

Design Optimization of Helical Compression Springs to Mitigate Axial Twist

Dr. Jordan E. Massad & Devin S. Plagge

Sandia National Laboratories
Albuquerque, NM

Raleigh, NC
July 16, 2019



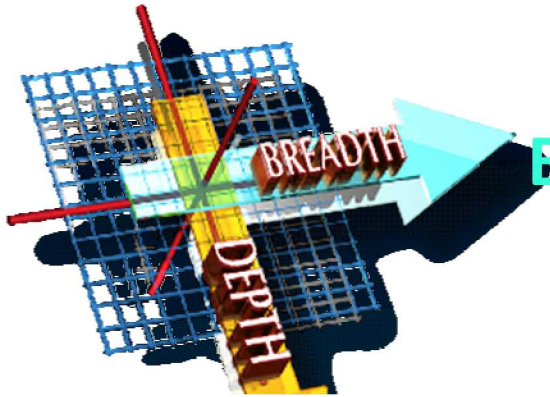
Sandia National Laboratories

- **Core Purpose:** help secure a peaceful and free world through technology.
- Provide objective, multidisciplinary assessments for complex problems.
- Focus on solutions with large science and technology content.
- Create prototypes for production and operation by industry.



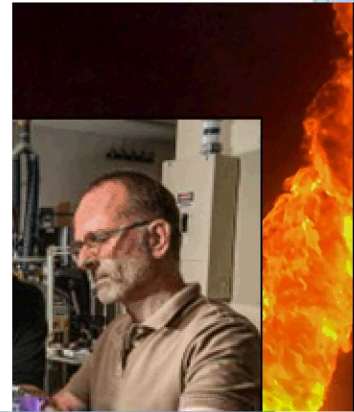
**U.S. DEPARTMENT OF
ENERGY**

Scope & Complexity of National Security

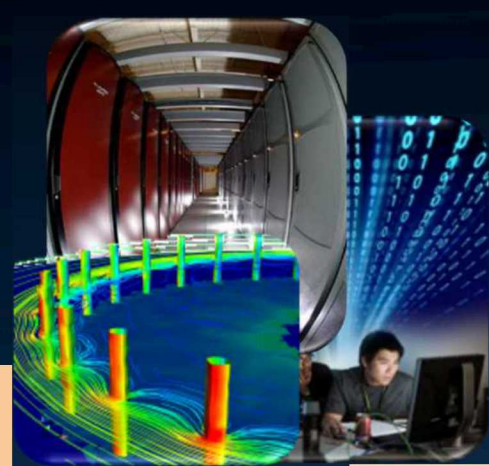


NL Applies both
BREADTH & DEPTH

solving the nation's most
challenging
problems.



Research Disciplines Drive Capabilities



High Performance Computing



Science & Technology Products



Renewable Systems & Energy Infrastructure

Computer Sciences

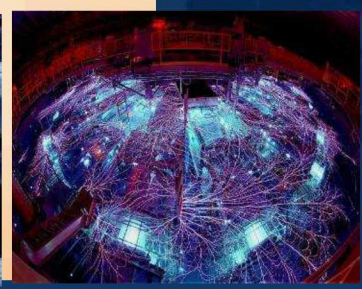
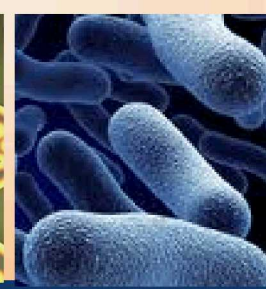
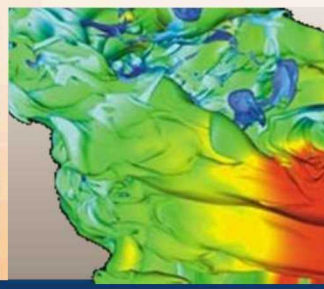
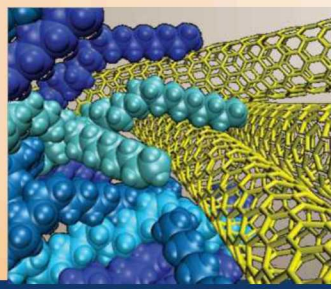
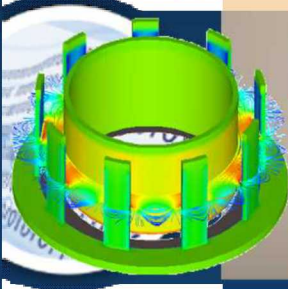
Materials

