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Malcolm Baldrige National Quality Award 2007 Award Recipient

A Study to Reduce the Arm Time Variation in the M549A1 and M550 Escapements

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Background

- **Issue:**
  - Current 40mm fuze production sees a wide range of arm times that lead to safety and reliability concerns
  - During testing, there are several arm time criticals at the escapement level for minimum arm time.
- **Goal:**
  - Reduce the arm time variability by tightening tolerances of dimensions that have the most effect on arm time
- **Solution:**
  - Build up finite element models (FEM) to conduct a critical characteristic analysis
  - Make use of a design of experiments (DOE) for deterministic models to limit the amount of FEM analyses required to get meaningful results

Overview

Brainstorming Session

- Narrowed entire escapement design down to 19 variables that were expected to impact arm time
- Decided on a minimum and maximum value to test for each variable

Design of Experiments

- Developed a computer experiment with 40 test cases
- Space filling design: tested each variable at 40 different levels between the minimum and maximum

Finite Element Analysis

- Analyzed the 40 cases of given input variables
- Output the resultant arm time of escapement for each case

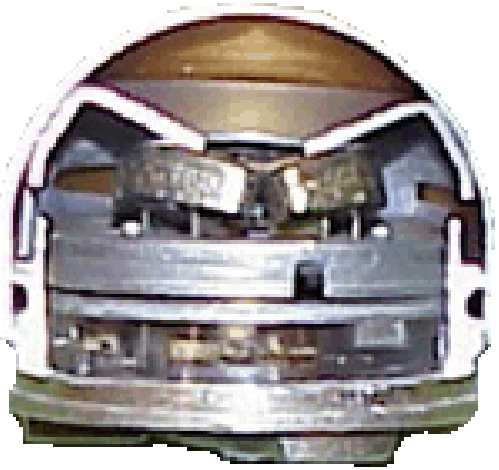
Statistical Analysis

- Used input variables and resultant arm times from FEA analysis to develop a statistical model
- Determined which variables had the greatest effect on arm time
- Statistical model can be used to quickly predict the effect of modifying input variables

