NATIONAL BUREAU OF STANDARDS REPORT

3761

DESIGN AND PERFORMANCE OF REMOTE THERMOSHIELD,
NAX-2-51

by

Richard N. Jansson
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Report to

Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.

NBS

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Design and Performance of Remote Thermoshield,
NAX-2-51 MODELS 001 and 002

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Heating and Air Conditioning Section
Building Technology Division

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Abstract

A temperature reference unit, called a thermoshield was developed which is believed to indicate the true dry bulb temperature of atmospheric air within ± 0.1 deg. F, even when the instrument and its proximity are in strong sunlight. The instrument is suitable as a standard reference unit for calibrating other weather instrument shelters. Another model has been constructed for remote installation aboard ship to be used in conjunction with automatic indicating and recording equipment located at a central monitoring station. Both models employ blowers to circulate ambient air over their sensing elements which are shielded from radiation by 1/2-liter Dewar flasks.

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1. INTRODUCTION

The development of a remotely-located miniature thermoshield with electrical recording devices is the result of a number of parallel events of the past several years.

In 1949 the Aerology Section of the Bureau of Aeronautics, while collaborating with the National Bureau of Standards on the thermoscreen project, suggested the replacing of the thermoscreen, where the added expense was justified, with an overall system consisting of a remotely located thermoshield and a recording system placed conveniently for observation. At about the same time the Air Force asked the Signal Corps to produce a small remote temperature measuring system for airborne use. The results of this development are still pending.

In 1950 the Aerological Section of the Naval Research Laboratory started the development of a remote system for recording weather data for aircraft using a vortex cooling principle to compensate for frictional skin heating on aircraft. This unit, near completion, is called the Vortex Thermometer. A ground-based model of this recording system, which is called the Aerological Recorder, is also nearing completion.

During the summer of 1952, as a part of the continued thermoscreen program carried on at the National Bureau of Standards, the further development of ventilated ambient temperature measuring units was found to be desirable. Throughout the tests of a prototype thermoscreen under the auspices of the Bureau of Aeronautics, the thermocouples inside the thermoscreen read consistently about 1/2 deg. F lower than the air temperature reference that had been used up to that time. This led to the development of the ambient air temperature sensing device described here.

The primary objective of the design was an instrument capable of indicating the temperature of atmospheric air without errors or effects due to solar or other radiation. The design was intended to provide not only practically complete shielding of the temperature sensing elements from outside radiation, but also prevention of heat transfer to or from the air stream between the inlet of the unit and the temperature sensing elements.

2. DESCRIPTION OF INSTRUMENTS

Model 001 Unit

Figure 1 shows a vertical cross-section of the model 001 type unit. It consists of a 1/2-liter Dewar flask inverted over a 2-inch OD thin-wall bakelite tube, a motor driven blower for air circulation and an outside enclosure. The tube supports the flask with a plastic hoop at the top and has small pieces of cork to keep the flask concentric. The tube is secured to a black bakelite disc at the bottom with glue, and a 4-1/2 inch OD brass tube surrounds the flask unit. The motor and blower are mounted at the top of the exterior tube. The whole unit is suspended from a hook at the top of the motor, with the axis of the unit vertical. The air flow through the unit was approximately 90 cfm corresponding to a velocity of about 4200 fpm in the intake tube.

For the tests at the National Bureau of Standards the 001 unit was instrumented with a copper-constantan thermocouple that was "loaded" with a 3/8-inch brass ball. The thermocouple was located at the upper end of the internal tube so it was exposed to direct radiation from below only within the small solid angle formed by the thermocouple and the bottom of the tube.

Model 002 Unit

Recently a model 002 unit was built for the Naval Research Laboratory. The design of this unit was similar to that of model 001 except that certain features were modified to make the model 002 unit suitable for shipborad use. It was built with the understanding that the Naval Research Laboratory would develop the instrumentation for indicating and recording the temperatures and the National Bureau of Standards would develop the thermal aspects of the enclosures for the sensing elements.

