Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 507209
UNCLASSIFIED	

TITLE

HOST STRUCTURE AND ACTIVE MATERIAL INTERACTIONS: IMPLICATIONS FOR DESIGN OF SMART MATERIALS

System Number:

Patron Number:

Requester:

Notes: Paper #6 contained in Parent Sysnum #507203

DSIS Use only:

Deliver to: DK

#507209 (6)

Host Structure and Active Material Interactions: Implications for Design of Smart Materials

V.G. DeGiorgi

Mechanics of Materials Branch, Naval Research Laboratory
Washington, D.C. 20375 U.S.A.

ABSTRACT

There is an increasing emphasis on incorporating smart materials into existing naval structures. Special purpose materials and devices which are a combination of active and passive materials are currently being designed for a wide variety of applications including space structures, control and noise reductions on helicopters, control and noise reduction system on conventional aircraft and quieting systems on submarines. Successful incorporation of active materials into structures requires an understanding of the performance characteristics of the modified structure in addition to an understanding of the performance characteristics of the un-incorporated active material. The latter does not provide sufficient information for the design of smart material. An understanding of the interactions between active and passive components is necessary for appropriate design of composite smart materials. This presentation will highlight issues which must be addressed in the design process.

The basic device examined is an active panel. Different configurations of actuator placement have been evaluated for different applications. In two of the design cases discussed, prototype panels have been built and tested. The primary active components are PMN actuators. Typical displacement requirements are in the micrometer range. Common issues which will be discussed are: loss of actuator authority resulting from interactions with the surrounding passive material, interaction stresses and strains at passive/active material junctions, mechanical coupling between individual active components and support structure influence on performance characteristics.

Host Structure and Active Material Interactions: Implications for Design of Smart Materials

V. G. DeGiorgi

Mechanics of Materials Branch
Code 6382
Naval Research Laboratory
Washington, DC 20375-5000
virginia@walkinghorse.nrl.navy.mil

CF/CRAD Meeting
April 22-24, 1997
Halifax, NS

Issues

Active - passive material interaction

Interfacial stresses

Compliance mismatch

Device softening

Reduction in actuator authority

↓

Performance Characteristics

Displacement response

Stress levels

Composite Smart Materials (CSM) for Defense and Dual Use Applications

A DARPA Funded Program

- Goal: Develop a smart composite material for acoustic quieting application. Major design goals include use of integrated actuators, sensors and electronics. Stand alone design will incorporate all required electronics and intelligence.

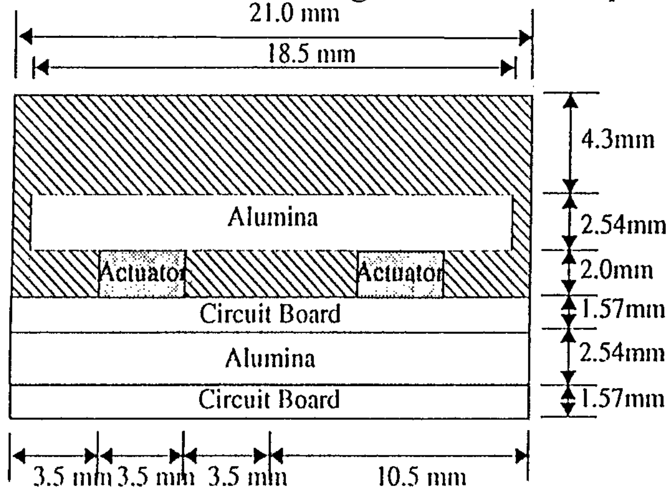
- Lockheed Martin
  - Program Management
  - Composite design, modeling and fabrication
  - Structural modeling
  - Controls
- AVX Corp.
  - Actuators and sensors
- VPI/VPT
  - Power supplies
  - Modeling
- AST
  - Acoustic design
  - Acoustic testing
- Signal Systems Corp.
  - Controls
- NRL
  - Structural modeling

CSM - Teaming or A Virtual Company

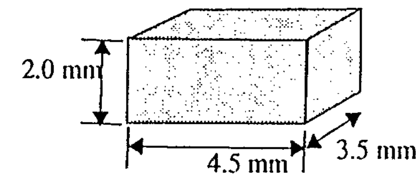
- Virtual Company concept
  - Reduce corporate protectiveness which hinders cooperative effort
  - Attitudes
  - Physical seperation
  - Communication technologies

- CSM Team utilizes
  - Phone/fax and other traditional means
  - Email/information and documents
  - Weekly tele-conferences
  - Special topic tele-conferences as needed
  - Video conferencing
  - Ad-hoc meetings scheduled in conjunction with other meetings or conferences
- Successfully developed team atmosphere on program