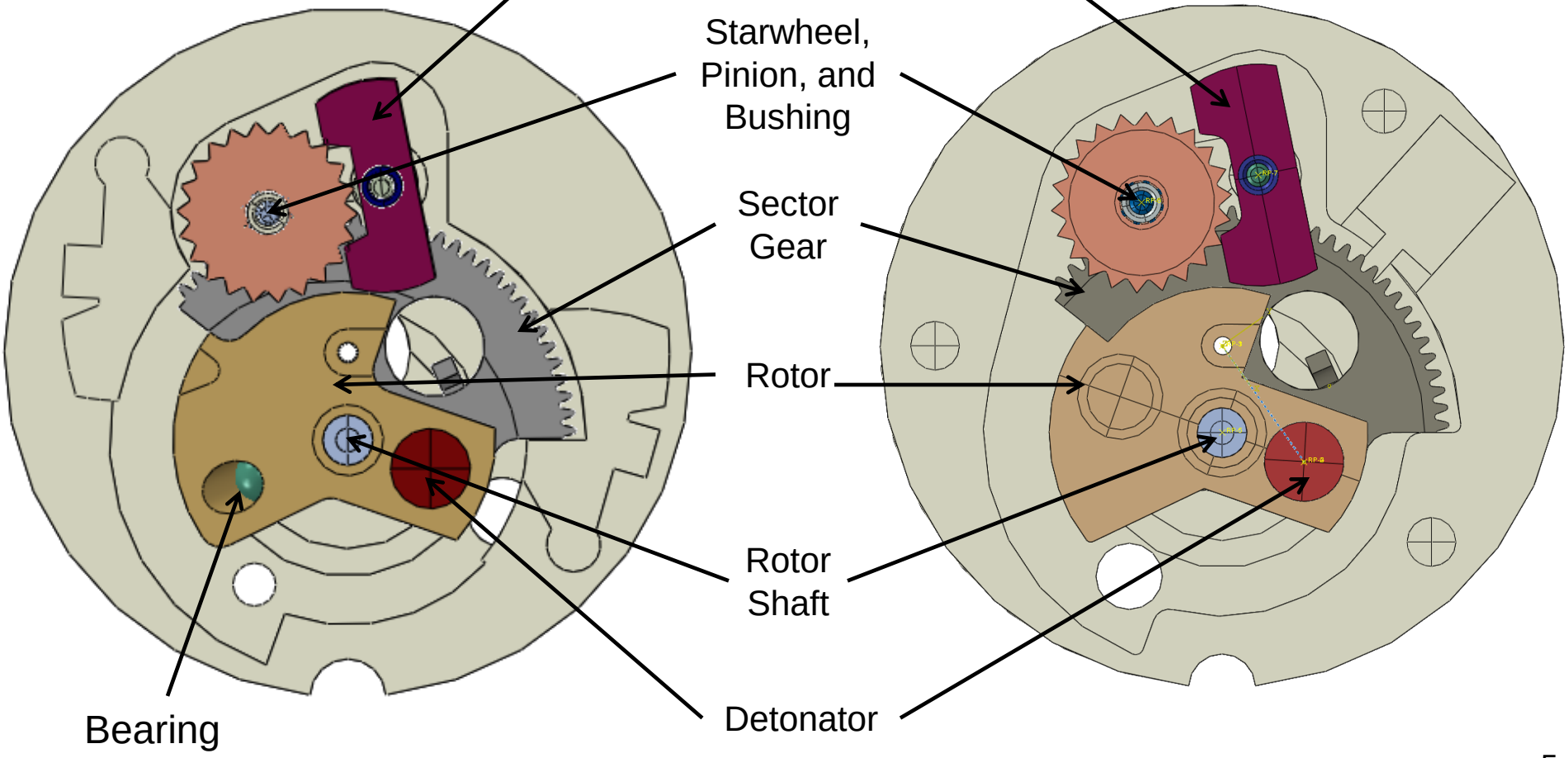
40mm Munitions

High Velocity M430A1 with M549A1 Fuze

Low Velocity M433 with M550 Fuze



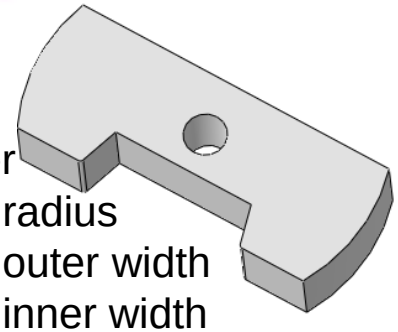
Escapement Models



Variables Investigated

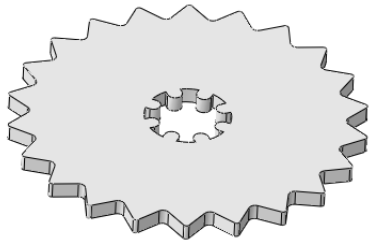
19 Variables

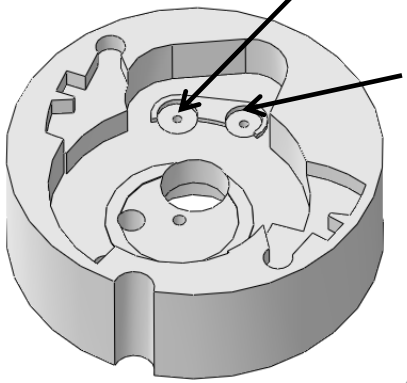
- Verge (5)
- Starwheel (5)
- Part/assembly interactions (3)
- Misalignment between house and cover (4)
- Rotor and detonator mass range (2- not shown)

