Low Volume, Low Power, Low Cost Advanced Guided Bullet and Mortar Flight Control Actuators

Professor Ron Barrett
Director of the Adaptive Aerostructures Laboratory (AAL)
Aerospace Engineering Department
The University of Kansas, Lawrence, Kansas USA

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

Joint Armaments Conference, Exhibition and Firing Demonstration
Dallas, Texas 19 May 2010

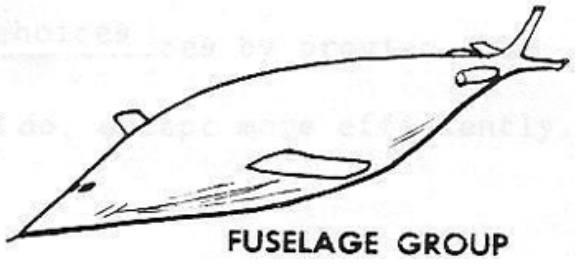
Outline:

I. Brief Introduction to Adaptive Materials & History

II. New Classes of Adaptive Actuators

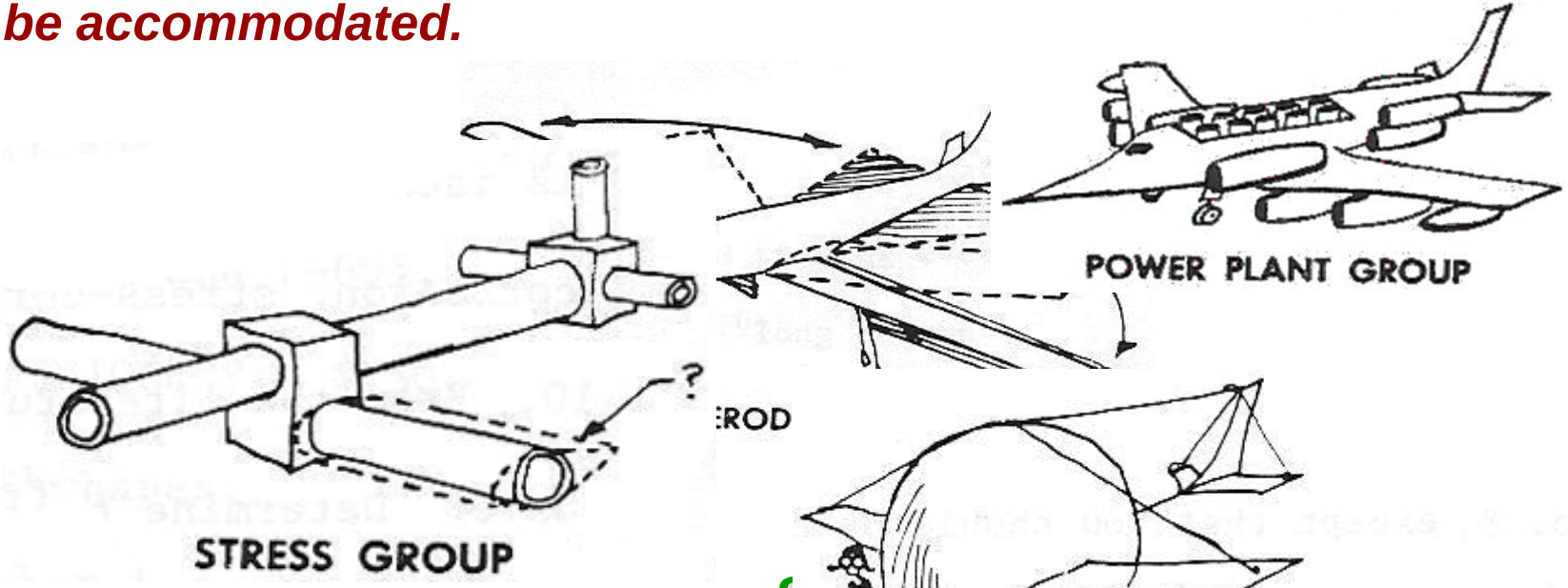
III. Summary of Adaptive FCS Properties and Designs

Adaptive Materials



Old Paradigm:

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



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Adaptive Aerostructures
A (Very) Brief Introduction

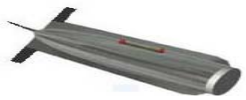
Most Useful Classes of Adaptive Materials:

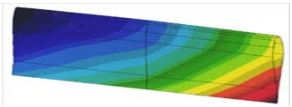
- **Shape-Memory Alloy -**
  High Deflection, Slow, Lots of Power

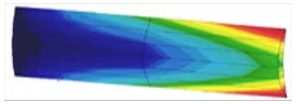
- **Piezoceramics -**
  Very Fast, Low Power

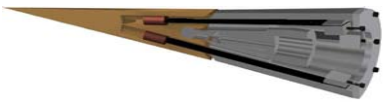
First 20 years of Programs with Lineage to Flying Adaptive UAVs

		Project	Modeling Technique		Test Techniques			Sponsor
			Closed or CLPT	FEM	Bench	Stand or Tunnel	Flight	
21	'94-95	Aeroservoelastic Flexspar Fin	3	3	3	3		AAL
22	**'95-96**	**Solid State Adaptive Hiller Servopaddle Rotor (Gamara)**	**3**		**3**	**3**	**3**	**NSF**
23	**'94-97**	**Flexspar Micro Aerial Vehicle Stabilator (Kolibri)**	**3**		**3**	**3**	**3**	**DoD CDTO**
24	'95-97	Barrel-Launched Adaptive Munition (BLAM)	3		3	3		AFOSR
25	'95-97	Smart Compressed Reversed Adaptive Munition (SCRAM)	3		3	3		WL/MNAV
26	'95-97	Monolithic Rotationally Active Linear Actuator (RALA)	3		3	3		WL/MNAV/Boeing
27	'97-98	Pitch-Active Torque-Plate Wing	3		3	3		AAL
28	'98-99	Range-Extended Adaptive Munition (REAM)	3		3	3		DARPA
29	'98-00	Hypersonic Interceptor Test Technology (HITT)	3		3	3		SMDC/Schafer
30	**'98-00**	**Coleopter MAV Flexspar Stabilators**	**3**		**3**	**3**	**3**	**DARPA**
31	**'00-01**	**Pitch-Active SMA Wing**	**3**		**3**		**3**	**AAL**
32	'00-01	Light Fighter Lethality Fin MicroFlex Actuator	3		3	3		TACOM/ARDEC
33	'01-02	Pitch-Active Curvilinear Fin Actuator	3		3	3		AMCOM
34	'01-03	Shipborne C'measure Range-Ex. Adaptive Munition (SCREA	3		3	3		TACOM/ARDEC
35	'00-03	Thunder Multilaminate RALA Fin	3		3			WL/MNAV
36	'00-03	Centerline Precompression Multilaminate RALA Fin	3		3			WL/MNAV
37	'02-03	Center Pivot Flexspar Fin	3					ARL
38	**2003-**	**StAB**	**3**	**3**	**3**	**3**	**3**	**TUD/TNO**
39	**2003-**	**Coleopter PBP Grid Fin**	**3**	**3**	**3**	**3**	**3**	**TUD**
40	**2003-**	**Coleopter PBP Turning Vane Flap**	**3**	**3**	**3**	**3**	**3**	**TUD**
41	**2003-**	**Twist-Active Wings for Extended-Range Gravity Weapon**	**3**	**3**	**3**	**3**	**3**	**WL/MNAV/Boeing**

