# Solid State Guided Bullet Flight Control Actuators

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*AAL ...Backroom for the Innovation-Driven Aerospace Organizations of the world...*

***Joint Armaments Conference, Exhibition and Firing Demonstration***
***Seattle, Washington 16 May 2012***

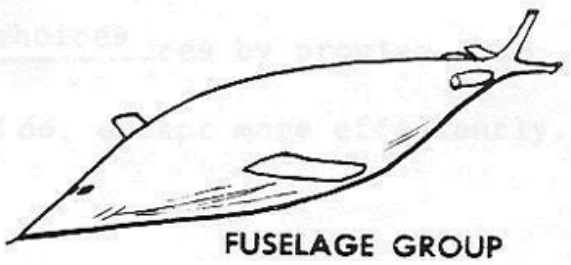
# Outline:

***I. Brief Introduction to Adaptive Materials & History***

***II. New Classes of Adaptive Actuators***

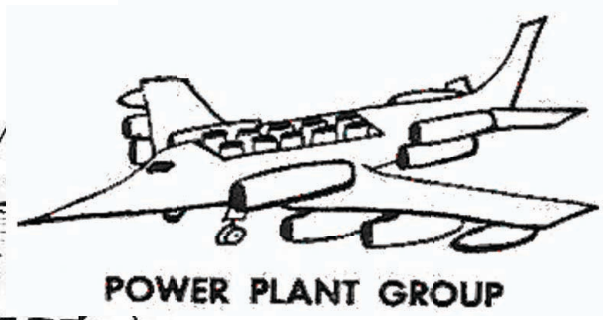
***III. Summary of Adaptive FCS Properties and Designs***

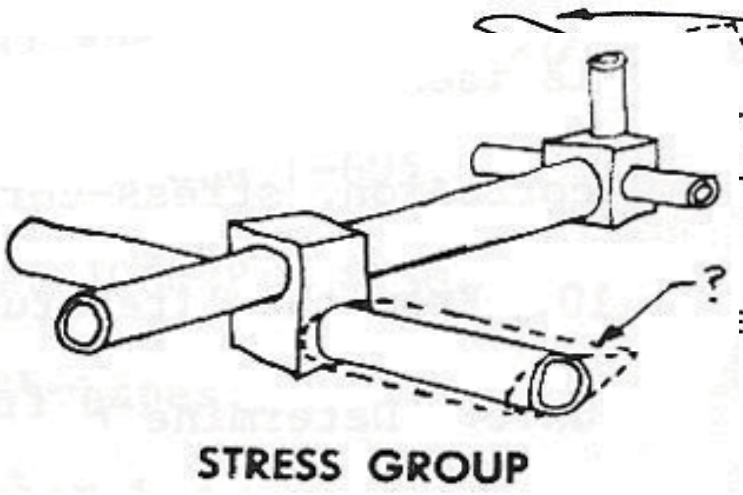
# Adaptive Materials

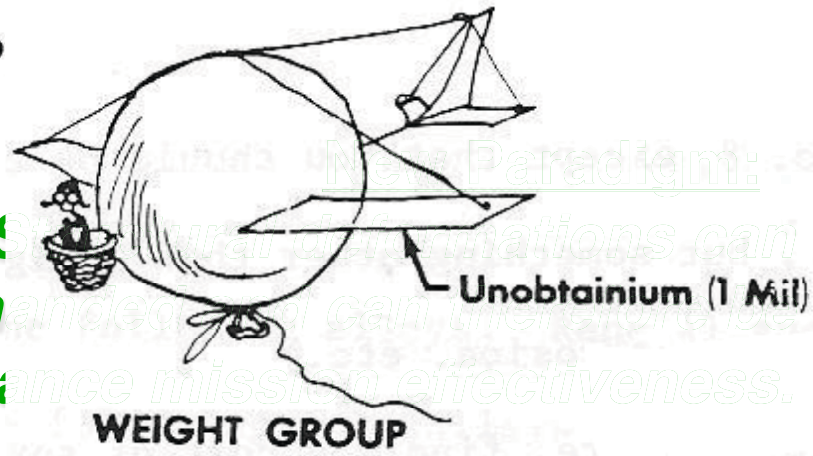



## Old Paradigm:

***Structural deformations indicate that a given loading state is occurring and must therefore be accommodated.***




## New Paradigm:

***Structural deformations can be commanded or can intentionally be used to enhance mission effectiveness.***

# Adaptive Aerostructures
## A (Very) Brief Introduction



**Most Useful Classes of Adaptive Materials:**

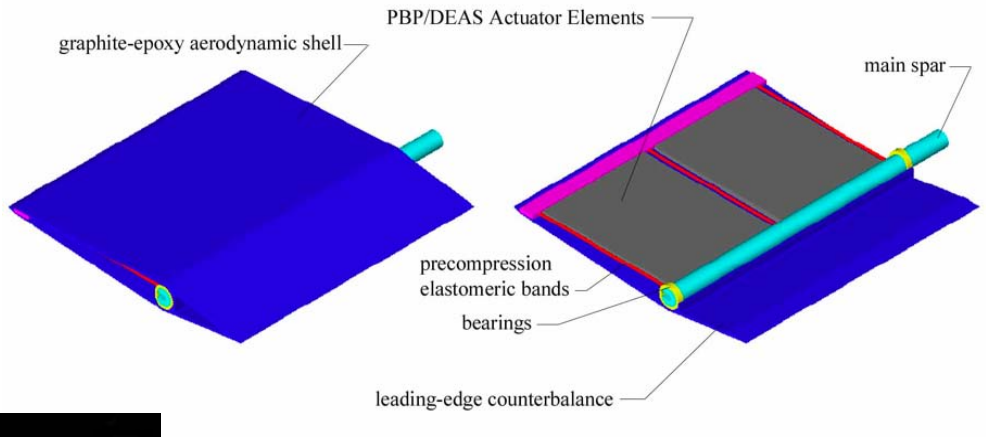
- **Shape-Memory Alloy -**
  **High Deflection, Slow, Lots of Power**

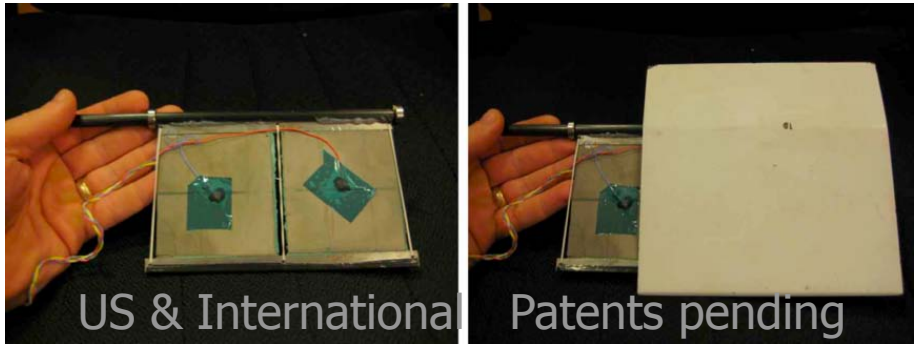
- **Piezoceramics -**
  **Very Fast, Low Power**