The model 002 unit is ventilated by a self-contained motor-driven blower housed within a 4-in. square aluminum tube 12-inches long (Figures 2 and 3). Also mounted within this tube is a spring-mounted Dewar flask which serves as an effective thermal shield for the temperature-sensitive element. The motor is bolted directly to the aluminum top cover to permit it to dissipate some of its heat to the outer walls and still be sheltered from weathering effects. The blower exhausts through the supporting strut a 2-inch diameter tube 14-inches long connected to a 4-inch transition piece (Figures 2 and 3) so that recirculation is prevented between the exhaust and the intake. The Naval Research Laboratory is proposing to use this exhaust air for humidity measurements.

The electrical connections are made with standard AN type Cannon connectors that are housed in the support strut flange. All connectors are mounted from the inside of the thermoshield housing so that any component (motor, thermometer, or defroster) may be removed without detaching any wires.

Figure 4 is a view of the model 002 thermoshield disassembled to show the principal components. The air enters

the bottom horizontal surface of the unit through an opening in the white nylon bottom plate. The air is given a circular motion as it flows upward through the inner aluminum tube by a plastic vane element from a Vortex Thermometer. This circular motion of the incoming air forces any entrained water particles away from the sensing element and toward the outer wall. The vane element supports and positions the temperature sensing element, which for test purposes consisted of a thermocouple attached to a brass slug of a thermal mass equivalent to that of the resistance thermometer element to be inserted by Naval Research Laboratory. This assembly, consisting of tube, vane, and thermometer, is surrounded by the inverted Dewar flask. After passing the temperature sensitive element the air passes downward between the tube and flask and upward around the outside of the flask to the blower.

This model was developed for mounting in remote locations on a ship with the recording systems located conveniently for the observers. The unit should be cleaned and oiled at intervals of 4 to 6 months. It may be removed from its support tube by releasing the latch, removing the electrical connectors, and removing the hinge pin (Figure 3).

Air flow measurements on the unit showed that the flow was about 8 cfm with a velocity at the thermometer of about 1200 ft/min.

Reference[1] found in the literature suggested the use of a Dewar flask as a thermocouple radiation shield.

3. TEST PROCEDURE AND RESULTS

Air Recirculation

Smoke flow tests and comparison of their temperature indications were made on the model 001 and 002 units. The smoke flow tests were used to determine whether recirculation occurred between outlet and intake of the units and to study the amount of air sampling. One of the original premises in the measurement of outdoor air temperature was that air masses move in small eddies or thermal streams and that a temperature-

sensing unit would have to move relatively large amounts of air to obtain a fair sampling of the air and an average of the air temperature in the vicinity of the device. A hand-type smoke generator was used to indicate air motion in the vicinity of the thermoshields.

It was observed that the model 001 unit sampled and mixed large amounts of air drawn from quite a distance from its inlet and exhausted the air horizontally at a high velocity above the intake level so that the exhaust air was thoroughly mixed with the ambient air before it had a chance to reenter the inlet.

The model 002 unit, on the other hand, circulated much less air and the tests indicated that only the air quite close to the intake opening was sampled. The air from this unit was exhausted at a much lower velocity and in a downward direction from the end of the support tube. The air was forced down to the level of the intake and recirculation could and probably did occur occasionally when the intake was down wind from the exhaust.

Temperature Tests

The temperature tests were conducted on a comparative basis between the two models because no absolute standard of greater precision was available for calibration purposes. For these tests the two units were mounted side by side on a counterweighted boom arm so as to sample the same air stream. This arm was rotatable so the units could be oriented in a desired direction with respect to the sun. The thermocouples in the two units were connected as a differential thermocouple with the leads connected to a portable potentiometer with a sensitive external galvanometer. The temperature differences were read as deflections on the galvanometer scale which had previously been calibrated in deg. F per millimeter scale division.

Preliminary tests were conducted in the very early morning using heat lamps as artificial radiation sources to selectively produce the solar heating effect upon the thermoshields. This method of test was discontinued because it was

recognized that the heat lamps did not produce the same radiation effects on the thermoshields as daytime solar radiation, particularly in regard to radiation from the ground. Also, the radiation intensity was unknown and could not be easily determined. Other tests were conducted in sunlight by alternately shading the units with large cardboard sheets. This method was unsatisfactory because only the units were shaded and because the shields were warmed above air temperature and induced stray thermal currents that at times affected the readings of the units under test.

