Active cavity radiometer type V

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Received 2 July 1980.
0003-6935/80/193256-02$00.50/0.

A new type of cavity sensor geometry has been implemented in the most recent of a series of solar flux pyrheliometers known as the active cavity radiometer (ACR). The new type V sensor design incorporates a modification of its predecessor, the ACR IV sensor,[1] that decreases the uncertainty with which cavity absorptance can be predicted by more than a factor of 10. The impact of this design on current solar pyrheliometry is to reduce detector absorptance uncertainty from that of the largest single contributor to overall uncertainty to a negligible level relative to the goal of making solar total flux observations with SI uncertainties of ±0.1% or less (International System of Units).

Both ACR IV and V sensors are 30° right circular conical cavities, fabricated by electrodeposition of 99.99% pure silver. The solar absorbing coating applied to the inner cavity surfaces is a specular black epoxy paint. An axial ray experiences six internal reflections before exiting the cavity, yielding a very high cavity absorptance with small uncertainty. A conservatively estimated paint reflectance of 0.1 with an uncertainty of ±0.05 yields a theoretical absorptance for a perfectly formed cavity of 0.999999 with an uncertainty of 3×10^{-6}. Clearly this theoretical limit is not achievable, since small departures from pure conical shape in the painted cavity surface cannot be entirely eliminated and the paint is not perfectly specular. The essential questions are how close to the theoretical limit an actual cavity's performance can be, and what variability might be expected in a series of cavities produced using the same types of component and procedure.

Early in the development of the ACR IV it became apparent that the potential effects of small irregularities in the cavity's painted surface were not the dominating source of error. The principal uncertainty arose through formation of a paint meniscus at the apex of the cavity. The size of the meniscus was minimized by removing as much of the accumulated paint as possible with a hypodermic syringe, yet the properties of the meniscus could neither be reproduced or predicted with ±0.05% uncertainty.

To evaluate the meniscus effect, ACR IV cavity samples were prepared and their reflectances measured by the Radiometric Physics Group at the National Bureau of Standards.[2] The results demonstrated a meniscus-enhanced reflectance at the apex of the ACR IV cavity that exceeded that elsewhere in the cavity by a factor of 10. Although the area of the retroreflecting meniscus is small, the mean effective absorptance, averaged over the cavity, was found to be 0.9994, considerably less than the theoretical limit that assumes no meniscus is present.

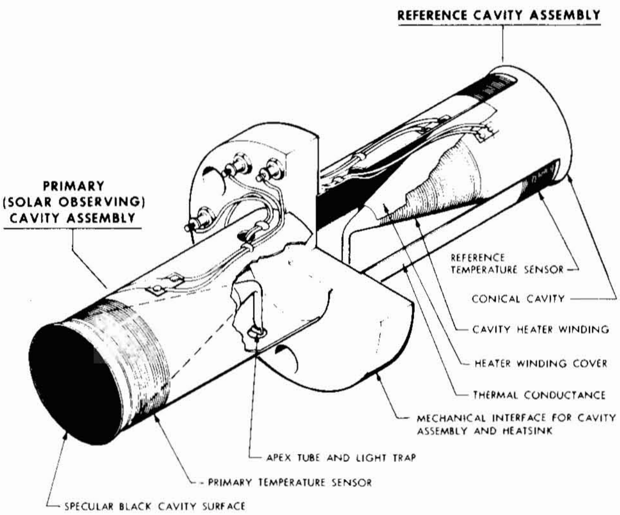

Fig. 1. Scale drawing of the active cavity radiometer type V sensor. Approximate dimensions: overall length, 8 cm; cavity diameter, 1 cm; diameter of mechanical interface, 3 cm.

The ACR IV specular cavity, even with the meniscus effect, if far superior to the diffuse black cavities used in previous ACRs.[3,4] But the potential variation in size of the ACR IVs meniscus retains a 0.06% source of uncertainty in its measurements that is uncomfortably large relative to the overall measurement error goal of 0.1%. While this error can be reduced by carefully measuring the properties of each cavity, it is not always feasible to do so. Our approach to the problem was to design a cavity sensor whose reflectance properties, once determined by the NBS, were reproducible through careful fabrication techniques with an uncertainty of ±0.05% or less.

