# DUAL USE OF ULTRASONIC PLATE WAVES: NDE AND ULTRASONIC MOTORS

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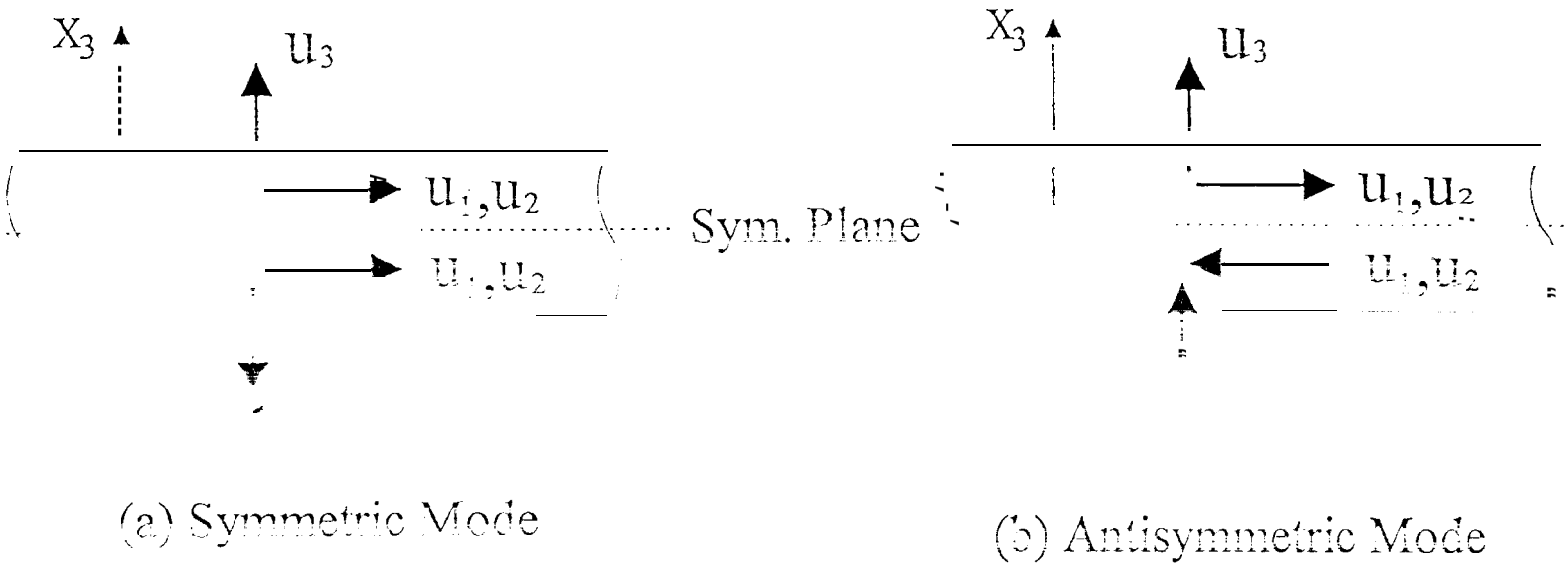
# BACKGROUND

- Plate waves have been the subject of NDE research and applications for many years.

- The analysis of the wave behavior in isotropic homogeneous materials was made by Lamb followed by many other researchers.

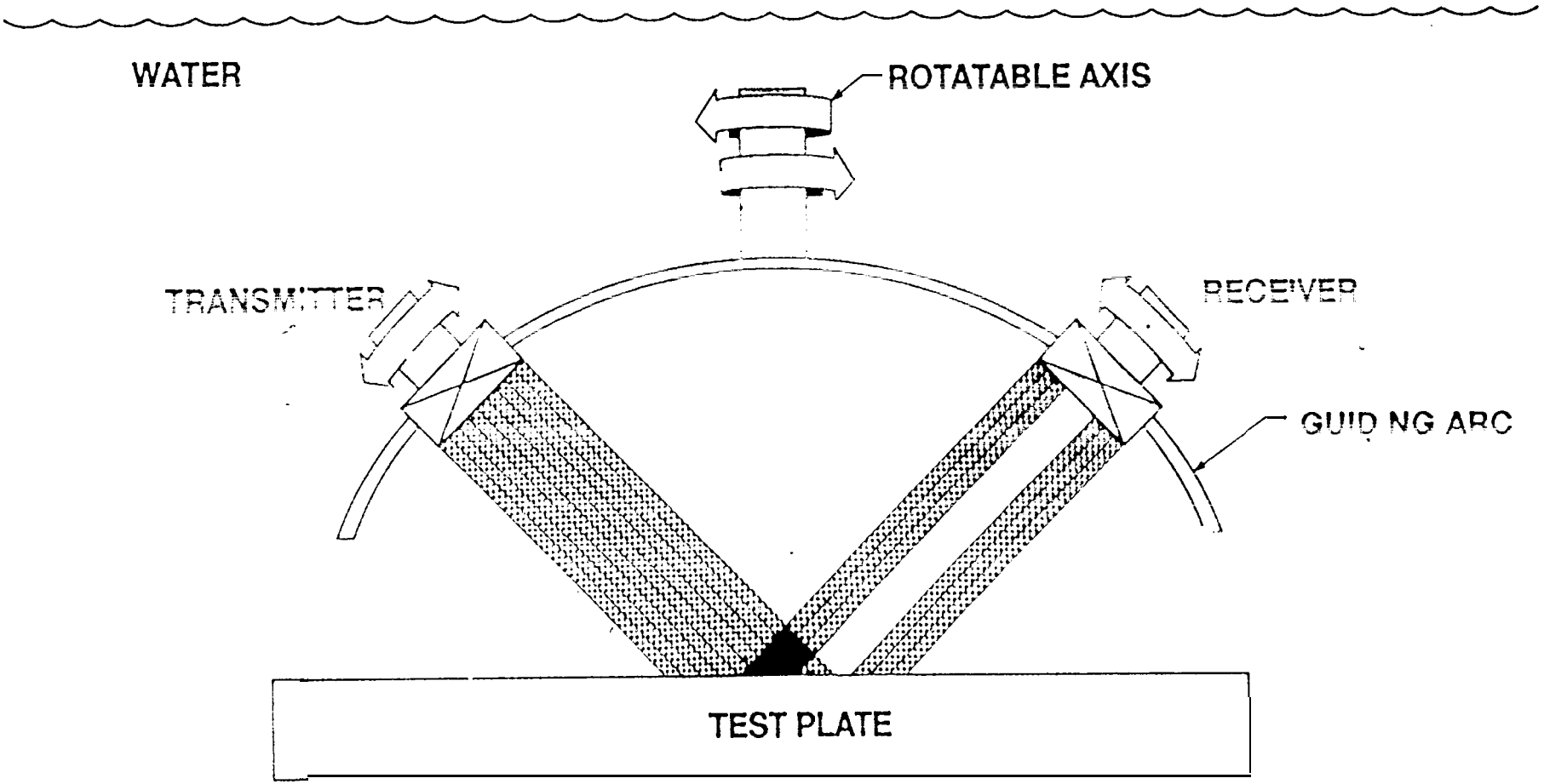
- In the last decade, methods were developed to analyze the wave behavior in anisotropic materials and the results were successfully applied to composites.

- In recent years, traveling flexural waves are increasing being used in actuation mechanisms.




Symmetric and Antisymetric Mode of Guided Waves

# EXPERIMENTAL SET-UP FOR COMBINED PBS AND LLW

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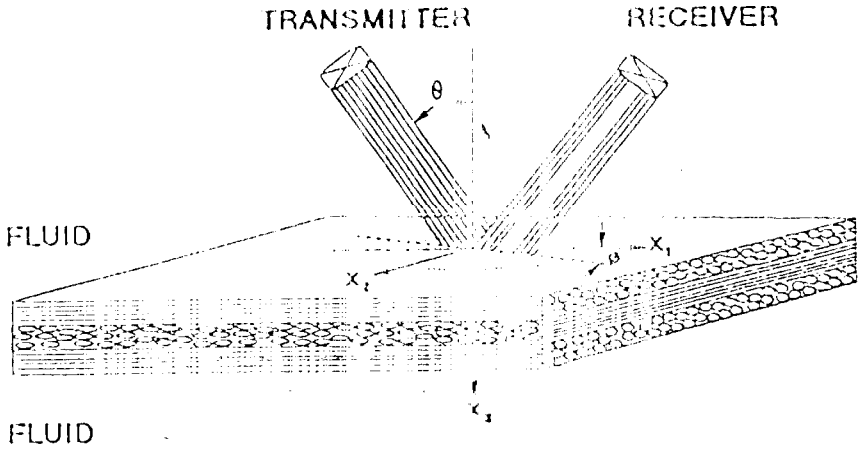



Figure 1: Schematic description of the leaky Lamb wave phenomenon and the experiment coordinate system.

