U.S. Army Research, Development and Engineering Command

Malcolm Baldrige National Quality Award 2007 Award Recipient

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Benefits of an Active Recoil Control System

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Agenda

- Recoil of Large Caliber Weapons
- Active Recoil
- Active Recoil applied to Soft recoil
- ADIM: A Case Study
- Conclusion

Introduction to Recoil of Large Caliber Weapons

- Recoil systems are designed to dissipate a short duration firing impulse over a greater time and distance
- Distributing the firing load reduces the impulse imparted to the supporting structure

- Traditional recoil systems are optimized for the maximum weapon impulse
- Limited compensation is possible at the cost of added complexity (i.e. elevation compensation)
- Most variables leading to atypical firing impulses are unaccounted for, including:
  - Propellant temperature
  - Munition lot variations
  - Lesser charge/increment fires
  - Hydraulic fluid properties (viscosity)
  - Manufacturing tolerances of the recoil mechanisms

- This results in underutilization of the available recoil stroke for most fires

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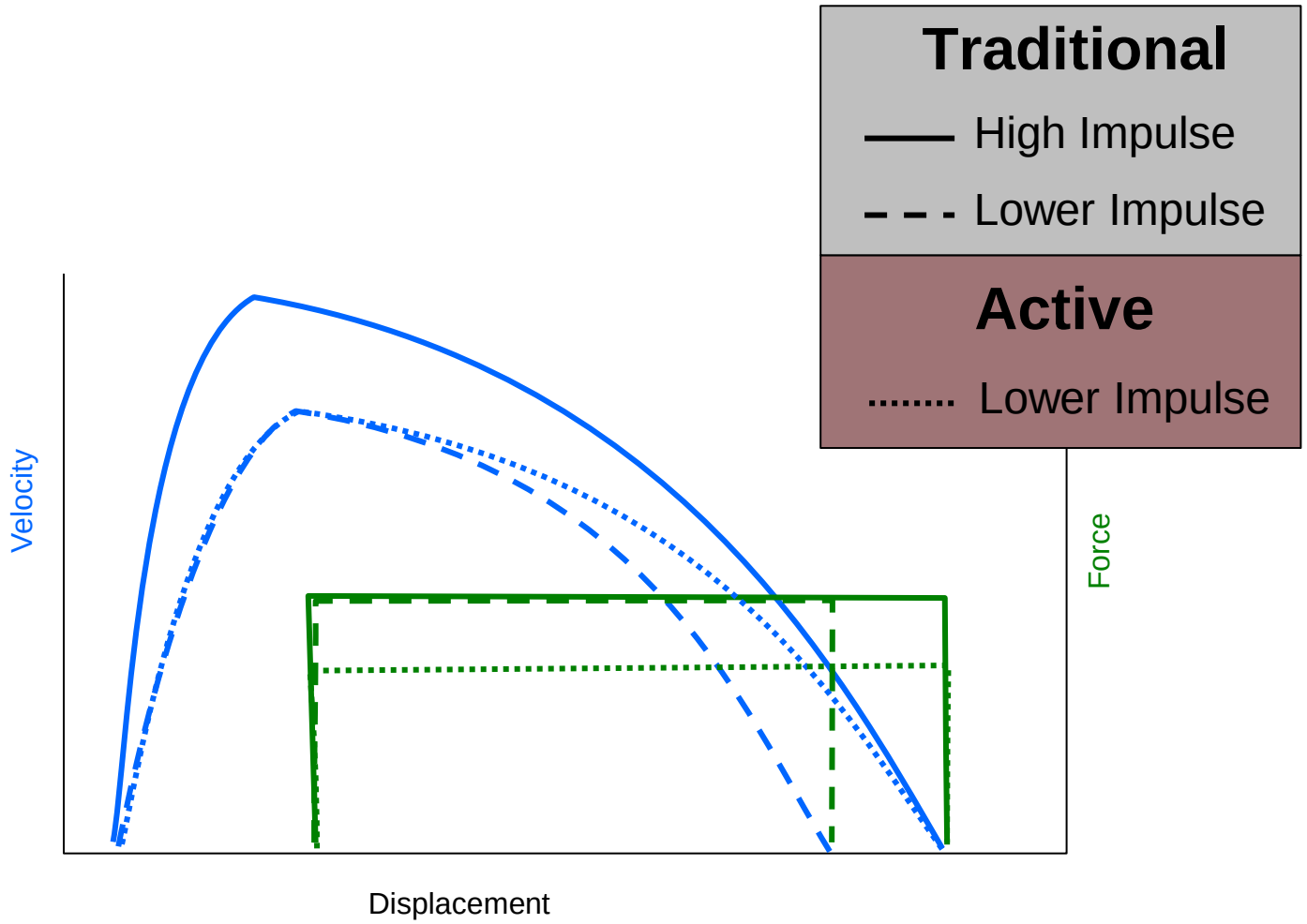
What is Active Recoil?

- Active recoil uses feedback from sensors to control the recoil system in real time
- By controlling the recoil forces the available recoil length can be fully utilized resulting in reduced impulses transmitted to the support structure
- At reduced charges/increments the optimization is more dramatic



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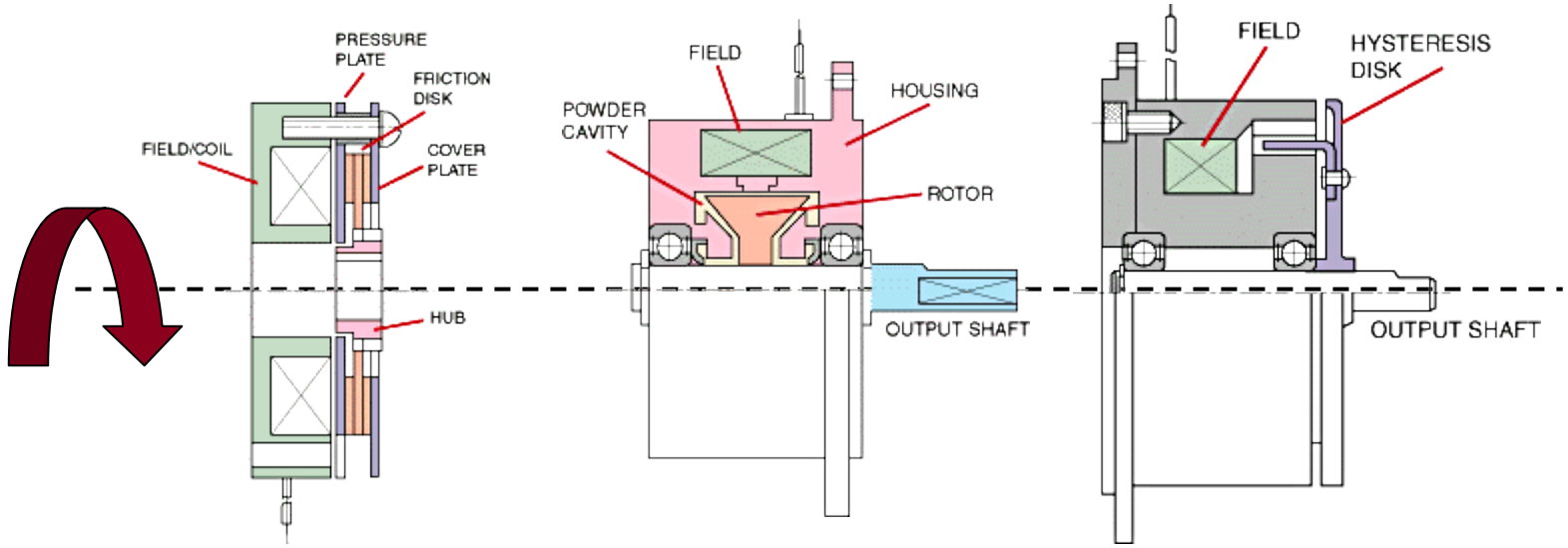
Possible Active Recoil Technologies

1. Variable Viscosity Fluid
   - Magnetorheological
   - Electrorheological
2. Variable Orifice Valve
3. Electric Motor
4. Mechanical Brake
   - Eddy Current
   - Friction Disc
   - Hysteresis
   - Magnetic Particle

Should Fail Safe!



