



# Adaptive Flight Control Surfaces: Revolutionizing Missile & Munition Flight Control Systems

## Professor Ron Barrett

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

*44<sup>th</sup> Annual Gun and Missile Systems Conference & Exhibition  
Hyatt Regency Crown Center, Kansas City, MO  
8 April 2009*



# Outline:



## *Purpose:*

***Describe to the Missile and Munitions Community the revolutionary weapon systems configurations and missions enabled by modern adaptive materials and aerostructures***



# Outline:



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

***II. History of Programs***

***III. New Actuator Class***

***IV. Current & Future Programs Enabled***

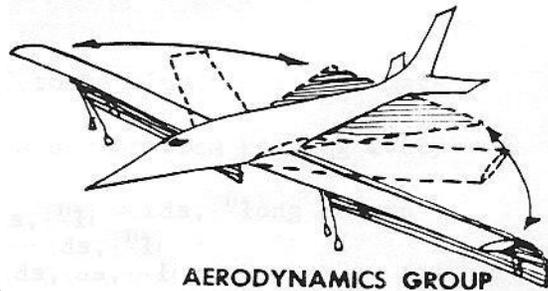
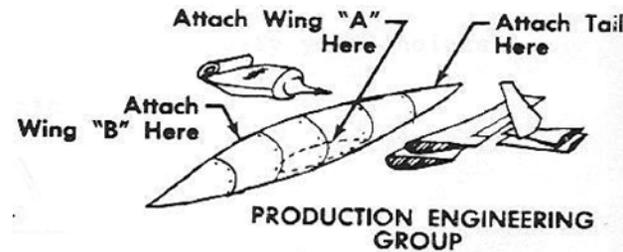
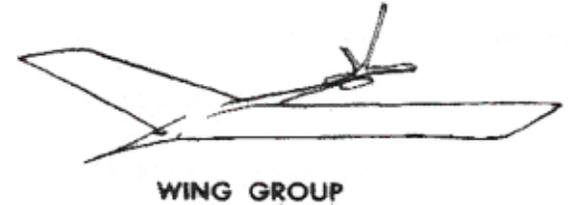


# Adaptive Materials

## ... A Paradigm Shift

### Old Paradigm:

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



### New Paradigm:

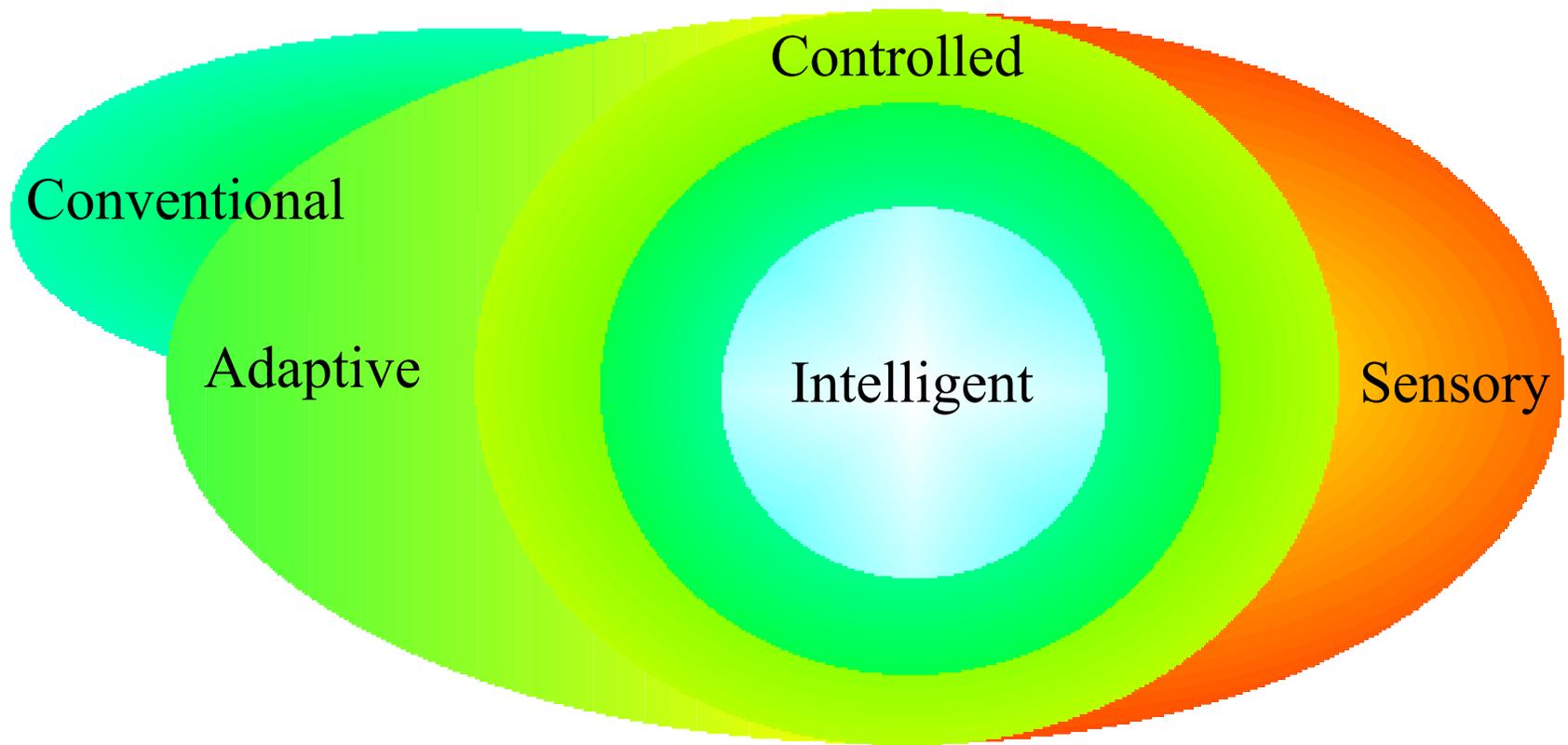
*Structural deformations can be controlled and can therefore be used to enhance mission effectiveness.*

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# Adaptive Materials: A (Very) Brief Introduction

## What are Adaptive Materials & Structures?



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# Adaptive Aerostructures: A (Very) Brief Introduction

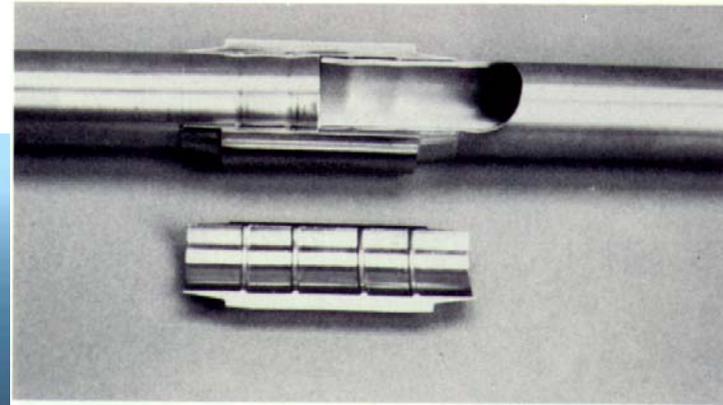
- Most Useful Classes of Adaptive Materials:
  - Shape-Memory Alloy -  
High Deflection, Slow, Lots of Power
  - Variable Rheology Materials -  
Good for clutching and changing stiffness
  - Piezoceramics -  
Very Fast, Low Power
  - Optically Adaptive Materials -  
Newest class, controllable color, luminosity,  
reflectivity, opacity



# Adaptive Materials in Aerospace



*Grumman F-14 the First aircraft fielded with man-made adaptive materials*



*Raychem Corporation Cryofit™ SMA Tube Coupler*



*Raychem Corporation Tinel Lock™ SMA Cable Shielding Termination*

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# Adaptive Materials in Aerospace