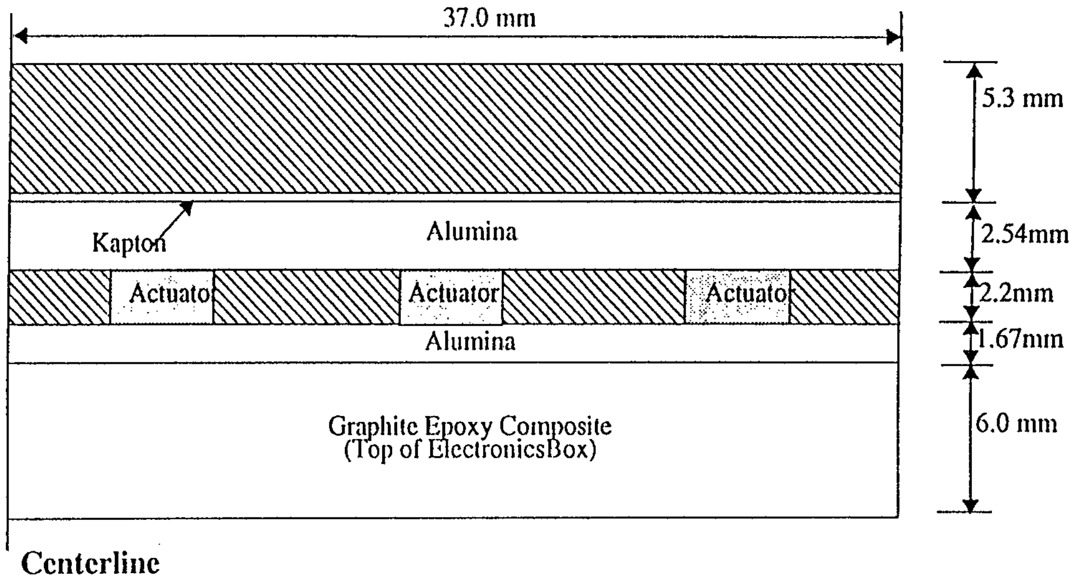
First Generation Design 4 Actuators per Piston, 4 x 4 array of Pistons per Unit Device



Basic 33 Chiplet Actuator



Second Generation Design 36 Actuators per Piston in 6 x 6 array, 1 Piston per Unit Device



