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DEVELOPMENT OF AN ISOTROPIC RADIATION SIMULATOR

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ABSTRACT

The development of a device to provide laboratory simulation of an isotropic distribution of radiation is described. Emulsions to be flown aboard space vehicles, which may be subjected to this type of radiation, can be tested initially in the laboratory by the use of this device, in conjunction with a high-energy particle accelerator.

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SPACE SCIENCES LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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DEFINITION OF SYMBOLS

Symbol	Definition
A	area of parallel incident beam (cm^2)
C	constant
$\frac{d}{dt}$, $(\dot{\ })$	first derivative with respect to time (sec^{-1})
$\frac{d^2}{dt}$, $(\ddot{\ })$	second derivative with respect to time (sec^{-2})
K	angular speed of cam motor (rpm)
N	number of protons per second
$\hat{n}$	unit normal to emulsion turntable surface
R	length of arm holding follower (cm)
r_c	radial length of cam when follower is at $\theta = 0$ position (cm)
r_f	radius of follower (cm)
t	time (sec)
α	lag angle, see Figure 5 (deg)
θ	follower angle (deg)
ρ	length of radial cam element measured from axis of rotation (cm)
ϕ	cam angle, see Figure 5 (deg)

Subscripts

f	follower
g	gravity
o	initial

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SUMMARY

Films for spacecraft use, which are sensitive to isotropic background radiation, are usually tested by exposure to high-energy particles emanating from an accelerator. Since the particles move in essentially parallel paths, the film is not irradiated in an isotropic mode. Laboratory use of the device described in this report furnishes a method to expose emulsions and other radiation-sensitive items to an isotropic distribution of radiation that is limited to half-space exposure.

INTRODUCTION

Films or emulsions are used during spacecraft missions for a variety of scientific purposes. A problem associated with this type of usage arises from the sensitivity of various emulsions to background radiation. That is, storage or use in an environment of relatively intense natural radiation may darken some undeveloped films to the extent that objects in the developed film are not sufficiently detectable.

The background radiation may, for example, consist of high energy protons which are characterized by an isotropic flux intensity. Simply stated this means that the number of protons incident upon a unit area of the film per unit time interval are arriving in equal amounts from all angles of the heavens (and not in parallel rays as from an accelerator). This isotropic radiation caused by protons is one of the types of background radiation expected aboard the S-IVB Orbital Workshop; consequently, various scientists are anxious to test their film to ensure that the emulsion sensitivity is properly chosen.

Although it is possible to generate the high-energy protons in accelerators at several facilities in this country, the proton beam which emerges is composed of particles traveling in essentially parallel paths. Space simulation, however, requires an isotropic distribution. The device described here moves the emulsion in such a way that, although the protons are of parallel incidence, the film "sees" them as an isotropic distribution.

ISOTROPIC RADIATION SIMULATOR

Figure 1 shows a parallel beam of radiation incident upon an emulsion.

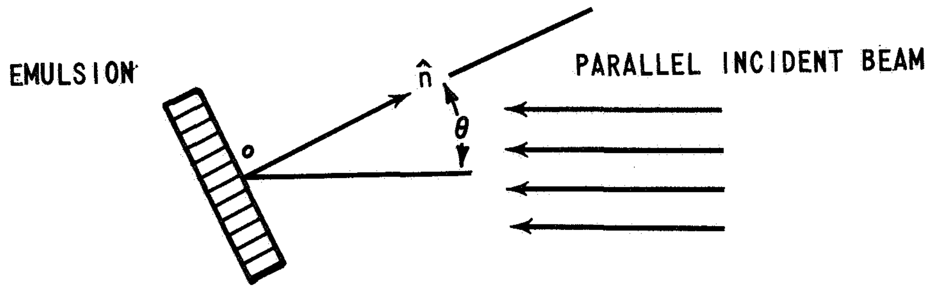


FIGURE 1. TWO-DIMENSIONAL VIEW OF PARALLEL INCIDENT BEAM AND EMULSION

The unit normal ($\hat{n}$) is shown at the emulsion's polar axis of symmetry. If the emulsion is rotated about an axis through point o, perpendicular to the plane of the paper, with a particular velocity so as to change θ, it is possible for the emulsion to "see" an isotropic distribution. If the angle which the parallel beam makes at any time with $\hat{n}$ is θ, then the intensity of the beam upon the flat emulsion will be $N \cos\theta/A$ (where N = number of protons/sec and A = area of parallel beam). The time rate of change of the intensity must be constant, which implies an isotropic* flux. Using the differential calculus,

$$\frac{d(N\cos\theta/A)}{dt} = \text{constant}$$

or

$$\frac{d(\cos\theta)}{dt} = \frac{A}{N} \times \text{constant}$$

---

* If the physicist's usual definition is used, which requires that an equal number of particles per sec per unit area per steradian be incident upon the emulsion from all solid angles of the half-space, the identical formulae result.

so that

$$\frac{d\theta}{dt} = \frac{C}{\sin\theta} \quad , \text{ where } C \text{ is another constant.}$$

