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Development of a Locking Setback Mass for Cluster Munition Applications: A UQ Case Study

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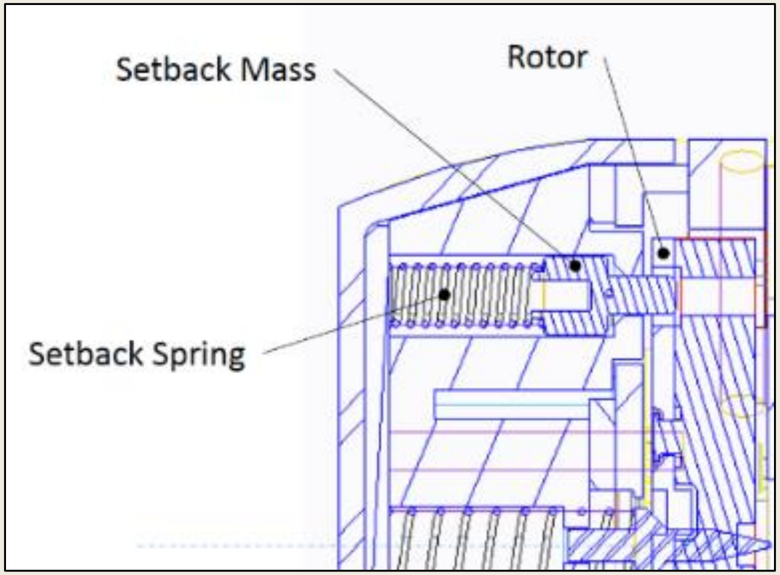
Background

- This effort covers the design of setback lock in the fuze of an artillery round
- The setback lock must meet 2 requirements:
  - **High Reliability**: It must move during a credible launch event to unlock the safe & arm device
  - **High Safety**: It must remain locked in the safe & arm device during a drop event



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Uncertainty Quantification (UQ) Approach

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- **Space Filling Design**: systematically place the design points uniformly throughout the design space to take maximum advantage of the deterministic simulation results
- **Simulation**: the design points were executed using the system math models that were developed to simulate setback and drop loads on the setback lock
- **Surrogate Models**: a closed form equation was fit to each of the responses (setback and drop) that approximates the result produced by the system math model for any point in the design space.
- **Optimization**: using the surrogate models for both setback reliability and drop safety, an optimization was performed to identify candidate designs that simultaneously maximized reliability and safety.
- **Model Calibration** *(in progress)*: candidate designs are being manufactured to be tested for setback reliability and drop safety and the results will be used to inform the surrogate models to improve their predictive capability
- **Final Predictions** *(planned)*: running Monte-Carlo simulations through the improved surrogate models, predictions for setback reliability and drop safety will be obtained. In these simulations, realistic distributions of each design variable (accounting for realistic tolerances) and noise variable will be used to predict the distribution of reliability and safety responses

Exploratory Design

- Larger design space
- Objective is to narrow down to a smaller region of viable designs

Factor	Units	Min	Max
Wire Diameter	inch	0.008	0.027
Mean Diameter	inch	0.080	0.125
Number of Coils	-	3	20
Free Length	inch	0.249	1.500
Lock Spring Wire Diameter	inch	0.010	0.015
Setback Force	lbf	2500	2800
Friction 1	-	0	0.5
Friction 2	-	0	0.5
Friction 3	-	0	0.5
Material	-	Steel	Titanium