*GE90-155B Turbofan on a Boeing 777 Fitted with SMA-Actuated Chevrons*



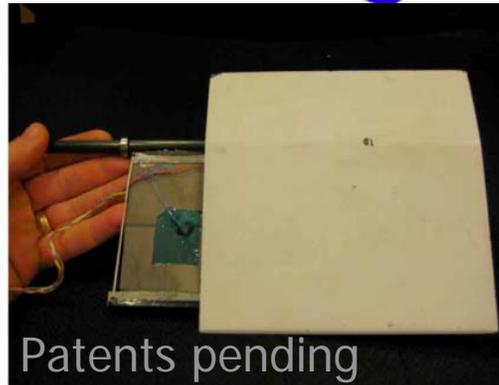
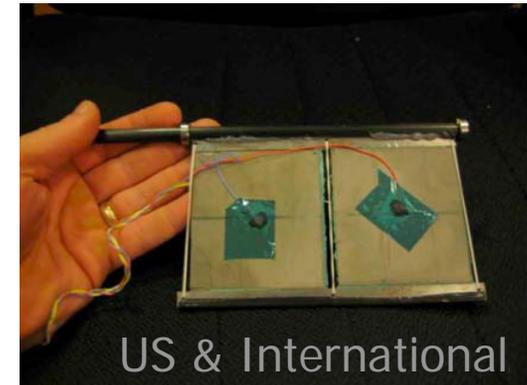
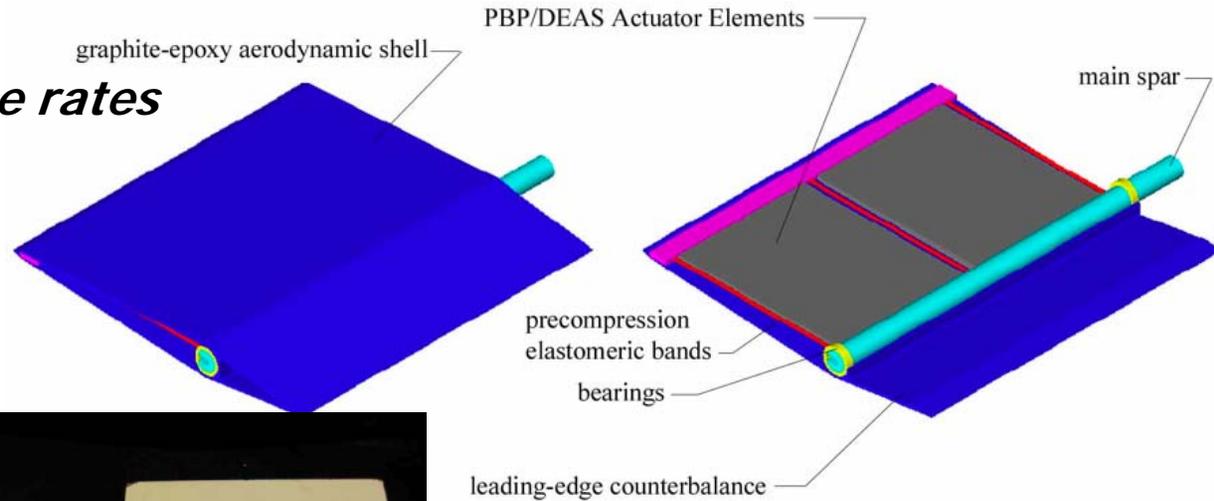
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# Adaptive Flutter Test Surfaces

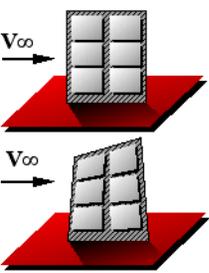
- **Solid State**
- **Order of magnitude less device weight**
- **Order of magnitude less installation weight**
- **Half the acquisition price of the conventional system**
- **Half the installation price and downtime of the conventional system**
- **Exacting Phase Control**
- **Flight Rated to Mach 3**
- **Half the flutter insurance rates**



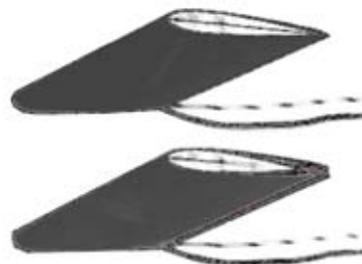
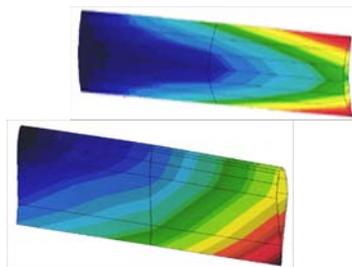
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# Early Adaptive Aerostructures

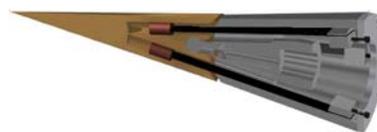


Twist & camber-active subsonic & supersonic wings



1st Pitch-Active Missile Fins

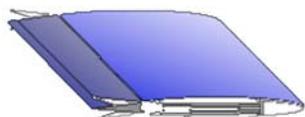
1st Adaptive Gun-Launched Munitions



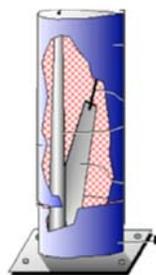
1st Adaptive Gravity Weapons

1985 1990 1995

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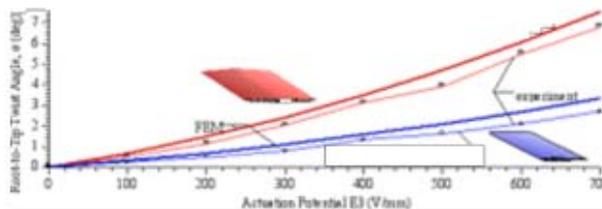


Twist-active plates & flaps

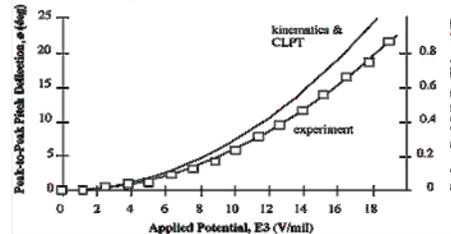


Crawley, Andersen, Spangler, Hall, Lazarus (MIT)

Good theory-experiment correlation



Flexspar Stabilizers



1st Flying Adaptive UAV



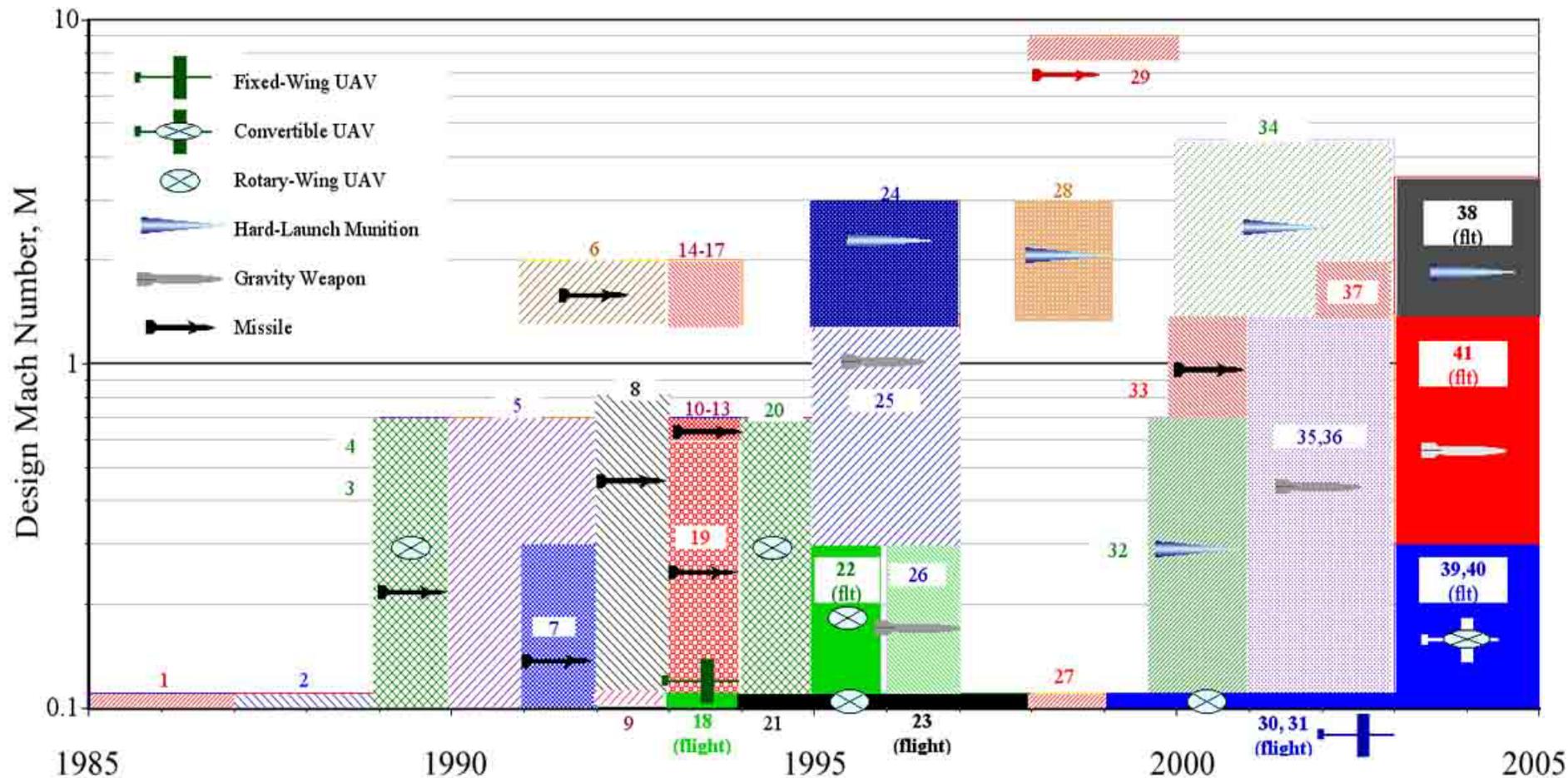
# First 20 years of Programs with Lineage to Flying Adaptive UAVs

	Project	Modeling Technique		Test Techniques			Sponsor
		Closed FEM or CLPT		Bench	Stand or Flight Tunnel		
21	'94-95 Aeroservoelastic Flexspar Fin	3	3	3	3		AAL
22	'95-96 Solid State Adaptive Hiller Servopaddle Rotor (Gama) (Gama)	3	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 (	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 W	3	3	3	3	3	WL/MNAV/Boeing

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# Overview of Programs with Lineage to Flying Adaptive UAVs



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# Brief Guided Round History

## M712 Copperhead 1975



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QuickTime™ and a MPEG-4 Video decompressor are needed to see this picture.

