More recently, TRW has validated a new method that uses simulation to establish the initial contact and compute the sliding contact between pads and disc. Simulation studies have determined that this approach accounts for the system contact conditions, enabling brake noise to be simulated, reducing the need for physical testing to tune models. The entire simulation process is contained within a single environment, which saves times by automating many aspects of the simulation process and setting up batch runs for design optimization or manufacturing variation analysis. This new simulation method will make it possible to design and build quieter brakes in less time than is possible with traditional methods.

Challenge of predicting brake squeal
It has been estimated that noise, vibration and harshness (NVH), including disc brake squeal, generate warranty costs of about US $1 billion a year to the automotive industry in North America alone and that at least $100 million of those expenses can be attributed to brake squeal. Automobile suppliers and original equipment manufacturers (OEMs) need the ability to identify the potential for a proposed design to squeal early in the process before millions of dollars have been invested in detailed design, prototyping and manufacturing tooling. And, since it's impossible to produce components to exact dimensions and material specifications, it's also important to determine whether small variations that are inevitable in the manufacturing process will cause a percentage of production builds to squeal.

Although all brake squeal causes are not fully understood, it is commonly accepted that brake squeal is initiated by instability due to the friction forces, leading to self-excited vibrations. This process is inherently more complex than the typical simulation problem that consists of the application of a measurable load to a structure. The current state of the art standard for simulating brake squeal uses a manual process to create couplings between the brake pads and discs. Dynamic analysis is then used to analyze the eigenfrequencies of the system to determine if squeal will occur.
TRW Uses New Simulation Method to Simulate Brake Squeal Problems Early in Design Process

The weakness of this method is that factors such as deflection may change the way in which the two surfaces come together. They may contact each other at an angle or with greater or less force than is expected. In the traditional method the uncertainty in the contact conditions is addressed by building and testing a physical prototype and comparing the measurements against simulation predictions to tune the model to match. Typically, the first try is a poor match, so the simulation is run over and over again, each time adjusting the contacts until the simulation accurately predicts the results of the physical testing.

Development of new simulation method

The problem with the traditional approach is that the physical testing required to validate the contact conditions is expensive and time-consuming. TRW wanted the ability to accurately simulate brake squeal without having to spend extra time and money on testing to manually correlate. TRW worked with ANSYS to accurately define contact conditions prior to physical testing by using a nonlinear static solution to establish the initial contact and compute the sliding contact between the pads and disc. ANSYS incorporated the entire brake squeal simulation process within its Workbench environment. This makes it possible to take advantage of existing tools to automate many aspects of the analysis process, including the ability to simulate expected manufacturing variation and determine whether or not the design meets robustness requirements.

The new simulation process jointly developed by TRW and ANSYS begins with importing the computer-aided design (CAD) model into ANSYS Workbench. The production intent parametric CAD model of the brake assembly incorporates component levels models such as the pad assembly, caliper, rotor and knuckle. The component models can incorporate manufacturing variability. After the initial import, ANSYS mechanical solutions automatically detect and perform setup for contacts or joints between parts of an assembly. ANSYS meshing technology provides multiple methods to generate a hex-dominant or a tet mesh depending on analysts’ requirements.

A major challenge of brake squeal prediction is capturing the linear behavior of the structure based on its prior linear or nonlinear preloaded status. Linear perturbation analysis is used to solve a linear problem from this preloaded stage. The linear perturbation analysis is essentially automated in ANSYS Mechanical. A nonlinear static solution is used to establish the initial contact and compute the sliding contact between the pads and disc. The applied loads and rotation of the disc creates the pre-stressed effect and friction contact generates an asymmetric stiffness matrix during static structural analysis.
The second phase of the linear perturbation analysis is a QR damped or unsymmetric modal analysis solver. The eigensolver uses the asymmetric stiffness matrix generated in the contact elements and may produce complex eigenfrequencies. The results of a perturbation analysis show the damped frequencies for each mode number and the stability or real part of eigenvalues. The positive real part of the coupled mode will induce instability in the system and may be a source of brake noise or squeal. Figure 4 shows that mode 9 has a positive real component and is a potential source of brake squeal. The analysis results also include the mode shapes that can provide useful diagnostic information that will help in changing the design to eliminate the instability.

### Determining robustness of a proposed design

In addition to accurately modeling the physics of brake squeal, another attraction of the new method is its ability to perform studies to determine the impact of small variations in variables such as dimensions, material tolerances, loads, etc. These variables change from build to build, and even though they remain within tolerance limits there’s a chance that they might increase or reduce the amount of noise produced by the brakes. With the present methods there is no way to know what these effects will be. The new method makes it possible to look at the robustness of a proposed design by determining in advance that if hundreds of thousands are built whether or not any will squeal.

ANSYS simulation tools operate in the ANSYS Workbench environment that makes it possible to determine the robustness of a proposed design as an extension of a single simulation. ANSYS DesignXplorer uses the Design of Experiments (DOE) method to determine a set of simulations that will explore the design space around the proposed design with a minimum number of simulation iterations. When the user clicks the Update All Design Points button, the first design point, with the first set of parameter values, is sent to the parameter manager in the Workbench integration platform. This drives the changes to the model from the CAD system to post-processing. The new design point is simulated and output results are passed to the design point table where they are stored.

The process continues until all design points are solved, defining the design space so that it can later be optimized. DesignXplorer then presents the expected output variation to determine whether or not the design meets robustness requirements. If not, the user can look at the sensitivity plot and other charts to determine which parameters need to be adjusted or tightened to obtain the required robustness. This information can also reveal which tolerances might be relaxed without compromising the design.
Conclusion
The new approach has demonstrated its capability in a series of simulations that were validated with physical testing. The validation studies demonstrated that it is possible to simulate brake noise and other output parameters such as mode shapes and frequencies without using physical testing to calibrate the results. Clearly, the new method can more accurately model the physics behind brake noise than the traditional approach. The ability to incorporate manufacturing variation into the simulation and predict what proportion of builds will squeal is another major advantage. TRW is moving to implement the new method into its design process for future brake programs and is confident that it will be able to substantially improve brake quality while reducing engineering costs and lead time.