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Blood Splatter 2

FINAL REPORT

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SUMMARY

This work is a continuation of that described in the DM&A report 94/5. The objective of the project is to identify the important parameters which govern the production of blood droplets when a mass is impacted on to a pool of blood. The specific objective of the work described in this report was to develop an experimental system capable of photographing blood droplets in flight so as to permit the accurate determination of their sizes and velocities.

A photographic system using a pulsed ruby laser and double or triple exposure shadow photography was developed. This system provided photographs that allowed the measurement of the velocity, size and flight angle of individual droplets. Six experiments were performed. Two experiments involved the use of a blood substitute and four used lamb's blood. The blood substitute was made from 2/3 saline and 1/3 glycerine. All experiments used a falling weight with an impact velocity of of about 5.5 m/s and an area of contact of about 8 cm^2 to generate the droplets. The maximum droplet velocity measured was 21.6 m/s and the average diameter of the droplets was determined to be 0.74 mm for the lamb's blood and 0.67 mm for the blood substitute. One experiment involved a triple exposure and was done to see if any deceleration of the droplets could be measured. The results show that the decrease in velocity over the short time between pulses could not be measured.

The photographic system developed has been shown to measure the droplet properties in flight and can now be used to study in more detail some of the parameters which govern the number, size and velocity of droplets, such as impact area, impact velocity and blood pool size.

1 OBJECTIVE

The objective of this project was to develop a photographic system capable of recording the flight of blood droplets caused by the impact of a blunt object on to a pool of blood, and subsequently be able to accurately determine the size and velocity distributions of these droplets.

2 THE EXPERIMENTAL SETUP

To create the impacts, a steel 1207 g cylinder was dropped from a height of 2.02 m through a vertical aluminum tube. The tube had longitudinal slots milled along the sides to allow the air in front of the falling weight to escape and not influence the blood pool situated in the impact area. The diameter of the cylinder was 41.2 mm and the length was 117.5 mm. The impact end of the cylinder was beveled so that the actual impacting diameter was 32.0 mm, to give an impact area of 8.0 cm^2. The cylinder impacted a pool of either a blood substitute (2/3 saline and 1/3 glycerine) or lamb's blood with an anticoagulent. Either 5 ml or 2.5 ml of liquid was used.

A rectangular plexiglass container with a vertical 17 mm wide slot was placed around the impact area so as to allow only a vertical plane of droplets to escape. The speed of the falling cylinder was determined by two reflecting sensor photodiode arrays separated by 10.0 cm. These photodiodes were used to start and stop a timer, and to initiate the laser light source via the appropriate delay so that the droplets would be captured in flight. The cylinder was attched to a light string which supported it before the initiation of the experiment. The string passed through a pulley above the tube and then to a retaining pin. To start the experiment the pin was removed which allowed the weight to fall freely. The falling cylinder triggered both diodes as it passed them, and the resulting signals were used to measure the speed of the cylinder, and to prepare the laser for firing. The cylinder impacted on to a steel disc with a slight indentation to hold the liquid pool. Figure 1 shows a scale drawing of the dropping mechanism.

The light source used for the photography was a Q-switched ruby laser which consisted of a Xenon flash tube coiled around a ruby crystal. A large bank of capacitors was discharged through the Xenon coil to energize the ruby rod. The laser pulses were generated by a Q-switching Pockels cell. This produced individual pulses each with a duration of approximately 100 ns and an output power of about 100 MW. The pulses could occur only during the time that the flash tube was on, which was about 1 ms. Double or triple pulses were used for these experiments with an interval between pulses of about 402 μs. This produced a double or triple image of the individual droplets in the plane of the slot in the plastic container which was perpendicular to the parallel beam of light from the laser.

A plan view of the optical system is show in figure 2. The narrow coherent beam from the laser was reflected by a plane mirror through a diverging lens. This produced a virtual point source which was placed at the principal focus of a parabolic mirror. The resulting parallel beam of light was approximately 25 cm in diameter and perpendicular to the plane of the droplets. After traversing the plane of the droplets the light impinged on, and exposed, a 25 cm $\times$ 10 cm sheet of Ilford FP4 black and white film which was exactly parallel to the plane of the droplets and perpendicular to the expanded beam from the laser. This shadowgraph system produced high resolution images of the droplets at a scale of one to one. The system was calibrated by making images of suspended spheres of known diameter.

The sizes of the droplets and their displacements between the double or triple pulses were measured directly from the recording films using an x-y digitizer. From these measurements the velocities of the droplets were calculated.

3 THE EXPERIMENTS

Six experiments were performed, two used a blood substitute and four used lamb's blood. The blood substitute was a mixture of 2/3 saline and 1/3 glycerine which is the correct mixture to match the viscosity of blood at 37° C. About 100 cc of lamb's blood was obtained from a freshly slaughtered animal and immediately mixed with about 0.5 cc of Hepalean, an anticoagulant. The conditions for each experiment are given in table 1.

Table 1: Event Description

Expt #	Substance	Pool Size (ml)	Impact Vel. (m/s)	Delay (μs)	Pulse interval (μs)
970303b	blood subs.	5	5.59	27.6	402
970303b	blood subs.	5	5.56	27.6	402
970310a	lamb's blood	5	5.54	27.6	402
970310b	lamb's blood	5	5.51	23.9	402
970310c	lamb's blood	5	5.47	23.9	402†
970310d	lamb's blood	2.5	5.52	23.9	402

† triple exposure

For all the experiments the impact speeds were about the same and in one case the pool size was reduced by half. The blood was placed, using a syringe, onto the impact disc which was heated in a bath of water to approximately 37°. The disc was heated to mimic body temperature since the material properties of blood are sensitive to temperature.