QuickTime™ and a decompressor are needed to see this picture.

QuickTime™ and a decompressor are needed to see this picture.

QuickTime™ and a H.264 decompressor are needed to see this picture.

## XM 982 Excalibur & ERGM



# Guided Round History

Reducing the caliber...

**M 247 Sergeant York 1977 - 1985**



QuickTime™ and a  
MPEG-4 Video decompressor  
are needed to see this picture.



# Guided Round History

## How to guide subscale rounds?

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

- Setback tolerance: 30,000 - 100,000g's
- Balloting, setforward, ringing impervious
- Compatible with supersonic control effectors
- Not affected by atmospherics (rain, dust, dirt, snow, etc.)
- High feedback command fidelity maintained during all flight phases
- 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



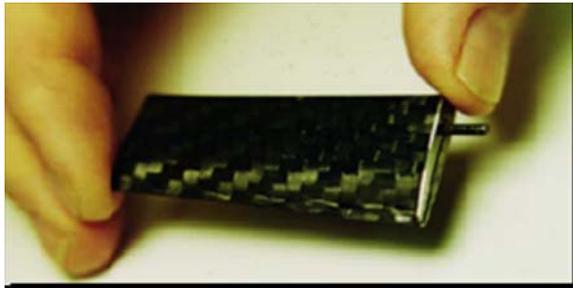


# One possible solution... from the MAV world

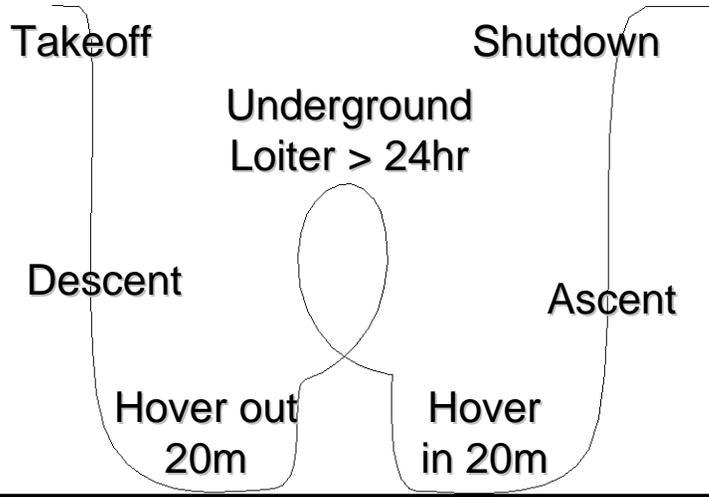
The 1st Micro Aerial Vehicle (MAV) -- by the DoD CounterDrug Technology Office 1994 - '98

QuickTime™ and a H.264 decompressor are needed to see this picture.

Enabled by Flexspar Piezoceramic Stabilators

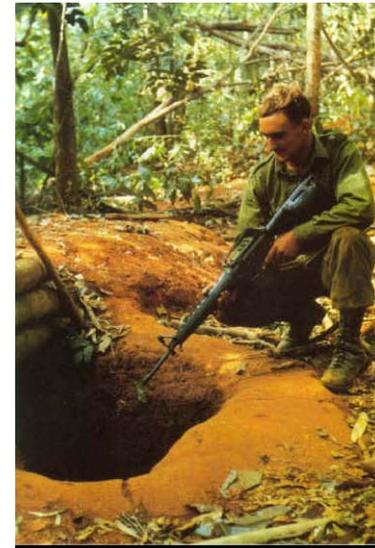


## Mission Profile:



Stabilator Characteristics:

- total mass 5.2g
- actuator mass: 380 mg
- max. static deflections:  $\pm 11^\circ$
- max power consumption: 14 mW
- pitch corner frequency: 47 Hz
- first natural frequency in pitch: 23 Hz



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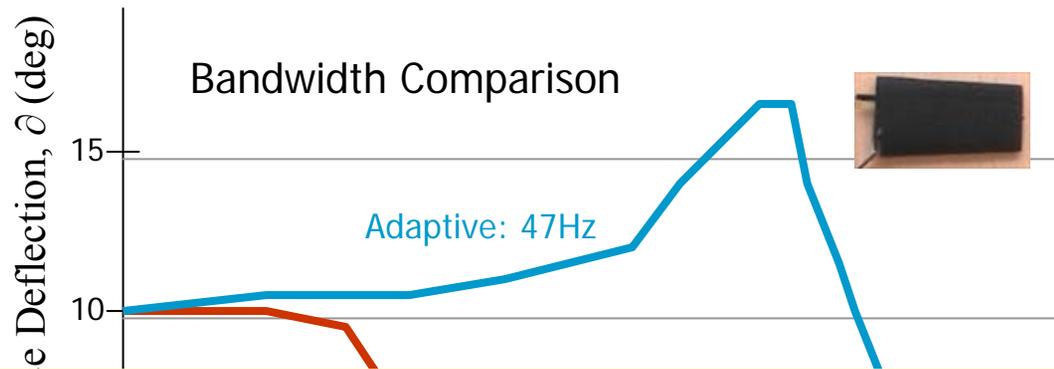
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# Advanced UAVs: Driving the need for Adaptive Actuators -- faster, lighter, stronger



## Adaptive Surfaces vs. Conventional Servos

- 96% reduction in power consumption
- 16x increase in bandwidth
- 99.2% decrease in slop
- 12% OWE savings
- 8% MGWTO savings

Operating Empty Weight Fraction



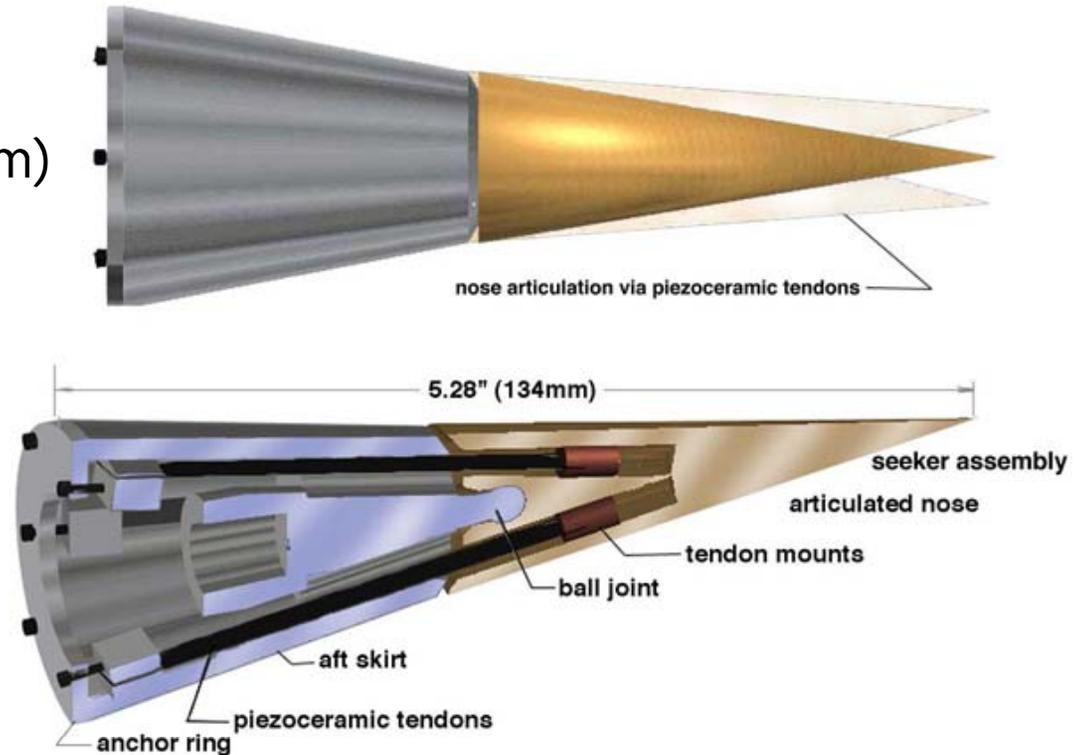


# Guiding Lower Caliber Rounds... More History

## Barrel-Launched Adaptive Mmunition (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



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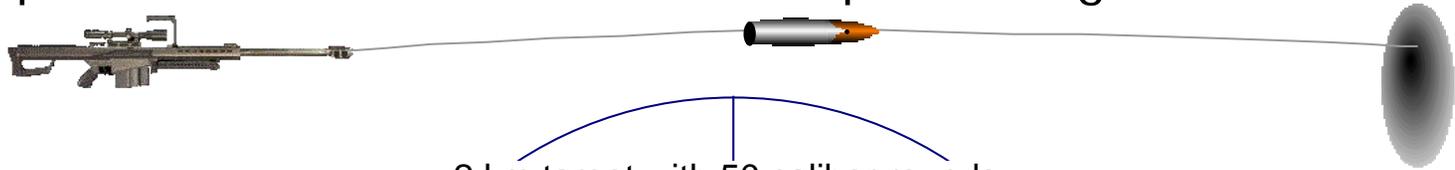


