TACOM

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13-16 August, 2001

NDIA Small Arms Conference

Little Rock, AR

# MEMS Safety and Arming Device for OICW


**US Army TACOM ARDEC**
**Fuze Division, AMSTA-AR-CCF-A**
**Adelphi, Maryland**
**301-394-0754**

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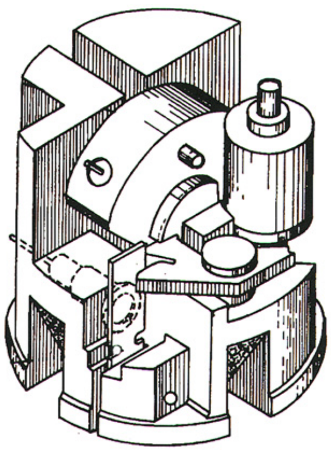
# Report Documentation Page

| Report Date | Report Type | Dates Covered (from... to) |
|---|---|---|
| 13Aug2001 | N/A | - |

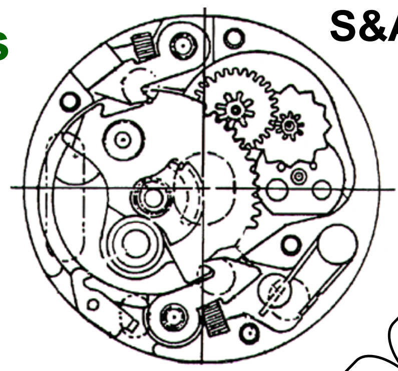
| | |
|---|---|
| **Title and Subtitle**<br>MEMS Safety and Arming Device for OICW | **Contract Number** |
| | **Grant Number** |
| | **Program Element Number** |
| **Author(s)**<br>Robinson, Charles H.; Wood, Robert H.; Bayba, Andrew; Hollingsworth, David | **Project Number** |
| | **Task Number** |
| | **Work Unit Number** |
| **Performing Organization Name(s) and Address(es)**<br>US Army TACOM ARDEC Fuze Division, AMSTA-AR- CCF- A Adelphi, Maryland | **Performing Organization Report Number** |
| **Sponsoring/Monitoring Agency Name(s) and Address(es)**<br>NDIA (National Defense Industrial Association) 211 Wilson Blvd, STE. 400 Arlington, VA 22201-3061 | **Sponsor/Monitor's Acronym(s)** |
| | **Sponsor/Monitor's Report Number(s)** |
| **Distribution/Availability Statement**<br>Approved for public release, distribution unlimited | |
| **Supplementary Notes**<br>Proceedings from the 2001 Joint Services Small Arms Symposium, Exhibition & Firing Demonstration 13-16 August 2001 Sponsored by NDIA, The original document contains color images. | |
| **Abstract** | |
| **Subject Terms** | |
| **Report Classification**<br>unclassified | **Classification of this page**<br>unclassified |
| **Classification of Abstract**<br>unclassified | **Limitation of Abstract**<br>UU |
| **Number of Pages**<br>21 | |

# Insertion of MEMS Technology

## Conventional Mechanical S&As



Missile S&A

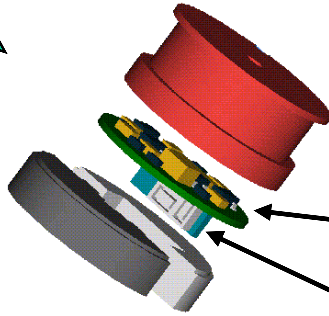


Artillery S&A

Incorporate the functions of a conventional mechanical S&A in a single S&A die integrated with a fuze circuit.

A MEMS mechanical S&A is not a “sensor” per se. Rather, its components intrinsically combine both sense and actuate functions in a single unpowered chip.

## Concept Fuze for OICW



Fuze Circuit

MEMS S&A die

# MEMS S&A Team

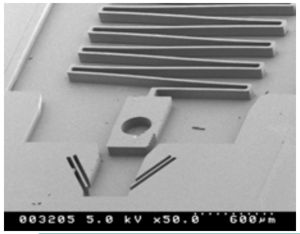
- **PM Small Arms - Customer**
- **JSSAP - Program Sponsor**
  - → OICW System Enhancements STO (Tech  Base Funding)
- **Engineering Development**
  - → TACOM ARDEC Fuze Division, technical and project lead
  - → China Lake, explosive train (MSF) development
  - → WECAC, MSF producibility
  - → ARL, engineering and test support
  - → Alliant Technology, test hardware

# MEMS Mechanical S&A

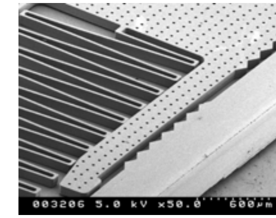
- **Goal - Demonstrate the Feasibility of:**
  - → MEMS mechanical S&A device for 20-mm OICW weapon system, with
  - → A compatible MEMS-scale firetrain (MSF)
- **Why OICW?**
  - → Reduce cost, weight, volume of S&A (increase lethality)
- **Why MEMS? (micro-electro-mechanical systems)**
  - → Robust in high-G environments---due to scaling laws
  - → Economies of high-volume production---via semiconductor industry
  - → High-accuracy miniaturization---feature resolution of 0.5 $\mu$m (0.02 mil)
  - → Readily integrated with fuze electronics---sandwich CMOS with MEMS chip
  - → Similar mechanical S&A architecture for many weapon systems
  - → Implement design changes via optical mask versus retooling production line

# Technical Approach

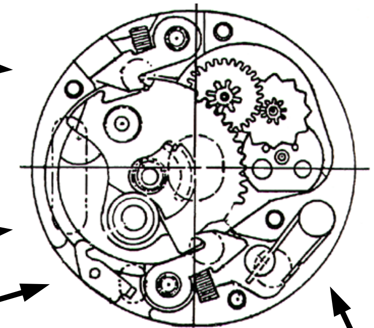
- **Concept, design, analysis**
  - → MEMS "inertial mechanical logic," two *inertial* locks, one *command* lock
  - → Map S&A functions to planar domain
  - → Firetrain is offshoot of NAWC-CL 'smart detonator" technology
- **Fabricate MEMS test structures and S&A prototypes**
  - → Inertial (zig-zag) delays, sliders, springs, locks, latches, anchors, rotors
  - → Need "high-aspect-ratio" to transport meaningful amount of energetics
    - **LIGA** (Deep X-Ray Lithography), 50-200-micron, Nickel features
    - **DRIE** (Deep Reactive Ion Etching), 80-300-micron, Silicon features
  - → Distinct from "low-aspect-ratio" multi-layer processes such as Sandia's
- **Demonstration Tests:**
  - → Bench demonstration of a MEMS-scale firetrain
  - → Flight demonstration of MEMS S&A hardware in Sept '01



