NATIONAL BUREAU OF STANDARDS REPORT

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AN EXPERIMENTAL AIR ZERO LOCATOR
DESIGN AND CONSTRUCTION

by

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for

Federal Civil Defense Administration

Contract No. CD-SR-57-30

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

AN EXPERIMENTAL AIR ZERO LOCATOR

DESIGN AND CONSTRUCTION

1. INTRODUCTION

1.1 Objectives

At the request of the Federal Civil Defense Administration, the design and construction of 16 experimental air zero locators were undertaken at the National Bureau of Standards. It was specifically requested that primary consideration be given to the selection of a screen material which would retain a visible record when subjected to thermal radiation of widely varying intensities. Further requirements were that the screen material should not deteriorate under normal atmospheric conditions, should have a threshold of sensitivity which will exclude records of sun tracks, and should not be ignited by intense thermal radiation of short duration.

In early discussions among representatives of the Federal Civil Defense Administration and the National Bureau of Standards, it was agreed that no lenses or other optical parts would be incorporated in the devices to be designed and constructed at the NBS. The record of an explosion was to be made by thermal radiation increasing the temperature of a spot on the screen material behind an aperture. If scorching or charring were to be used as the record, the selection of a screen material with a threshold of sensitivity which would exclude recordsof sun tracks would be greatly simplified. However, this would introduce a new problem of selecting a material with a threshold of sensitivity which would give a record of an explosion at a distance sufficiently great to permit examination of the record immediately after the explosion.

The ultimate objective of the present program was to obtain sufficient data from the experimental units to present recommendations for the design of an air zero locator that could be produced by mass production methods. This requires that the screen material, in addition to having the physical properties to meet the requirements specifically mentioned above, must have sufficient strength, rigidity, etc., to be handled, printed, aligned, etc., by mechanical means.

A screen material which ideally complies with some of these requirements is not at all suitable for others; consequently, it is necessary to effect some sort of compromise.

1.2 Background

No information was immediately available on screen materials used for this specific purpose and the limited time available precluded any appreciable experimentation. Consequently, the following analysis led to the selection of the screen materials installed in the air zero locators.

When an inert, homogeneous and opaque semi-infinite solid is exposed to radiant energy of short duration, the temperature rise of its surface is given approximately by

$$t = \frac{A_1 a Q_1}{\sqrt{k d c}} \qquad (1)$$

where A_1 is a constant
- a, the absorptivity of the material for the incident radiant energy
- Q_1, the amount of incident radiant energy per unit of area
- k, the thermal conductivity
- d, the density

and c, the specific heat.

Equation (1) holds approximately for paper-like materials up to the temperature at which burning is initiated.

Analyses of transient heat flow in composite materials show that Equation (1) also holds approximately for paper-like materials greater than about 0.020 inch in thickness in contact with other materials. The specific heat is practically the same for all pressed papers which might be 0.020 inch or more in thickness and the thermal conductivity is roughly proportional to the density. Therefore

$$t = A_2 \frac{a Q_1}{d} \qquad (2)$$

where A_2 is a constant.

It is seen from Equation (2) that for a given amount of radiant energy per unit area, the temperature rise of the surface of a pressed paper is greater for materials with high absorptivity and low density. The absorptivity

should not be so high that the record, if made by scorching or charring, would not be readily distinguishable from the paper itself, and the density should not be made so low as to impair the usefulness of the material in other respects.

Consideration was given to temperature-sensitive papers which change color or appearance when heated to some temperature below that at which scorching takes place on paper such as the melting temperature of a wax. Commercial papers of this type are very thin and, in order to prevent ignition by intense radiation, it would be necessary to bring them into good thermal contact with a backing material. In the absence of any information as to how this might affect their performance and as to the stability of such papers under various atmospheric conditions, it was decided to install pressed-paper boards in the air zero locators. This was to be done in such a way as not to preclude overlaying the boards subsequently with temperature-sensitive paper.

After examination of Standard Paper Sample Sheets of the Government Printing Office, two pressed-paper boards were selected primarily because of their ready availability in the thickness desired and their established stability under various atmospheric conditions. One board was designated No. 212, Railroad Board, Ash Gray, 0.019 inch thick and the other, No. 222, Photo Mount Board, Gray, 0.040 inch thick.

Both boards were available in any quantity desired. The No. 212 board is of the type used in pressboard binders and, as the name implies, the No. 222 Photo Mount Board is used for that purpose. Both of these boards are widely used in offices and laboratories, and experience has demonstrated that they remain reasonably stable for long periods of time. However, the photo mount board will delaminate if immersed in water.