Acoustic Tile

System Integration
Team Leader
Lockheed Martin

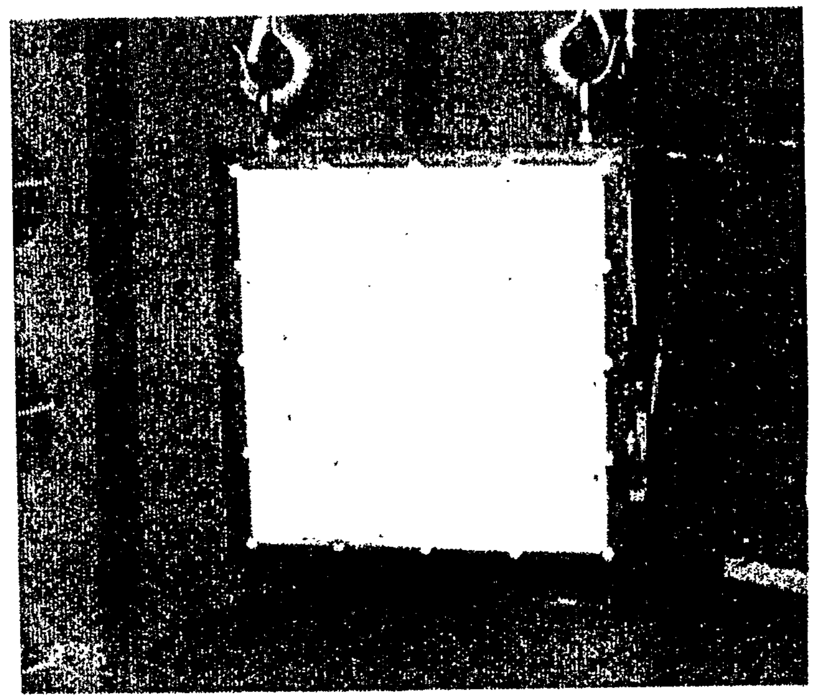
Actuators
AVX

Electronics
VPT / VA Tech

Control
SSC

Testing
AST

Modeling
NRL



Acoustic Piston

System Integration
Team Leader
Lockheed Martin

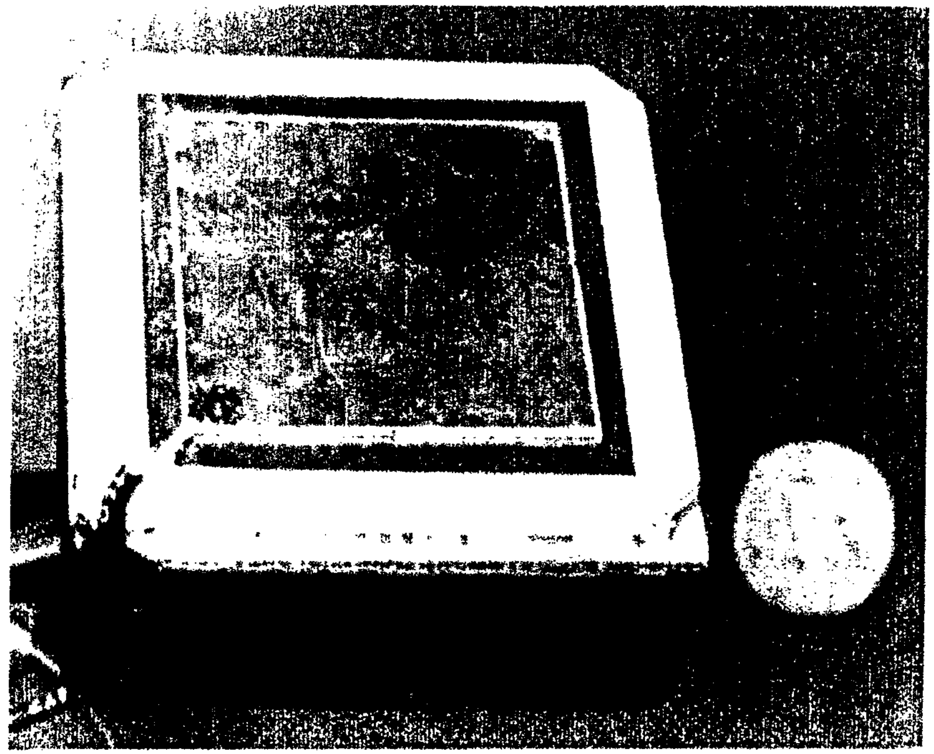
Actuators
AVX

Electronics
VPT / VA Tech

Control
SSC

Testing
AST

Modeling
NRL



Acoustic Piston

System Integration
Team Leader
Lockheed Martin

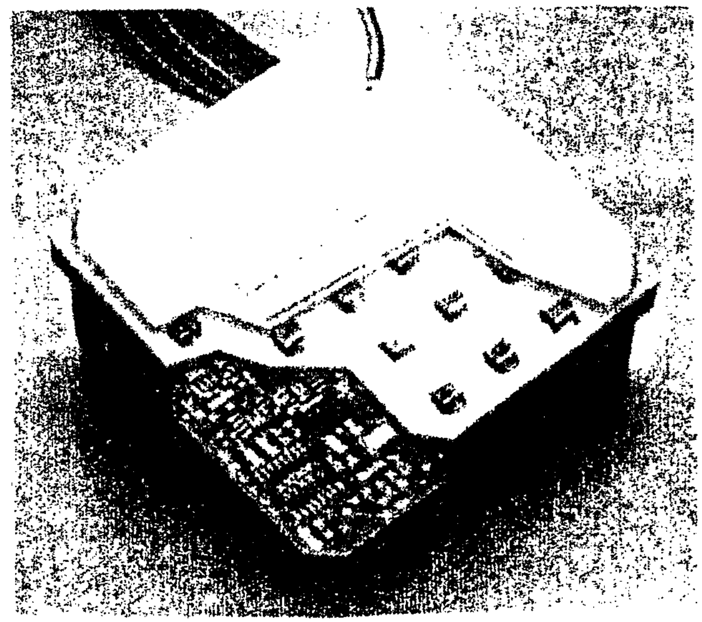
Actuators
AVX

Electronics
VPT / VA Tech

Control
SSC

Testing
AST

Modeling
NRL



Cut Away View

Generation 1 and 2 Finite Element Analysis

Model

2D - 3 Actuator using symmetry - Static analysis - 2340 8-noded elements

Basics

ABAQUS

Piezoelectric material properties

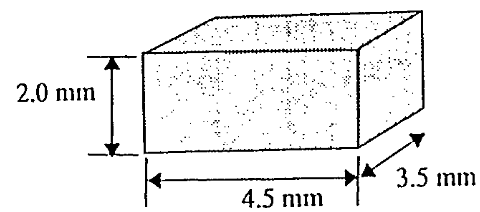
All materials explicitly included in model