4 METHOD OF ANALYSIS AND RESULTS

The positions of the identifiable pairs, or triplets in one case, of droplet images were digitized using a x-y digitizing table. With the film on the digitizer it was difficult to see the individual droplets so for each experiment the films were placed on a light table and the images of the droplets were transferred manually to a transparency. The positions were measured by placing the cross-hairs of the digitizer on the transferred images of the droplets, and storing the resulting x-y coordinates in a computer. Two fixed reference markers were used to give the orientation. One was the edge of the impact disc and the other a point on its surface. No scale factor was required because the negatives were at 1 to 1 scale.

Experiments 970303b and 970303c were performed and analyzed first. It was found that the impact disc bounced up slightly after an impact, and that some of the droplets were escaping through a gap under the plexiglass case. This latter effect was detected because it was observed that there were some droplets below the upper surface of the impact disc. These errors were corrected in the subsequent experiments, including those using the lamb's blood.

The speed of each droplet was determined by measuring the distance between its images on the film and dividing by the time interval between the laser pulses of 402 μs. The speeds ranged from about 1.6 m/s to 21.6 m/s. The inclination to the horizontal of each droplet trajectory, and the droplet diameter, measured using a magnifying reticle with a graded scale of 0.1 mm, were also measured. The x-y coordinates, relative to the centre of impact, of the first image of each droplet, and the flight angle, speed, and size of each droplet are given in tables 2 to 7. The digitized images of the droplets for each experiment are shown in figure 3 to 8. The origin of each plot is at the center of the pool. From about 7 to 45 droplets can be clearly seen in each experiment. In each figure it may be note that as the pairs of droplet images get further away from the blood pool their separation is generally greater. This is because the droplets that are further away from the impact area at the time of the exposures have a higher velocity.

The frequency distributions of droplet size for the blood substitute and the lamb's blood are shown in figures 9 and 10. The most frequent size for the blood substitute is about 0.67 mm while for the lamb's blood it is about 0.74 mm. It should be noted that there were undoubtedly smaller droplets which could not be measured because of their size and possibly speed. Some experiments were done using a shorter delay in the initiation of the laser in an attempt to detect faster droplets. What appeared in the resulting films was a fine high speed mist in which individual droplets could not be identified. It appears that there may have been large numbers of very small droplets in all the experiments travelling at significantly higher velocities than 21.6 m/s.

The experiment using three exposures was performed to see if the deceleration of the droplets due to air drag could be measured. No significant difference in the droplet displacements during the intervals between the first and second and between the second and third pulses could be detected.

5 DISCUSSION AND CONCLUSIONS

The purpose of this project was to develop a photographic system that would be capable of measuring both the velocity and size of individual blood droplets in flight caused by the impact of a blunt mass into a pool of blood. In experiments with a blood substitute, and in those using lamb's blood with an anticoagulent, good measurements of the speed, flight angle and droplet size were obtained. The photographic system and the experimental arrangement are now available for further studies of the production and flight characteristics of droplets created by the impact of a blunt body on to a pool of blood. With this system the significant variables, such as impact area, striking velocity and pool size can be studied. All of these parameters, and the ratio of the impact area to the pool area, appear to govern the velocity and size distribution of the droplets.

In the limited number of experiments performed in this project the average size of the droplets from the blood substitute was 0.67 mm and from the lamb's blood was 0.74 mm. The velocities of the observed blood droplets ranged from about 1.6 m/s to 21.6 m/s. The impact speed of the weight was about 5.5 m/s.

It was found that using the 17 mm wide slot in the plexiglass box surrounding the blood pool, a large number of droplets were produced in the field of view of the optical system. The number of recorded droplets was doubled or trebled by the multiple exposures so that in some cases it was difficult to identify which two or three images corresponded to the same droplet. In future experiments the slot width should be reduced to allow fewer droplets to escape.

The laser was capable of producing a triple exposure over a time period of 800 μs, but the multiple exposures significantly reduced the contrast between individual images. In experiment 970310c seven triplets were found. The third pulse of the laser was not very intense and made the corresponding images even harder to see. With some fine tuning of the laser system it should be possible to obtain good triplet images, but it is unlikely that this technique will give accurate measures of the droplet deceleration. Alternative techniques need to be developed to measure this parameter.

The blood substitute appeared to give adequate results but the velocity of the droplets was somewhat less than that for the real blood. A better matching of the viscosity will be required to obtain better agreement.

It was found in preliminary experiments that if the pool size was much larger then the impact area, the take-off angles of the droplets were significantly larger. The liquid underneath the falling weight appears to jet out at high speed and collide with the surrounding liquid which is not directly impacted by the falling weight. These high speed droplets are then deflected to higher angles by the surrounding liquid. The pool sizes used in the experiments described here were all slightly larger than the the impact area and hence in all cases have some droplets with large flight angles.

Acknowledgements The authors gratefully acknowledge the helpful conversations with Fred Carter of Carleton University and Brian Yamashita of the Forensic Identification division of the Royal Canadian Mounted Police. The assistance of the staff of Lilydale Food Products of Langford, BC, who provided the fresh lamb's blood, is also gratefully acknowledged.