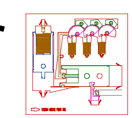
# Enabling Technology:  MEMS



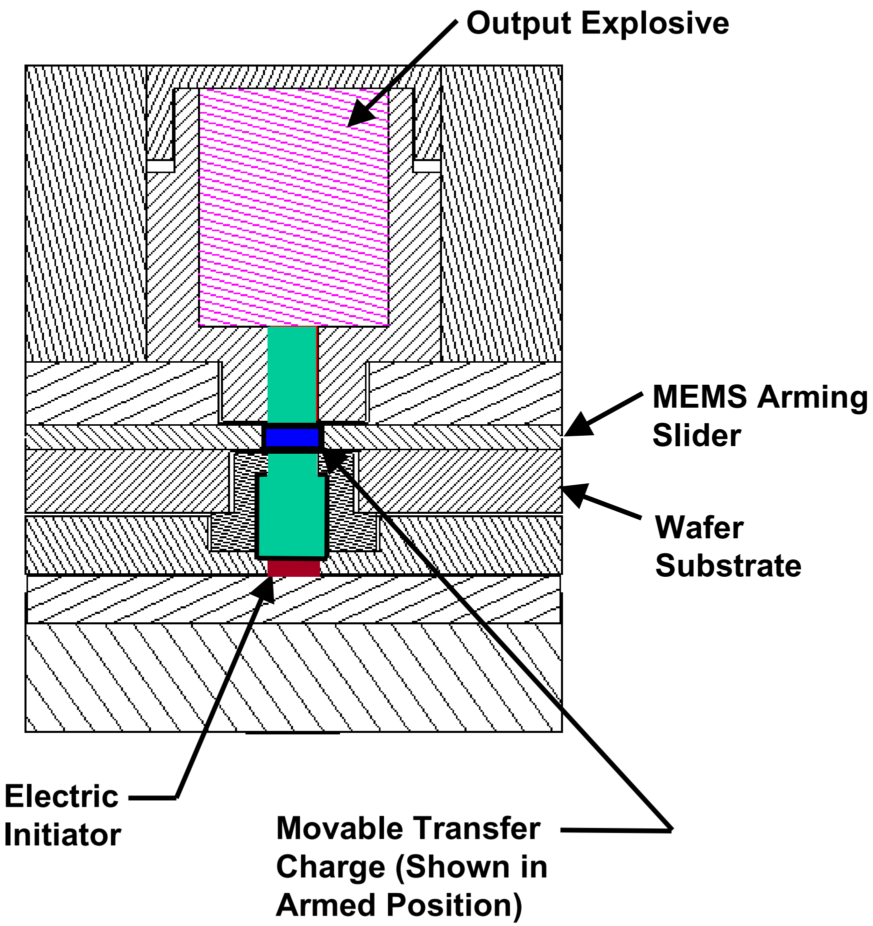
- **BAD Things About *Conventional Mechanical High-G S&As***
  - → Large parts count
  - → Pick-and-place assembly
  - → Dissimilar materials
  - → Lubrication (can denature)
  - → Miniature ‘clockworks’ (shrinking domestic industrial base)
  - → Large ‘cube’ of S&A could be used other ways



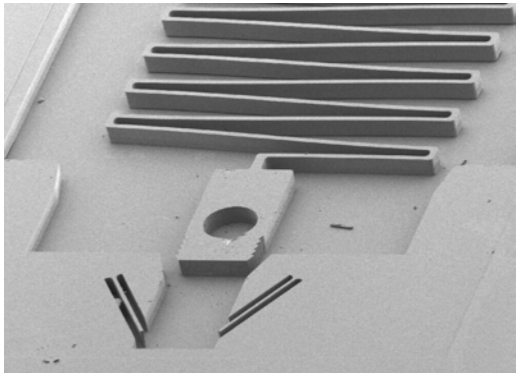
- **GOOD Things about *MEMS Mechanical High-G S&As***
  - → Moving parts fabricated ‘in situ’ (wafer level assembly)
  - → All functional parts of same material (nickel)
  - → No lubrication
  - → Commonality for use across multiple high-g applications
  - → Greatly reduced mass of lead-containing explosives in MSF



