NBSIR 80-2037

Impact on Human Eyes by Propelled Objects

Robert E. Berger
James A. Huckeba

Product Safety Technology Division
Center for Consumer Product Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

May 1980

Report to:

Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, Maryland 20016

NBSIR 80-2037

IMPACT ON HUMAN EYES BY PROPELLED OBJECTS

Robert E. Berger
James A. Huckeba

Product Safety Technology Division
Center for Consumer Product Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

May 1980

Report to:
Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, Maryland 20016

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*
Luther H. Hodges, Jr., *Deputy Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

IMPACT ON HUMAN EYES BY PROPELLED OBJECTS

The identification of injury mechanisms and tolerance criteria for non-penetrating ocular contusions from projectile impact has been of continuing interest in the ophthalmologic community. Several experimental simulations of the injury process have been examined with animal eyes _in vivo_ and _in vitro_[1-3]. Most of this work has been concerned with low mass/high speed projectiles, such as BB's. Recently, however, there has been an increased awareness of the potential for such injuries from larger, slower moving propelled objects as are associated with projectile toys. The U.S. Consumer Product Safety Commission is studying this problem as part of their toy safety program.

In previous work[4], a mathematical model, based on elastic, quasi-static theories of impact, was developed to describe eyeball deformation during impact and to predict the likelihood of injury. Based on this work, a test method was developed to evaluate the injury potential of propelled objects[5]. The validity of the test method is traceable to the mathematical model; that is, for a range of projectiles (whose characteristics represent the range of masses, geometries, and velocities of toy projectiles), the response of the test method correlated well with the predictions of the mathematical model.

The present paper describes high speed motion picture analysis of impacts on enucleated human eyeballs by missiles which are representative of toy projectiles. The purpose of this work was to determine whether measured deformations of enucleated eyeballs correlate with deformations predicted by the math model. Suitable agreement would support the use of the proposed test method for evaluating projectile toys.

High speed motion picture analysis was also used by Delori, Pomerantz, and Cox[3] to observe the deformation of enucleated pigs' eyes when impacted by BB's. They reported that "no attempt was made to normalize intraocular pressures." (The pressure of the pigs' eyes was very low: 15 to 20 scale readings on the Schiotz tonometer; normal is 5 scale readings[3].) This suggested a secondary purpose for the present work, namely, to evaluate the experimental deformation of eyeballs at normal intraocular pressure.

Materials and Methods

Eyeballs and Molds

Enucleated human eyeballs (not usable for transplants) were contributed by a local eyebank. The eyeballs were tested within 24 hours of death, having been kept refrigerated from the time of enucleation until shortly before testing.

Each eyeball was mounted in a separate gelatin mold as described by Delori et. al.[3]. The container was made with flat glass plates and had dimensions of 5x5x8 cm. The procedure for mounting the eyeballs differed

from that employed in the aforementioned study. First, the container was filled with a liquid 10% gelatin mixture which was allowed to gel. Next, a cone-shaped crater was cut into the exposed surface of the gelatin, and the eyeball was positioned in the crater (see sketch in figure 1). Lastly, liquid gelatin was added to the container to fill the rest of the crater and to adjust the gelatin level relative to the eye. Because the new gelatin was constrained to a thin layer in immediate contact with the already cooled and previously set gelatin in the container, the newly added mixture gelled within about ten minutes. The boundary between the new and old gelatin was visibly indistinguishable. Impact experiments began immediately after the new gelatin had set.

Before mounting, the intraocular pressures of the enucleated eyeballs were negligible compared to normal (15-20 scale readings on Schiotz tonometer; normal is 3-5 scale readings, about 17-24 mm Hg). The pressure of the eyeballs could be increased by injecting water through the optic nerve. However, in preliminary impact experiments, the pressure was observed to have decreased after every impact.

In order to obtain multiple impact data with each eyeball, a method was devised to adjust the intraocular pressure prior to each impact. A small needle was inserted through the optic nerve stub and secured in place by suturing the stub around the needle. Thin flexible tubing, attached to the needle, ran through the gelatin and back out the exposed surface to a syringe filled with water. (During the eyeball mounting process, a narrow trench was cut into the set gelatin to accommodate the needle and tubing.) Liquid could thus be added to the eye prior to each impact to readjust the intraocular pressure. The pressures were adjusted so that the tonometer would register in the normal range. After impact, pressures dropped to 6-10 scale readings.

