TACOM

Lethality, Survivability, Mobility and Sustainment for America's Army

Smart Materials and Structures for the Multi-role FCS Ammo Suite

6th International Cannon Artillery Firepower Symposium & Exhibition

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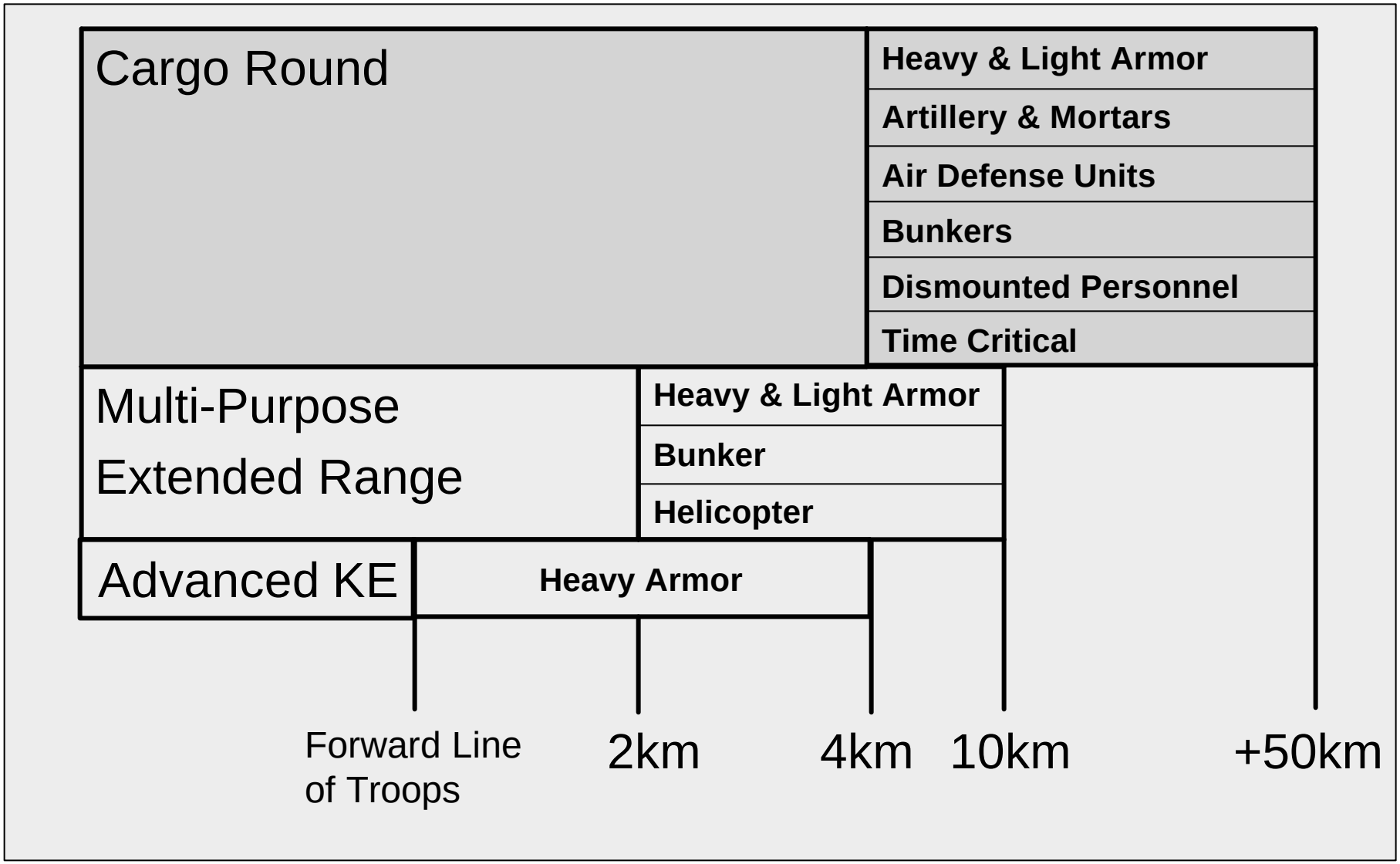
What makes the Notional Future Combat System a hard problem?