# Commercial Adaptive Aerostructures:

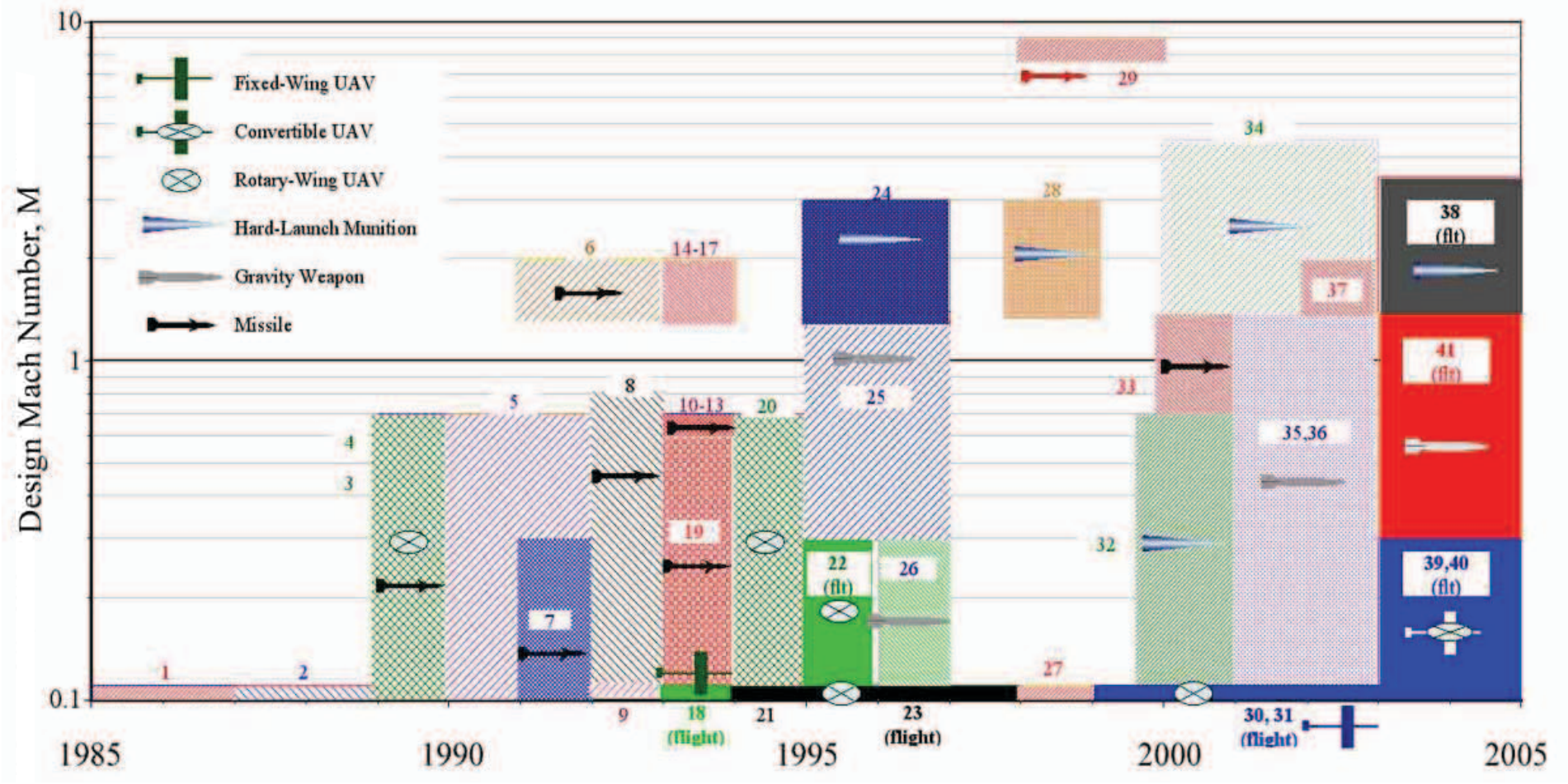
## Adaptive Flutter Test Surface

- ***Solid State***
- ***Order of magnitude less device weight***
- ***Half the acquisition cost of the conventional system***
- ***Exacting Deflection & Phase Control***
- ***Flight Rated to Mach 3***
- ***Half the flutter insurance rates***



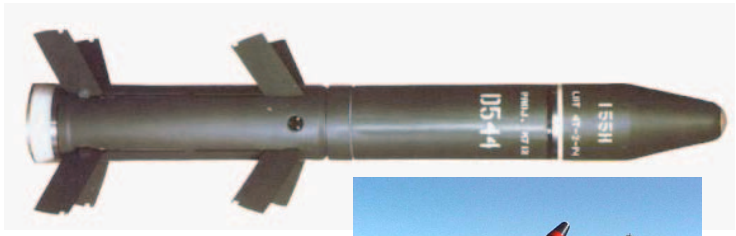

# Overview of Programs with Lineage to Flying Adaptive UAVs




R.

# Brief Guided Round History

## M712 Copperhead 1975




**XM 982 Excalibur & ERGM**

All information from public sources

R. M. Barrett 2 May 2012 Unclassified

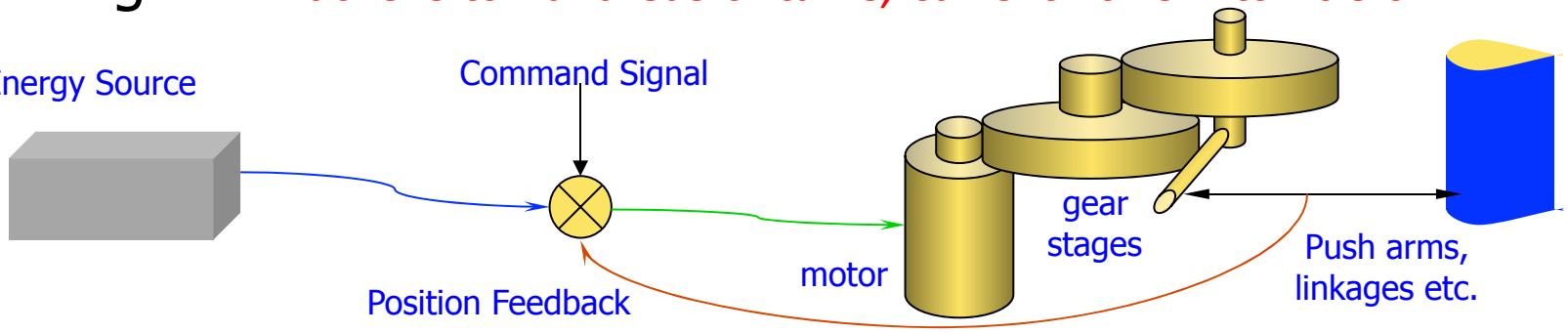
# Low Caliber Flight Control Actuator Needs...

