Low Volume, Low Power, Low Cost
Advanced Guided Bullet and Mortar 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
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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.

be commanded and can therefore 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 Aerospace Products:

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

SkyShaker Technologies
US & International   Patents pending

Background/History New Actuator Classes    Adaptive FCS & Optics
First 20 years of Programs with Lineage to Flying Adaptive UAVs

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<td>ARL</td>
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Overview of Programs with Lineage to Flying Adaptive UAVs

Design Mach Number, M

- Fixed-Wing UAV
- Convertible UAV
- Rotary-Wing UAV
- Hard-Launch Munition
- Gravity Weapon
- Missile

Background/History
New Actuator Classes
Adaptive FCS
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

Adaptive

no windings, current flows \( \mu A \) to mA

Magnetic Field \( \alpha \) no. of windings x current
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
Adaptive Aerostructures Laboratory… from Aha! To Flight

One possible solution... from the MAV world

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

Mission Profile:

- Takeoff
- Descent
- Hover out 20m
- Hover in 20m
- Ascent
- Underground Loiter > 24hr
- Shutdown

Enabled by Flexspar Piezoceramic Stabilators

- 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

Stabilator Characteristics:

Background/History             New Actuator Classes Adaptive FCS
Gravity Weapons

Weapon Compression

Smart Compressed Reversed Adaptive Munition (SCRAM)

piezoelectric adaptive flight control actuators in strakes

conventional Mk 83 bomb body (14” dia)

bluff nose kit with weapon fuse and power supply

composite empennage kit

upper fuse well for weapon initiation

lugs

aft fuse well

forward fuse well

composite nose kit

Active Stabilator Control

14" switchblade fins

72"

flight configuration

adaptive fins

PZT strake actuators

power supply

GPS antenna

GPS autopilot

gyro, altimeter and cold gas generator

nose cap and bag cover

Background/History

New Actuator Classes

Adaptive FCS
Interceptors

SMDC HI TT Program 1997 - 2000

Hypersonic

5ms Fully Proportional Response

Pitch, Roll, Yaw control

Background/History  New Actuator Classes  Adaptive FCS
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

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%

Crosswinds (Von Kárman Spectrum)

\[ V \sim \chi^2(\nu) \]

- 75th%: 5.21 kts
- 90th%: 6.95 kts
- 95th%: 8.15 kts
- 99th%: 10.7 kts
- 99.9%: 14.2 kts

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

Muzzle Velocity
- 1% change error ~ 99cm

2 km target with 50 caliber rounds

Muzzle Velocity

Background/History

New Actuator Classes

Adaptive FCS

Unclassified
All information from public sources
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

- 1.5 Hz sinusoidal excitation
- ±72 Vac excitation level
- fin on
- 74°F

[Graphs showing peak-to-peak deflection vs excitation voltage and frequency]
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 SBI R 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

\[ F = k\Delta x \quad \text{ verses } \quad F \neq k\Delta x \]

Eureka!
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:

[Diagram of actuator assemblies]
PBP Actuators: Fastest around...

Best performance in the adaptive structures industry:

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

![Graph showing End rotation angle and Input command top/bottom actuator elements]
PBP Actuators: Real Performance!

Mach 3 Testing - FCS works well!
### PBP Actuators: Munitions Comparisons

Smaller, Lighter, Cheaper - the Name of the Game

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<th>Conventional Electromagnetic FCS</th>
<th>Adaptive/ PBP FCS</th>
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<tr>
<td>Volume</td>
<td>14cc</td>
<td>5.1cc</td>
</tr>
<tr>
<td>Mass</td>
<td>69g</td>
<td>4.2g</td>
</tr>
<tr>
<td>Peak Power</td>
<td>148W</td>
<td>2.6W</td>
</tr>
<tr>
<td>Deadband/Slop</td>
<td>± 0.38°</td>
<td>± 0.002°</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>22 Hz</td>
<td>189Hz</td>
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<tr>
<td>Acquisition Cost</td>
<td>$187 ea.</td>
<td>$12.30</td>
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<tr>
<td>(100,000 shipsets)</td>
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*Background/History: New Actuator Classes Adaptive FCS*
PBP Actuators: Moving up in caliber to fuses - Easy!

Mortar Fuses

Howitzer Fuses

Background/History New Actuator Classes Adaptive FCS
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

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

Short Course for: Program Managers & Practicing Engineers

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?