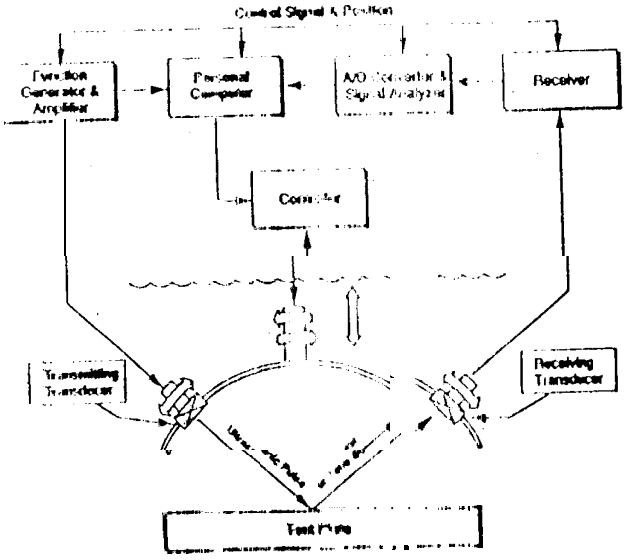
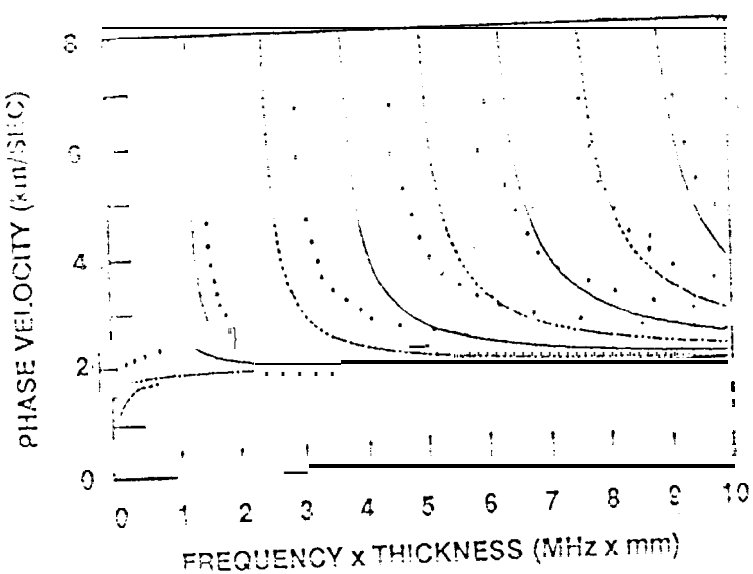


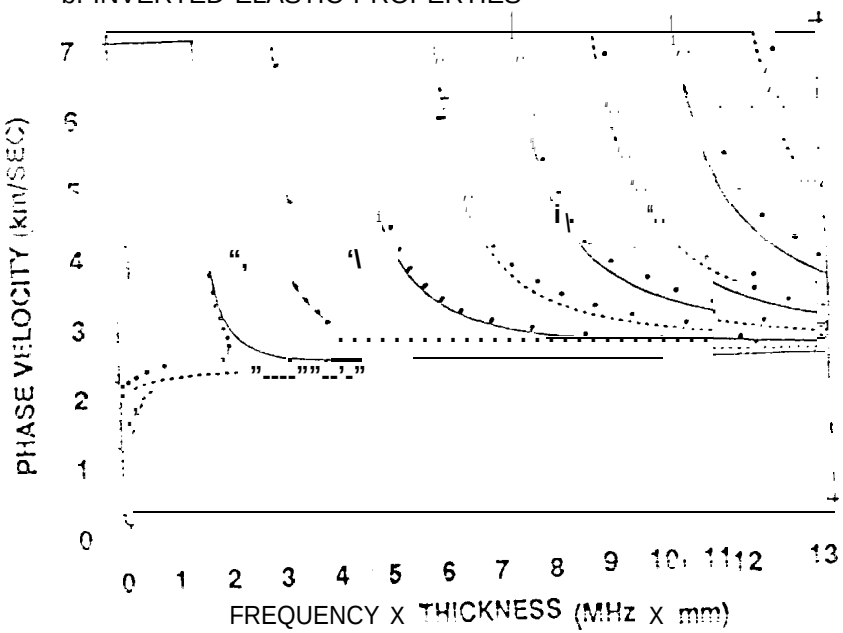

Figure 2: Experimental set-up with pitch-catch system for oblique insonification experiments.

# THEORETICAL AND EXPERIMENTAL DISPERSION CURVES FOR GRAPHITE/EPOXY UNIDIRECTIONAL LAMINATE TESTED ALONG THE FIBERS

a. ASSUMED ELASTIC PROPERTIES




b. INVERTED ELASTIC PROPERTIES

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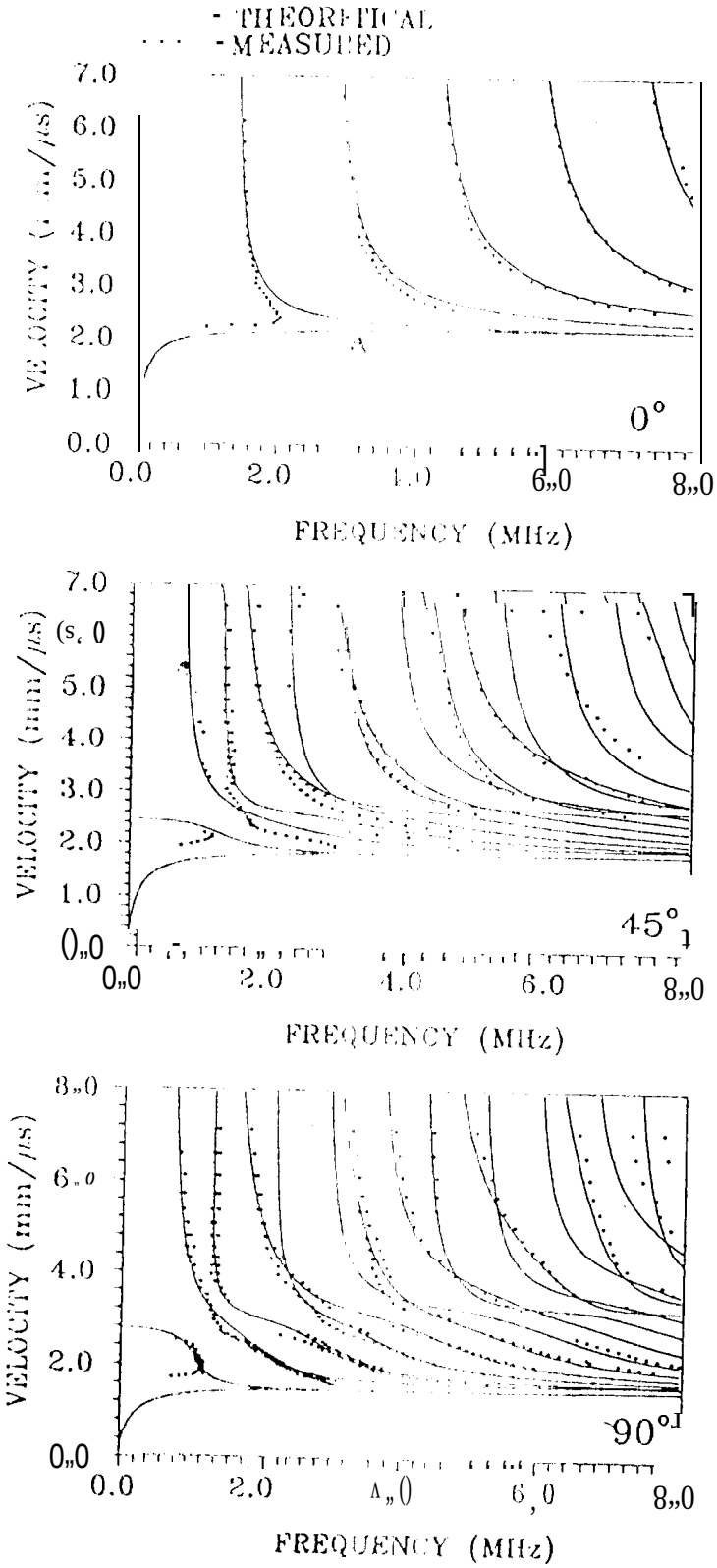