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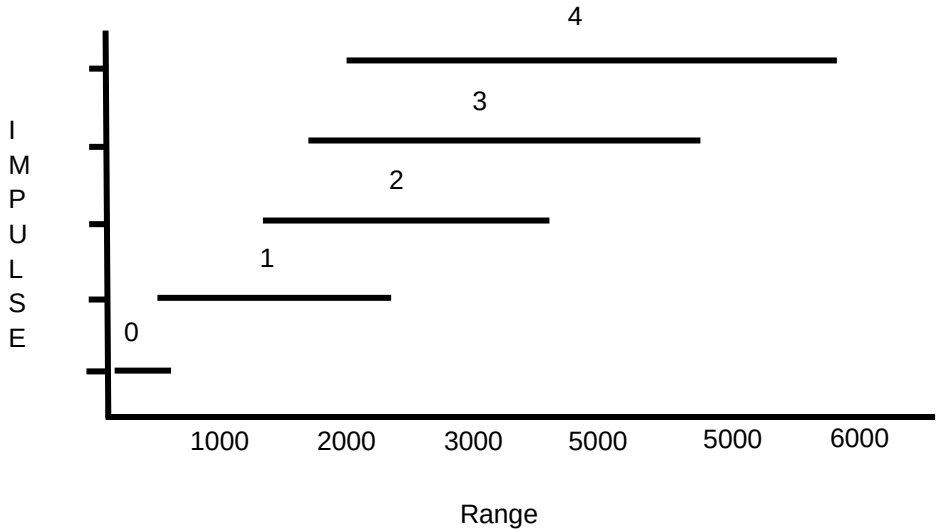
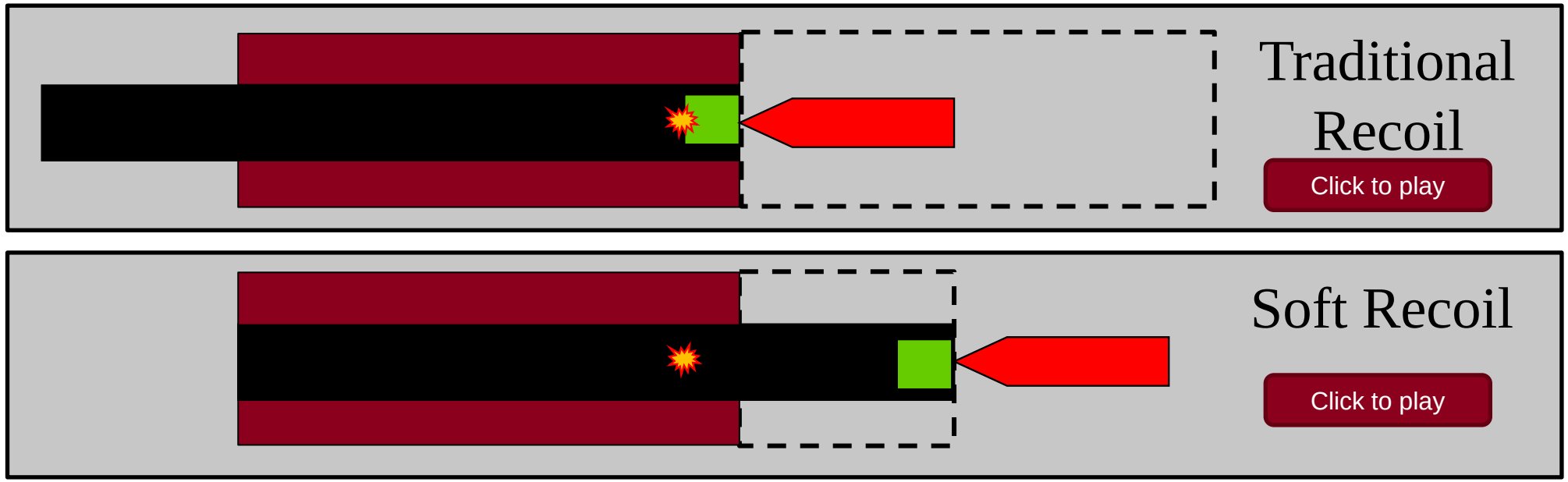
Where does active recoil make sense?

- Active Recoil Applied to Traditional Recoil
  - Potential Benefits
    - Utilize the entire recoil stroke for all charges/increments
    - Perform elevation compensation with active recoil device
    - Simplify recoil buffer
    - Loosen manufacturing tolerances
    - Perform diagnostics/prognostics on recoil components
    - Increase fatigue life of structure
  - Drawbacks
    - Does not improve force curve for max firing impulse
    - Support structure must still be designed to handle max firing load
    - Requires power
  - Conclusion
    - Historically, the sensors and processing hardware required to implement active recoil produced marginal benefits for the cost
    - Given modern technologies, it may make sense to revisit active recoil



What About Soft Recoil?

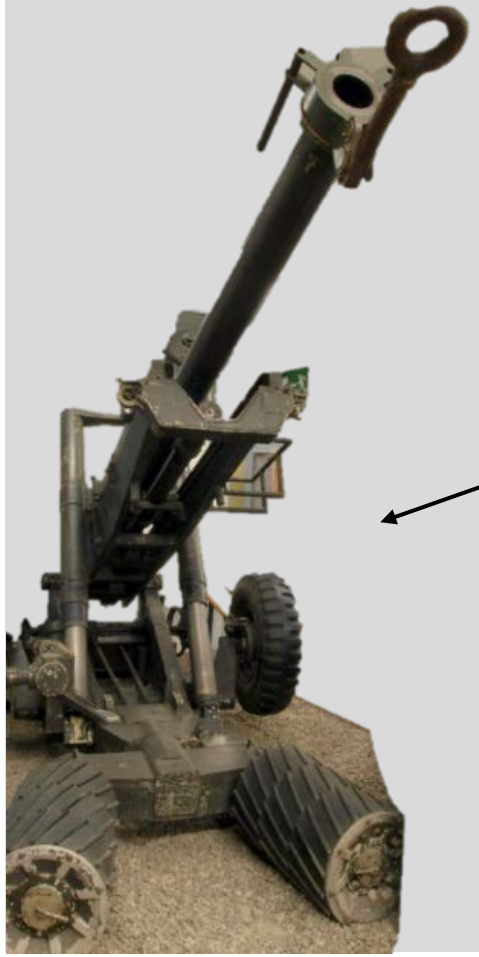
Traditional vs. Soft Recoil



- Benefits
  - For similar recoil masses, initial recoil velocity in traditional recoil is ~twice that of soft recoil.
  - Recoil stroke can be shortened **or** recoil force can be reduced.