# Micro-Scale Firetrain per MIL-STD-1316, and Material Selection




**High Aspect Ratio**

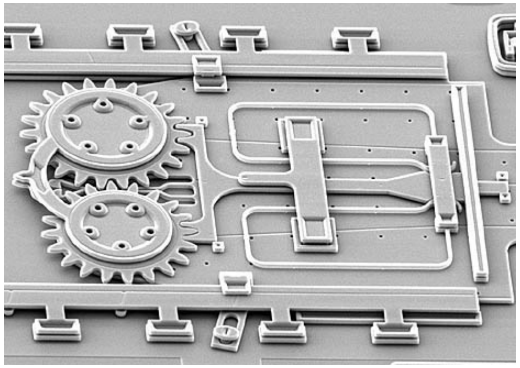


**ARDEC**

**200-μm Nickel**

**Inertially-Actuated**

**Surface Micro-Machined**

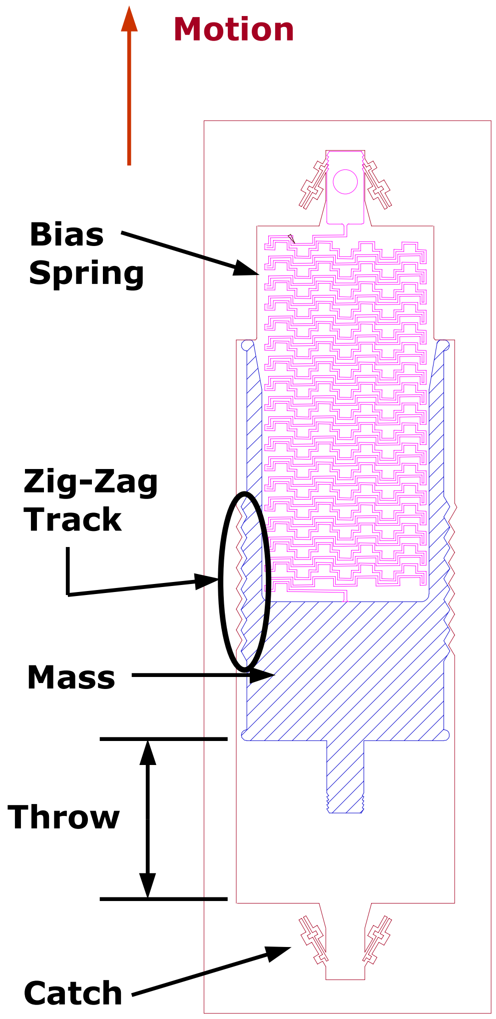


**Sandia**

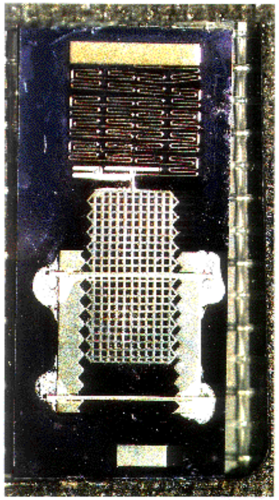
**2-μm Poly-Si**

**Electrically Actuated**

# Zig Zag Inertial Delay Slider Design



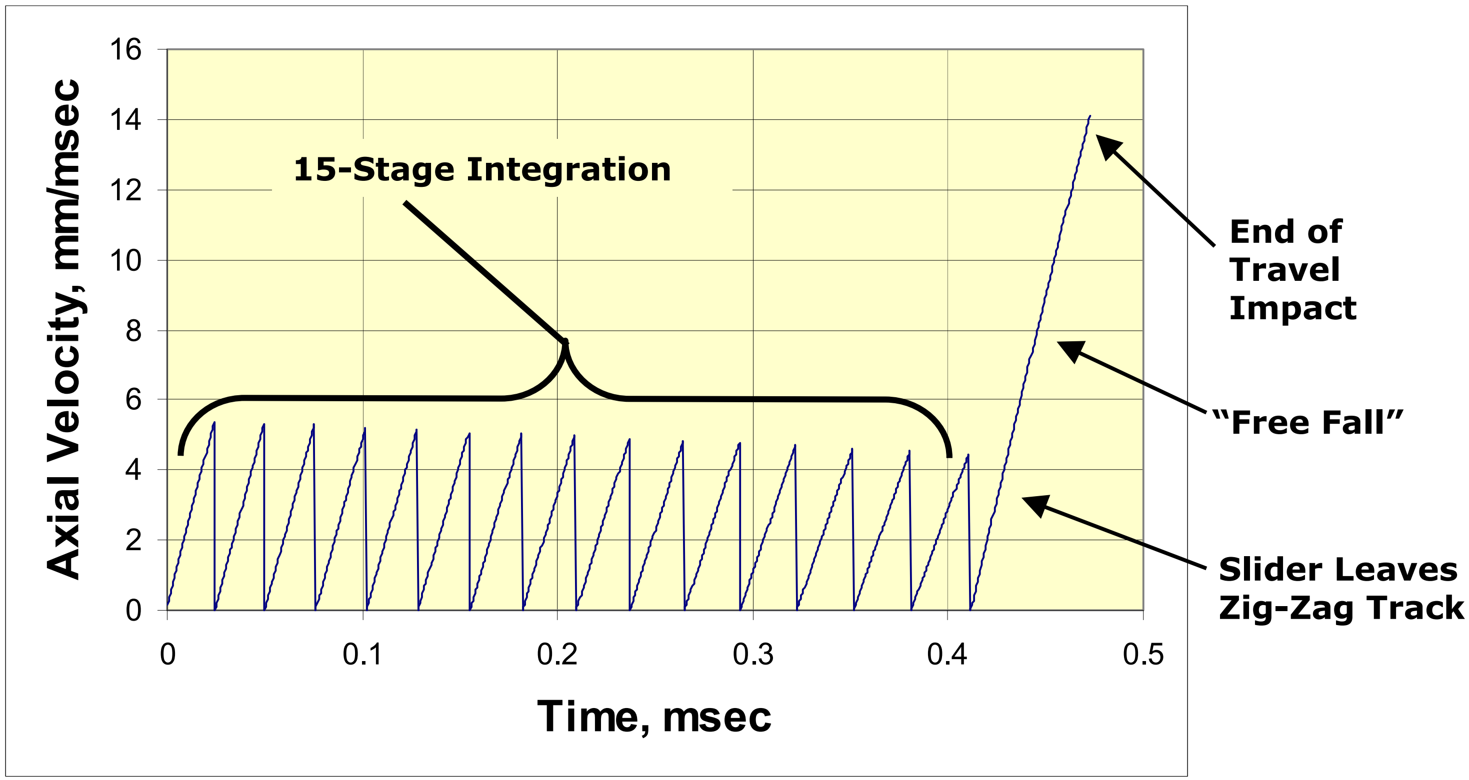

- Requirement: <u>40-ft Drop Safety</u>
- Integrates axial acceleration pulses (e.g. setback) → ΔV
- Removes first lock on MEMS arming slider
- Spring resets mass after small inputs
- Design variables:
  - → slider mass
  - → "throw" distance
  - → number of zig-zag (stop/start) "stages"
  - → rack parameters (pitch and depth)
  - → spring stiffness and bias
- First prototype demonstrated in 1996 →