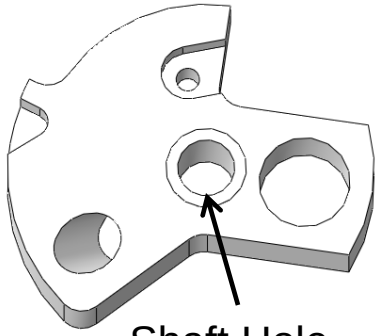


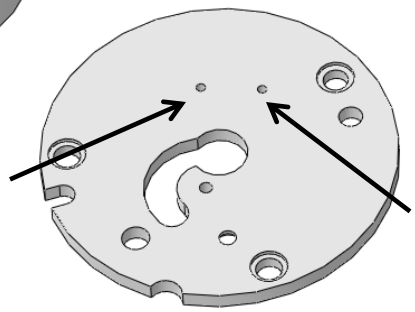
•Diameter
•Contact radius
•Contact outer width
•Contact inner width
•Opening width

•Diameter
•Thickness
•Tooth gap
•Tooth angle
•Tooth radius









Variables Investigated

Variables (units)
Verge Diameter (in)
Verge Opening Width (in)
Verge Contact Radius (in)
Verge Contact Width (in)
Verge Contact Inside Width (in)
Starwheel Diameter (in) *
Starwheel Thickness (in)
Starwheel Tooth Gap (in)
Starwheel Tooth Angle (°)
Starwheel Tooth Radius (in)
Verge/Starwheel Distance (in) *
Pinion/Rotor Distance (in)
Rotor/Rotor Shaft Interaction (in)
Rotor Density (g/cc)
M55 Detonator Mass (grams)
Housing and Top Plate Alignment, Verge, X (in) *
Housing and Top Plate Alignment, Verge, Y (in) *
Housing and Top Plate Alignment, Pinion, X (in) *
Housing and Top Plate Alignment, Pinion, Y (in) *