- Setback tolerance: 5,000 - 200,000g's
- Balloting, setforward, ringing impervious
- Compatible with supersonic control effectors
- Not affected by atmospherics (rain, dust, dirt, snow, etc.)
- 20 yr storage life
- -40 to +145°F
- Lightweight (<1g), Low Volume (<1cc), Low Power (10's of mW)
- High bandwidth (>200 Hz)
- Production shipset costs in single dollars... at most

# Flight Control Technologies



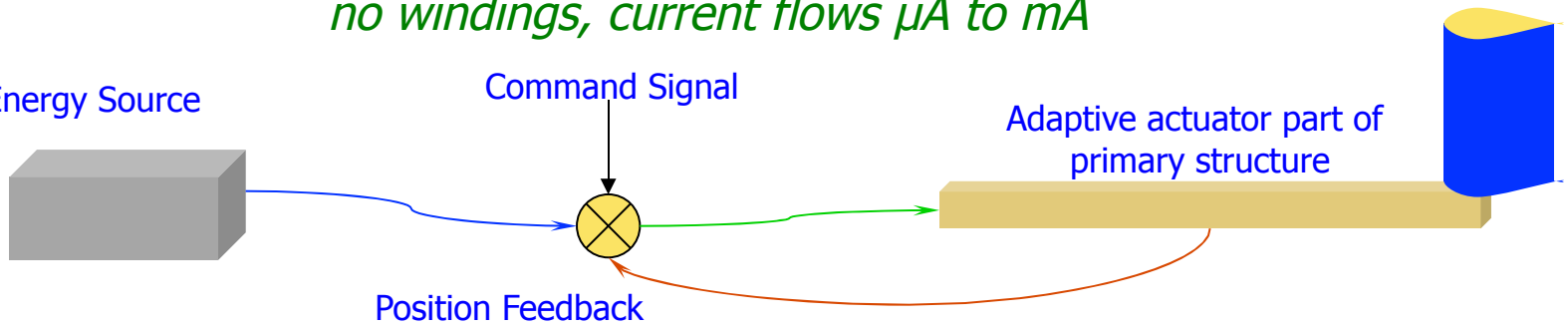
## Electromagnetic *dozens to hundreds of turns, current flows A to 10's of A*




*Magnetic Field $\alpha$ no. of windings x current*

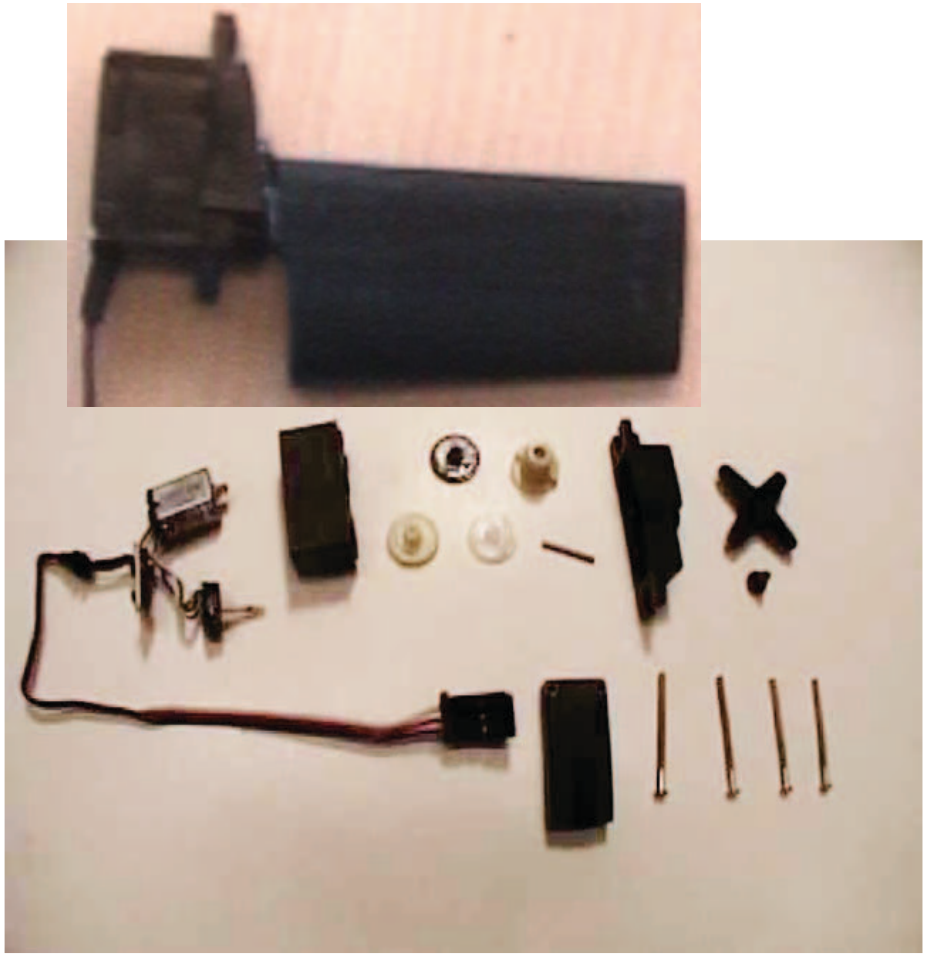
## Adaptive

*no windings, current flows μA to mA*



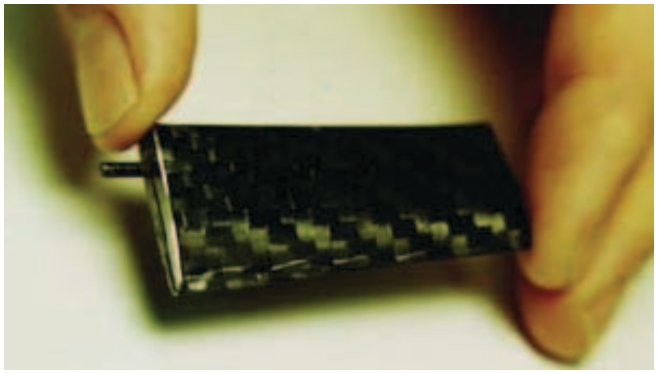
# The First MAV... Driving Adaptive FCS

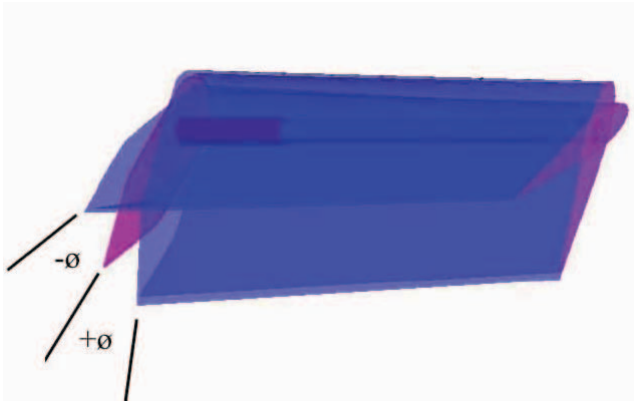
## Conventional Electromagnetic



36 components, 830μT @10cm

## Adaptive Stabilators



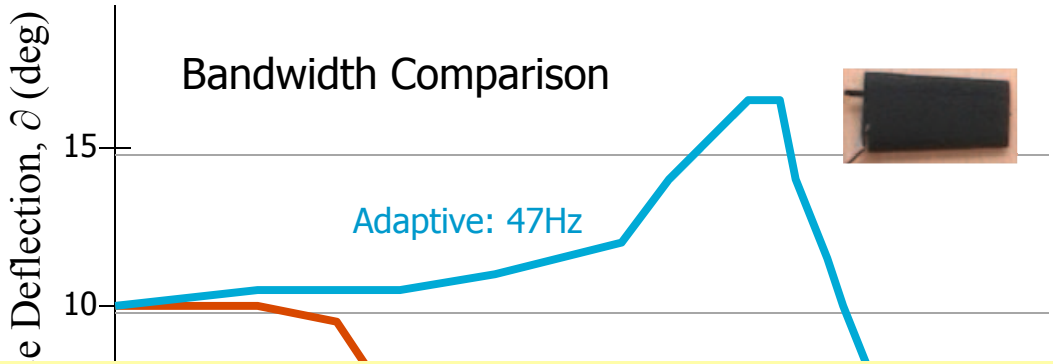



5 components, 0.6μT @10cm

*Earth's Magnetic Field: 30 – 60 μT*

# Advanced MAVs:

## Driving the need for Adaptive Actuators -- faster, lighter, stronger




## Adaptive Surfaces vs. Conventional Servos

- 96% reduction in power consumption
- 16x increase in bandwidth
- 99.2% decrease in slop
- OM reduction in part count
- 12% OWE savings

