SAND2022-7595C

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Multi-Objective Optimization of Mechanism Margins in Simcenter 3D Motion

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2022 Department of Energy Digital Twin Conference

June 8, 2022

SAND2022-7595 C

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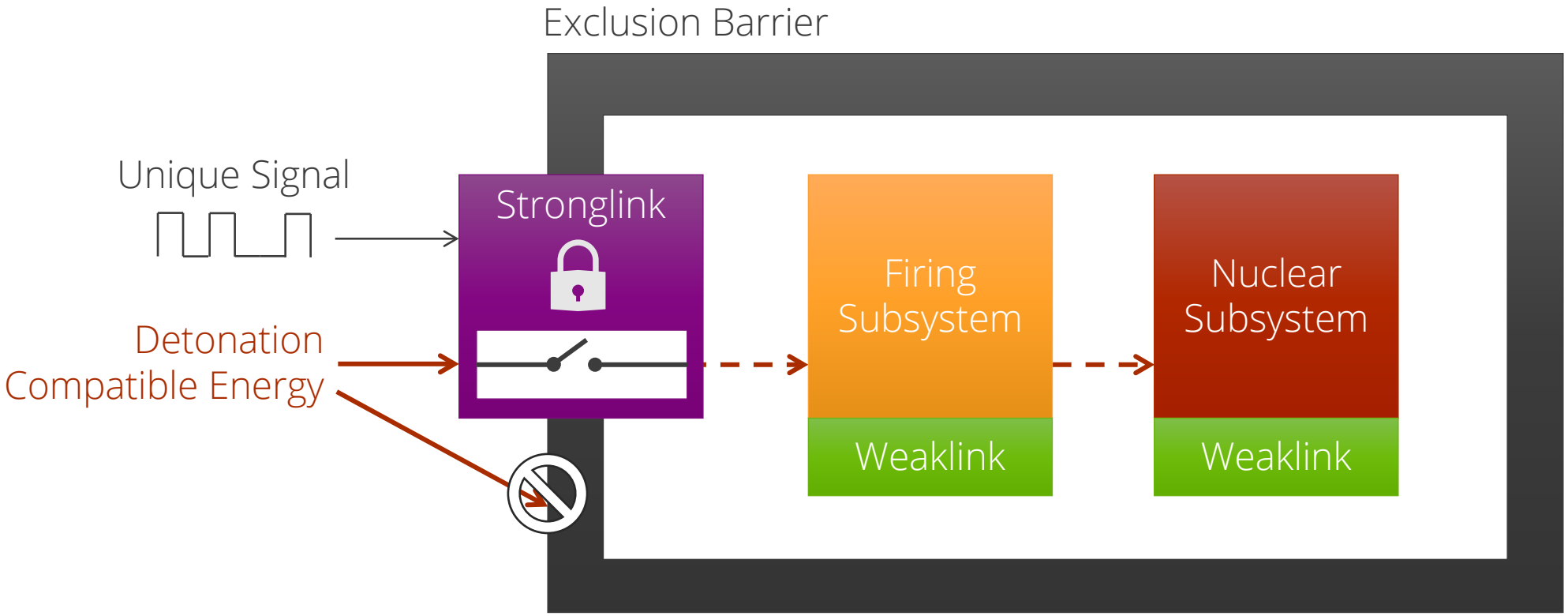
U.S. DEPARTMENT OF ENERGY

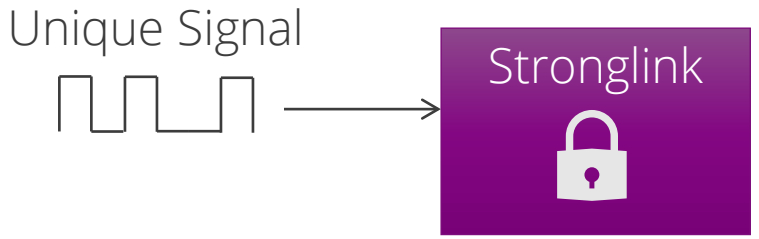
NNSA

Enhanced Nuclear Detonation Safety (ENDS) & Stronglinks



Stronglinks are engineered devices that are central to the ENDS philosophy and the principles of isolation, incompatibility, and inoperability.