Projectiles

To maintain accurate impacts, a system was designed[5] in which a cylindrical nylon guide travels in a linear ball bushing on a projectile launcher (described below). The leading edge of the guide was drilled and tapped to accommodate a set of hemispherical caps (see figure 2). For this experiment, two caps, with radii 0.635 and 1.27 cm, were used. To increase the mass of the projectiles, brass weights could be inserted between the guide and the caps.

The projectile launcher is shown in figure 3. A plunger rides in an aluminum support tube and is attached to a spring which may be compressed to three alternate stop positions. When released from the stop, the spring uncoils and causes the plunger to impact the nylon guide end of the projectile. The nylon guide then advances in a linear ball bushing mounted within the aluminum support tube and remains in the bearing during impact.

The velocity of the projectile is measured by a meter which records the time interval required for edges A and B of the guide tube (figure 2) to interrupt a light beam. A window in the aluminum support tube allows

the beam to penetrate the window in the projectile guide tube. The velocities achieved by the projectiles depend on the stop position to which the spring is compressed and the mass of the projectile. Velocities can be further varied by adjusting the tension on the spring with the screw at the rear of the aluminum support tube.

In this experiment, the masses of the projectiles varied between 1.5 and 8 g; the velocities varied between 2.5 and 15 m/sec. It was felt that the range of parameters observed on toys[4] would be well represented by the experimental range of tip geometries, masses, and velocities.

Cinematography

Motion pictures at 8,000 frames per second recorded each impact event. The firing of the projectiles was synchronized to insure that the film in the camera was moving full speed at the time of impact. Enlargements of the motion pictures were analyzed frame by frame, carefully measuring the deformations of the eyeball, especially the displacement of the projectile toward the eyeball. (This displacement is thus the decrease in the anterior-posterior diameter of the eyeball.)

Results

For eyeballs with normal intraocular pressure, the observed deformations were restricted to the region of the eyeball immediately surrounding the tip of the projectile. A typical example is shown in figure 4, where the eyeball is seen both before impact and at the moment of maximum projectile displacement. The increase in the diameter at the equator is on the order of 1 to 2%. In preliminary experiments with unpressurized eyeballs, equatorial expansions on the order of 10 to 12% were observed.

The displacement of an eyeball at normal pressure is shown as a function of time in figure 5. The characteristics of the projectiles which impacted the eyeball are also shown. In general, the displacement, y, increases with the projectile kinetic energy, T_o, and the duration of impact, Δt, increases as the velocity, V, decreases. These general trends were predicted by the elastic, quasi-static mathematical model discussed earlier[4], i.e.,

$$y \propto \frac{T_o^{2/5}}{D^{1/5}} \quad , \quad \Delta t \propto \frac{y}{v}$$

D is a geometric parameter defined by

$$D = \frac{D_1 D_2}{D_1 + D_2}$$

where D_1 and D_2 are the diameters of the projectile and eyeball, respectively. The coefficients of proportionality depend upon the material properties of the eye and projectile.

In figure 6, the measured maximum projectile displacements are plotted as a function of $T_o^{2/5}/D^{1/5}$ for the impacts on three normally pressurized enucleated human eyeballs (each represented by a different symbol). To vary the value of $T_o^{2/5}/D^{1/5}$, projectile configurations were changed for each impact. For each eyeball a straight line was fit to the data by the method of least squares. A reasonable correlation exists between the predictions of the mathematical model and the results of the experiment. The figure also suggests that non-negligible differences exist in impact response for different donors. For fixed projectile characteristics (fixed value of $T_o^{2/5}/D^{1/5}$), differences on the order of 1 mm exist in the maximum displacement.

Discussion

Large gross deformations in unpressurized pigs' eyes were also observed in the earlier study of Delori et al[3] (the projectile of that study was quite different: BB (.345 g) travelling at 62 m/sec). These authors (and others) have propounded a mechanism of contusive injury: namely, the stretching of the anterior sclera perpendicular to the impact direction (sometimes referred to as "eyeball expansion"); in combination with the posterior displacement of the lens, this expansion causes high stresses in the chamber angle region and the vitreous base. Although the gross expansion is not nearly so exaggerated when the eyeball is at normal pressures, there is no evidence to suggest that the proposed mechanism of contusive injury needs to be modified. It appears as though the eyeball expansion in pressurized eyes may only be significant in the immediate vicinity of the corneo-scleral junction.