# Guiding Small Arms Rounds... More History

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

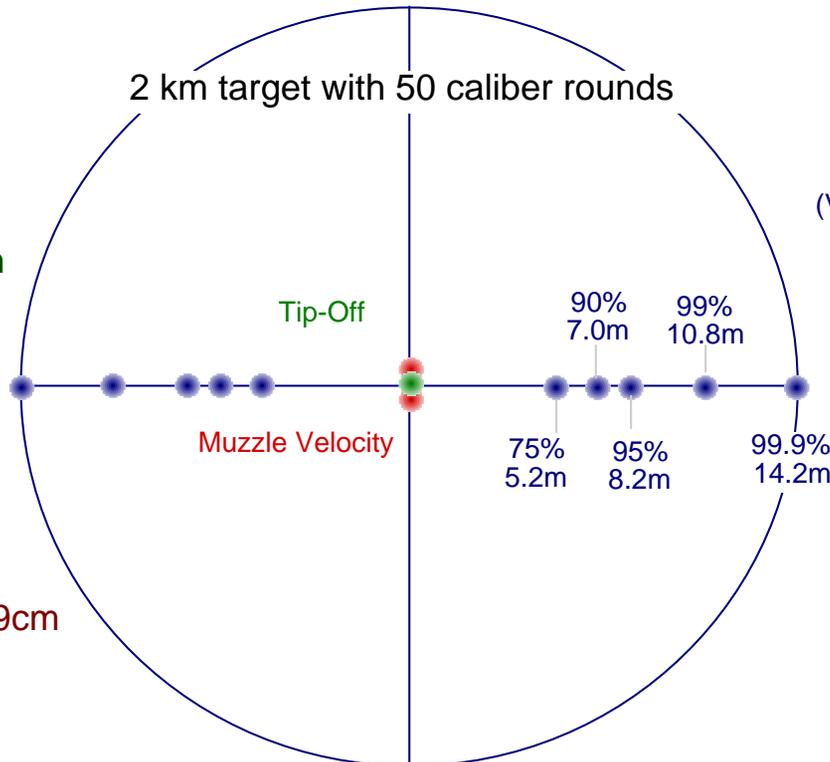
TACOM-ARDEC (Picatinny-APG) Phase I SBIR

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



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

Muzzle Velocity  
 1% change error ~ 99cm



Crosswinds  
 (Von Kármán Spectrum)

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

$V_{av} = 4.03$  kts

75th%: 5.21 kts

90th%: 6.95 kts

95th%: 8.15 kts

99th%: 10.7 kts

99.9%: 14.2 kts

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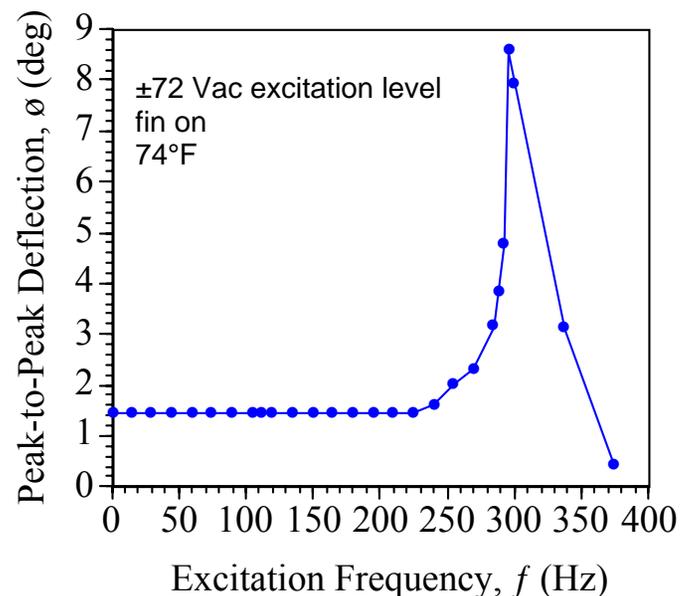
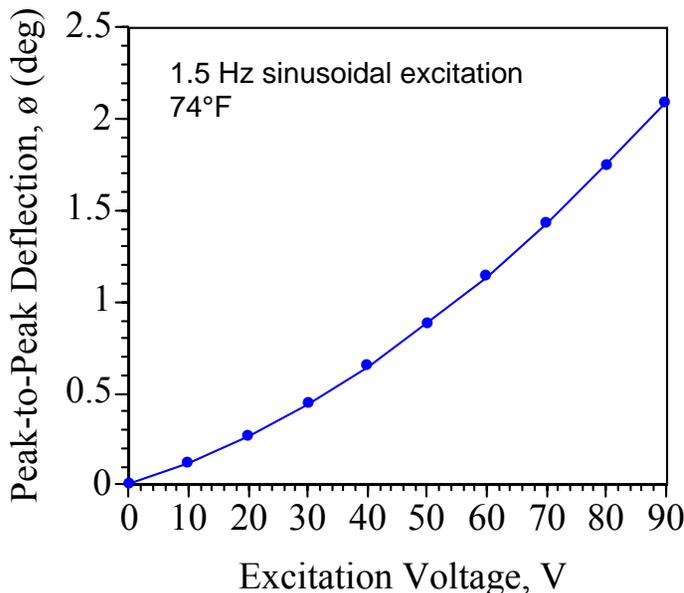
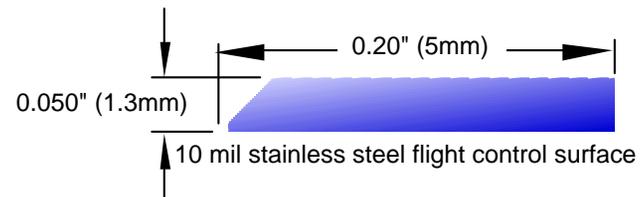
# Guiding Small Arms Rounds... More History

## 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



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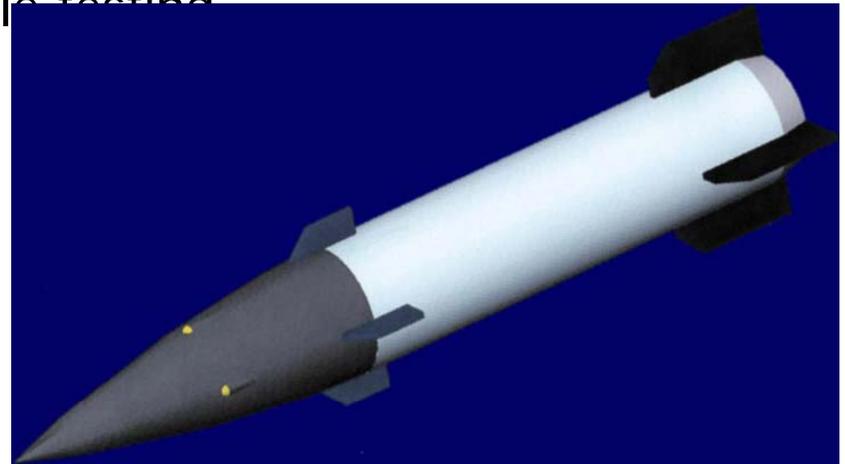
# Guiding Small Arms Rounds... More History

## 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

QuickTime™ and a  
MPEG-4 Video decompressor  
are needed to see this picture.





# Guiding Small Arms Rounds... More History

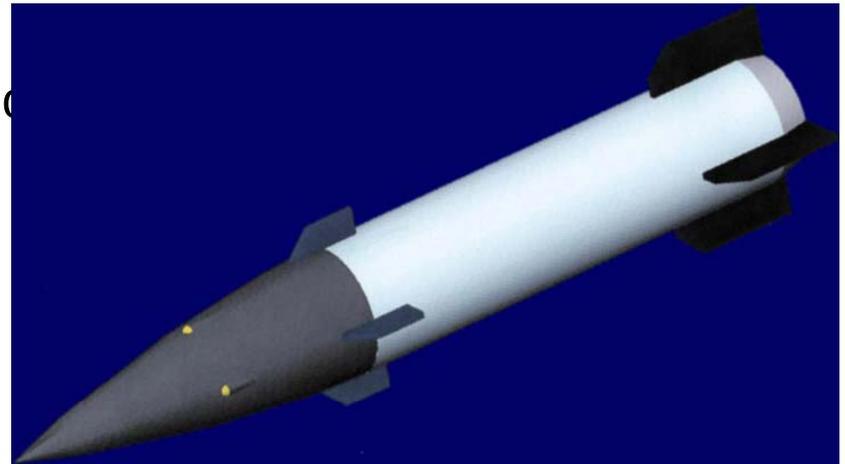
## Shipborne Countermeasure Range-Extended Adaptive Munition (SCREAM) Program 2001 - '03

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 c

Now Where???





# Guiding Small Arms Rounds... The Ephphany!

Discoveries from Europe... 2003 - 2004



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# PBP Actuators: Real Performance!