Since the 001 unit circulated a greater quantity of air and produced greater air movement near the unit it is probably better from a heat transfer standpoint and thus more accurate than the 002 unit which was modified for shipboard use. The 001 model should probably be used where greater accuracy is desired and when serviceability is not a determining factor. Because of the appreciable difference in air circulation comparative tests were conducted on the two units using the 001 unit as a reference.

Table 1 is a summary of the test conditions under which the two thermoshields were compared and the differences in temperatures indicated by the two units.

Data taken under test condition A were obtained in the morning about 9:00 AM EST on clear sunny days, but the units were in such a location with respect to local shrubbery that adequate and well-ventilated shade was provided for both units and their environment. The units were exposed to very little radiation under this test condition and the difference in indicated temperature was much less than 0.1 deg. F.

The data recorded on sunny afternoons with the grass sward under the units in strong sunlight, summarized under condition B in Table 1, show that radiation increased the difference in the indicated temperature of the two units quite markedly. The temperature difference ranged from 0.10 to 0.24 deg. F for this group of tests with model 002 indicating the higher temperature. Data summarized under condition C in the afternoon show that an overcast sky decreased the temperature difference between the

two units. These results indicate that model 002 was adversely affected by solar radiation to a greater degree than model 001.

Special tests under condition D were made to discover the cause of the temperature rise in model 002 when strongly irradiated. By removing the vortex vane from the intake tube of model 002 the air flow was approximately doubled with a consequent decrease in the temperature indicated by this model. Under these conditions model 002 indicated a temperature 0.08 deg. F lower than model 001 on the average when both were exposed to strong afternoon sunshine.

To further show the effect of the air flow rate on the accuracy of the thermoshields, the air flow rate in model 001 was drastically reduced and a comparison made with model 002 without the vane in the latter unit. Under these conditions the average difference in temperature of the two units was 0.22 deg. F with the 002 unit reading the lower value.

These results indicate the desirability of a high air flow rate through the thermoshield and show that the vortex vane had an adverse effect on the accuracy of the model 002 unit in bright sunshine. The vortex vane is considered desirable, however, in wet weather to deflect entrained water droplets from the temperature sensitive element.

The rate of response of the temperature sensitive element was much higher in the model 001 unit than in the other unit. This was attributable to the higher air flow rate and to the lesser thermal mass of the sensitive element in the model 001 unit. The thermal mass of the vortex vane in the 002 unit would also make the sensing element in that unit less responsive to sudden temperature changes. The test in which the air flow in the 001 model was reduced further illustrated the importance of air flow rate on the rate of response because no sudden variations in temperature were indicated during this test.

TABLE 1

COMPARISON OF TWO THERMOSHIELDS

MODELS 001, 002

Date	Time EST	Wind, Knots	Sky	Difference in Indicated Temp[b] deg. F
Condition A: Units Shaded				
9-28-53	9:25	2-3	Clear	<< 0.1[a]
9-29-53	9:05	calm	Clear	<< 0.1
9-30-53	9:05	2-3	Clear	<< 0.1
Condition B: Units in Bright Sunshine				
9-28-53	13:40	2-3	Clear	0.16
9-29-53	13:15	slight	Clear	0.18
9-30-53	13:00	2-3	Clear	0.20
2-5-54	13:15	5-15	Clear	0.10
2-7-54	14:22	gusts	Clear	0.24
Condition C: Sky Overcast				
2-8-54	15:45	0-5	Very Hazy	0.07
Condition D: Special Tests				
a) Model 002 with vane removed:				
2-7-54	15:00	0-5	Clear	-0.08
b) Model 002 with vane removed; Model 001 with restricted air flow:				
2-7-54	14:45	0-5	Clear	-0.22

a. The symbol << 0.1 means "much less than" one tenth degree Fahrenheit.

b. A positive difference means model 001 indicated a lower temperature.