Engineering Sciences

Nanodevices & Microsystems

Bioscience

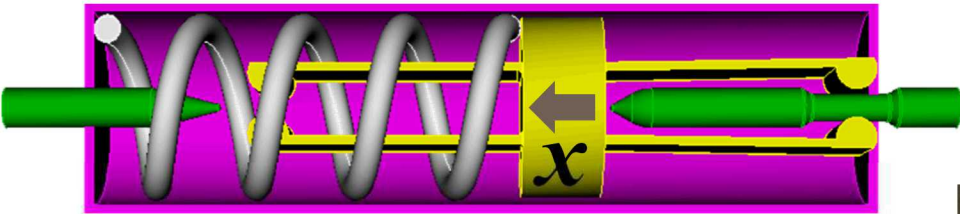
High Energy Density Science



Research Disciplines

Previous Teams' Analyses

Rocket Sled Track Switch Concept (2010)



$$m\ddot{x} = F_{sled} - (F_{spring} + F_{friction} + F_{contact} + F_{drag})$$

$$x(0) = 0, \dot{x}(0) = 0$$

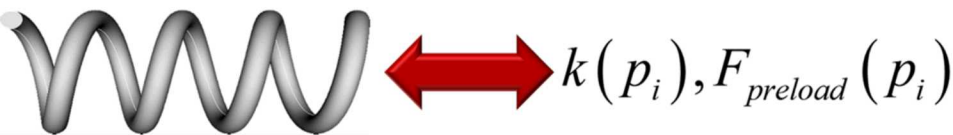
$$0 = \frac{d}{d\epsilon} \{ a(t)(m^0 + \epsilon\delta_m) - (m^0 + \epsilon\delta_m) \left(\frac{d^2}{dt^2}(x^0 + \epsilon h) \right) - (P^0 + \epsilon\delta_p) - (k^0 + \epsilon\delta_k)(x^0 + \epsilon h) \}$$

Quantified Significance of Spring Forces

$$-\text{sgn}(\epsilon \frac{dh}{dt}) h \frac{d}{d\epsilon} f(x^0 + \epsilon h) - \frac{d}{d\epsilon} C(x^0 + \epsilon h) (\epsilon \frac{dh}{dt}) - \frac{dh}{dt} C(x^0 + \epsilon h)$$



Helical Compression Springs (2015)



$$F_{spring} = kx + F_{preload}$$

$$\frac{d_{w}^{max} - 2d_w > d_h > d_h^{min}}{L_{free}} \frac{L_{total} - L_{solid}(d_w, N_a, \epsilon c)}{N_p - 1} \geq g_{min}$$

$$\frac{d_h + G}{8N_a (d_i + d_w)} \frac{G(L_{free} - L_{solid})}{4\pi N_a (\epsilon c)} \left[\frac{d_w (4d_i^2 + 9.46d_i d_w + 3d_w^2)}{d_i (d_i + d_w)^3} \right]$$



There's a Twist!

Rocket Sled Track Switch Concept (2010)

$$m\ddot{x} = F_{sled} - (F_{spring} + F_{friction} + F_{contact} + F_{drag})$$

$$x(0) = 0 \quad \dot{x}(0) = 0$$

A spring optimized for performance and manufacturability...

...may not be optimized for implementation and integration.