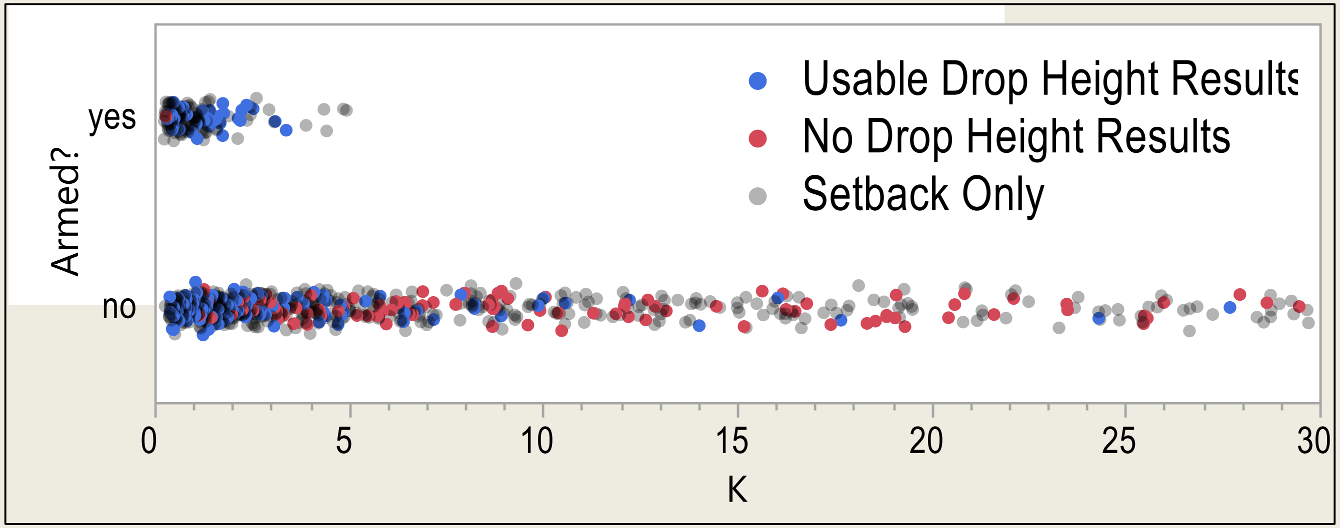
Simulations

2 different numerical simulations were run to obtain predictions for the reliability and safety within the design space:

	Setback Reliability	Drop Safety
Simulation	Expose the setback lock to gun launch loads	Expose the setback lock to varying acceleration profiles corresponding to a drop event
Response	Maximum displacement of the setback lock	Maximum drop height at which the setback spring would remain safe
Run Time	< 1 sec	~ 1 min
UQ Design	1000 run MaxPro Space Filling	300 runs (3 out of 10 slices of the full 1000 run design)