A combination of indirect and direct fire functionality…

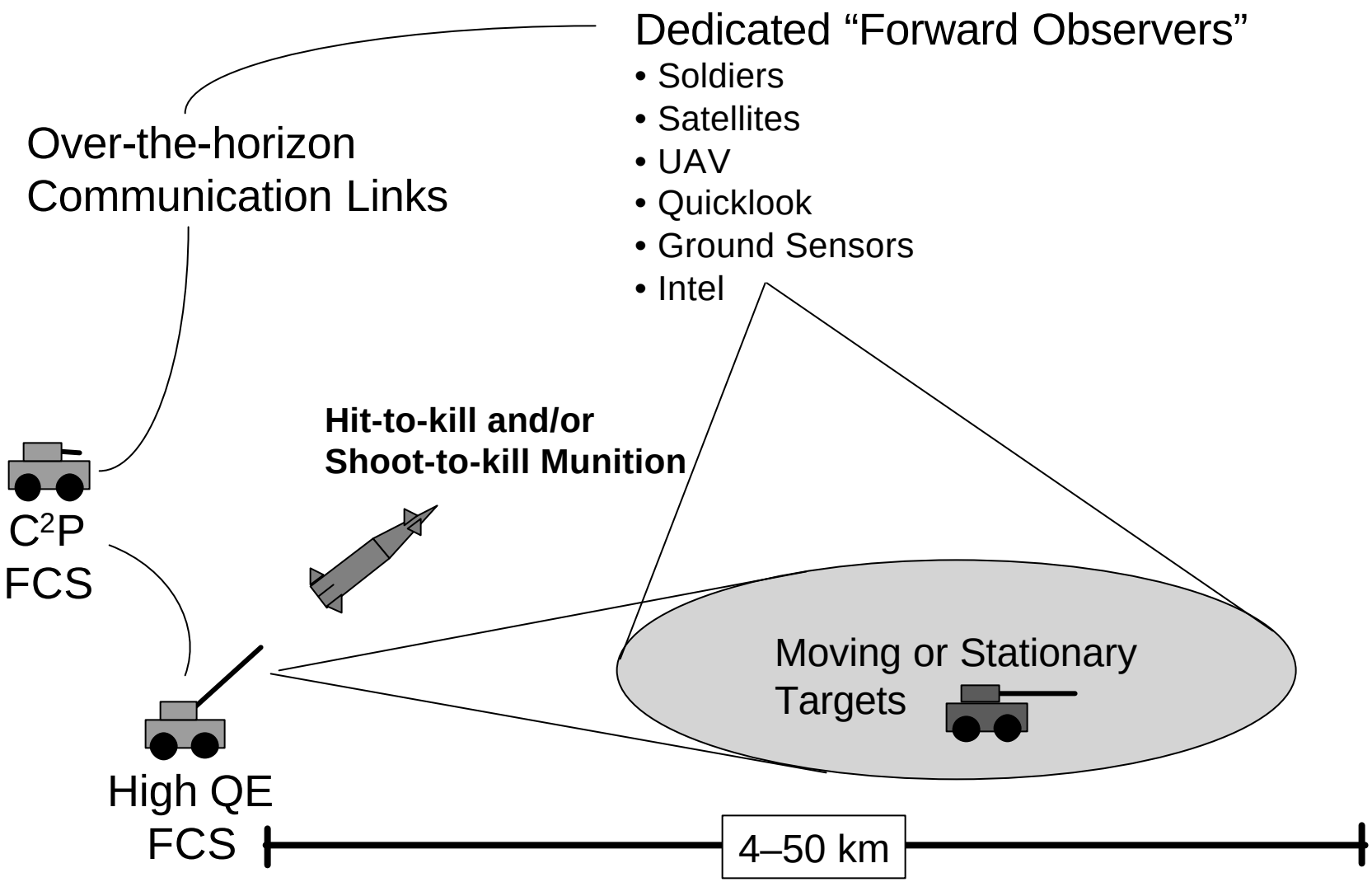
(+)

in a vehicle that weighs 20-50 tons less than either system alone!