Other factors considered in the selection of these boards were:

(a) Surface Finish: Both boards were very uniform in texture and free from surface defects that might impair their serviceability.

(b) Printing Qualities: Both boards were suitable for letterpress printing and for writing or ruling with pen or pencil and have good erasing qualities.

(c) Absorptivity: The absorptivity for sunlight of the No. 212 board was 73 percent and that for the darker side of the photo mount board was 81 percent.

(d) Color: Both boards were approximately neutral gray. Scorch or char marks, printing, etc. are readily discernible.

(e) Mechanical Properties: Both boards had ample strength, hardness, rigidity, etc. for the intended purpose.

(f) Density: The density of both boards was about 0.8 gm/cm^3. This density (and thermal conductivity) results in a threshold of sensitivity greater than that desired. However, some sacrifice had to be made in this respect to obtain the other desirable features.

From the results of reports on the critical energies required to char various materials, it is estimated that each of the boards selected should char at a critical energy of 3.5 cal/cm^2.

For the purpose of calculating, approximately the amount of radiant energy per unit area received on a screen behind an aperture at different distances from nuclear explosions with different amounts of energy release, it is convenient to make certain simplifying assumptions. These are:

(1) The fireball is a sphere with uniform radiance.

(2) The fireball is stationary in space, during the brief interval in which the thermal radiation is near a maximum.

(3) The atmospheric attenuation is negligible.

(4) The plane of the aperture is perpendicular to a line through the centers of the fireball and aperture.

(5) The screen is parallel to the plane of the aperture.

Let R = radius of the fireball
D = distance from the fireball to the aperture
r = radius of the aperture
f = distance from plane of aperture to the screen
Q = amount of radiant energy per unit area at the aperture
and Q_1 = maximum amount of energy per unit area incident on the screen.

then $Q = A\,\frac{r^2}{D^2}$ (3)

where A is a constant.

When $\frac{R}{D}$ is less than $\frac{r}{f}$,

$$Q_1 = Q$$

and the radius of the area on the screen receiving energy Q_1 is

$$r' = r - \frac{R}{D} f \qquad (4)$$

When $\frac{R}{D}$ is greater than $\frac{r}{f}$,

$$Q_1 = \left(\frac{D}{R}\right)^2 \left(\frac{r}{f}\right)^2 Q \qquad (5)$$

and the radius of the area on the screen receiving energy Q_1 is

$$r' = \frac{R}{D} f - r \qquad (6)$$

In both the above cases, the radius of the area on the screen outside of which no radiation is received is

$$r'' = r + \frac{R}{D} f \qquad (7)$$

The distance (f) between the screen and the plane of the aperture selected for the air zero locators was the result of a compromise. As seen from Equation (5), decreasing f increases the amount of energy incident on the screen but this will decrease the angular resolution. The distance selected, 1 5/8 inches, gives a displacement of about 0.03 inch on the screen for one degree change in the azimuth or elevation angle at low values of these angles.

The screens were made four inches square with grids that permitted reading the azimuth and elevation angles directly. A print of the grid is shown in Figure 1. The distance between successive vertical lines corresponds to 5 degrees. An appropriate scale was cemented to each screen for which the total range of azimuth angles was 100 degrees.

There was considerable uncertainty regarding the optimum size of aperture for the air zero locators because of the absence of information regarding the energy release of the explosions and of the range of the ratio r/R. As seen from Equation (5), increasing the size of the aperture increases the amount of energy incident on the screen and also the area over which energy is received. The latter, in general, decreases the accuracy with which the direction of the explosion can be read from the record.

From an analysis of curves relating the amounts of thermal energy delivered from explosions of different sizes to the distances from the explosions[1] an expression may be obtained which approximates the curves over the anticipated energy range. Thus,

$$Q \approx 1500 \left(\frac{R}{D}\right)^2 \qquad (3a)$$

Substituting this in Equation (5), which applies

when $\frac{R}{D}$ is greater than $\frac{r}{f}$,

we obtain an approximate expression for Q_1, the maximum amount of energy per unit area incident on the screen:

$$Q_1 \approx 1500 \left(\frac{r}{f}\right)^2 \qquad (5a)$$

(when $\frac{R}{D}$ is less than $\frac{r}{f}$, then $Q_1 = Q$)

The following table lists the values of Q_1 calculated from this expression, for several aperture sizes and f = 1.625 in.

Table 1. Estimated Maximum Thermal Energy for Various Sizes of Apertures

Diameter of aperture	Q_1
in.	cal/cm²
1/16	0.6
3/32	1.2
1/8	2.2
3/16	5.0
1/4	8.9

[1] The Effects of Atomic Weapons, Los Alamos Scientific Laboratory, June 1950, Fig. 6.42.