- Fraction of the weight, size & power consumption of US Actuators  
(i.e. much smaller actuator bays)
- 200+% deflection increases
- Higher bandwidth
- Lower cost
- Lower g-sensitivity

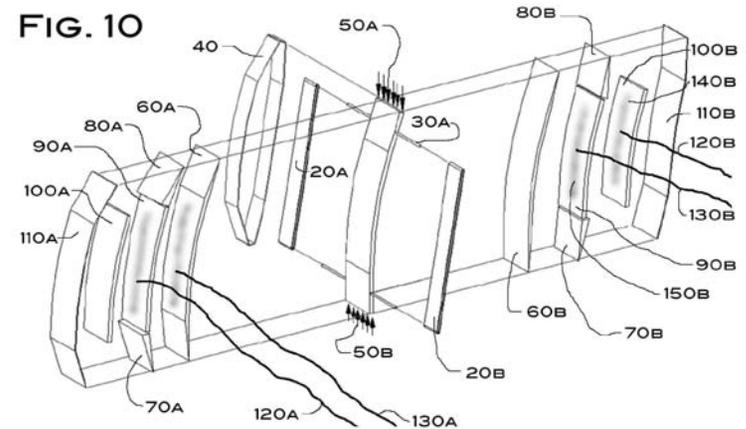
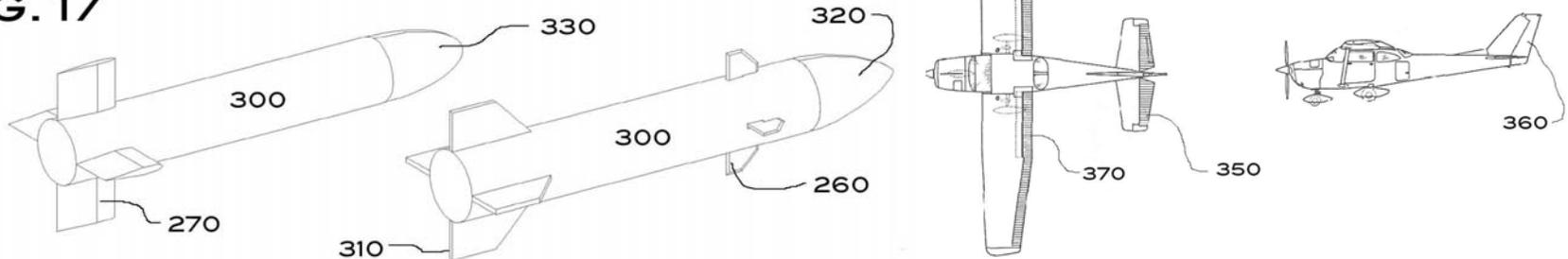


FIG. 17



Worldwide patent application: 18 Jan. 2005

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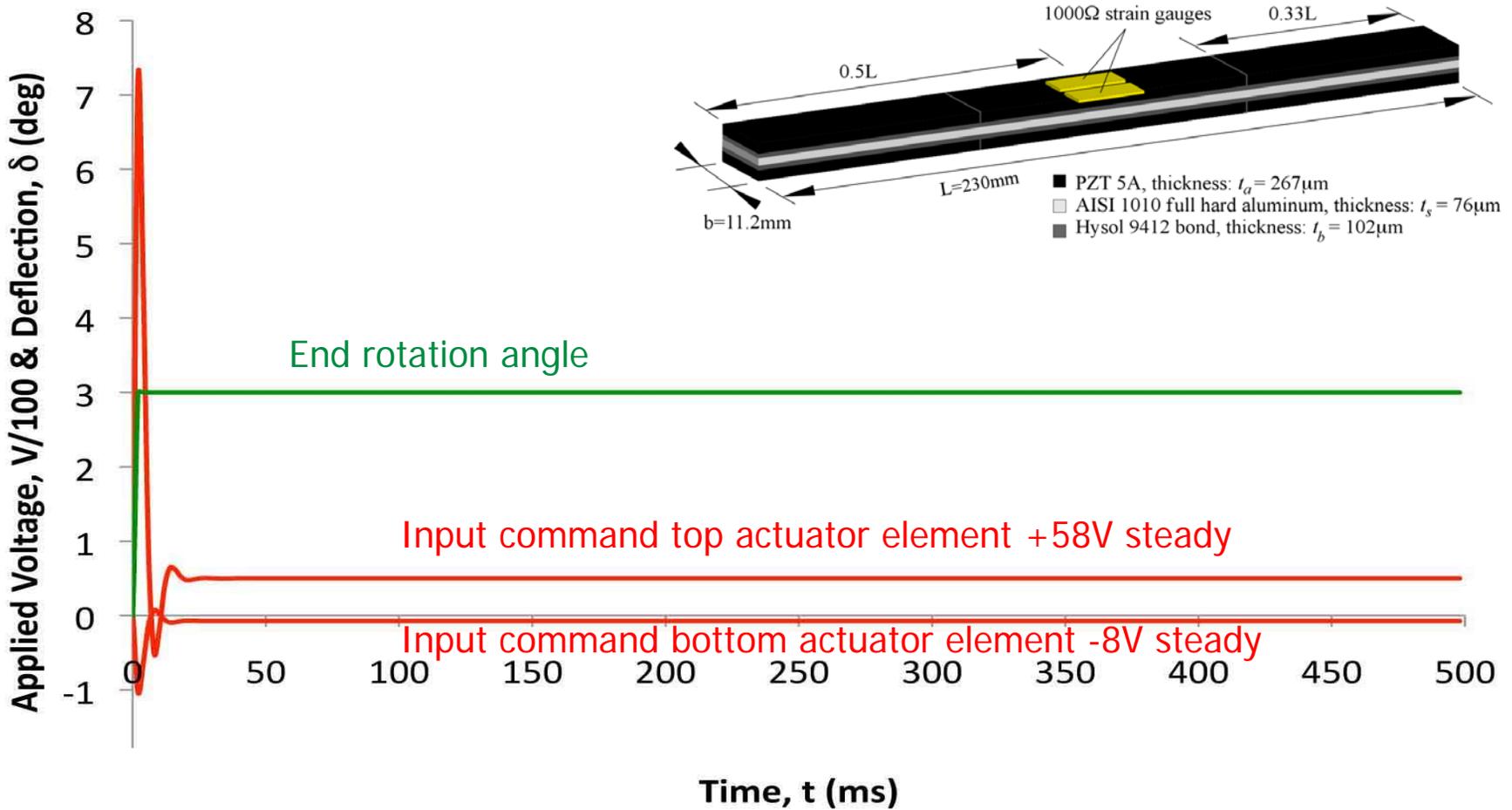




# PBP Actuators: Real Performance!

Best performance in the adaptive structures industry:

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

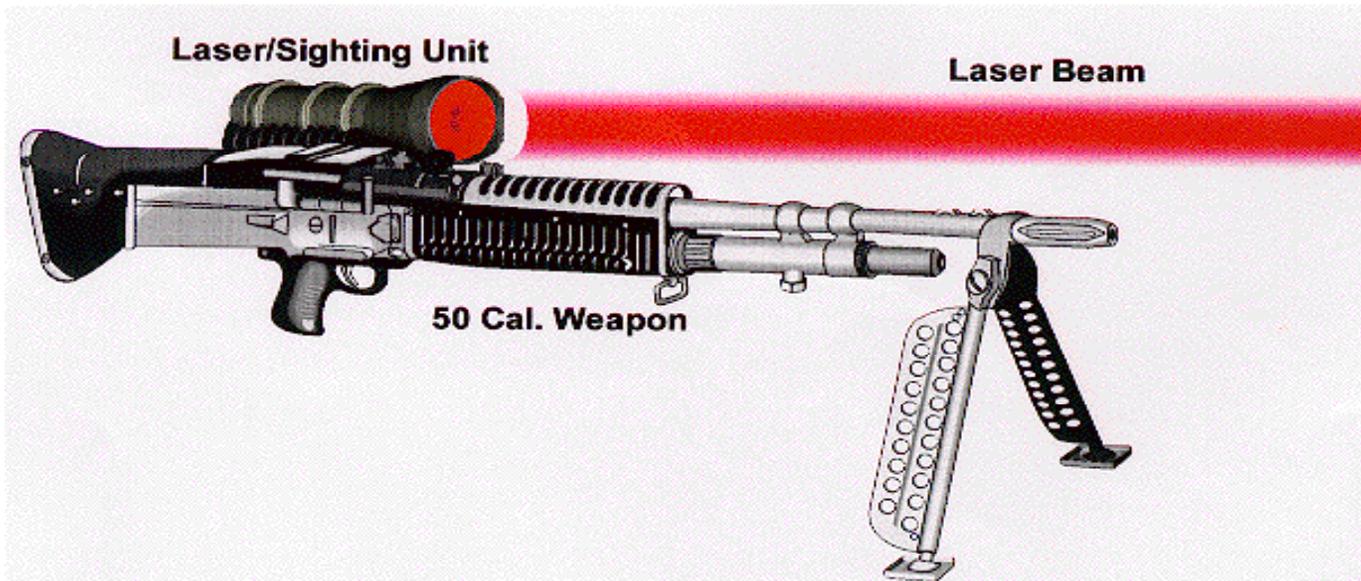


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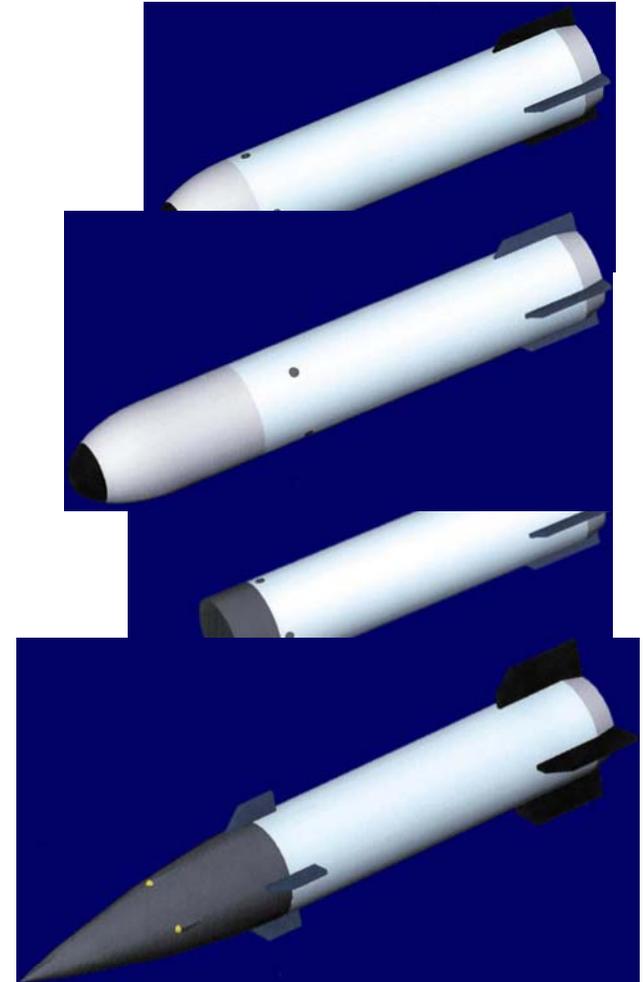
# PBP Actuators: What to do with them???

- Guided rounds of many calibers
  - Lethal & nonlethal missions
- Countermunitions



# Families of Steered Piezoelectric Enhanced Adaptive Rounds (SPEARs)

- Roll Stabilized Recon. SPEAR
- Full Control Recon. SPEAR
- Full Control KE SPEAR
- High Maneuverability/ Counterweapon SPEAR





# Countersniper with SPEARs & Nanemometers

Nanemometers sense not pressure,  
but 3-D particle velocity



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# Countersniper with SPEARs & Nanemometers

QuickTime™ and a  
MPEG-4 Video decompressor  
are needed to see this picture.

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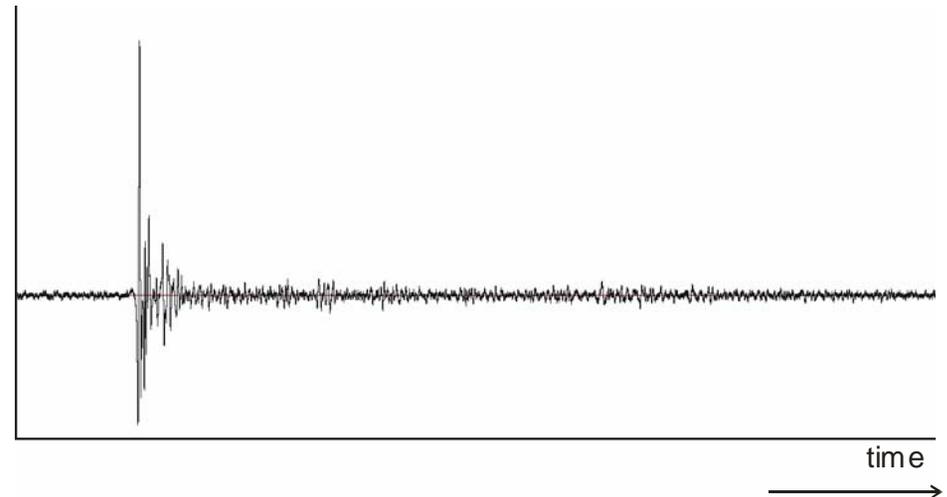


# Countersniper with SPEARs & Nanemometers

## Gun shot localization



- Real time
- > 1km for hand gun
- Single sensor





# Countersniper with SPEARs & Nanemometers

QuickTime™ and a  
H.264 decompressor  
are needed to see this picture.





COTS  
technology

inactive fins

# Roll Stabilized SPEAR

"Look Over the Hill"

Supersonic MAV mission tungsten nose



active  
fins

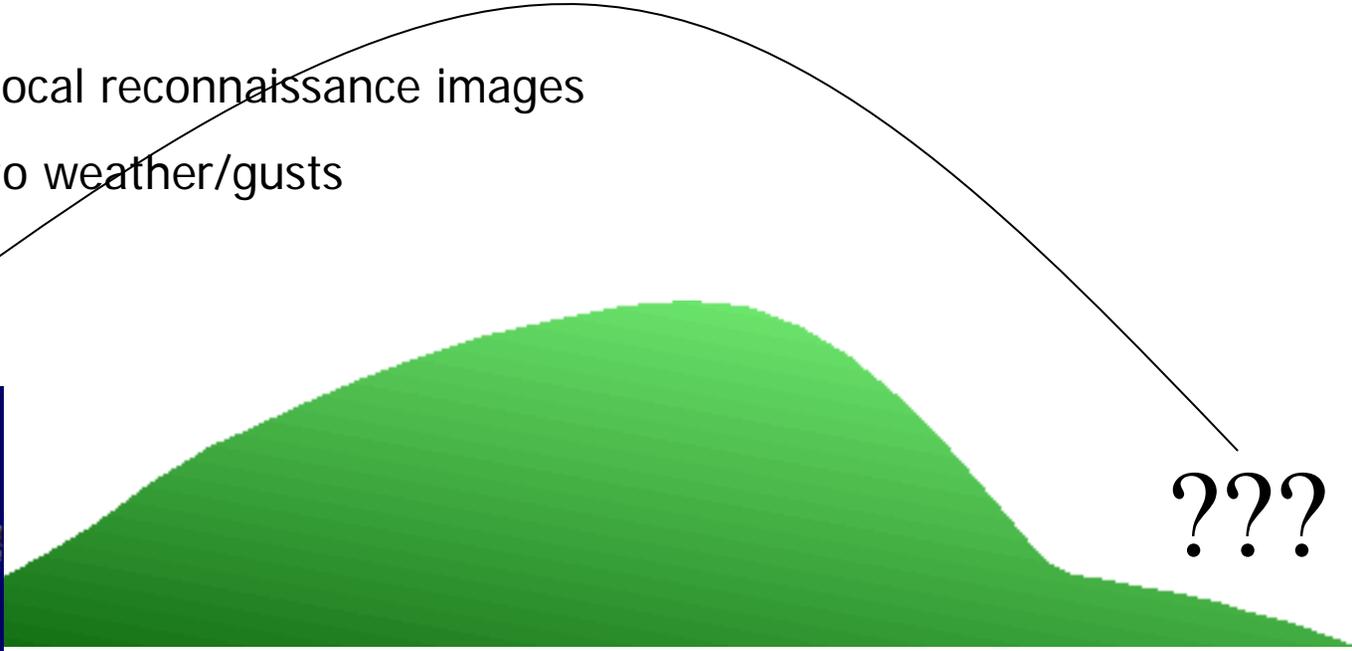
camera

rollsonde sensors

Tactical Benefits:

- Fastest way to get local reconnaissance images
- Totally impervious to weather/gusts
- ~ \$20/round