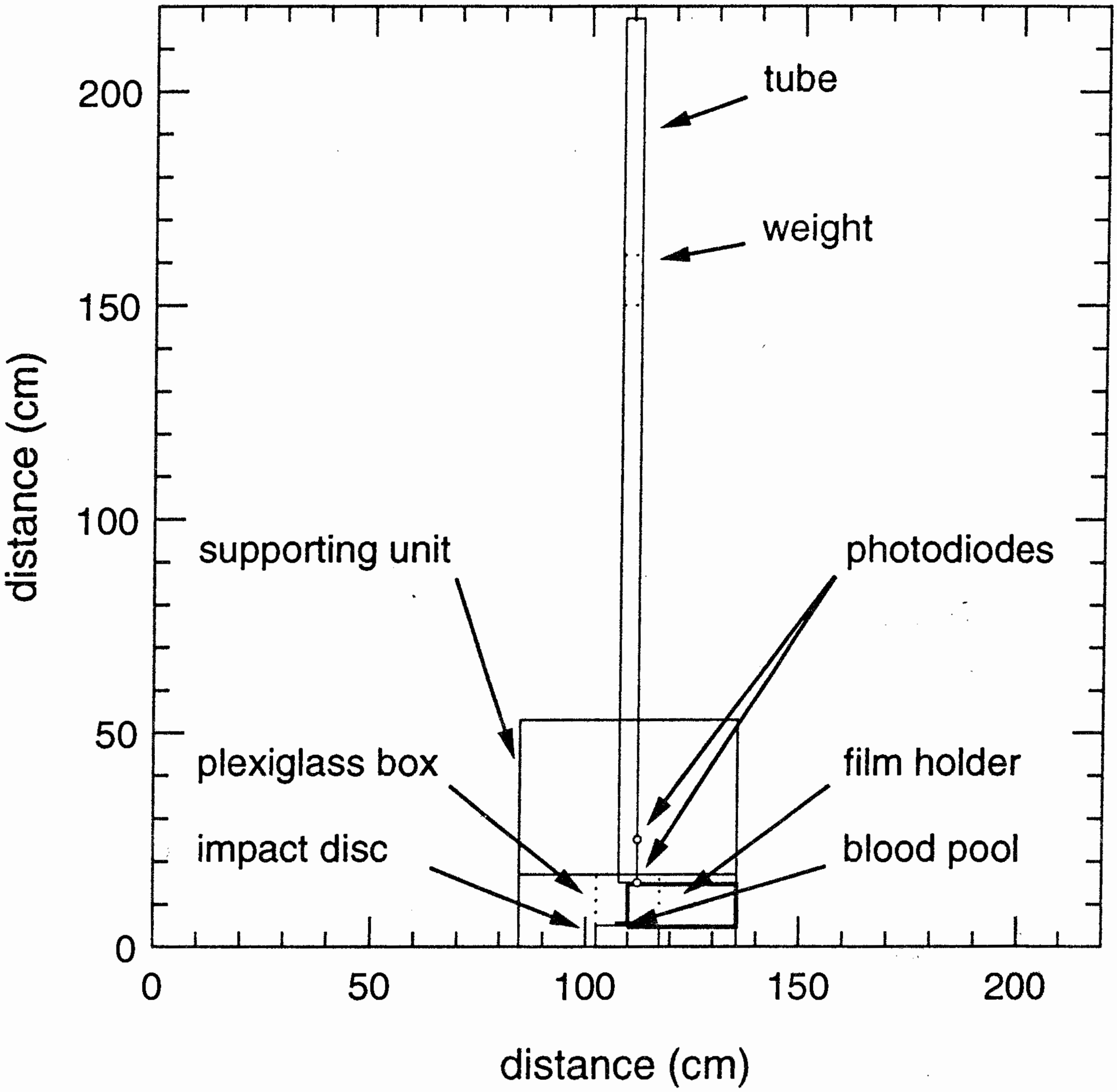

Figure 1: A scale drawing of the dropping mechanism.

