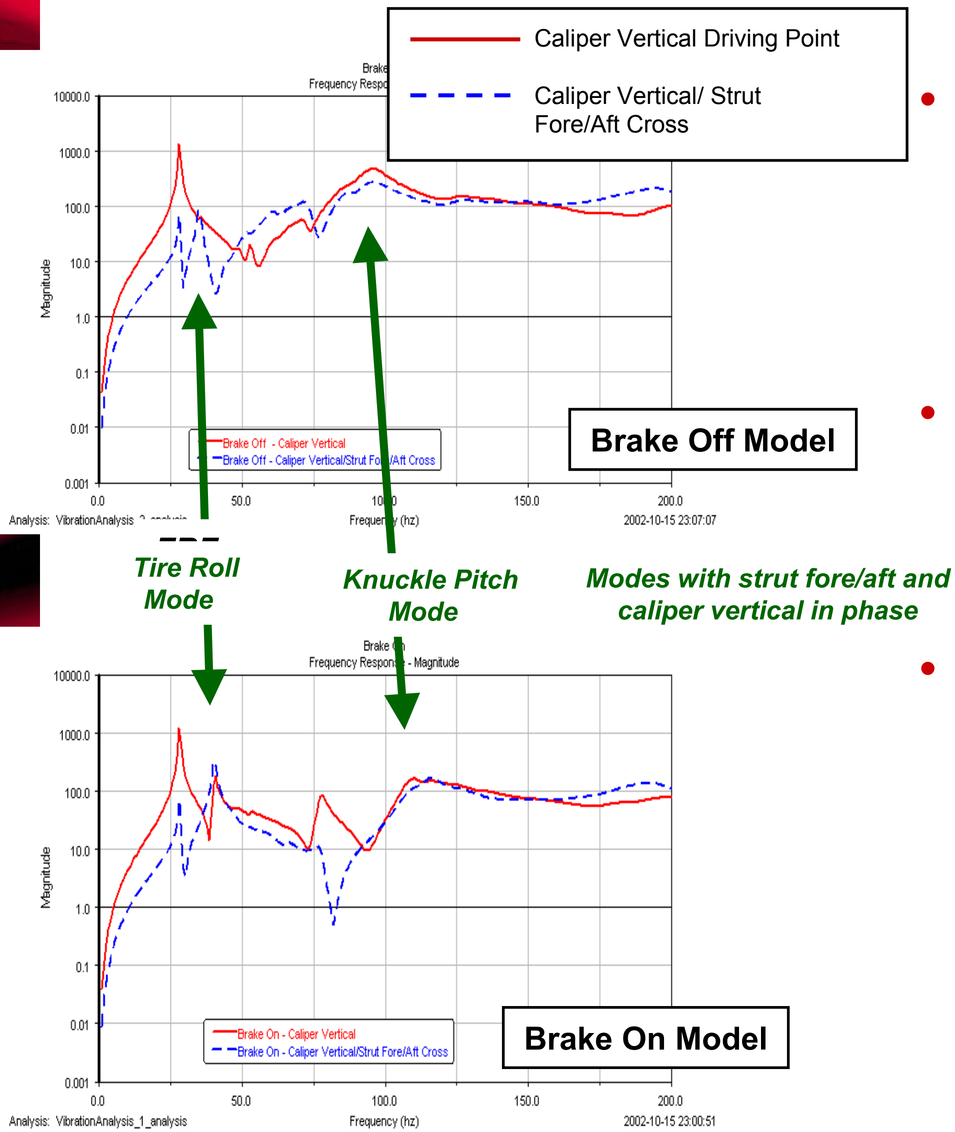
Strut and Caliper Acceleration Spectrum



Acceleration PSD

- **Response has peaks occurring at orders of 34 Hz.**
- **Stick-slip frequency occurs at 2nd order.**
- **Note: Test data stick-slip frequency occurred at 4th order. MTS experience is stick-slip can occur at 1st - 5th order.**

