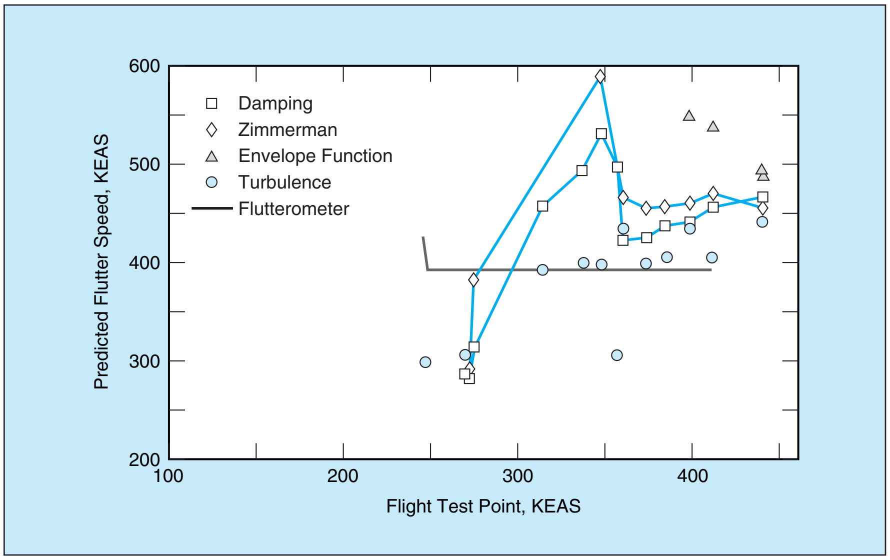


Figure 1. **Flutter Speeds** were predicted during envelope expansion by five different methods.

previous test points. The predicted speeds at the test points are plotted in Figure 1.

The predictions depicted in Figure 1 can be easily summarized. The data-based methods yield poor predictions for low-speed data but produce reasonable predictions that converge on the correct answer as the envelope is expanded to include high-speed test points. The flutterometer produces a reasonable worst-case prediction of flutter speed immediately and remains conservative throughout the envelope expansion.

An analysis of Figure 1 reveals the nature of the prediction methods. In the data-driven methods, one attempts to compute the exact speed associated with the onset of flutter. In the flutterometer (model-based) method, one attempts to obtain a conservative prediction of the worst-case flutter speed. It is expected that the data-driven methods should yield highly accurate predictions at test points close to flutter and that the particular implementation of the flutterometer should not reduce conservatism despite the analysis of data from high-speed test points.

The nature of the prediction methods indicates a method for efficient envelope expansion. A flight test should be initiated at low-speed test points and the flutterometer should be used to obtain a conservative estimate of the flutter speed. As the test proceeds, the airspeed should be increased until the system nears the speed of instability predicted by the flutterometer. At this point, the envelope should be expanded to high-speed test points by relying heavily on the data-based methods to finalize an accurate prediction of the exact speed at which flutter will be encountered.

This work was done by Rick Lind and Marty Brenner of **Dryden Flight Research Center**. *Further information is contained in a TSP (see page 1).*
DRC-01-57

Piezoelectrically Actuated Microvalve for Liquid Effluents

Power consumption and size would be reduced.

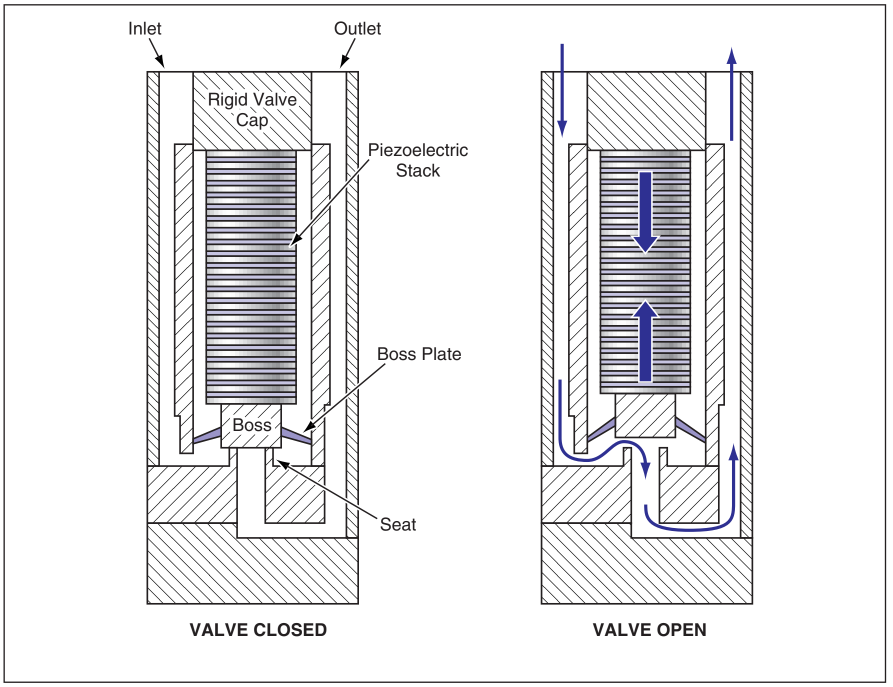
NASA's Jet Propulsion Laboratory, Pasadena, California

Modifications have been proposed to effect further improvement of the device described in "Improved Piezoelectrically Actuated Microvalve" (NPO-30158), *NASA Tech Briefs*, Vol. 26, No. 1 (January 2002), page 29. To recapitulate: What is being developed is a prototype of valves for microfluidic systems and other microelectromechanical systems (MEMS). The version of the valve reported in the cited previous article included a base (which contained a seat, an inlet, and an outlet), a diaphragm, and a linear actuator. With the exception of the actuator, the parts were micromachined from silicon. The linear actuator consisted of a stack of piezoelectric disks in a rigid housing. To make the diaphragm apply a large sealing force on the inlet and outlet, the piezoelectric stack was compressed into a slightly contracted condition during assembly of the valve. Application of a voltage across the stack caused the stack to contract into an even more compressed condition, lifting the diaphragm away from the seat, thereby creating a narrow channel between the inlet and outlet. The positions of the inlet and outlet, relative to the diaphragm and seat, were such that the inlet flow and pressure contributed to sealing and thus to a desired normally-closed mode of operation.