It was realized that the energy through the smaller apertures might not be sufficient to give a record on the pressed-paper boards but that it might be sufficient to give a record on temperature-sensitive paper. Furthermore, it would not be difficult to increase the size of the apertures in the field if they proved to be too small.

Figure 2 is a photograph of one of the completed air zero locators. An assembly drawing is shown in Figure 3.

Figure 4 is a photograph of one of the devices with the top raised to show one of the screens in place. Details of the casting which constitutes the cover and the aluminum faces to which the screens are cemented are shown in Figure 5.

Details of the housing which contains the apertures are shown in Figure 6 and of the apertures in Figure 7. Details of the casting which supports the housing and permits rotating and leveling are shown in Figure 8.

All of the parts in the 16 units were made from stock materials or castings and are interchangeable.

The critical elements in the design and construction of the air zero locators are:

(1) Each surface to which the screen is attached must be perpendicular to the adjacent surfaces and to the top.

(2) The top must be flat with an index line to permit leveling and aligning the screens.

(3) The planes containing the apertures should be at a fixed and known distance from the screens.

(4) The principal aperture should be aligned with the grid on the screen behind it.

(5) Each locator must be provided with means for rotating and leveling the cover and housing as a unit.

(6) Means must be provided for anchoring each unit so that it will remain stationary at a desired location.