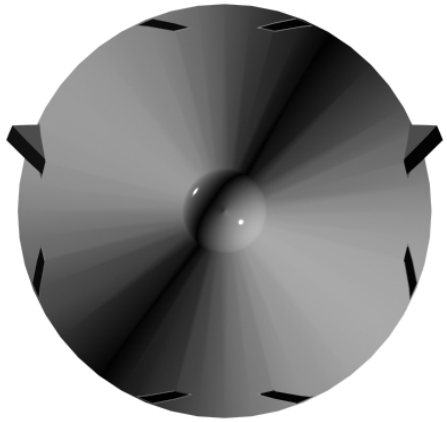
# Interceptors

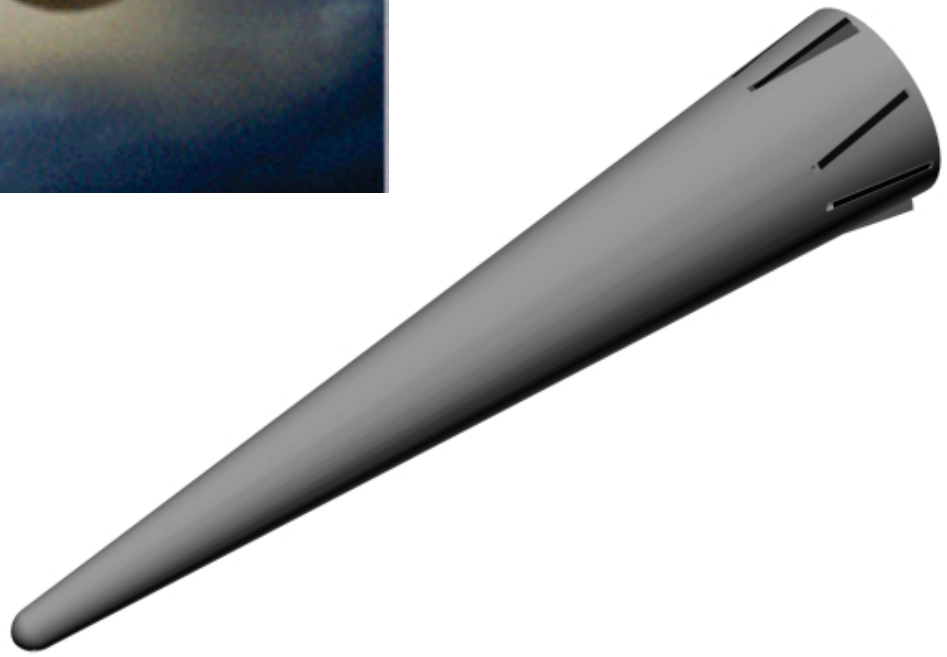
**SMDC HITT Program 1997 - 2000**

**Hypersonic**

**5ms Fully Proportional Response**

**Pitch, Roll, Yaw control**





# Guiding Lower Caliber Rounds... More History

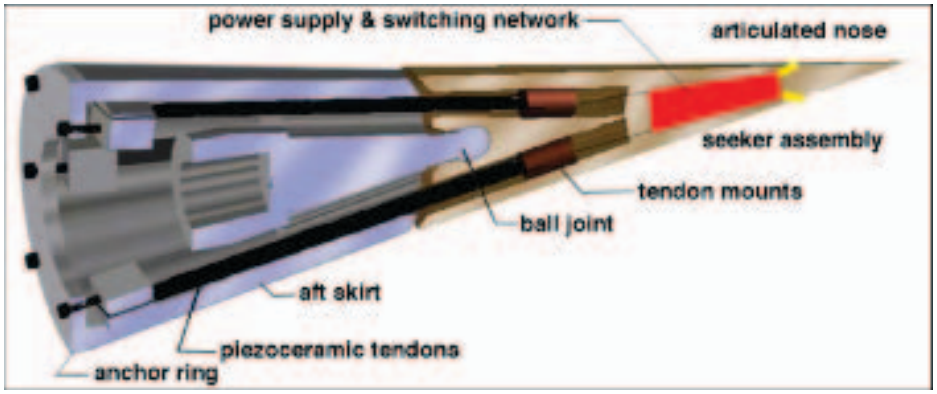
## Barrel-Launched Adaptive Munition (BLAM) Program 1995 - '97

USAF/AFRL-MNAV

- Aerial Gunnery (20 - 105mm)
- Extend Range w/2g maneuver
- (Eglin AFB tests '97)

(Mach 3.3 tests '96-'97)

- Increase hit probability
- Increase probability of a kill given a hit
- Reduce total gun system weight fraction

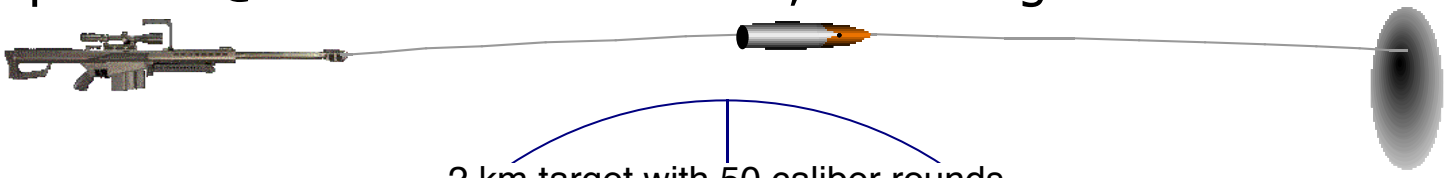


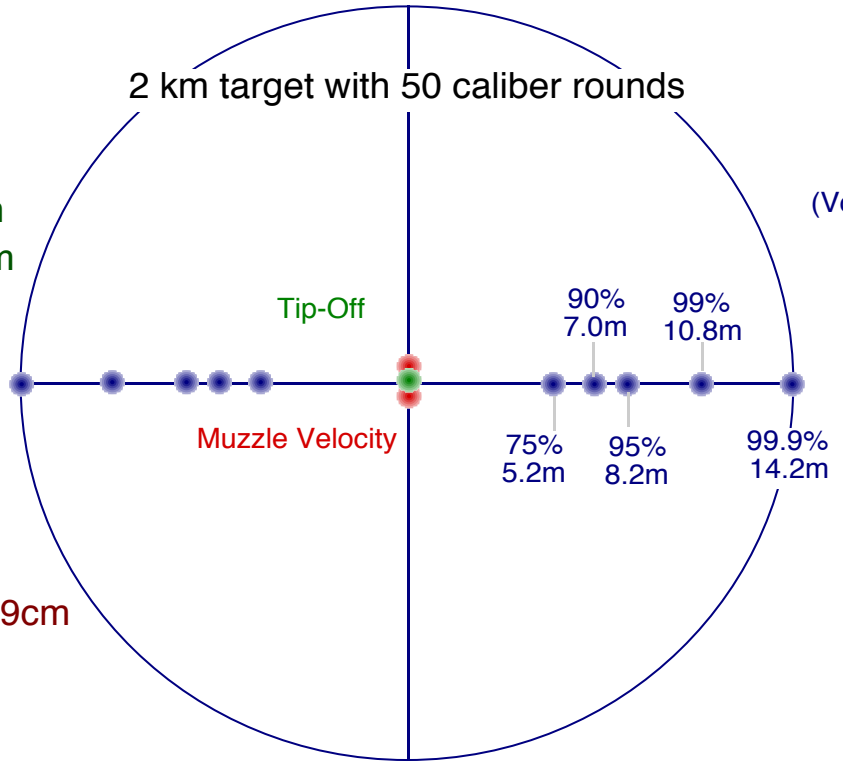
# Guiding Small Arms Rounds... More History