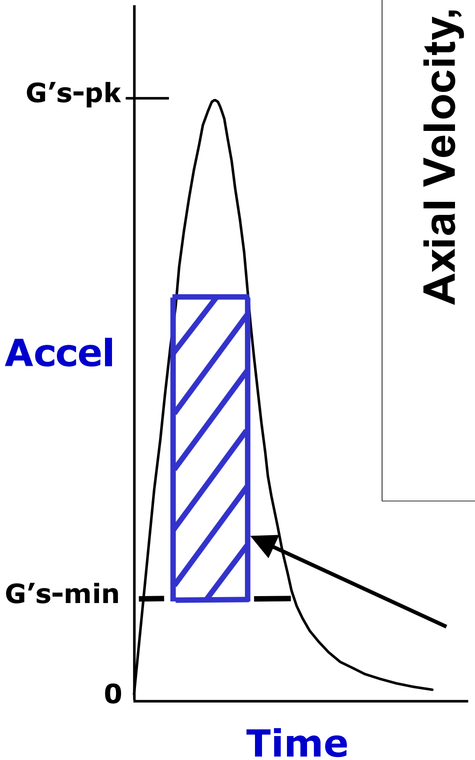
- Patent no. 5,705,767

# Calculated Zig-Zag Slider Motion

## (Spring Pre-Bias, 45kG OICW Launch Acceleration)



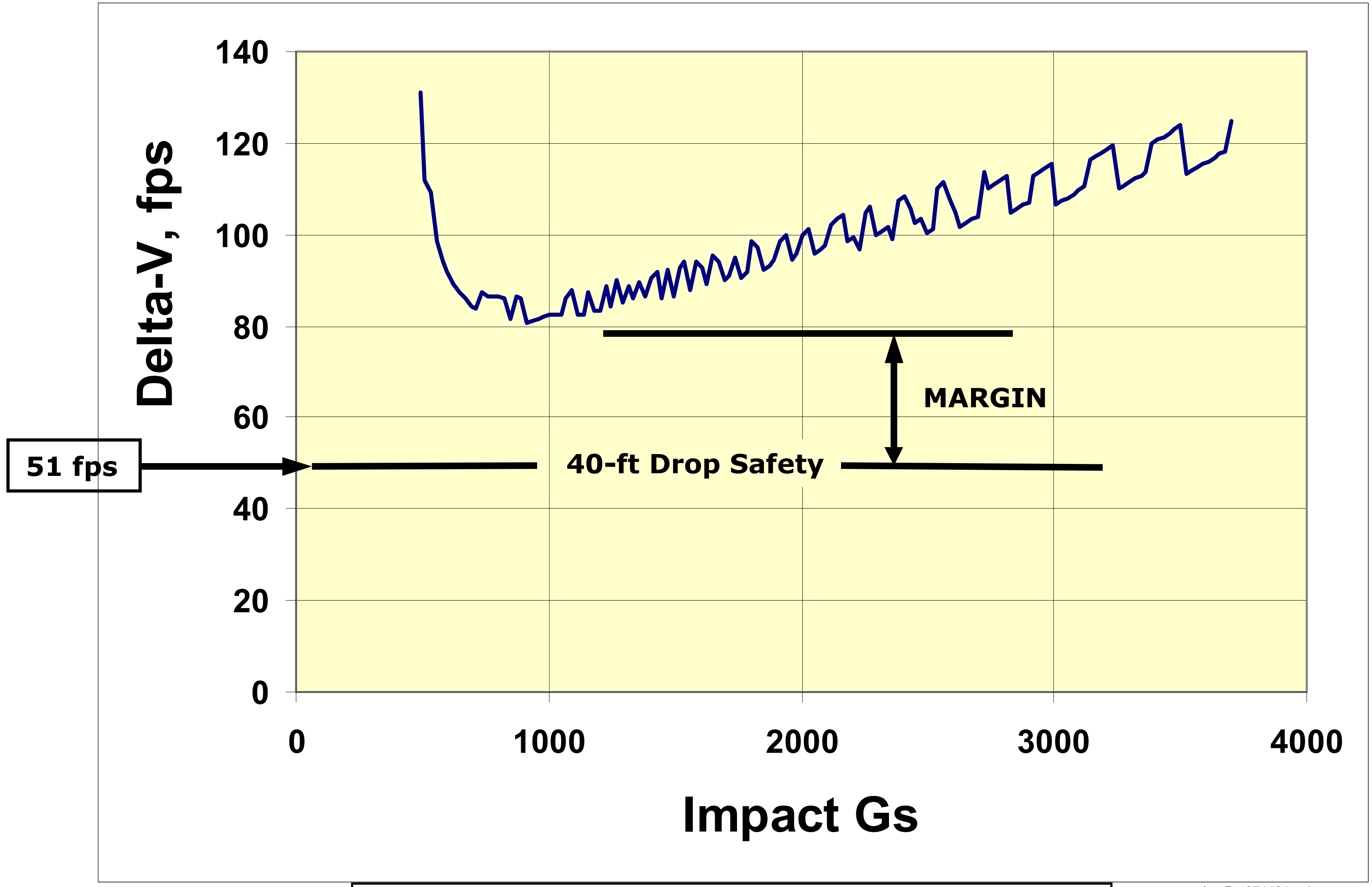

**Launch Acceleration Curve**




**$\Delta$V = (Acceleration)(Time)**

**= Area Under Curve**

# Calculated Zig-Zag Slider Arming Curve




ArmDat071101a.xls

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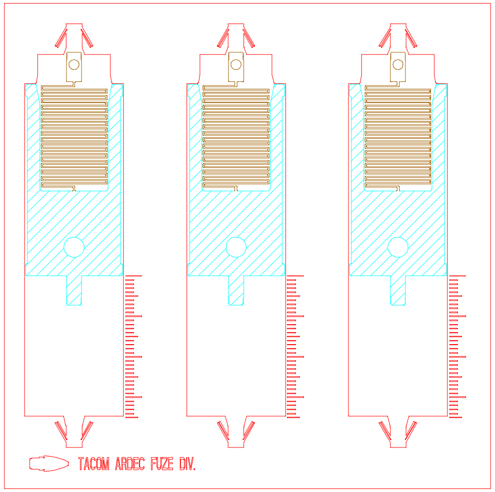
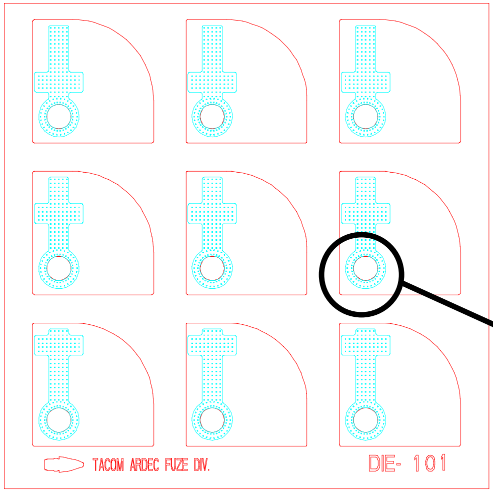
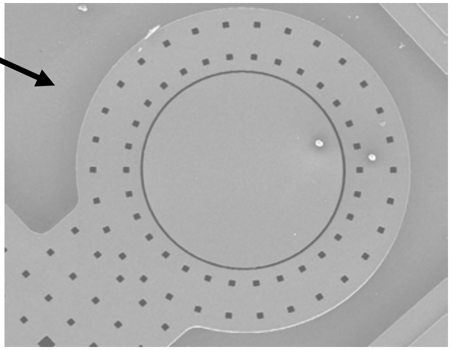
# DRIE-Fabricated Silicon Structures Used to Prove out Concepts and Generate Data