ILLUSTRATIONS

TABLES

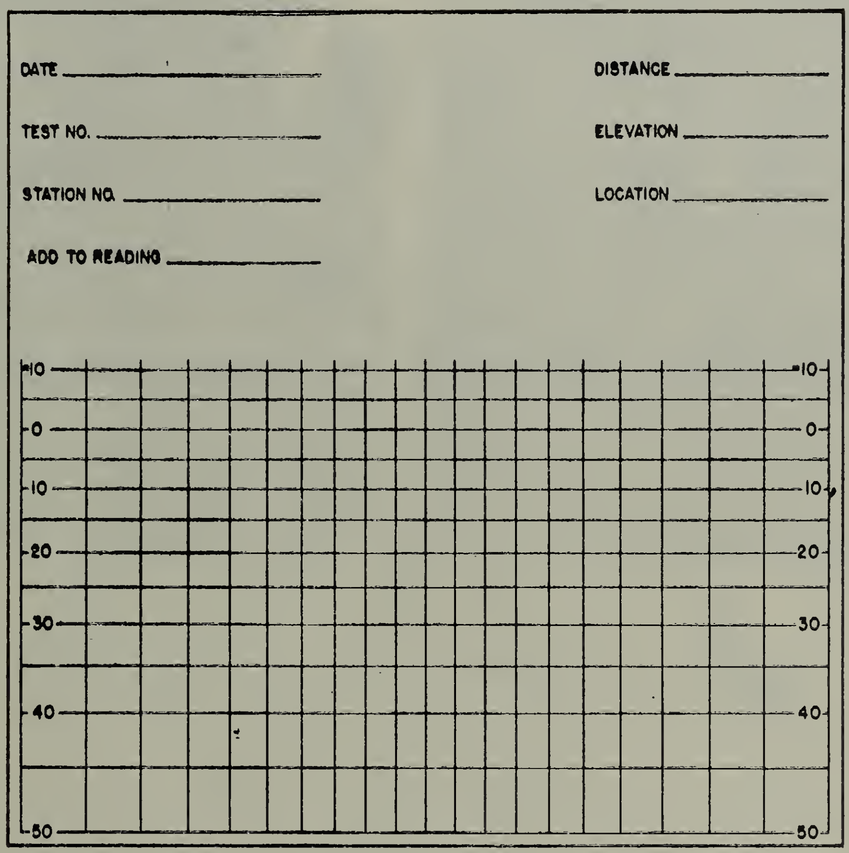

Figure 1. Grid Markings Printed on Screens

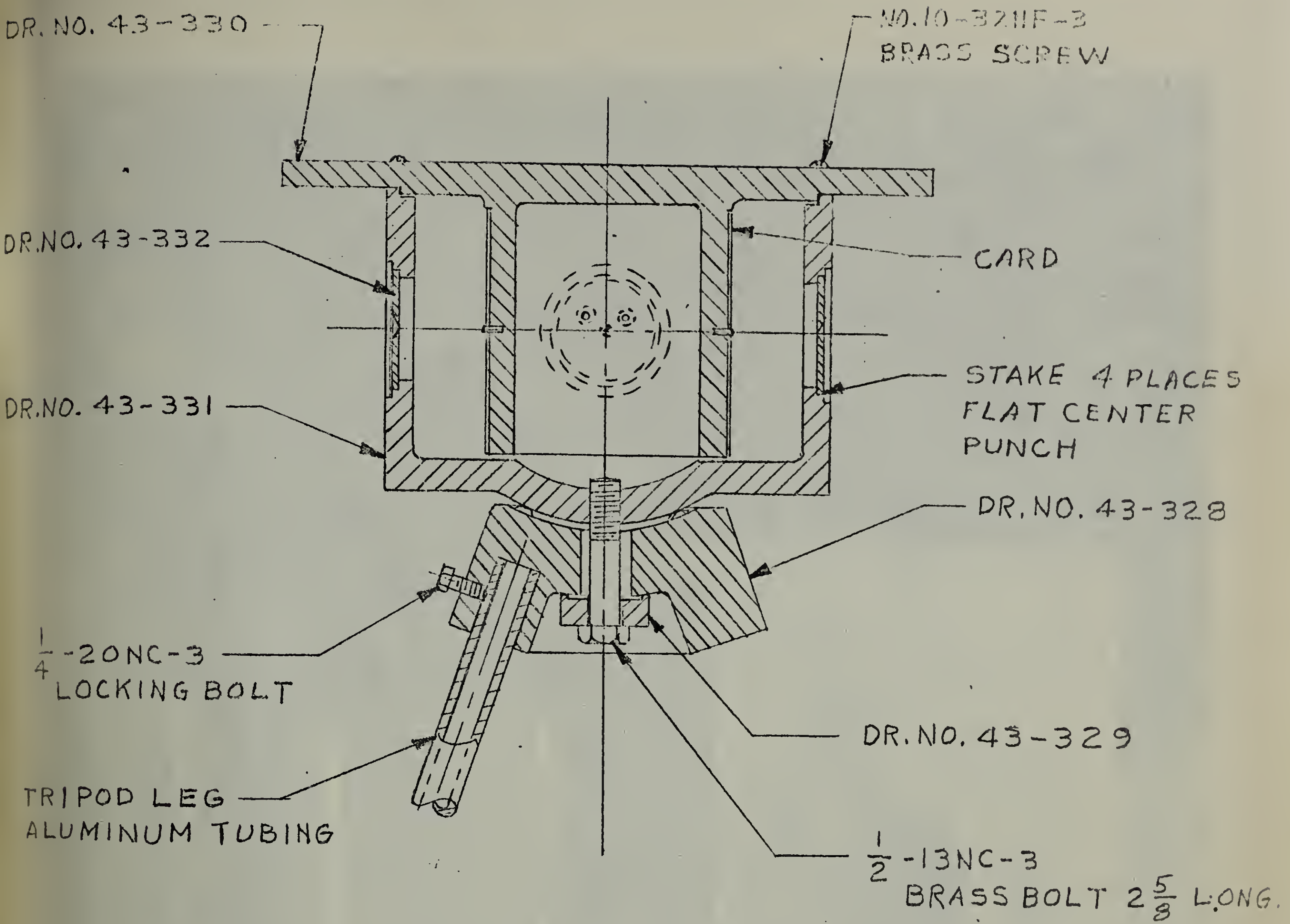

