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PROGRESS REPORT

ANALYSIS OF FIREBALL GROWTH AT SANDSTONE

By

R. C. Orphan
W. B. Murray
R. A. Houghton

J-7 Photographic Analysis Sub-Group

~~Weapons Data~~

[redacted]

ABSTRACT

A card catalog file of useful information on the X-ray, Yoke and Zebra films was set up after a preliminary scanning of each film. Following this, measurements of fireball diameter vs. time in the region before the light minimum were started. The results of these fireball measurements are summarized in graphs at the end of this report. In general, it was found that in the region where the fireball diameter and the shock front coincide the fireball diameter increases in proportion to

$$D \sim (a + t)^{0.374 \pm .005} \qquad (1)$$

where t is in milliseconds and the diameter is in meters, and a is an apparent displacement in the time variable. Relative yields for the three Sandstone bombs were determined and the results compared with Radio-chemistry data. It can be said that the comparison by two separate methods was good. The Yoke shot relative to X-ray varied from the radiochemistry results by 6 per cent. The Zebra shot relative to X-ray differed from radiochemistry results by less than 2 per cent.

FILM CATALOG

All available Sandstone films showing fireball growth were scanned and a card filing system set up in which data such as tower position, film speed, focal length and film quality were noted. Special features such as presence of spikes, blisters, dust skirt, timing pips and the light minimum were also mentioned on each film's card. This catalog proved useful during later measurements and more data was added to each card as it became available. Seventy-nine films were reviewed.

FIREBALL MEASUREMENTS

Before the actual measurements were begun, several possible methods of scaling were investigated. A series of concentric circles was inscribed accurately on a block of Aluminum, then photographed and reduced and the negative used as a rule to measure the fireball along several diameters. The photographing of a 1/64" ruler was also tried. The use of millimeter lined graph paper was also tried. A combination of all 3 methods was finally used; the particular choice depended on the fireball size and intensity for a particular frame. Since our measurements resulted in a ratio of fireball size to film width for each frame, the changing of measurement methods was permissible as long as we were consistent within each frame.

The fireball diameters were measured within 0.1 mm. Four

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readings of fireball diameter for each frame and two readings of film width were made. Averages were computed and the results substituted in the following formula to obtain fireball diameter in meters:

$$DFB = 4.877 \left[\frac{D}{W} \times \frac{FD\ (feet)}{FL\ (mm)} \right] \qquad (2)$$

where,

DFB = diameter of fireball in meters

W = film width in arbitrary units as read on the Recordak

D = fireball image diameter in same unit as W as read on the Recordak

FD = object distance; distance from zero point to camera tower in feet

FL = focal length of camera lens used

Errors in the object distance and the focal length are negligible as compared with other errors if the figures in the Davis report[1] are correct. Errors in the fireball diameter are well within 1 per cent after corrections for blisters are applied.

DETERMINATION OF THE TIME VARIABLE

The determination of the time variable involved two steps:

First, the time between frames was obtained from the 1 millisecond timing pips on most of the films. Many of the films

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1 ANNEX 7, Part I of Scientific Director's Report (Section 2)

did not have timing pips; and so could not be used in these determinations. A plot of time vs. frame number gave a very accurate value for this measurement. Although the Fastax cameras accelerate during their run, this did not have any appreciable effect in the time interval investigated.

Second, the zero point of time was determined to within 0.01 millisecond in most of the films. The linear plot of time vs. frame number mentioned above could be used to determine the zero point of time to within one frame which is a considerable error.

However, using the arbitrary time scale obtained thereby, a linear plot could be made of fireball diameter vs. time. As this curve is the same for a particular explosion and passes through the origin, those films which had measurements below 1 millisecond could be corrected to within 0.01 millisecond. Those films whose initial frames were fogged could not be corrected in this manner. A table of the films read, the film speed, and the error in the zero point of time is given in the following table:

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Film Number	Film Speed frames/sec	Error in Zero Point of Time millisec.
Z1F1	9580	0.01
Z1F2	9500	0.01
Z1F3	9260	0.01
Z1F6	7715	0.01
Z1F7	6871	0.01
Z1F8	7218	0.01
Z1F10	487	1.03
Z1F11	564	0.89
Z4F2	7500	0.01
Z4F7	6333	0.01
Z4F8	7714	0.01
Y1F1	10580	0.01
Y1F3	8940	0.01
Y1F6	7420	0.01
Y1F8	6900	0.07
Y1F9	6130	0.01
Y1F10	360	1.36
Y1F11	450	1.11
Y3F1	9600	0.01
Y3F2	9310	0.01
Y3F7	7550	0.01
Y3F8	8000	0.01
X1F1	8000	0.01
X1F2	1680	0.30
X1F3	7340	0.07
X1F5	5940	0.08
X1F6	5000	0.10
X1F8	4930	0.10
X1F10	620	0.81
X2F1	6020	0.01
X2F2	5166	0.01
X2F4	4780	0.10
X2F8	4000	0.13

From this table, it can be seen that the slower running films introduce so large an error in the zero point of time as to prohibit their use.

DIAMETER OF FIREBALL VS. TIME CURVES

The growth of the fireball diameter with time for the various bombs is shown on Figures 1, 2 and 3. All of the experimental points measured are included on the graph and the best curve considering all of these points has been drawn through them. It should be remarked here that when points of single films were plotted an excellent straight line graph was obtained with practically no spread of points. However, when a composite graph of all of the films taken of a single shot was made a spread of points such as is seen Figures 1, 2 and 3 resulted and the choice of the best straight line was not nearly as easy as in the case of the single film graphs.

In the region above 1.5 ms. and before the light minimum (where the shock front and the fireball diameters are coincident) these D vs. t graphs all follow closely a curve of the form $D = C(a \pm t)^k$ where C, a and k are constants. J. E. Mack in LA-531 has plotted a similar curve for the Trinity Bomb. Table I summarizes and compares his results and the Sandstone results as regards these three constants. It is to be noted that the three Sandstone bombs all agree within the experimental error for the constant k; their value being nearly 0.374. However, the Trinity value for k has been computed to be 0.404 ± 0.008. This variance in the value of k between the Sandstone shots and the Trinity shot may well be due to the difference in the region over which the measurements were taken. The Trinity measurements were taken as far out as 0.400 seconds in a region well beyond the light minimum. So far we have not been able to get measurements beyond 30 milliseconds for the Sandstone films. Further, the experimental points of the Trinity curve seem to be generally low in the region before the light minimum, for a k = 0.404. This would indicate that, if the Sandstone films could be measured as far out as the Trinity films were, the value of k might approximate 0.4, in agreement with theory. Below the time value of 1.5 milliseconds there is a considerable dropping off of the curves resulting from smaller diameter values. It is presumed that this deviation is due to the fact that for very small diameters and times the effect of bomb material on the fireball growth is appreciable.

The apparent displacement in the time variable, which is indicated by the constant a, has the effect of producing a slight curvature in the D vs t plot.

RELATIVE YIELDS

The above data was used to determine the relative yields of the Sandstone bombs. Two methods were used. The first compares the yields as a function of the diameter to the 5th power. The second method involves a plot of t/D vs D (Figure 4) and here the yields are compared as a function of D^3 at a constant t/D. Of course, the second method is the more accurate since D^3 instead of D^5 is involved.

Table II summarizes the results of these two methods as well as comparing them with the Radio-chemistry data for the same bomb models. There is some discrepancy (6 per cent) between Radio-chemistry and fireball growth methods for the Yoke shot when their yields are compared in this way. Zebra compares very favorably and X-ray was used as the basis of comparison.

LA notebook #2704 contains the complete data taken thus far in the analysis for all films measured. This book, together with the card index file previously mentioned, constitutes the source of information for the Sandstone results discussed in this report.

PROVISIONAL SCHEDULE OF FILM INTERPRETATION WORK

1. Measurements of shock wave intersection with water from Bikini Able films.
2. Investigation of the position and growth of spikes on Sandstone Films.
3. Investigation of shock front in and beyond the light minimum. Preliminary work indicates that the shock front

cannot be followed, but positive prints may show up this part of the phenomena.

4. Measurement of the ball of fire in the region beyond the light minimum.
5. Investigation of the cloud chamber effect.
6. Investigation of the early stages (<1ms) to determine groundstrike and whether the fireball bounces up above the original position of the bomb.
7. Investigation of the later stages including Mach front, dust skirt, curtain and measurements on the cloud.
8. Further investigation of the blisters found on the fireball as to their size, position, possible cause, etc.

