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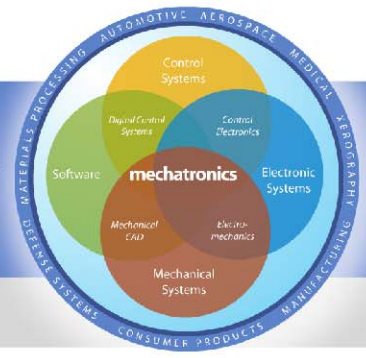
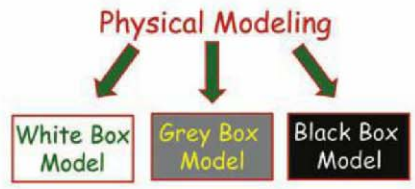
# MECHATRONICS IN DESIGN



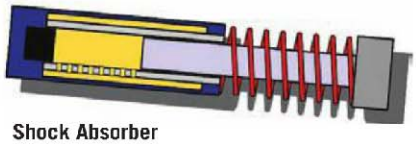

## Excelling in Shades-of-Grey Real World

Grey-box modeling combines the physical and empirical to solve problems.

**In a world** where problems are often ignored and allowed to fester for months or years, engineers do not have that option, as engineering problems ignored may lead to financial collapse or, worse, loss of life. Engineers solve problems to help people, and they do that with a sense of urgency. In many situations, a combination of human-centered design with state-of-the-art technology yields feasible and sustainable solutions. In more complex situations, physical insight may be incomplete and engineers perform experiments to validate what they do understand and inform what they don't. This approach to problem solving is called grey-box modeling and it existed long before the name was invented.




**Model Boxes Diagram**



**Shock Absorber**

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Let's use as an example the automobile/motorcycle shock absorber. Looking from the inside, it consists of a cylinder surrounding a movable piston. Moved by a shock from the outside, the piston compresses oil inside the cylinder through holes in the wall, thus dampening oscillations. A spring pushes the piston back to its original position, and a rubber stopper prevents the piston from impacting the walls of the cylinder when shocks are too strong. The shock absorber comprises the interaction of the mechanical movements of rigid bodies, the viscoelastic dynamics of fluids, the elastic behavior of springs, and the deformations of elastic-plastic materials. Looking from the outside, we only are aware of the phenomenological properties. We observe aspects like nonlinear stiffness, nonlinear viscous damping at high frequencies, and hysteretic effects at low frequencies, but we are not able to assign these phenomena to the individual parts of the shock absorber.

The shock absorber is integrated into a suspension system that must be designed and controlled. Mathematical equations are needed to predict the behavior of both the shock absorber and the integrated suspension system. Therefore, a mathematical model of this physical system must be created and this model is based on simplifying assumptions. Depending on the nature of the simplifying assumptions, models of varying complexity and fidelity result. Information about the real system comes from two different sources: looking from the inside and looking from the outside. Looking from the inside, we apply the laws of nature, together with the constitutive equations of the components, to the physical model to generate the mathematical equations of motion. These are solved by numerical simulation to predict the behavior of the physical model, which must be experimentally verified. Because we use our insight and understanding of the way the system works to create the model, we call this model a white-box model and it is an approximate image of the physical system. Looking from the outside, measurements alone of the real system give no insight into the real system, and thus no understanding of how the real system works is brought into the construction of the model. A mathematical model is chosen which fits optimally the measured data. This type of model is called a black-box model.

In reality, modeling is always something in between these two views, resulting in a grey-box model. White-box models are approximations of reality and always need experiments to identify parameters in the model, validate model predictions, and show where the model is deficient. The set of possible black-box models should always be guided by some knowledge of the inner workings of the real system. Since the focus of the engineer is solving the problem, the grey-box modeling approach is intuitive and obvious. Engineers contribute to society not only technological solutions to problems, but a solution process that transcends boundaries. **DN**