The quantity $\frac{d\theta}{dt}$ is the relative angular velocity at θ which the emulsion must have about a perpendicular through point o so that the parallel incident beam can be effectively seen as an isotropic distribution. This velocity profile can be generated by designing a special cam and follower mechanism. An application of the branch of mechanical engineering known as kinematics of machinery shows that the cam will be able to continuously cycle the emulsion, at most, from only $\theta = 0$ to 90 degrees and return. If one looks at an area of the emulsion for this mode of operation, it may be seen that the radiation tracks caused by one ray are similar to those shown in Figure 2. Obviously this

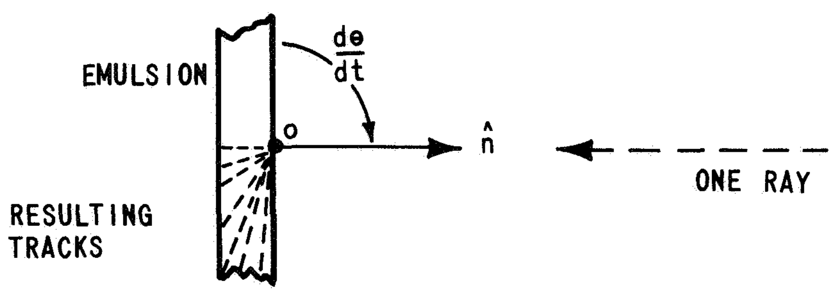


FIGURE 2. MAGNIFIED VIEW OF RADIATION TRACKS IN EMULSION FROM ONE INCIDENT RAY

0 → 90 degree sweep is not an adequate isotropic distribution; but, if we rotate the emulsion at constant velocity about its polar axis (coincident with $\hat{n}$) as we simultaneously rotate about point o with the velocity $\frac{d\theta}{dt}$, the tracks will have a three-dimensional isotropic distribution, limited to half-space exposure.

The essential features of the Isotropic Radiation Simulator are shown in Figure 3. The turntable motor is held by the cradle. The cam provides the $\frac{d\theta}{dt}$ angular velocity to the cradle which rocks the turntable and its attached emulsion. The turntable motor simultaneously spins the emulsion about $\hat{n}$. Placing the follower (a small roller bearing) on the cradle yields a very compact design, and allows electrical operation of the turntable motor without

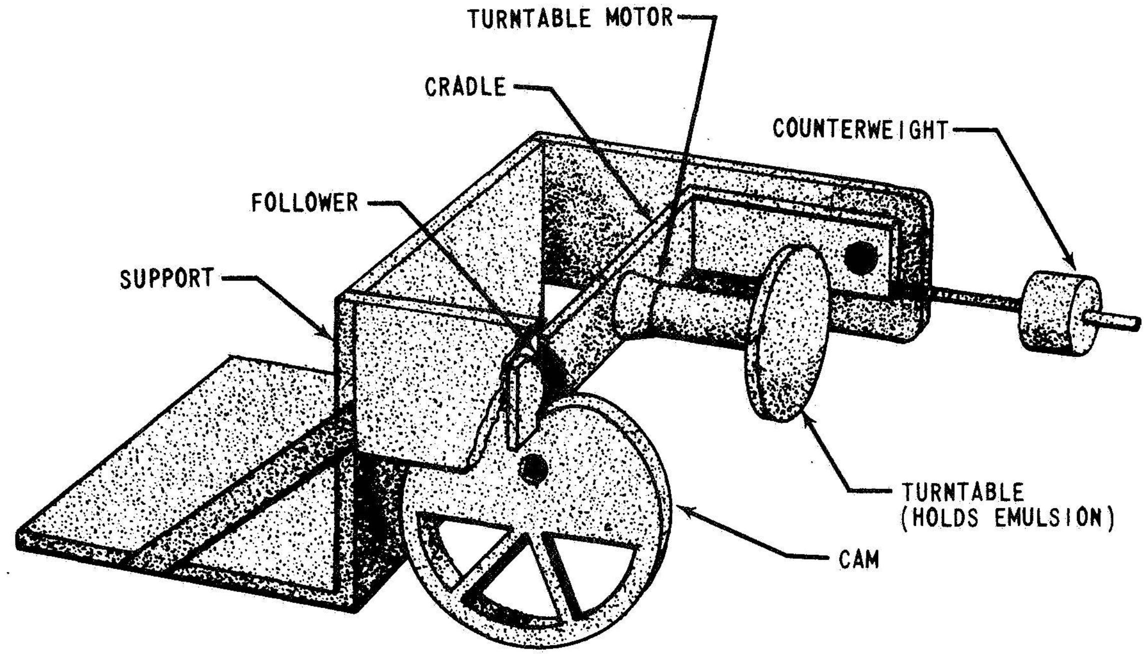


FIGURE 3. SKETCH OF ISOTROPIC RADIATION SIMULATOR

slip-rings. The cam motor rotates at 10 rpm, the turntable at 350 rpm, and no springs are required to hold the follower to the cam. From kinematic considerations (discussed in the next paragraph), the cam exposes the emulsion to an included angle of ±15 degrees to ±83 degrees between whose limits the isotropic simulation is effected, as depicted in Figure 4. The tracks are shown in two dimensions, but since the emulsion is spinning about $\hat{n}$, the tracks are isotropically spread in three dimensions.