Figure 3. Air Zero Locator Assembly Drawing

AIR ZERO LOCATOR ASSEMBLY

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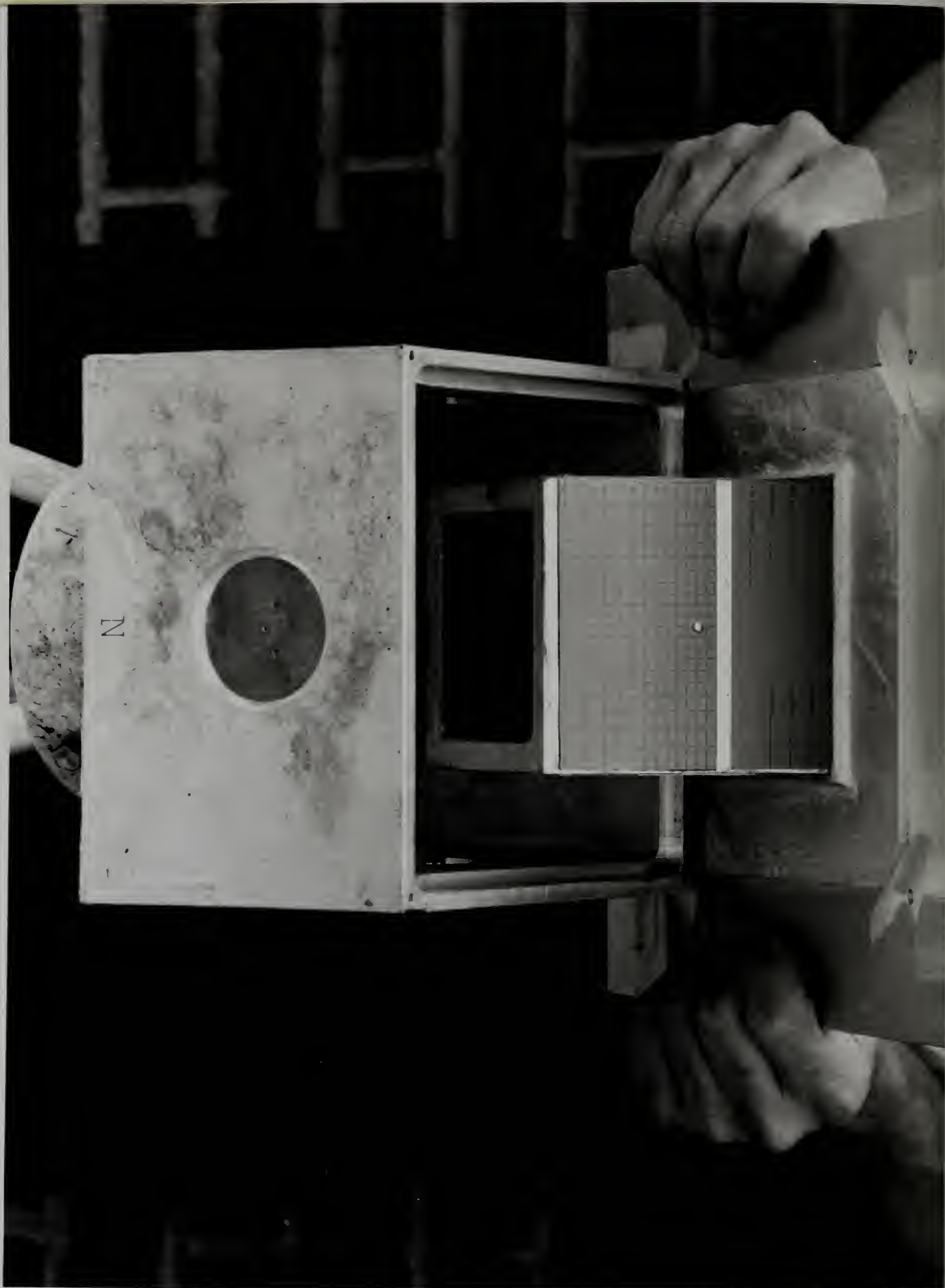
DIV. SEC.	43-333	