- THEORETICAL
- MEASURED
VELOCITY (mm/μs)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0°
0.0
2.0
6.0
8.0
FREQUENCY (MHz)
VELOCITY (mm/μs)
7.0
5.0
4.0
3.0
2.0
1.0
45°
0.0
2.0
4.0
6.0
8.0
FREQUENCY (MHz)
VELOCITY (mm/μs)
8.0
4.0
2.0
0.0
90°
0.0
2.0
8.0
FREQUENCY (MHz)

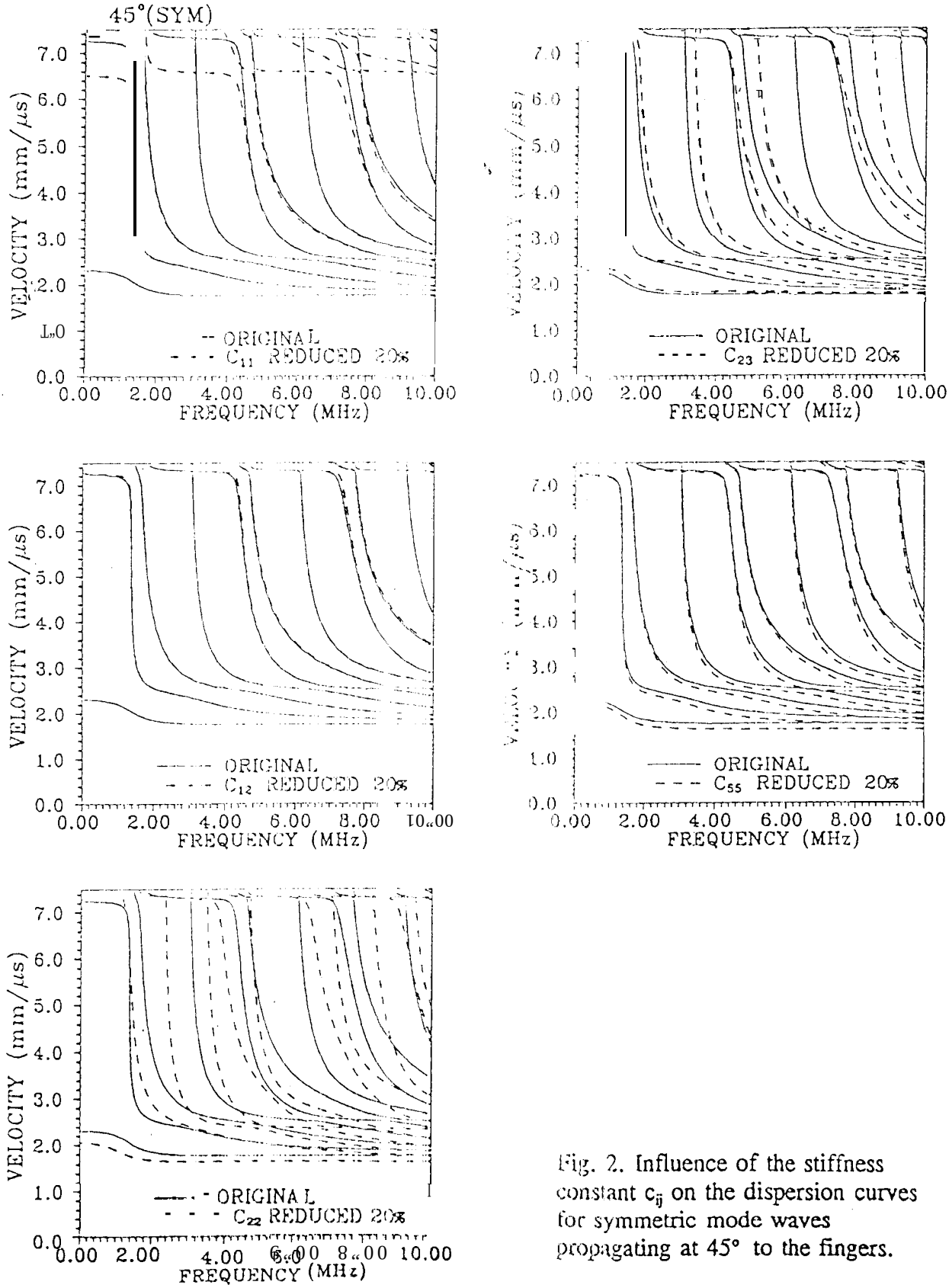
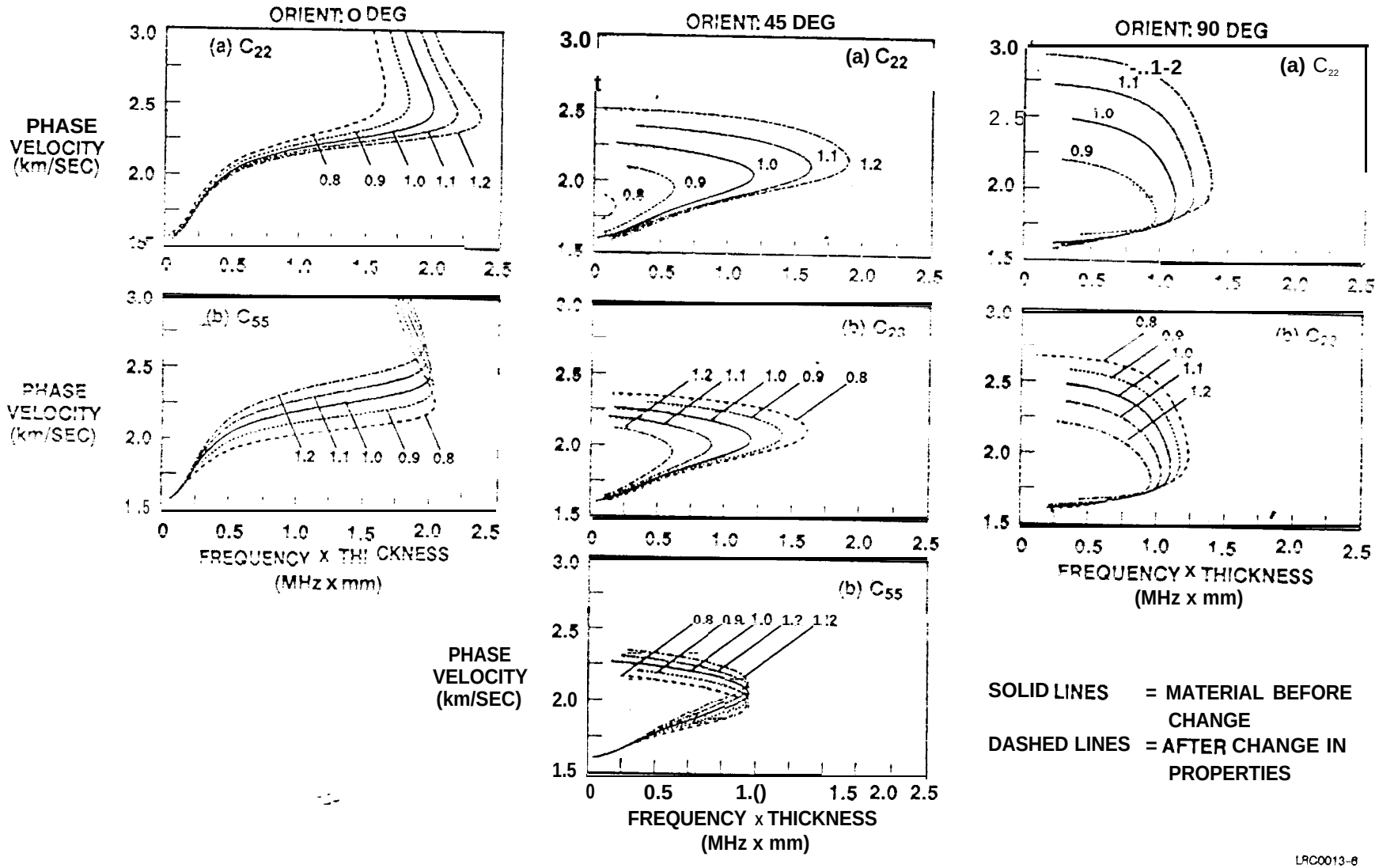



Fig. 2. Influence of the stiffness constant $c_{ij}$ on the dispersion curves for symmetric mode waves propagating at 45° to the fingers.