## Range-Extended Adaptive Munition (REAM) Program 1998 - '99

TACOM-ARDEC (Picatinny-APG) Phase I SBIR

- Guide 50 cal sniper rounds against targets moving up to 100km/hr
- 10cm dispersion @2km under 99% winds, variable grade to 10%






Tip-Off Rate:
4 rad/s error ~ 25cm
12 rad/s error ~ 75cm

Muzzle Velocity
1% change error ~ 99cm

Crosswinds
(Von Kárman Spectrum)

$V \sim \chi^2(\nu)$

Vav = 4.03 kts
75th%: 5.21 kts
90th%: 6.95 kts
95th%: 8.15 kts
99th%: 10.7 kts
99.9%: 14.2 kts

# Guiding Small Arms Rounds... More History

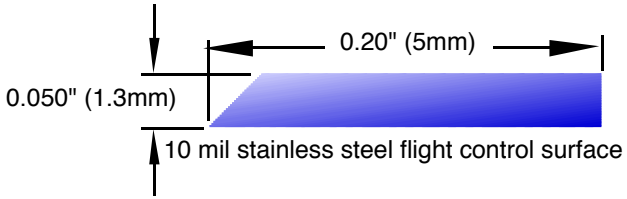
## Range-Extended Adaptive Munition (REAM) IRAD 1999 - 2001

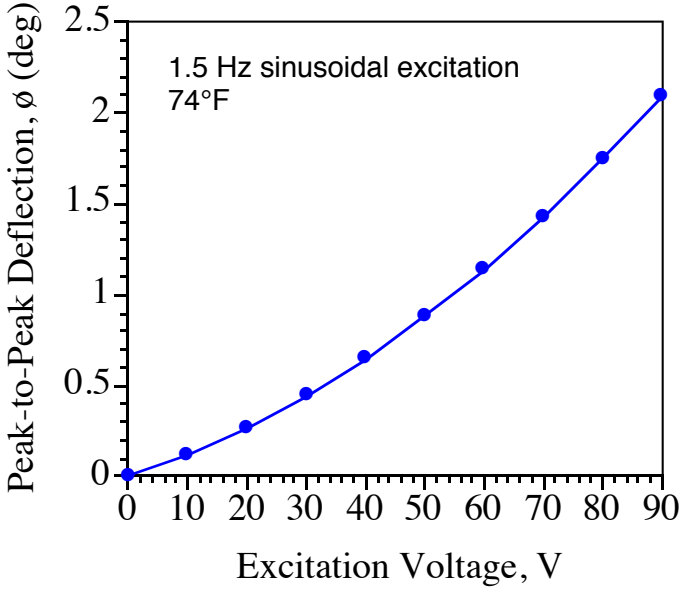
BAT-Lutronix Corp. developed supersonic piezoelectric FCS actuators

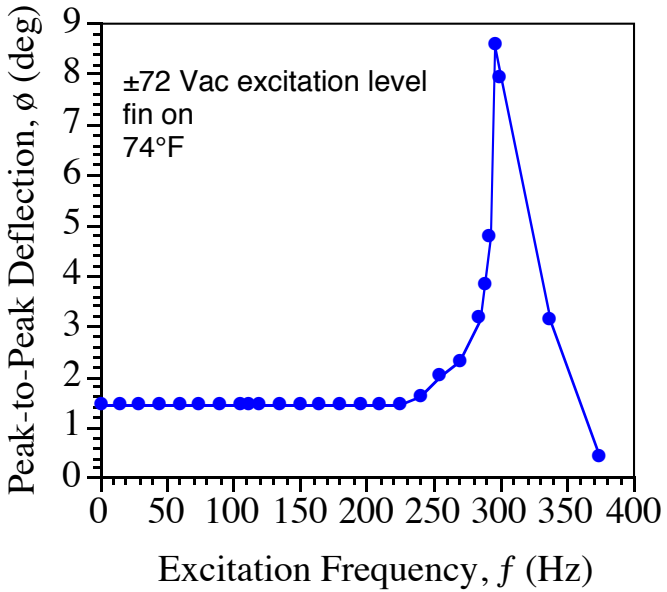


### Flight Control Surface and Actuator Performance

Max Power Consumption: 28 mW
Nominal Power Consumption: 3.5 mW
Static Power Consumption: < 1$\mu$W
Design Mach Range: 0.8 - 4.5, STP
Design Accelerations: 25k g's



# Guiding Small Arms Rounds... More History

## Shipborne Countermeasure Range-Extended Adaptive Munition (SCREAM) Program 2001 - '03

DARPA-TACOM ARDEC SBIR Phase II

- Change from sniping to countering high jinking rate sea-skimming missiles
- Change from 0.50 caliber to 40mm
- Change from ~2g's of maneuver authority to many tens of g's
- Entire FCS passed 41,000g shock table testing

# Guiding Small Arms Rounds... More History

**Shipborne Countermeasure Range-Extended Adaptive Munition (SCREAM) Program 2001 - '03**

DARPA-TACOM ARDEC SBIR Phase II

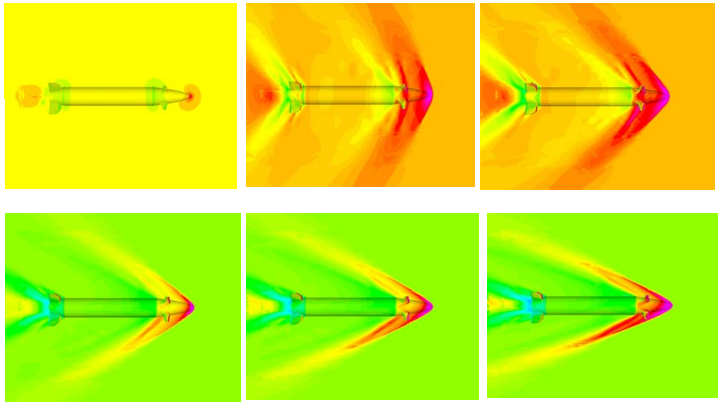
SCREAM Actuator Challenges:

- Long actuator bay length
- Difficulty pushing beyond 50,000g's
- Low deflection -- ~ok for sniper, not ok for SCREAM

Hmmm...