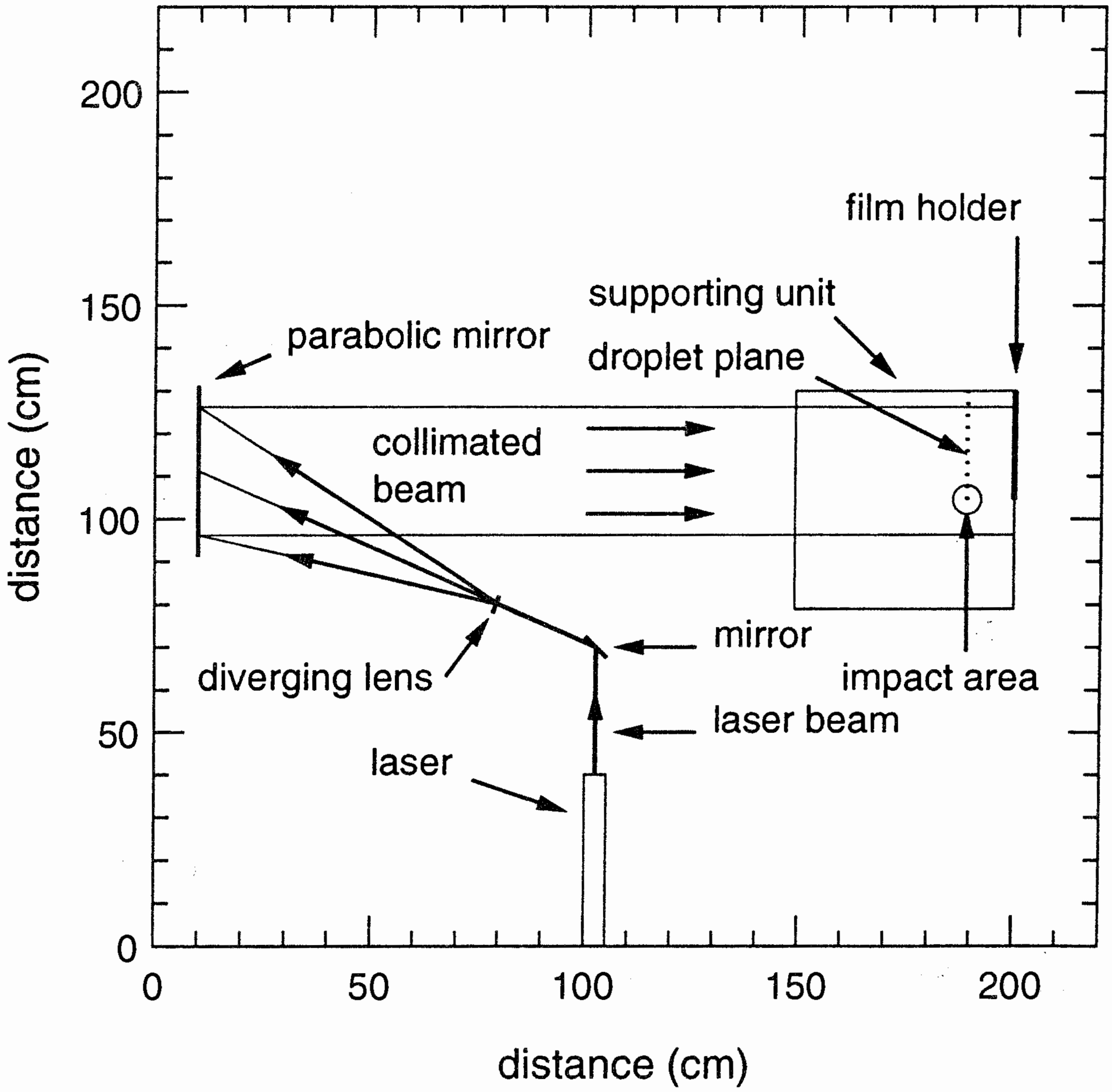

Figure 2: A plan view of the optical system used to photograph the droplets in flight.

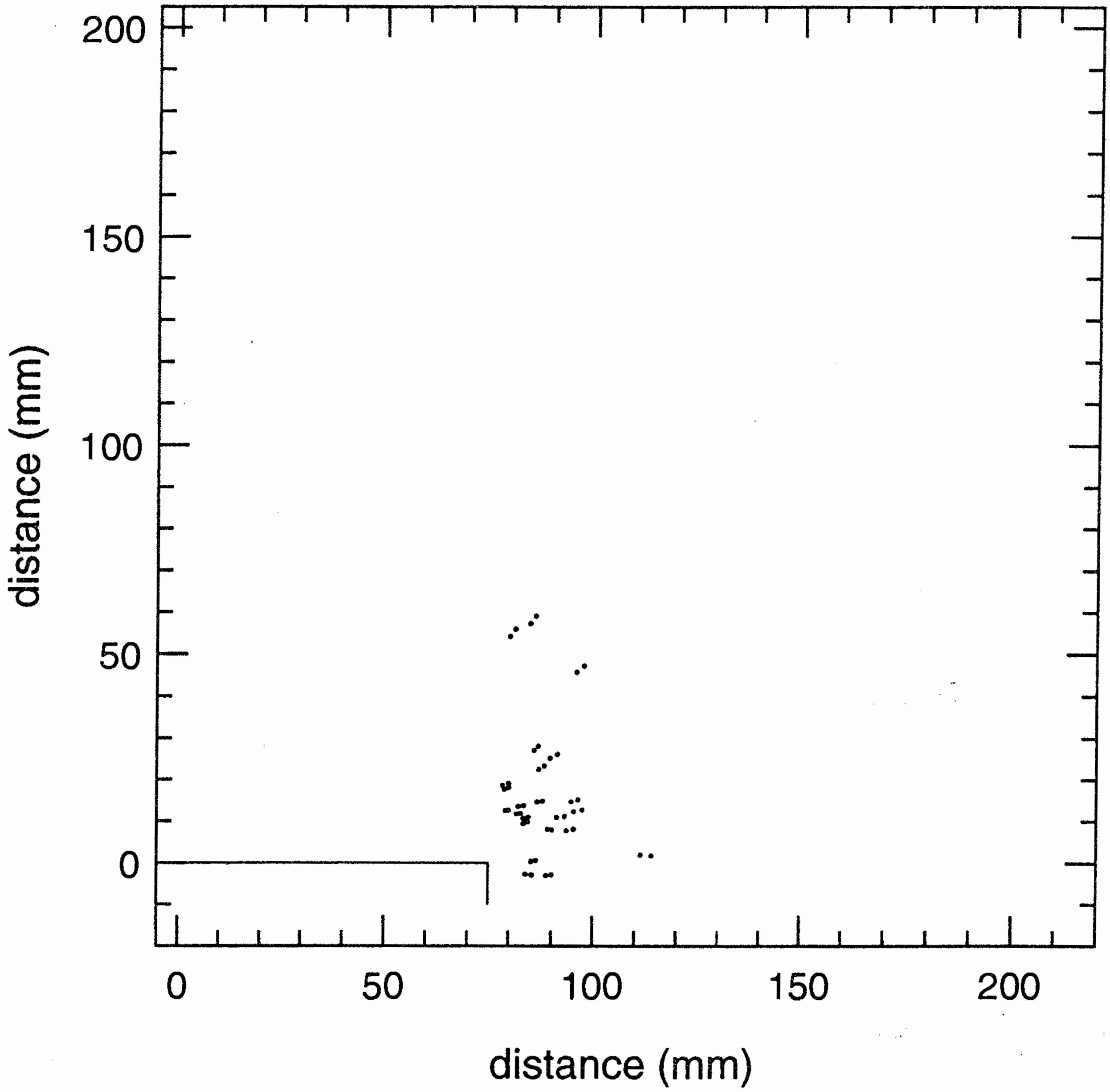

Figure 3: Digitized image of a double exposure shadowgraph of droplets in flight for experiment 970303b(blood substitute). Origin of plot is at the center of the impact area.