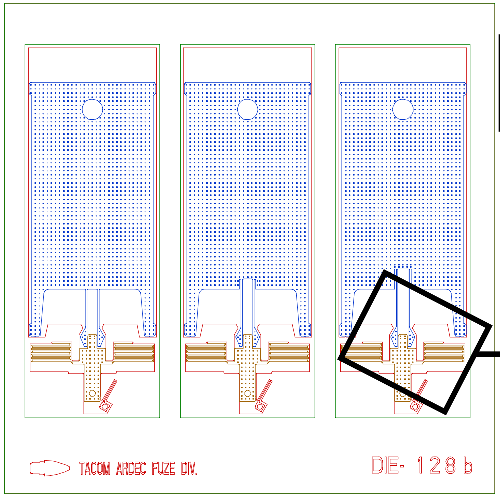



**Spring/Mass with Latches**

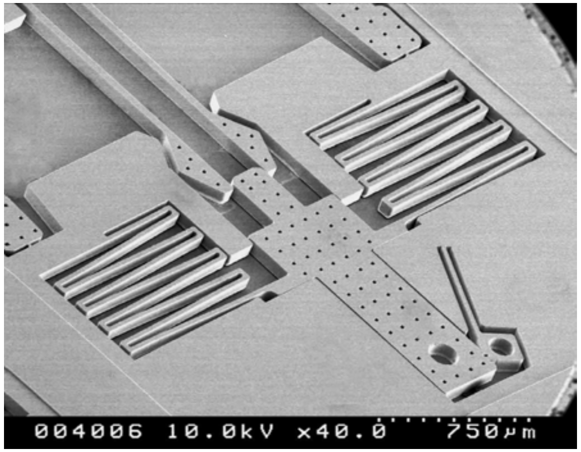


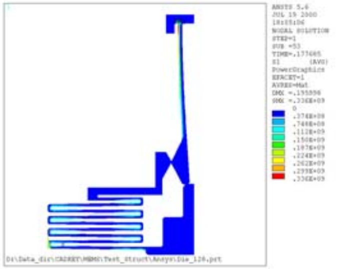

**Rotors (varying radial clearance and torque)**






**Reversible Anchors**



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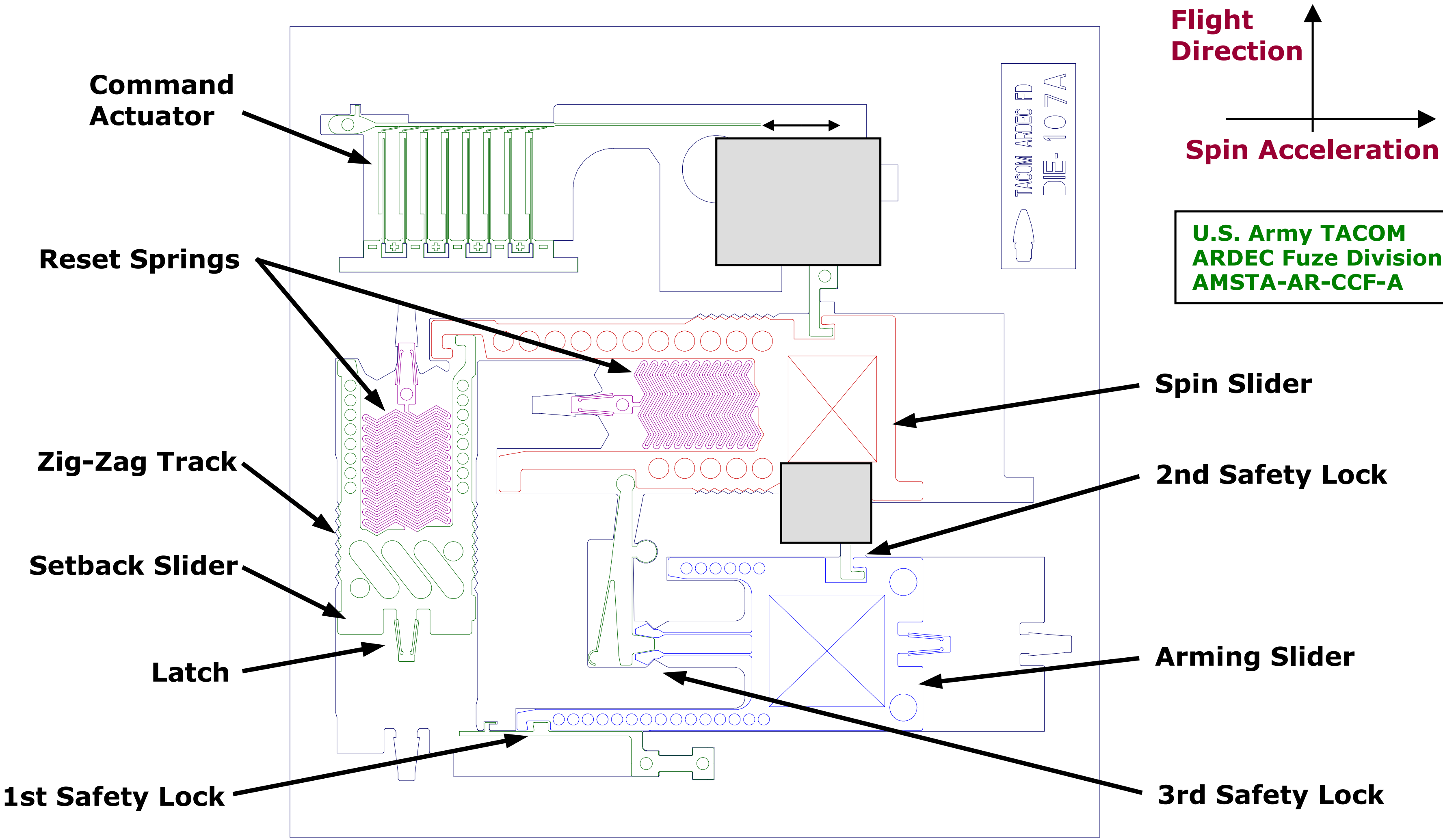
# MEMS Mechanical S&A for OICW