Figure 4. Air Zero Locator, Cover Raised to Show Screen



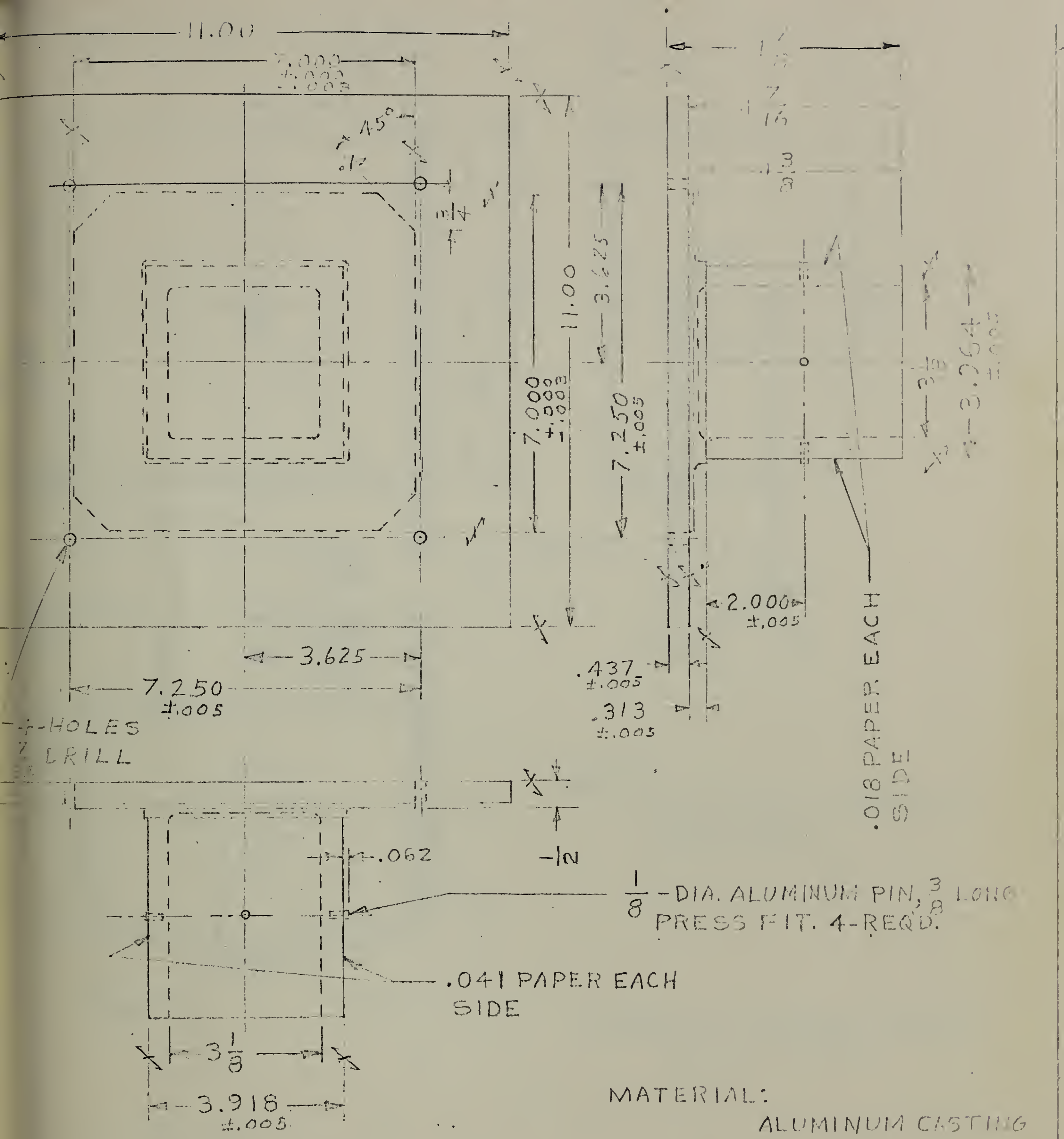


Figure 5. Air Zero Locator Cover, Details

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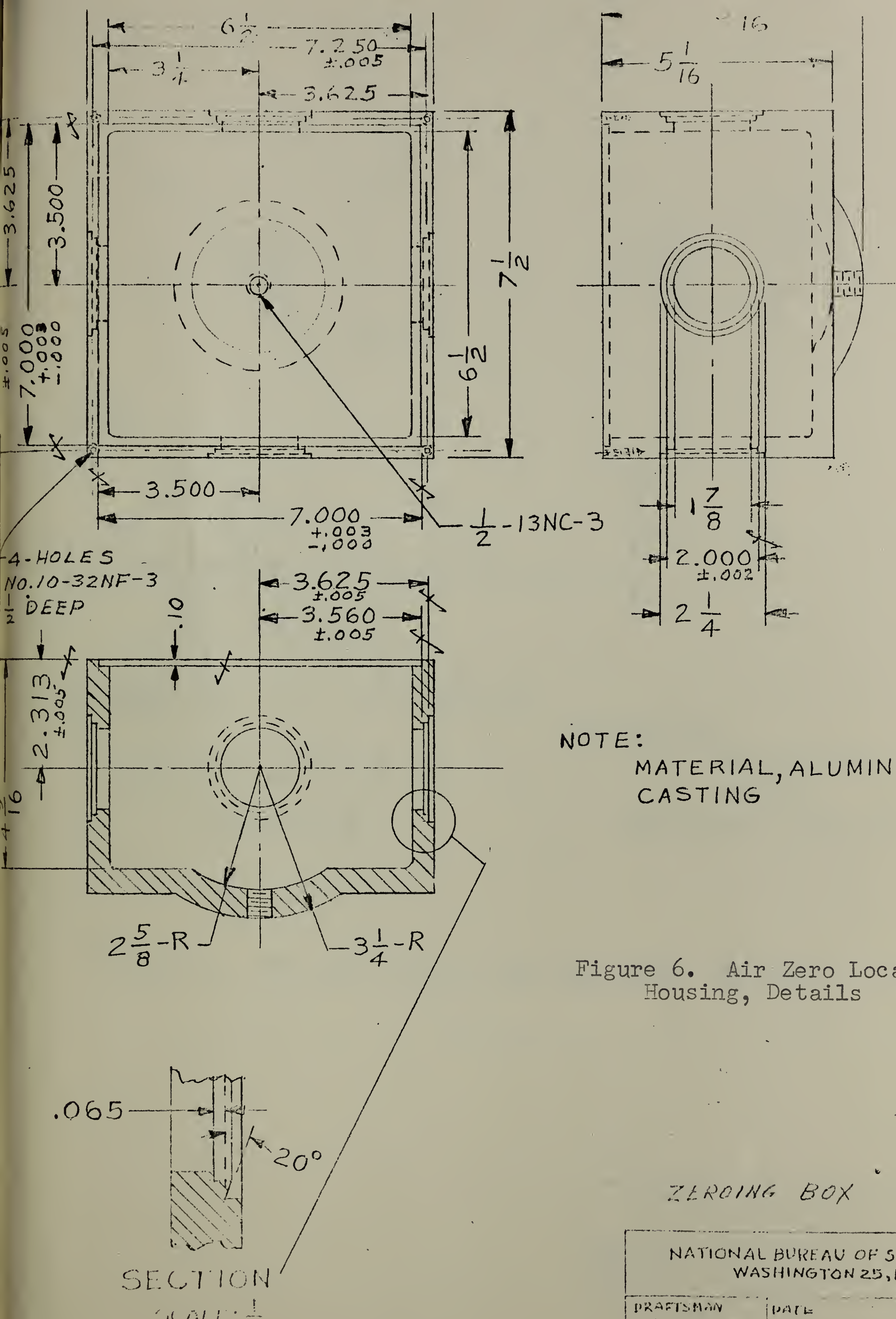