# LLW DISPERSION CURVES OF FUNDAMENTAL MODES . FOR A UNIDIRECTIONAL GRAPHITE/EPOXY PLATE AND ± 10- AND ± 20-PERCENT CHANGES IN ELASTIC CONSTANT

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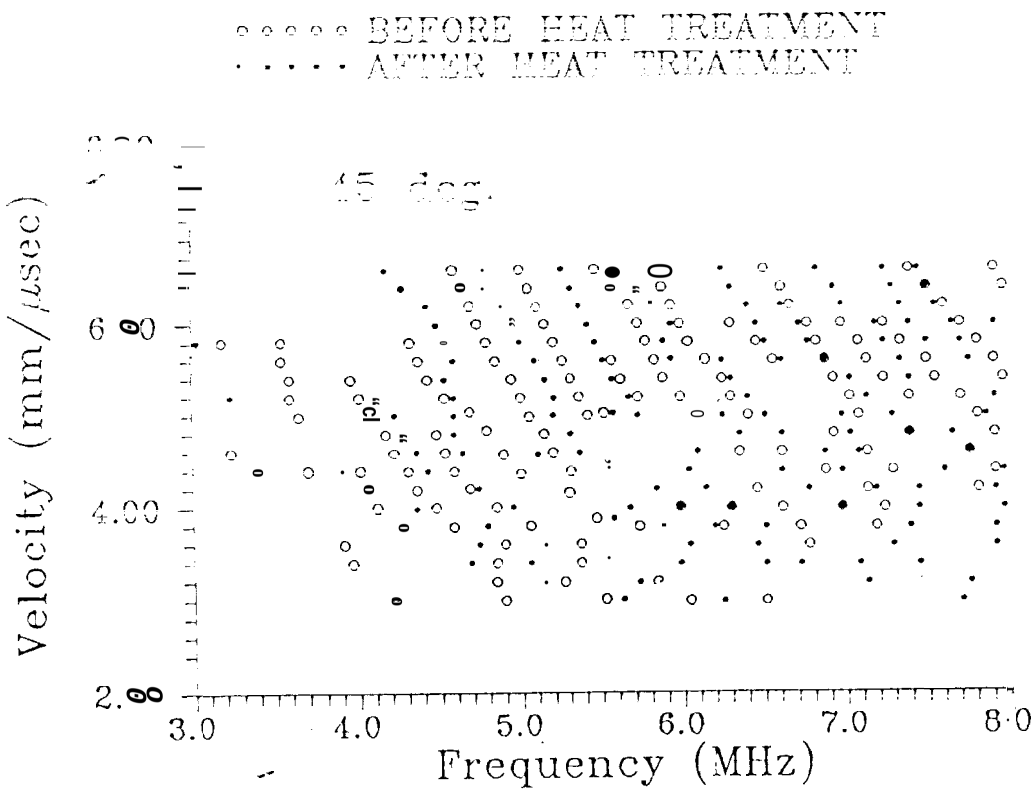
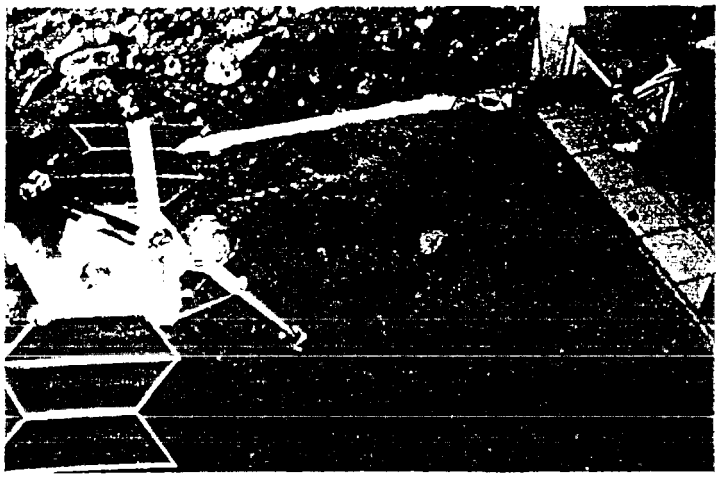
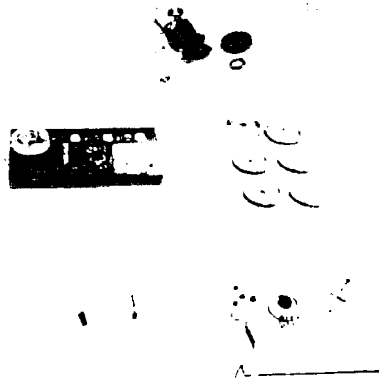
Measured dispersion data for a mu tilayered Gr/Ep composi e before and after heat treatment for wave propagation 45 $^{o}$ o the fiber.

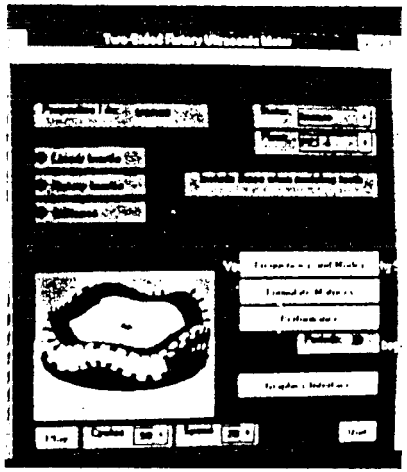


# TECHNOLOGY CONCEPT & DEVELOPMENT APPROACH

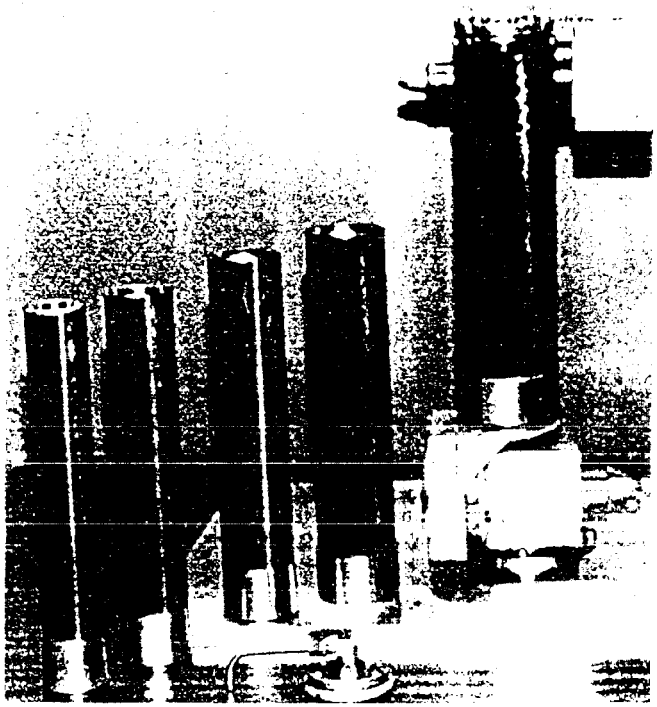


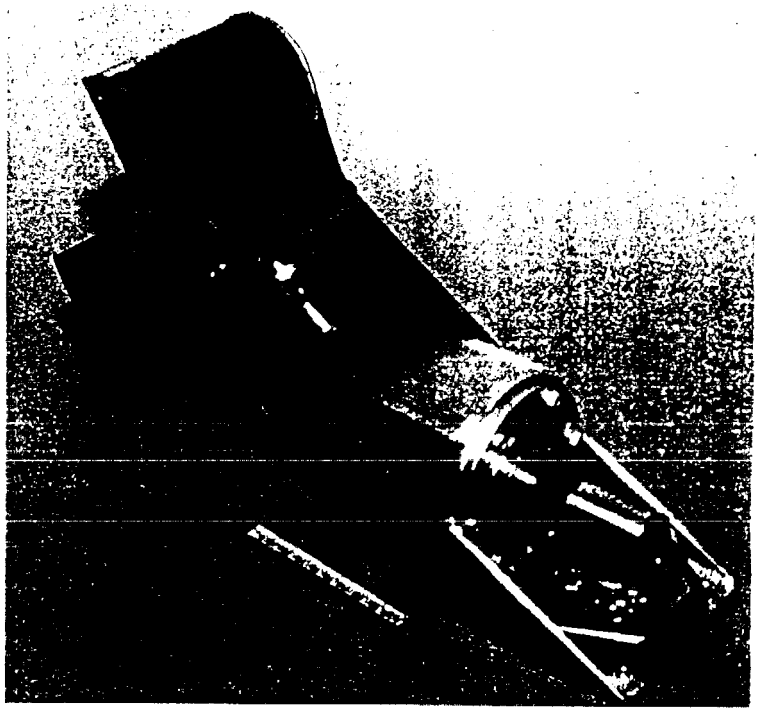
- **planetary science** enablement: sample acquisition, **near-field spectroscopy & micro-viewing, micro-instrument emplacement, etc.**
- **lander (surface platform) based manipulator,** coring, drilling and other active devices
- mass, power, size reductions commensurate with MSP and NMP flight objectives
- direct Mars science community participation