Multi-role FCS Ammo: Target Sets & Effective Ranges



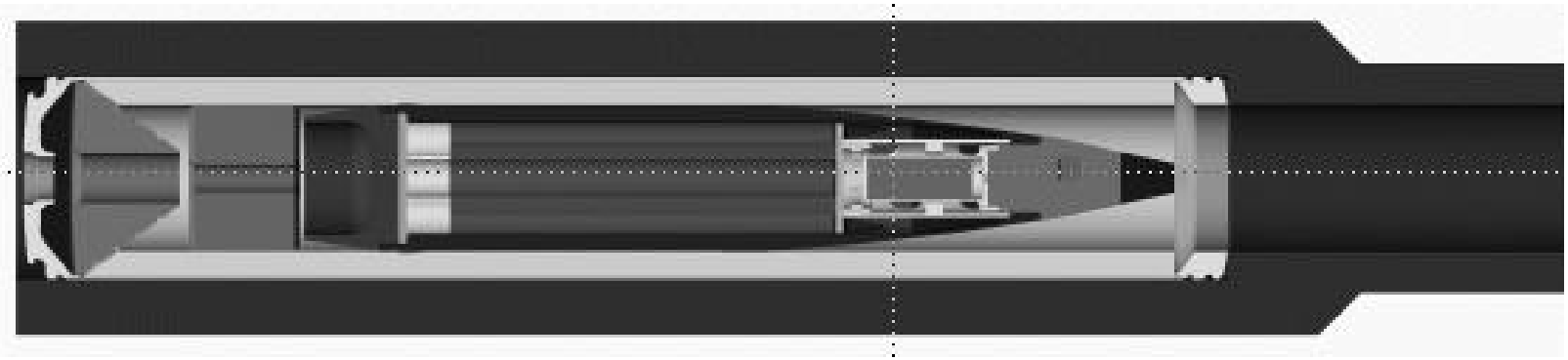
Notional Operational Concept



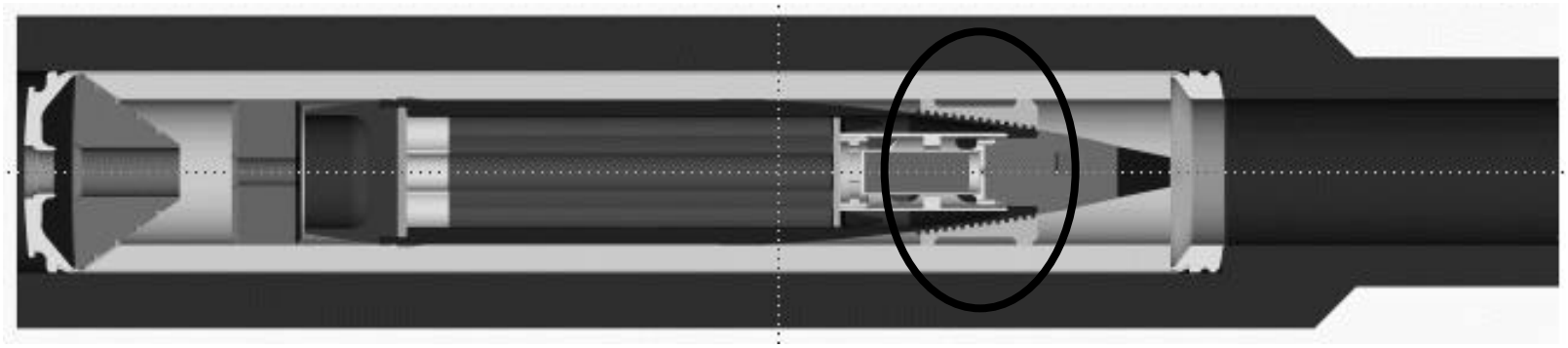
The Smart Cargo Round is <u>one of three</u> munition *systems* required by the notional Future Combat *System*

"A System of Systems"