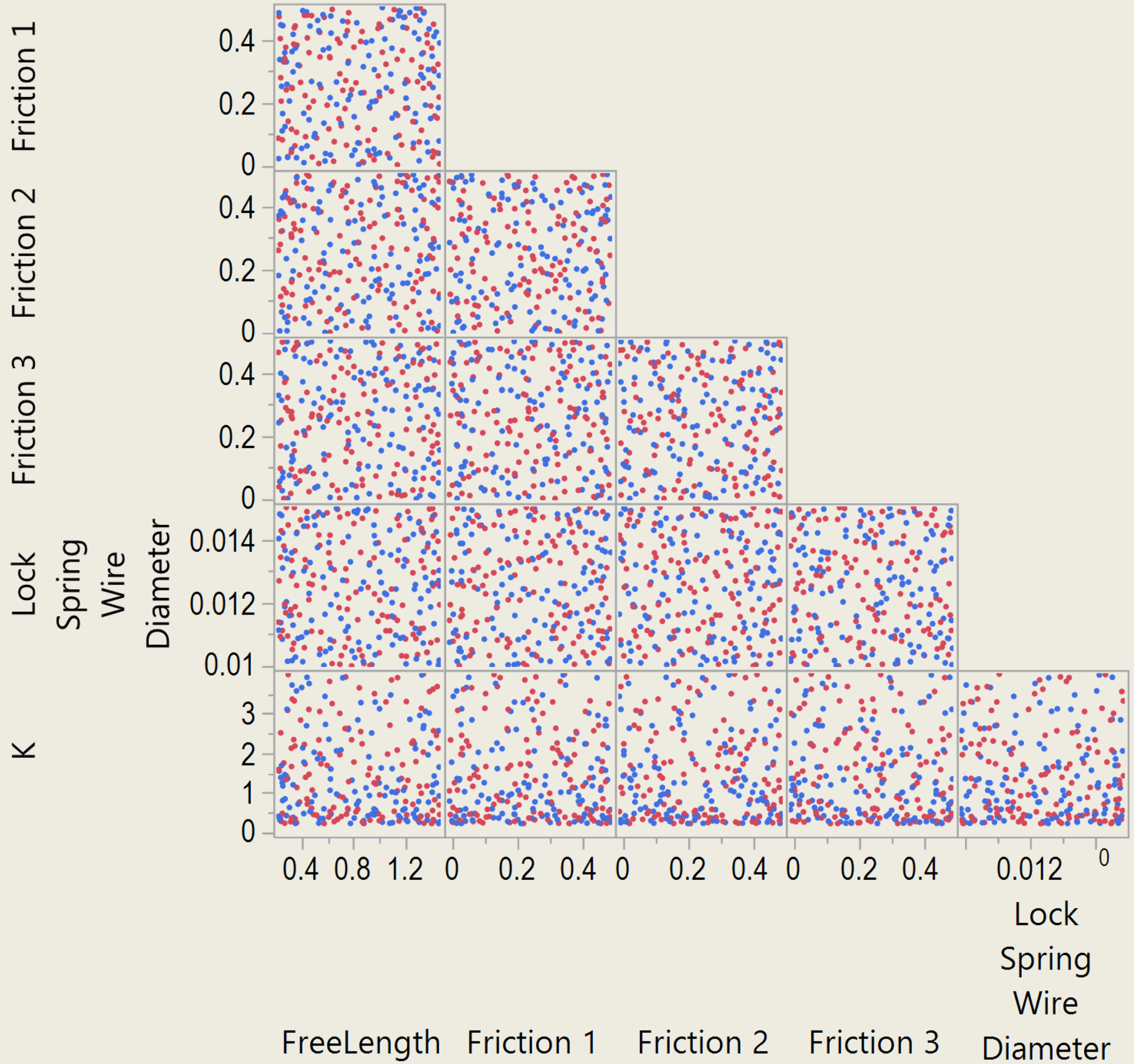
Exploratory Results

- Limitations in the simulation made it impractical to obtain drop height results for around ½ the runs
- An investigation of the raw data showed that the vast majority of runs that failed to produce results had higher values of the spring constant K
  - K can be calculated from the wire diameter, mean diameter, and the number of coils
- In addition, all the runs that did not give drop height results also did not arm
- Based on this, the follow-on designs focused on the area of the design space where the spring constant, K, is between 0.25 and 4