Optimized Spring Manufacturability

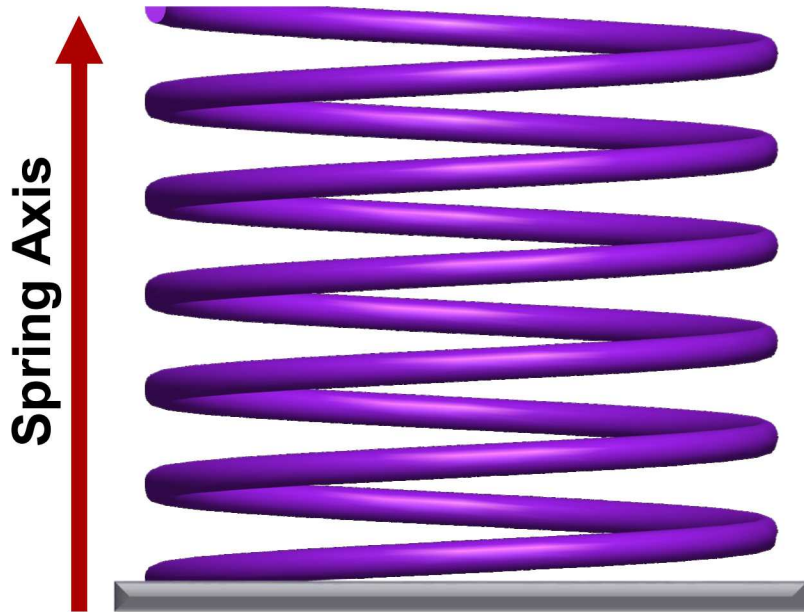
$$\frac{d_o^{max} - 2d_w > d_i > d_i^{min}}{L_{free} \sqrt{2(2\nu+1)}} \quad \frac{L_{hard} - L_{solid}(d_w, N_a; ec)}{N_f - 1} \geq g_{min}$$

$$\frac{d_i}{d_w} + 1 \leq C_{max} \quad UTS > \frac{G(L_{free} - L_{hard})}{4\pi N_a(ec)} \left[\frac{d_w(4d_i^2 + 9.46d_i d_w + 3d_w^2)}{d_i(d_i + d_w)^3} \right]$$

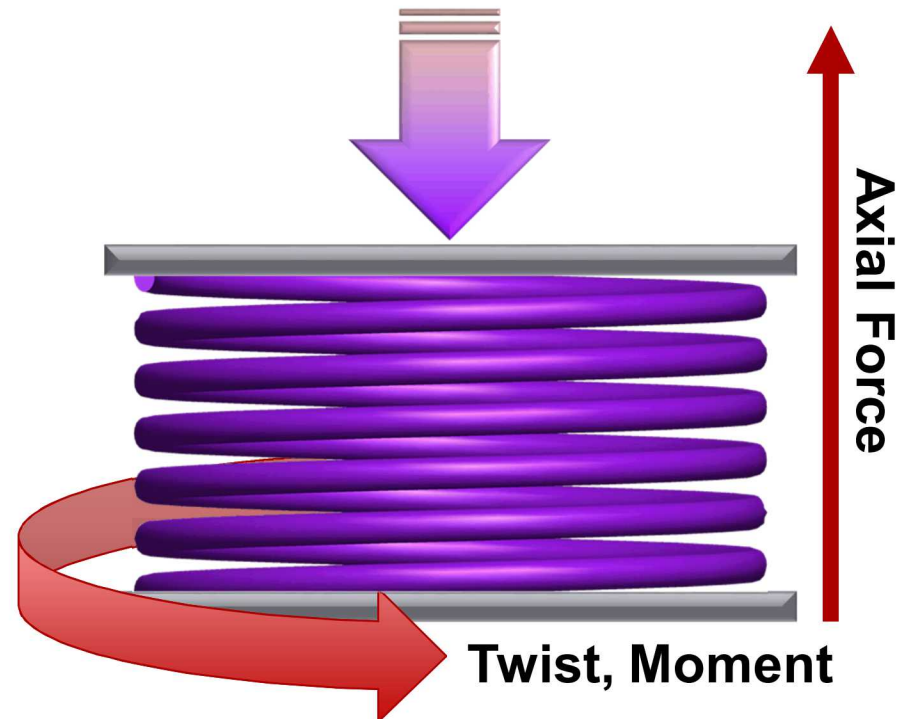

There's a Twist!

- **Ideal**: helical compression springs generate only an axial force when compressed.
- **Practice**: helical compression springs tend to **twist** slightly about their axis when compressed.