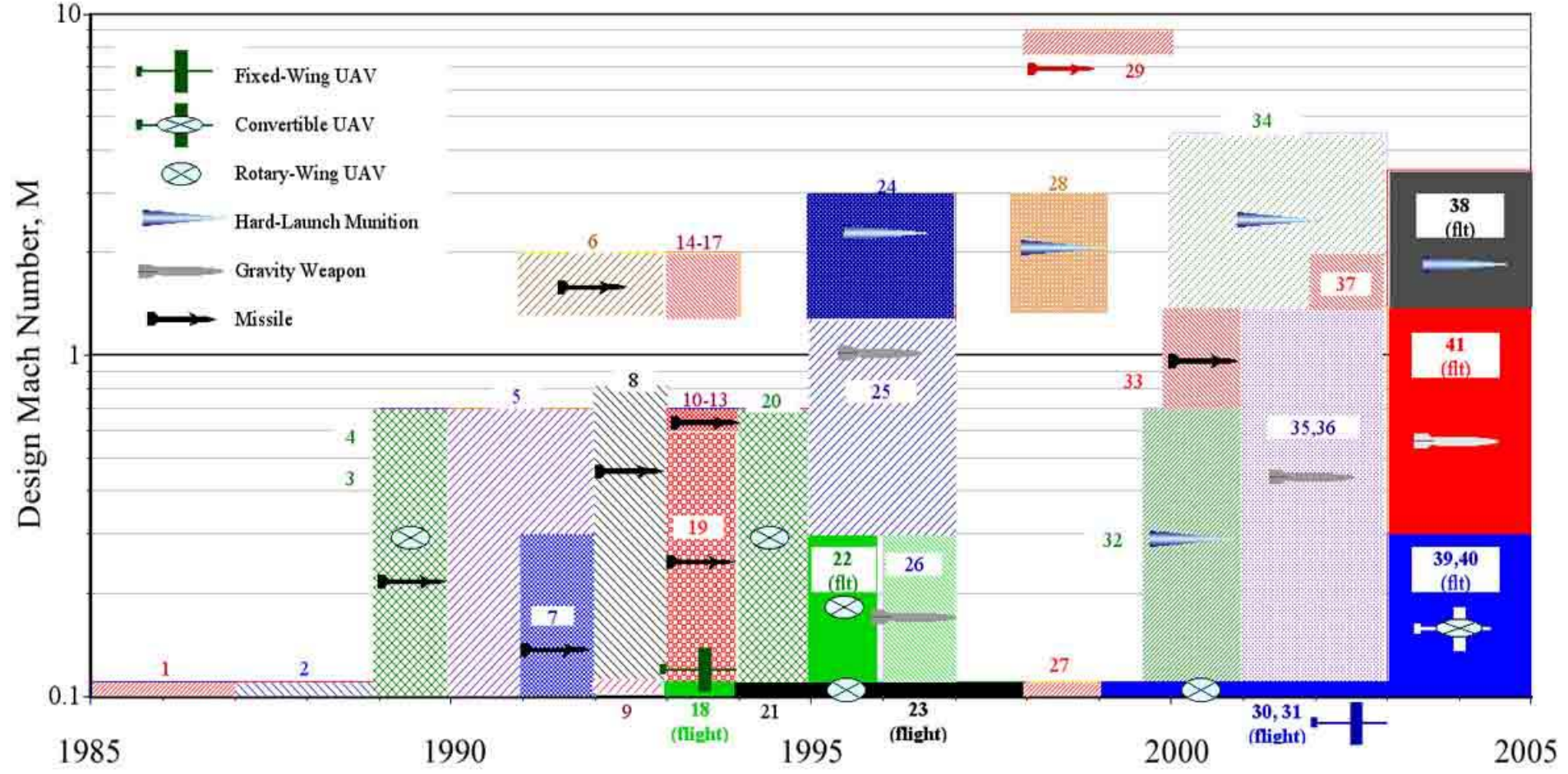








Overview of Programs with Lineage to Flying Adaptive UAVs



R. M. Ba

Brief Guided Round History

M712 Copperhead 1975

XM 982 Excalibur & ERGM

Guided Round History

What's needed in a low caliber FCS actuator?

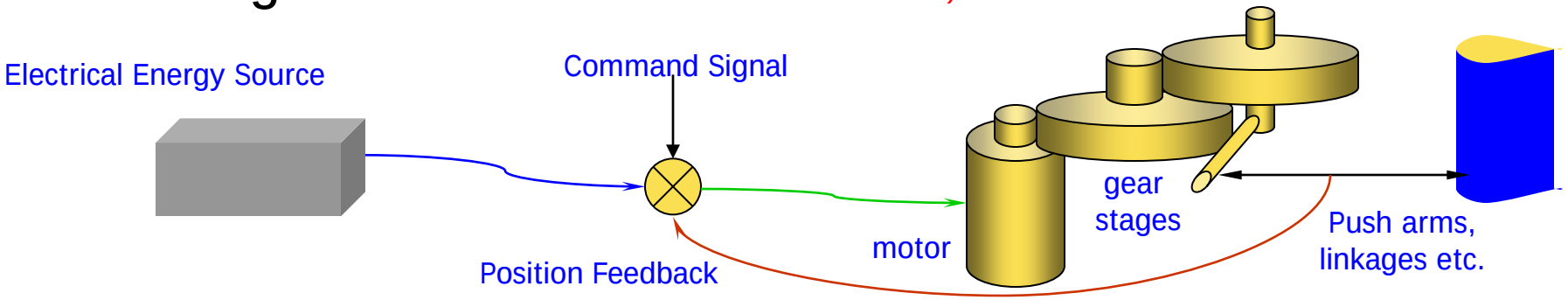
What is needed in such a flight control actuator???

- 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

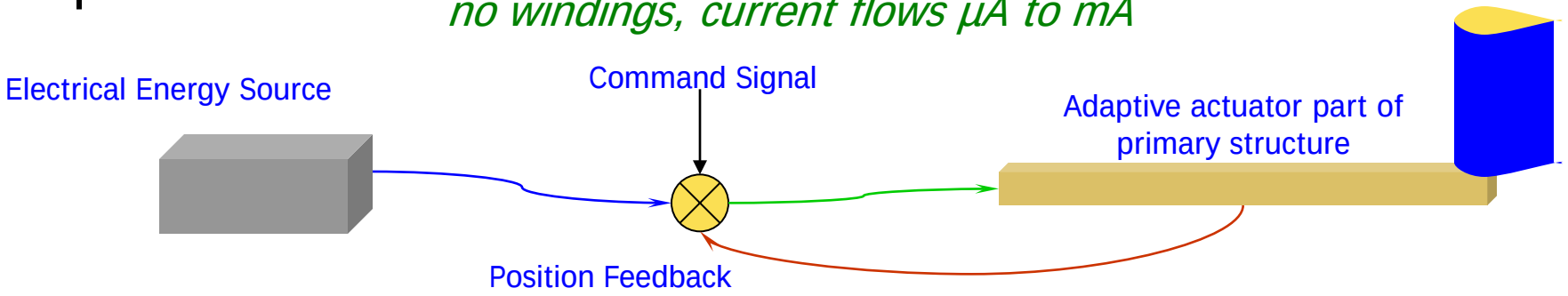
dozens to hundreds of turns, current flows A to 10's of A