TABLE I

Explosion	Constant of Proportionality C	Apparent shift in time constant a	Exponential Constant K
Trinity *	70.4	4×10^{-4}	.404 ± .008
X-ray	81.2	$.7 \times 10^{-4}$	.375 ± .005
Yoke	84.2	1×10^{-4}	.373 ± .005
Zebra	69.8	1.4×10^{-4}	.374 ± .005

* LA-531

TABLE II

Relative Yields (Sandstone Bombs)

	Radio-Chemistry Results	Fireball $(R/R)^5$	% Error from R.C.	Fireball $(R/R)^3$	% Error from R.C.
X-ray	1	1	-	1	-
Yoke	1.32	1.25	5.4	1.24	6.0
Zebra	.50	.49	2.0	.50	0.0

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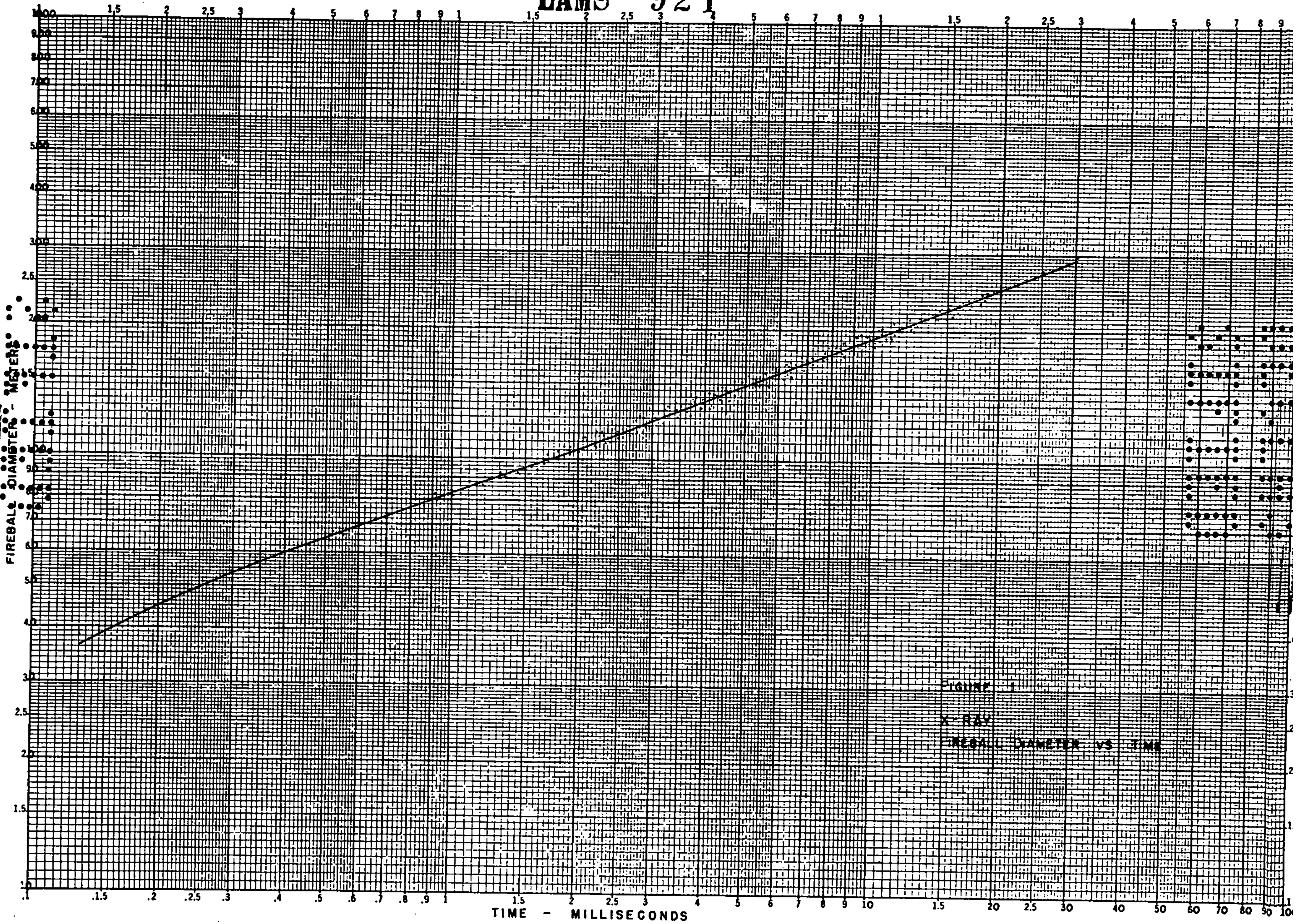