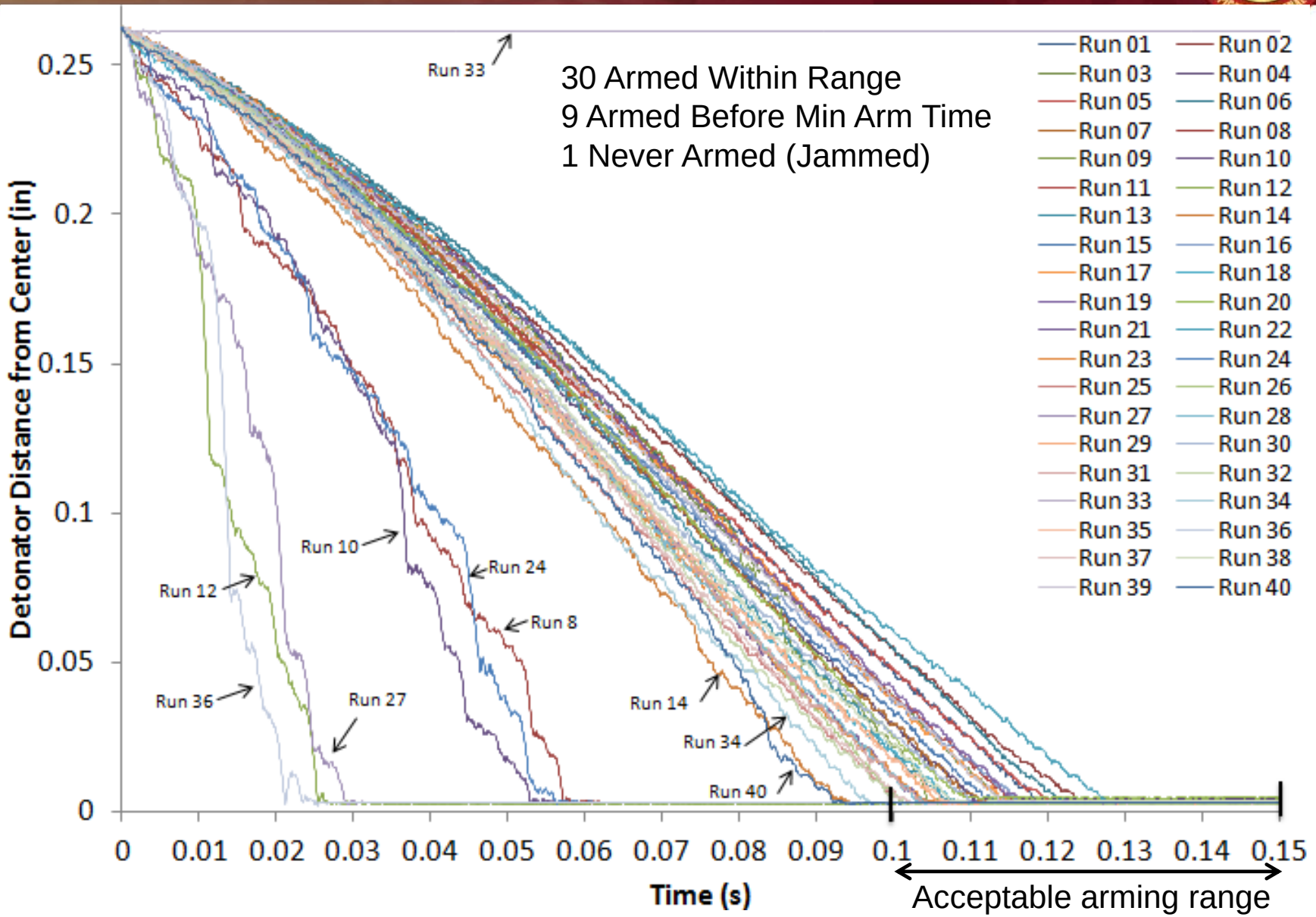
Analysis Set Up

- Model simulates the spin arming test of the M549A1 and M550 escapements
- Spin test ramp-up time not included in model
  - Assumes spin locks/detent have already retracted (therefore, no need to include in model)
  - Entire model given an initial angular velocity of 12,000/3,750 rpm (M549A1 & M550 respectively)
- General frictionless contact applied between all parts
- Angular velocity Boundary Condition of 12,000/3,750 rpm max applied to Escapement Housing and model allowed to run out 150/350 ms