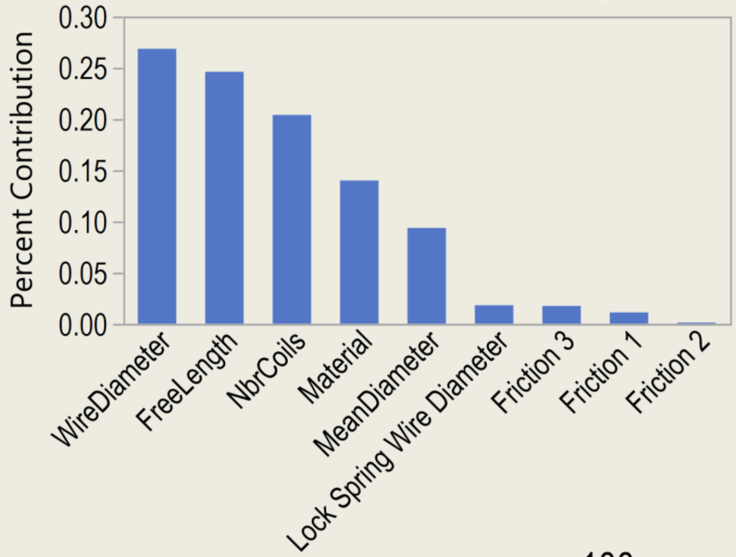
Final Design: Drop Safety

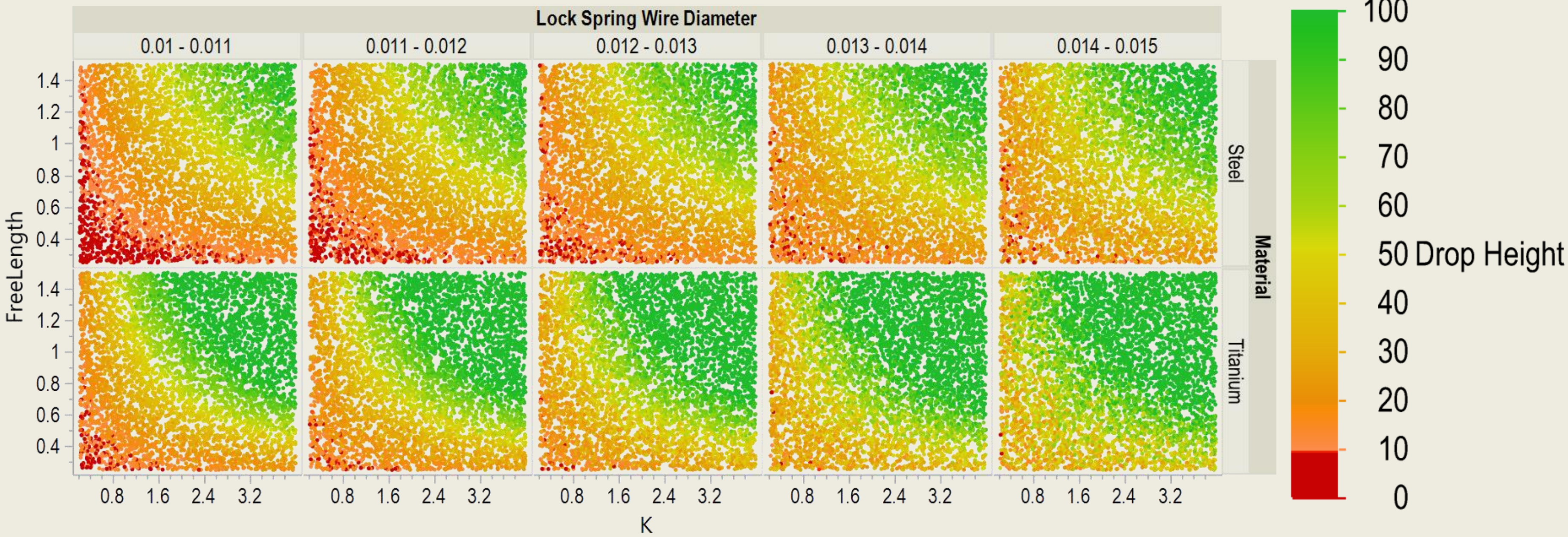
- Starting Point: 146 runs from original design with spring constants less than 4
- Augmentation: 100 additional space filling design points