4. DISCUSSION

There are four principal ways in which heat may enter thermoshield NAX-2-51 to cause an error in the indicated temperature by raising the temperature of the air flowing past the temperature-sensing element.

1) By transfer from the exterior enclosure.
2) By radiation reflected or emitted from the ground and absorbed on the under surfaces of the thermoshield housing or entering the air inlet.
3) By conduction of heat along the bottom surface of the thermoshield from the outer casing toward the inner tube.
4) By circulation of exhaust air that has been warmed by motor heat or radiant energy absorbed by the thermoshield.

The following equation can be used to express the relation between the heat transferred to the entering air and the temperature rise of the air:

$$q = mc\Delta t$$

where q = heat absorbed, Btu/hr

m = mass flow of air, lb/hr

c = specific heat of air under test conditions = 0.24

Δt = difference between indicated temperature and true air temperature, deg. F.

If it were assumed that the same amount of heat was transferred to the air entering each of the two models of the thermoshield, the following relation would exist:

$$m_1 c\Delta t_1 = m_2 c\Delta t_2$$

or

$$\frac{m_1}{m_2} = \frac{\Delta t_2}{\Delta t_1} = \frac{v_1}{v_2}$$

where v_1 and v_2 = volumes of air circulated in models 001 and 002, respectively, cfm.

Under the conditions that produced the greatest temperature difference shown in Table 1, $\Delta t_2 = \Delta t_1 + 0.24$, $v_1 = 90$ cfm, and $v_2 = 8$ cfm.

Thus
$$\frac{\Delta t_1 + 0.24}{\Delta t_1} = 11.3$$

$$\Delta t_1 = 0.023 \text{ deg. F}$$
$$\Delta t_2 = 0.26 \text{ deg. F}$$
$$q = 2.2 \text{ Btu/hr}$$

Based on these assumptions the error in the model 001 thermoshield for the worst conditions reported in Table 1 was about 0.02 deg. F and the amount of heat transferred to the entering air was 2.2 Btu/hr, whereas the error in the model 002 thermoshield was about 0.26 deg. F.

Calculations, with certain assumptions, were made to estimate the approximate magnitudes of the first three ways of heat transfer to the inlet air listed above. Heat transfer from the housing through the Dewar flask to the inner tube was estimated to be very small, both because the Dewar flask has a very low heat transmission coefficient, and because there were four surfaces between the outer surface of the unit and the inner surface of the inlet tube from which heat was removed by the high velocity air stream after it had passed the temperature sensing element. The third item listed, the conduction of heat along the bottom surface of the thermoshield from the outer casing toward the inner tube, also was found by computation to be very small.

Radiation absorbed by the under surface of the thermoshield can be separated into two kinds (1) radiation emitted by the ground or grass surface and (2) solar and sky radiation reflected from the ground or grass surface. Assuming the grass surface to have been about 10 deg. F warmer than the air, radiation emitted from it and absorbed by the under surface of the model 001 thermoshield would have been about 0.9 Btu/hr. Assuming that at the time of the test under consideration the total radiation incident on a horizontal surface was about 145 Btu/hr per square foot, and that from 5 to 10 percent of this was reflected upward, the absorption of such radiation by the undersurface of the Model 001 thermoshield would have been from 0.7 to 1.4 Btu/hr. The total

heat transferred by absorbed radiation is estimated therefore to have been from 1.6 to 2.3 Btu/hr. This is in reasonable agreement with the air heat gain of 2.2 Btu/hr calculated previously from the difference in the temperature indications of the two units.

These figures provide reason to believe that the error of this type of thermoshield is due chiefly to heat gain by absorption of radiation incident from below, assuming a constant rate of air flow through the unit. If the thermoshield were mounted over a ship's deck, or over bare or paved ground, the temperature difference between the surface and the thermoshield could be much greater than 10 deg. F and the heat transfer by directly-emitted radiation would be correspondingly greater. The absorption of solar radiation reflected from the surface could also be markedly different, depending on the solar reflectivity of the surface. Absorption of either kind of radiation could be minimized by making the under surface of the thermoshield as reflective as possible to both solar and low temperature radiation. Elevating the thermoshield to a greater height above the surface, if the latter were of large extent, would not affect the gain of heat by radiation from the surface, but might reduce errors, not considered in this report, due to sampling of air heated by proximity to warmer surfaces when the objective is to ascertain the temperature of the atmosphere not affected by local conditions. Further research might reveal that a radiation shield could be designed that would appreciably reduce the incident radiant energy from below, but the problems in such a design appear to be very difficult.