Magnetic Field α no. of windings x current

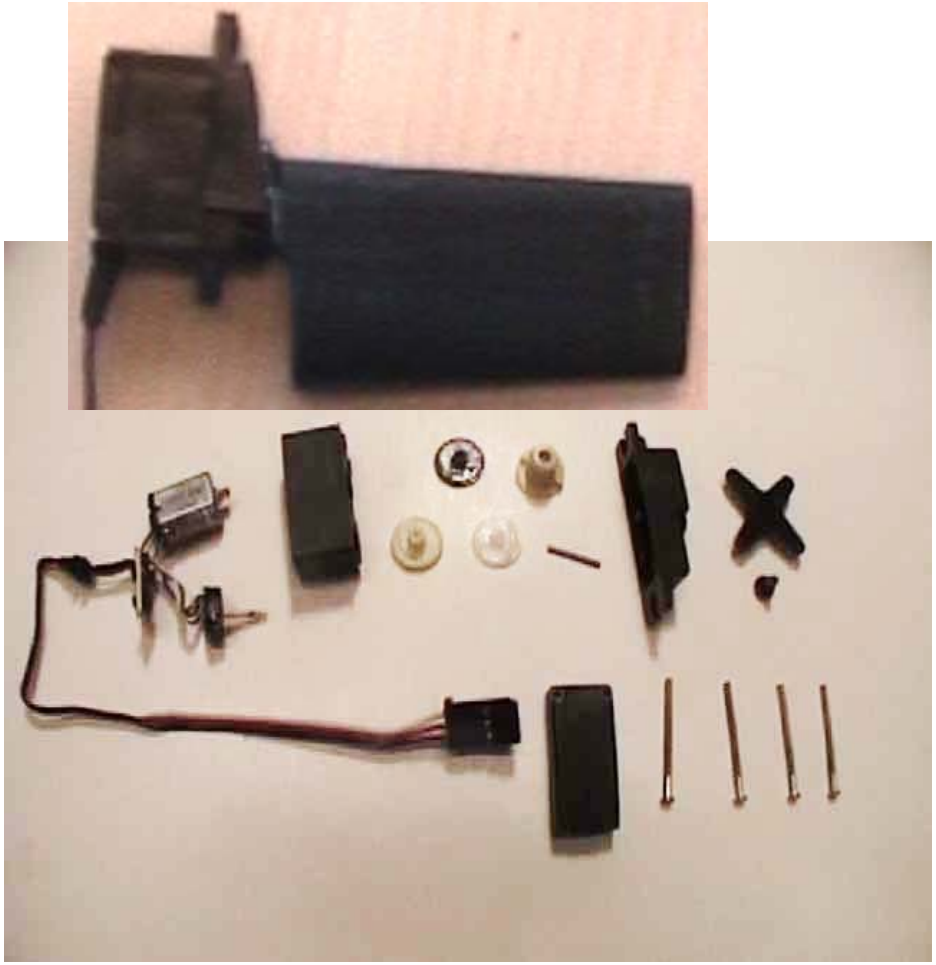
Adaptive

no windings, current flows µA to mA



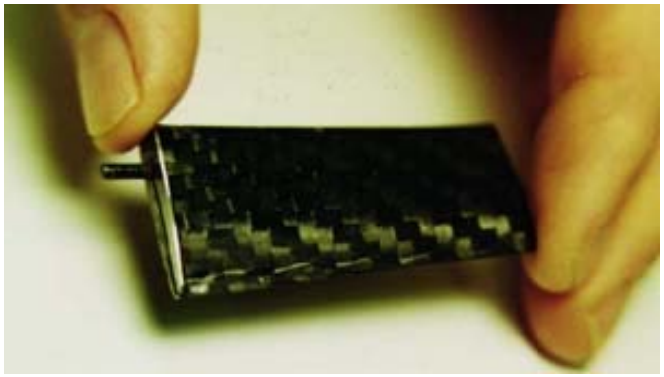
The First MAV… Driving Adaptive FCS

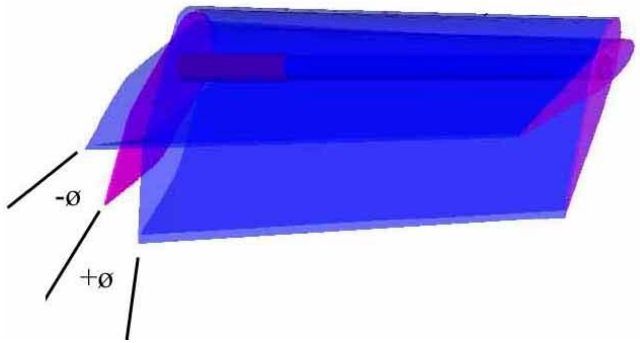
Conventional Electromagnetic



36 components, 830µT @10cm

Adaptive Stabilators



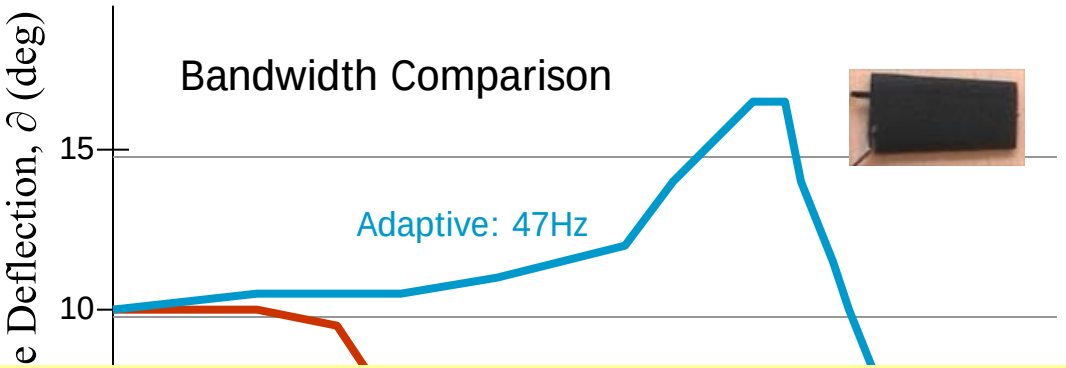


5 components, 0.6µT @10cm

Earth's Magnetic Field: 30 – 60 µT

Advanced UAVs:

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



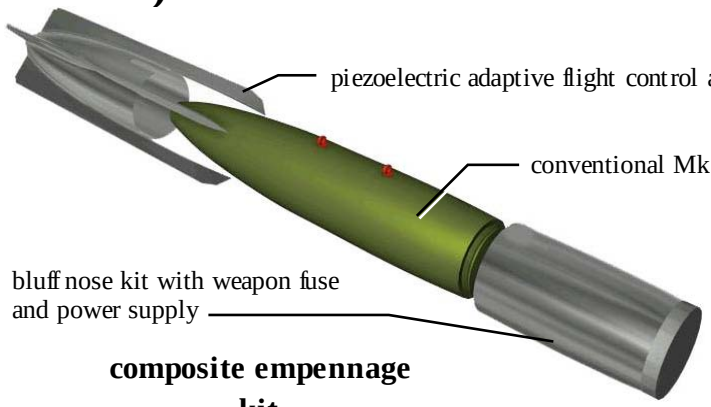
Adaptive Surfaces vs. Conventional Servos

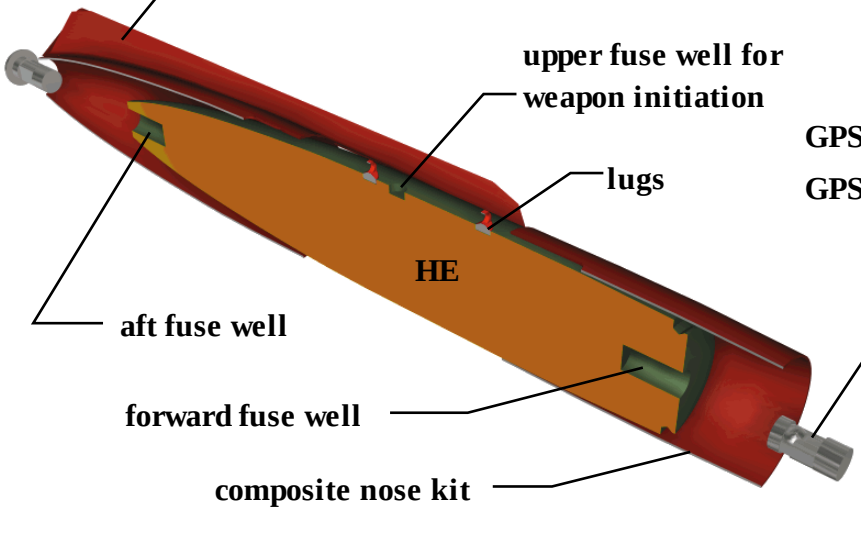
- 96% reduction in power consumption
- 16x increase in bandwidth
- 99.2% decrease in slop
- OM reduction in part count
- 12% OWE savings

Gravity Weapons

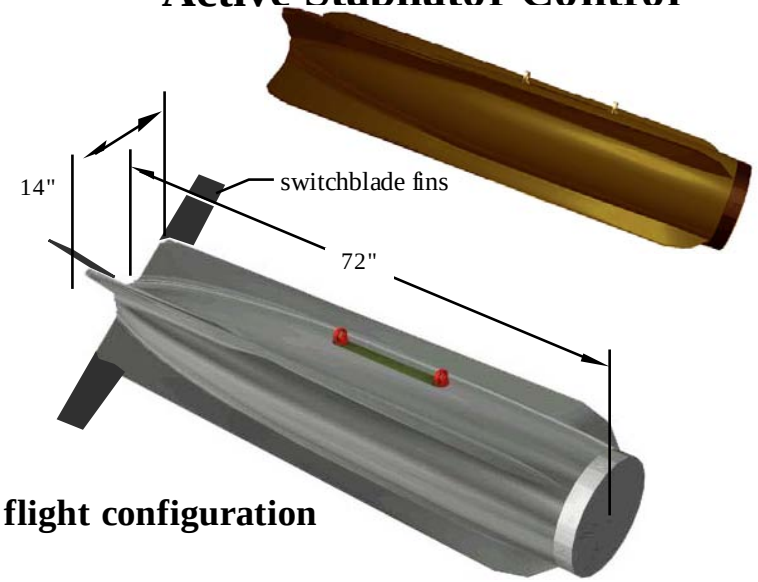
Weapon Compression

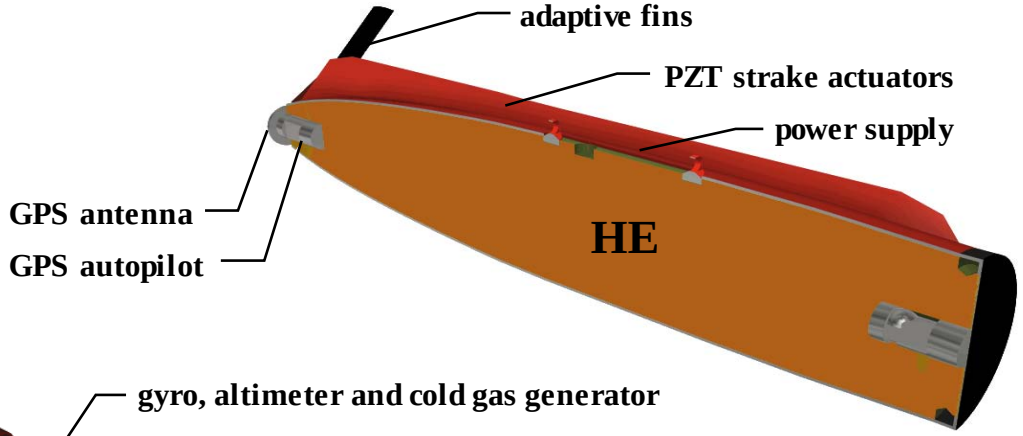
Smart Compressed Reversed Adaptive Munition (SCRAM)





