“Micro Adaptive Flow Control Applied to a Spinning Projectile”

SCORPION Self-Correcting Projectile for Infantry Operation

J. McMichael, A. Glezer and A. Lovas, GTRI
P. Plostins, G. Brown and J. Sahu, USARL

in collaboration with:
Mike Heiges, Kevin Massey, GTRI
Dave Lyon, Dave Hepner, Tom Harkin, USARL
Mark Allen, Brian English, Chris Rinehart, Georgia Tech
GOAL: Demonstrate a Guided Spinning Projectile using MAFC Technology

Objectives:
1. Demonstrate MAFC control authority and guidance algorithm for a medium caliber munition
2. Provide a suite of validated advanced design tools
3. Establish technology transitioning pathways for tactical systems

Pacing Technologies:
- MAFC actuators
- Flow control concept for spinning projectiles
- Flight control algorithm
- Initialization and INS for spinning projectile
- Compact, g-hardened electronics and packaging
- Design Tools: Integrated CFD and Flight Dynamics
Aerodynamics Flight Tests

Predicted Mass properties
Mass: 171 grams
cg from nose: 44 mm
Iaxial: 354.7 g*cm²
Itrans: 806.4 g*cm²

Classic Spin Stabilized Yaw Helix
Looking Down Range

Theta vs Psi - 6DOF Analysis

Sensor Suite  Battery
Telemetry Antenna  Solar Sensor Array
Transient Flow Behavior

Phase-locked PIV images acquired over first 12 milliseconds ($T_{act} = 1$ msec)

- Actuator runs for 6 cycles
- Starting vortex shed on first cycle
- Flow turning nearly complete after a few cycles
- Global effects completely developed in 1-2 convective time scales

Approved for Public Release: Distribution Unlimited
Continuous Synthetic Jet Circulation Control

D = 80 mm
U₀ = 37 m/s
α = 0°
Uj = 31 m/s
Without Spin
f = 1000 Hz

Simulation by Juburaj Sahu, ARL
Coupled CFD-SIXDOF Simulation
Aerodynamic Force, Fy (Side Force)

Clip Plane - Turbulence
TIME=0.520300

Turbulence

Range, m
Dynamic Stress Waves Due to Launch

Local Transient Loads Exceed Nominal Launch Accelerations

Full 3-D Dynamic Structural Analysis of SCORPION Projectile During Launch

Dynamic Response During Launch

Effective Stress

1.00e+04
8.00e+03
6.00e+03
4.00e+03
2.00e+03
0.00e+00

3-axis Mag
4 Radial Accels (AO)

1-axis Axial Accel
2-axis Radial Accel
Control Electronics Calibration and High-G Ground Experiments

Spin simulated to initiate maneuver

Simulating Magnetic Field

- Developed High-G packaging to survive launch acceleration. GTRI-supplied electronic boards.
- Unit functioned appropriately after shock

High-G Shock (8,000 G's)

Before Shock

After Shock

Assembled Jet
Velocity 34 m/s

Scorpion Open Loop Controller Flow Measurement

Hot Wire Flow Measurements

Flow Velocity (m/s)

Time (sec)
Open Loop Electronics and Control System Assembly

- Interface Connector
- Battery
- Processor Board
- Open Loop Electronics Assembly
- Boost Converter
- Driver Board
- Flight Hardware
After launch, wait 0.5 seconds, then activate at maximum voltage at same roll angle each revolution.

Activate for 1/4 revolution (about 4 diaphragm cycles) such that force generated will be horizontal (left or right, as selected)

On approximately 4 ms, and off 12 ms each revolution
Actuator Timing

Duration

Phase

Period

Mag J
Mag K
Trigger Index
Driver

Time (sec)

Amplitude

0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04

0 0.0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4

Divert Flight Test Firing Protocol
Initialization of the Flight Control System
SCORPION ONBOARD SENSORS

Onboard Sensors include:

- Axial and 2-axis Radial Accelerometer (3 Components of Translational Accelerations)
- 3-axis Magnetometer (Along Projectile Principal Axes – Same as Accelerometers)
- Pitch and Yaw Rate Sensors
- 2 Centripetal Acceleration Sensors (Roll Rate)

The inertial sensors respond to the projectile dynamics of launch and flight and provide measurements needed for projectile guidance. The sequence of events in a typical maneuvering Scorpion flight are readily apparent in the sensor data.

- Angle to the magnetic field from axial magnetometer
- LAUNCH
- TARGET IMPACT
- START MANEUVER
- END MANEUVER
- GROUND IMPACT

TIME (s)

Sigma_M (deg)
Holes in the Target!!!

Scorpion Test Results
With Closed Loop
Muzzle Velocity
Control

Flight Configuration
Scorpion Technology Program Accomplishments

- Demonstrated Micro-Adaptive Flow Control for divert of subsonic guided 40 mm grenade
- Demonstrated Multi-disciplinary physics modeling – flew munition through the computer using High Performance Computing
- First divert ever of a spin stabilized munition system at 60 hertz spin rate
- Developed a miniature, G hard, on board flight control system
- Demonstrated initialization at muzzle exit – Velocity - Orientation
- Demonstrated open loop divert
- Demonstrated closed loop guidance to the target on major error source - Velocity
- Cut on target dispersion due to muzzle velocity variation to one third of the system value
25mm Scorpion

Control Mechanism Module

Inertial Sensor and Control Module

25mm Scorpion Projectile
17mm IMU (ARL) **tightly integrated** with processor (GTRI), power management (ARL/GTRI), interface hardware (GTRI), and control mechanism module (ARL).
25 mm Divert Video

T+437.564 ms
Milestones

- 25 mm Scorpion Completed
- 25mm instrumented projectile
- Driver board design
  - Addresses 6 actuators (limited by size)
- Single actuator maneuver
- Multiple actuator initiation
- Projectile recovery
- Reduced state flight software
  - Utilizes magnetometer and axial accelerometer
  - Algorithms need to develop and mature
  - Tradeoff between functionality (research instrumentation and control guidance…) and practicality (size, processor capability, & time/cost).

25mm ACSW With Combustion Actuator
Scorpion Technology
Future Technology Insertions

- Designated and Moving Targets
- Munition Dispersion Control
- Designated and Moving Targets Long Term

Long Term
- Dispersion Control
- Laser Designation
- Point Burst Kill
- Multiple Burst Optimization
- Swarming Munitions

Other Transition Opportunities
- Sub-munition flight control
- Smart Fuzing
- Warhead dynamic orientation
- BDA platform stabilization
- Subsonic micro-missile roll control

Future R & D Areas
- Laser Designation
- Micro-Technology for Prox - Fuzing

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