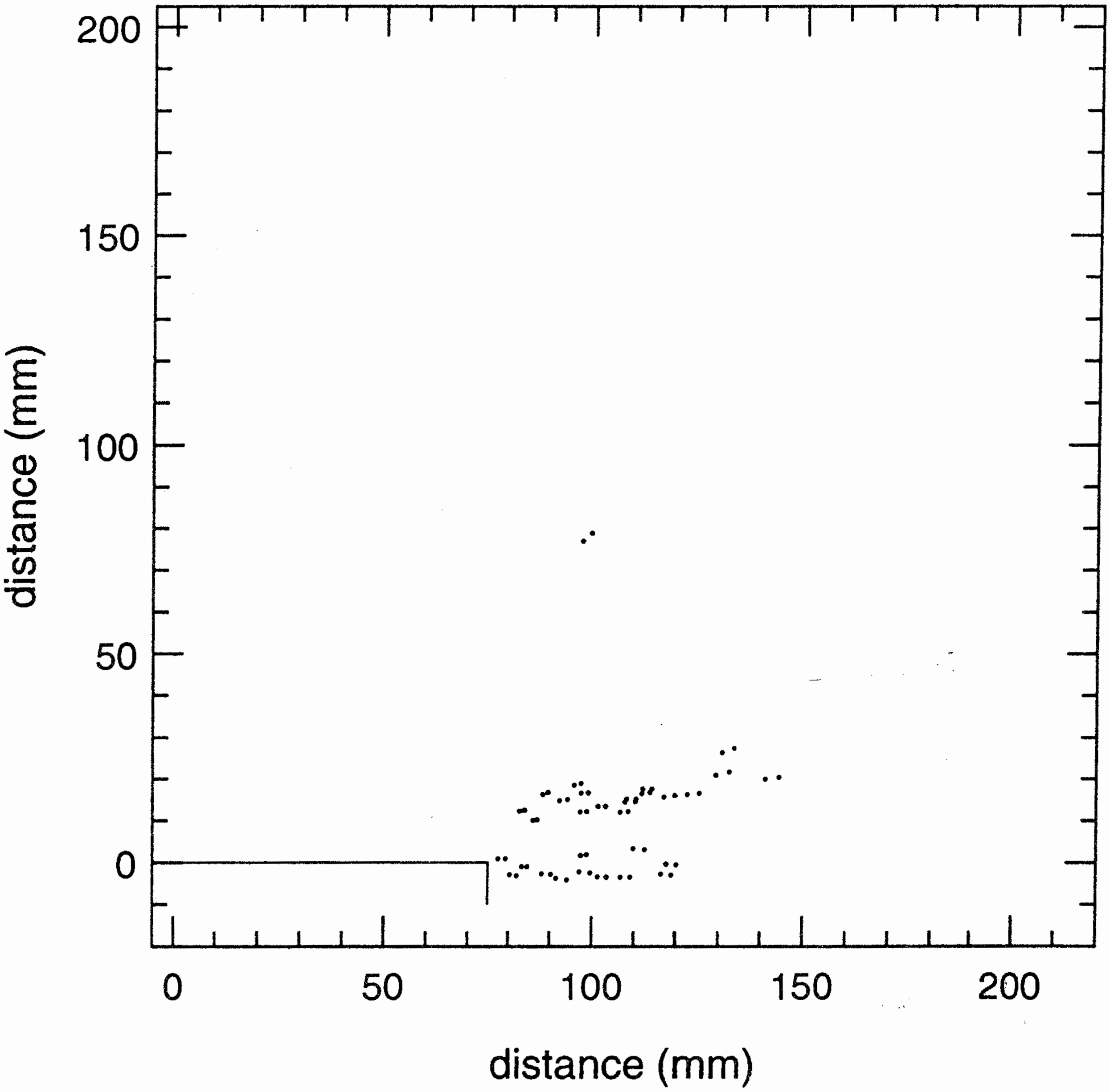

Figure 4: Digitized image of a double exposure shadowgraph of droplets in flight for experiment 970303c(blood substitute). Origin of plot is at the center of the impact area.