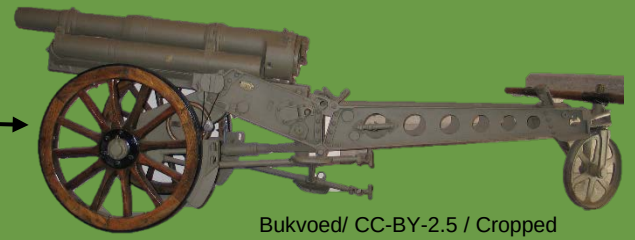
Employment of Soft Recoil in Modern Weapons

Experimental



Fielded

1906 — Mountain Gun, 65mm Howitzer, France



Bukvoed/ CC-BY-2.5 / Cropped

1966 — MK-19, 40mm Grenade Launcher, US NAVY

1970 — 2B9 Vasilek, 82mm Mortar, USSR

1975 — XM204, 105mm Howitzer, US ARMY

1997 — ATLAS, 105mm Howitzer, US ARMY

2011 — Hawkeye, 105mm Howitzer, Mandus Group RIA

Deutscher Friedensstifter / CC-BY-2.0 / Cropped

2013 — ADIM, 81mm Mortar, US ARMY

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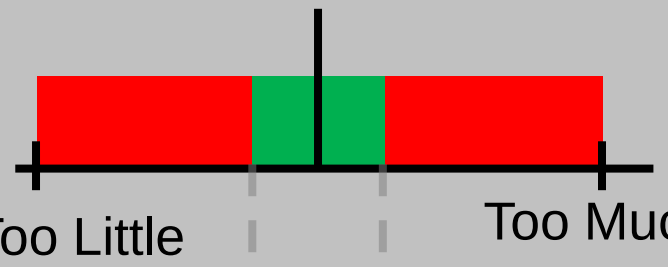
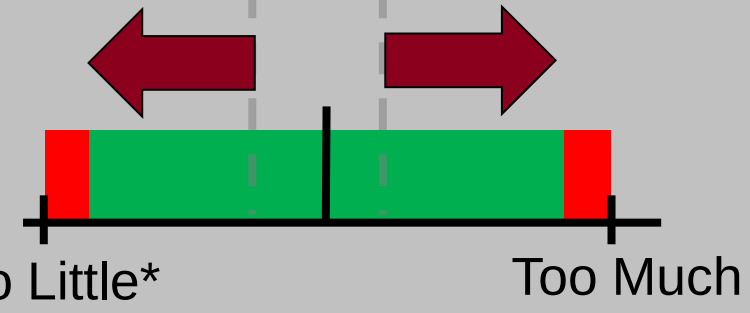
Soft Recoil Challenges Solved with Active Recoil

	Ignition Timing	Impulse
Soft Recoil		
Soft Recoil w/ **Active Recoil**		

*Must know prior to firing

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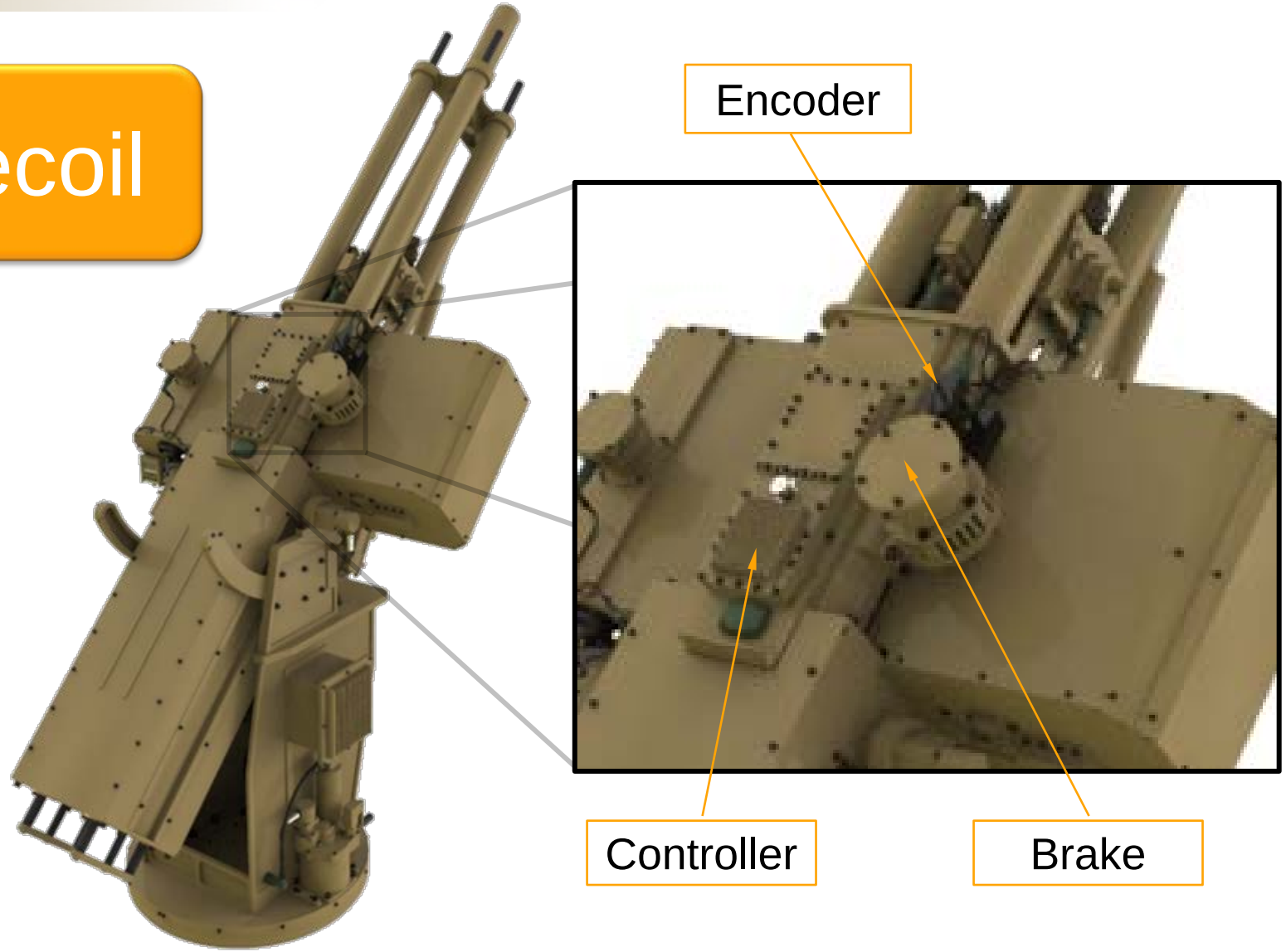
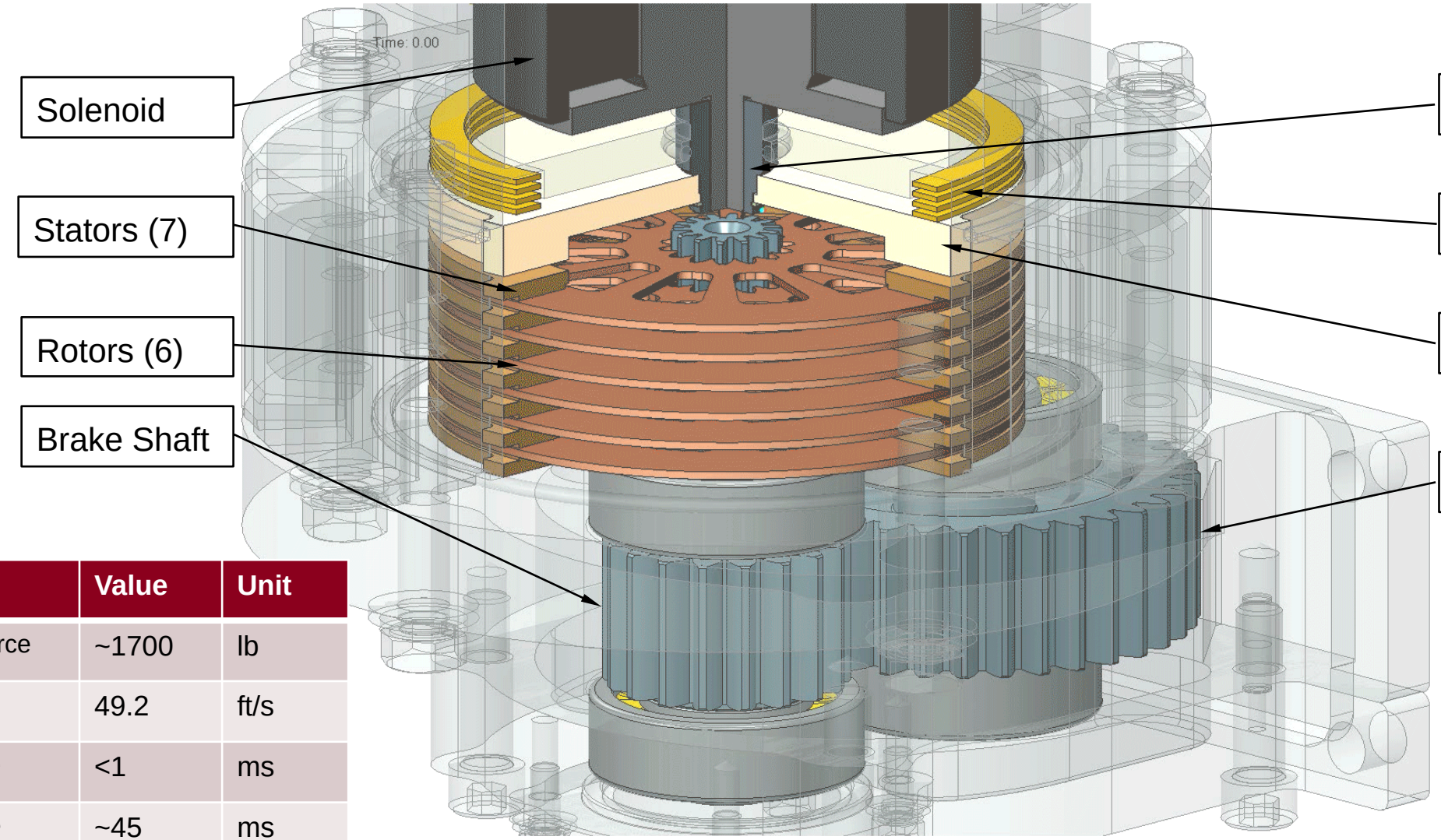
Active + Soft Recoil