Active Stabilator Control





All information from public sources

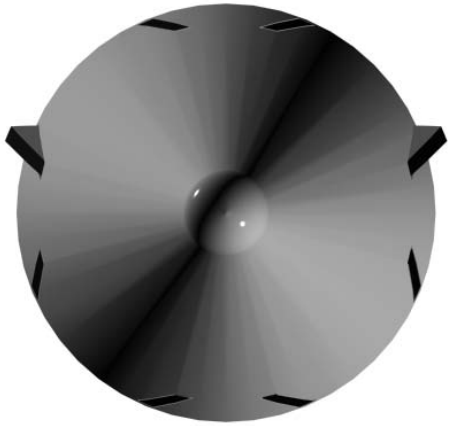
Interceptors

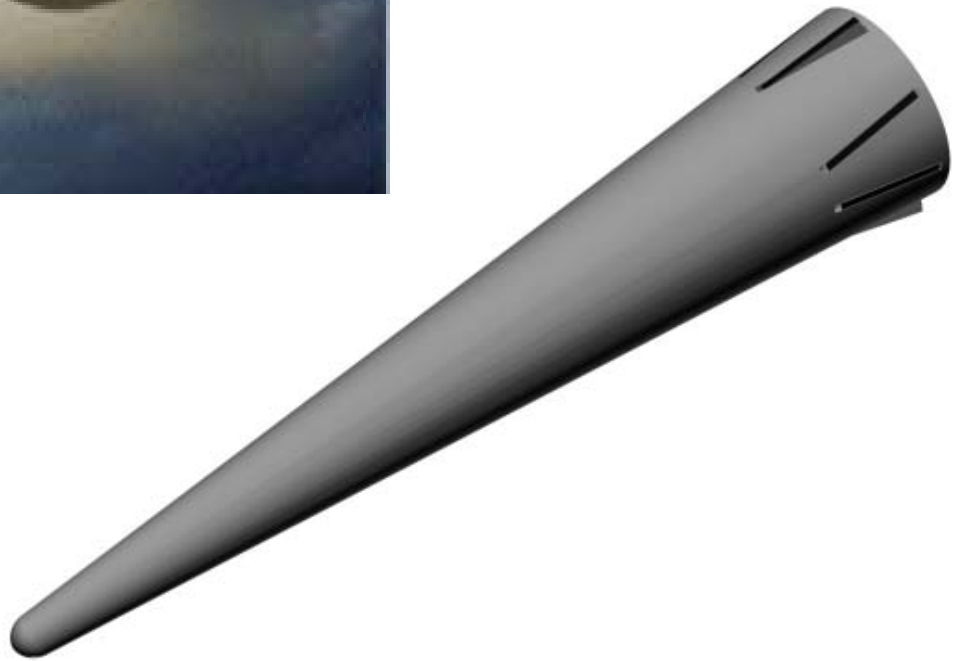
SMDC HITT Program 1997 - 2000

Hypersonic

5ms Fully Proportional Response

Pitch, Roll, Yaw control

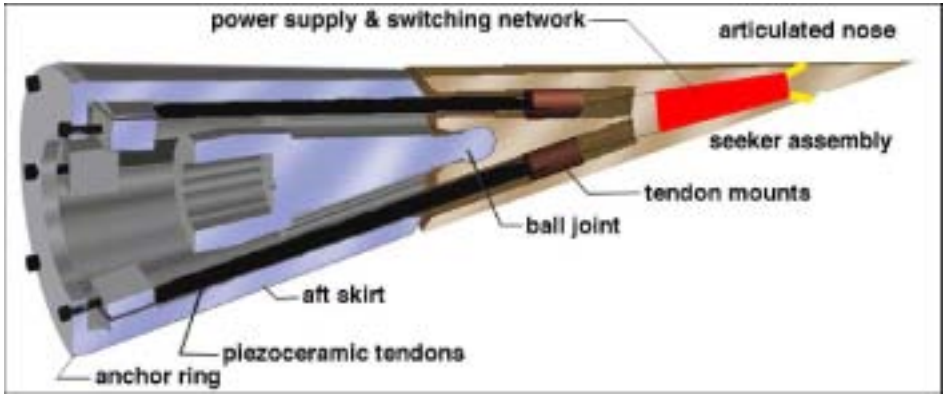




Guiding Lower Caliber Rounds… More History

Barrel-Launched Adaptive Munition (BLAM) Program 1995 - ‘97

USAF/AFRL-MNAV



- Aerial Gunnery (20 - 105mm)
- Extend Range
- 2g maneuver

(Eglin AFB tests ‘97)

(Mach 3.3 tests ‘96-’97)

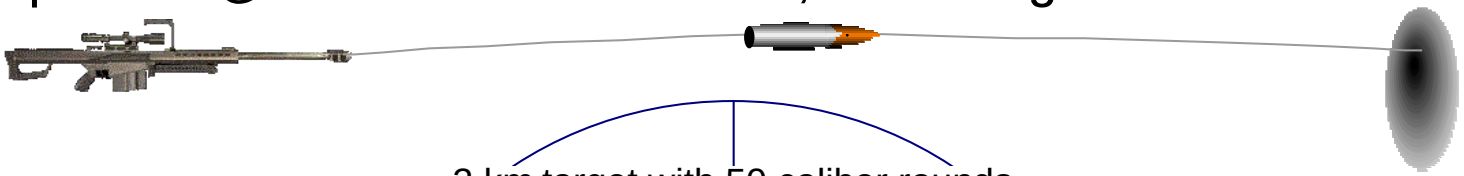
- Increase hit probability
- Increase probability of a kill given a hit
- Reduce total gun system weight fraction

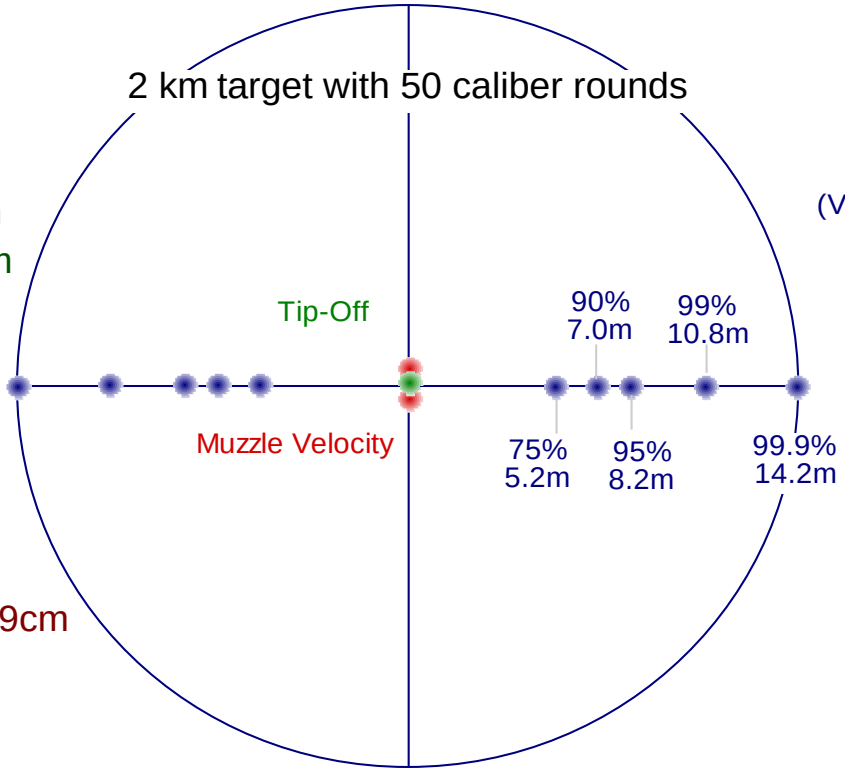
Guiding Small Arms Rounds… More History

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

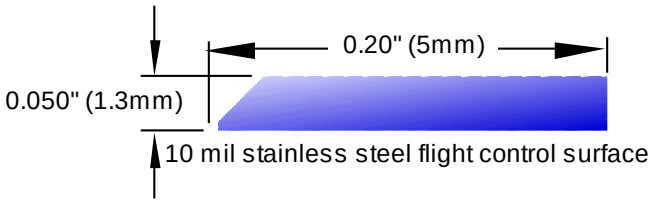
Guiding Small Arms Rounds… More History

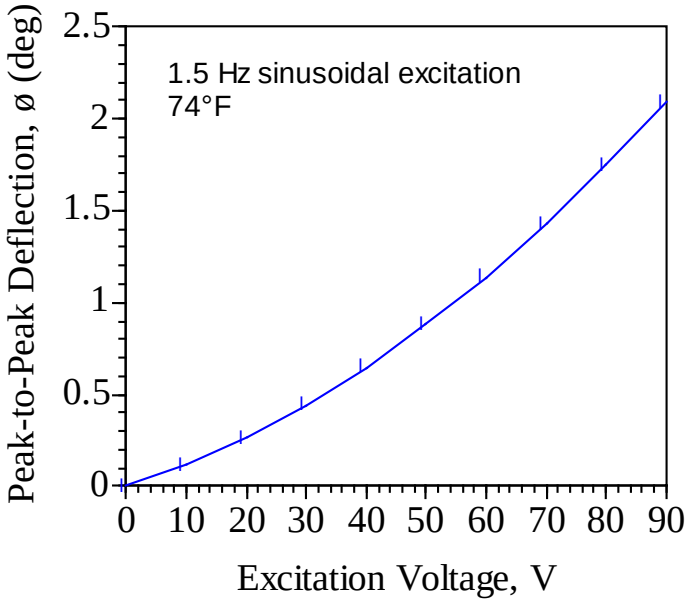
Range-Extended Adaptive Munition (REAM) IRAD 1999 - 2001