Fixed (Rigid) connection between baseplate and support box

2D - Plane Strain and Plane Stress conditions examined
- 5^{o} and 20^{o}C
- Adhesive connection between actuator and base
- Rigid connection between actuator and base

Active Material

Basic 33 Chiplet Actuator



PMN chiplets

Similar to AVX 1418 actuators

Layered actuators

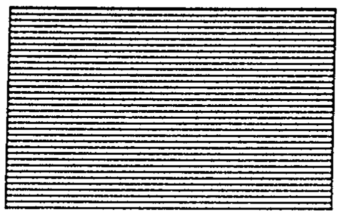
PMN

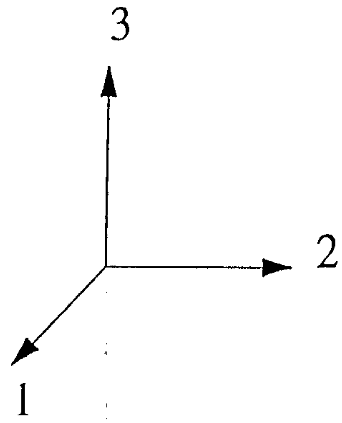
Modeling Simplifications

Piezoelectric - Linear approximation of PMN electrostrictive behavior

Monolithic - Approximate layered behavior

Piezoelectric Material Properties





PMN Chiplets

	5°C	20°C
d_{33}	9.35×10^{-10}	8.30×10^{-10}
d_{31}	-4.68×10^{-10}	-4.15×10^{-10}
d_{32}	-4.68×10^{-10}	-4.15×10^{-10}

n=93 layers

Layered

- Increased displacement/voltage response
- Each layer acts as individual actuator
- More complex but standardized fabrication