FIGURE 1
X-RAY
FIREBALL DIAMETER VS TIME

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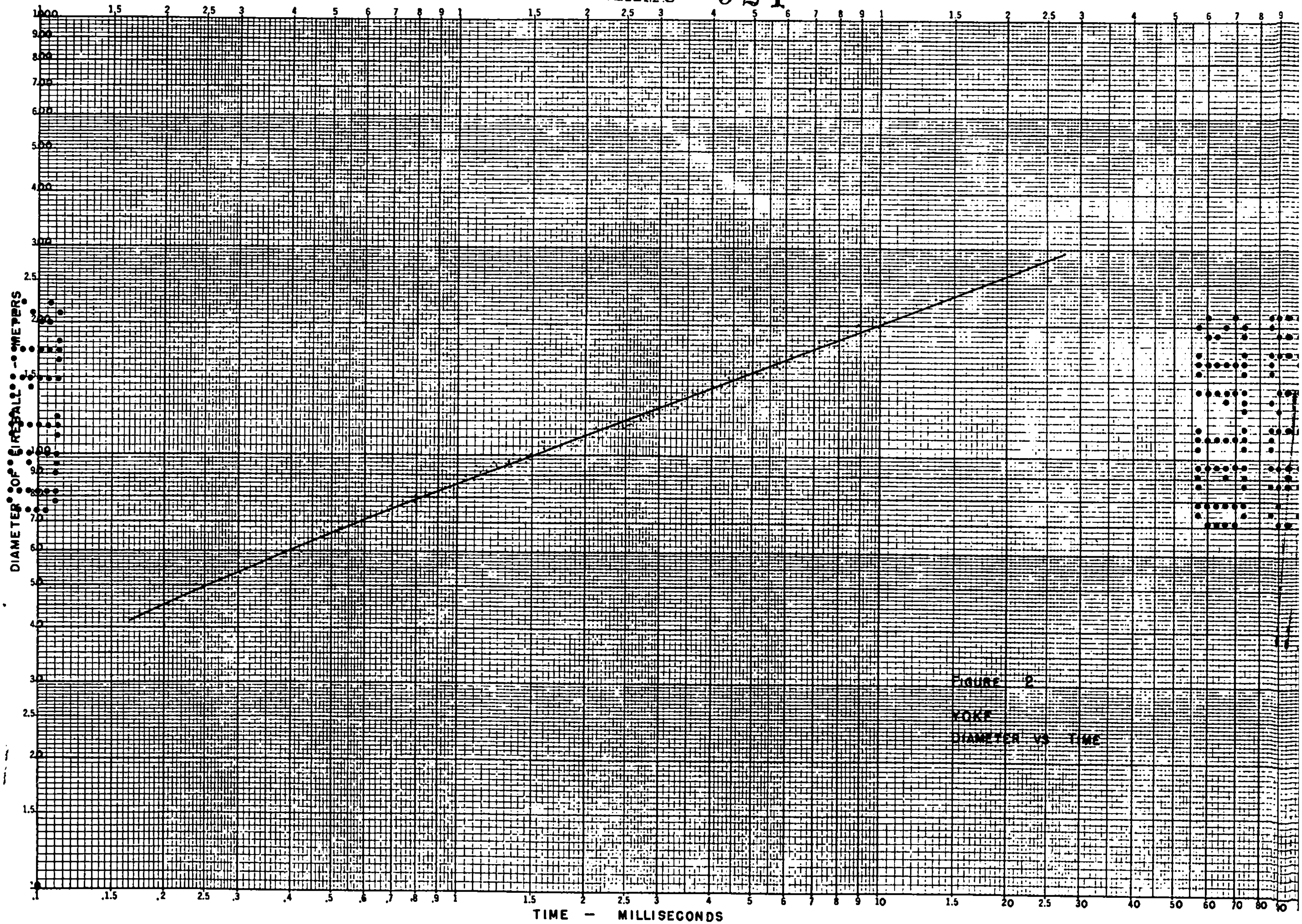