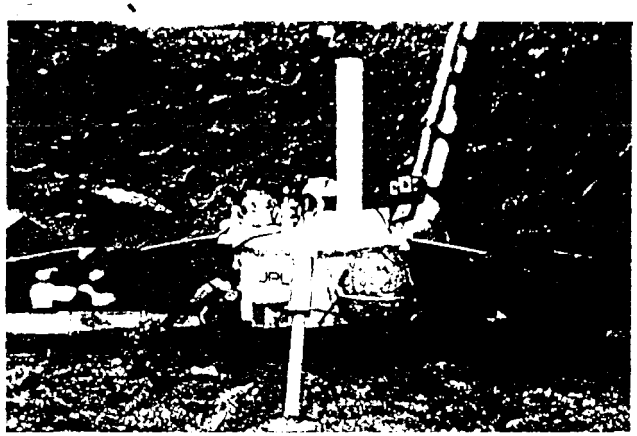


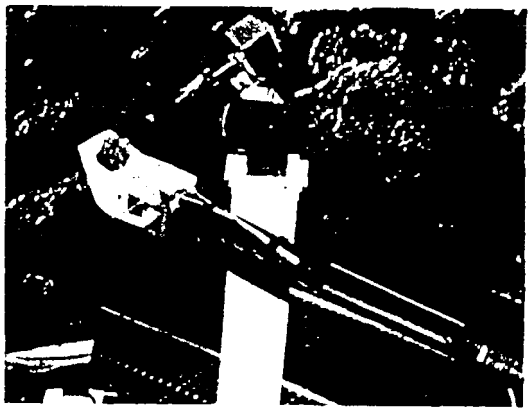


# Micro-Lander Dexterous Manipulator

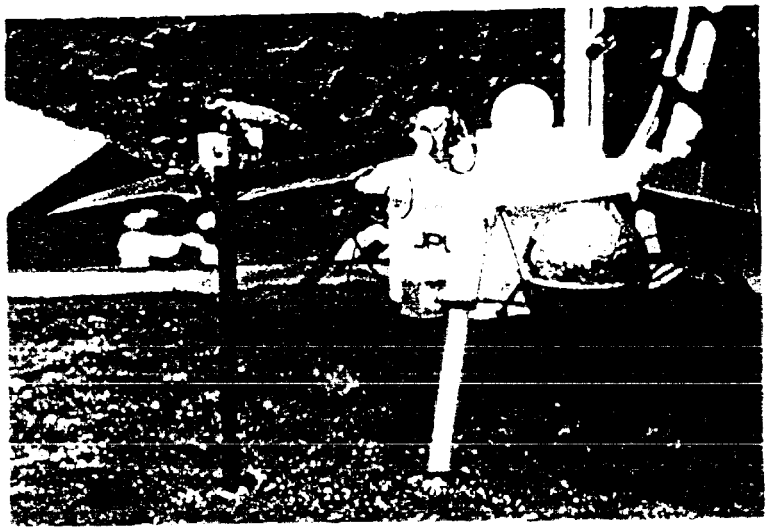


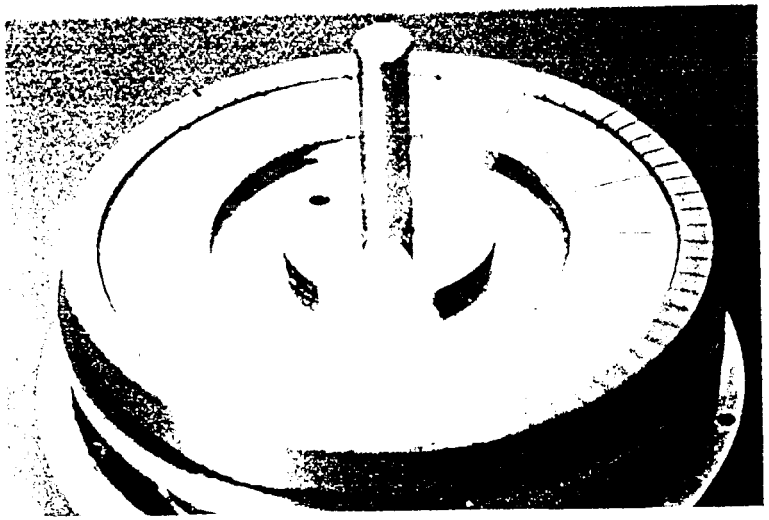






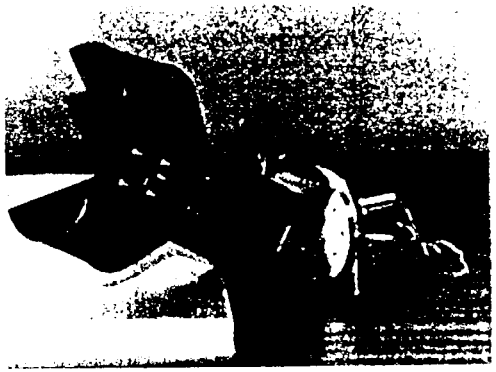
# FY95 ENABLING TECHNOLOGY ACHIEVEMENTS (Level 2)





## Task Highlights

- conception of gas-deployable segmented link structure (graphite epoxy) enabling MSP optimized science payload packaging/mounting (Phase B/C EM spec: arm & actuation: 3.5 kg, 2 meters, 10 liters, 1.5 kg end-arm payload)
- complementary end-effector development based in composite monocoque body and solid state motor actuation (50-70% mass reduction, minimized drive train requirements)
- development of new class of low mass, high torque (low speed), high efficiency and large holding force motor: cooperative with MIT and QMI, Inc. -- 25 in-lb device recently demoed



# ULTRASONIC MOTORS - BACKGROUND

<u>Operation principle</u>: Traveling plate/surface waves cause surface particles to move in a circular motion. This motion is used to propel the rotor.

- The motion is the result of accumulated minute displacements.
- Piezoelectric discs, i.e. stator, are use to excite the wave.
- Maximum performance is obtained at the resonance frequency.

- Ultrasonic motors are emerging new technology in consumer products (camera, etc.).

- No space qualified -ultrasonic motor.

# ADVANTAGES OF ULTRASONIC MOTORS

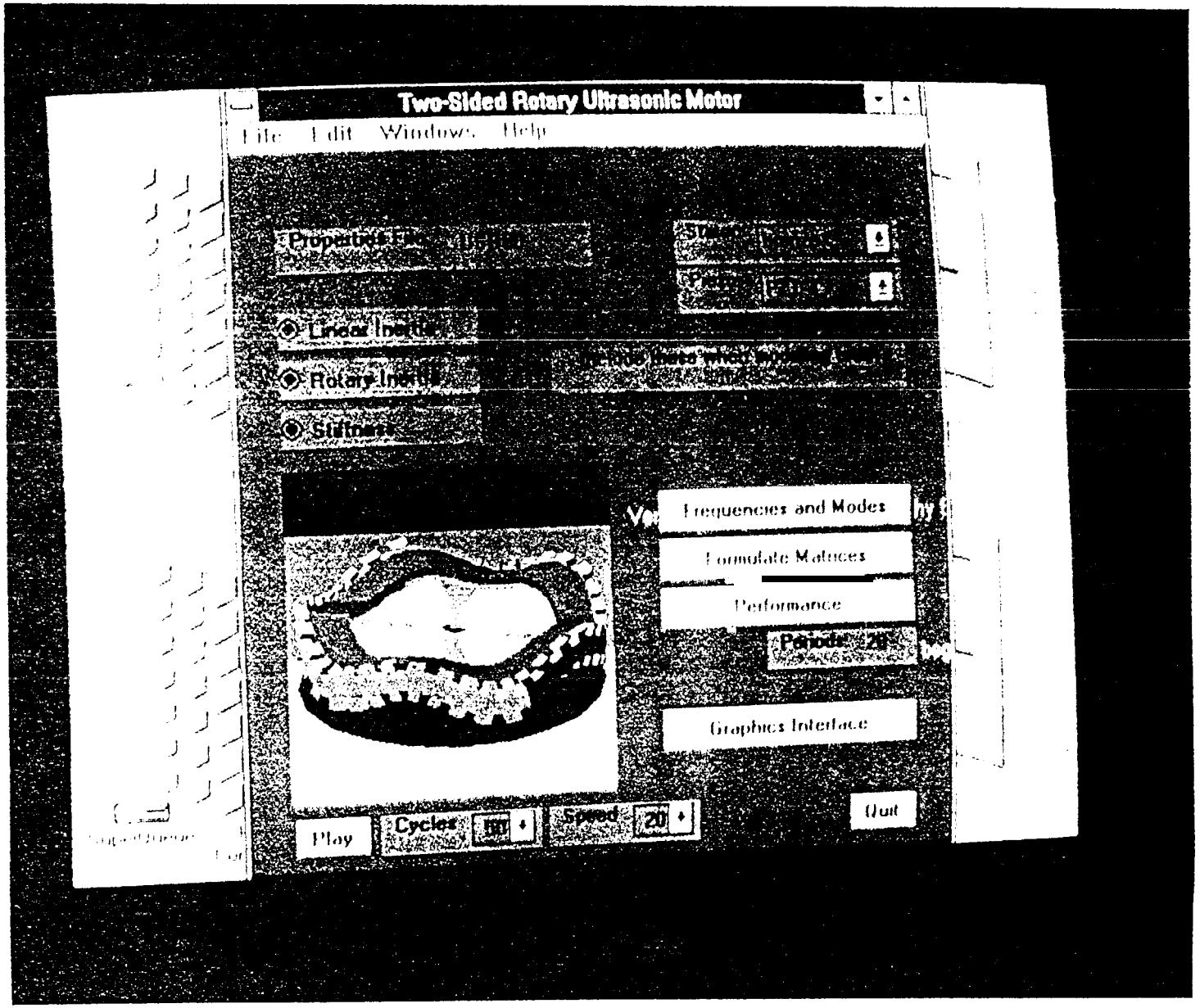
Ultrasonic motors offer superior alternative to conventional motors.