Parameter	Value	Unit
Ammunition Caliber	81	mm
Ammo Capacity	20	rounds
Range	300-6300	m
Traverse	360 cont.	degrees
Elevation	-3 to 85	degrees
Weight	~2300	lbs
Recoil Force	<10,000	lbf
Recoil Force (w/ Active Recoil)	<2,000	lbf

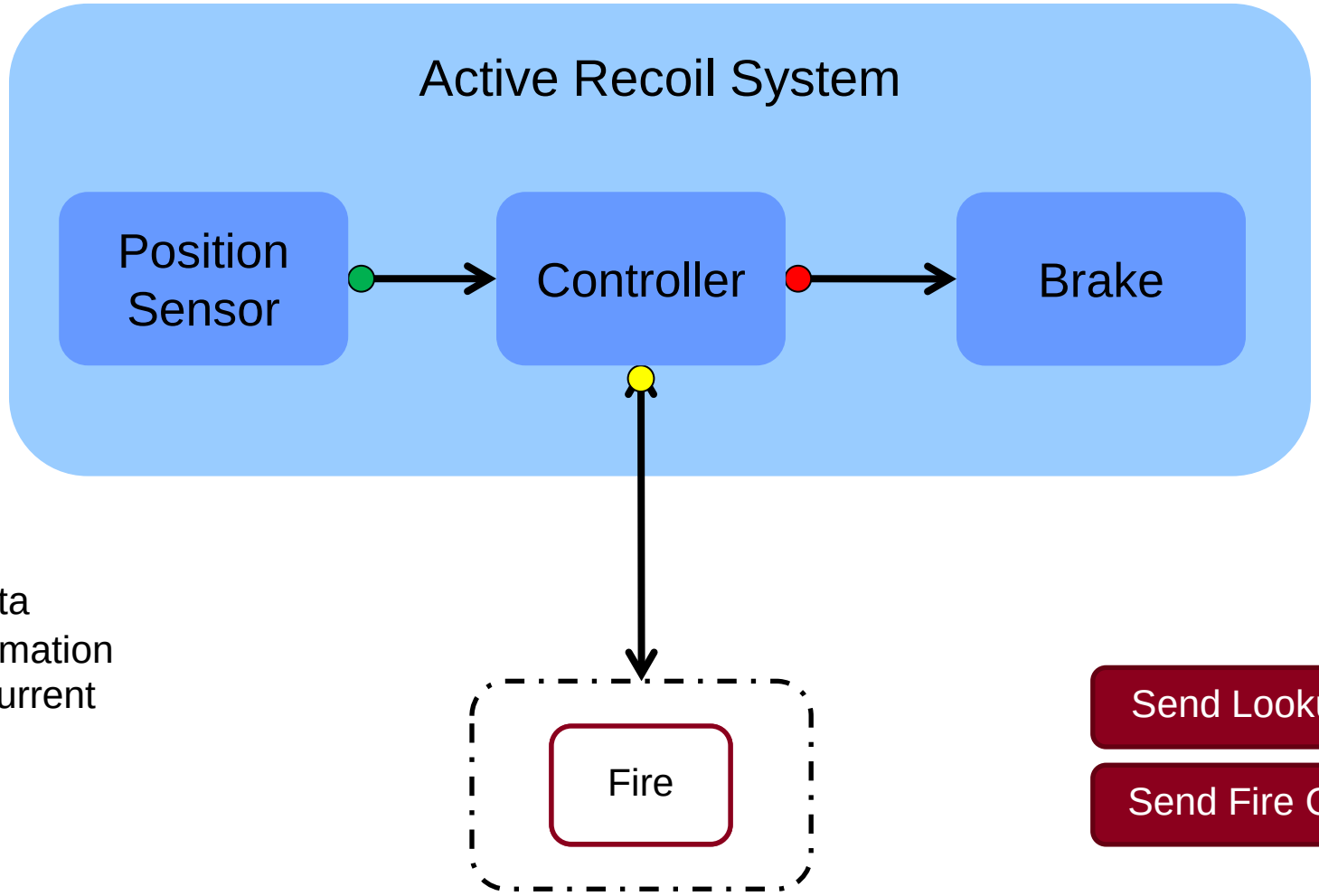


ADIM Active Recoil Brake

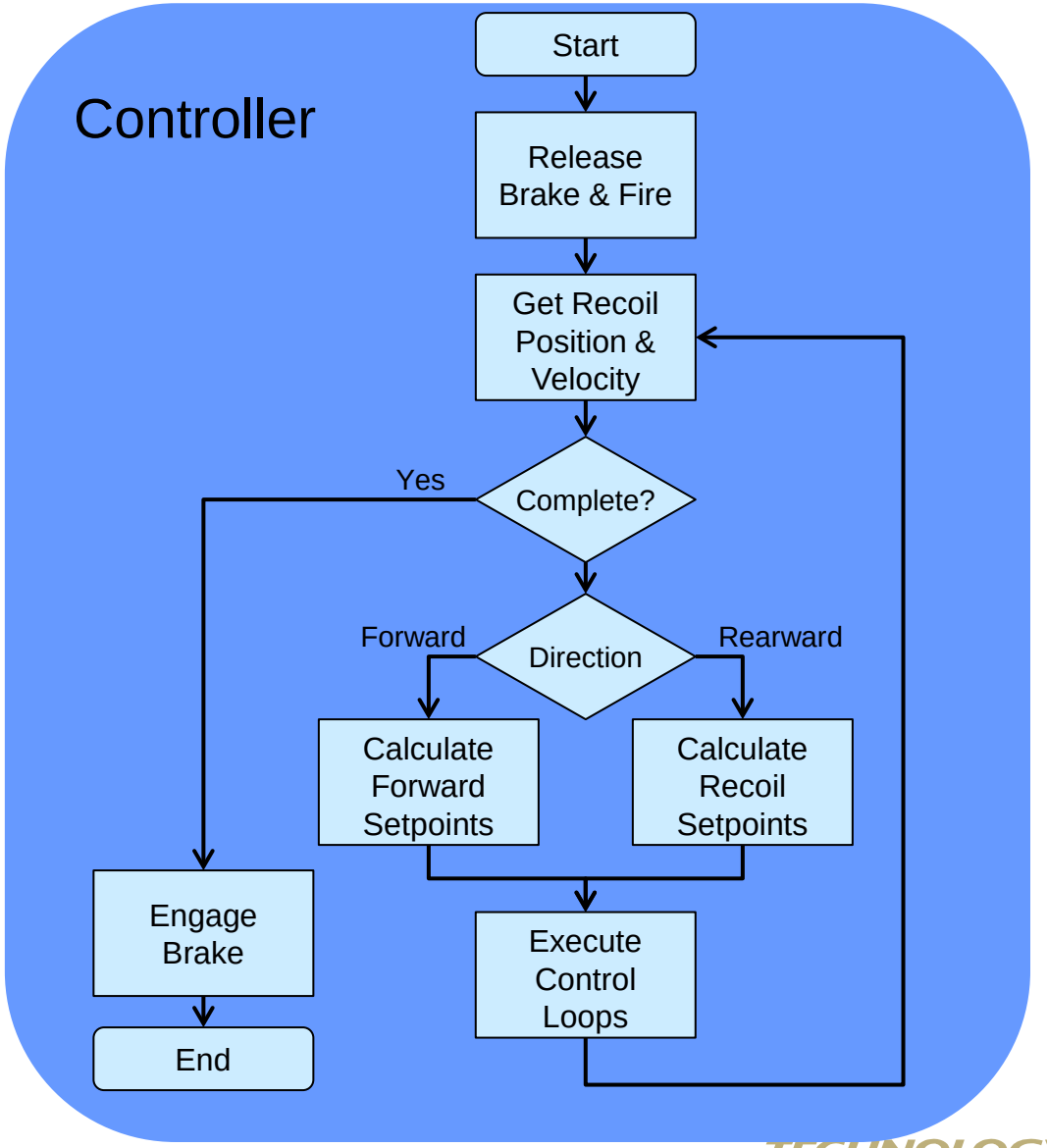


Parameter	Value	Unit
Max braking force	~1700	lb
Max Velocity	49.2	ft/s
Brake On Time	<1	ms
Brake Off Time	~45	ms
Release Current	~10	A