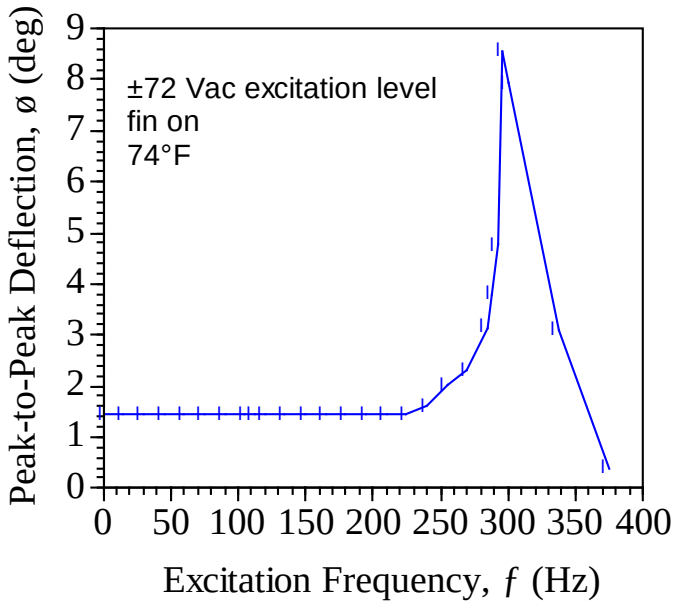
BAT-Lutronix Corp. developed supersonic piezoelectric FCS actuators

Flight Control Surface and Actuator Performance

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





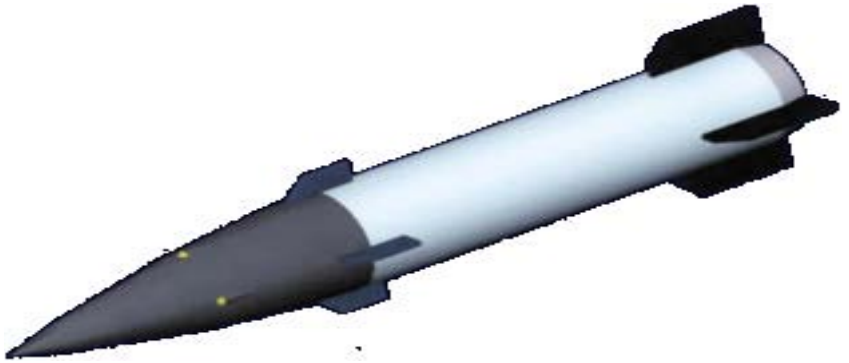


Guiding Small Arms Rounds… More History

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

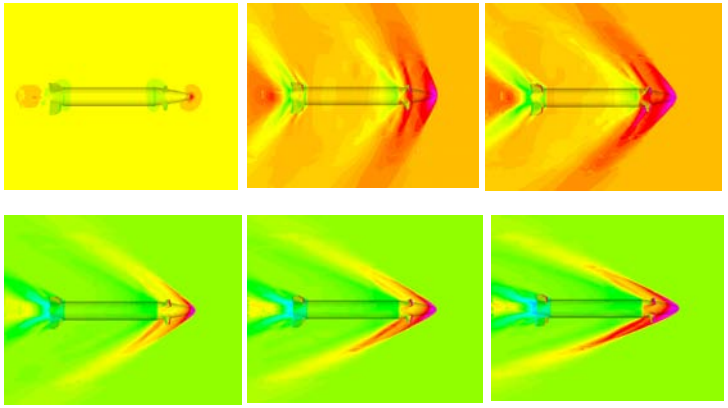
SCREAM Actuator Challenges:

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

Hmmm…

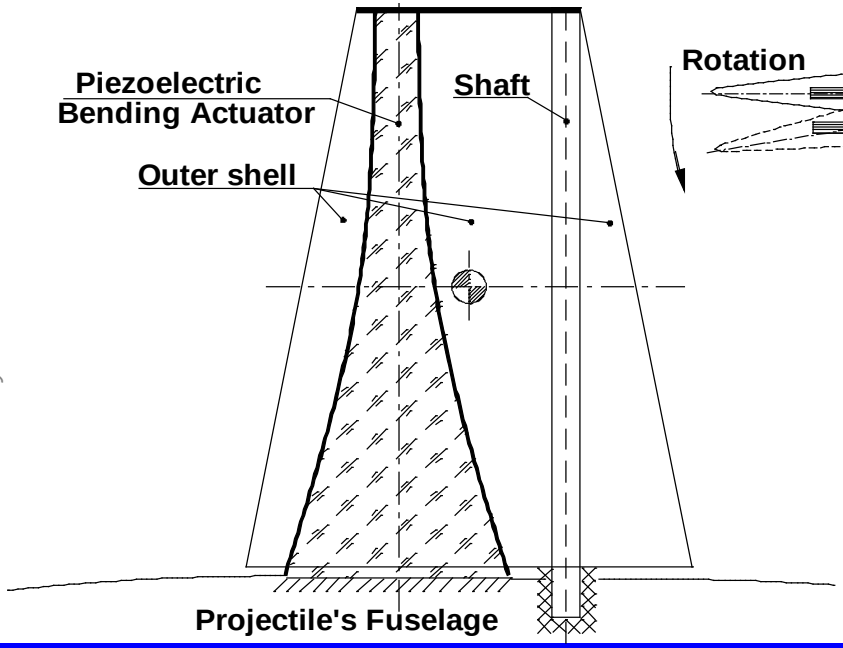
Other Adaptive FCS Efforts

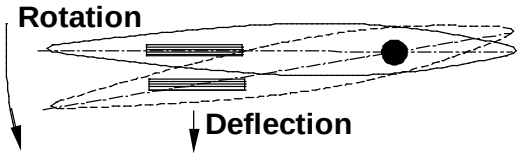
Rabinovitch & Vinson 2000 - present



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

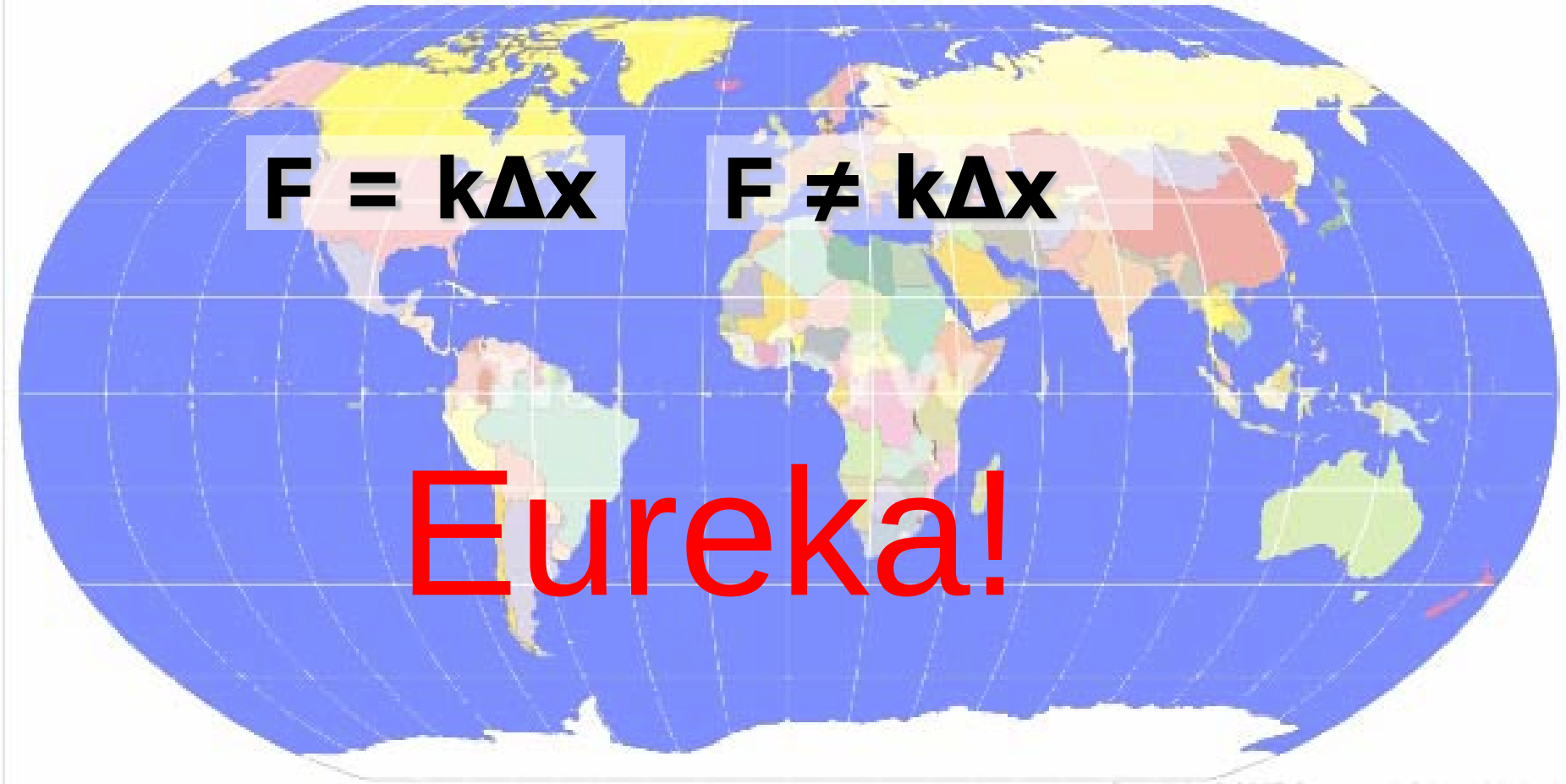
Now Where???