Concept 1: Full-bore translation



Concept 2: Sabot on nose with minimum translation

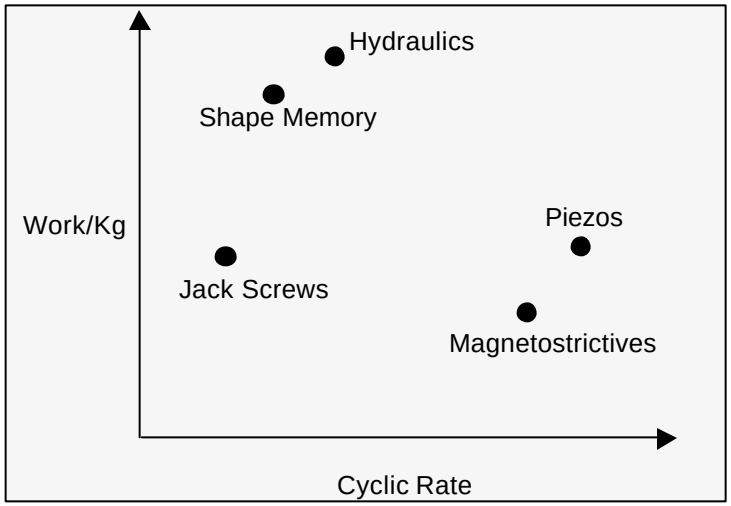


Smart Cargo Concept Design Issues

- **To support the FCS 20 ton goal <u>and</u> 3x the number of "stowed kills" per combat load, the Smart Cargo Round will:**
  - **Maintain 155mm lethality in a 105mm round**
  - **Utilize "cased telescope cartridge" design principles**
  - **Without rocket assist, <u>match</u> the range of of the "best" 155mm rocket-assisted round (M549)**
- **From FY00-03, ARDEC will explore the feasibility of using smart materials & structures to:**
  - **Reduce the volume required for the Control Actuation System (CAS)**
  - **Increase range via innovative approaches to exploiting control surface shape changes, aeroelasticity and high bandwidth servo control**

What are Smart Materials and Structures?

- **Structures and materials that sense external stimuli and respond with active control in real, or near-real time**
  - **A combination of technology areas – materials, sensors, actuation, control algorithms & architectures**
- **Key features –**
  - **Possibly an enabling technology for low-volume projectile Control Actuation Systems**
  - **Embedded in structure or externally mounted**
  - **Many smart materials have very high energy densities v.s. cyclic rate**
  - **A few materials respond directly to the environment**
- **Typical smart structures for actuation:**
  - **Shape memory alloys (SMA)**
  - **Piezoelectric & electrostrictive ceramics**
  - **Magnetostrictive materials**
  - **Electro- and magneto-rheological fluids**
  - **Elastomers & electroactive polymers**



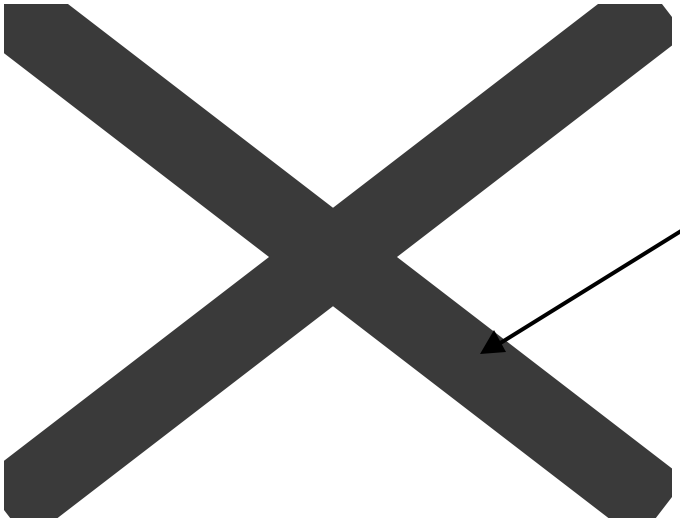
DARPA and the Army Research Office have been developing active control applications of Smart Materials and Structures over the last six years…

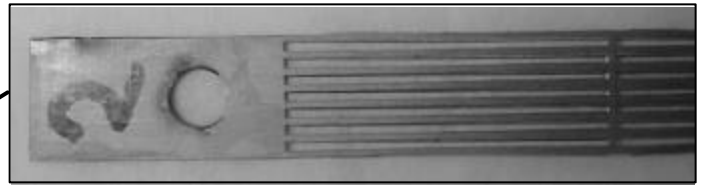
Application	Technology Readiness Level
Rotorcraft – Active Twist Blades (fiber & tube twist) & (tabs)	Level 6 - Mach scale hover test of integrated blades (1998)
Vortex Wake Control (vortex tabs on control planes)	Level 6 - NSWC Carderock 36” Water Tunnel, (3Q 1998)
Smart Wing (structure morphing w/ tubes & wires)	Level 6 - Scale F/A 18 Wings at NASA wind tunnels (1996 & 1998)
Smart Skin (self and radiated noise cancellation)	Level 4 - LM ATC Lab Test (1998)
Smart Panel (structure acoustic & vibration isolation)	Level 3 - ¼ scale lab prototypes (1997)

Example SBIR Concept

(Mide' Corp)