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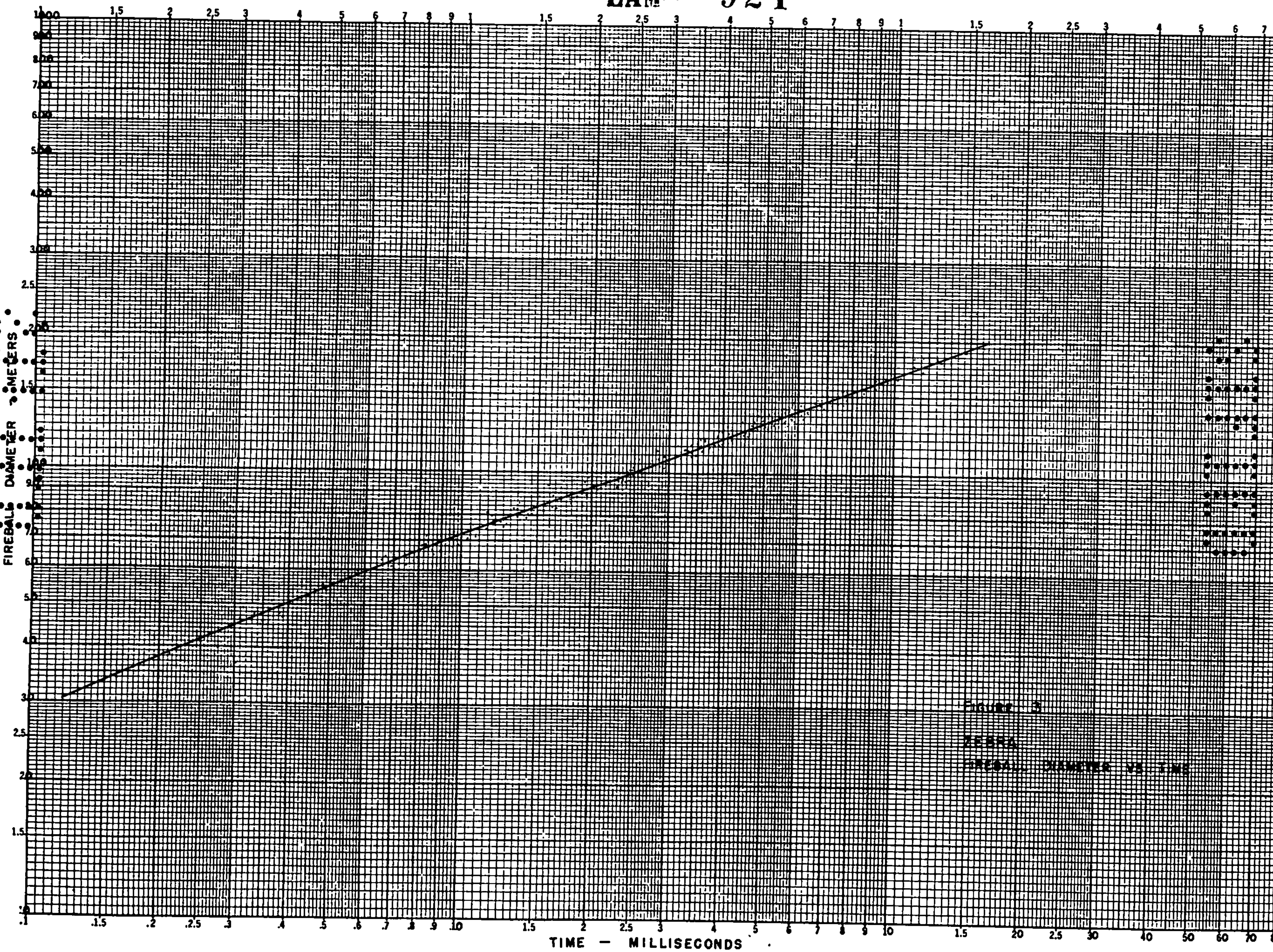