The amount of recirculation of exhaust air was variable depending on the velocity and direction of the wind. The smoke tests indicated that the model 002 thermoshield was somewhat more susceptible to recirculation than model 001. However, this factor was probably of little significance, because the difference in indicated temperature for the two units was consistently less than 0.1 deg F for the tests made in the shade or with cloudy skies.

Not all of the heat entering the thermoshield by the first three ways described above would necessarily effect a rise in indicated temperature unless the air stream was well-mixed as it passed through the inlet tube. Model 002 equipped with the vortex vane probably mixed the air in the inlet tubes very thoroughly.

As pointed out in Test Procedure, no attempt was made to provide an absolute calibration of either model of the thermoshield. It is believed, however, that an artificial environment could be created in a specially-designed enclosure that would provide accurately-controlled and steady air temperatures and in which known values of radiation could be imposed on the devices under test to simulate the effects of solar radiation without destroying the constancy of the air temperature. In such an environment, which would probably be quite costly, a laboratory model of the thermoshield with better radiation shielding than either of those described in this report could be used as a reference unit for calibration of the models designed for shipboard or shore use.

The results showed that these devices conformed reasonably well to their design specifications. However, some modifications of the model 002 unit would probably increase its accuracy. These modifications include increasing the air flow by means of a larger blower or by reducing the resistance to air flow of the vortex vane, relocating the exhaust outlet to reduce the likelihood of recirculation, and devising a satisfactory shield, if possible, to reduce radiation from below.

(1) Huebscher, R. G. and Parmelee, G. V.

"Shielding of Thermocouples from the Effects of Radiation." Transactions, A.S.H.V.E., 52: 183-190, 1946