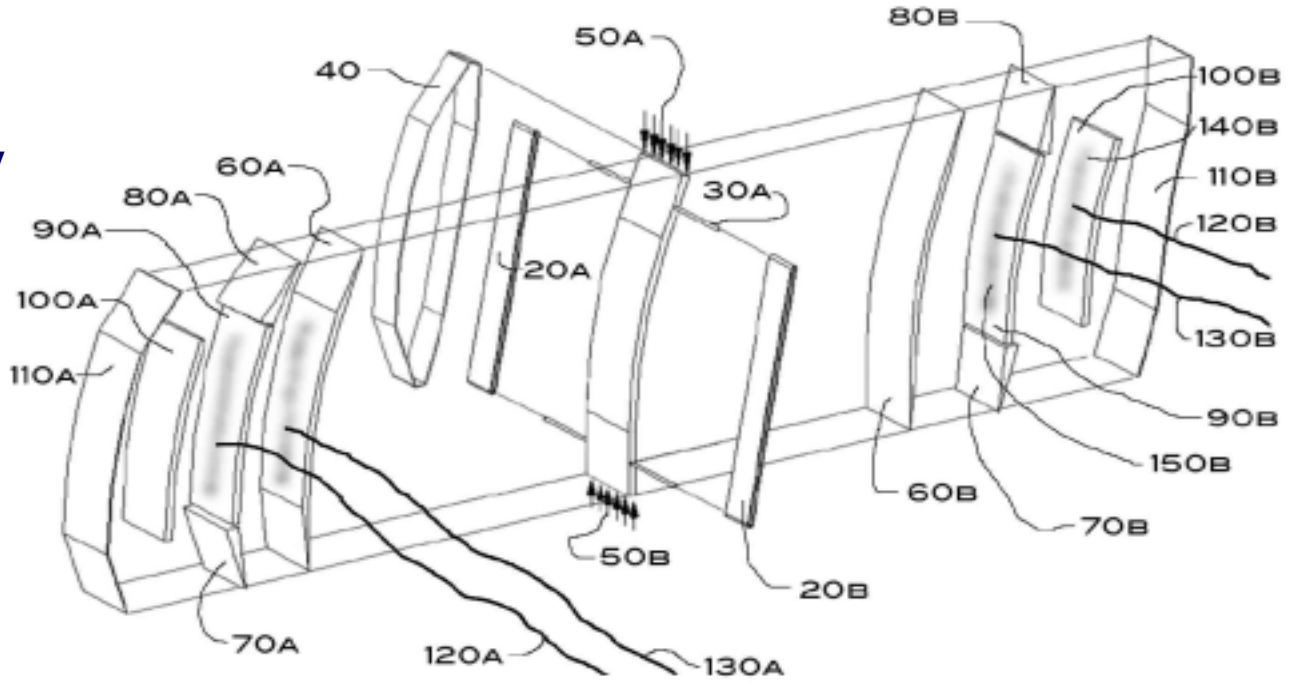
Guiding Hard-Launched Rounds… The Ephphany!

Discoveries from Europe… 2003 - 2004



PBP Actuators: The FCS Solution

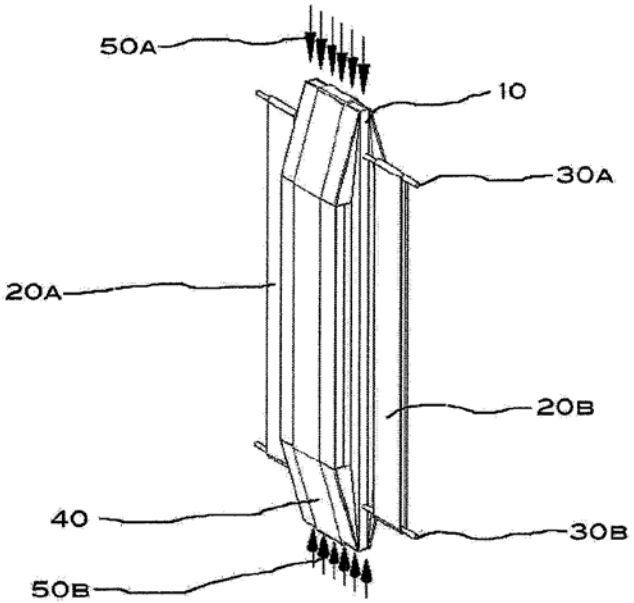
- Fraction of the weight, size & power consumption of US Actuators (i.e. much smaller actuator bays)
- 300+% deflection increases with full force/moment capabilities
- Higher bandwidth
- Lower g-sensitivity
- Lower cost

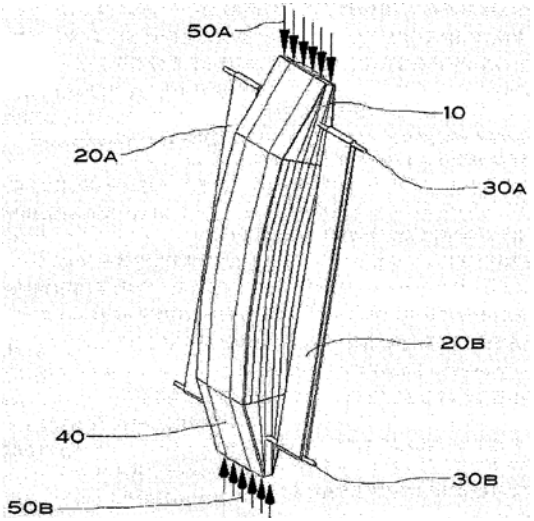


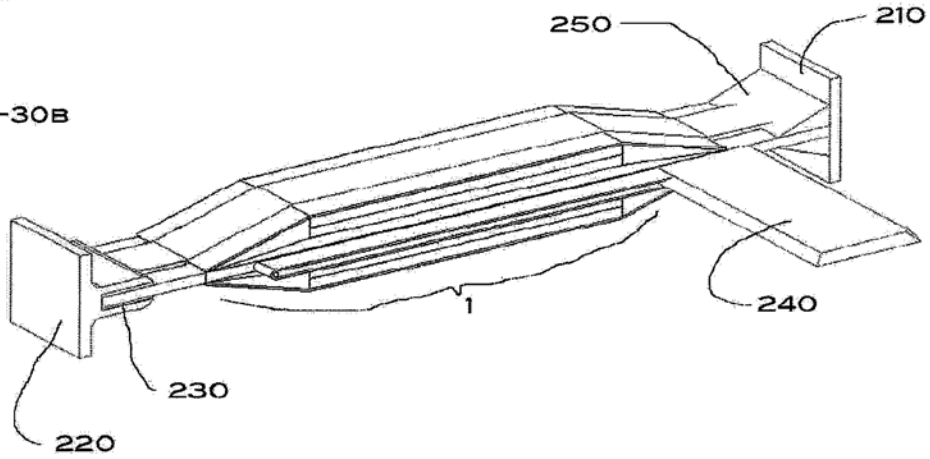
Worldwide patent application: 18 Jan. 2005

PBP Actuators: Actuator Layout

Assembled, functioning actuator:

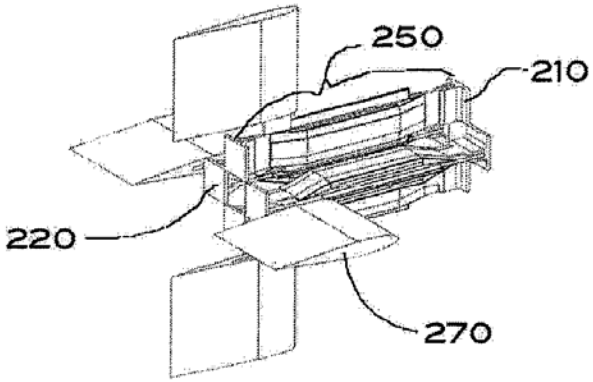


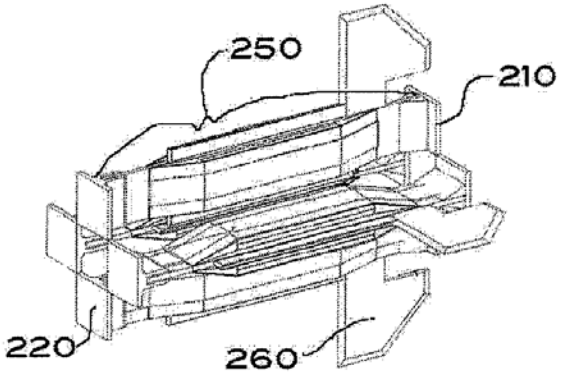


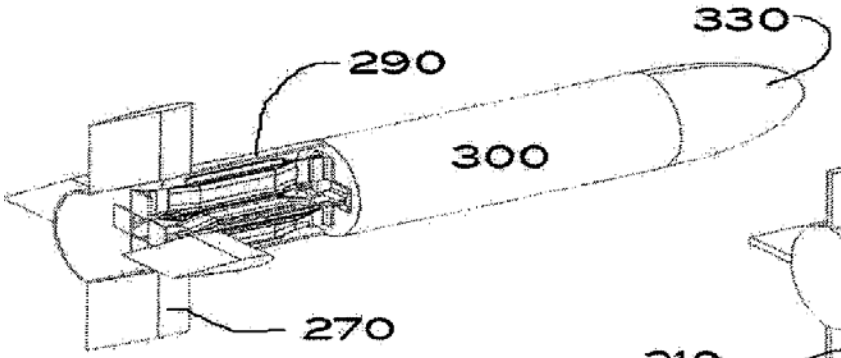


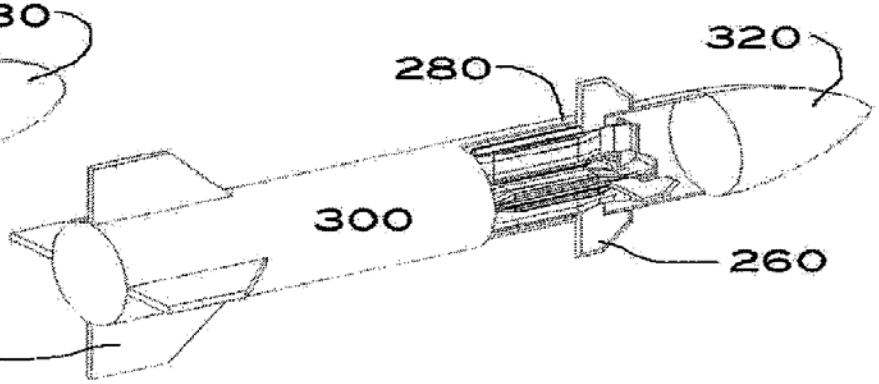
PBP Actuators: Assemblies

Assembled Hard-Launch Capable Actuator FCS Units:





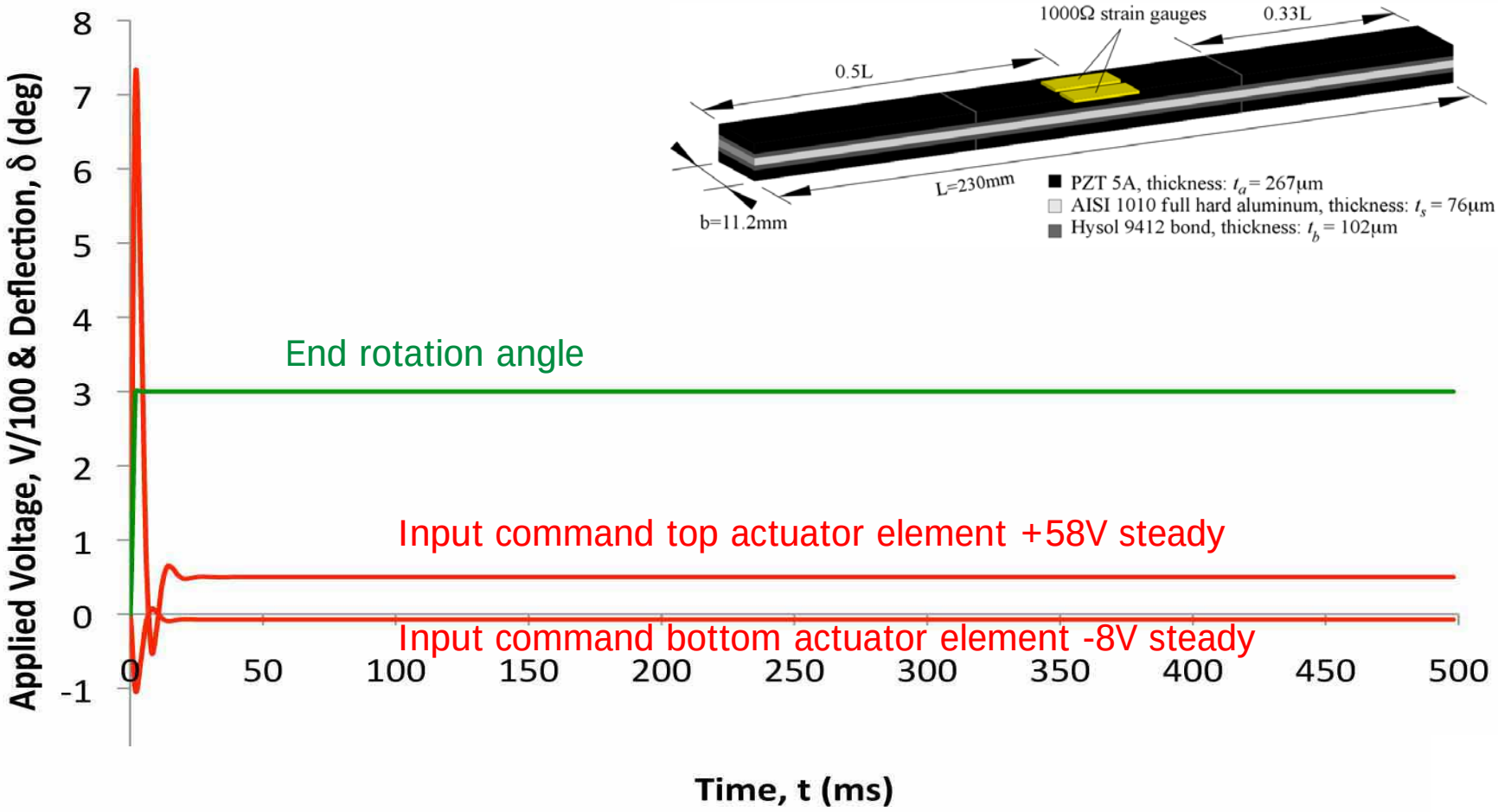




PBP Actuators: Fastest around…

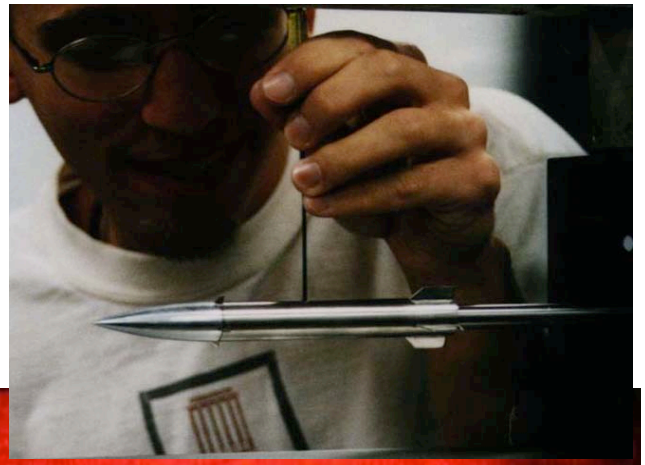
Best performance in the adaptive structures industry:

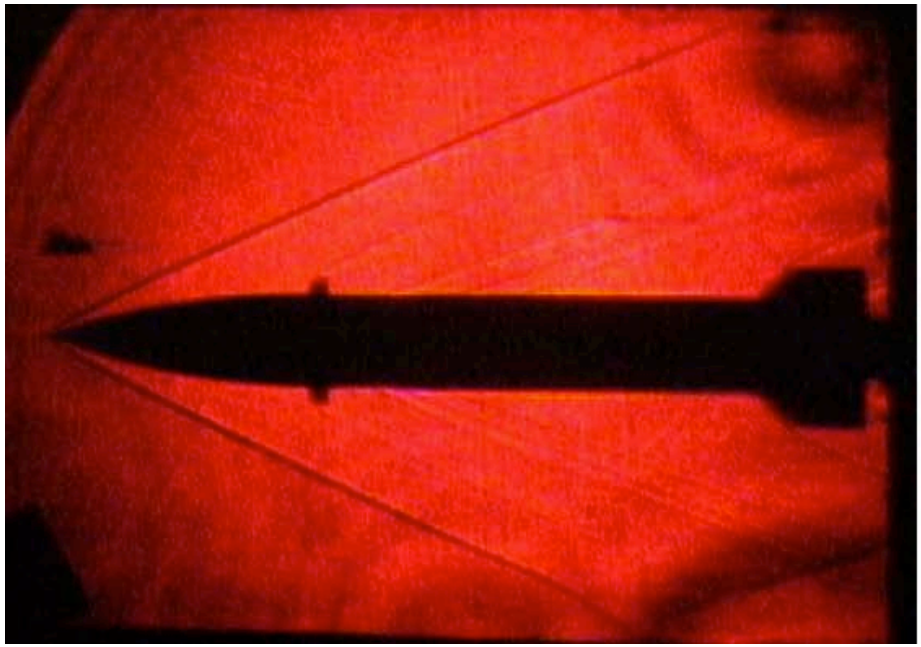
- **1kHz equivalent bandwidth**
- **Driving 0.40/.50 cal Mach 4.5 canards**



PBP Actuators: Real Performance!

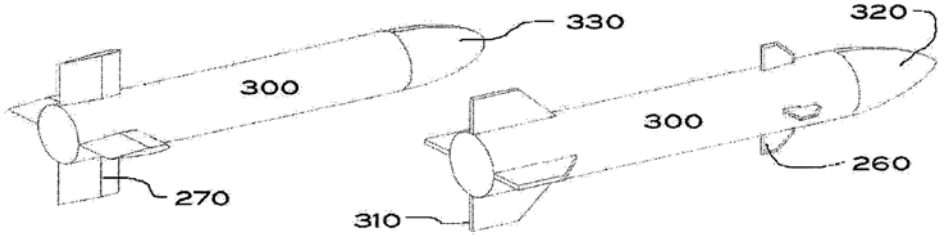
Mach 3 Testing – FCS works well!

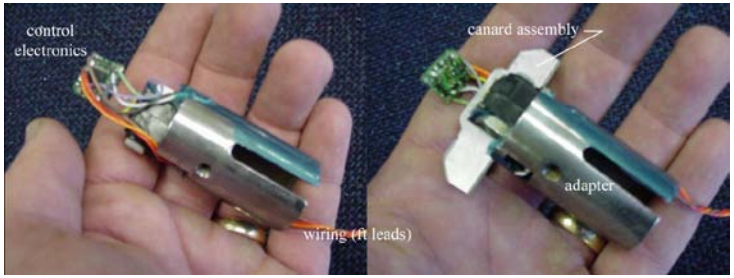




PBP Actuators: Munitions Comparisons

Smaller, Lighter, Cheaper – the Name of the Game

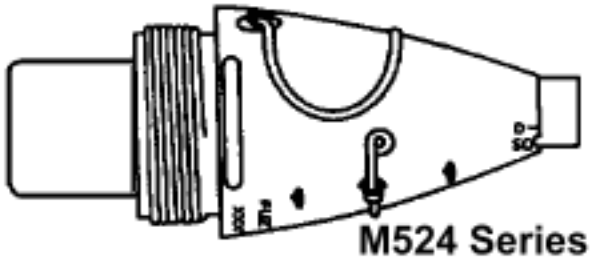




	Conventional Electromagnetic FCS	Adaptive / PBP FCS
Volume	14cc	5.1cc
Mass	69g	4.2g
Peak Power	148W	2.6W
Deadband/Slop	±0.38°	±0.002°
Bandwidth	22 Hz	189Hz
Acquisition Cost (100,000 shipsets)	$187 ea.	$12.30

PBP Actuators: Moving up in caliber to fuses – Easy!

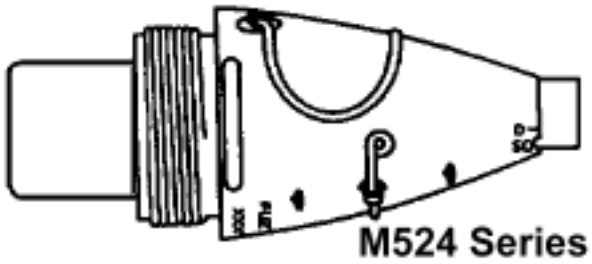
Mortar Fuses



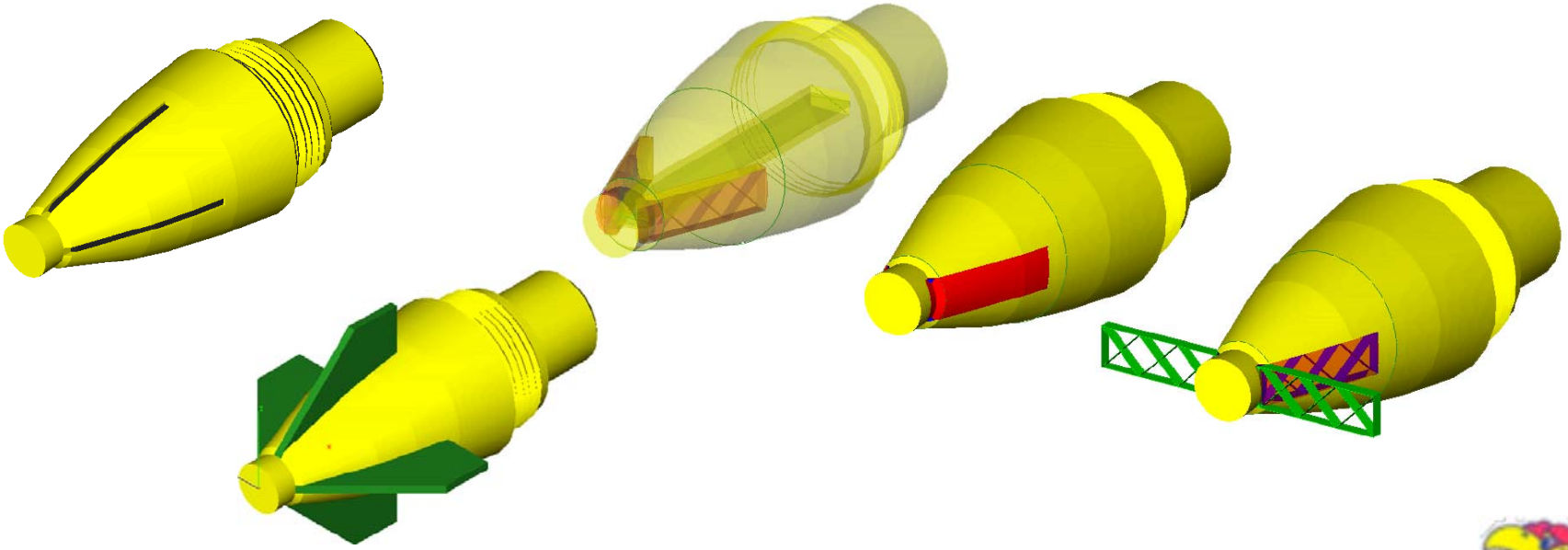
Howitzer Fuses

PBP Actuators: Moving up in caliber – Easy!

Fuse PBP FCS Designs



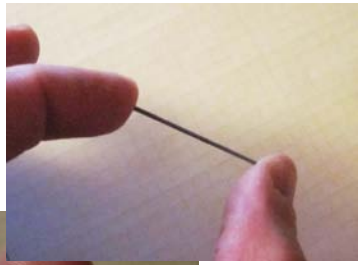
Designs to drive both blade and grid-fin control surfaces full pitch, roll & yaw from apogee for ~8cc volume, through 100 Hz, <1W

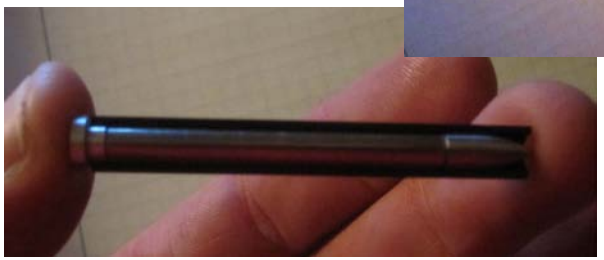


PBP Actuators: The Next Challenge

Bring 0.50 Cal. Sniper Performance to a Weapon with an M-16 Form

- **M-16 form factor**
- **Tight Dispersion @ meaningful ranges**
- **Impervious to 99% atmospherics**
- **Flat trajectory**





$13.81/round (lots of 100,000)

Industrial & Government Partners

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?