Unique Signal Stronglink Overview



Unique Signal Stronglink Overview
- Mechanical device with mechanical discrimination of an electrical signal
- Consists of 4 elements
  - *Actuators*
  - *Discriminator*
  - Energy shutter
  - Status monitor(s)

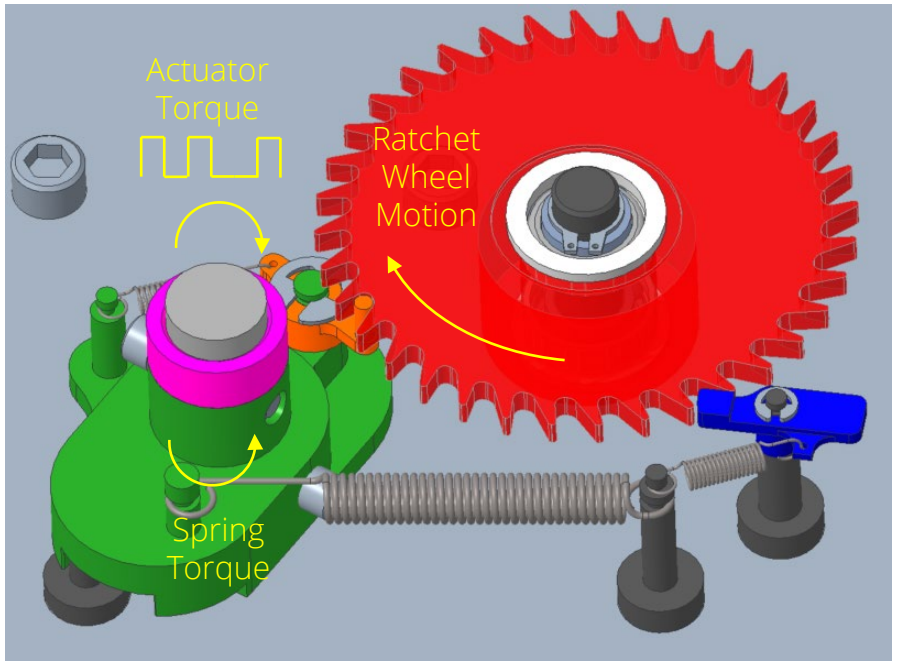
Cannot share a stronglink design in this presentation, but…

… actuator & discriminator behavior is typically similar to a ratchet mechanism

Sounds simple, BUT …
- Geometry is miniature, complex, and highly constrained
- Must operate in a range of environments (acceleration, vibe, temperature, etc.)
- Stringent reliability and safety requirements (“always/never”)

Therefore, we seek to profoundly understand and to maximize performance in development

Representative Ratchet Mechanism (not a stronglink & no discrimination)



Note: Mechanism pictured is for illustrative purposes only and was not the focus of this work

Multi-Objective Design Optimization with SC3D Motion

A core design challenge for stronglinks is balancing margins:

- Actuator torque >> spring torque
- Spring torque >> mechanism torque

Balancing margins has traditionally been time-consuming and iterative

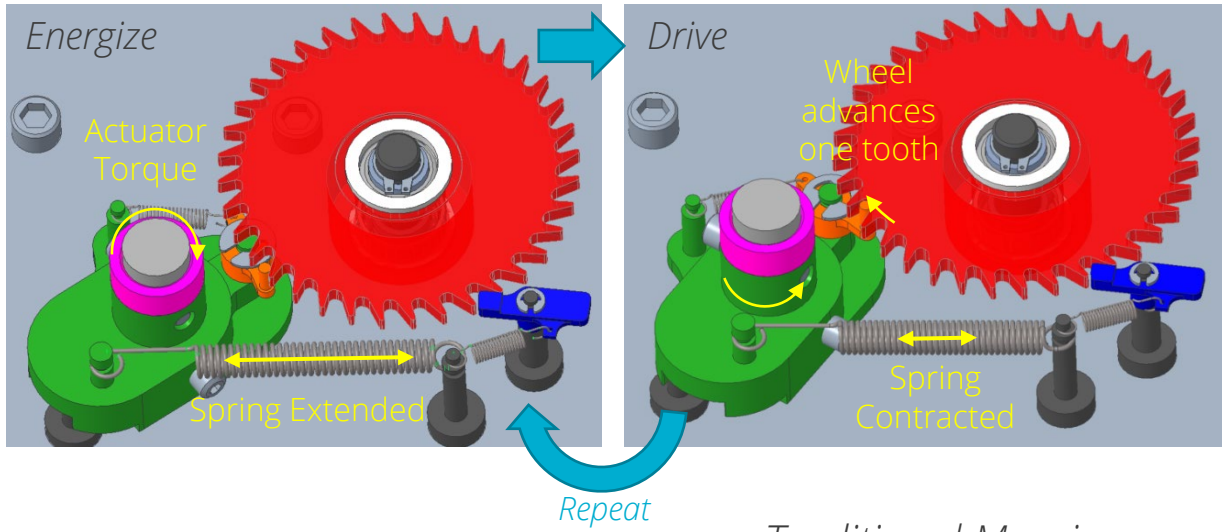
New approach: Multi-objective design optimization/exploration using…

- Simcenter 3D Motion
- Simcenter 3D Design Exploration (HEEDS)

Desired outcomes:

- *Simplify* and *accelerate* the design process
- *Improve margins* from one hardware build to the next (e.g., Dev 1 to Dev 2)

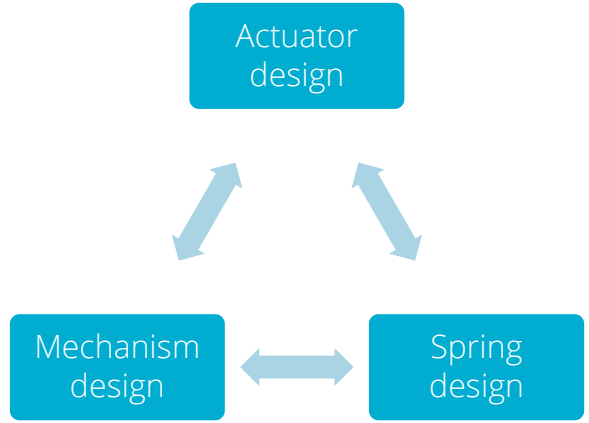
Representative Ratchet Mechanism Operation



*Ratchet Motion Animation**

*Kinematic (not dynamic); springs not visible

Traditional Margin Balancing Process



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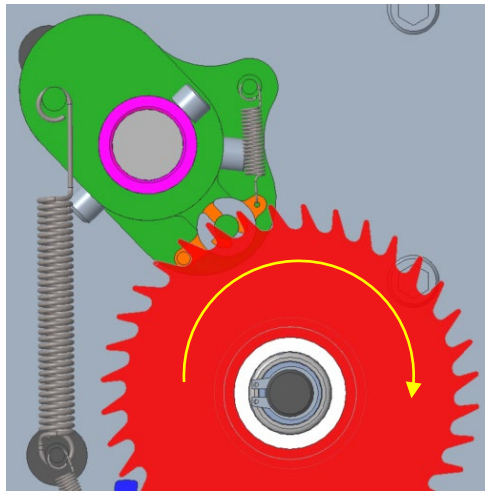
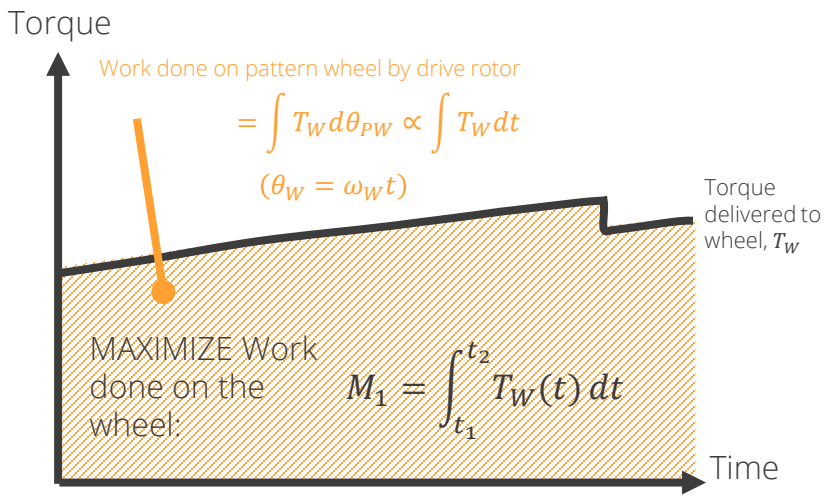
Optimization via Dual Simulations & Metrics