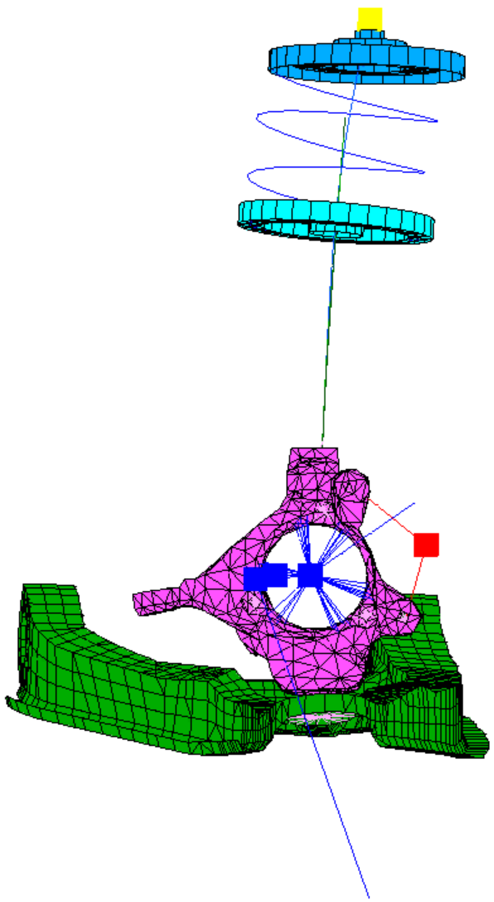
Modes that affect Groan



FRF

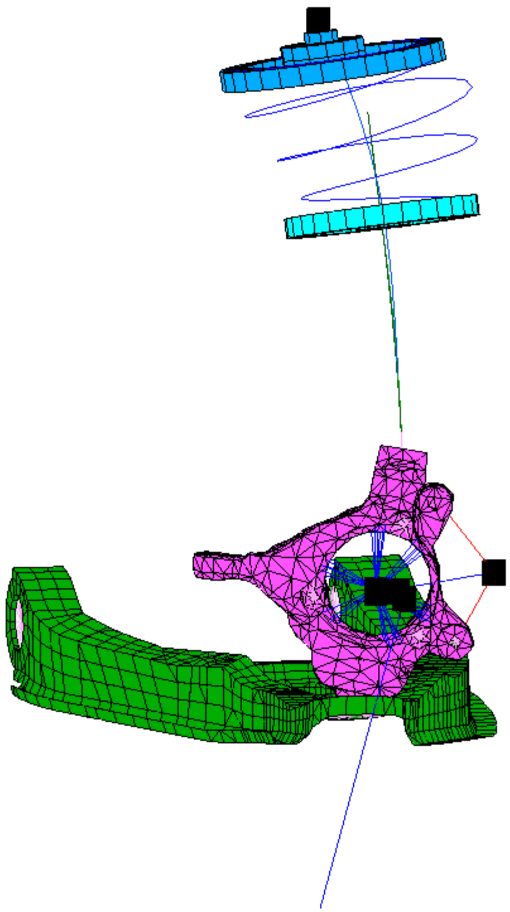
- "Brake On" model has rotational connection between caliper and rotor.
- "Brake On" model is stiffer so some modes have higher frequency.
- Modes that show coupling of caliper vertical response and strut fore/aft response are associated with groan.

Tire Roll Mode – Brake Off - 35 Hz



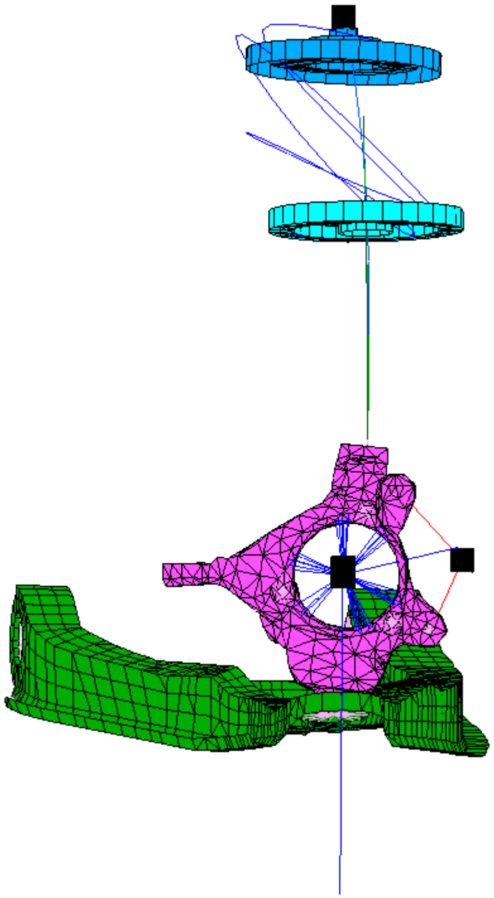
- **Overall suspension moves in fore/aft direction.**
- **Tire rolls and rotor rotates to accommodate.**
- **Strut bends.**

Tire Roll Mode – Brake On - 40 Hz



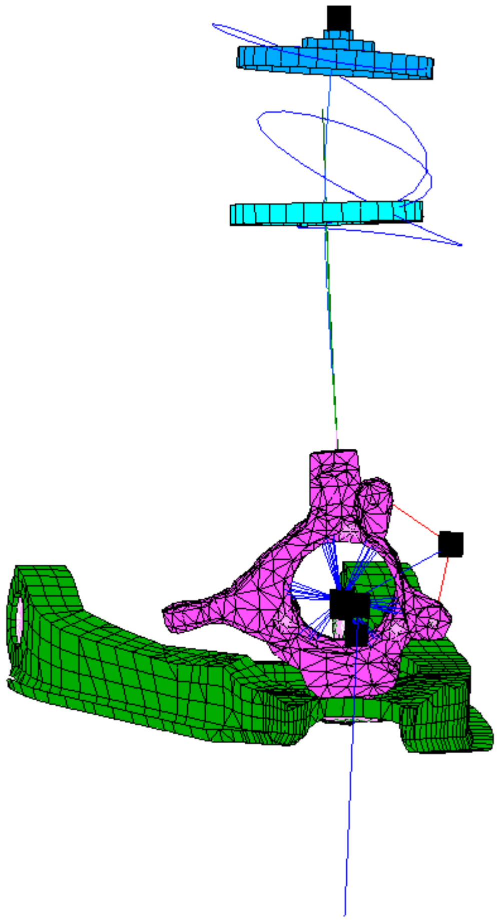
- **Overall suspension moves in fore/aft direction.**
- **Tire rolls and rotor/knuckle rotate to accommodate.**
- **Strut bends.**