The elastic model[4] is, of course, a gross simplification of the impact behavior of a system as complex as an eye. As explained in the earlier report, its purpose is to suggest the relative importance of projectile characteristics (mass, velocity, geometry) to the likelihood of eye injury. As seen in figure 6, the measured displacements of the anterior surface of the eye are related to a parameter which characterizes the projectile. This is not to suggest that the elastic model is appropriate (actually, the model is being asked to represent data in a range where deformations are finite - the ratio of displacement to the length of the anterior/posterior axis approaches 1/3); rather, that the model is able to represent some gross aspects of eyeball deformation.

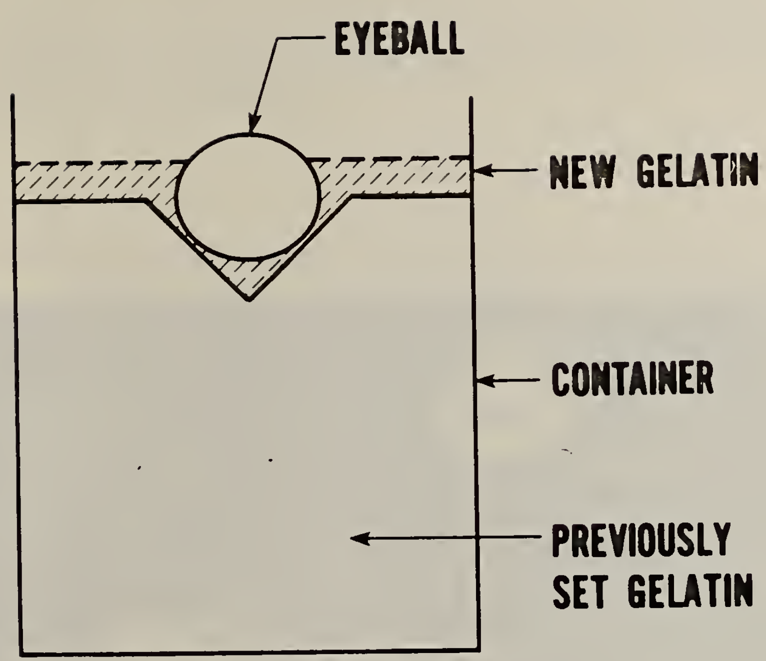

FIGURE 1. Sketch illustrating procedure used to mount eyeballs in gelatin molds.

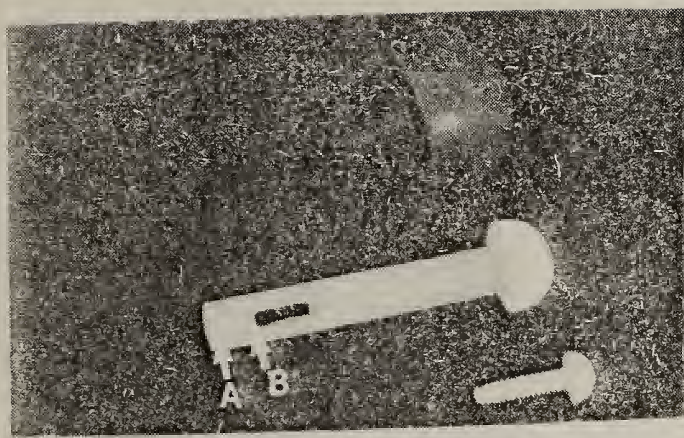

FIGURE 2. Projectile guide tube with hemispherical caps. Distance AB used in velocity measurements.