Uncompressed

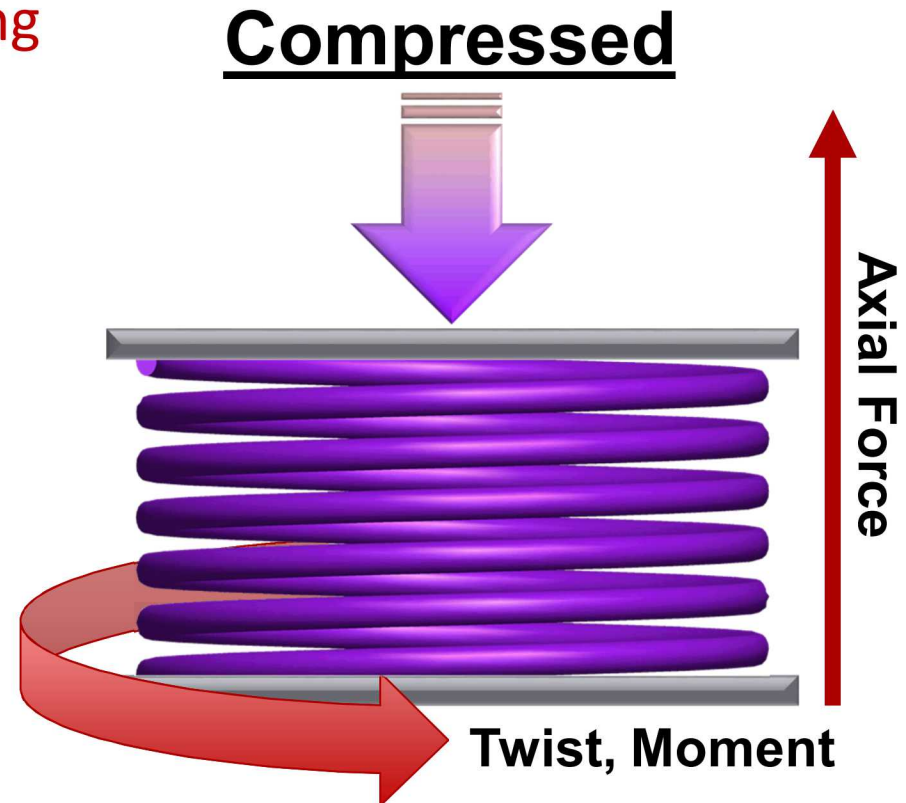


Compressed



Axial Twist Complications

- Spring twist action can generate **unintended forces** on mating parts.
- Compressing spring for installation: twist action can **misalign mating parts**.
- Resisting the twist can lead to pent-up spring forces that **alter intended spring behavior**.
- Stick-slip friction of rotating end coils could lead to **erratic axial spring forces**.



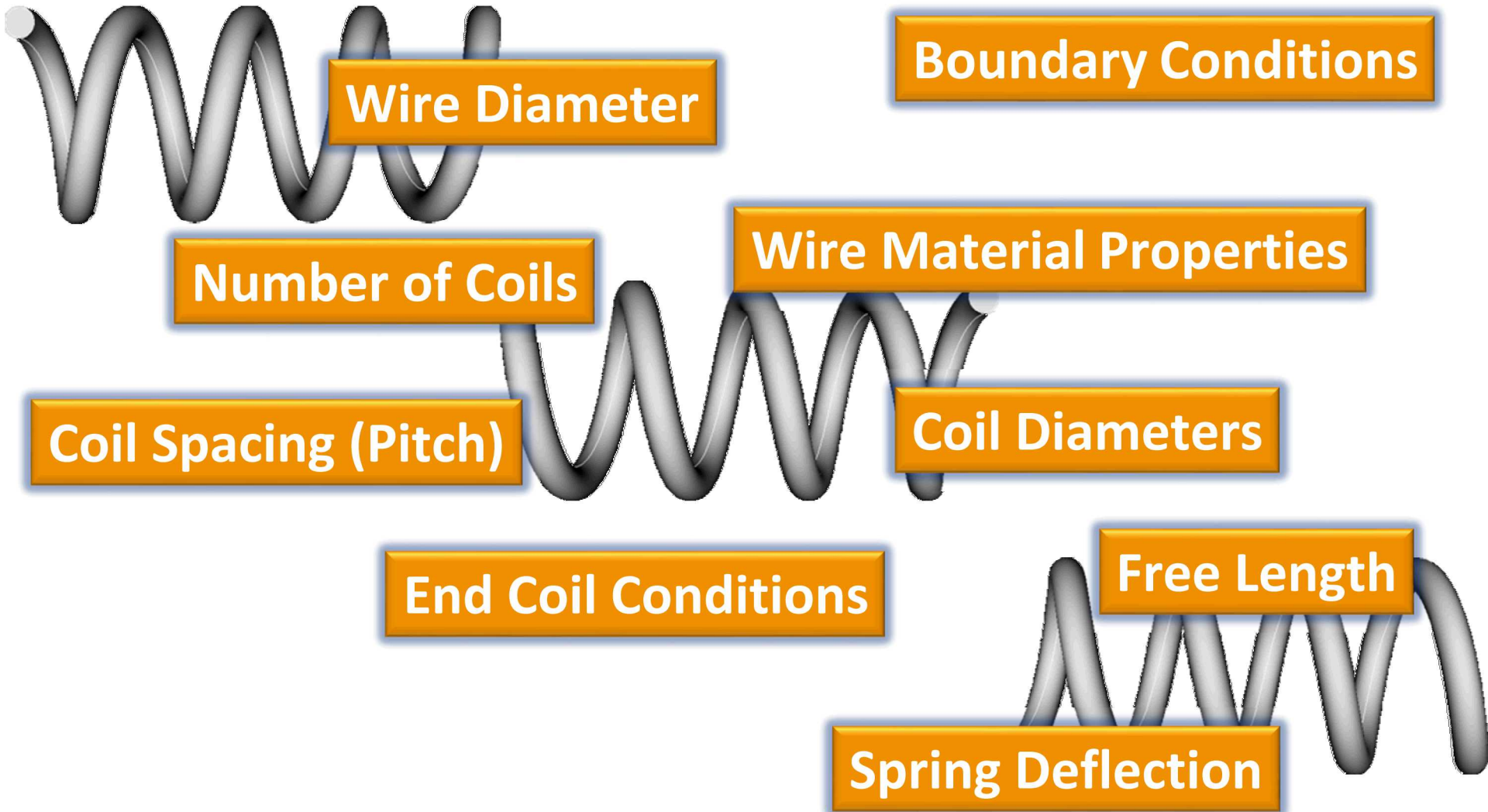
Mitigate the Axial Twist?