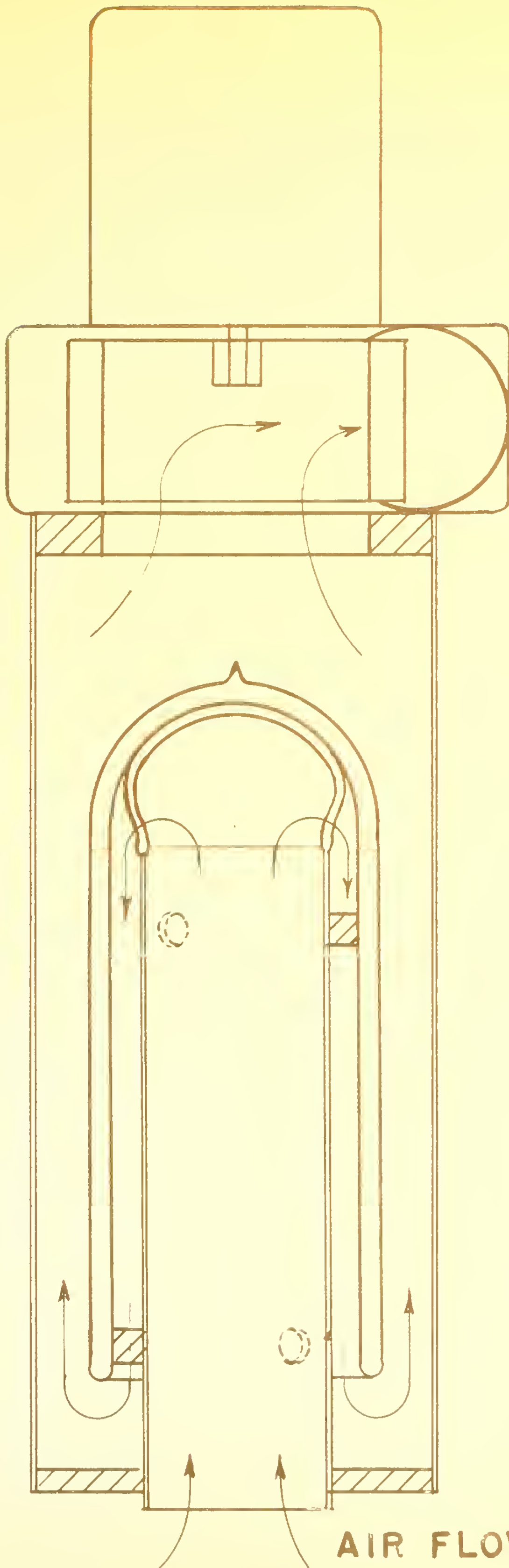


FIG. 1

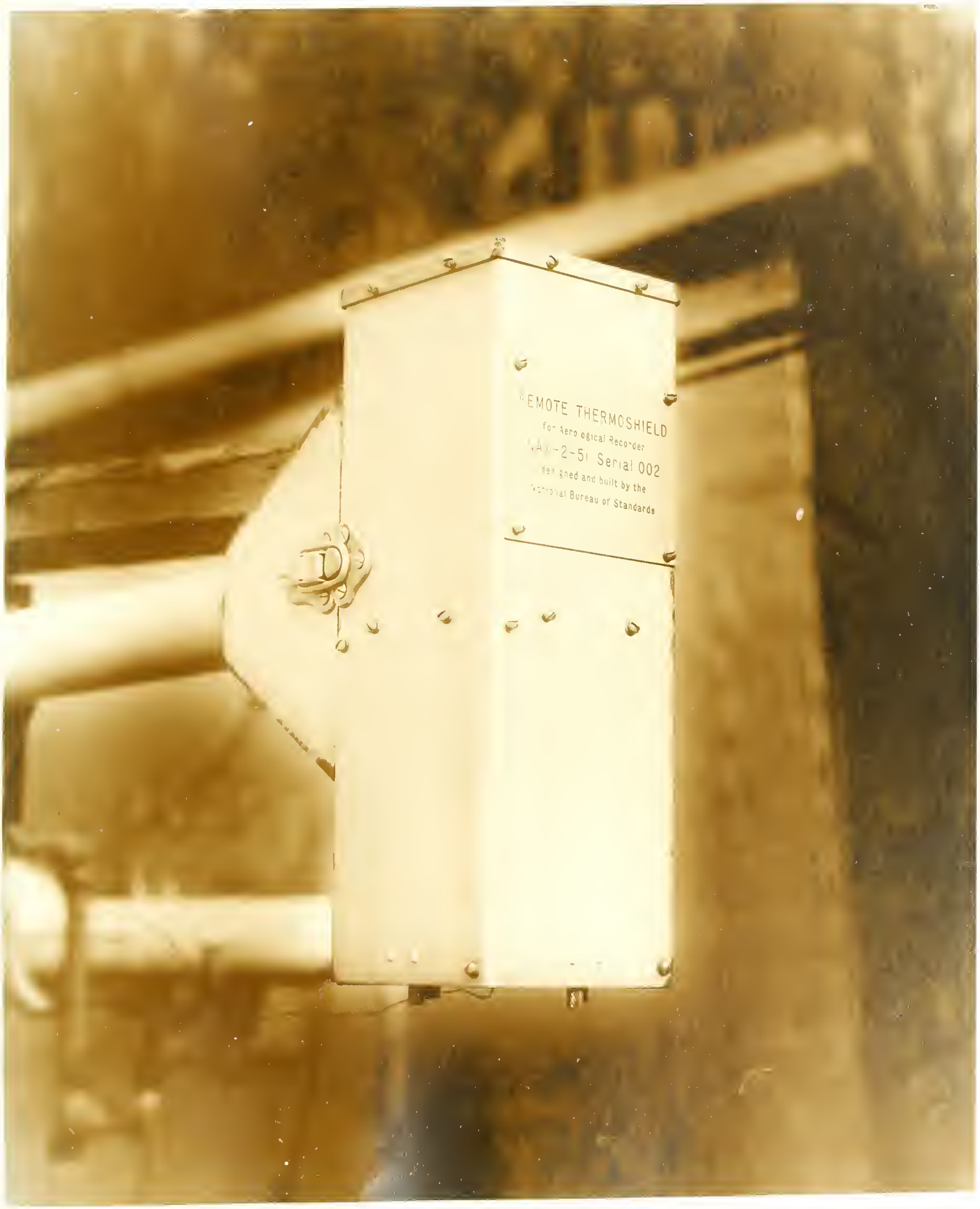


