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bricant fails. Failure is defined when the friction coefficient rises beyond a predefined limit, which is usually two to three times the starting friction coefficient. The lifetime of the lubricant is then quantified as the total number of ball orbits completed divided by initial amount of lubricant on the ball. Typically, four tests are done for each condition and their results averaged for statistical significance in the test data. Relative lifetimes for various materials can be compared and can be directly correlated with relative lifetimes in real applications.

This work was done by Stephen V. Pepper and William R. Jones, Jr. of **Glenn Research Center**, *Edward Kingsbury of Interesting Rolling Contact, and Mark J. Jansen of the University of Toledo. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17912-***1.**

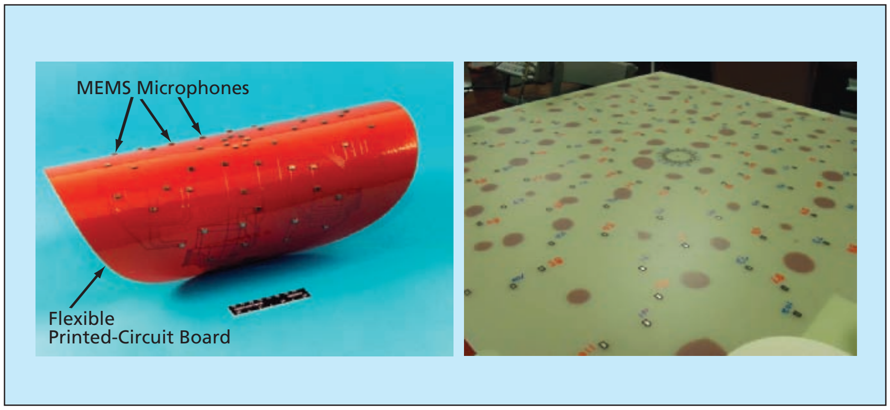
Arrays of Miniature Microphones for Aeroacoustic Testing

MEMS microphones are mounted on flexible printed-circuit boards.

Langley Research Center, Hampton, Virginia

A phased-array system comprised of custom-made and commercially available microelectromechanical system (MEMS) silicon microphones and custom ancillary hardware has been developed for use in aeroacoustic testing in hard-walled and acoustically treated wind tunnels. Recent advances in the areas of multi-channel signal processing and beam forming have driven the construction of phased arrays containing ever-greater numbers of microphones. Traditional obstacles to this trend have been posed by (1) the high costs of conventional condenser microphones, associated cabling, and support electronics and (2) the difficulty of mounting conventional microphones in the precise locations required for high-density arrays. The present development overcomes these obstacles.

One of the hallmarks of the new system is a series of fabricated platforms on which multiple microphones can be mounted. These mounting platforms, consisting of flexible polyimide circuit-board material (see left side of figure), include all the necessary microphone power and signal interconnects. A single bus line connects all microphones to a common power supply, while the signal lines terminate in one or more data buses on the sides of the circuit board. To minimize cross talk between array channels, ground lines are interposed as shields between all the data bus signal lines. The MEMS microphones are electrically connected to the boards via solder pads that are built into the printed wiring. These flexible circuit boards share many characteristics with their traditional rigid counterparts, but can be manufactured much thinner, as small as 0.1 millimeter, and much lighter with boards weighing as much as 75 percent less than traditional rigid ones.



An **Array of MEMS Microphones** (left) and a **Face Sheet** (right) are shown. The array is formed on a flexible printed-circuit board. The array can readily be affixed to a curved wind-tunnel surface for use in aeroacoustic testing. The face sheet containing small rectangular cutouts for the microphones is placed over an array like that on the left to provide a smooth outer surface.

For a typical hard-walled wind-tunnel installation, the flexible printed-circuit board is bonded to the tunnel wall and covered with a face sheet that contains precise cutouts for the microphones. Once the face sheet is mounted, a smooth surface is established over the entire array due to the flush mounting of all microphones (see right side of figure). The face sheet is made from a continuous glass-woven-fabric base impregnated with an epoxy resin binder. This material offers a combination of high mechanical strength and low dielectric loss, making it suitable for withstanding the harsh test section environment present in many wind tunnels, while at the same time protecting the underlying polyimide board.

Customized signal-conditioning hardware consisting of line drivers and anti-aliasing filters are coupled with the array. The line drivers are constructed using low-supply-current, high-gain-bandwidth operational amplifiers designed to transmit the microphone signals several dozen feet from the array to external acquisition hardware. The anti-alias filters consist of individual Chebyshev low-pass filters (one for each microphone channel) housed on small printed-circuit boards mounted on one or more motherboards. The mother/daughter board design results in a modular system, which is easy to debug and service and which enables the filter characteristics to be changed by swapping daughter boards with ones containing different filter parameters. The filter outputs are passed to commercially-available acquisition hardware to digitize and store the conditioned microphone signals. Wind-tunnel testing of the new MEMS microphone polyimide mounting system shows that the array performance is comparable to that of traditional arrays, but with significantly less cost of construction.

This work was done by Qamar A. Shams, William M. Humphreys, Bradley S. Sealey, Scott M. Bartram, Allan J. Zuckerwar, Toby Comeaux, and James K. Adams of **Langley Research Center**. *Further information is contained in a TSP (see page 1). LAR-17171-1*