Resulting displacement

$\Delta_{33}=\Sigma\delta_{33}$

Equivalent material properties

$d'_{33}=nd_{33}$

$d'_{31}=d_{31}$

$d'_{32}=d_{32}$

Verification of Simplified Piezoelectric Model

Analytical	1.85×10^{-6} m
FEM one actuator model	1.85×10^{-6} m
Electrical circuit model*	1.9×10^{-6} m

*D. T. Lindner, "An Integrated Model of a PWM Switching Amplifier and Electrostrictor Actuator," CSM Progress Report dated 12 April 1996, VPI, Blacksburg, VA.

Material Properties

Material	E (GPa)	Poisson's Ratio	Failure Stress (MPa)
Alumina	372.0	0.25	172.0
Polymer Filler	23.0	0.30	-
Kapton	3.1	0.30	-
Adhesive	3.1	0.30	-
Graphite composite	165.0	0.30	380.0
Ceramic actuator	80.0	0.30	6.9 (Tensile) 60-70 (Comp.)

Structural Evaluation

Stress levels in actuators greater than critical stress for all cases considered

Location of maximum stress is interface between active and passive materials

Rigid connections cause significant increase in stress levels at critical location

Location of maximum stress at corners of actuators

Actuators modeled with sharp corners, stress concentation

- Real actuators - rounded corners with finite radii

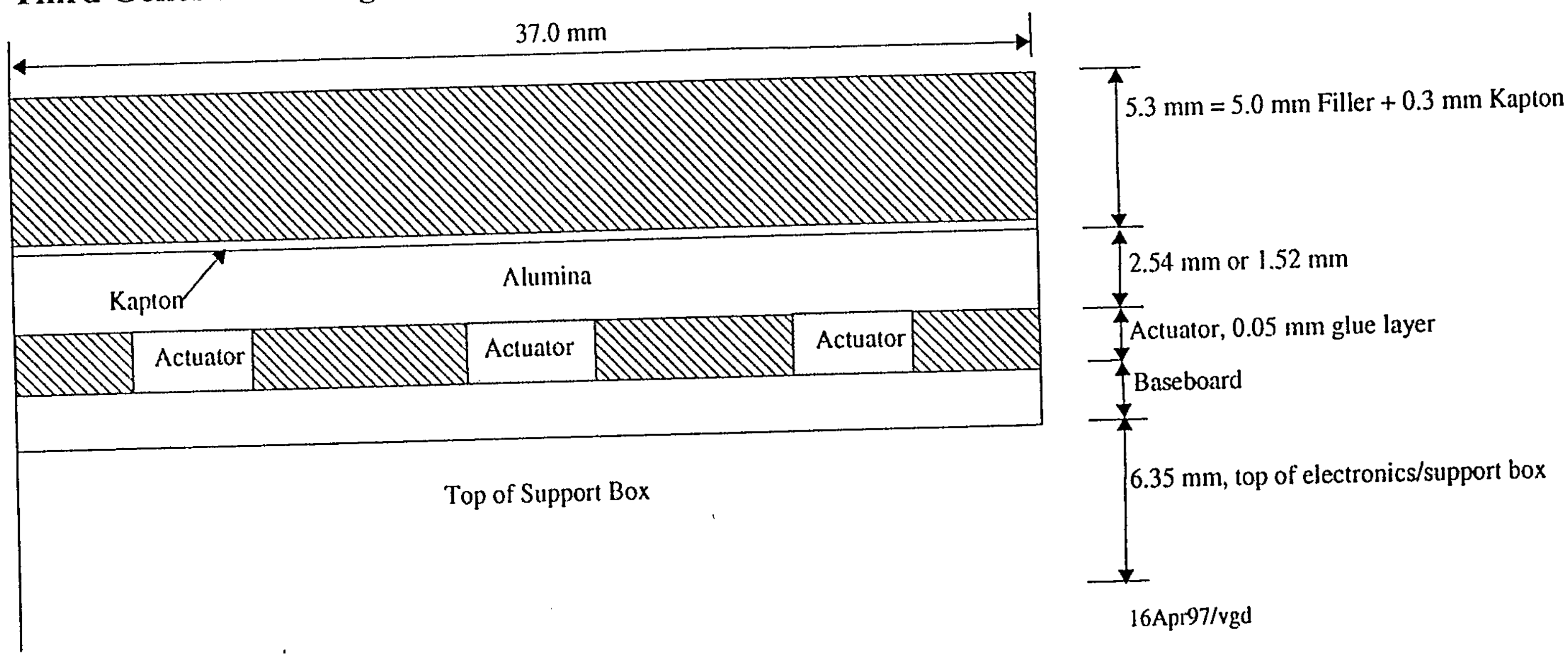
- Artifact of 2D modeling

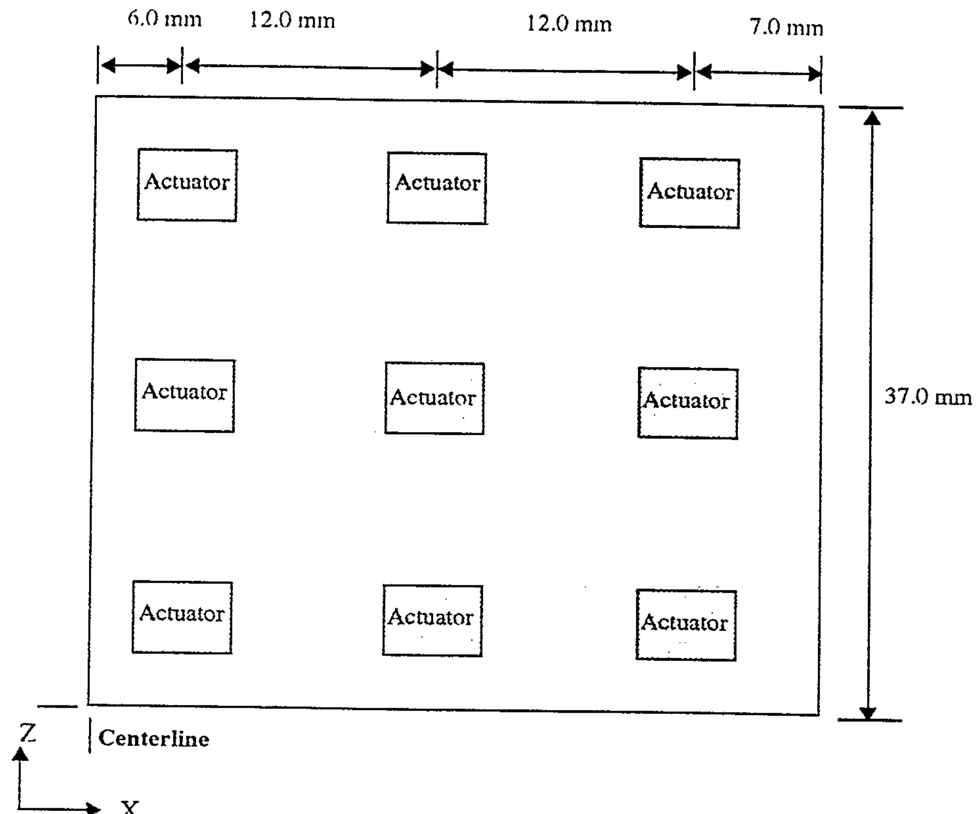
Third Generation Design Options

- Actuator Type
  - 1418 vs. 1812
  - availablity, cost & performance
- Headmass Thickness
  - 0.025, 0.040, 0.060, 0.100 inch alumina
  - performance
- Baseplate Thickness and Material
  - 1.57 mm thick alumina (original)
  - 0.040 inch thick alumina
  - 0.065 inch thick fiberglass circuit board
  - availablity, cost & performance
- Support Box Configuration
  - impact on electronics
  - performance