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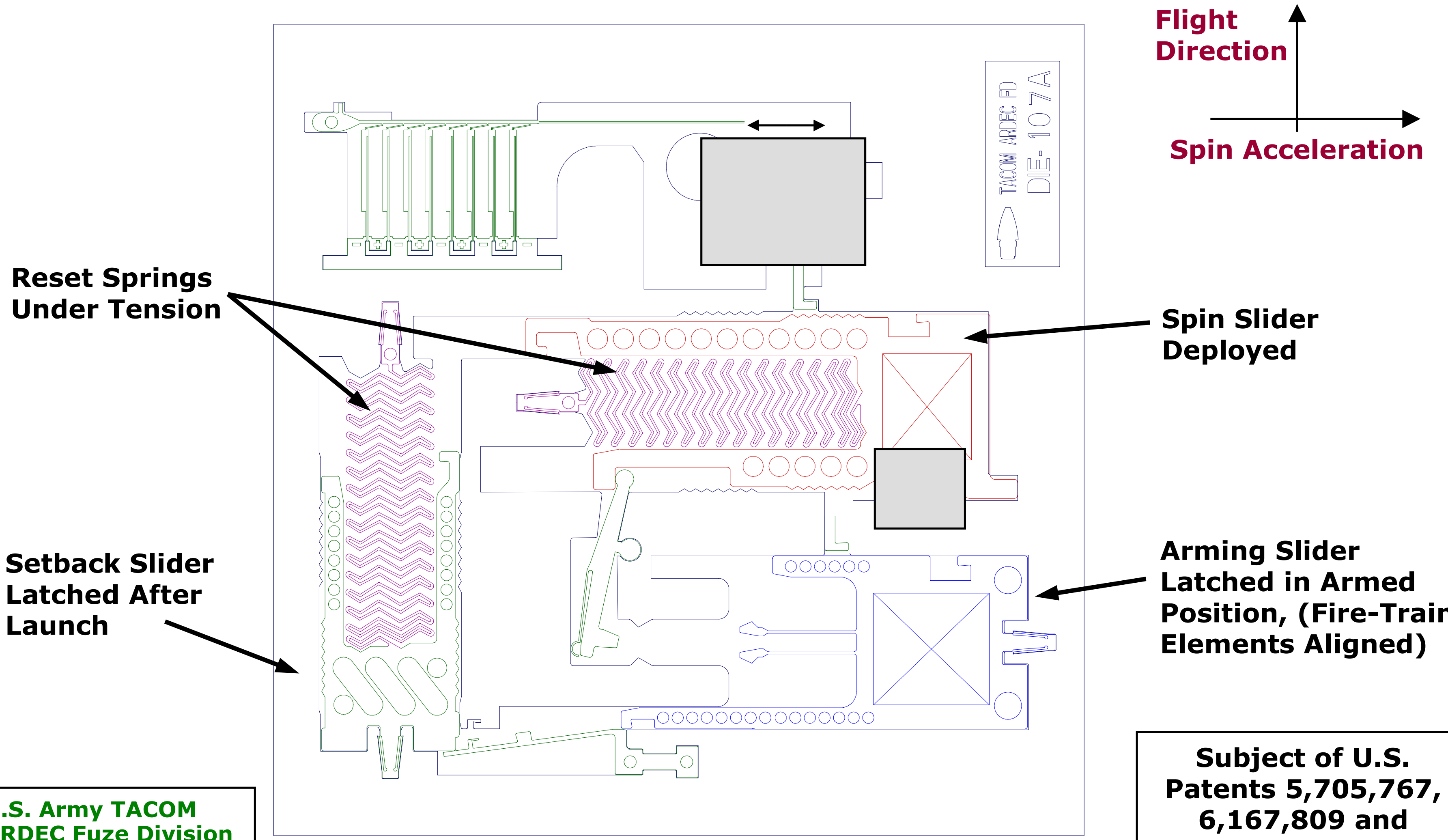
# MEMS Mechanical S&A for OICW: Armed

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ARDEC Fuze Division
AMSTA-AR-CCF-A

Subject of U.S. Patents 5,705,767, 6,167,809 and Patents Pending

# Technical Issues / Challenges

## Micro-Scale Firetrain (MSF)

→ Demonstrated MSF at NAWC-CL using MEMS S&A parts, June 2001

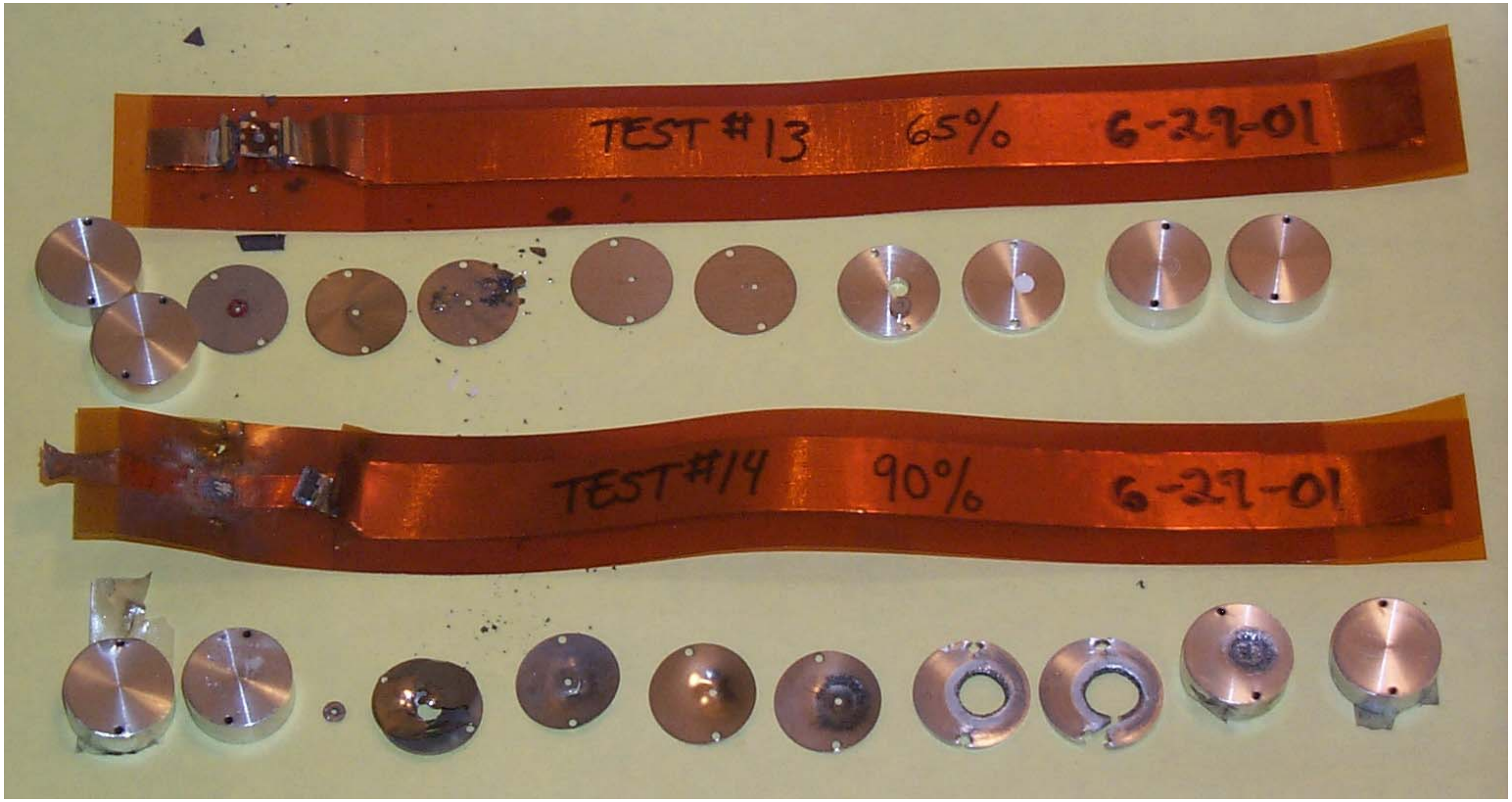
- **Test quantity was 24 units, four times that for the November '00 tests**
- **Samples distributed between safe, armed, and partially armed**
- **Obtained no detonations when in safe position**
- **Armed units detonated**
- **Partial-arming tests yielded a first cut on the 50% point (it is near 75% armed)**