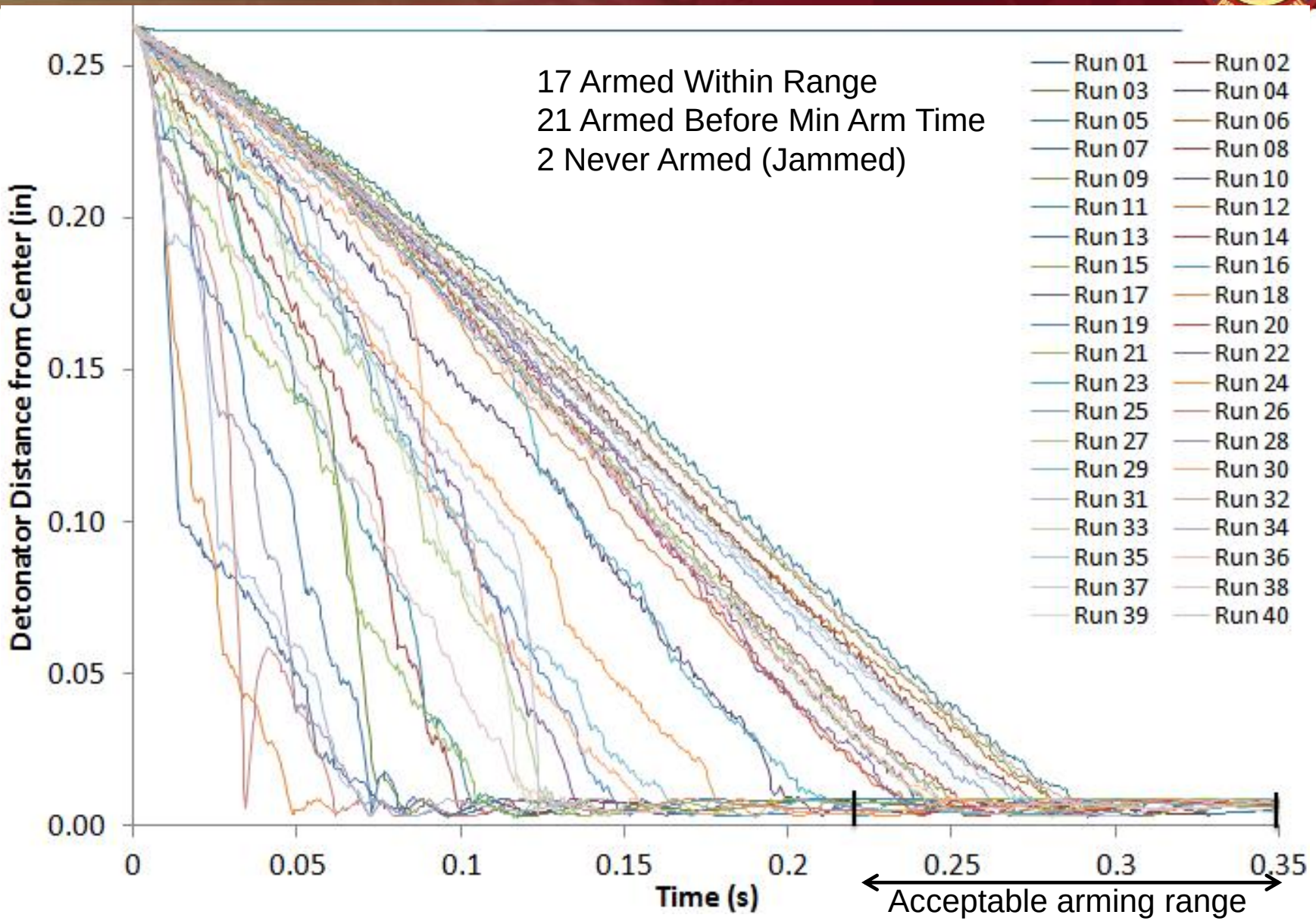
Analysis Set Up

- A few models were run allowing for deformation
  - Represents most accurate model results
    - Contractor dimensioned models within 3% of average arm time from previous test data
  - Each analysis took 1-2 weeks to run
- The same models were run again with only rigid body dynamics accounted for.
  - Each analysis took 1-2 days to run
- Model results were then compared
  - M549A1
    - Some plastic damage in starwheel teeth in deformable model not accounted for in rigid body model
    - Rigid models armed up to 5% slower than deformable models
  - M550
    - No plasticity observed in deformable model
    - Rigid models armed up to 5% faster than deformable models