NOTE:
MATERIAL, ALUMINUM CASTING

Figure 6. Air Zero Locator Housing, Details

ZEROING BOX

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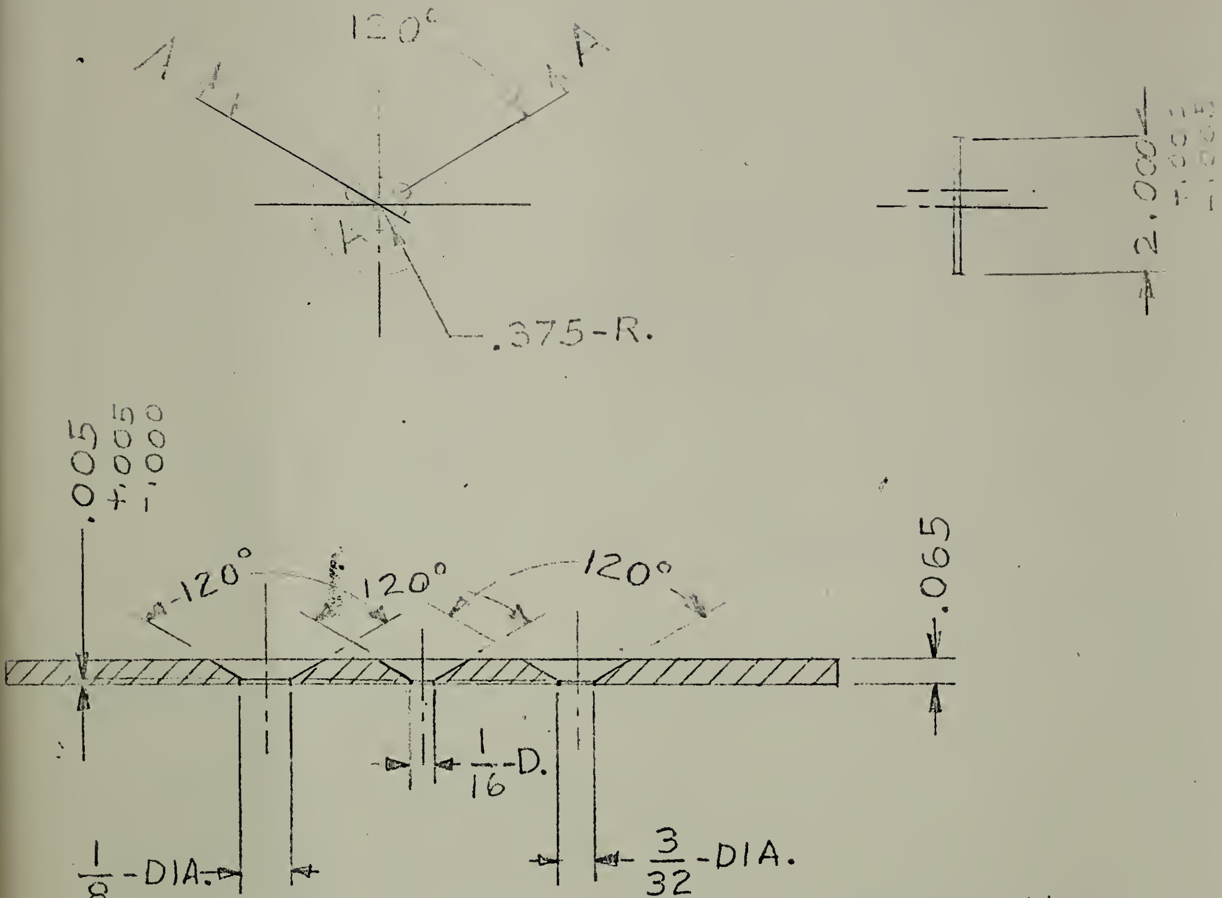