- Allow spring to twist unconstrained when compressed.
 - Reduce friction to let end coils slide on mating surfaces: **unreliable**; may have to introduce lubricants.
 - Engineer mechanisms to rotate with spring (freely rotating mounts, etc.): **complicates overall design and assembly**.
- Radically redesign the helical compression spring.
 - *Machined* springs offer advanced designs that eliminate axial twist; may **not meet stringent tolerances**
 - Radical designs are **likely incompatible** with spring industry's current guidelines.

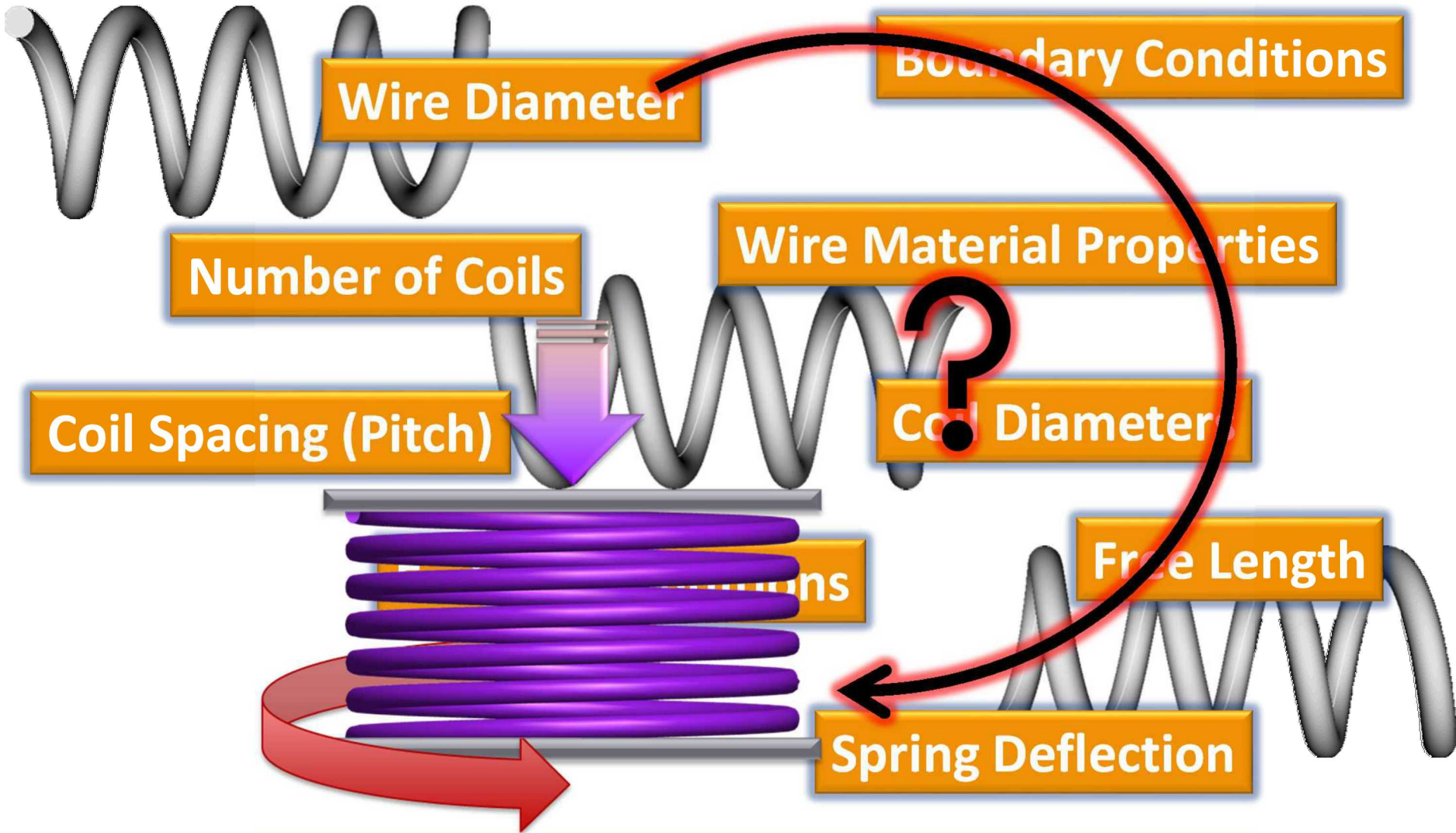
Are there conventional designs that mitigate axial twist?