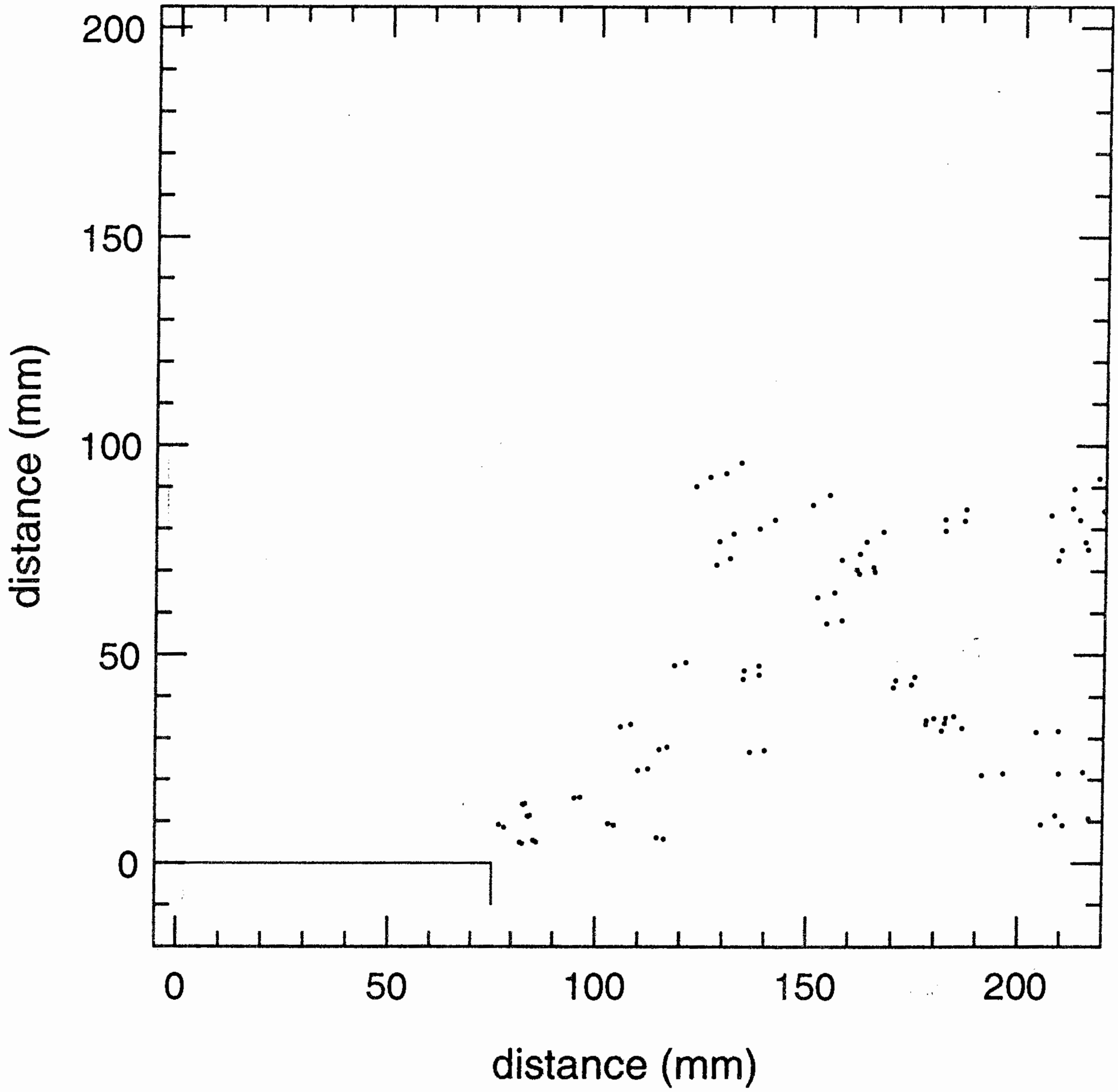

Figure 5: Digitized image of a double exposure shadowgraph of droplets in flight for experiment 970310a(lamb's blood). Origin of plot is at the center of the impact area.

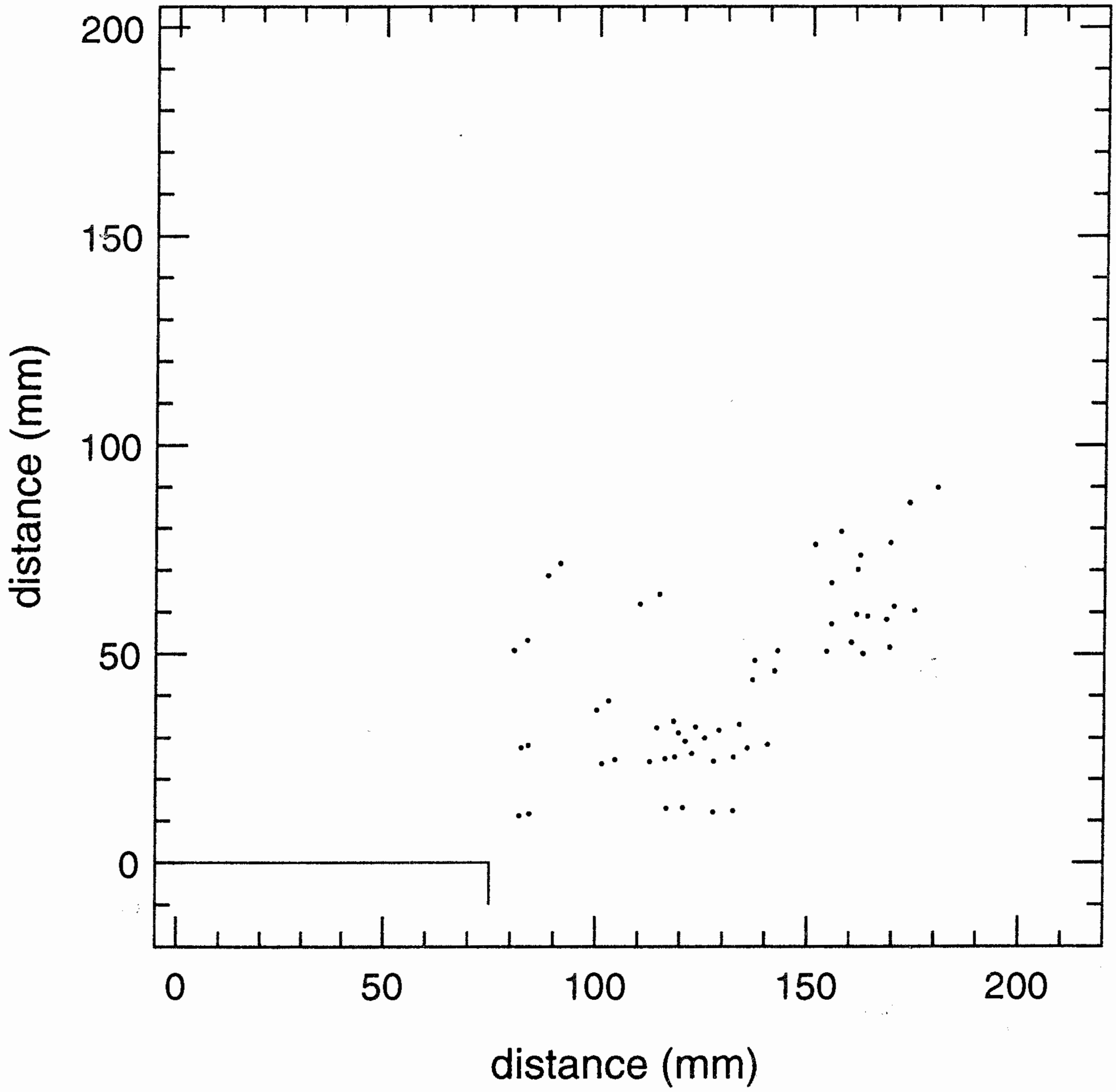

Figure 6: Digitized image of a double exposure shadowgraph of droplets in flight for experiment 970310b(lamb's blood). Origin of plot is at the center of the impact area.