Results: Drop Safety

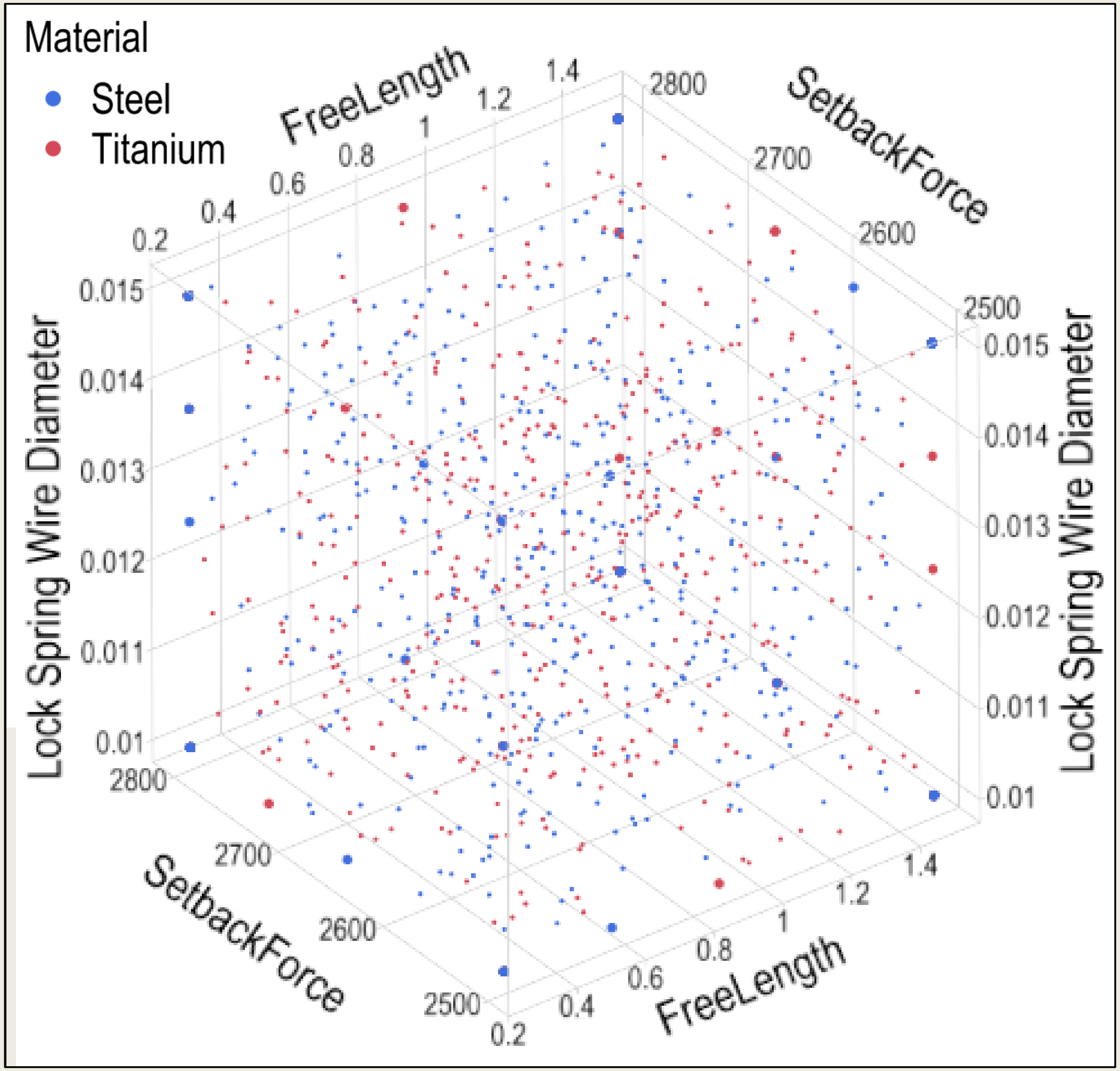
- Gaussian process model fit to the data
- Relative influence of each factor on the response (right)
- Drop height response based on important variables; red regions indicate safe drop height < 10 ft (below)