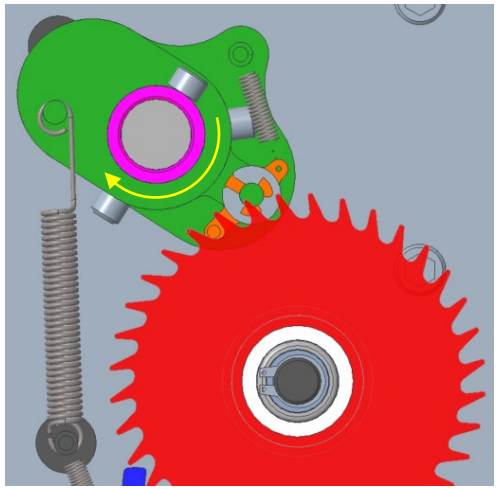
Drive Simulation



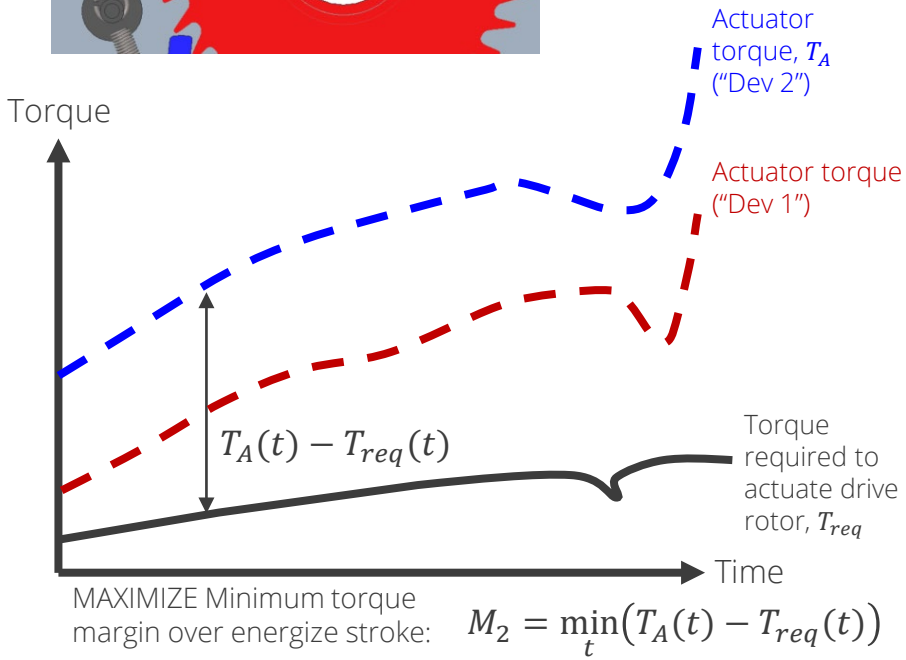
Drive wheel quasi-statically through one index & measure torque delivered, T_W