ADIM Active Recoil Control Overview



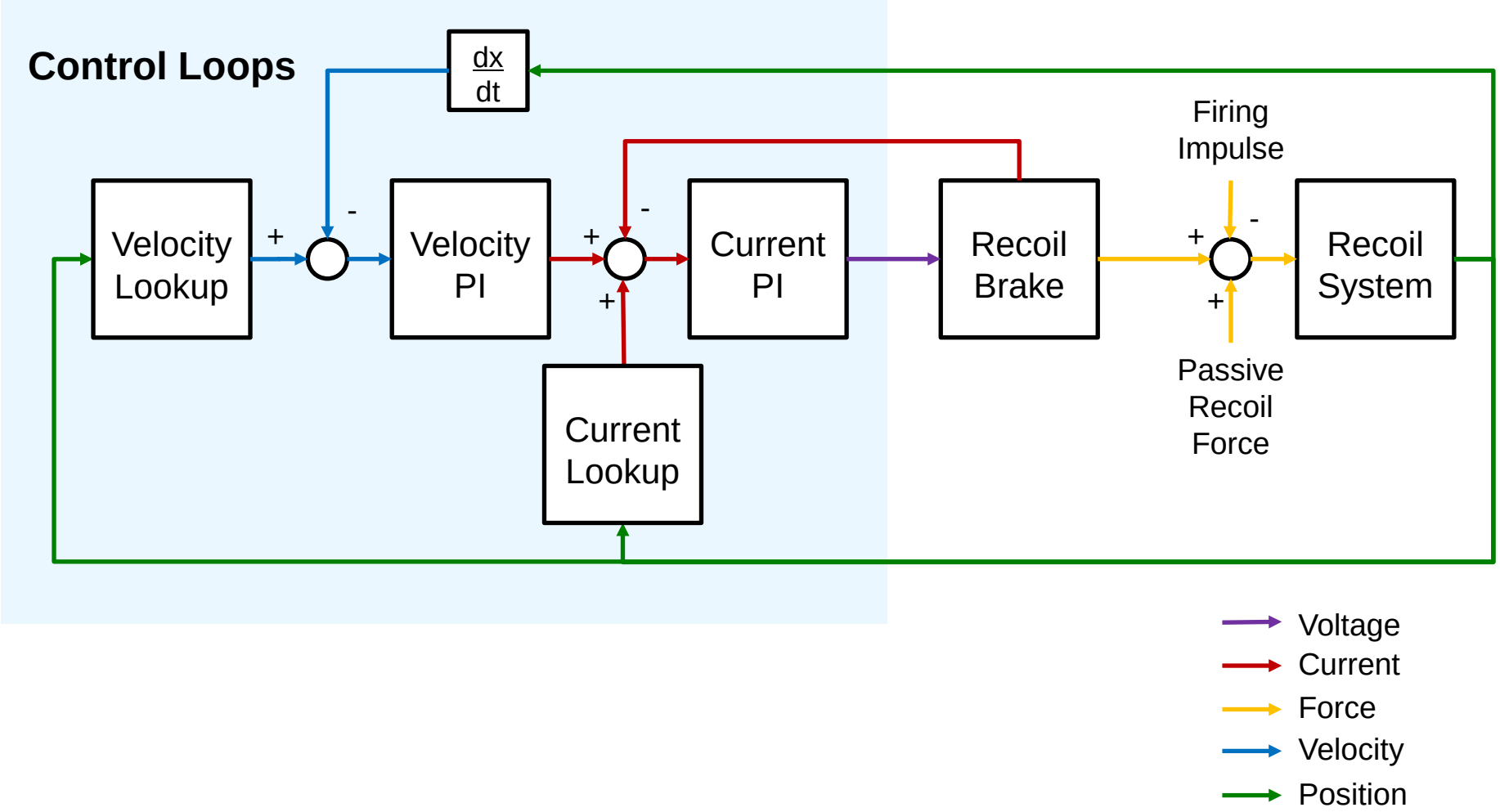
ADIM Active Recoil Control Flowchart



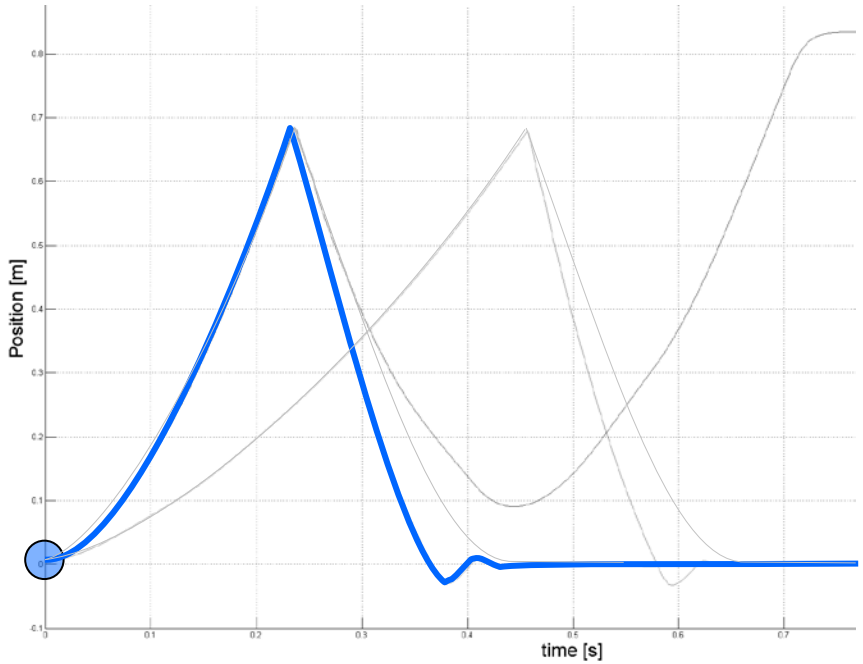
ADIM Active Recoil Control Loop

Control System Variables

- Controlled Variables
  - Solenoid Current
  - Recoil velocity
- Disturbance Variables
  - Firing Impulse
  - Passive Recoil Force
- Manipulated Variables
  - Solenoid current

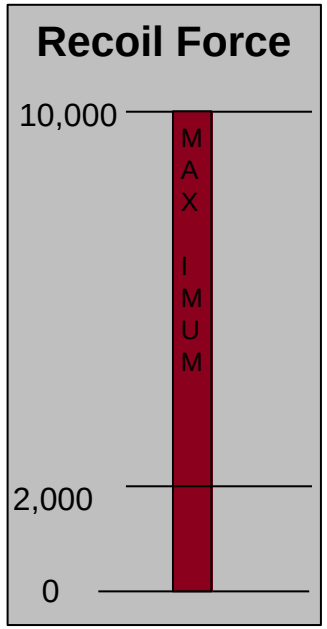


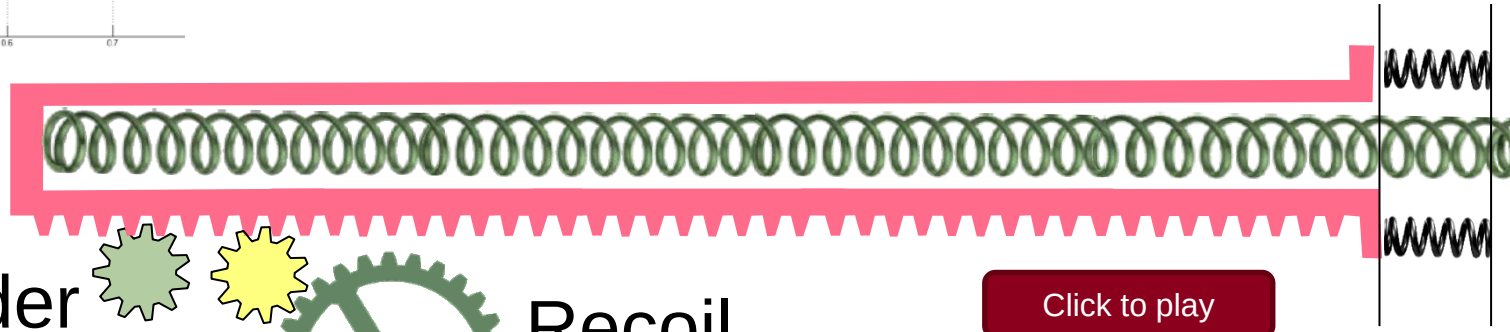
ADIM's employment of Soft Recoil combined with Active Recoil