ANALYSIS OF CAM OPERATION

The two motions required for the Isotropic Radiation Simulator are the constant velocity rotation about $\hat{n}$ and the cam rotation. The cam profile is developed from the previously derived equation $\frac{d\theta}{dt} = \frac{C}{\sin\theta}$. The design can be initiated by assuming the constant C = 1. If we examine the integral equation

$$\int_{t_o}^{t} C\,dt = \int_{\theta_o}^{\theta} \sin\theta\,d\theta ,$$

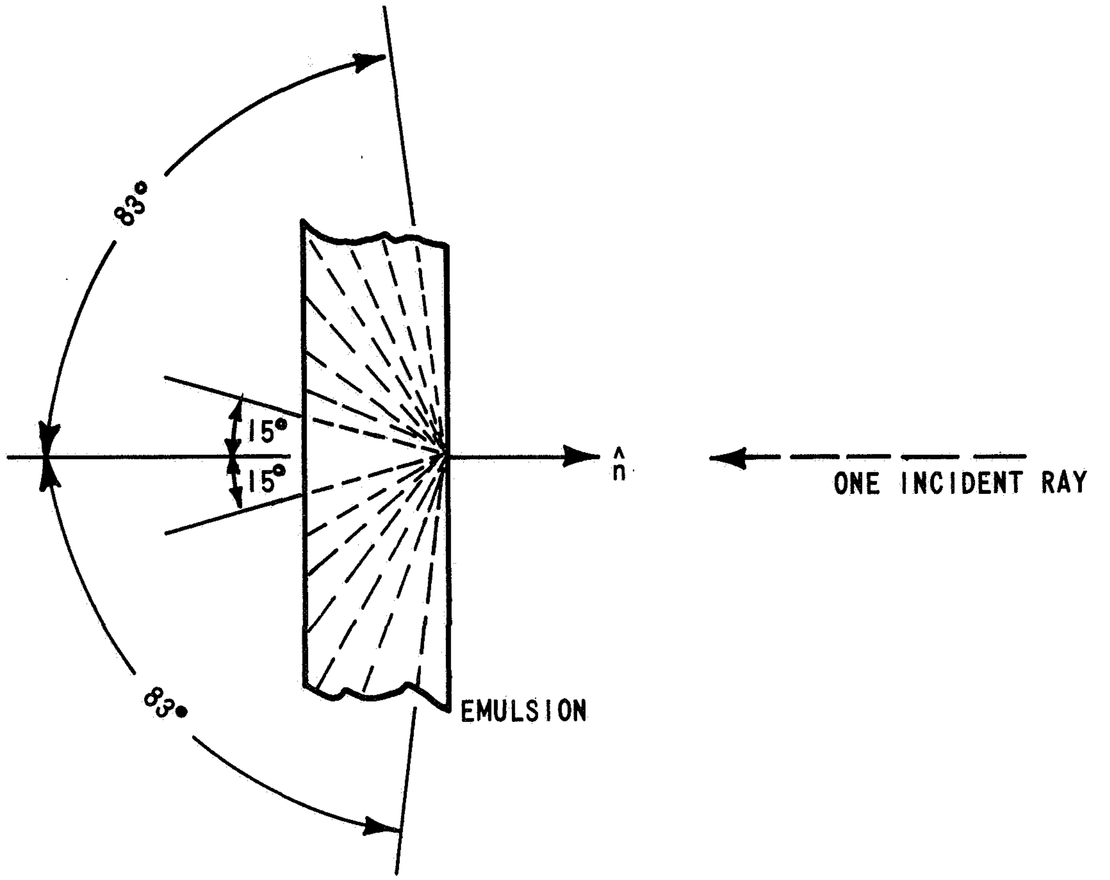


FIGURE 4. REGIONS OF ISOTROPIC OPERATION

with its solution

$$t - t_o = \frac{\cos\theta_o - \cos\theta}{C},$$

then for an excursion of $0 \leq \theta \leq 90$ degrees the choice of $C = 1$ implies a rotation of the emulsion from 0 to 90 degrees in 1 second (Fig. 5). Once the mechanism has been designed on this "unit" basis it may then, in practice, be operated at any multiple of this speed; in fact, cam rotation of 10 rpm and turntable rotation of 350 rpm are the chosen nominal operating speeds. The cam is to be driven by a constant-speed motor. If ϕ is the angle which any radial line from the center of rotation of the cam makes with that vertical radial line corresponding to the follower position at $\theta = 0$ degrees (Fig. 5), then $\frac{d\phi}{dt} = K$, where K is the angular speed of the cam motor.