Energize Simulation



Drive rotor quasi-statically and measure torque, T_{req}



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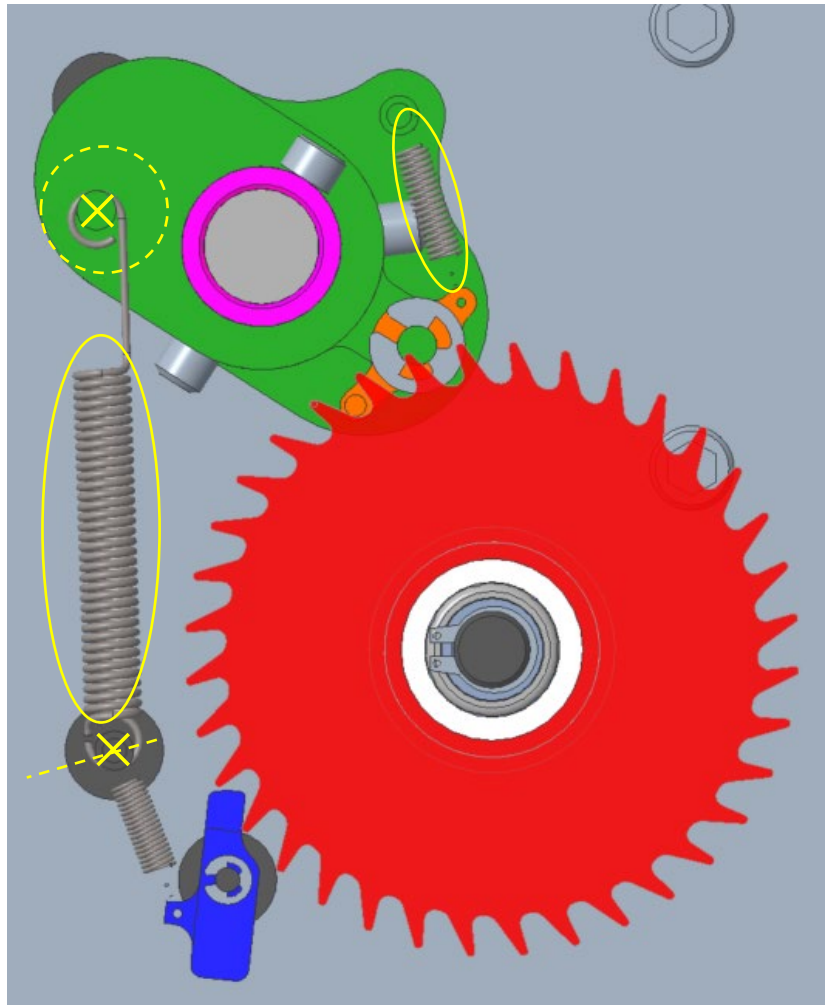
Design Variables and Constraints

Design variables: spring properties
- Force at max extension
- Stiffness
- Connection locations

Constraints: evolved with experience
- Achievable spring properties established from spring design software
- Constraints on spring connection locations per physical space and engineering judgement