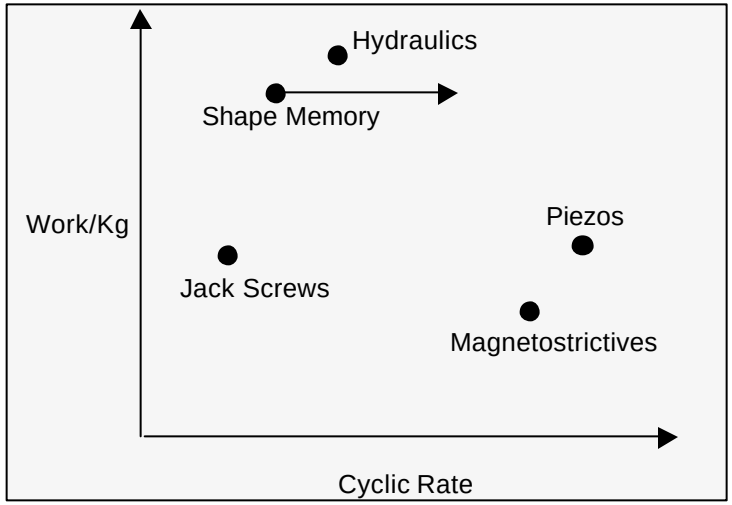
Control Surface (fin/wing/canard)





Micro-channel SMA increase BW

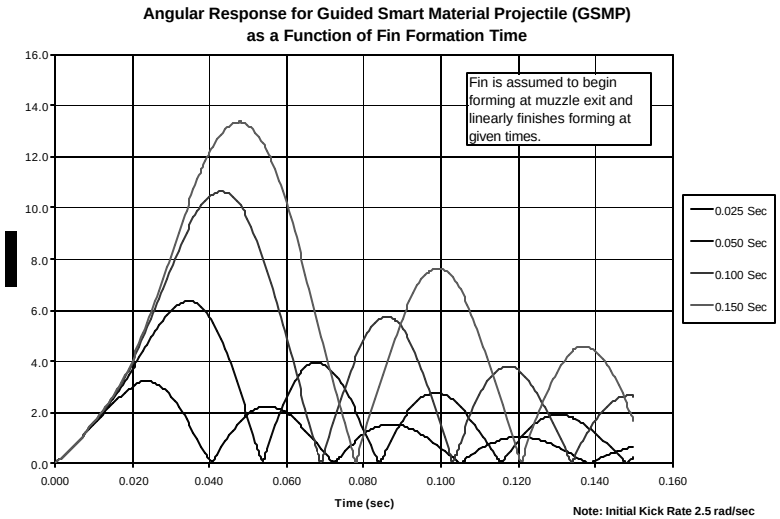
Antagonistic system embedded in projectile wall



Whole bodies of aerodynamic research are open to exploitation with smart structures and materials

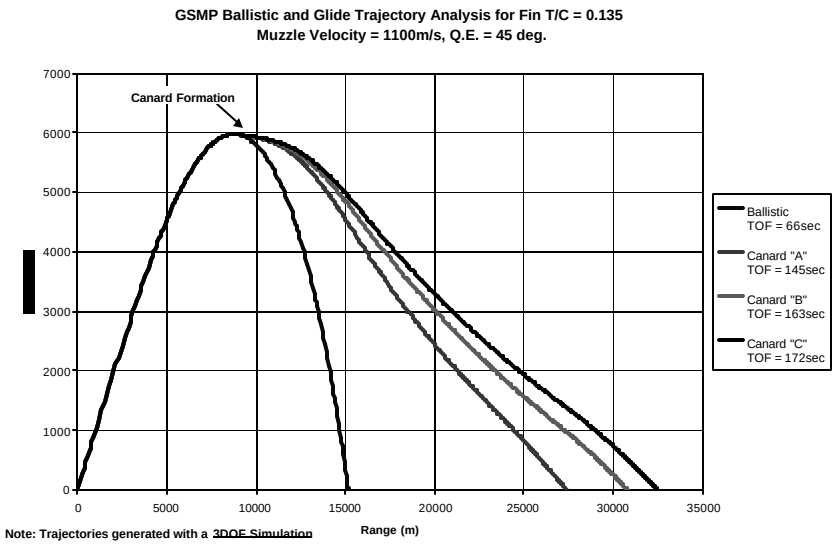
- **Mechanical benefits**
  - + Reduces control actuation system volume
  - + Higher performance and reliability
- **Aerodynamic benefits –**
  - + Increase altitude through lower supersonic drag
    - - active boat tailing & thinner control surfaces
  - + Increase range in subsonic glide
    - - Projectile body shape (ellipse/camber)
    - - Control surface shape (active camber)
    - - Decrease trim drag (eliminate hinge pivot)
    - - Exploit unsteady aero-elasticity (resonance for plunging)
  - + Increase stability (body shape changes to move center of pressure)
  - + Increase control actuation system bandwidth
    - - faster actuators
    - - possibly stabilize unstable system