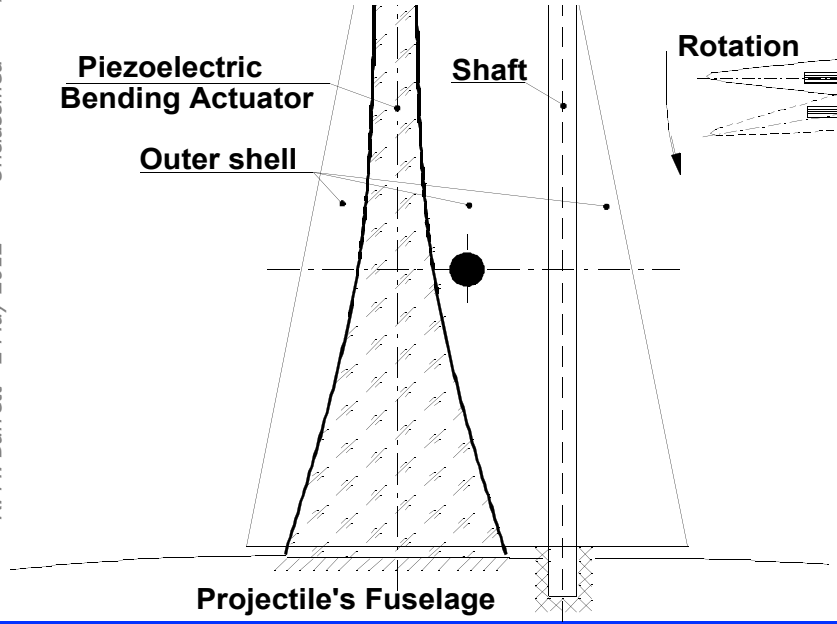
# Other Adaptive FCS Efforts

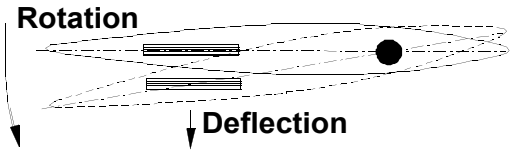
## Rabinovitch & Vinson 2000 - present



again... low authority
can't survive balloting, setback unsteady aero...

*Now Where???*



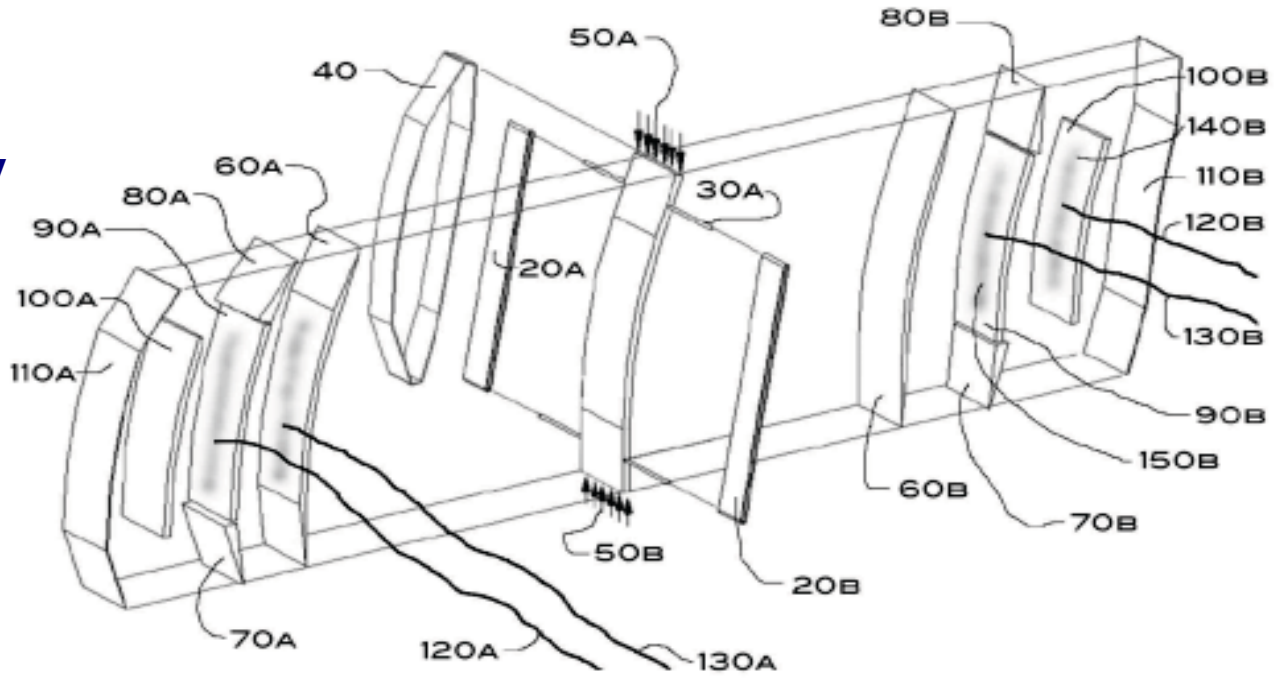



# Guiding Hard-Launched Rounds... The Ephphany!

## Discoveries from Europe... 2003 - 2004

# PBP Actuators: The FCS Solution

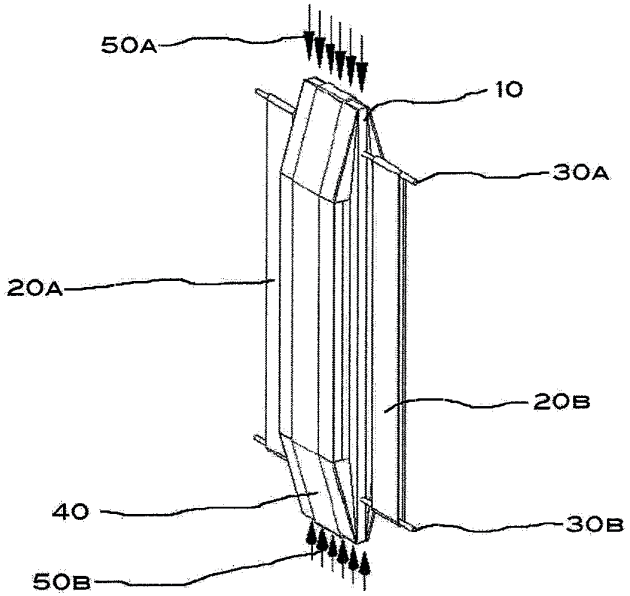
- Fraction of the weight, size & power consumption of US Actuators (i.e. much smaller actuator bays)
- 300+% deflection increases with full force/moment capabilities
- Higher bandwidth
- Lower g-sensitivity
- Lower cost