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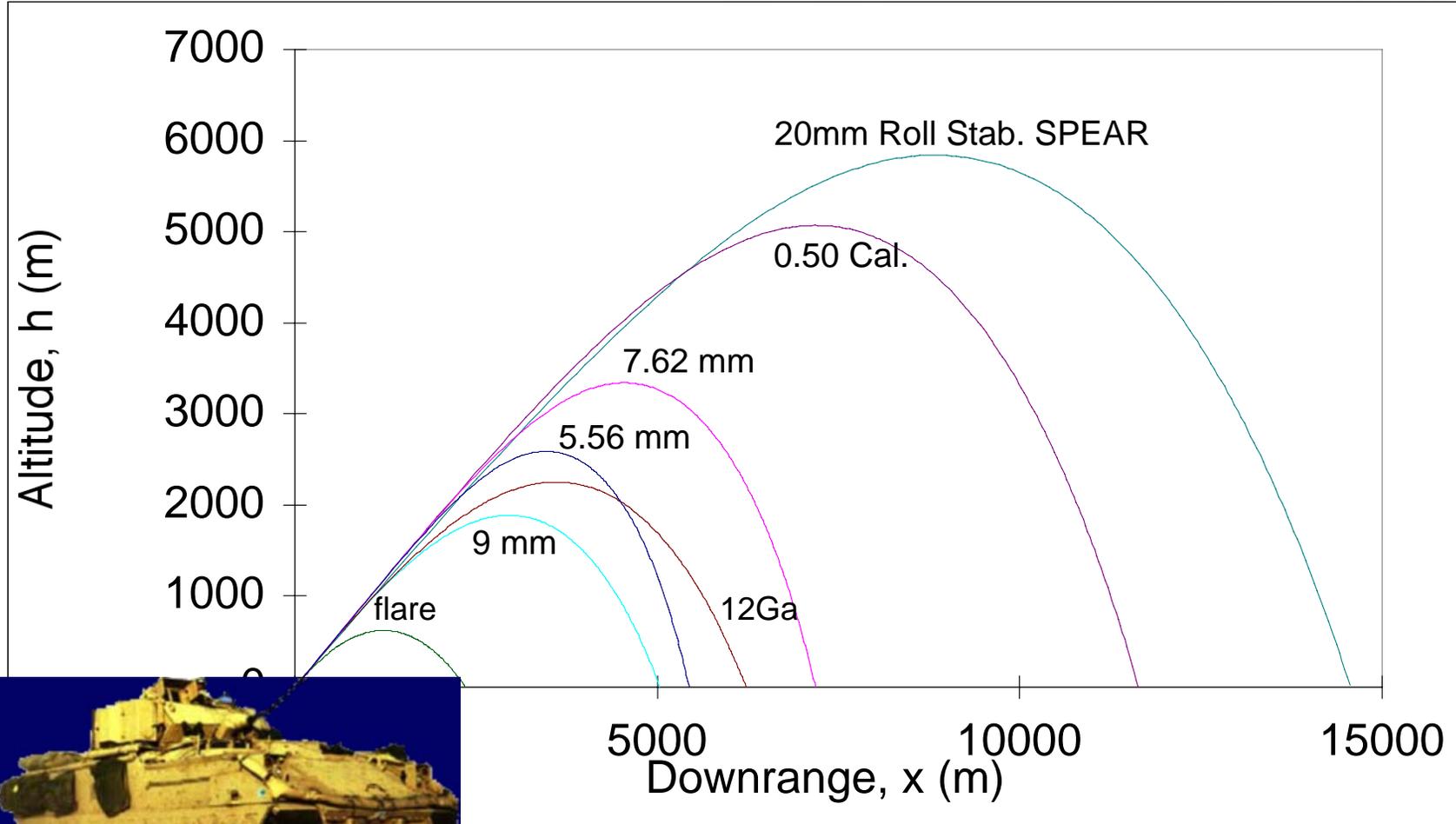
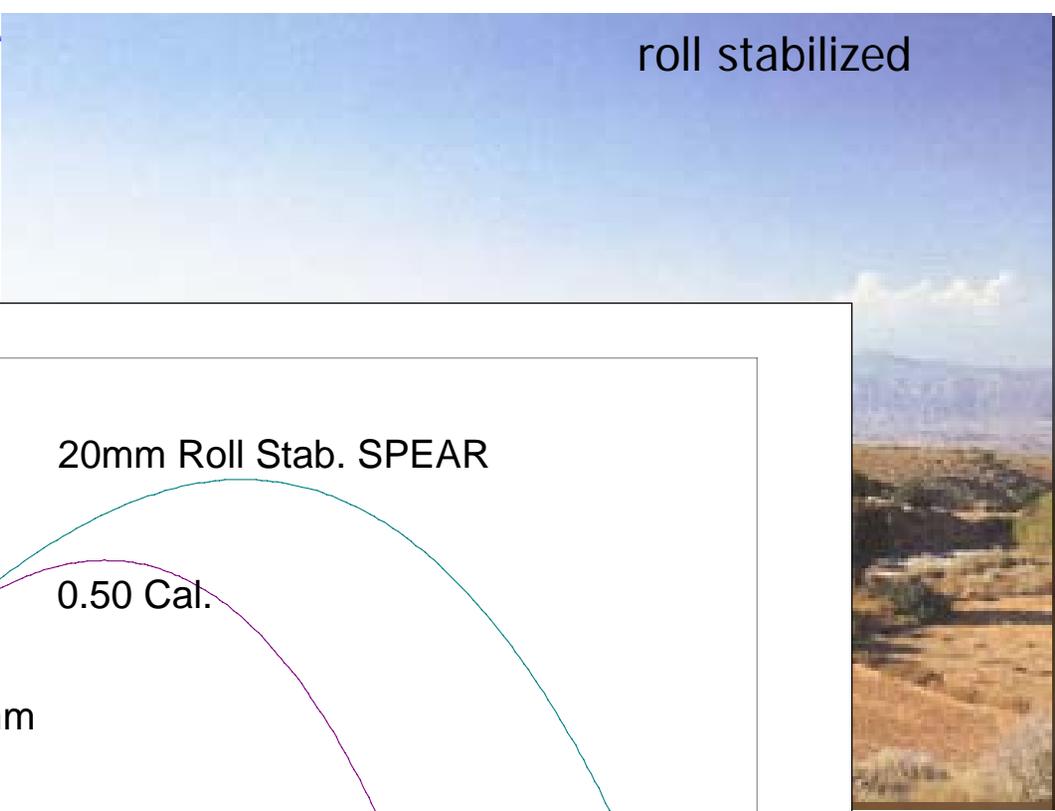
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# Roll Stabilized Recon. SPEAR



# Full Control Recon. S

Full Battlefield

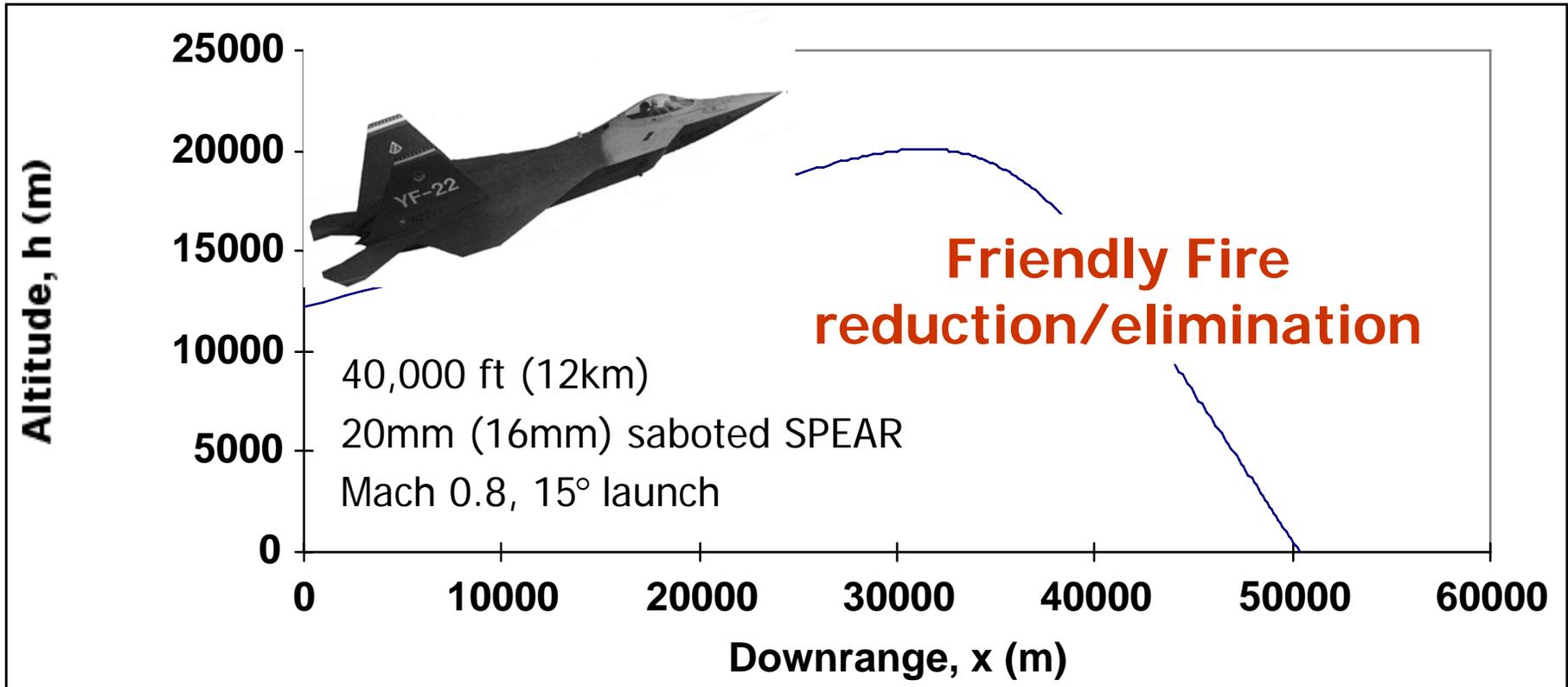
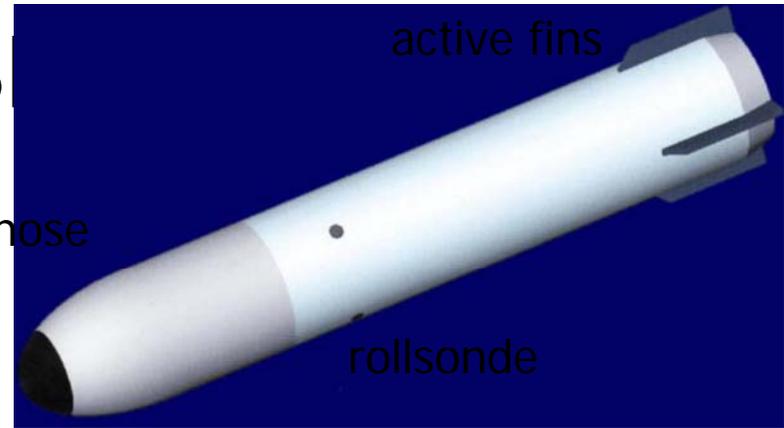
Reconnaissance