Results- M549A1

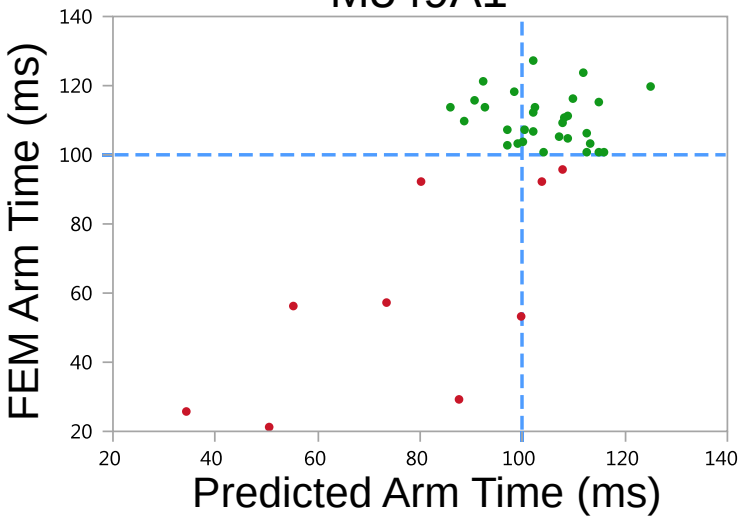


Results- M550



Statistical Model Results

M549A1



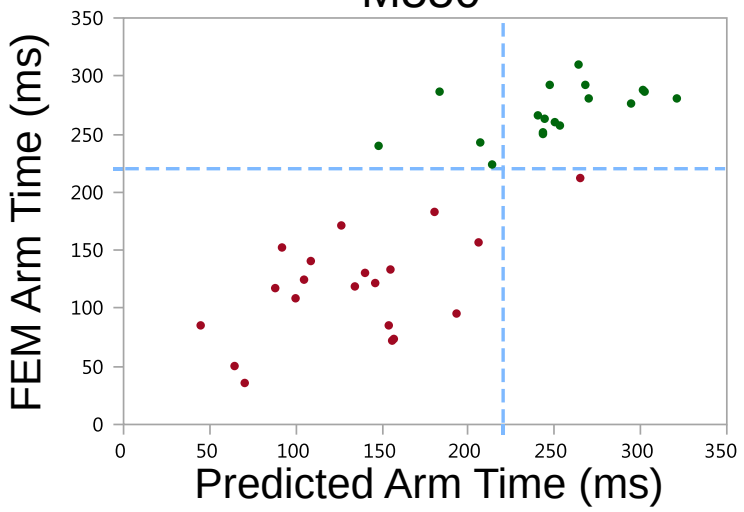
Predictor variables for this statistical model:

- Starwheel Diameter
- Starwheel Overall thickness
- Starwheel Tooth Angle
- Rotor Density
- Top Plate Alignment (Verge Holes) X Axis

Predictor variables for other statistical models:

- Verge/Starwheel Distance
- Top Plate Alignment (Pinion Holes) X Axis
- Starwheel Tooth Radius

M550



Predictor variables for this statistical model:

- Starwheel Diameter
- Verge Contact Width
- Starwheel Tooth Gap
- Verge/Starwheel Distance
- Mass of M55 Detonator
- Top Plate Alignment (Verge Holes) X Axis
- Top Plate Alignment (Pinion Holes) X Axis

Predictor variables for other statistical models:

- Top Plate Alignment (Verge Holes) Y Axis
- Top Plate Alignment (Pinion Holes) Y Axis

Conclusions

- The DOE and full statistical analysis concluded with similar results for arm time of both M549A1 and M550 fuzes.
- All the factors for arm time variation were rooted from the interaction between the Verge and Starwheel.
- 40mm Fuze arming time is affected by changes in component tolerances. The modeling and analysis completed for the reliability study determined the following factors as the driving forces for arm time variation:
  - Verge Hole Alignment of Top Plate with Escapement Housing
  - Pinion Hole Alignment of Top Plate with Escapement Housing
  - Starwheel Diameter
  - Starwheel Tooth Angle
  - Verge and Starwheel Distance