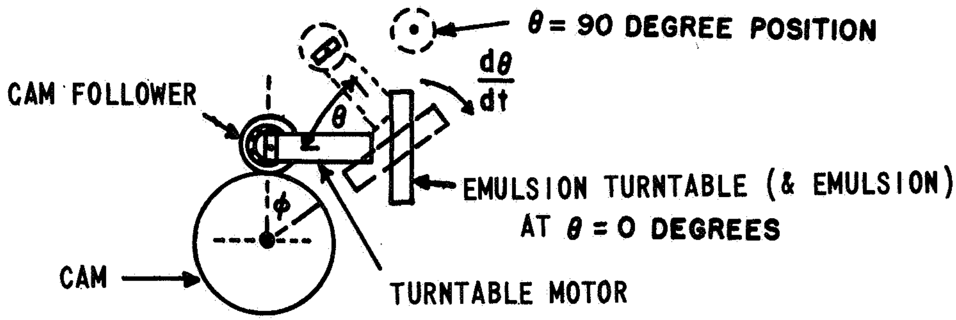


FIGURE 5. MOTION OF CAM FOLLOWER AND EMULSION TURNTABLE

Figure 6 depicts the essential geometry of the cam and follower. When the cam has rotated ϕ degrees, the follower is at θ degrees. However, the follower does not lie vertically above A (as it did for $\theta = 0$ degrees), but is at a lag angle α from the vertical. This angle is given by:

$$\alpha = \tan^{-1} \frac{R - R\cos\theta}{R\sin\theta + r_f + r_c} .$$

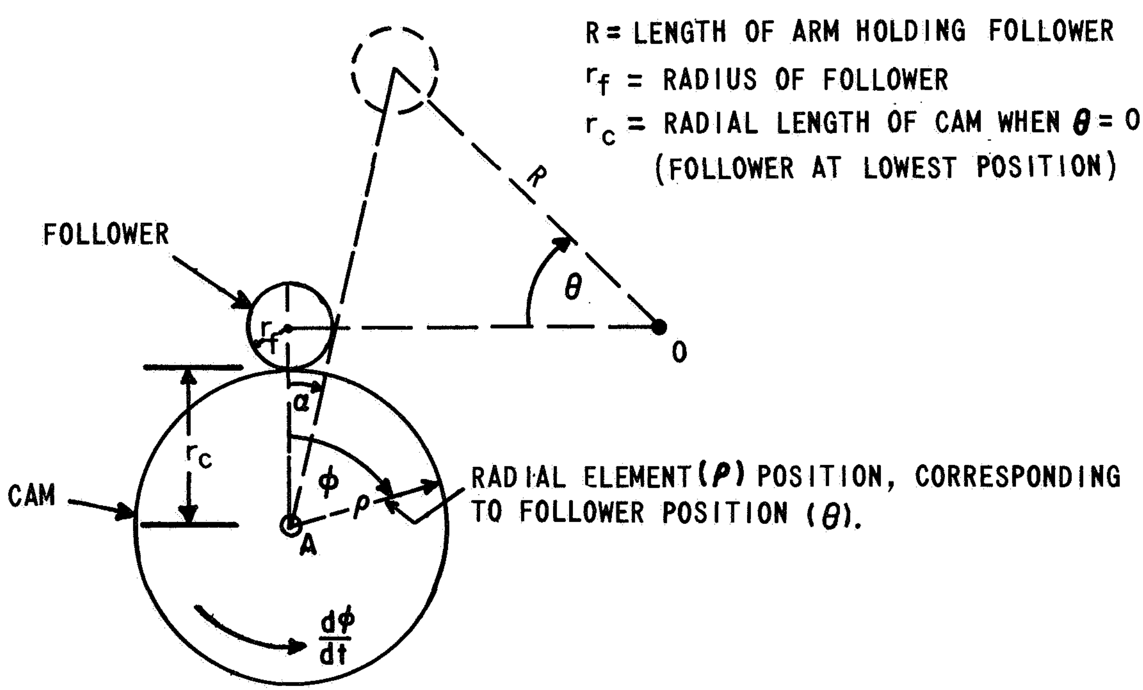


FIGURE 6. CAM-FOLLOWER GEOMETRY

The length of a radial cam element corresponding to follower position θ is

$$\rho = \frac{R - R\cos\theta}{\sin\alpha} - r_f .$$

From the former equation for α ,

$$\sin\alpha = R(1 - \cos\theta)/\sqrt{(R - R\cos\theta)^2 + (R\sin\theta + r_f + r_c)^2}$$

so that

$$\rho = \sqrt{2R^2(1 - \cos\theta) + 2R(r_f + r_c)\sin\theta + (r_f + r_c)^2} - r_f .$$

Thus, at $\theta = 0$ degrees, the cam radial element is $\rho_{0\ \text{degrees}} = r_c$ (Fig. 6); at $\theta = 90$ degrees,

$$\rho_{90\ \text{degrees}} = \sqrt{2R^2 + 2R(r_f + r_c) + (r_f + r_c)^2} - r_f .$$

