Engineering Notes

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Experimental Investigation of a Fluidic Sun Sensor

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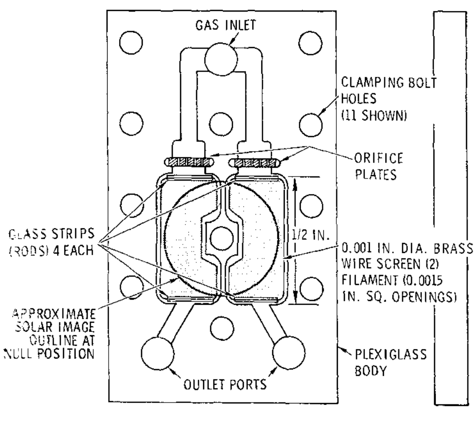
Introduction

DEVELOPMENT of a fluidic sun sensor makes possible the design of an entire attitude control system for spacecraft and missiles with both attitude rate and position feedback using fluidic devices only and avoiding interfaces with electro-optical devices that would otherwise be required.

Detector Element—Design and Operation

A fluidic sun sensor includes a solar-radiation detector, any optical magnification and/or shading, and any fluid amplification that may be needed. In the design approach selected the detector element is heated by solar radiation, and this heat is transmitted to cold gas flowing past the heated material. With cessation of solar radiation absorbed by the detector element, the heat stored by the element is gradually dissipated by radiation to space and by heat loss to the cold gas streams.

When the detector points directly at the sun, the solar image is centered in the detector face. The detector is divided into two identical halves (see Fig. 1). With uniform radiation across the entire plane of the detector, the filament in each half absorbs the same amount of radiation and is heated to approximately the same temperature. Cold gas, supplied from a common manifold, flows through four dropping restrictors and is injected into the two filament chambers. The four dropping restrictors are sized so as to insure sonic flow of gas into each filament chamber under all conditions. The gas is heated as it flows past the filament and its flow rate is unaffected since the flow is "choked" at each restrictor. However, the total temperature and, therefore, the total pressure of the gas (downstream of these restrictors) increases with heating, and thus becomes a useful and measurable parameter in determining the amount of solar radiation impinging upon either of the two twin detector halves. Differential heating of the detector halves occurs upon misalignment of the detector plane perpendicular with the sun line. This can be brought about by the use of either sun shades or a lens that projects the sun's image so as to fill the detector face. As a result of this differential heating, the gas temperature on one side of the detector increases while that on the other side decreases. With this type of operation, the sun sensor output signal is of a push-pull form and is well suited to direct coupling with a push-pull fluid amplifier.



CHANNEL DEPTH: 0.050 IN.

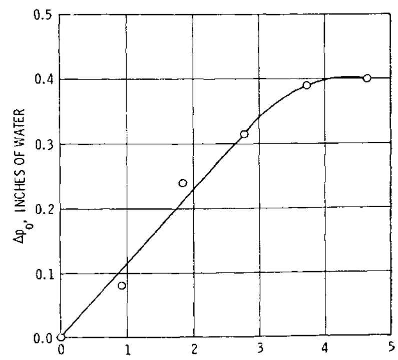
Fig. 1 Fluidic sun sensor detector element breadboard model design.

Breadboard Test Results

A scaled schematic of the breadboard unit, showing construction details, is presented in Fig. 1. For a heating filament, a 70% copper wire screen was used with 0.001-in.-diam wire spaced every 0.0025 in., leaving gaps 0.0015 in.[2] The copper alloy wire screen was chemically treated to blacken it for maximum radiation absorptivity. Inspection of the screen, following treatment, revealed that the black finish was stable and highly resistant to abrasion from normal handling. In addition, the screen retained sufficient strength and ductility to allow for handling, cutting, and installation in the detector body. The finished screen was cut to size (about $\frac{1}{4}$ in. $\times$ $\frac{1}{2}$ in.) and was cemented to 0.030-in.-diam glass rods with Dow Corning Silastic RTV-731, a bonding agent rated for temperatures to 500°F. The glass rods were cemented to the beds of the filament cavities with epoxy. In this way, the filaments were thermally isolated from the plexiglass body.

The body of the detector, with its various channels and cavities, was cut on a pantograph using a 10:1 master; the

Fig. 2 Fluidic sun sensor detector element calibration (Δp_0 is defined as deviation in Δp at zero-degree sun angle).



Received December 2, 1968; revision received April 21, 1969. The work described was conducted in the Control Systems Laboratory of TRW Systems Group, Redondo Beach, Calif., as part of a company-sponsored independent research and development program. The reader is referred to Ref. 1 for more complete information. The fluidic sun sensor design was based on a concept originally disclosed by H. V. Fuller and H. D. Garner, both of NASA Langley, in 1966 (see Ref. 2).