Knuckle Pitch Mode – Brake Off - 94 Hz



- **Knuckle rotates relative to rotor.**
- **Strut bends.**
- **Tire mostly still.**

Knuckle Pitch Mode – Brake On - 104 Hz



- Knuckle and rotor pitch and translate vertically.
- Strut bends.
- Tire mostly still.

Strain Energy of Tire Roll Mode

Mode/Load Number ----> 2

Frequency (Hz) ----> 40.6

Group ID	Group Name	
1	STRUT	15.59
2	LOWER ARM	2.25
3	KNUCKLE	7.78
4	TIRE MASS A	----
5	TIRE MASS B	----
6	TIRE MASS C	----
7	TIRE SPRING A_B	10.93
8	TIRE SPRING B_C	1.69
9	TIRE PATCH SPRING	1.85
10	TIRE SPRING AT AXLE	----
11	STRUT TO BODY SPRING	3.57
12	KNUCKLE TO STRUT SPRING	11.37
13	KNUCKLE TO BODY SPRING AT TIRE ...	2.51
14	LOWER ARM BUSHING FRONT..........	1.54
15	LOWER ARM BUSHING REAR	4.11
16	BALLJOINT SPRING	0.63
17	WHEEL BEARING - KNUCKLE SPRING ...	2.17
18	WHEEL BEARING MASS	----
19	WHEEL BEARING - BODY AT AXLE	0.02
20	ROTOR MASS.......................	----
21	FRICTION SPRING	----
22	KNUCKLE TO CALIPER SPRING	----
23	TIRE SPRING	33.99
25	CALIPER MASS	----

Total Percent Energy ----> 100.00

- Most strain energy is in tire model.
- Strut significant.
- Knuckle to strut connection stiffness also important.

Strain Energy of Knuckle Pitch Mode

Mode/Load Number ----> 14

Frequency (Hz) ----> 104.8

Group ID	Group Name	
1	STRUT	38.16
2	LOWER ARM	2.80
3	KNUCKLE	1.62
4	TIRE MASS A	----
5	TIRE MASS B	----
6	TIRE MASS C	----
7	TIRE SPRING A_B	29.18
8	TIRE SPRING B_C	12.61
9	TIRE PATCH SPRING	0.05
10	TIRE SPRING AT AXLE	----
11	STRUT TO BODY SPRING	2.11
12	KNUCKLE TO STRUT SPRING	0.92
13	KNUCKLE TO BODY SPRING AT TIRE ...	----
14	LOWER ARM BUSHING FRONT...........	6.02
15	LOWER ARM BUSHING REAR	0.98
16	BALLJOINT SPRING	0.22
17	WHEEL BEARING - KNUCKLE SPRING ...	5.14
18	WHEEL BEARING MASS	----
19	WHEEL BEARING - BODY AT AXLE	----
20	ROTOR MASS........................	----
21	FRICTION SPRING	----
22	KNUCKLE TO CALIPER SPRING	----
23	TIRE SPRING	0.17
25	CALIPER MASS	----