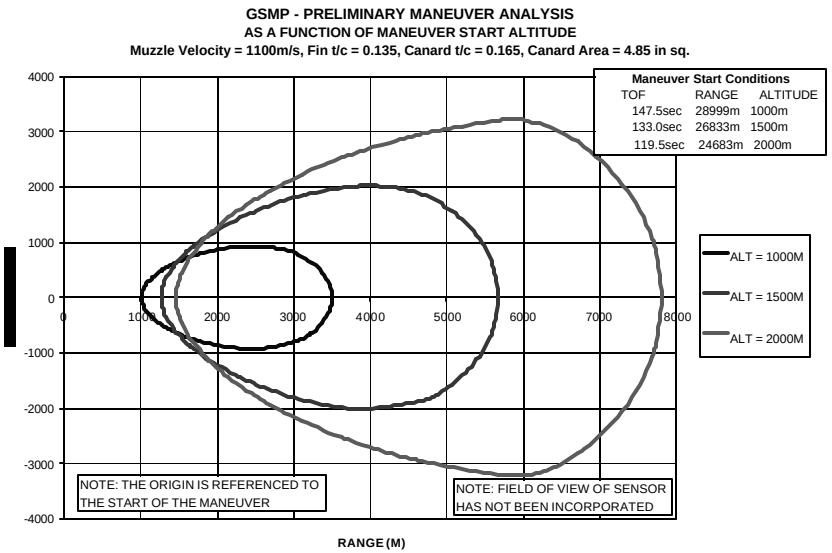
Generation of the Baseline "Design Space"



	Canards	Wings	Fins
Lift	X	X	X
Stability	X	N/A	Baseline
Maneuver	X	X	X

Analysis output: Moments to generate _____ with _____ at _____ location on round



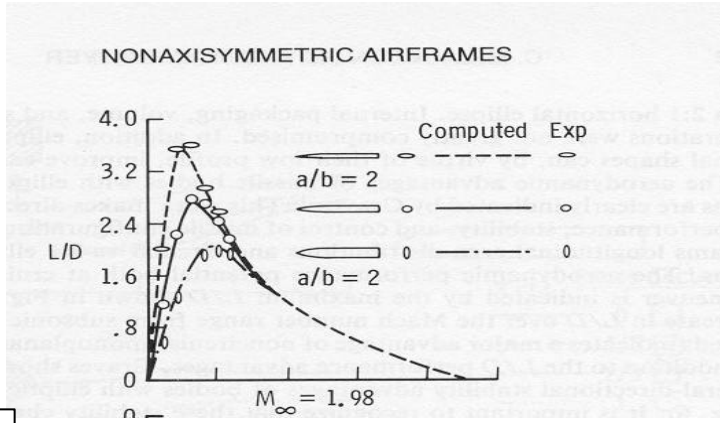


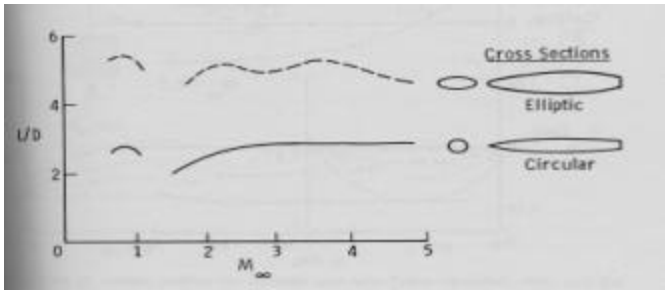
Work done by TACOM-ARDEC Aeroballistics Team

Details: Active aerodynamic shape changes

+ Increase range in subsonic glide

- Projectile body shape (ellipse/camber)





Jackson, C.M. and Sawyer, W.L. “Bodies with noncircular cross sections and bank-to-turn missiles” in “Tactical Missile Aerodynamics”, Vol 141 Eds. Hemsch and Nielsen, (AIAA, New York) 1986