If the cam were to turn one revolution while the emulsion turntable rotated 90 degrees, there would be a discontinuity in the cam, since $\rho_{0\ \text{degrees}} \neq \rho_{90\ \text{degrees}}$. To circumvent this difficulty, the cam is caused to turn 1/2 revolution for a 90 degree rotation of the turntable. This leads to a single-axis-of-symmetry cam which has the profile of a modified cardioid and a cam motor speed of K = 180 degrees/sec. For any given θ position of the follower, the lag angle α must be added to ϕ in order to obtain the true cam angle $(\alpha + \phi)$ corresponding to the cam radial element ρ which is in contact with the follower at that instant. Because

$$t - t_o = \frac{\cos\theta_o - \cos\theta}{C} ,$$

we have

$$t = 1 - \cos\theta ,$$

with $C = 1$ and $\theta_o = 0$ degrees, and $t_o = 0$ seconds. Also

$$\frac{d\phi}{dt} = K$$

yields

$$\phi = 180(1 - \cos\theta) ,$$

upon integration and substitution of t and K. Thus a tabulation of the true cam angle $(\alpha + \phi)$ versus ρ, for all follower positions, may be made for purposes of machining the cam.

Since the angular velocity of the follower is

$$\frac{d\theta}{dt} = \frac{1}{\sin\theta} ,$$

the angular acceleration is

$$\frac{d^2\theta}{dt^2} = -\frac{\cos\theta}{\sin^3\theta} .$$

At $\theta = 0$ degrees, the acceleration is infinite. This corresponds to the cusp of the modified cardioid. Since the follower would have to be physically as small as a point to follow the cam profile into the cusp, and since the angular accelerations are so large in that region (which induces prohibitively large Hertz stresses in the follower and cam), an engineering trade-off is made which allows the follower to start its motion at $\theta = 15$ degrees instead of 0 degrees. Because of the lag angle α, when the cam angle ϕ is 180 degrees, the follower angle is 83 degrees. These are the regions of isotropic operation shown in Figure 4. A graph of angular acceleration of the follower imposed by the cam versus the angular acceleration caused by follower inertia resulting from gravity is shown in Figure 7. Since the inertia accelerations of the follower assembly (follower, cradle, turntable motor, turntable, and emulsion) are greater than the acceleration imparted to the follower by the cam, no springs or other positive contact devices are needed. This lends simplicity to the design, and reduces wear on the cam and follower. The design details for the remainder of the mechanism are probably best indicated by the two engineering drawings, Figures 8 and 9, which give the assembly and detail drawings for the various parts. Not shown are the tabulation of cam angle $(\alpha + \phi)$ versus ρ used for machining the cam profile, the counterweight, and the calculations for dynamically balancing the cam. Figure 10 indicates, however, the different elements of the mechanism including the counterweight, the balanced cam, and the electrical controls.