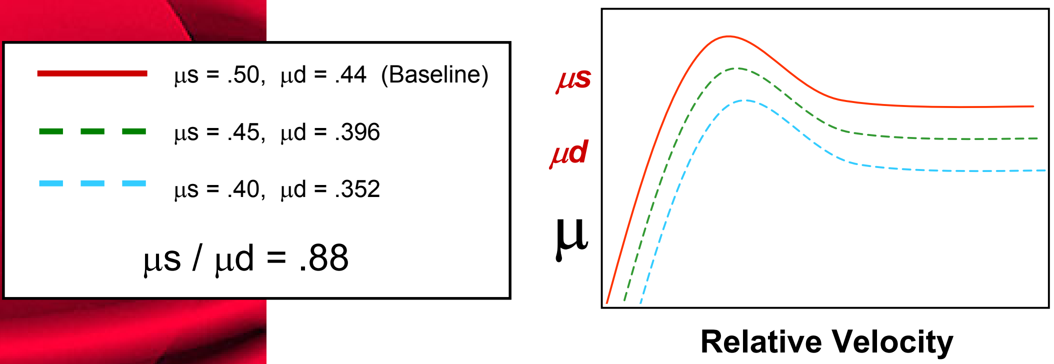
Total Percent Energy ----> 99.98

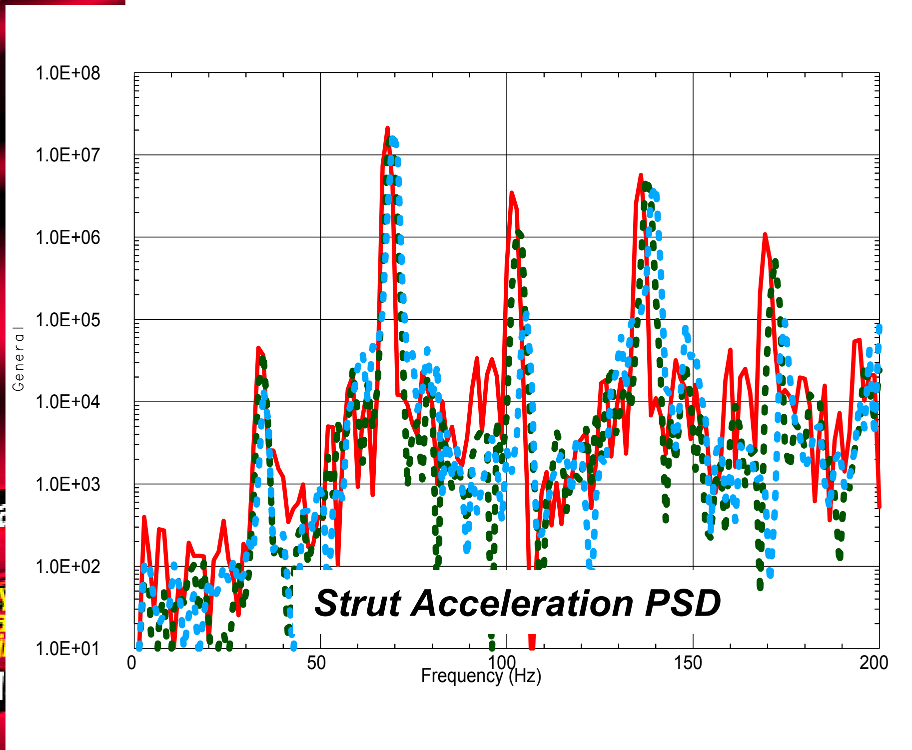
- **Mostly strut bending mode.**
- **Some tire stiffness.**

Groan Design Studies

- **Design Parameters Studied**
  - **Friction parameters**
  - **Knuckle to strut joint stiffness**

Effect of Static and Dynamic Friction





- **Ratio of static friction to dynamic friction held constant at .88.**
- **Decreasing both friction values:**
  - **Little effect**
- **Indicates that the slope of friction curve is most important aspect of friction parameters.**