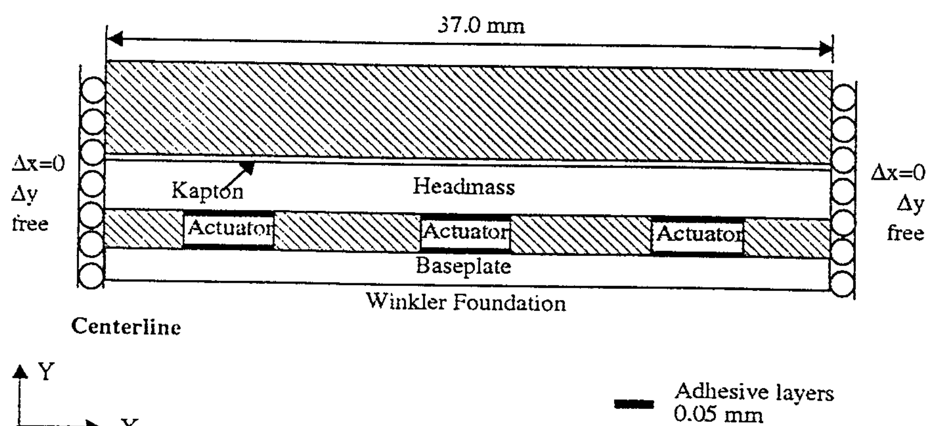
Third Generation Design

18 Actuators per Piston in 3 x 6 array, 2 Piston per Unit Device





One quadrant of device layout showing actuator position



Cross section of quadrant modeled

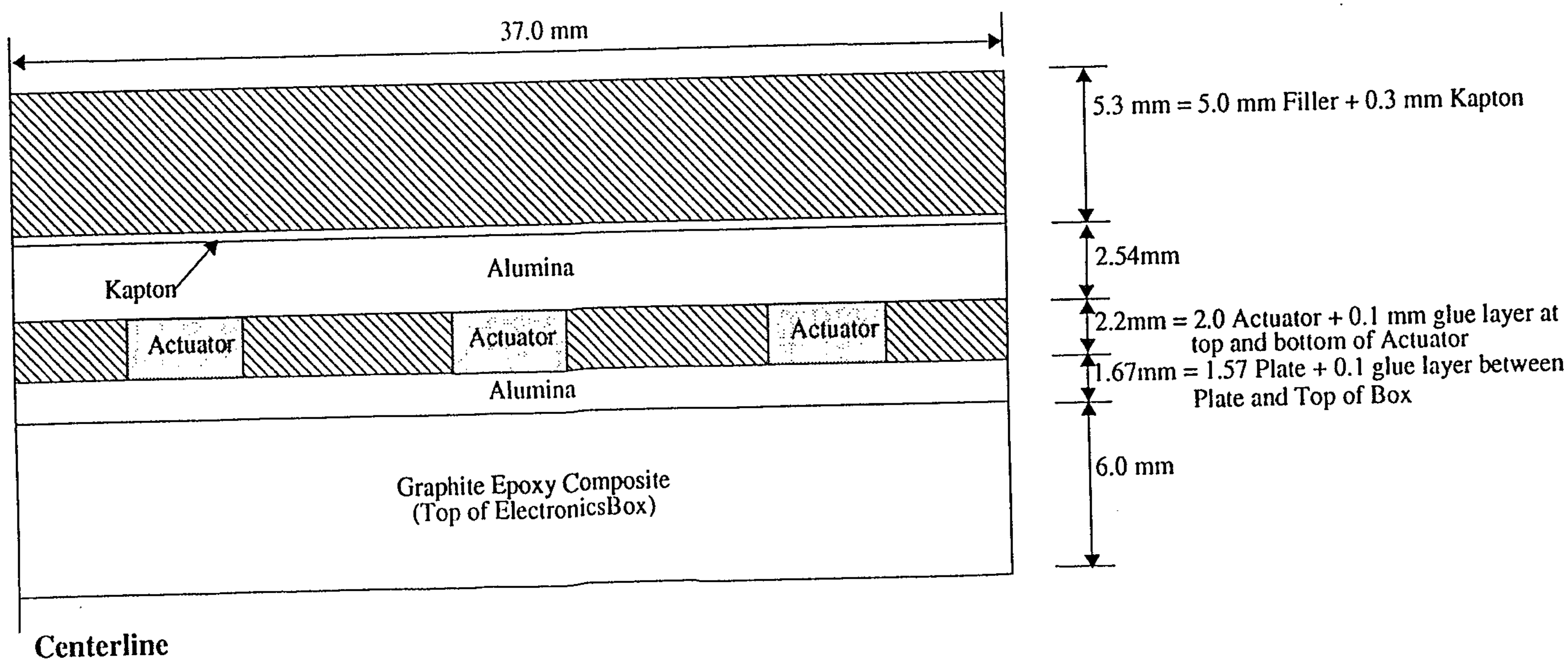
Device Layout and Section Modeled of
76.2 x 76.2 mm piston

Device Design Conditions

ΔVoltage = 24 Volts

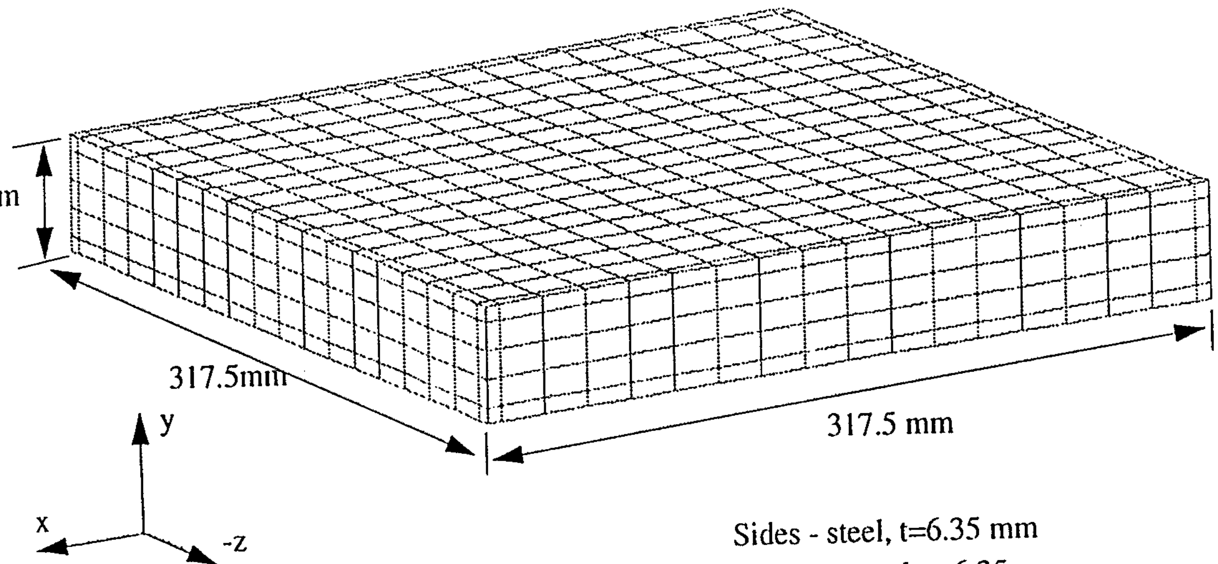
18 Actuators per piston
Piston dimensions ~1.5 inch x 3 inch