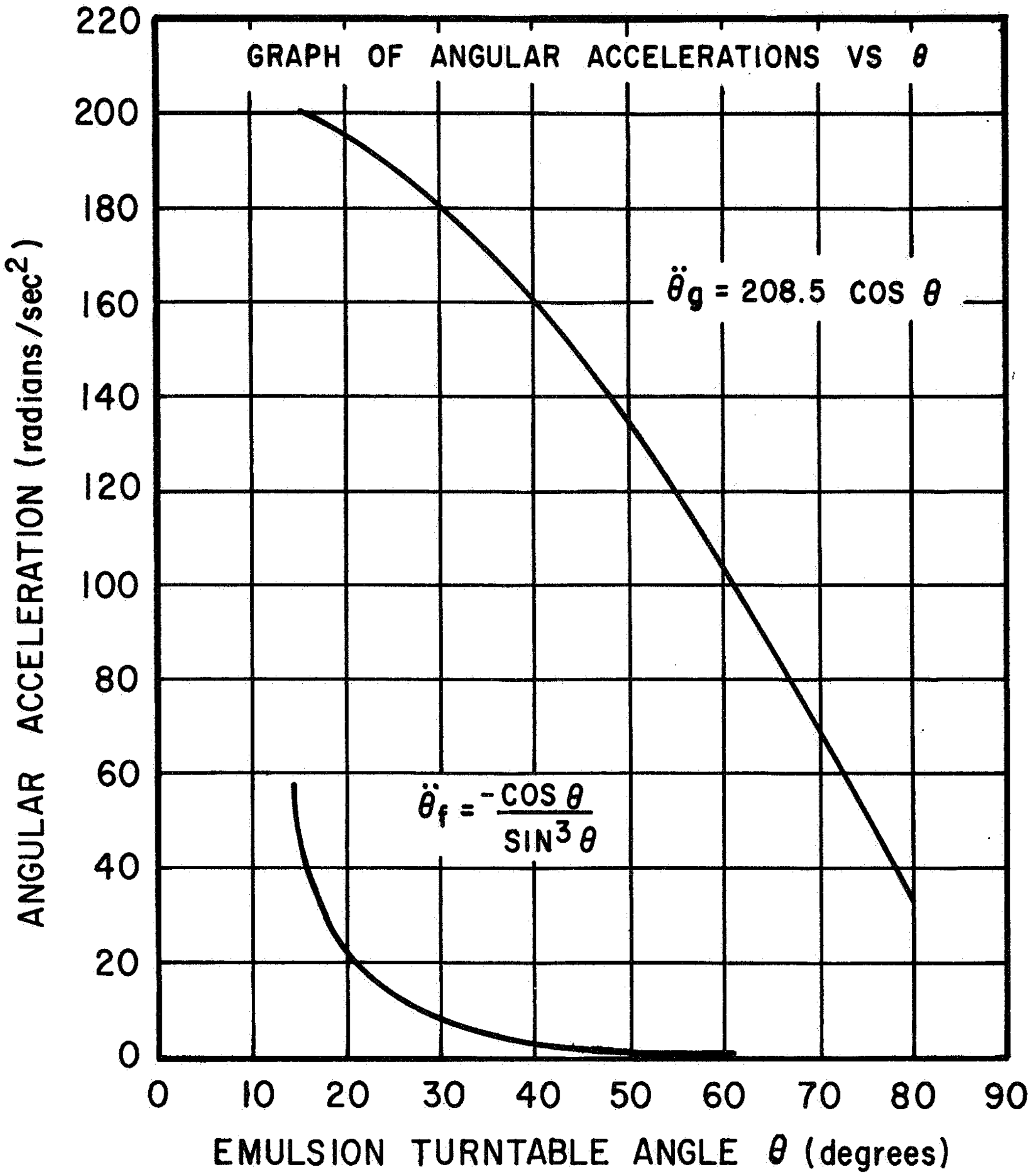
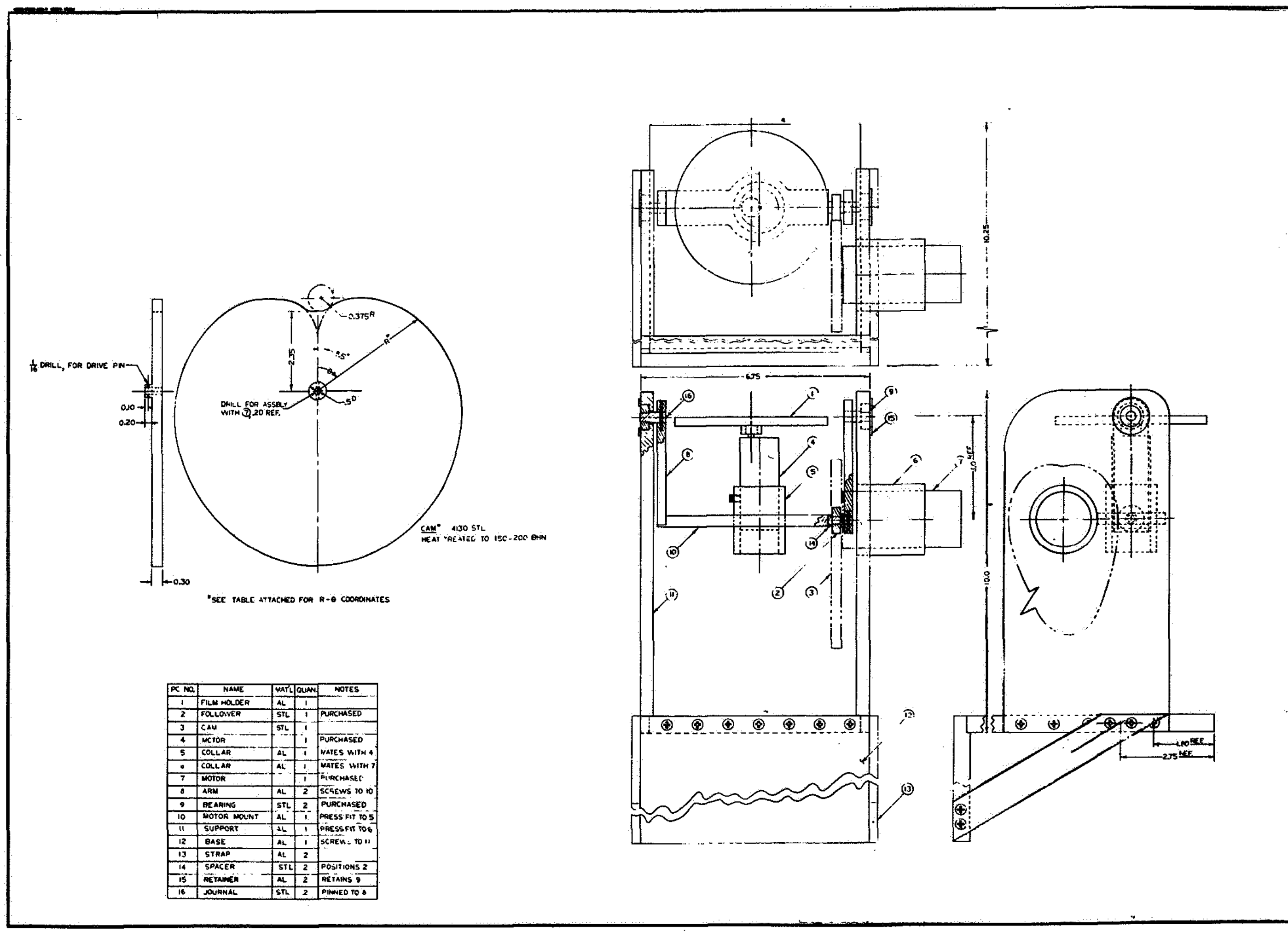