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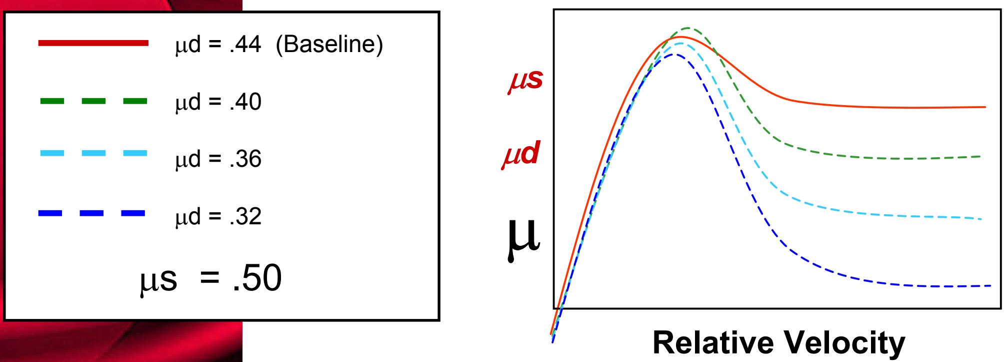
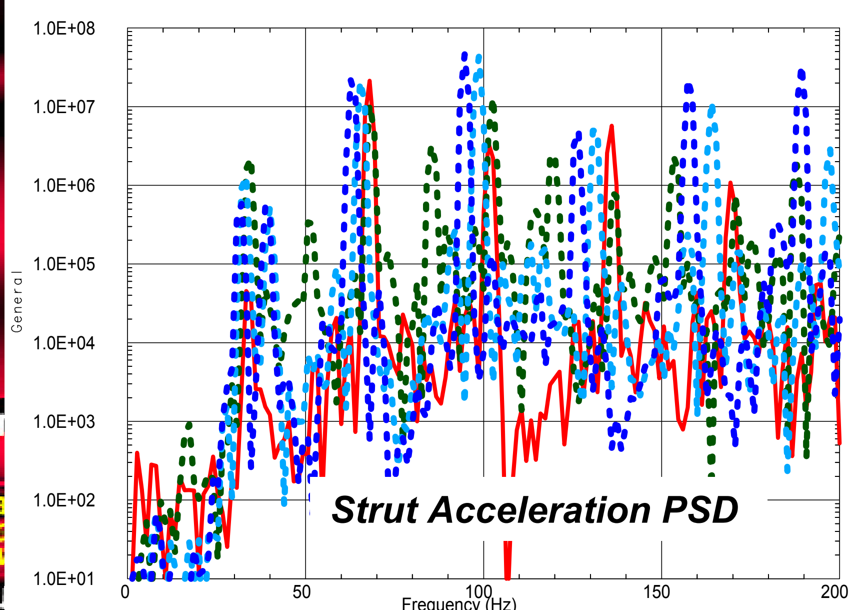
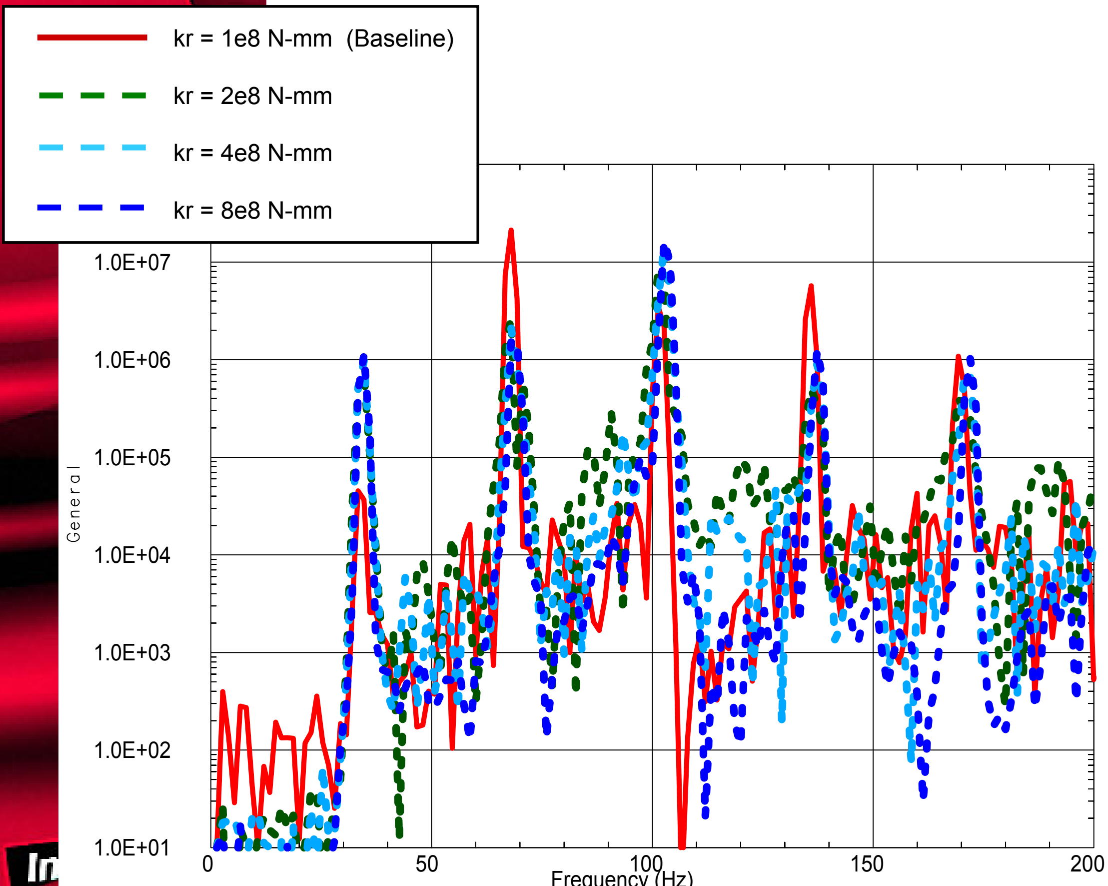
Effect of Dynamic Friction





- **Decreasing dynamic friction effect:**
  - **Order shifts lower.**
  - **Amplitude of orders changes.**
- **Stick-slip frequency becomes 1st order frequency.**
- **May not tune as well to P/F.**