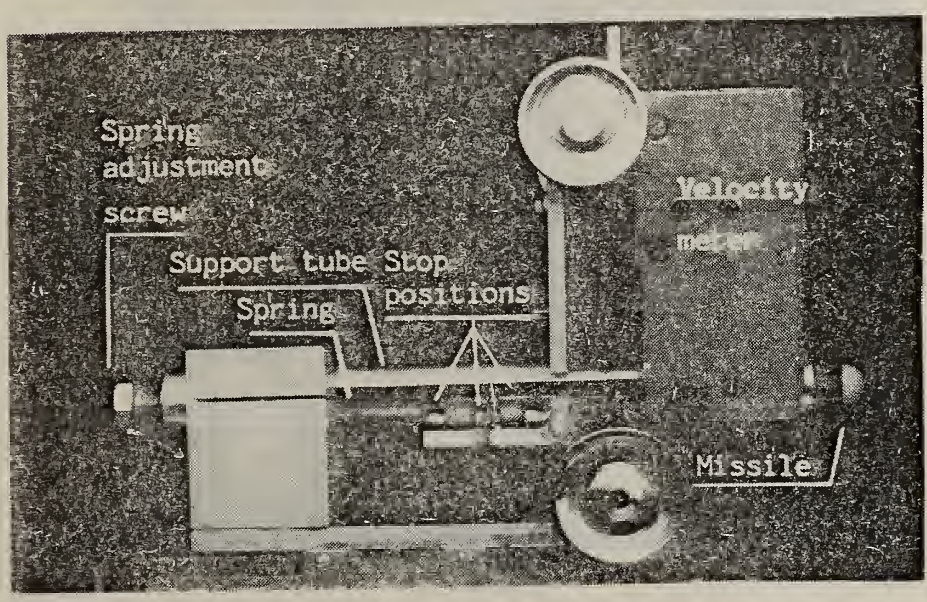

FIGURE 3. Projectile launching system.

Figure 4a.

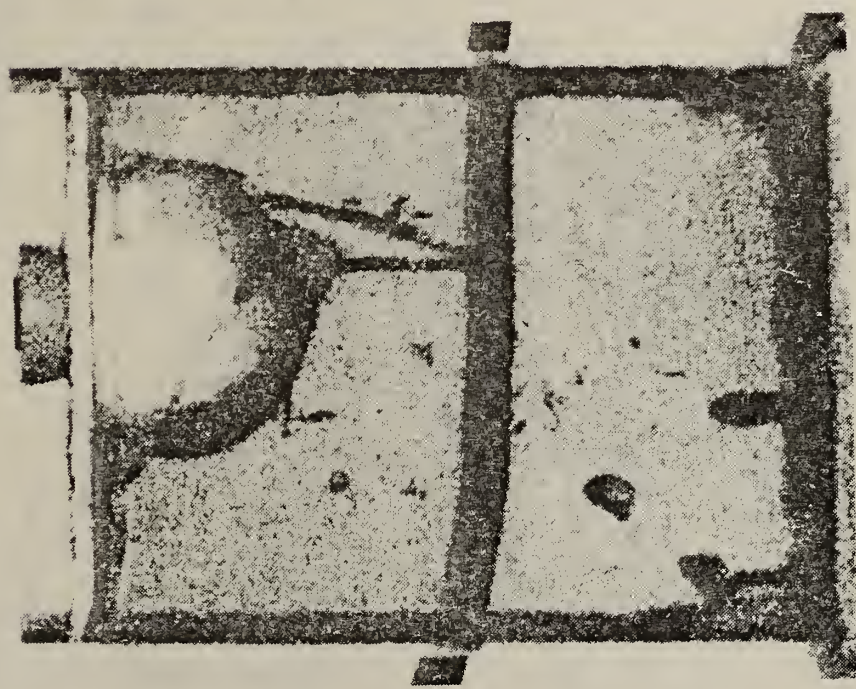

Figure 4b.

FIGURE 4. Example of eyeball deformation (a) before impact, (b) at moment of maximum projectile displacement (shadow in (b) is wire used in velocity measurement).