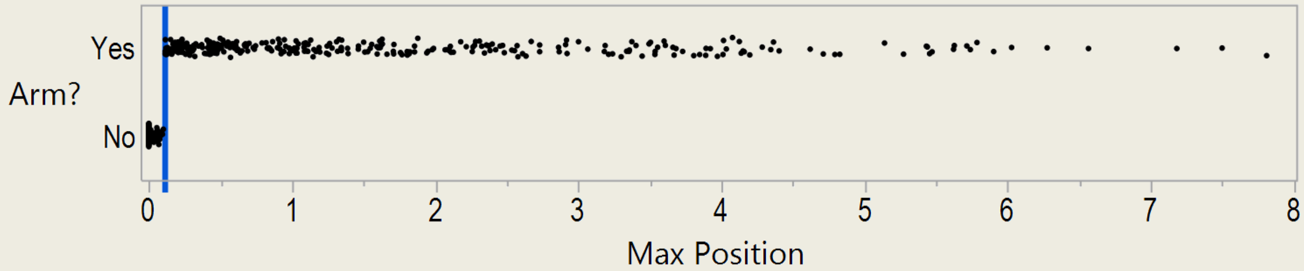
Final Design: Setback Reliability

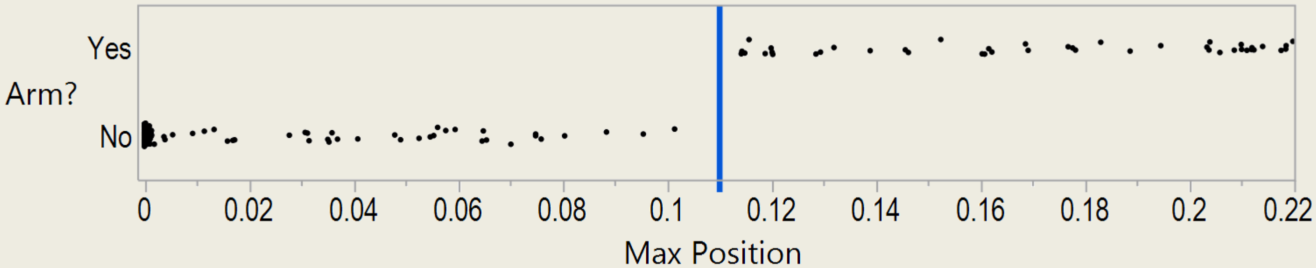
- Starting Point: 507 runs from original design with spring constants less than 4
- Augmentation: 400 space filling runs and 100 I-optimal runs (assuming a 3rd order model)



Results: Setback Reliability

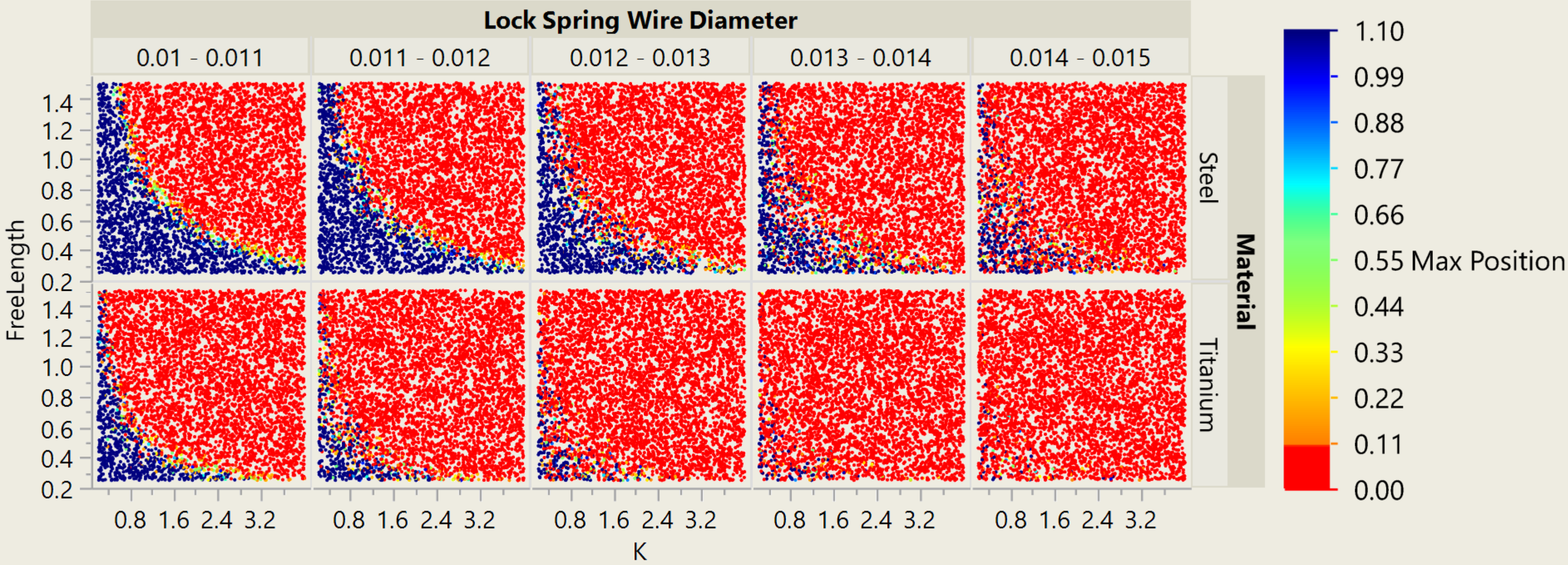
- Max Position raw data shown below
- Some issues with the data:
  - About half the runs had max positions equal to 0
  - Decent amount of results with max position much higher than the 0.11 arm requirement that we care about
- Tried Gaussian process model, logistic regression model, and other generalized regression techniques
- Final, best fitting model used generalized regression with data censoring and elastic adaptive net penalized regression assuming a lognormal distribution