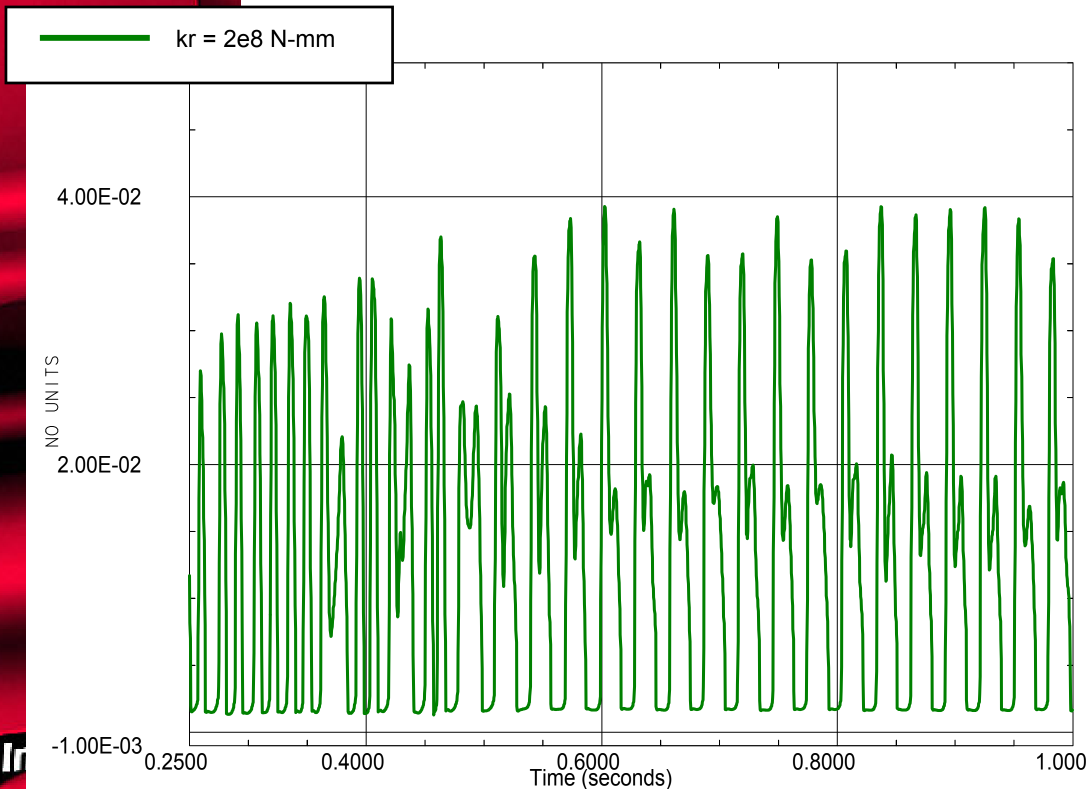
Increasing Knuckle-Strut Joint Stiffness



Strut Acceleration PSD

- **Increasing joint stiffness effect:**
  - **Order frequency do not shift.**
  - **Order amplitudes change.**
  - **Stick-slip frequency becomes combination of several frequencies.**

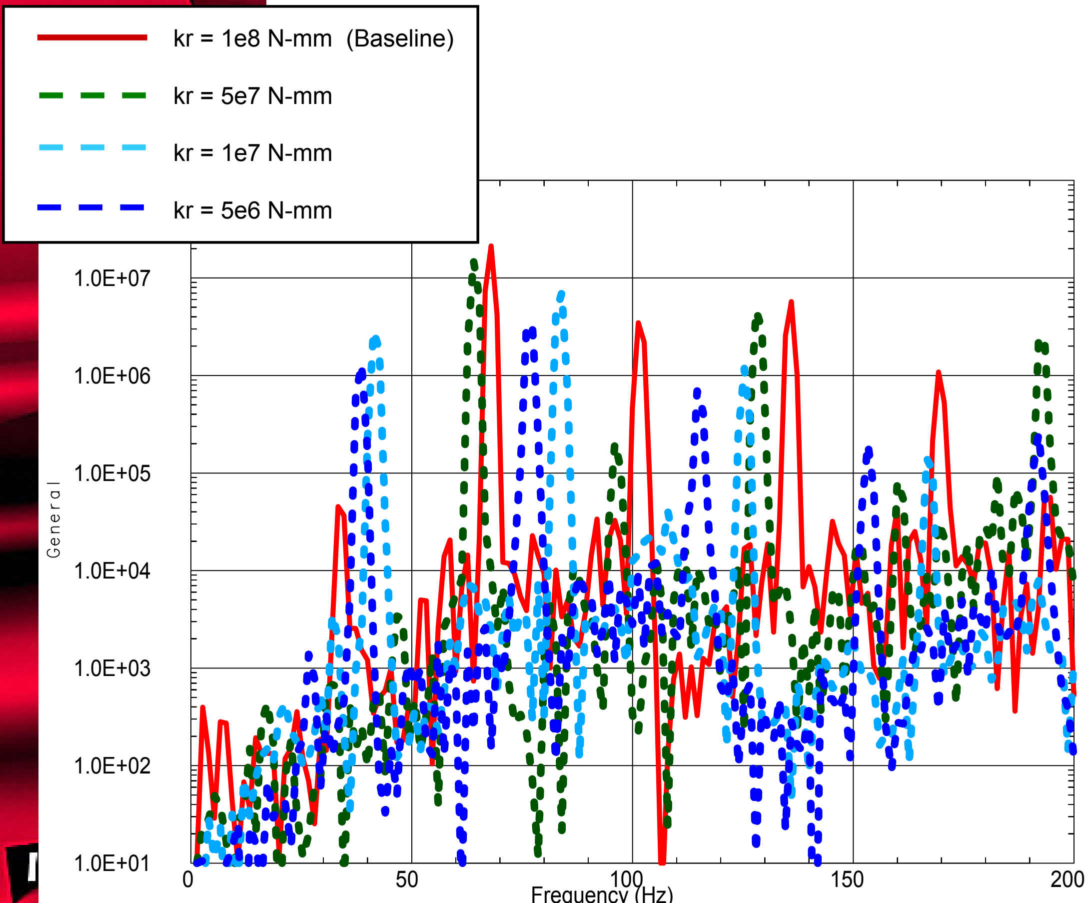
Increasing Knuckle-Strut Joint Stiffness



