Adaptive Imaging and Guided Fuse Technologies

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

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Purpose:

Describe to the fuze community the state of the art in adaptive optics and flight control technologies
Outline:

I. Background & Brief Introduction to Adaptive Materials

II. History of Programs

III. New Classes of Adaptive Actuators

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.
Adaptive Materials: A (Very) Brief Introduction

What are Adaptive Materials & Structures?

- Conventional
- Adaptive
- Intelligent
- Sensory
- Controlled

Background  History  New Actuator Classes  Future Programs
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 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**
First 20 years of Programs with Lineage to Flying Adaptive UAVs
Overview of Programs with Lineage to Flying Adaptive UAVs

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

Background      History      New Actuator Classes       Future Programs
Brief Guided Round History

M712 Copperhead 1975

XM 982 Excalibur & ERGM
Guided Round History

Reducing the caliber...

M 247 Sergeant York  1977 - 1985
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.)
- 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
Adaptive Materials Actuation... Different

Hydraulic/Pneumatic

- Pressure Source
- Command Signal
- Position Feedback
- Actuator
- Push arms, linkages etc.
- Effector

Electromagnetic

- Electrical Energy Source
- Command Signal
- Position Feedback
- Motor
- Gear stages
- Push arms, linkages etc.

Adaptive

- Electrical Energy Source
- Command Signal
- Adaptive actuator part of primary structure
- Position Feedback
US Army FOG-M FCS...
One possible solution... from the MAV world

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

Enabled by Flexspar Piezoceramic Stabilators

Mission Profile:

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

Stabilator Characteristics:

- total mass 5.2g
- actuator mass: 380 mg
- max. static deflections: ±11°
- max power consumption: 14 mW
- pitch corner frequency: 47 Hz
- first natural frequency in pitch: 23 Hz
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
Gravity Weapons
Interceptors

SMDC HITT Program 1997 - 2000

Hypersonic
5ms 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

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
Guiding Small Arms Rounds... More History

Range-Extended Adaptive Munition (REAM) IRAD 1999 - 2001
BAT-Lutronix Corp. developed supersonic piezoelectric FCS actuators
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 Small Arms Rounds... The Ephphany!

Discoveries from Europe... 2003 - 2004

\[ F = k\Delta x \quad F \neq k\Delta x \]

Eureka!
PBP Actuators: Real Performance!

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

Worldwide patent application: 18 Jan. 2005
PBP Actuators: Real Performance!

Assembled, functioning actuator:
PBP Actuators: Real Performance!

Assembled Hard-Launch Capable Actuator FCS Units:
PBP Actuators: Real Performance!

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

Input command top actuator element +58V steady
Input command bottom actuator element -8V steady

End rotation angle
PBP Actuators: Real Performance!

Mach 3 Testing - FCS works well!
PBP Actuators: Moving up in caliber - 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
Families of Steered Piezoelectric Enhanced Adaptive Rounds (SPEARs)

- Roll Stabilized Recon. SPEAR
- Full Control Recon. SPEAR
Roll Stabilized SPEAR

“Look Over the Hill”
Supersonic MAV mission tungsten nose

Tactical Benefits:
• Fastest way to get local reconnaissance images
• Totally impervious to weather/gusts
• ~ $20/round

Background History New Actuator Classes Future Programs
Roll Stabilized Recon. SPEAR

Necessity of Roll Stabilization

Smooth bore/obturating band launch 20mm:
roll rate > 8rps

flare
12Ga
Full Control Recon. SPEAR

Full Battlefield Reconnaissance

40,000 ft (12km)
20mm (16mm) saboted SPEAR
Mach 0.8, 15° launch

Friendly Fire reduction/elimination

tungsten nose

camera

rollsonde

active fins

Background   History   New Actuator Classes   Future Programs
Micro Optics Steering w/ piezo

±2° through 1kHz
fully proportional
sizable down to 20mm rounds
hardened through 10,000g's
solid state
20+yr life
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

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

2/3 of the aircraft made in the Western World are made in Kansas
Aerospace = largest manufacturing industry of the state
40,000 - 70,000 aerospace workers
More aerospace economic volume per capita than any other state

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