The ACR V solution to the meniscus problem is a simple but effective one. The basic geometry and construction is the same as the ACR IV, but with a 5-mm long tube at the apex (with 0.5- and 0.25-mm outside the inside diameters, respectively). In the process of fabricating the cavity assembly (see Fig. 1) the paint must be applied after joining the cavity to the thermal conductance. One end of the 5-mm apex tube, which has been bent through a 90° arc, is accessible through a small hole in the thermal conductance. During the painting process excess paint is drawn out through the tube, preventing formation of a meniscus at the apex. Following the paint curing process the end of the tube is crimped shut, forming an effective light trap. The resulting ARC V sensor is a meniscus-free cavity whose absorptance should approach the theoretically predicted value more closely that that of the ACR IV.

The ACR V sensors were fabricated and sent to the NBS for reflectance characterization to determine both their effective cavity reflectance and reproducibility. The NBS re-

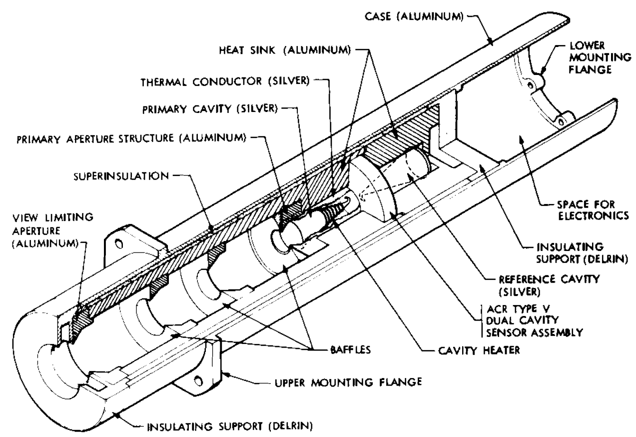

Fig. 2. Scale drawing of the ACR V module developed for solar total flux monitoring on Spacelab 1.

sults yielded effective reflectances of 120 ppm and 115 ppm for the two, with an experimental uncertainty of 20 ppm.

The ACR V design appears to have the desired properties and improvements relative to the ACR IV. The results for the first two samples indicate that its effective cavity absorptance is 0.999880 or greater, with an uncertainty of ±0.000020. Equally important, these properties are as reproducible as the uncertainty of the reflectance characterization experiment.

The principal uses for the ACR V are defining the radiation scale in SI units and monitoring total solar flux in flight experiments. An ACR V sensor unit will participate in a radiometric scale definition experiment as part of the Fifth International Pyrheliometric Comparisons to be held at Davos, Switzerland, in1980. The first use of the ACR V in flight observations of the total solar flux will occur in 1981 as part of a sounding rocket experiment. ACR V sensors are employed in a Spacelab 1 solar total flux experiment currently in the hardware implementation phase at the Jet Propulsion Laboratory. (Fig. 2.)

The goal of defining the radiation scale at the solar total flux level with ±0.1% SI uncertainty should be achievable with the ACR V sensor. The uncertainty of the effective absorptance of pyrheliometric sensors for solar radiation, until recently their dominant source of experimental error, has been reduced to ±0.002% in the ACR V design.

The author acknowledges the valuable contributions of J. Geist and E. Zalewski (Radiometric Physics Group, National Bureau of Standards, Gaithersburg, Md.) whose state-of-the-art detector characterization technology provided the definitive quantitative determination of ACR types IV and V cavity properties.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract NAS 7-100, sponsored by the National Aeronautics and Space Administration.

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3. As a reference point for past solar measurements, an ACR IV cavity geometry with diffuse 3-M velvet black paint was measured by NBS, yielding a mean absorptance of 0.9978 with an uncertainty of ±0.002.[2]
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