FIGURE 7. ANGULAR ACCELERATION OF FOLLOWER CAUSED BY CAM ($\ddot{\theta}_f$) AND BY INERTIA FORCES RESULTING FROM GRAVITY ($\ddot{\theta}_g$)



PC NO.	NAME	MAT'L	QUAN.	NOTES
1	FILM HOLDER	AL	1	
2	FOLLOWER	STL	1	PURCHASED
3	CAM	STL	1	
4	MOTOR		1	PURCHASED
5	COLLAR	AL	1	MATES WITH 4
6	COLLAR	AL	1	MATES WITH 7
7	MOTOR		1	PURCHASED
8	ARM	AL	2	SCREWS TO 10
9	BEARING	STL	2	PURCHASED
10	MOTOR MOUNT	AL	1	PRESS FIT TO 5
11	SUPPORT	AL	1	PRESS FIT TO 6
12	BASE	AL	1	SCREWS TO 11
13	STRAP	AL	2	
14	SPACER	STL	2	POSITIONS 2
15	RETAINER	AL	2	RETAINS 9
16	JOURNAL	STL	2	PINNED TO 8

FIGURE 8. ASSEMBLY DRAWING OF ISOTROPIC RADIATION SIMULATOR
(dimensions in are in inches)

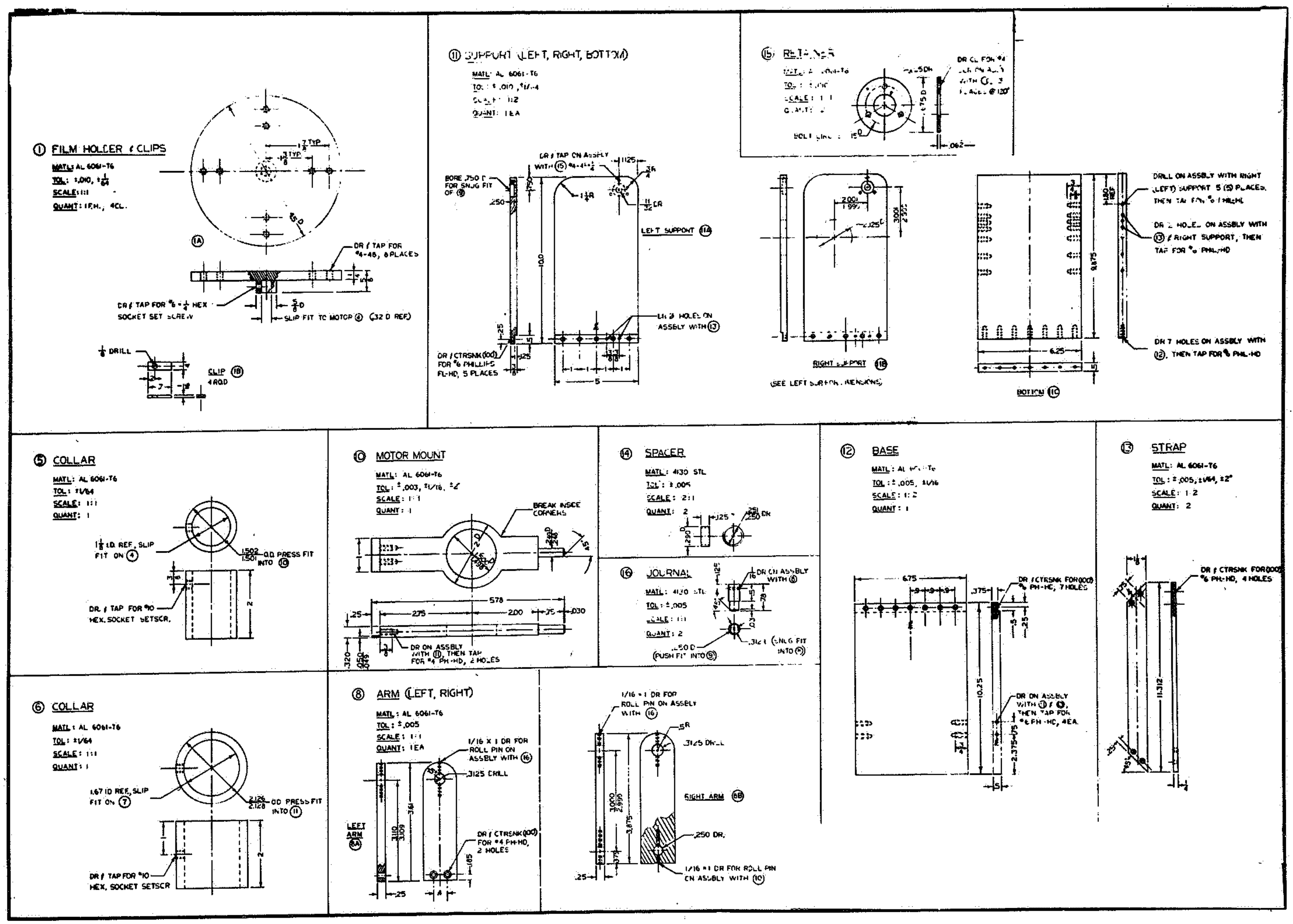


FIGURE 9. DETAIL DESIGN DRAWING OF ISOTROPIC RADIATION SIMULATOR
(dimensions are in inches)