tungsten nose

camera

active fins

rollsonde



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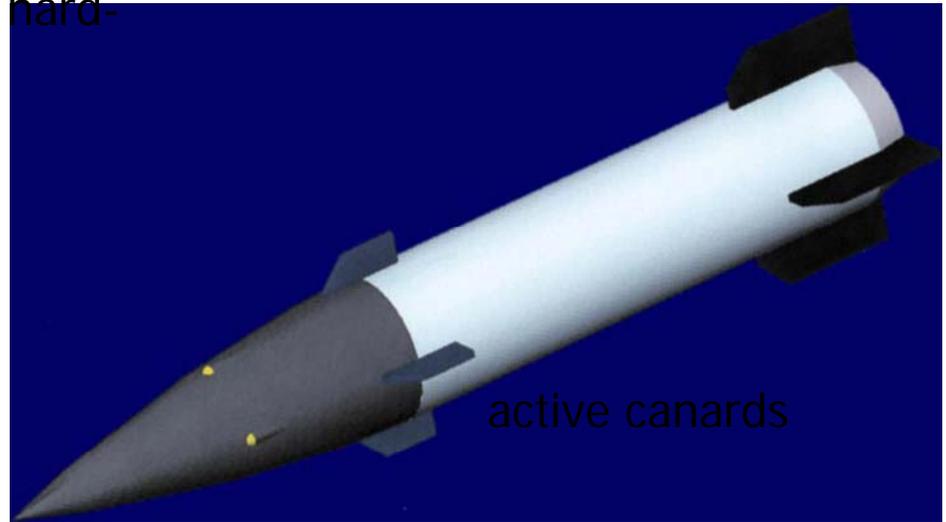


# Weapon/Counterweapon SPEAR

## Weapon mission:

Impart high-g missile performance to hard-launch projectiles

inactive fins



active canards

tungsten tangent ogive nose

## Counterweapon mission:

Defeat all Higher Caliber Weapons

## Method:

- Overmatch Bandwidth
- Overmatch Control Authority
- KE and/or HE

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# Counterweapon SPEAR

Selected Missions

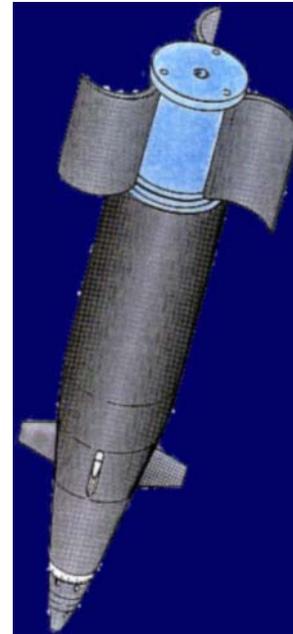
*Counter artillery*  
*Counter gravity weapon*



*Air superiority & invulnerability*



*Transport Protection*



*High-g sea-skimming missile defeat*

*Countersniper*

*Counter small arms*



*Vehicle & Structure Protection*



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# Sniper Threat Defeat

## Change in Gun & Projectile Design Philosophy

### Old

- Big Gun w/long rifled barrel
- Highly toleranced barrel
- Stiff barrel
- High tolerance on powder, rounds
- Hard-mounted sight
- Incapable of self-defense mode

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- Unguided, spinning rounds
- Rounds fly ballistically
- Rounds vulnerable to winds, elevation, etc.
- Target moves in 1-3 sec. TOF

### New

- Light, smooth barrel gun
- Looser barrel tolerances
- Less stiff barrel
- Insensitive to variations in charge
- Gyrostabilized floating sight
- Can fire unguided, rounds rapidly for self defense



- Guided despun rounds
- Rounds fly flat trajectory
- Rounds insensitive to winds, elevation, etc.
- Target tracked

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# Guided Indirect Fire Aerial Rounds

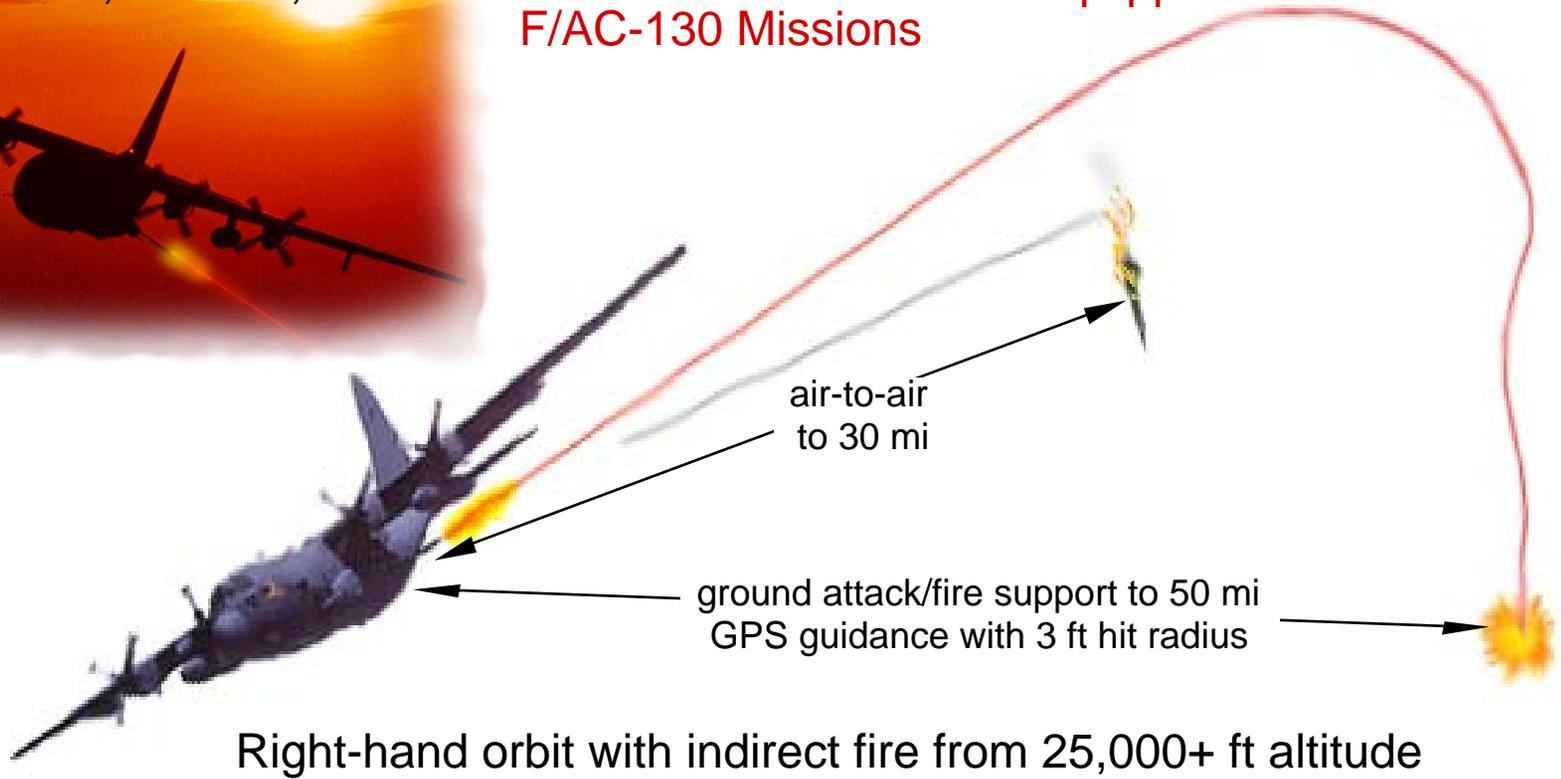
**Increase stand-off range & accuracy of fire support/ground attack by an order of magnitude**

## Current/Conventional Approach

Left-hand orbit support with direct fire ~ 4,000 - 12,000 ft



## Potential 105mm BLAM-equipped F/AC-130 Missions



within 2 minutes after first round, fire bases can receive return fire





# Questions?

... and a few interesting facts about Kansas...

**Hilly, wooded Lawrence, home of the University of Kansas**  
**45 min. West of Kansas City**



*A very blue dot in a very red state: Lawrence ~ Kansas as Austin ~ Texas*

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Transportation Hub, Flight Test  
Light Aircraft Manufacturing



Avionics

R&D, Flight Test, Aircraft Design  
Missiles, Munitions, UAVs

Airline Aircraft Maintenance

Insurance

Spares

Interiors

Avionics

Salvage

Airframe Design, Development,  
Production