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+ Increase altitude through lower supersonic drag

- active boat tailing & thinner control surfaces

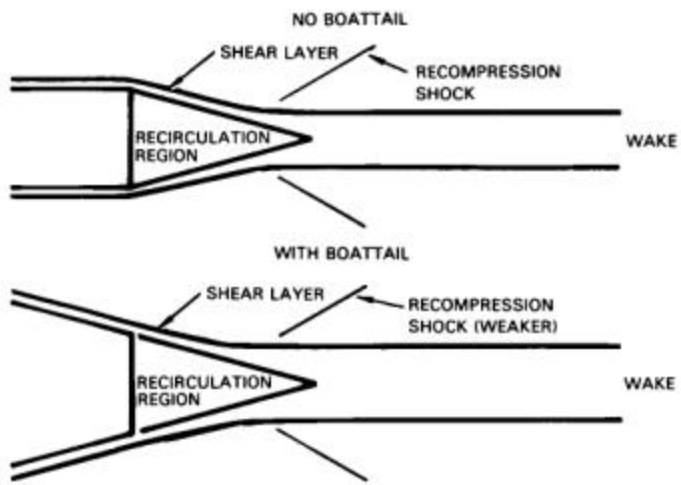


Fig. 19 Base flow patterns.

Jenn, A.A. “Drag Prediction Methods for Axisymetric Missile Bodies”, in “Tacticle Missile Aerodynamics, “Vol 142 Eds. Hemsch and Nielsen, (AIAA, New York) 1992

Details: Active aerodynamic shape changes

+ Increase range in subsonic glide

- Exploiting unsteady aerodynamics

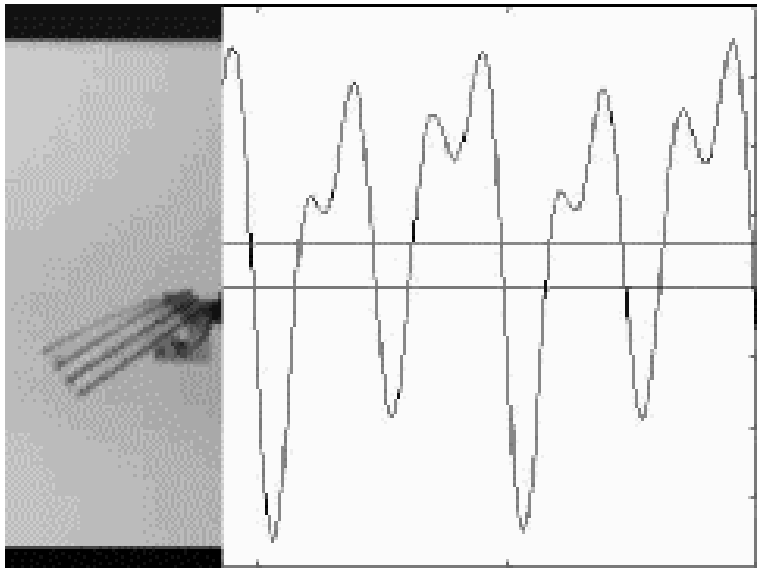
The following details presented by: Dr. Kenneth Frampton

Exploiting Unsteady Aerodynamics & Aeroelastic Effects

- Traditional flight control achieved through steady aerodynamic effects.
- Unsteady aeroelastic effects are avoided for safety/reliability reasons
- Short life and minimal safety considerations will permit these effects in munitions
- We *can* exploit unsteady aerodynamics and aeroelastic effects to efficiently guide munitions

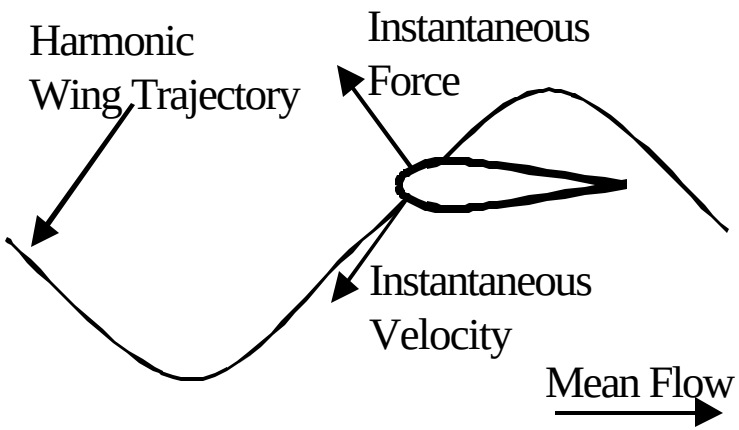
Birds and Insects Exploit Unsteady Aerodynamics; So Can We

- Existing DARPA program seeks to develop Ornithoptic Flying Robotic Insects.
- A key technology is the development of aeroelastic wings for flapping flight.
- Investigations have demonstrate the importance of unsteady effects in the generation of thrust.