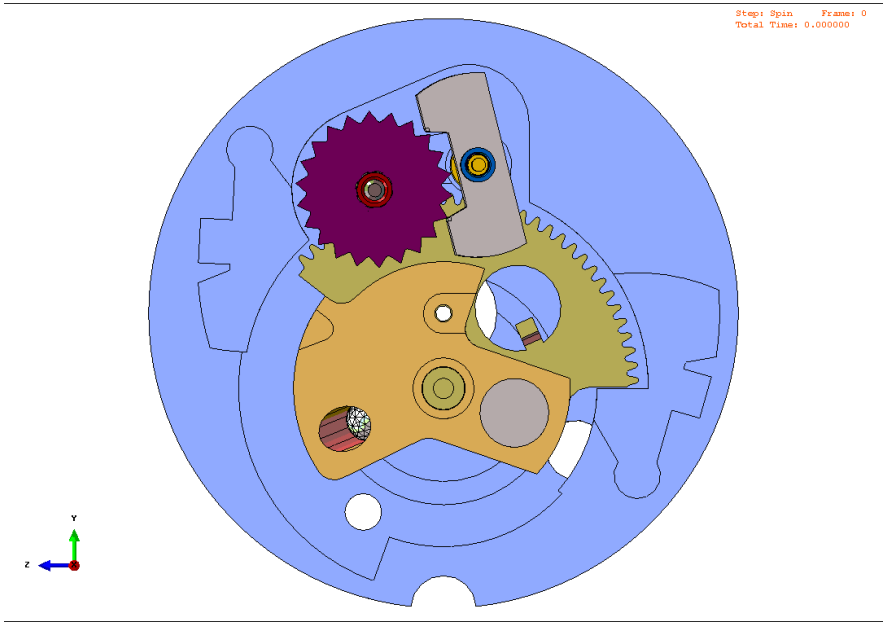
Backup Slides

Plans

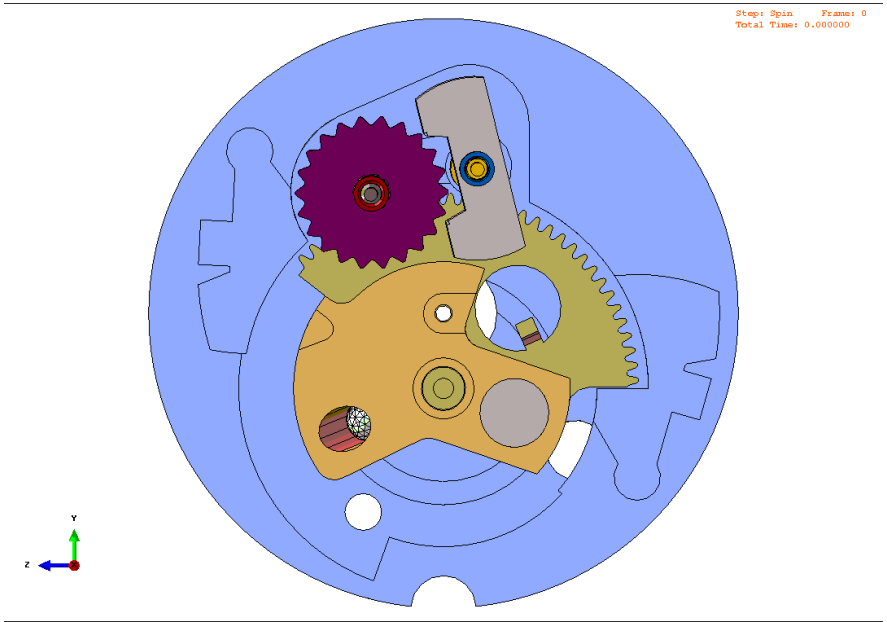
- Perform arm time testing on escapement models to validate results.
- Run a similar analysis on the centerplate assembly in each model to determine how sensitive its reliability is to its dimensions

Results- M549A1

Conforming Arm Time

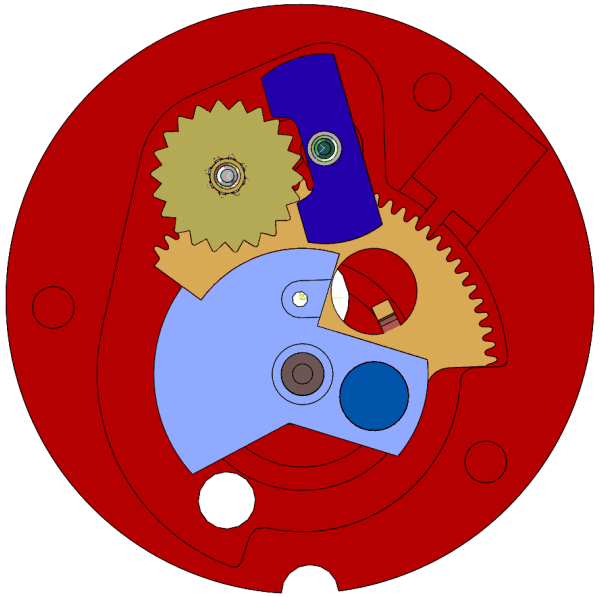


Zip Arm



Results- M550

Conforming Arm Time



Zip Arm