- Without gear, average of 10 times higher torque **density**
- Simpler construction
- Not affected by magnetic field or radiation
- Self-holding force
- Low speed operation allowing direct drive
- Motor is compact with a -pancake shape and easy to miniaturize
- Can be designed annular for electronic packaging
- Lower cost

# Comparison of existing electromagnetic (EM) and ultrasonic (US) motors

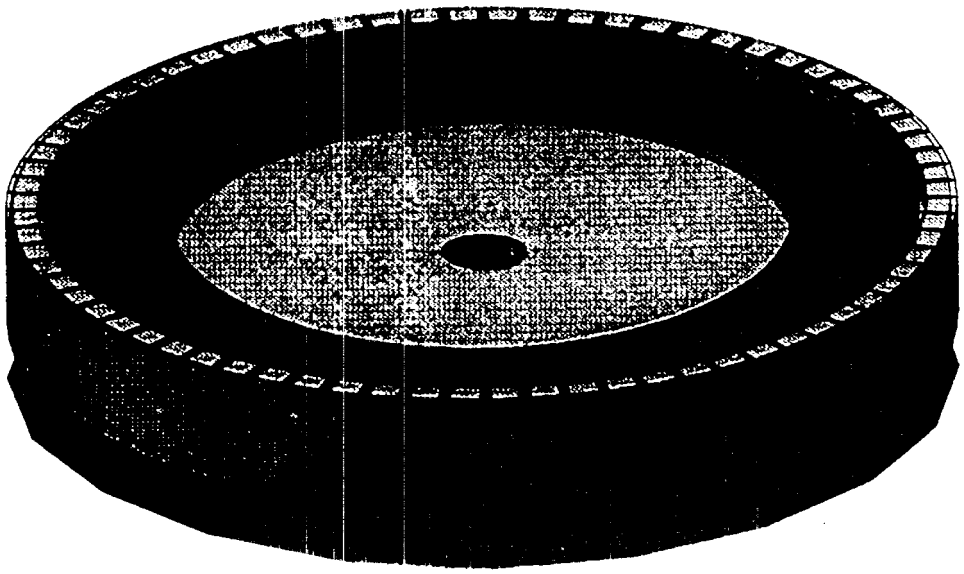
| # | Type | Description | Manuf. | Stall Torque (in. oz) | No-load Speed (rpm) | Mass (g) | Torque Density - without gear (Nm/kg) |
|---|---|---|---|---|---|---|---|
| 1 | EM | DC, Brushless | Aeroflex | 1.4 | 4.0K | 256 | 0.04 |
| 2 | EM | DC Brush | Maxon | 1.8 | 6.0K | 38 | 0.45 |
| 3 | EM | AC/3-phase | Astro | 10.7 | 11.5K | 340 | 0.21 |
| 4 | US | Traveling wave - Disc | Panasonic | 11.0 | 0.8K | 70 | 1.10 |
| 5 | US | Stand. Wave - Rod Torsion | Kumada | 189.0 | 0.12K | 150 | 8.80 |
| 6 | US | Traveling wave - Disc | Shinsei | 13.0 | 0.3K | 33 | 2.70 |
| 7 | US | Traveling wave -Ring | Canon | 17.0 | 0.08K | 45 | 2.30 |