Multiple pistons per panel
Independent control/performance



Material Properties
(Textbook/Average vs. Measured)

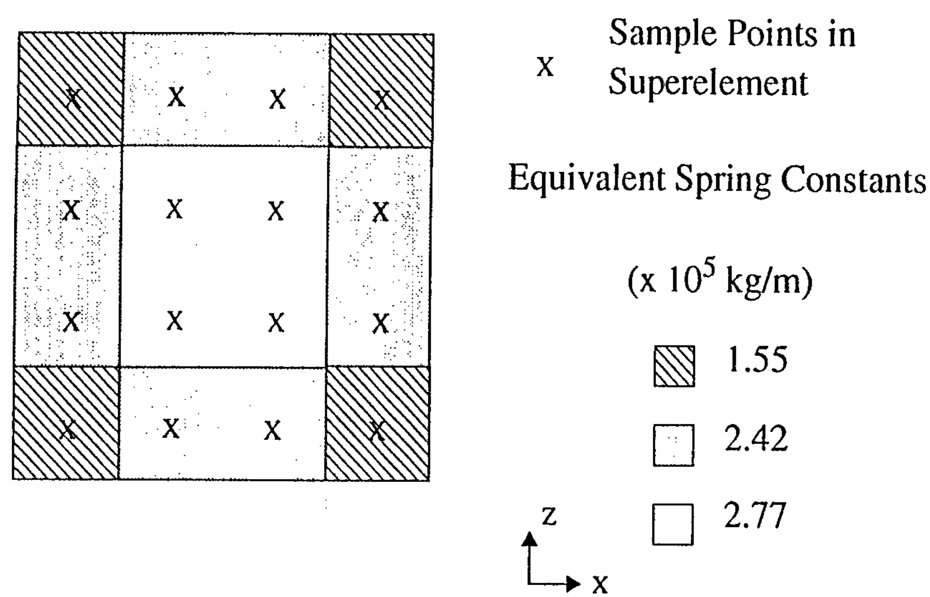
Material	E (GPa)	Poisson's Ratio	Failure Stress (MPa)
Alumina	~~372.0~~ 360.0	0.25	172.0
Polymer Filler	~~23.0~~ 2.5	0.30	-
Kapton	3.1	0.30	-
Adhesive	3.1	0.30	-
Graphite composite	165.0	0.30	380.0
Ceramic actuator	~~80.0~~ 71.0	0.30	6.9 (Tensile) 60-70 (Comp.)



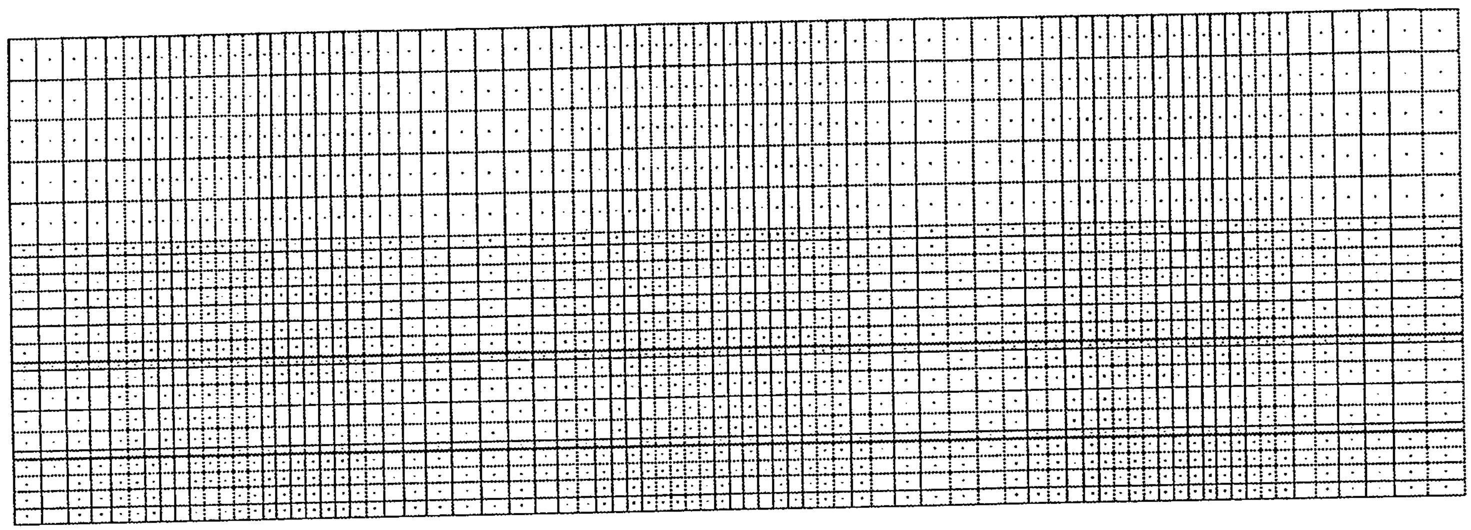
Sides - steel, t=6.35 mm
Bottom - steel, t=6.35 mm
Top - graphite epoxy composite, t=6.35 mm