Rotor-Pad Relative Velocity Time History

- **Stick-slip frequency transitions from 2nd order to combination of 1st order and 2nd order.**

Reducing Knuckle-Strut Joint Stiffness



Strut Acceleration PSD

- **Decreasing joint stiffness effect:**
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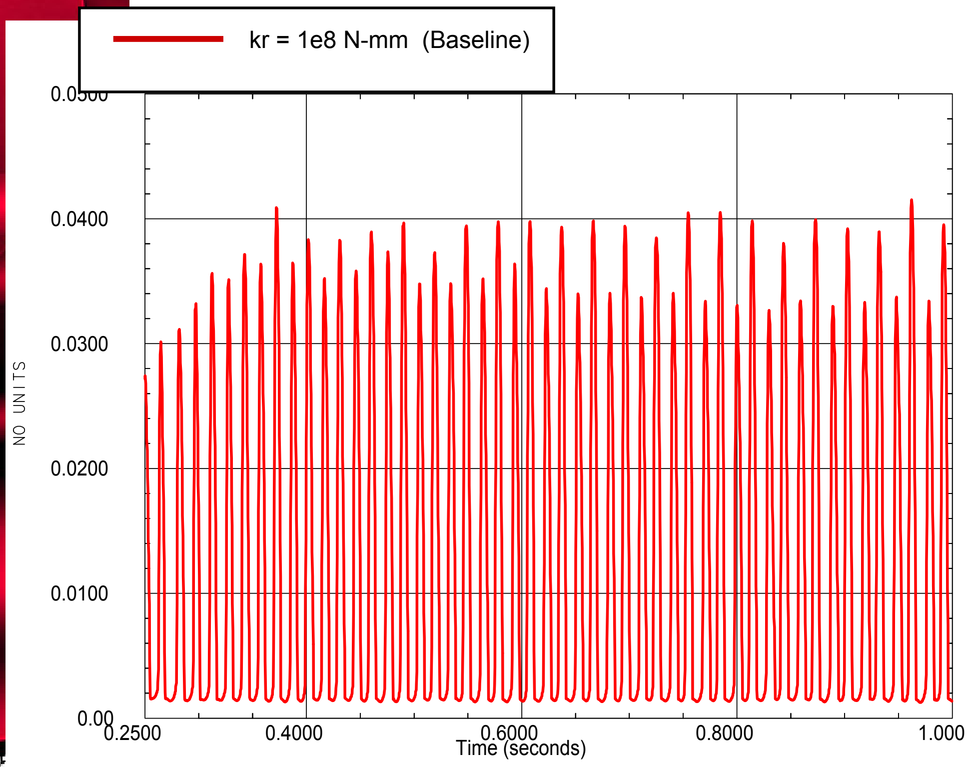
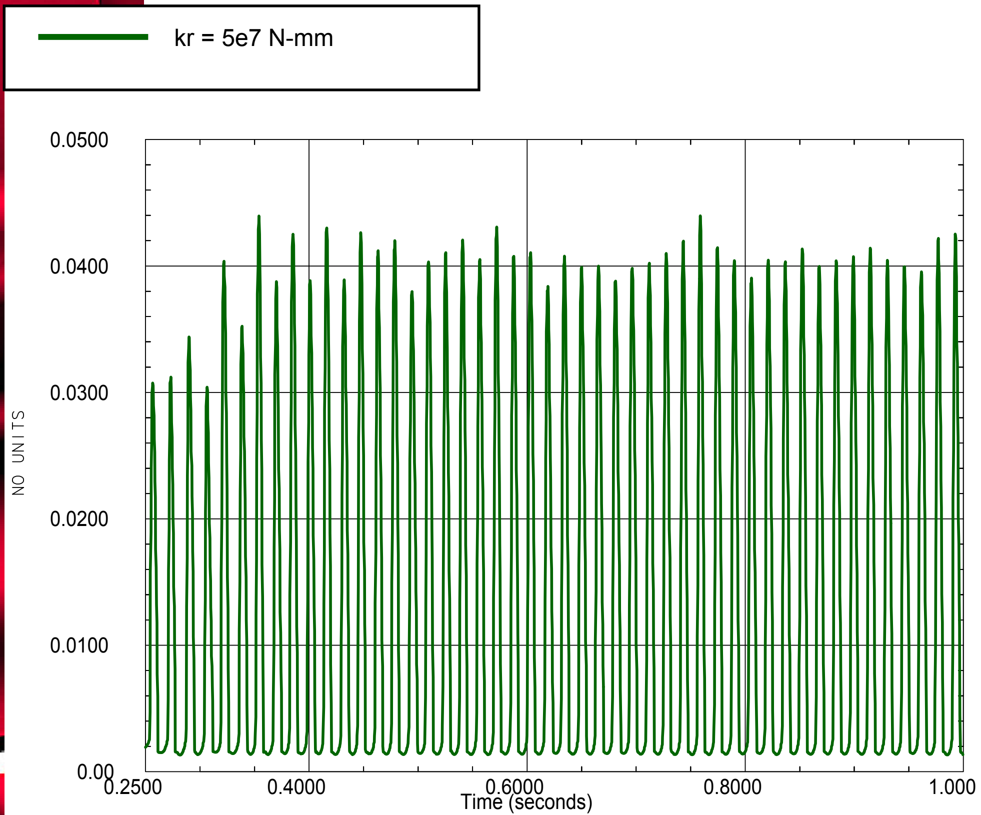
  - **Amplitude of orders changes.**