# A Computer Code Developed to Allow Animation of the Motor Operation for Optimized Design

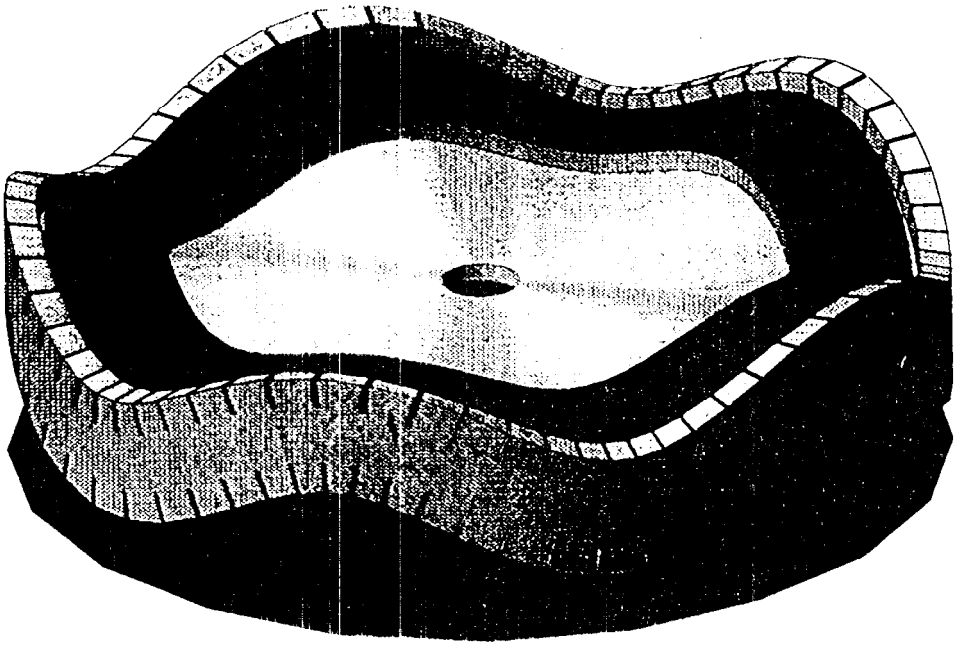


# Piezoelectric Motor - Stator Model

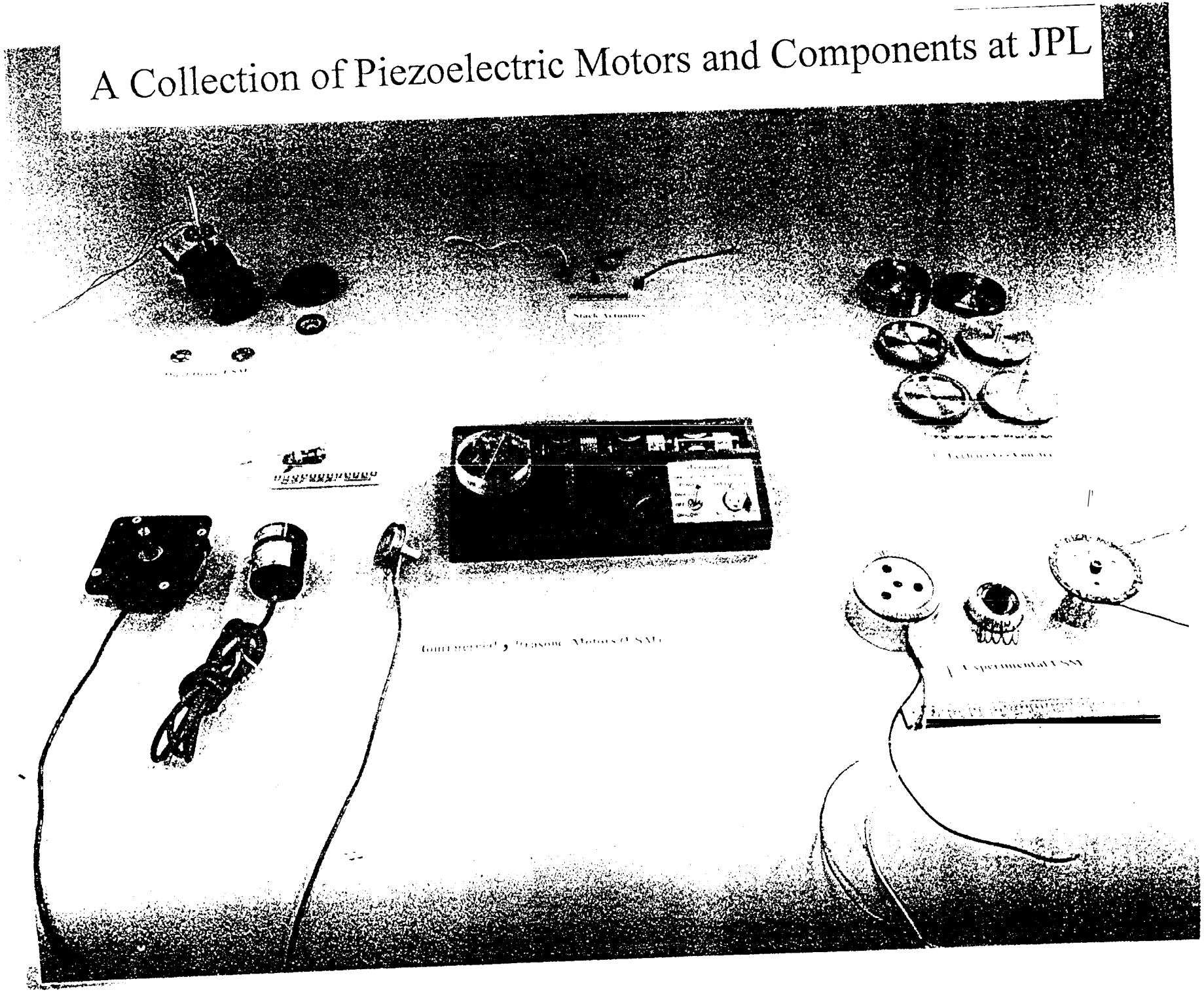
a. Stationary



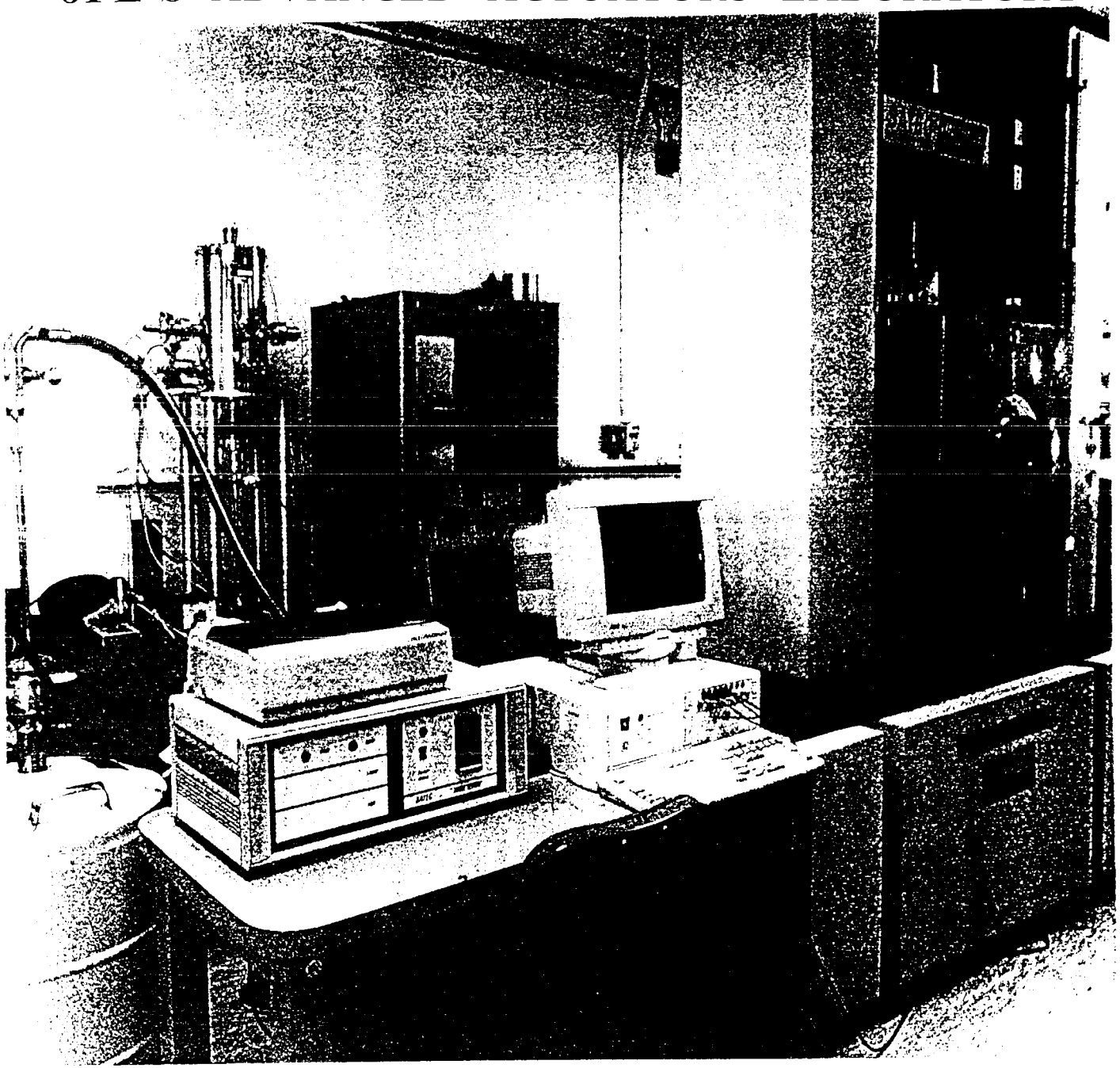
b. At arbitrary actuation position



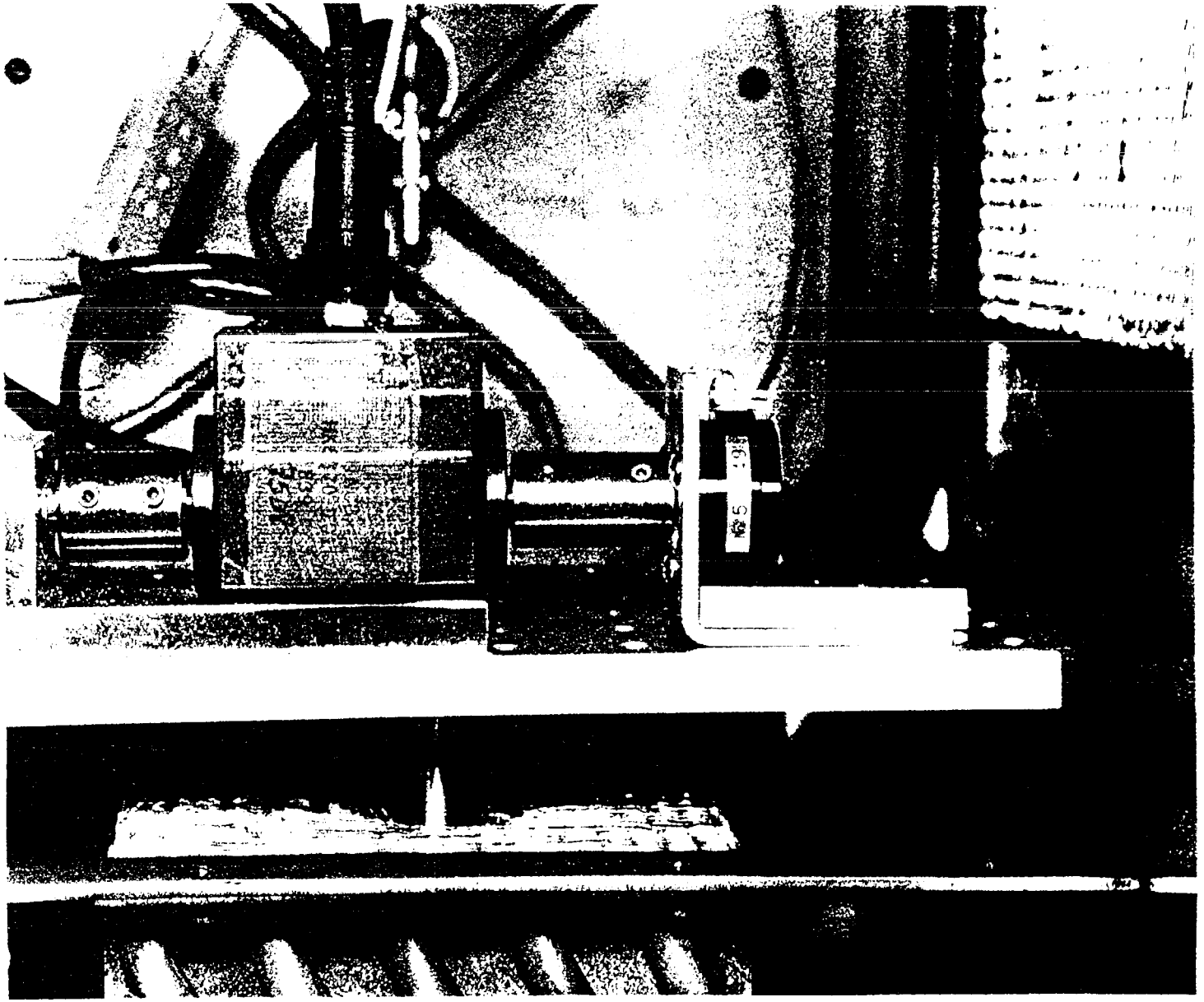
# A Collection of Piezoelectric Motors and Components at JPL