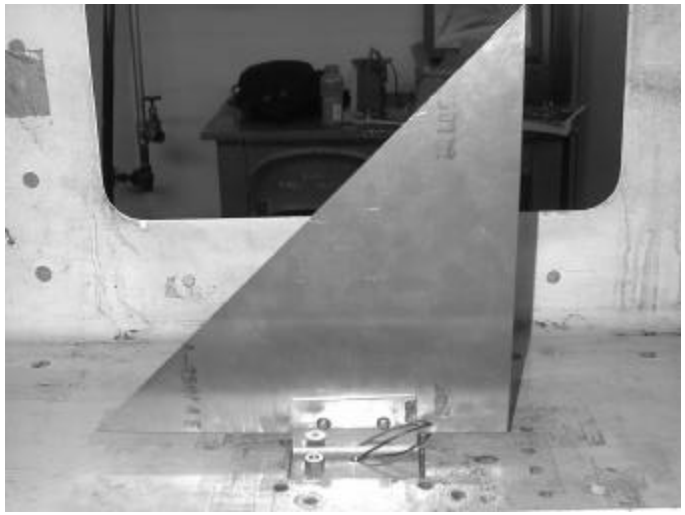
Aeroelastic Fixed Wings For Flight Control

- A plunging airfoil in mean flow will generate thrust.
- This phenomena can be exploited to generate flight control forces.
- Elastically tailored wings posses aeroelastic resonance that generates such a motion.
- Efficient excitation with smart materials creates flight control without control surfaces.



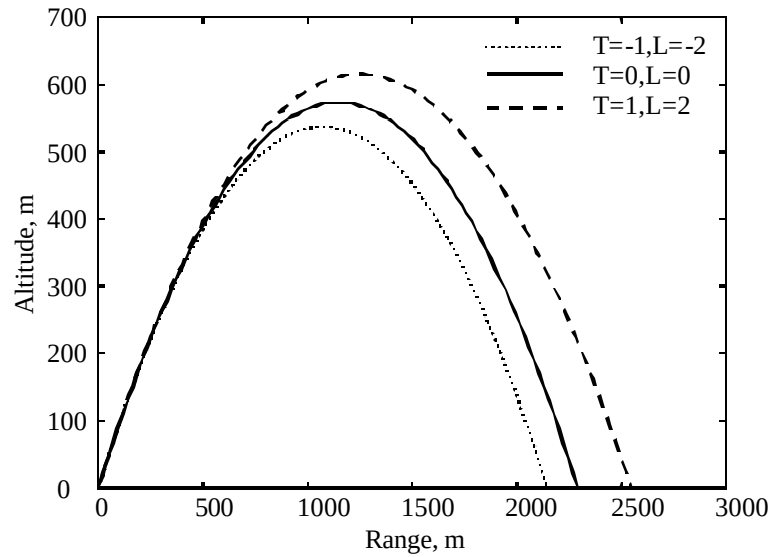
Aeroelastic Fixed Wings Wind Tunnel Tests

- A delta wing wind tunnel test has been developed.
- Aluminum flat-plate winglet with embedded piezoceramic actuators to produce desired motion.
- Plan is to establish the needed elastic response to generate maximum thrust.



Theoretical Extended Range Control Example

- A 60mm mortar is equipped with SMA airfoils
- Excitation at tailored aeroelastic resonance produces lift/drag forces
- End result is the ability to increase range by 250 meters or decrease by 150 meters
- Addition of appropriate guidance and control will result in a dramatic increase in accuracy



ARO Young Investigator Proposal for Smart Munitions

- Primary goal is to investigate the application of smart materials technology to the development of guided munitions.
- Investigation of unsteady aerodynamic exploitation is of particular interest.
- 3 year plan including
  - Developing aeroelastic models
  - Seeking optimal actuator/structural design for the generation of aerodynamic control forces
  - Conduct wind tunnel tests to validate the findings.