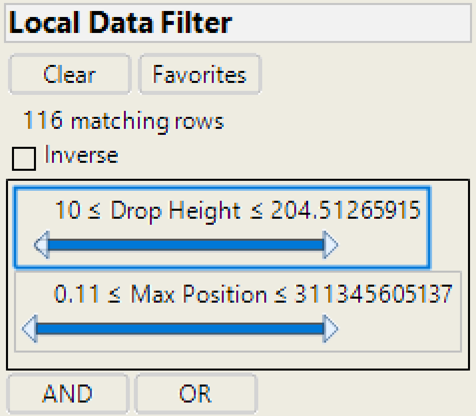
Results: Setback Reliability

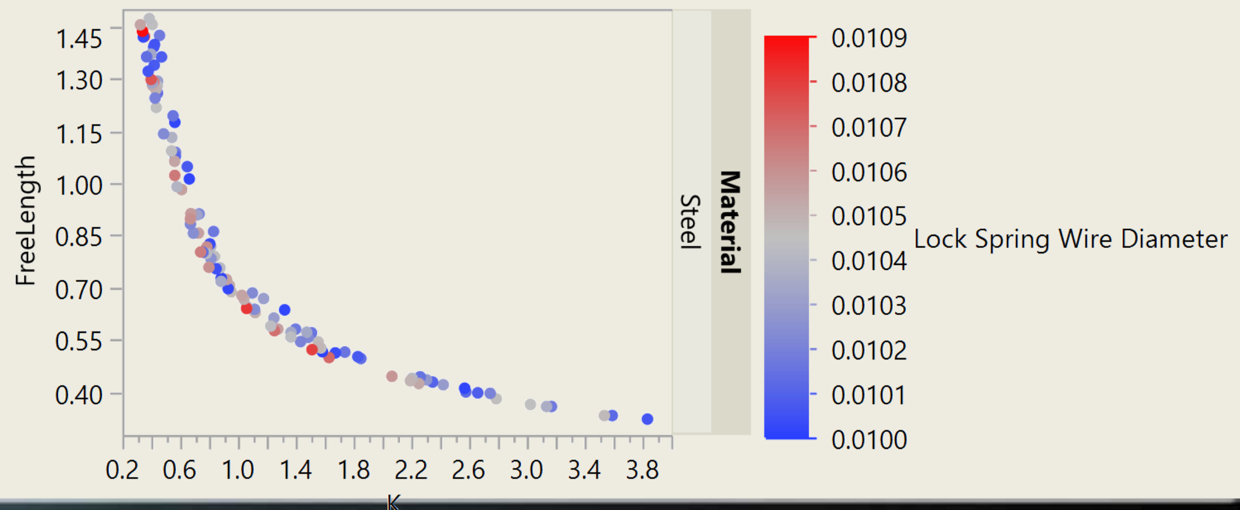
- Max Position as a function of all design variables
- Red shows positions less than 0.11 which correspond to a no arm



Optimization

- Goal at this point was to pick several optimized designs that we can manufacture and test
- Used random sampling of the design space and data filtering to narrow down to high reliability and high safety designs
- Set noise variables at worst case scenarios
  - High friction during setback
  - Low friction during launch
  - Low setback accelerations
- 8 Candidate designs picked from reduced data set using DOE





Path Forward

- Currently, the 8 candidate designs are being manufactured
- Plan to conduct adaptive sensitivity (go/no-go) testing on the designs
  - Stimulus: Acceleration
  - Output: Arm or No Arm
- Test data will be used to calibrate the model
  - Find any bias
  - Better estimate for the friction
- Calibrated model will be used to pick a final design and make reliability and safety predictions of that design to feed the reliability predictions of the full artillery round