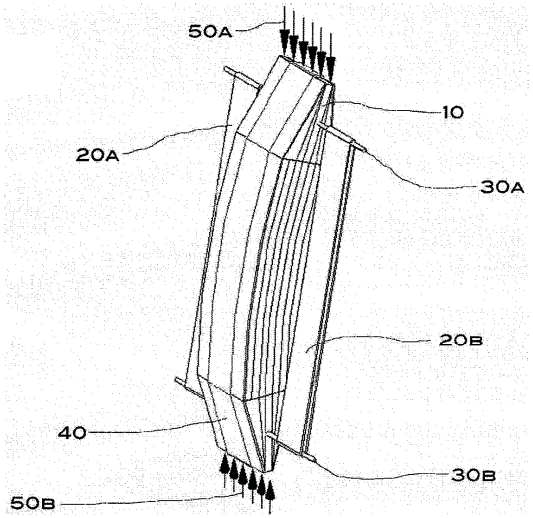


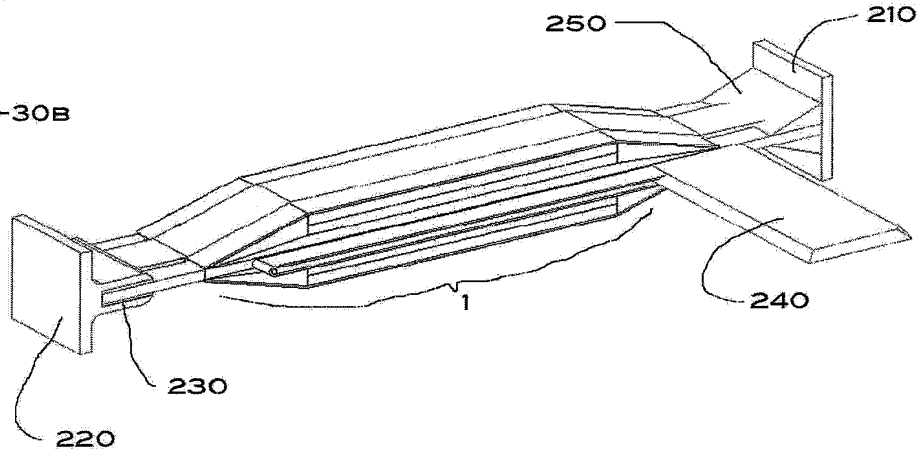

US PAT. 7,898,153 ISSUED 2011

# PBP Actuators: Actuator Layout

Assembled, functioning actuator:

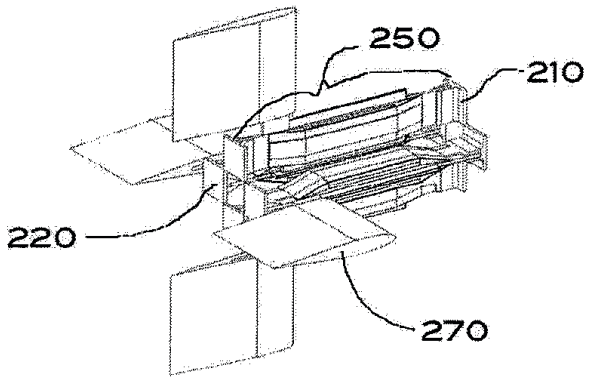


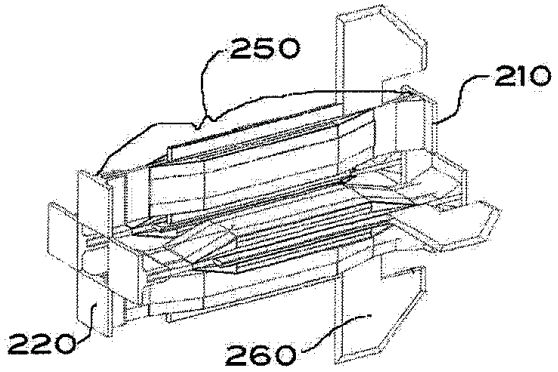



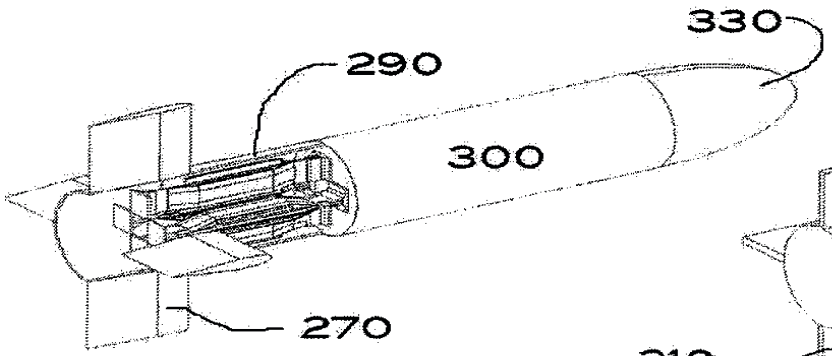



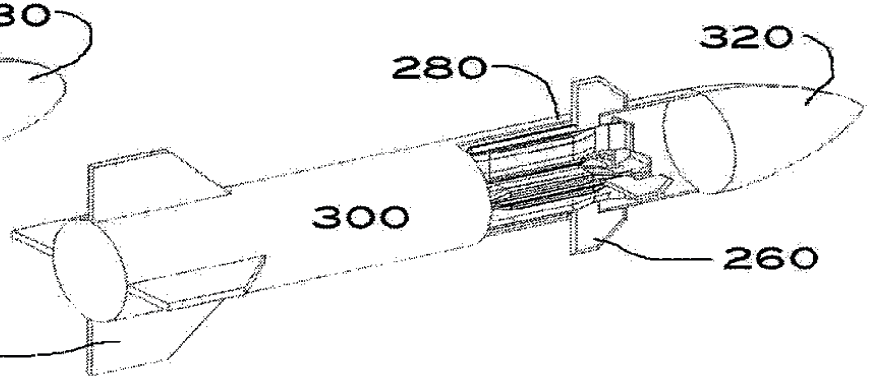
# PBP Actuators: Assemblies

Assembled Hard-Launch Capable Actuator FCS Units:



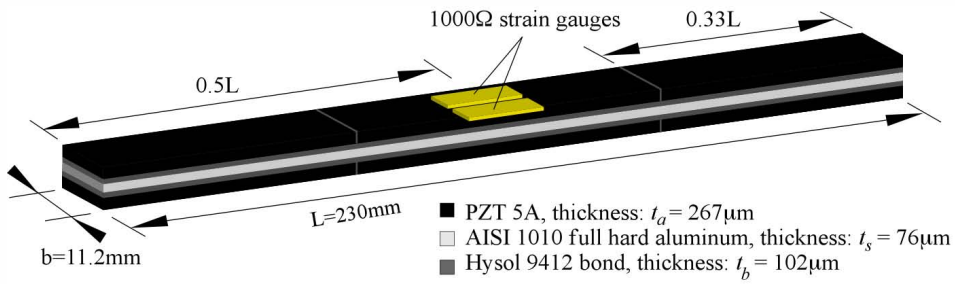



# PBP Actuators: Fastest around...

**Best performance in the adaptive structures industry:**

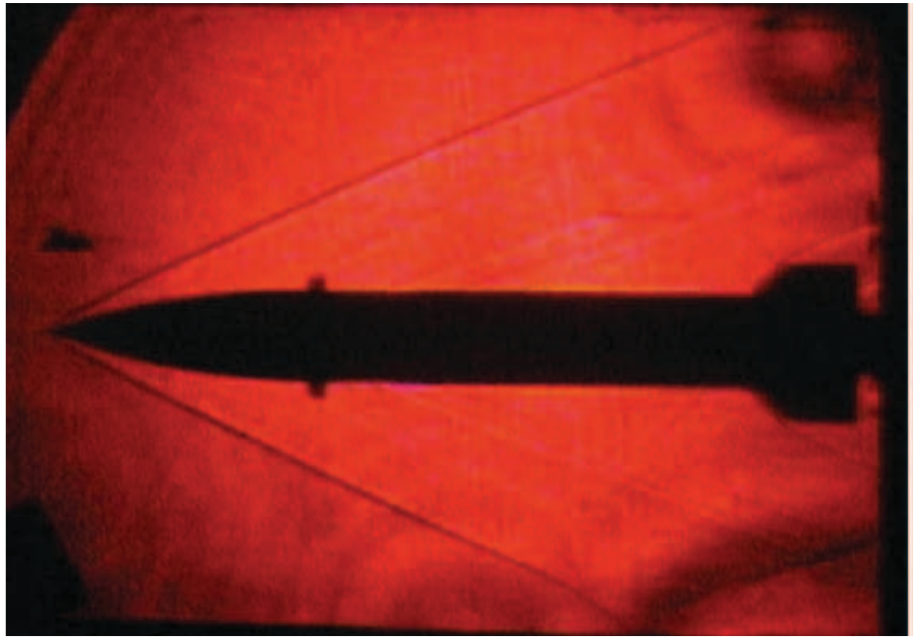
- **1kHz equivalent bandwidth**
- **Driving 0.40/.50 cal Mach 4.5 canards**