SECTION A-A-A

SCALE: 2/1

MATERIAL:
ALUMINUM
PLATE
NO. REQ'D. 4 PER UNIT

Figure 7. Air Zero Locator Aperture Plate, Details

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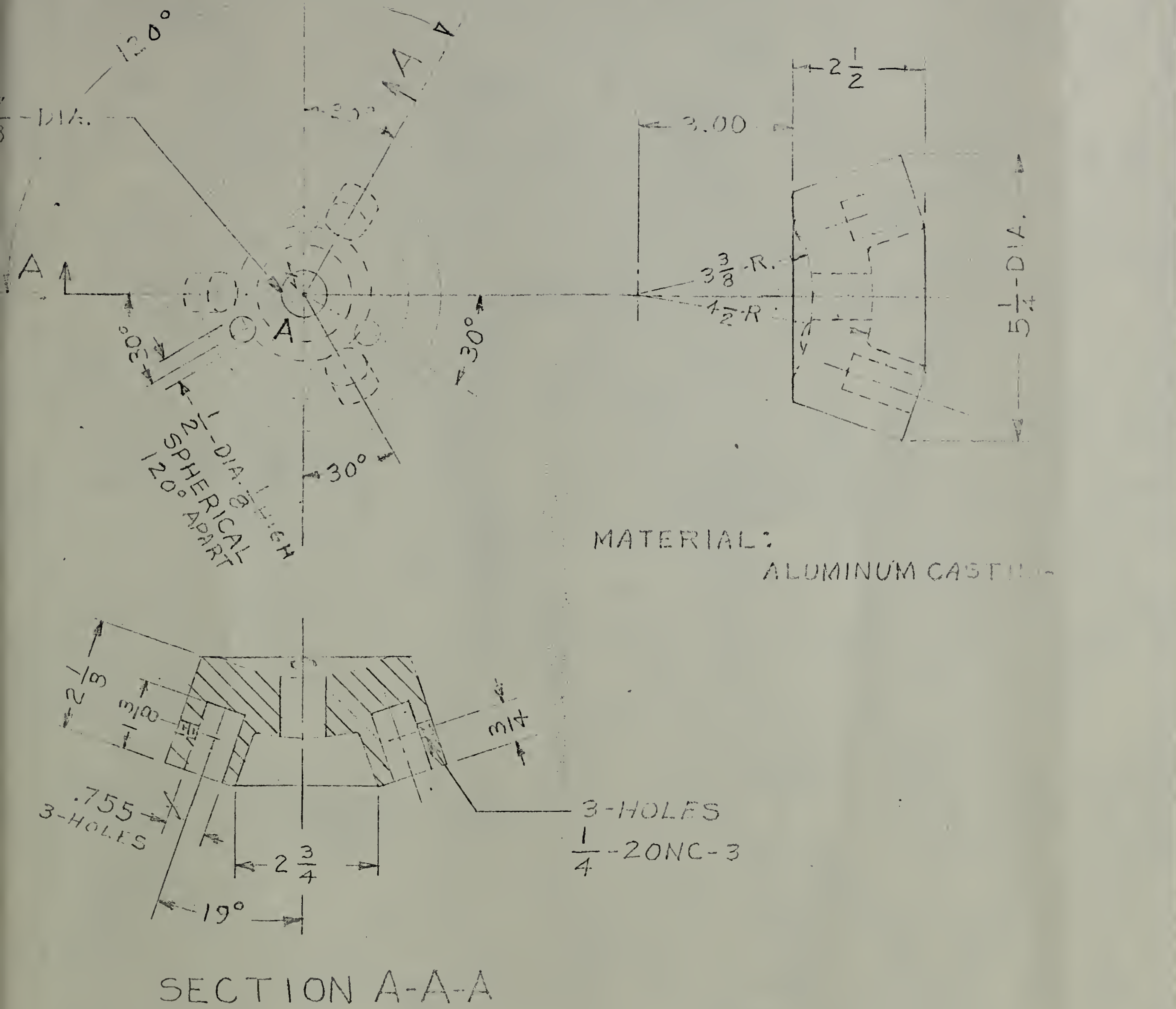

Figure 8. Air Zero Locator Tripod Head, Details

TRIPOD HEAD

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5-3-57

SCALE 1/3

IV SEC.

43-328