Finite Element Model of Support Box

Used to Calculate Spring Stiffness for Winkler Foundation
Model Information
ABAQUS
1620 elements: 20 noded solid elements
Support box modeled as filled with polymer material

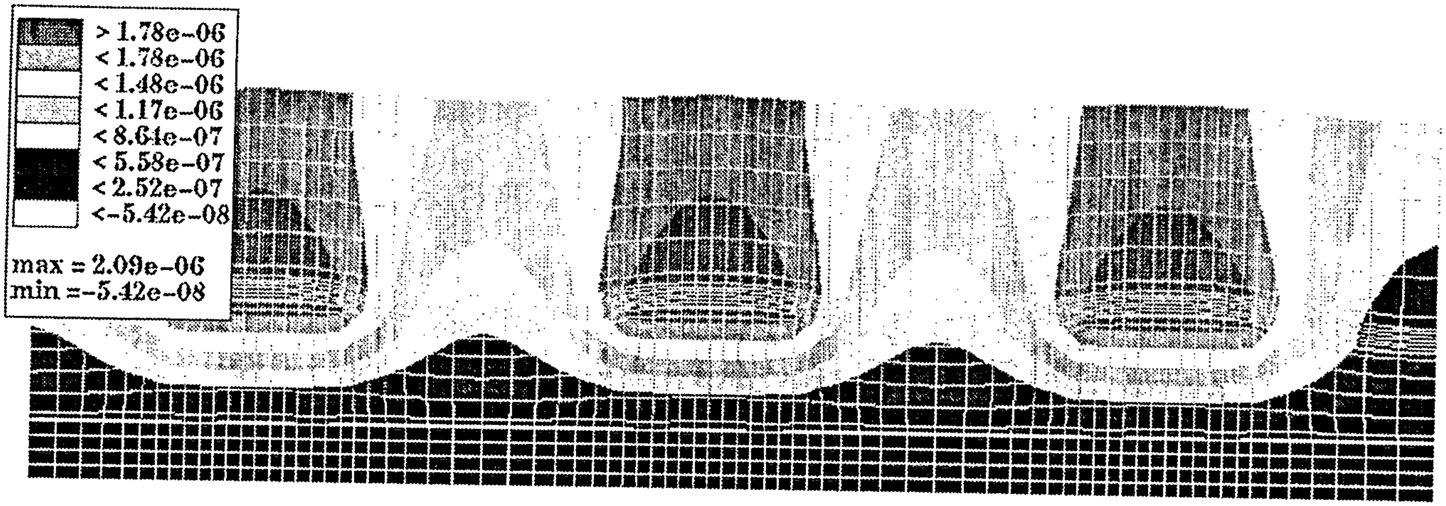


Calculated Equivalent Spring Stiffness Values from Support Box Model



Finite Element Mesh of Composite Panel

ABAQUS 1872 elements: 8 noded 2D CPE8 and 8E elements
157 linear spring elements for Winkler Foundation



Vertical Displacement Contour Plot

1418 actuators, 1.57 mm alumina baseplate and 0.64 mm headmass
Displacement reported in meters.
Magnification factor of 5×10^5 for deformed shape.

Calculated Displacement

2D Structural FEM Model

2.54 mm headmass

Location	1418 Alumina Baseplate (micro-m)	1418 Fiberglass Baseplate (micro-m)	1812 Alumina Baseplate (micro-m)	1812 Fiberglass Baseplate (micro-m)
Bottom of Actuator	-0.10	-0.31	-0.10	-0.30
Top of Actuator	1.94	1.74	1.34	1.16
Top of Headmass	1.88	1.70	1.28	1.12
PVDF	1.87	1.69	1.27	1.11
Top of Device	1.80	1.64	1.20	1.06
Total Stroke	2.04	2.05	1.44	1.46

NRL, Code 6380

Calculated Displacement

2D Structural FEM Model

1418 actuators with alumina baseplate

Headmass Thickness (mm)	Displacement at Top of Headmass (mirco-m)	Displacement at Top of Device (above actuator) (micro-m)	Difference in displacement at Top of Device (above actuator & centerline between actuators) (micro-m)
0.64	2.07	1.64	0.5
1.02	2.03	1.69	0.34
1.52	1.95	1.75	0.17
2.54	1.88	1.80	0.05

NRL, Code 6380

Performance and Structural Evaluation

Actuator authority significantly effected by passive materials

- Wave-pattern in top surface displacement
- Wave-pattern in headmass
- Significant actuator back surface displacement
- Headmass thickness has a significant impact on flatness of device
- Passive materials have significant effect on device displacement authority
  - ~50% reduction at top surface
  - Must know for device design
- Stress levels fall to acceptable levels when actual material properties are used
- Compliant filler material required for acceptable stress levels

Final Thoughts

- Smart materials/devices are complex structures; limited simplification possible
- Interactions will drive system performance
- Device performance is objective, not isolated performance of smart component
- Support structure has direct affect on performance
- Need an understanding of system/device loss mechanisms for effective design
- Material variablity can greatly affect analysis results