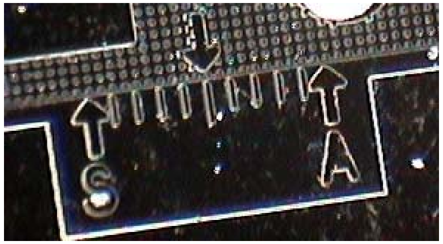
→ Next steps

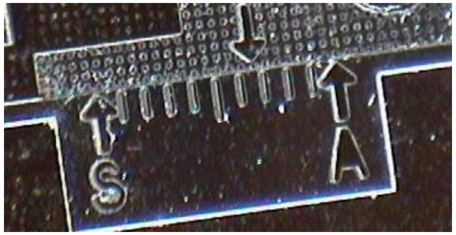
- **More firetrain demonstrations next month (Sept '01)**
- **Will be in sufficient quantities for a statistical analysis**
- **TACOM-ARDEC WECAC investigating economical explosive loading methods for MSF**

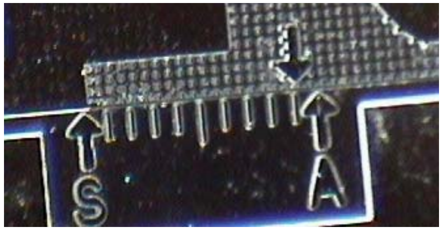
→ Environmental: *MSF* has *95% less lead-containing explosives than the* M100

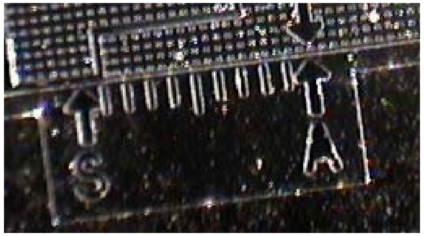
# Microscale Firetrain (MSF) for MEMS S&A, Preliminary Testing, June 01

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# Technical Issues / Challenges

## MEMS Mechanical S&A for OICW: <u>GETTING PARTS</u>

**A. Demonstrated concepts, designs, analyses, properties of structures in *silicon***

- Defining features and implementing 'mechanical logic" appears viable
- DRIE (silicon) parts delivery later this month, BUT…

a. Fabrication cycle time is long (~ 6 months) and yield is low (< 20%)

→ **Pursuing "massively parallel iterations," trying many approaches at once**

b. 'Stiction': parts don't release or they release and then re-adhere

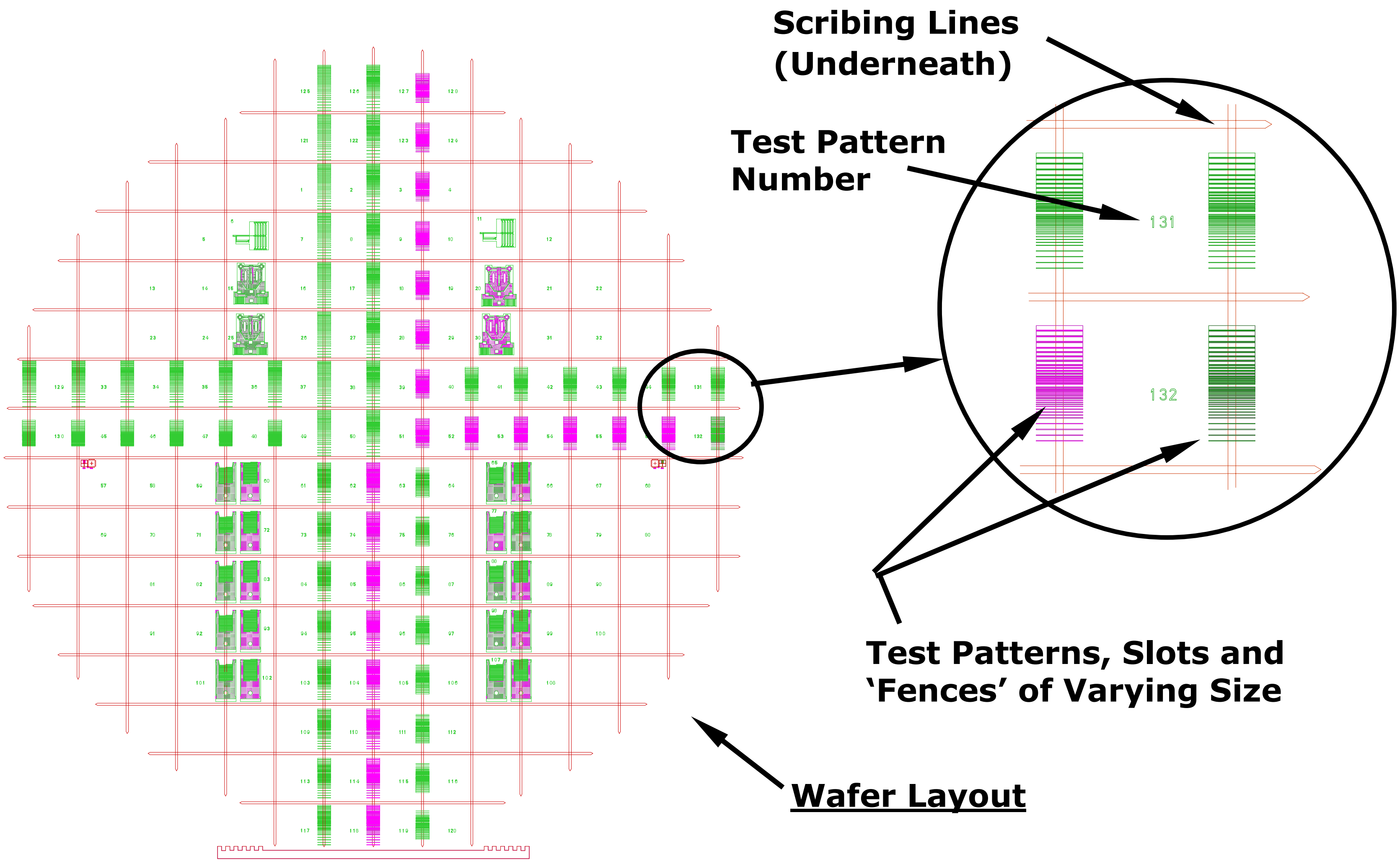
→ **Developed special process methods to avoid liquid immersion**

c. Impact testing showed silicon parts vulnerable at high strain rates

d. Silicon for demonstrating concepts, need ductile material for functional parts

**continued…**

# Test Patterns to Investigate Silicon Deep-Etch Process Variation

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# Technical Issues / Challenges