Charge 4

No Braking





Click to play

Encoder

Recoil Brake

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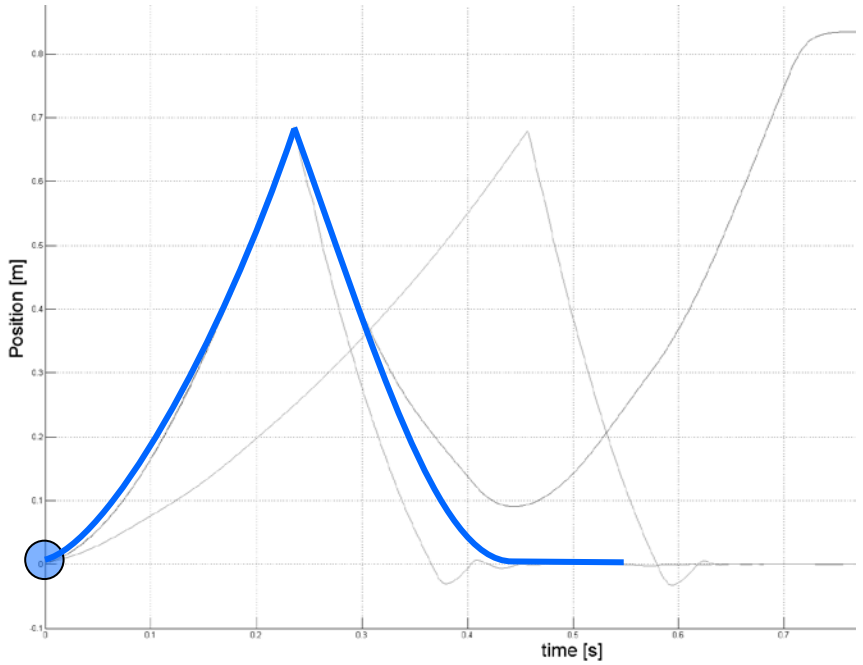
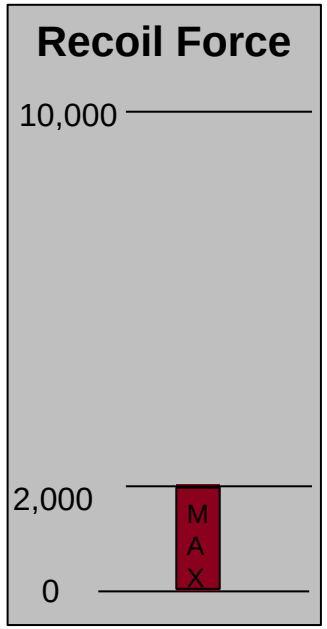
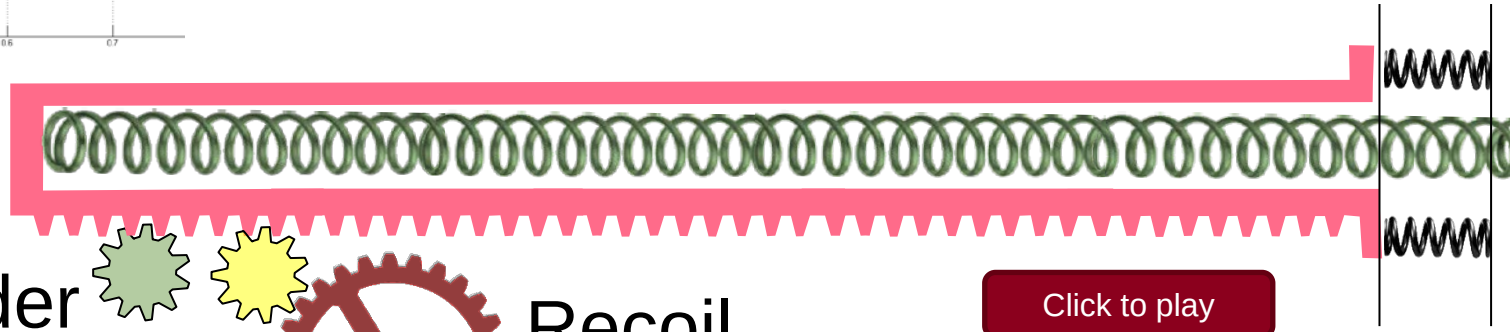
ADIM's employment of Soft Recoil combined with Active Recoil



Charge 4

Braking on recoil stroke





Encoder

Recoil Brake

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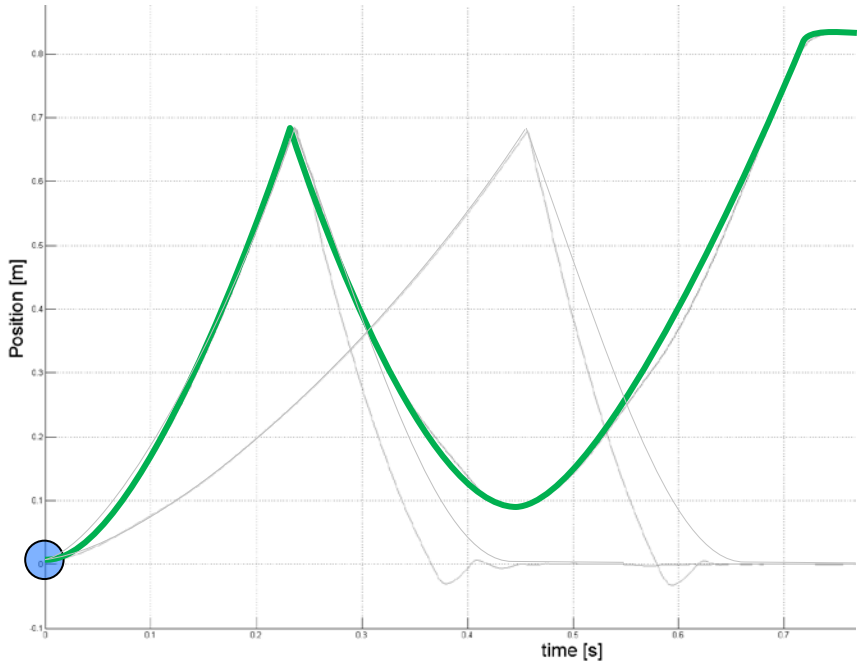
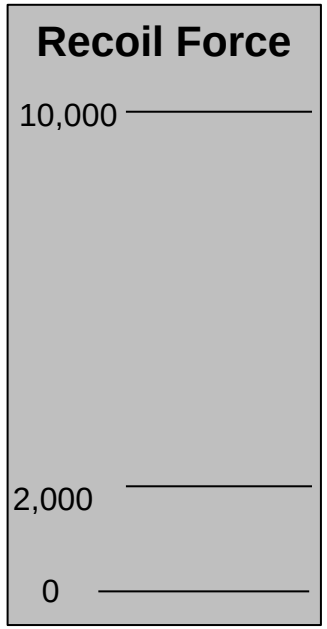
ADIM's employment of Soft Recoil combined with Active Recoil