FIG. 2

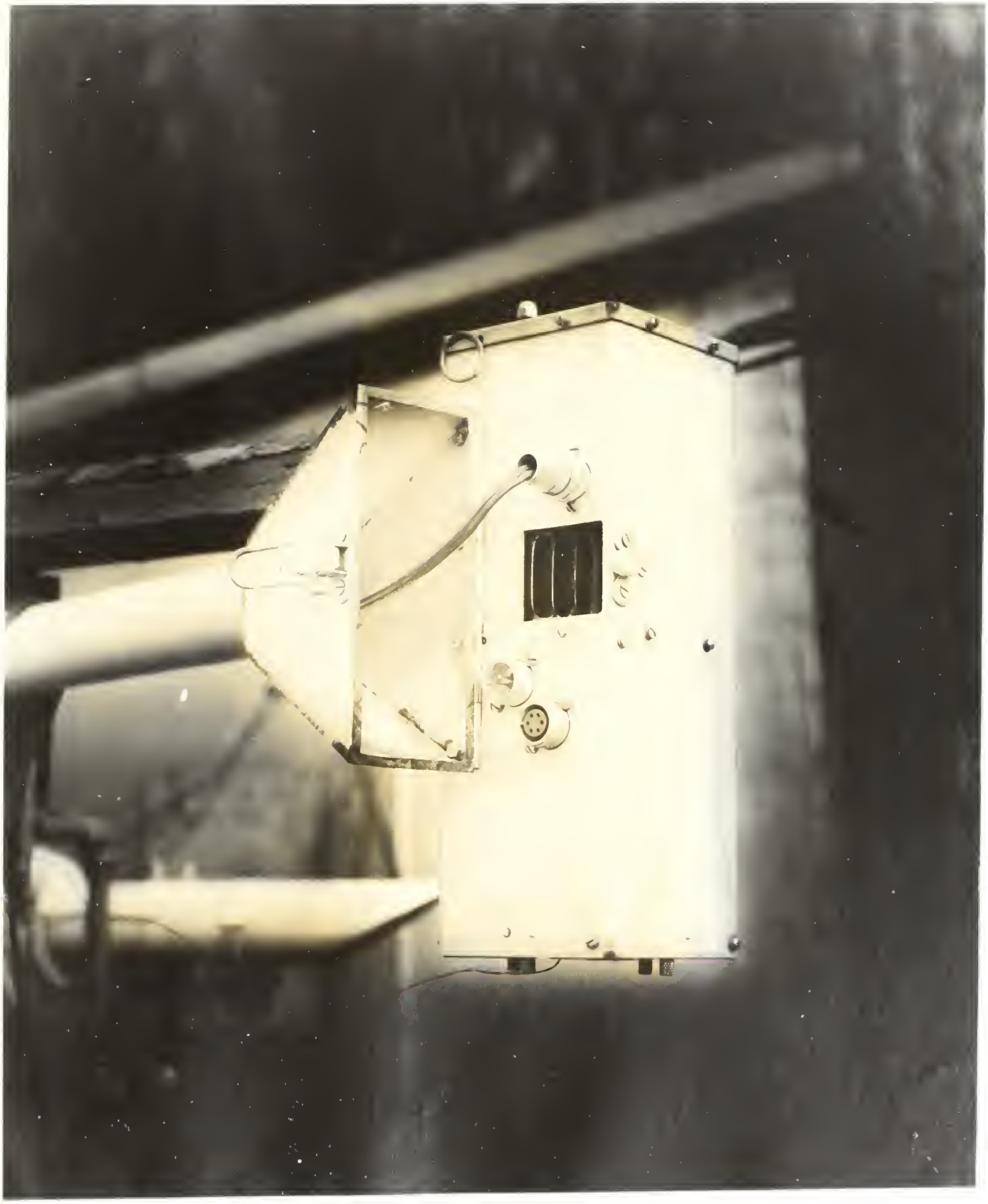
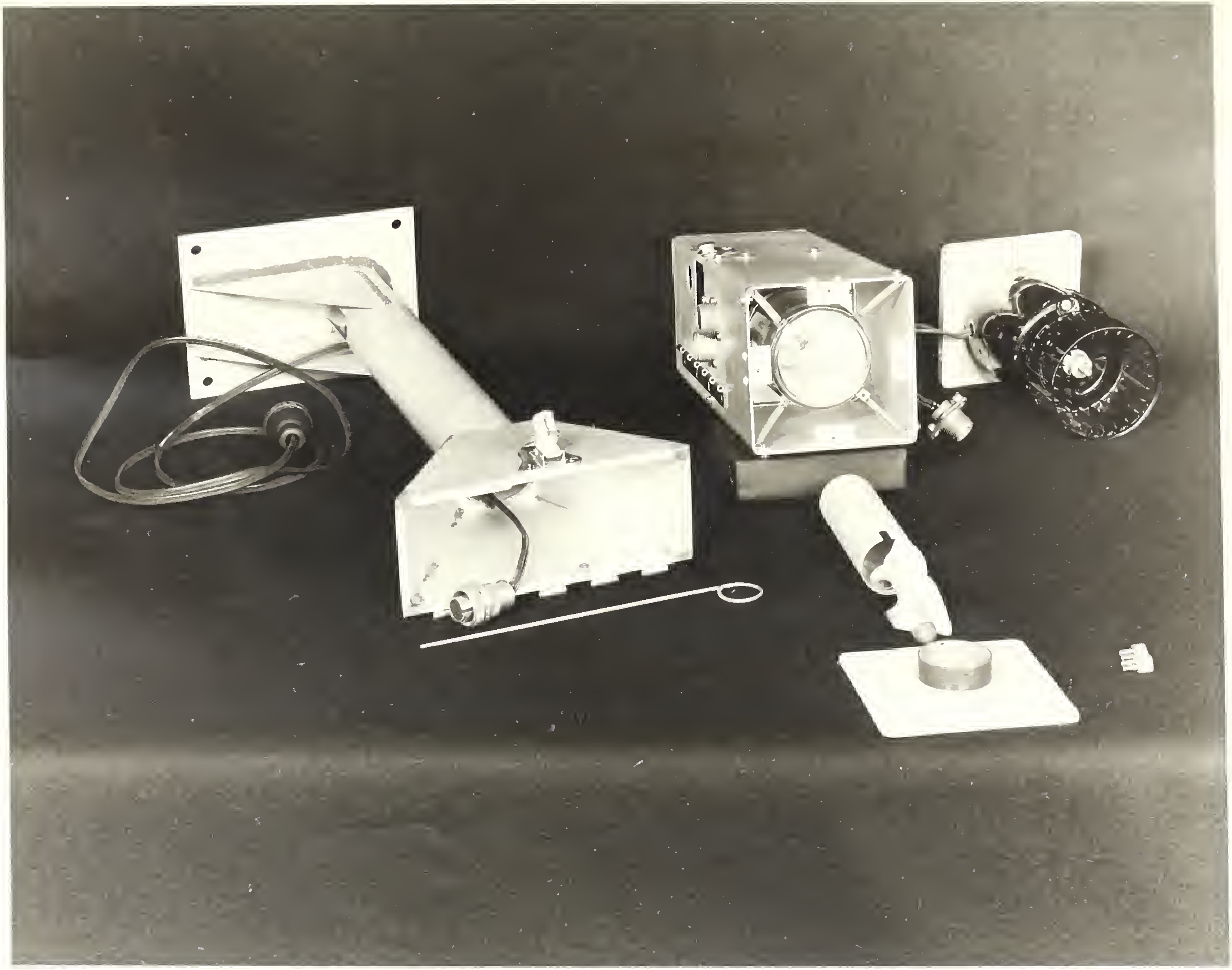


FIG. 3

FIG. 4



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