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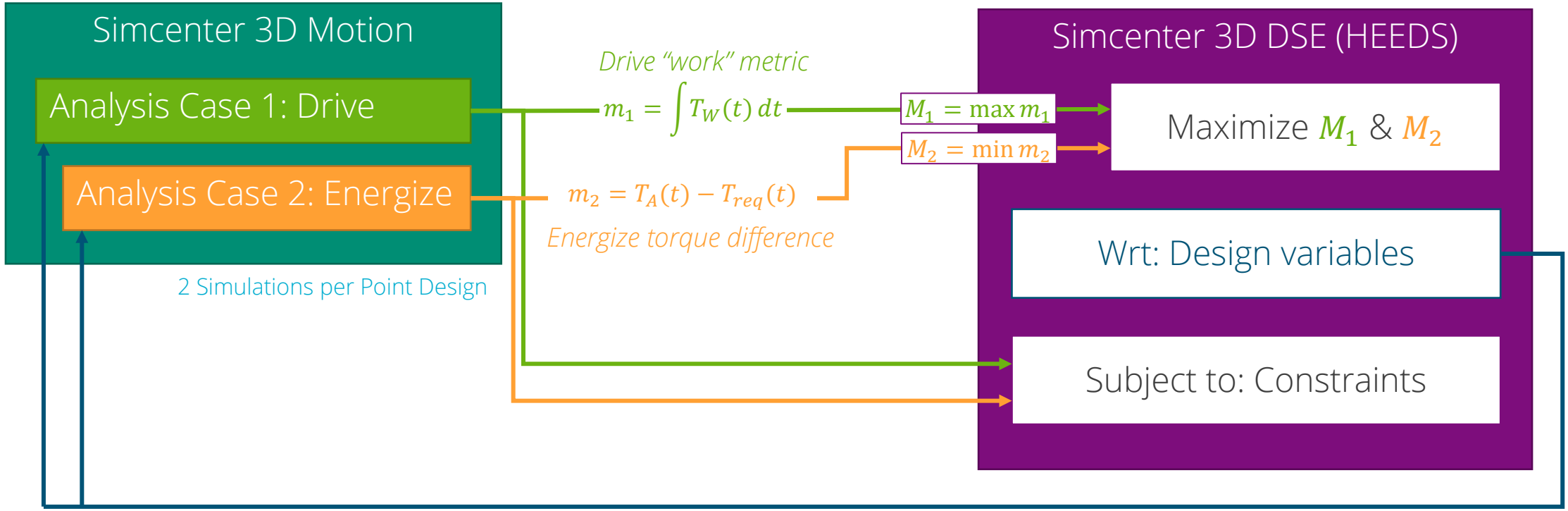