What Determines Axial Twist?



Map Spring Properties to Axial Twist?

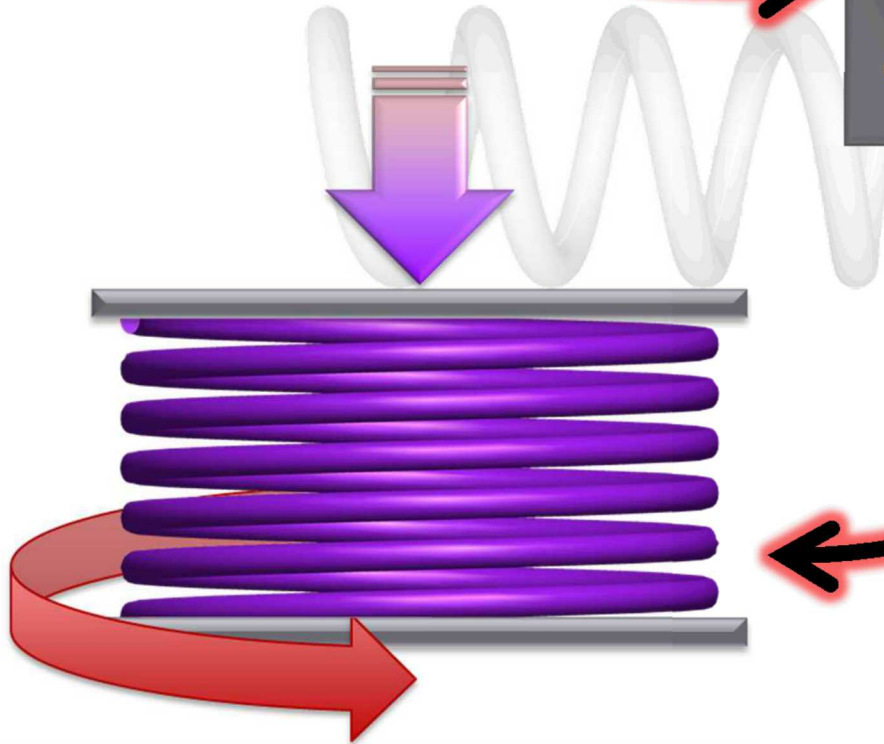


Model-based Approach Desired

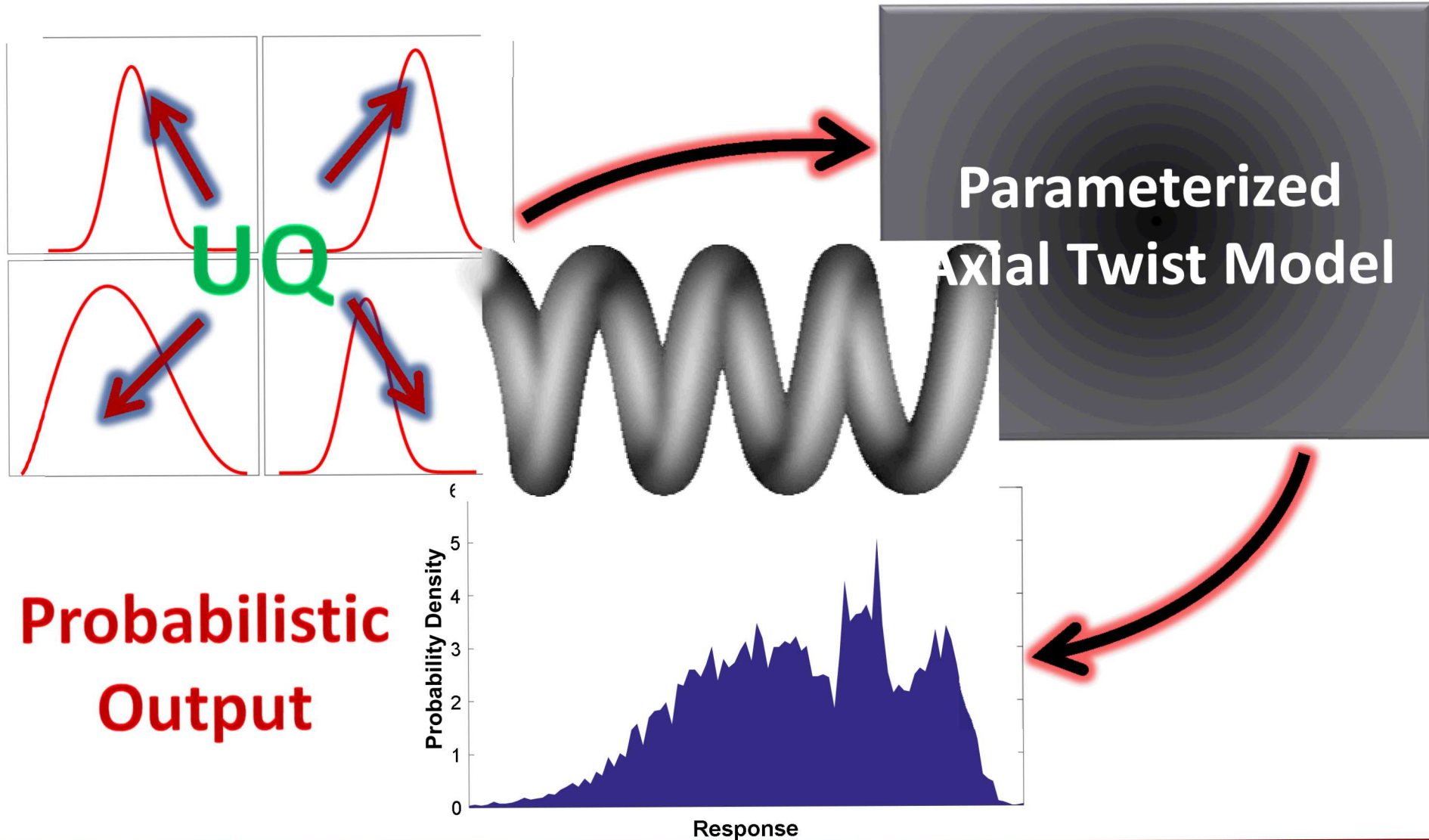
Wire Material Properties

Coil Diameters

Free Length



Empower Uncertainty Analysis



What Sandia Wants to Know

How can axial twist be mitigated in conventional helical compression springs?

Some Questions to Address

- What is a computationally-efficient model of axial twist as a function of spring parameters?
- What is an optimal spring when axial twist is considered?

Addressing this problem can help enhance our analysis capabilities from spring design through implementation.

- *Banner: what is the range of axial twist resulting from multiple spring parameter tolerances?*
- *Hulk: are there spring designs that maximize the probability of spring performance under uncertain conditions?*