# PBP Actuators: Real Performance!

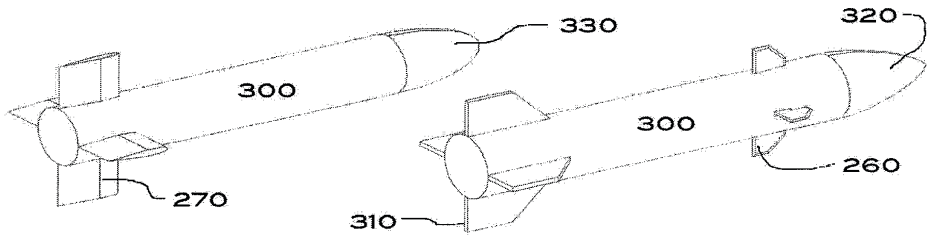


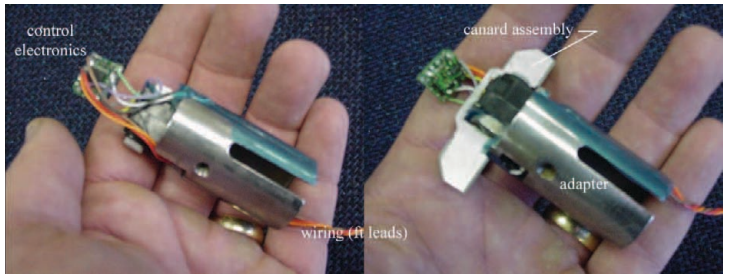
**Mach 3 Testing – FCS works well!**



# PBP Actuators: Munitions Comparisons

## Smaller, Lighter, Cheaper – the Name of the Game



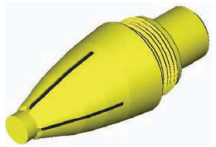



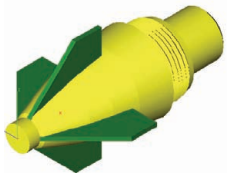

| | Conventional Electromagnetic FCS | Adaptive/PBP FCS |
|---|---|---|
| Volume | 14cc | 5.1cc |
| Mass | 69g | 4.2g |
| Peak Power | 148W | 2.6W |
| Deadband/Slop | ±0.38° | ±0.002° |
| Bandwidth | 22 Hz | 189Hz |
| Acquisition Cost (100,000 shipsets) | $187 ea. | $12.30 |

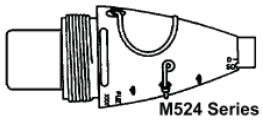
# PBP Actuators: The Next Challenge

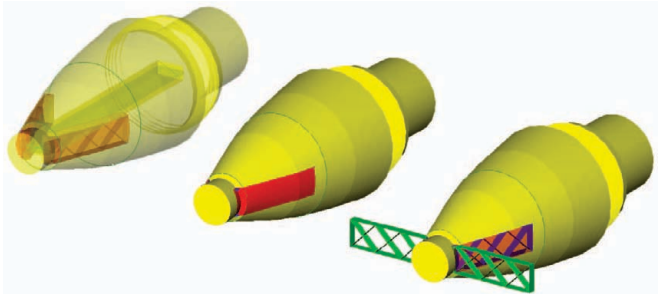
- **Supporting Efforts akin to Sandia's Guided Bullet**

# Adaptive Actuators: Rq'd & Available Bandwidth

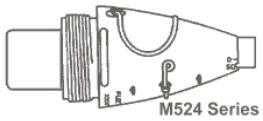


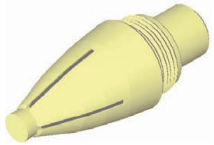


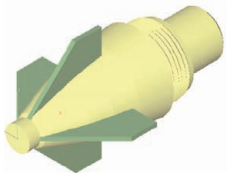


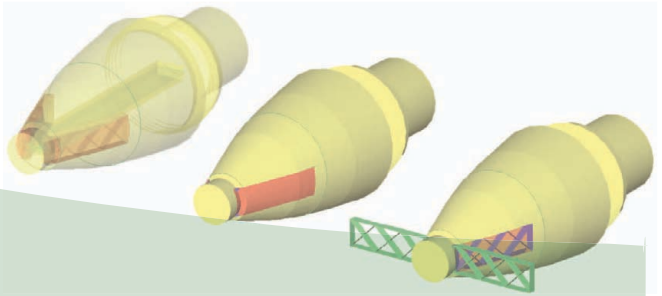



# Adaptive Actuators: Available Bandwidth & Deflection



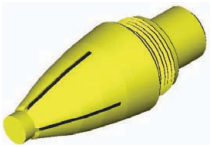


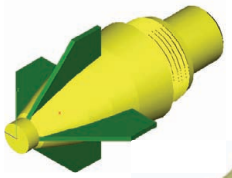


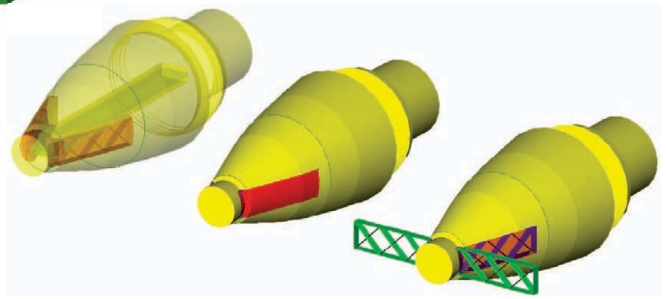


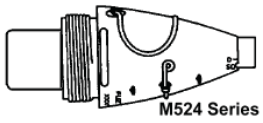

R. M. Barrett 2 May 2012 Unclassified All information from public sources

# Adaptive Actuators: Available Bandwidth & Deflection










# Adaptive Materials and Aerostructures for Missiles, Munitions and UAVs

Short Course for:
Program Managers &
Practicing Engineers



## Open/Unrestricted Course

(all materials from public documents, can be taught worldwide)
2 – 14 hrs, on site, up to 2 days

1. Nomenclature
2. History of the Field
3. Adaptive Material Properties and Modeling Techniques
4. Electrical Interface and Control
5. Aircraft Applications and Programs
6. Missile & Munitions Fundamentals & Programs thru early 2000's
7. Helicopter & UAV
8. Limitations
9. Future Directions

## ITAR/EAR Restricted Course

(materials from restricted sources, proof of US citizenship req'd )
2 – 21 hrs, on site, up to 3 days

1. Nomenclature
2. History of the Field
3. Adaptive Material Properties and Modeling Techniques
4. Electrical Interface and Control
5. Aircraft Applications and Programs
6. Missile & Munitions Fundamentals & Programs thru today w/advanced weapons concepts
7. Helicopter & UAV
8. Limitations
9. Future Directions

# Questions?