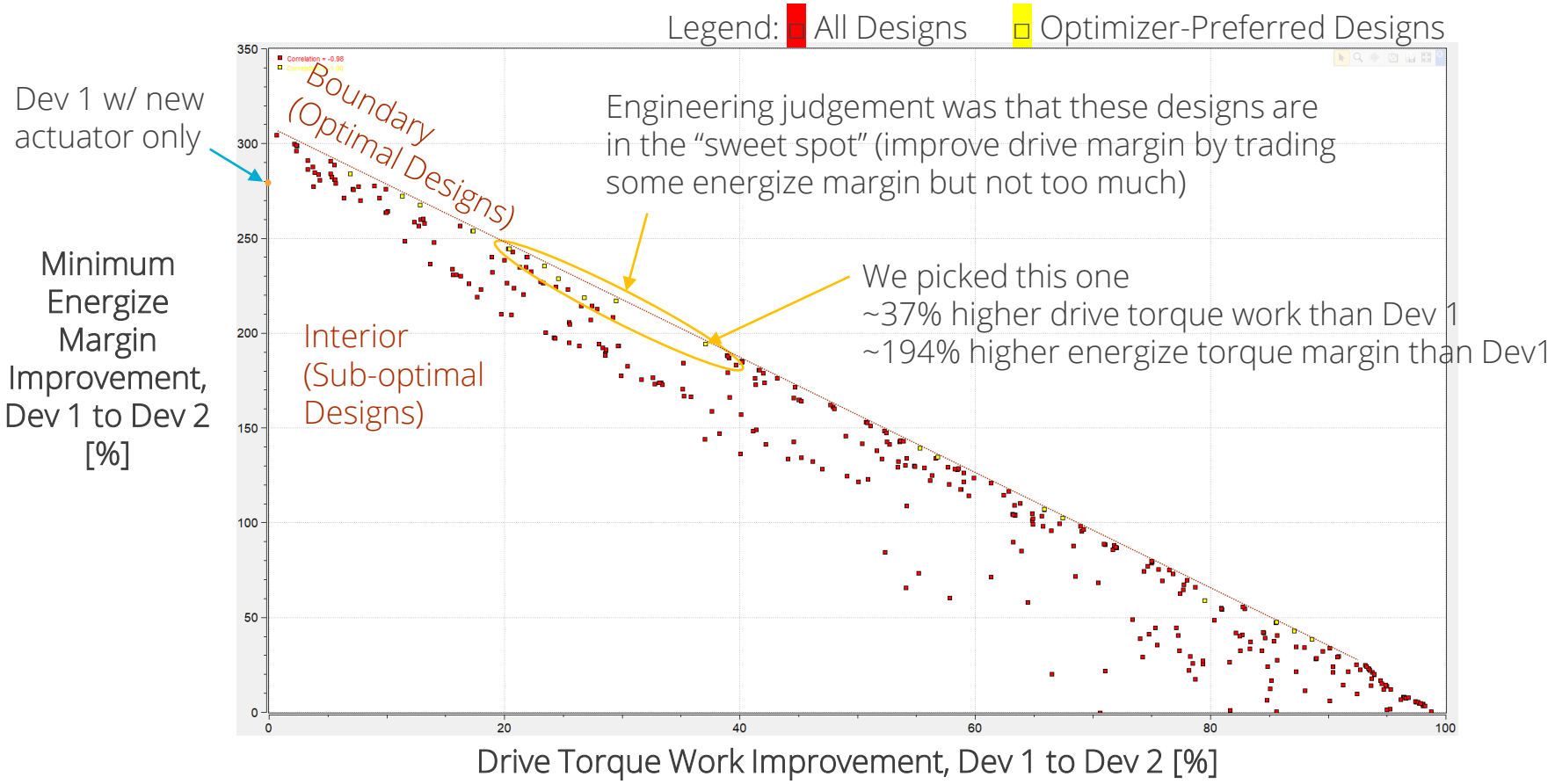
Simcenter 3D Motion & Design Space Exploration (HEEDS)