Charge 3

No Braking



Encoder

Recoil Brake

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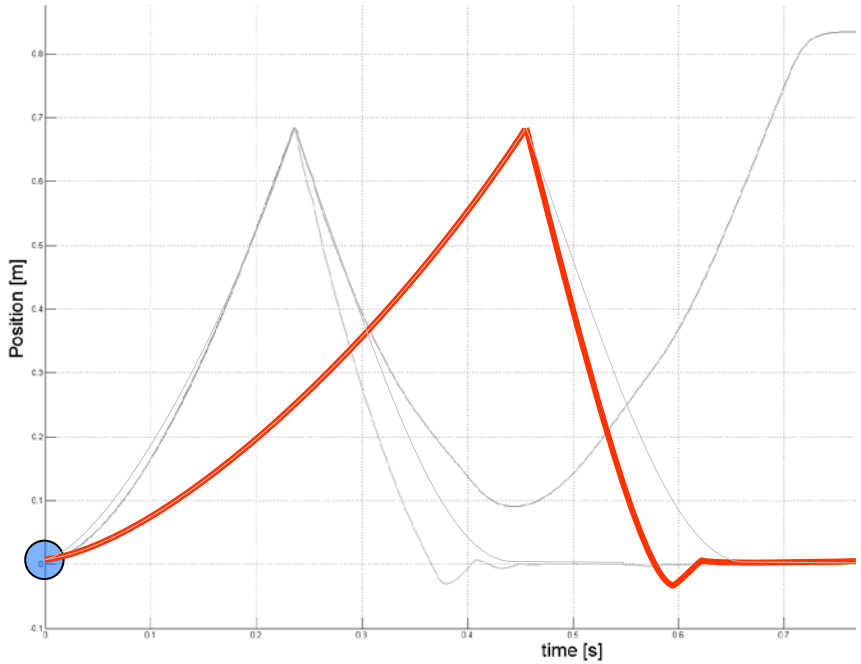
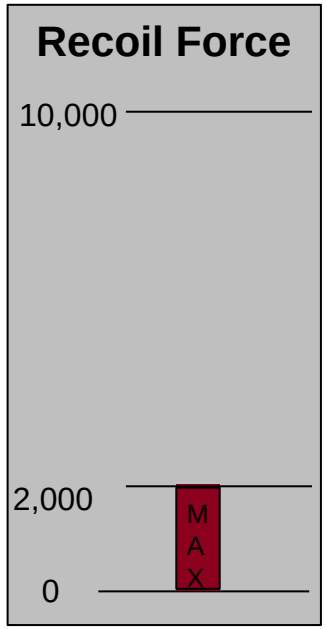
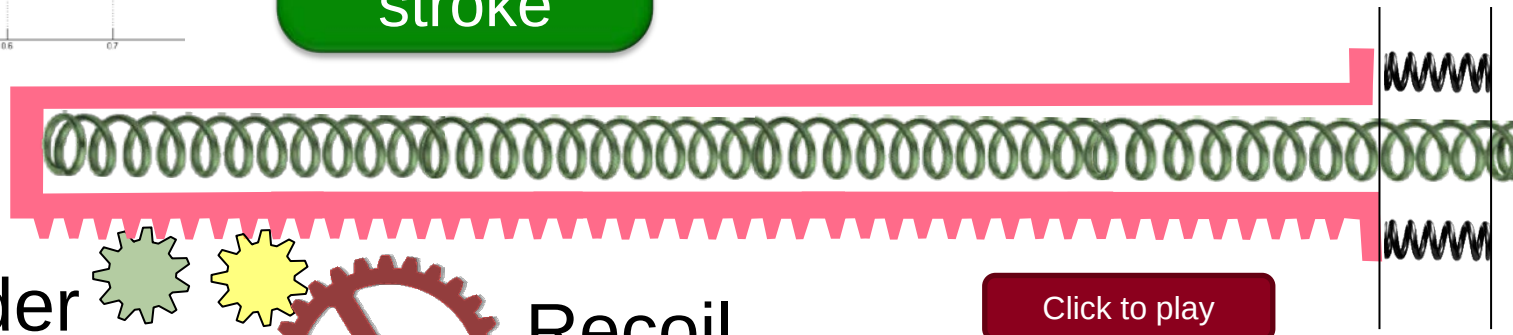
ADIM's employment of Soft Recoil combined with Active Recoil



Charge 3

Braking on forward stroke





Encoder

Recoil Brake

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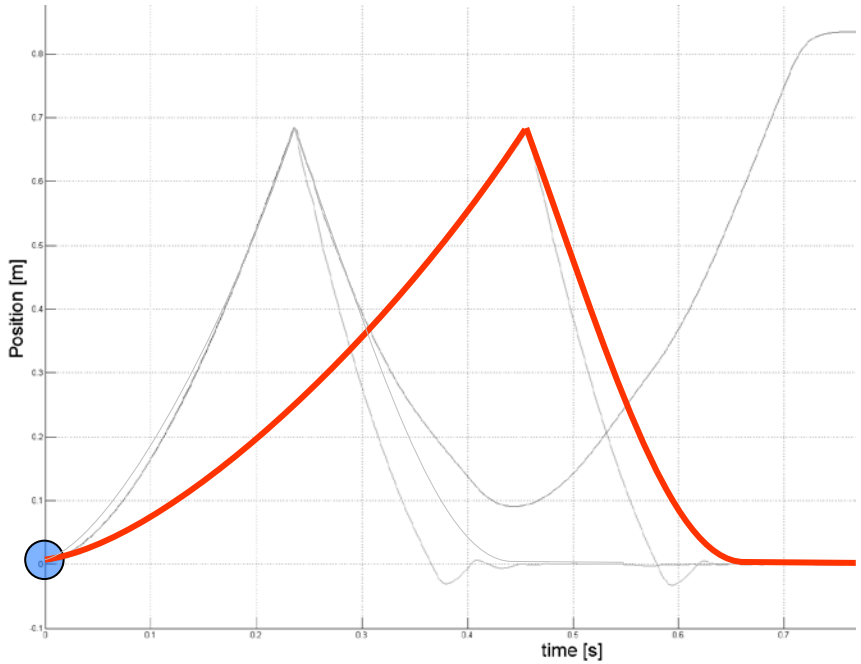
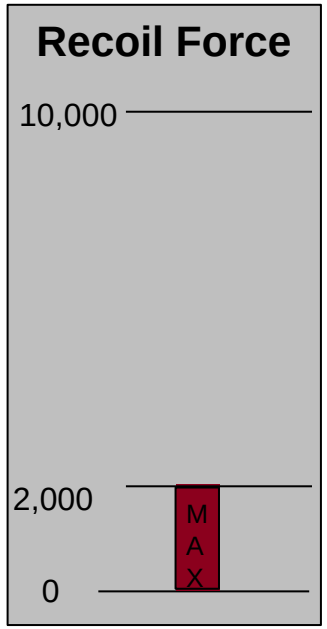
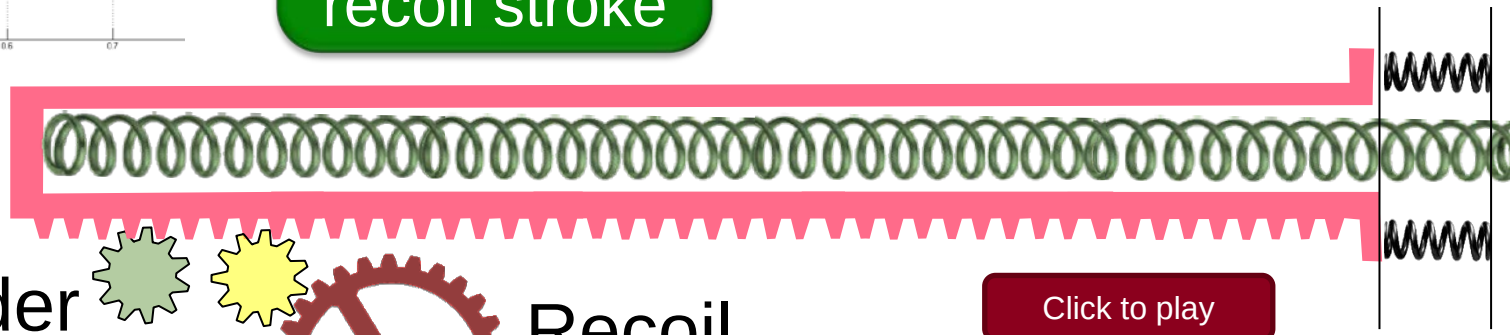
ADIM's employment of Soft Recoil combined with Active Recoil



Charge 3

Braking on forward & recoil stroke





Encoder

Recoil Brake

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Conclusion

ADIM 2015

- Active recoil on ADIM prototype
  - Reduction of forces
  - Improved handling of variations
  - Going forward

- Future of Active Recoil
  - More viable then in the past
  - Application to other weapon systems

- Questions?

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Information sources

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