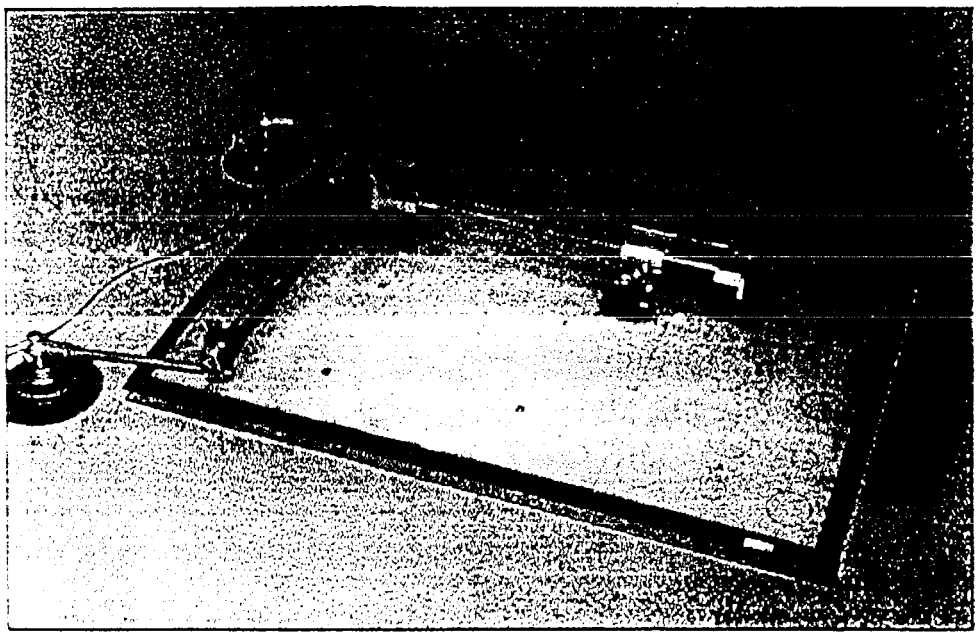
# JPL'S ADVANCED ACTUATORS LABORATORY



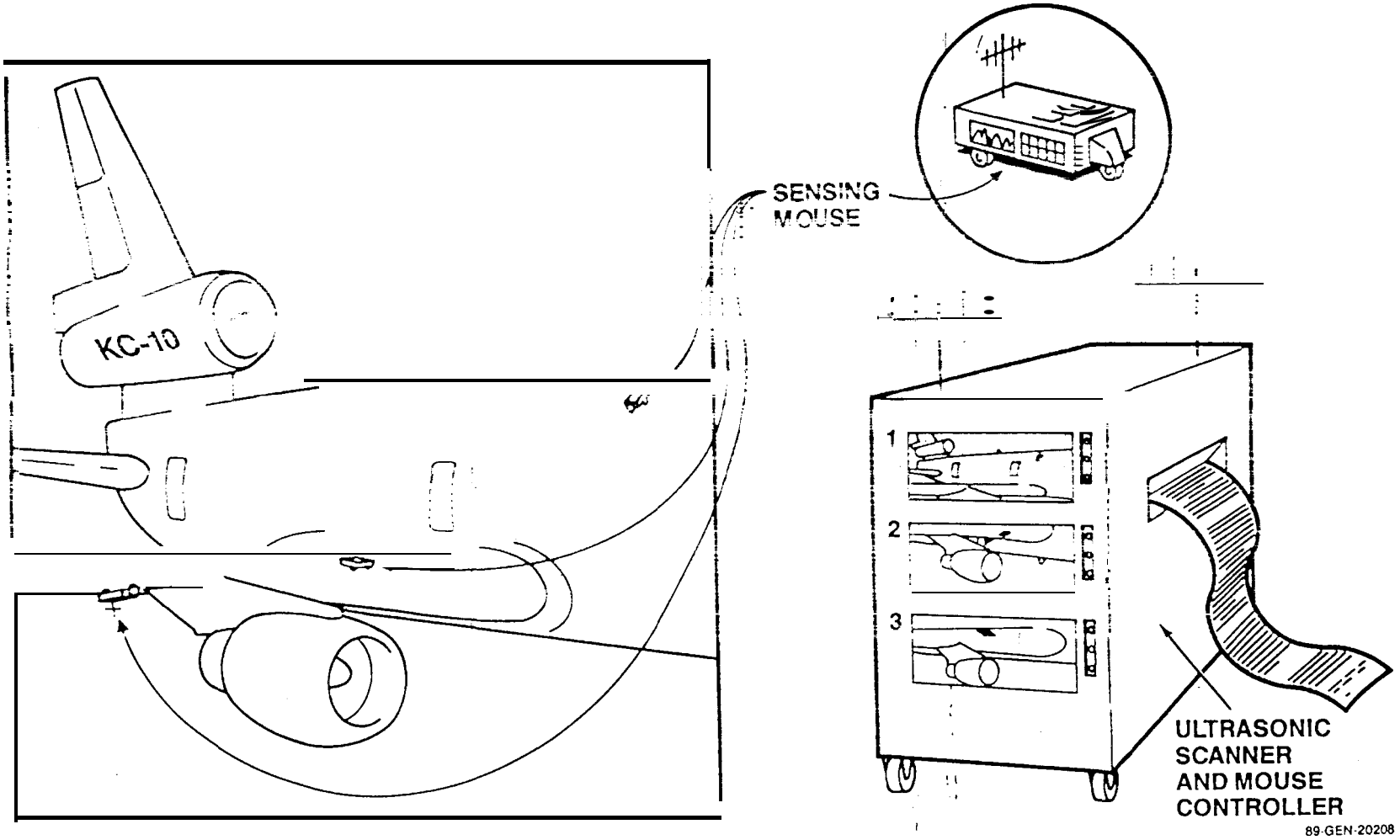
# A Piezoelectric Motor Connected to a Torque Gauge in the JPL Test Chamber (Cryogenic Temperatures and Vacuum)



# PORTABLE C-SCAN DEVICE



# AUTOMATIC FULL SCALE NDE



# MACS POTENTIAL TASKS

*INSPECTION INSTRUMENTS PAYLOAD*

- Visual inspection - video camera, D-Sight
- Tap testing - woodpecker (Mitsui WP631, Tapometer & Impactoscope)
- Eddy-Current - CrackFinder, Magneto Optical Imager
- Ultrasonics - Aircoupled, Ames Smart Bubbler, transducer array

*PAINT REMOVING MECHANISM*

- Laser induced heat
- Localized heat source such as microwaves
- RF Induced heating

# SUMMARY

- The development of NDE methods using plate waves is expanding into field applications and use of dry coupling techniques.

- Improved analytical techniques of evaluating the transfer of friction forces through the USM interface as well as methods of inducing stronger displacements from piezoceramics are expected to improve USM performance.

- Application of USM are expected to grow to many areas which miniature low mass, compact actuators are needed.