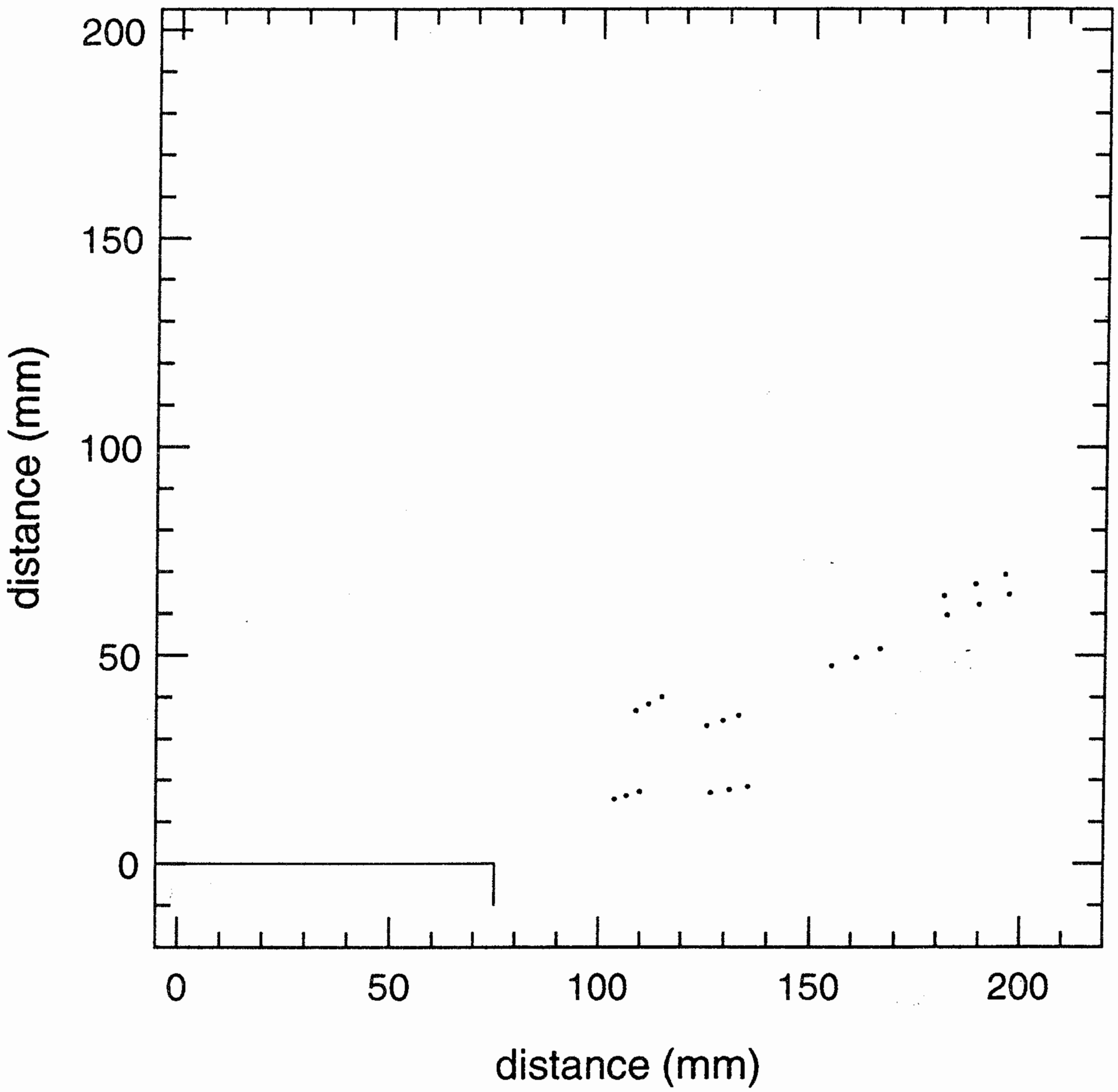

Figure 7: Digitized image of a triple exposure shadowgraph of droplets in flight for experiment 970310c(lamb's blood). Origin of plot is at the center of the impact area.