Reducing Knuckle-Strut Joint Stiffness



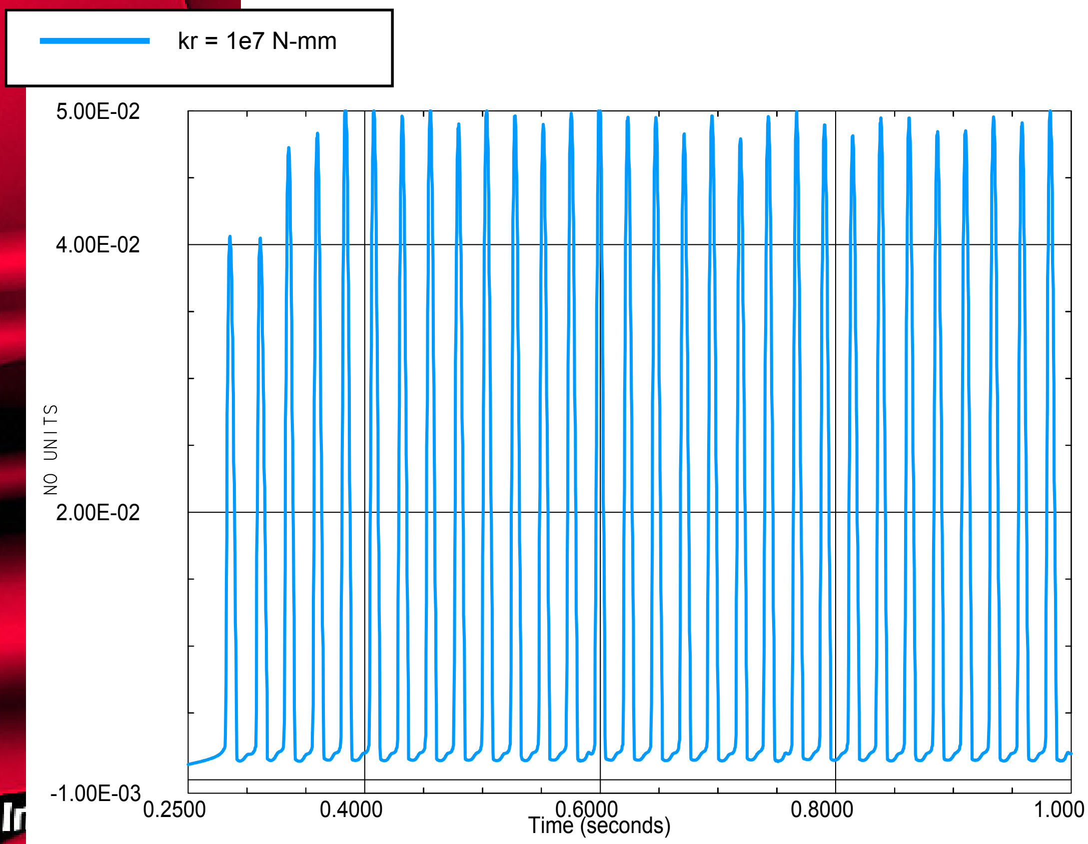
- **Stick-slip frequency is 2nd Order frequency at 68 Hz.**

Reducing Knuckle-Strut Joint Stiffness



- **Stick-slip frequency is 2nd order and shifts lower to about 62 Hz.**
- **Amplitude increases slightly**

Reducing Knuckle-Strut Joint Stiffness



Rotor-Pad Relative Velocity Time History

- **Stick-slip frequency becomes 1st order frequency.**
- **1st order frequency shifts higher to about 40 Hz. (from 34Hz)**
- **Amplitude increases significantly**
- **May not tune as well to P/F.**

Summary of Project Results

- **ADAMS model can be built to simulate groan behavior for a:**
  - **MacPherson Strut Quarter Suspension Model**
  - **with Tire Model**
  - **Enhanced friction model**

- **Instability interacts with fundamental wheel roll mode that occurs from 20 - 50 Hz.**

- **Noise comes from higher order harmonics of this oscillation**
  - **Strut bending mode amplifies response**
  - **Stick-slip frequency can change orders**

Summary of Project Results

- ADAMS model combined with FRF analysis can identify critical suspension modes that affect groan.

- Important Design Parameters:
  - Slope of friction curve
  - Strut stiffness
  - Strut/knuckle joint stiffness

- More study needed
  - to develop effective groan noise reduction measures.
  - Better understand mechanism of order switching