Goal: Balance margins while maximizing performance



Simcenter 3D Design Space Exploration linked to Motion enables intelligent exploration of designs with relatively high fidelity.

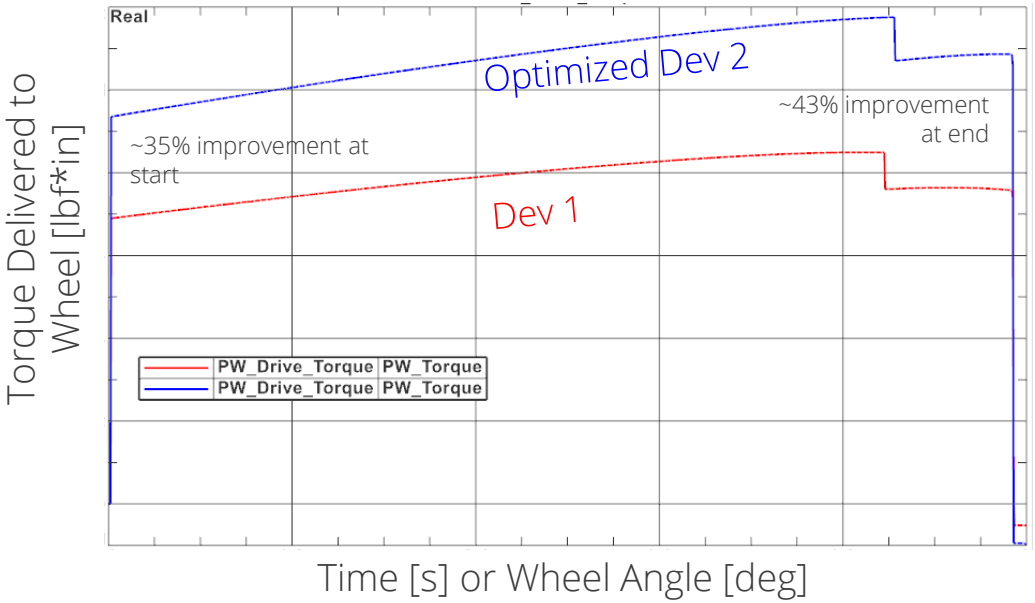
Optimization Results



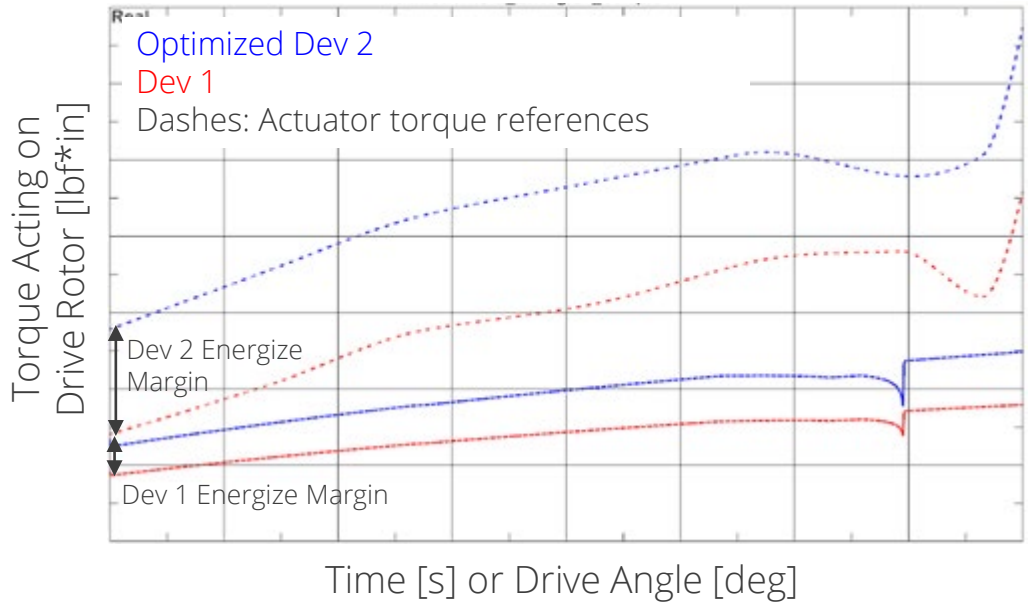
Optimization-based approach allows for rapid identification of high-performing designs, giving design engineers options.

Summary of Selected Dev 2 Design

Torque Delivered to Wheel over 1 Index



Torque to Actuate Drive



In summary, for chosen Dev 2 design compared to Dev 1…

- 37% increase in drive torque work
- Nearly 3X improvement in minimum energize margin
- Starting energize torque margin (as ratio T_A/T_{req}) ~ 2.25
- Relatively modest changes to design

Initial demonstration of multi-objective optimization to balance margins was a success!

Epilogue – Another Stronglink Design

Rapid redesign was needed *mid-procurement* for another similar stronglink device moving from Dev A to Dev B. In the same week…

- Dev A unit failed to operate (drive) in a specific environmental condition
- Dev B simulations showed reduced drive margin compared to Dev A

Multi-objective optimization approach was rapidly implemented in redesign

- Similar formulation
- Rapid evaluation of design options
- New point design with *much-improved margin* but *modest changes* established *in <2 weeks*

Static Torque Margin [Available/Necessary]

	Dev A	Dev B Original	Dev B Redesign
Worst-Case Energize	1.10	1.48	1.48
Worst-Case Drive	1.44	1.19 ⇨	2.19

Multi-objective optimization proved its worth in a time-constrained situation!

Acknowledgement: Spencer Grange

Conclusions and Future Work

Conclusions

- Multi-objective design optimization using SC3D Motion & DSE was used to optimally balance drive and energize margins in two stronglink mechanisms
- This new approach yielded *higher-performing* designs *in less time* than traditional approaches

Future Work

- Refine approach, especially with respect to defining constraints
- Move approach into regular use (need documentation, broader awareness)
- Explore putting other design aspects in-the-loop
  - Spring design?
  - Fine-tuning of actuator designs?

Thanks for listening!