The basic principles of design and operation of the proposed improved valve would be the same as those of the prior valve. However, there would be important differences in design details, leading to improvements, as summarized below:

- The piezoelectric stack would be highly miniaturized (only 0.9 by 0.9 by 10 mm) and manufactured with high precision. The interior volume of the valve would be only 0.1 cm^3.
- Whereas the prior valve consumed a power of 2 W when actuated at a frequency of 100 Hz, the proposed improved version would consume only 0.1 W at 100 Hz. The combination of miniaturization and decreased power demand would be made possible by, among other things, utilization of a mode of piezoelectric actuation known in the art as d_{31}. (The term "d_{31}" signifies one of three independent moduli of piezoelectricity as well as the mode of actuation to which this modulus applies. In the d_{31} mode, the application of an electric field along one axis produces a longitudinal contraction along a perpendicular axis.)
- Unlike in the prior valve, the piezoelectric stack would be isolated from the fluid to be controlled. Hence, it would not be necessary to take special measures to protect the stack against the fluid and, even more specifically, it would not be necessary to coat the stack with a dielectric material for protection against an electrically conductive liquid.
- The design would include several features that would increase the ability of the valve to control a fluid at high pressure.

Like the prior valve, the proposed im-



The **Valve Incorporating the Proposed Improvements** is depicted here in a simplified and partly schematic cross section, and not to scale.

proved valve (see figure) would include a base that would contain a seat, an inlet, and an outlet. The piezoelectric stack would be connected to a valve boss at one end and to a rigid valve cap at its other end. In the absence of an applied potential, the valve boss would be pressed against the valve seat, so that flow would be blocked. The application of a potential of 60 V across the stack would cause the stack to shrink, pulling the valve boss away from the seat and thereby opening a flow channel between the inlet and the outlet.

In order to increase the spring bias of the valve toward the closed position and thereby help to minimize leakage in the absence of an applied potential, the boss plate would be slightly stretched. The force generated by the piezoelectric actuator would be about 100 N — enough to overcome both the tension in the boss plate and the pressure-aided valve-closing force at an upstream-to-downstream differential pressure as large as 300 psi (≈2 MPa).

This work was done by Eui-Hyeok Yang of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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Refer to NPO-30562, volume and number of this NASA Tech Briefs *issue, and the page number.*

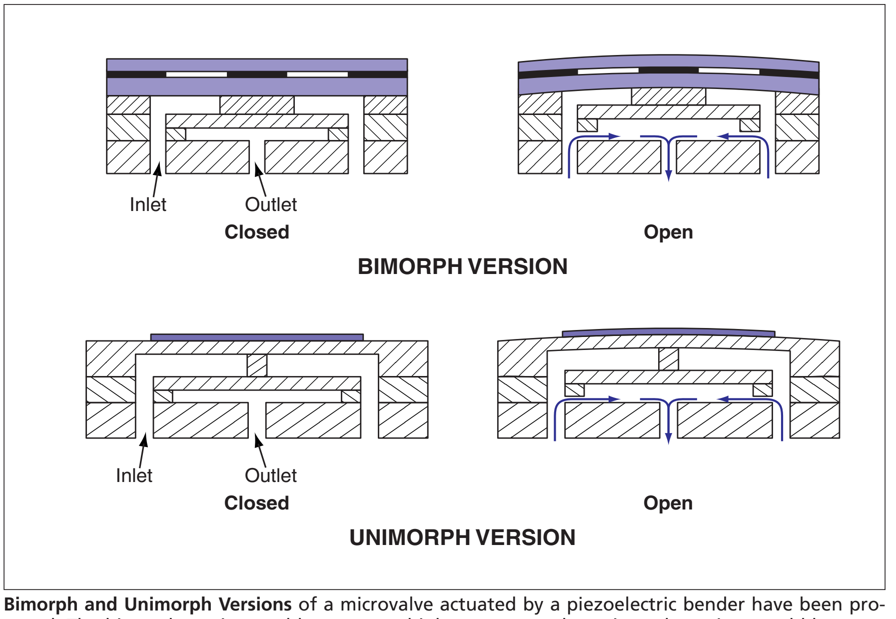
Larger-Stroke Piezoelectrically Actuated Microvalve

Liquids carrying small particles could be handled.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed normally-closed microvalve would contain a piezoelectric bending actuator instead of a piezoelectric linear actuator like that of the microvalve described in the preceding article. Whereas the stroke of the linear actuator of the preceding article would be limited to ≈6 µm, the stroke of the proposed bending actuator would lie in the approximate range of 10 to 15 µm — large enough to enable the microvalve to handle a variety of liquids containing suspended particles having sizes up to 10 µm. Such particulate-laden liquids occur in a variety of microfluidic systems, one example being a system that sorts cells or large biomolecules for analysis.

In comparison with the linear actuator of the preceding article, the bending actuator would be smaller and less massive. The combination of increased stroke, smaller mass, and smaller volume would be obtained at the cost of decreased actuation force: The proposed actuator would



Bimorph and Unimorph Versions of a microvalve actuated by a piezoelectric bender have been proposed. The bimorph version could operate at higher pressure; the unimorph version would be more compact.