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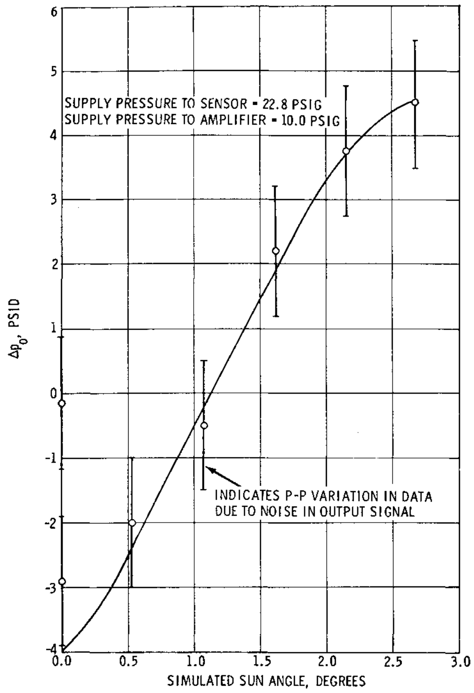

Fig. 3 Fluidic sun sensor over-all calibration.

material used was plexiglass, 0.062 in. thick with a cutting depth of 0.050 in. The inlet restrictors consist of two plates, each containing four 0.005-in.-diam orifices, 0.031 in. apart.

During testing of the fluidic sun sensor, there was a slight mismatch in pressure drops on the two sides of the detector, and as a result, null signal corresponded to the high end of the unilateral differential-pressure gage monitoring the sun sensor output signal. The range of the gage null adjustment was sufficient to enable nulling in one direction, but not in the other. Therefore, data were obtained in one direction only as indicated in the data plotted for steady-state sun sensor performance in Fig. 2. The linear range is shown to be about $\pm 3.0°$. The supply pressure to the detector element was 22.8 psig, while the pressure just downstream of the detector inlet restrictors was about 0.25 psig at null signal. A slight mismatch (null offset) is understandable in this situation where the output differential pressure is read in tenths of an inch of water. This is a much more stringent operating condition than that to be encountered in a space application where ambient pressure would be practically zero rather than 14.7 psia. Since the inlet restrictor must be choked, the supply pressure (absolute) must be at least twice the absolute output pressure, hence the 22.8 psig (37.5 psia) supply for lab testing.

In the laboratory, the inlet restrictor pressure drop is about 22.5 psi. A difference of 1% in the pressure drops across the two "parallel" inlet restrictors corresponds to a null offset of 6.2 in. of water. In space, where the inlet restrictor pressure drop would be about 0.50 psi, a 1% mismatch represents a null offset of 0.1 in. of water. This is better than an order-of-magnitude improvement in matching requirements.

After completing the testing of the breadboard model as previously described, additional testing was conducted with the detector output connected to a high-gain fluid amplifier. It was expected that a high-gain amplifier would be required to bring the signal strength, i.e., the over-all sun sensor gain, up to a level compatible with fluidic circuitry. The results of this test are presented in Fig. 3. The null offset is attributed primarily to the detector as previously mentioned. The noise band indicated is based on observations of the pressure gage fluctuations and cannot be considered more than indicative of what the noise might be if measured rigorously.

References

[1] Miller, W. V., "Fluidic Sun Sensor for Solar-Pointing Fluidic Attitude Control," *Proceedings of the 1969 Joint Automatic Control Conference*, AIAA, Boulder, Colo., 1969.

[2] Garner, H. D. and Fuller, H. V., Jr., "A Survey of Potential Applications to Spacecraft Attitude Control," *Proceedings of the 1966 SAE Fluidics Symposium*, Society of Automotive Engineers, 1966.

Like and Unlike Impinging Injection Element Droplet Sizes

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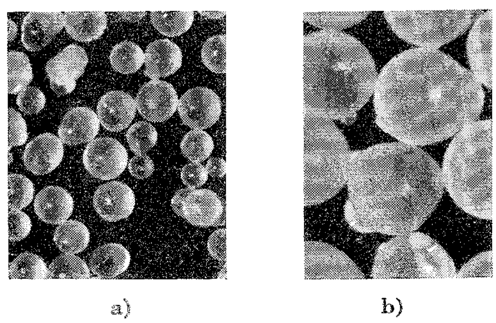
THIS study of the measurement of spray droplet sizes by a frozen wax technique was a portion of a larger study[1] on the combustion of sprays. Of a number of prior studies using particle freezing techniques (e.g., Ref. 2–4), the work by Joyce[4] was most applicable to the present study. The liquid paraffin wax he sprayed from fuel atomizer nozzles gave frozen particles that were sticky and tended to sinter upon standing. As a result, particle sieving operations were laboriously carried out by hand, using a stream of water to separate the particles and induce them to pass through each screen. We improved his technique by using a better-suited wax and extended it to the study of sprays from unlike impinging injector elements (i.e., fuel impinging on oxidizer as in unlike doublet or four-on-one injector elements) by using both heated water and molten wax as propellant simulants.

Some initial tests were made with food-preserving paraffin wax which had a melting point of 130°F and a block point temperature (the temperature at which two wax-coated surfaces stick together sufficiently to mar either surface) of 90°F. This wax yielded particles that had good sphericity but were sticky enough to make sieving difficult. In contrast, Type 270 wax, a product of the Petrochemicals Division of Shell Chemical Company, with a melting point of 140°F, and a block point temperature of 120°F gave particles having equally good sphericity but the particles were not sticky and had sieving characteristics comparable to dry sand. Figure 1 shows photomicrographs of two sieve cuts from one test.



a) b)

Fig. 1 Photomicrographs of wax particle sieve cuts: a) 0–125μ; b) 250–297 μ.

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