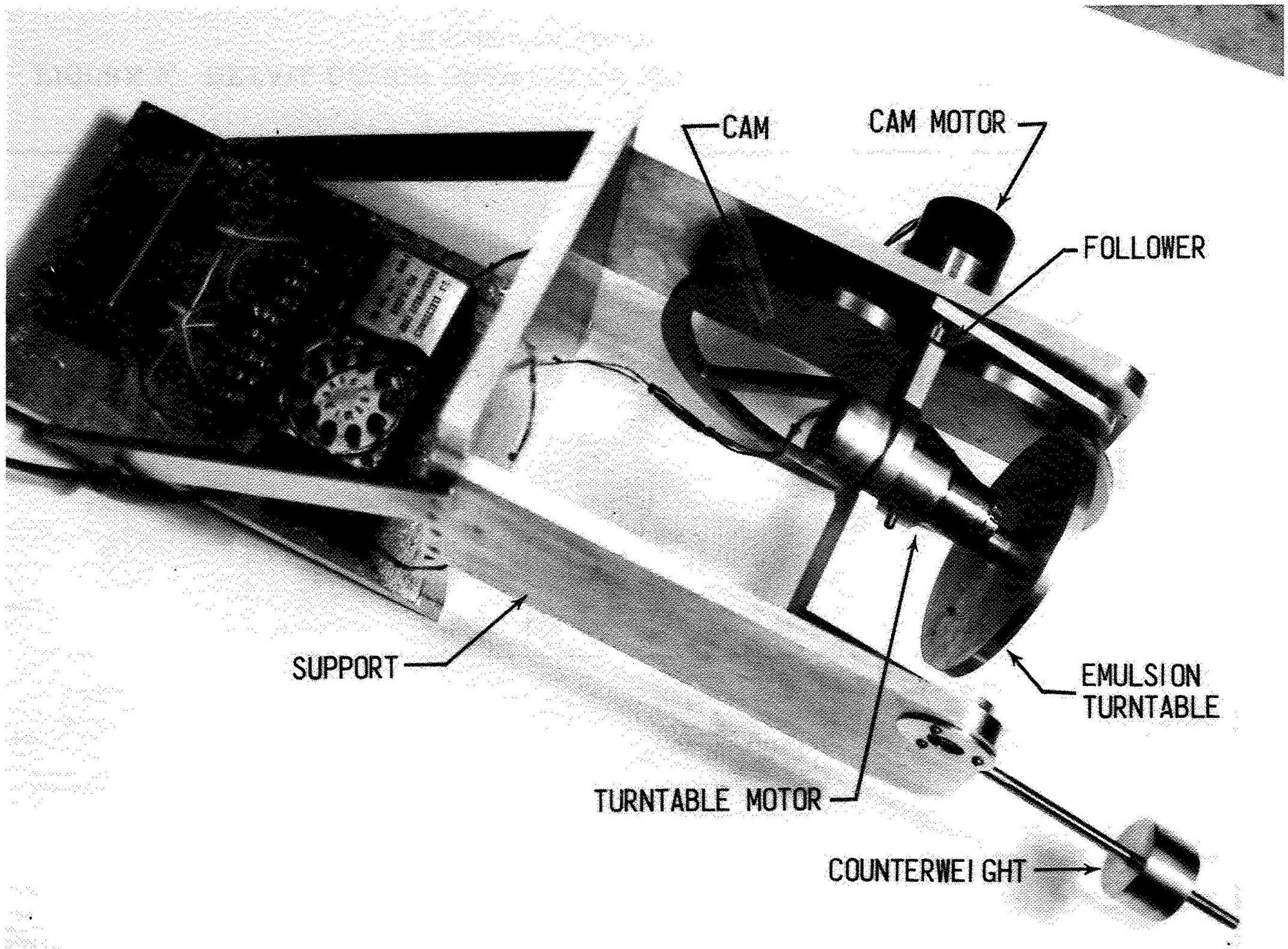


FIGURE 10. OVERHEAD VIEW OF ISOTROPIC RADIATION SIMULATOR
(dimensions are in inches)

CONCLUSIONS

This report outlines the development of a device to simulate isotropic radiation (as one might perceive in space) originally derived from a parallel radiation source provided by high-energy particle accelerators found at laboratories in the United States.

Although the device was designed for laboratory irradiation tests of emulsions to be flown aboard spacecraft, it may be used to test other items such as solar cells, for example, whose performance may also be degenerated by isotropic radiation.

In assembling the Isotropic Radiation Simulator, since the electric motors, circuit elements, bearings, and cam follower were all scrap parts, while the support structure and cam were manufactured from material on hand, the cost of the device was very small.

APPROVAL

TM X-53780

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By Lester Katz

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

for Henry Stern

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