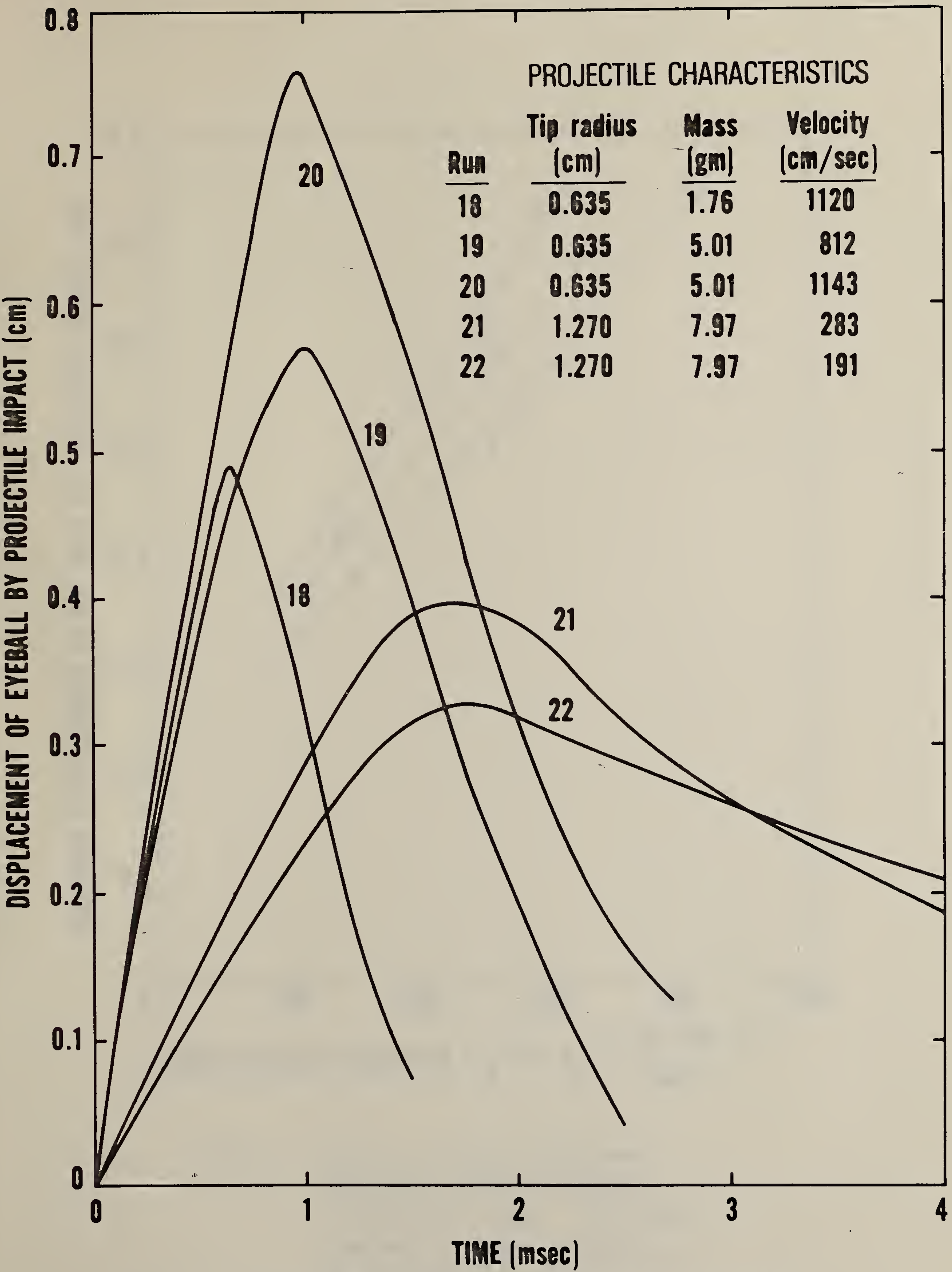

FIGURE 5. Projectile displacement versus time for the impacts of several projectiles against the same eyeball.