FIGURE 3
ZEBRA
FIREBALL DIAMETER VS TIME

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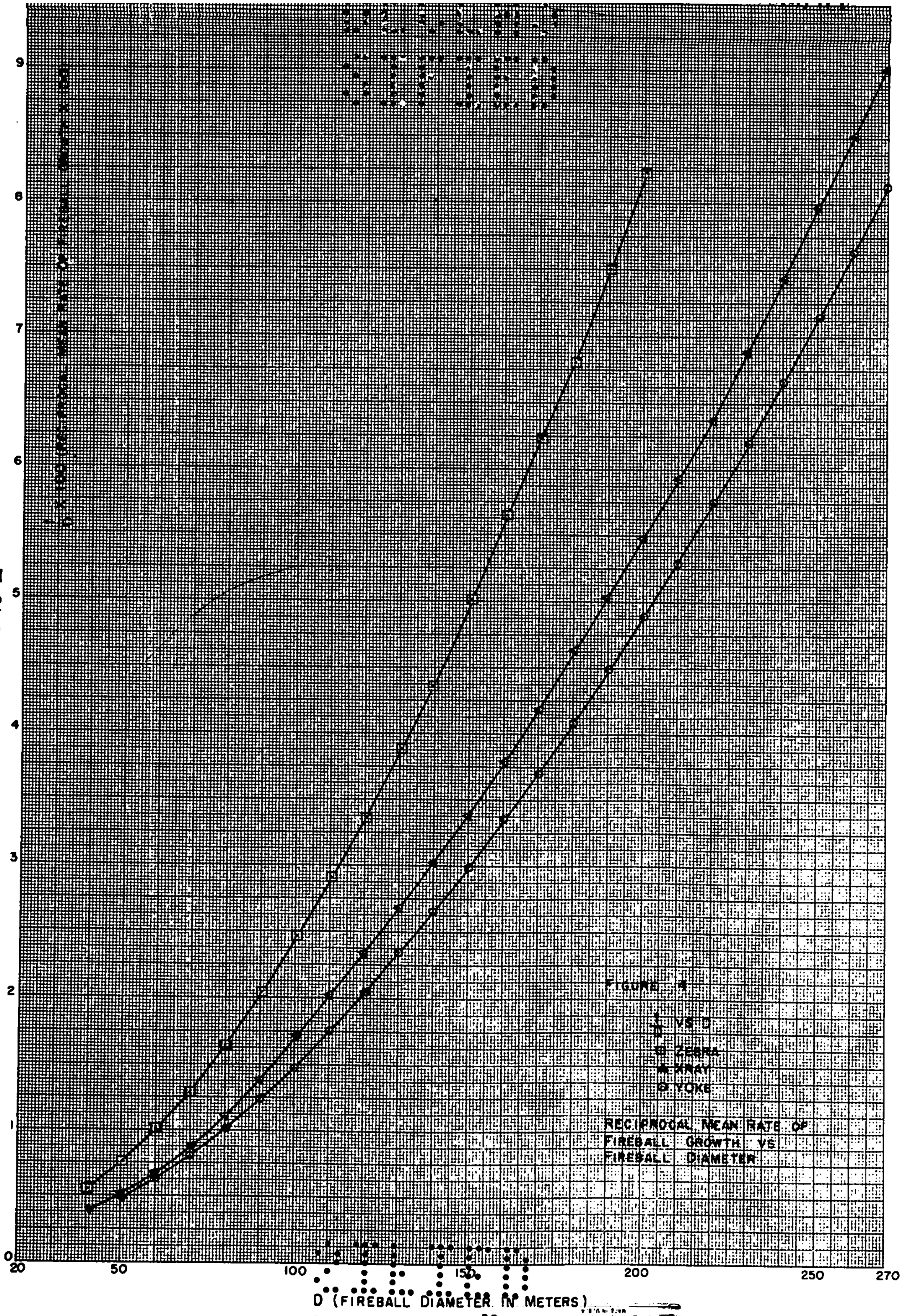
0
1
2
3
4
5
6
7
8
9
20
50
100
150
200
250
270
D (FIREBALL DIAMETER IN METERS)
FIGURE 4
VS D
ZEBRA
XRAY
YOKE
RECIPROCAL MEAN RATE OF
FIREBALL GROWTH VS
FIREBALL DIAMETER

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