## MEMS Mechanical S&A for OICW: GETTING PARTS, continued

**B. Next stage is move to nickel (LIGA) parts for ductility**

**C. Anticipate improved MEMS fabrication methods in future**

- Manufacturability based on high-volume "printing" of nickel parts via LIGA "master"
- With improved firetrain can resort to well-established HAR fabrication techniques

**D. Doing a MEMS S&A cost study for OICW production**

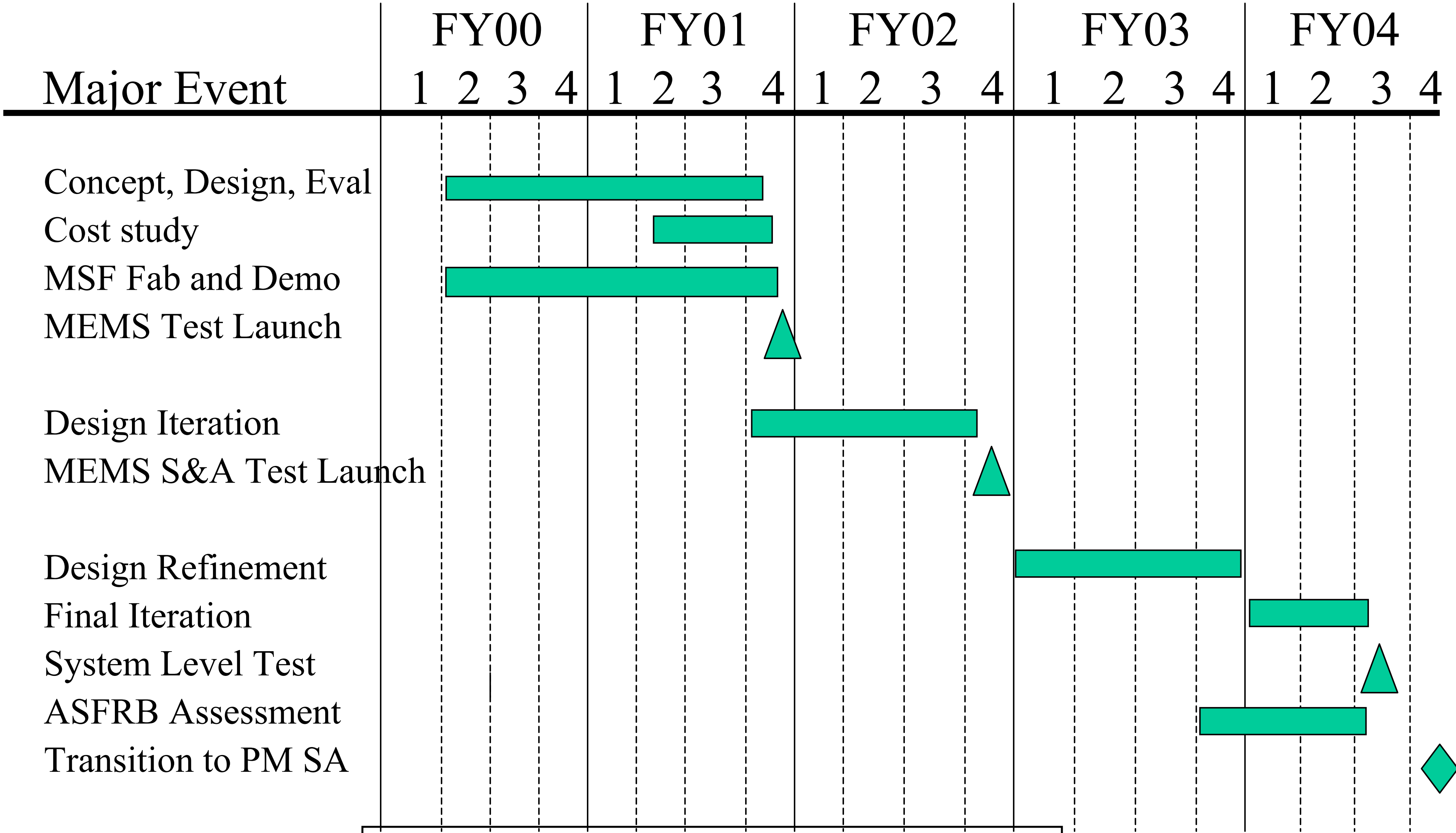
- Consulting high-throughput MEMS manufacturers
- "Assuming 10M parts using advanced MEMS technology five years from now…"
- Investigating breakthrough wafer-scale explosive loading techniques for MEMS

# SUMMARY

- **MEMS - Enabling Technology for Fielding of OICW and OCSW**
  - → Meet S&A cost and volume (lethality) targets
  - → Revolutionize fuzing for small arms
- **Technology Barriers Remain:**
  - → "MEMS is an emerging technology" (M. Huff, CNRI MEMS Exchange, July 2001)
    - **New fabrication technologies still coming on line**
    - **Infrastructure is behind the demand curve…judicious prototyping**
  - → We will continue to work out the feasibility…
  - → But *the next major challenge will producibility*.

# MEMS S&A for OICW

## (OICW System Enhancements STO)

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# OICW System Enhancements

## Technology Readiness Level (TRL) Maturity

| FY01 | FY02 | FY03 | FY04 |
|---|---|---|---|

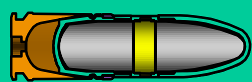
**TRL=4**

- Preliminary Fuze Architecture
- Demo MEMS/MEI Components in Test Barrel

**METRIC**

- MEMS component function & survivability – go/no go
- MEI Initiation – go/no go
- MEI out of line safety – go/no go
- Parts count to 5

**TRL=5**



- Army Fuze Safety Review Board
- Weapon Fire MEMS/MEI S&A

**METRIC**

- Demonstrate complete S&A System including MEI
- Meets the intent of MIL-STD-1316
- 75% vol reduction

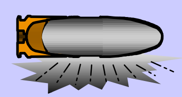
**TRL=2**

- Identify Direct Fragmentation Concept/ M&S

**METRIC**

- Assess potential for 20% increase over baseline lethality – go/no go

**TRL=4**

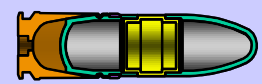


- Demo directed fragmentation

**METRIC**

- Arena test - Direction conical or angular – go/no go
- Exceeds PDRR baseline lethality

**TRL=5**



- Demonstrate Directed AB Concept in conjunction with Std OICW fuze

**METRIC**

- P(I) >50%

**TRL=6**

- Complete System Test
- Performance and Ltd Environmental Evaluation

**METRIC**

- Assess to MIL-STD-1316 design criteria
- Validate unit cost 50% < than $5.50
- Environmental stresses – MIL-STD-331