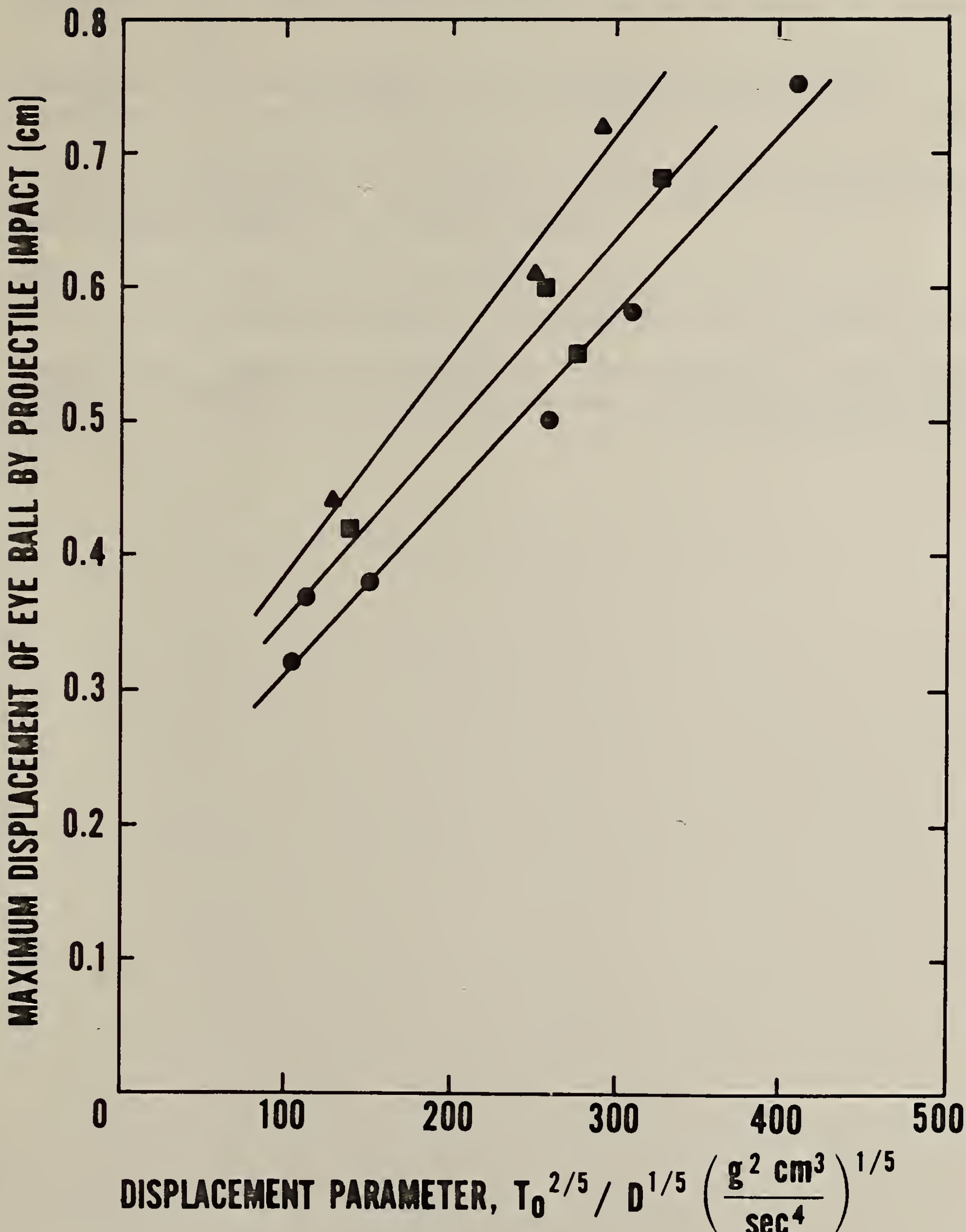

FIGURE 6. Maximum projectile displacement versus displacement parameter, $T_0^{2/5}/D^{1/5}$, which was predicted by mathematical model. Each symbol represents a different eyeball. The straight lines were fit to the data for each eyeball.

References

1. WEIDENTHAL, D.T.. Experimental Ocular Contusion, Archives of Ophthal., 71, 77-81 (1964).

2. WEIDENTHAL, D.T. and SCHEPENS, C.L., Peripheral Fundus Changes Associated with Ocular Contusion, Am. J. Ophthal. 62, 465-477 (1966).

3. DELORI, F., POMERANTZ, O., and COX, M.S., Deformation of the Globe Under High Speed Impact: Its Relation to Contusion Injuries, Investigative Ophthal., 8, 290-301 (1969).

4. BERGER, R.E., A Model for Evaluating the Ocular Contusion Injury Potential of Propelled Objects, J. Bioengineering, 2, 345-358 (1978).

5. BERGER, R.E., System for Assessing Eye Injury Potential of Propelled Objects, J. Research of the National Bureau of Standards, 84 (1), 9-19 (1979).

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO.	2. Gov't. Accession No.	3. Recipient's Accession No.
NBSIR80-2037		

4. TITLE AND SUBTITLE

Impact on Human Eyes by Propelled Objects

5. Publication Date

MAY 1980

6. Performing Organization Code

7. AUTHOR(S)

Robert E. Berger, James A. Huckeba

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

National Bureau of Standards
Department of Commerce
Washington, D.C. 20234

13. Type of Report & Period Covered

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

High speed motion pictures were employed to observe experimental impacts on enucleated human eyeballs by low speed missiles which are representative of toy projectiles. A procedure was devised to adjust the intraocular pressure prior to each impact. For similar impact conditions, the gross deformation of eyeballs with normal pressure was not as severe as had been previously reported for eyeballs with near zero pressure. The maximum displacement was measured for several eyeballs with normal pressure. These displacements were shown to correlate with the predictions of a mathematical model which had been used to develop a test method for toy projectiles.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Contusion; eyeball deformation; impact; ocular injury; projectiles; safety

18. AVAILABILITY [XX] Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	13
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$5.00

USCOMM-DC