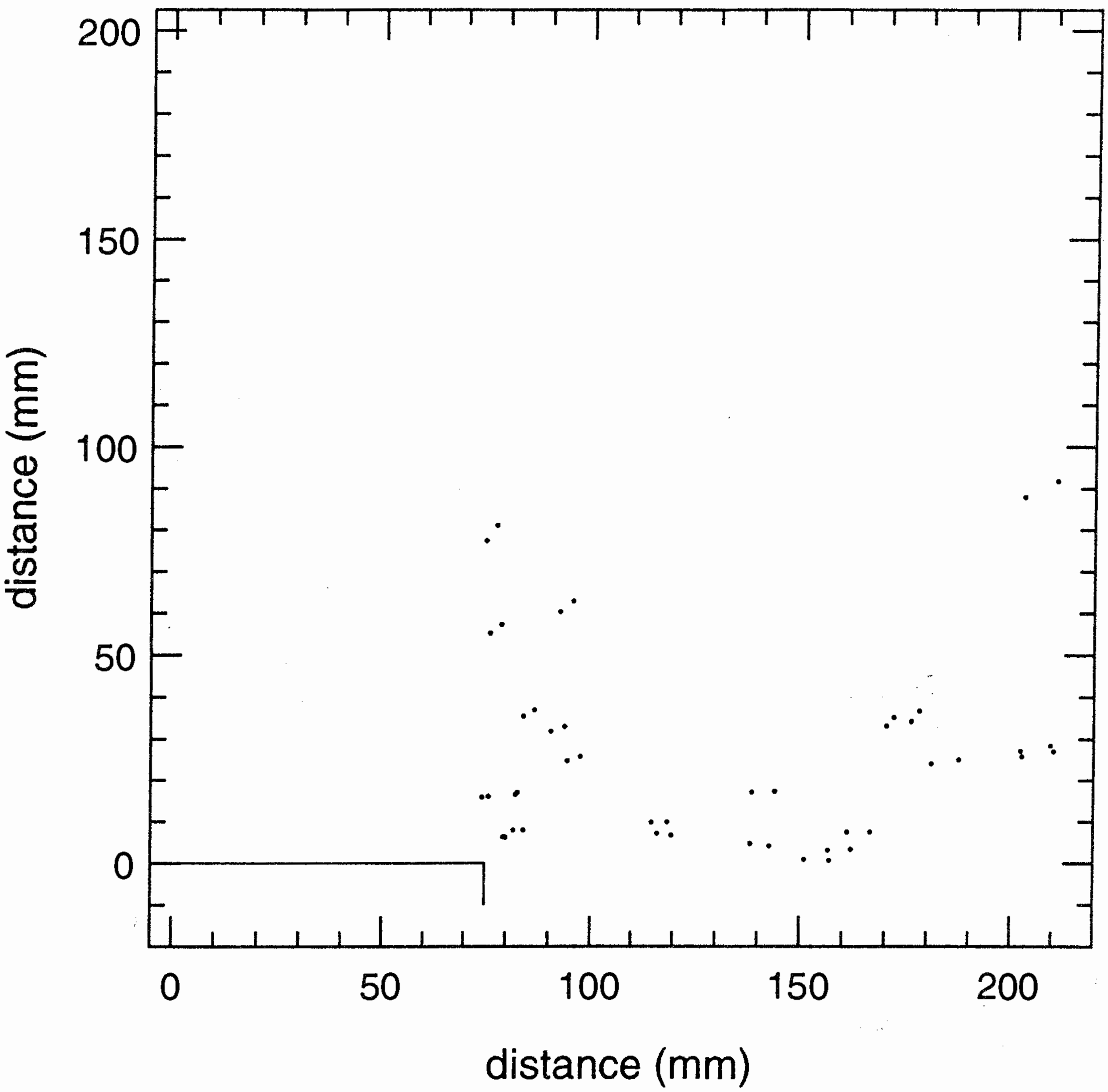

Figure 8: Digitized image of a double exposure shadowgraph of droplets in flight for experiment 970310d(lamb's blood). Origin of plot is at the center of the impact area.

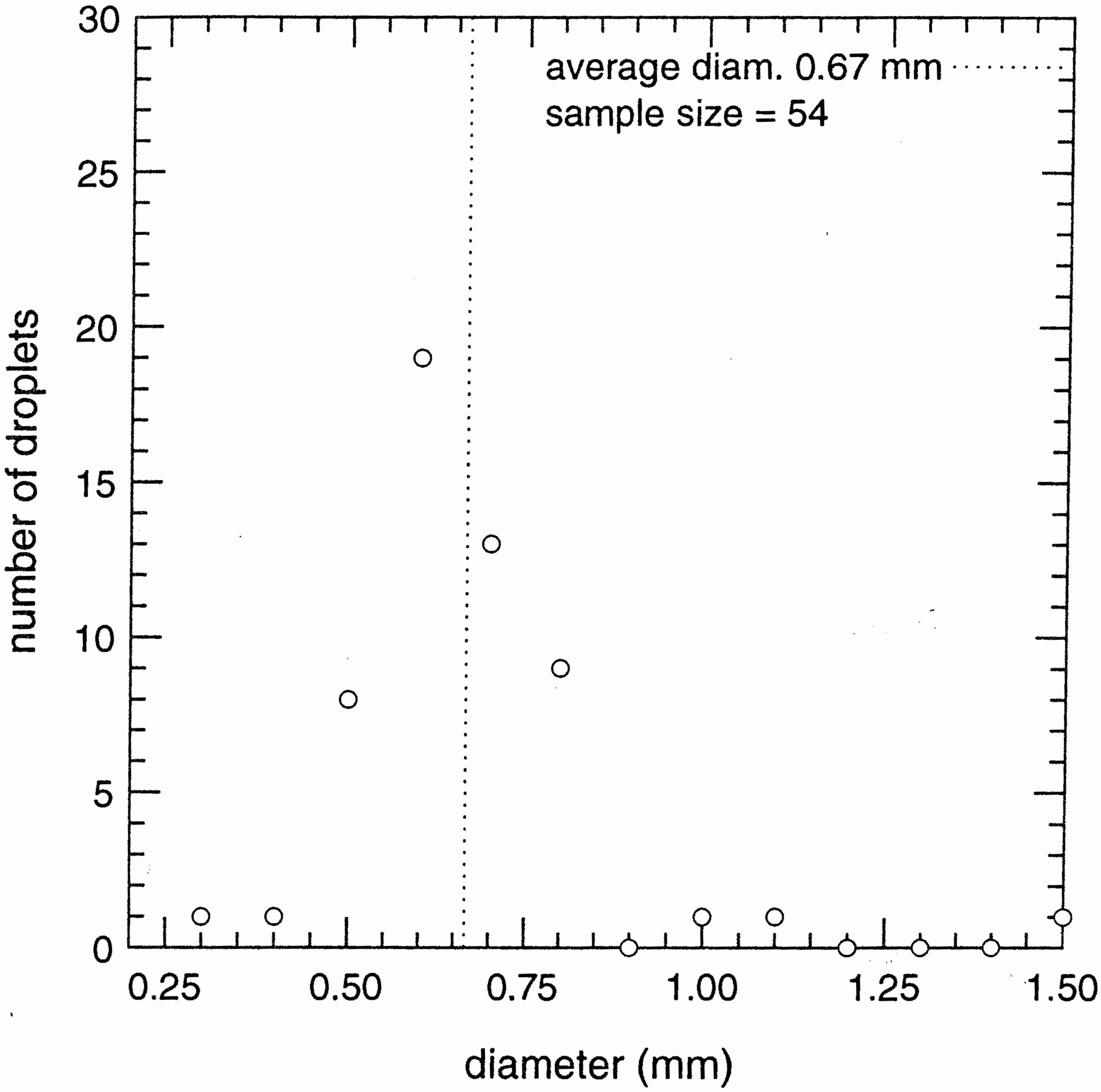

Figure 9: Frequency distribution of the droplet size for the two experiments using a blood substitute.

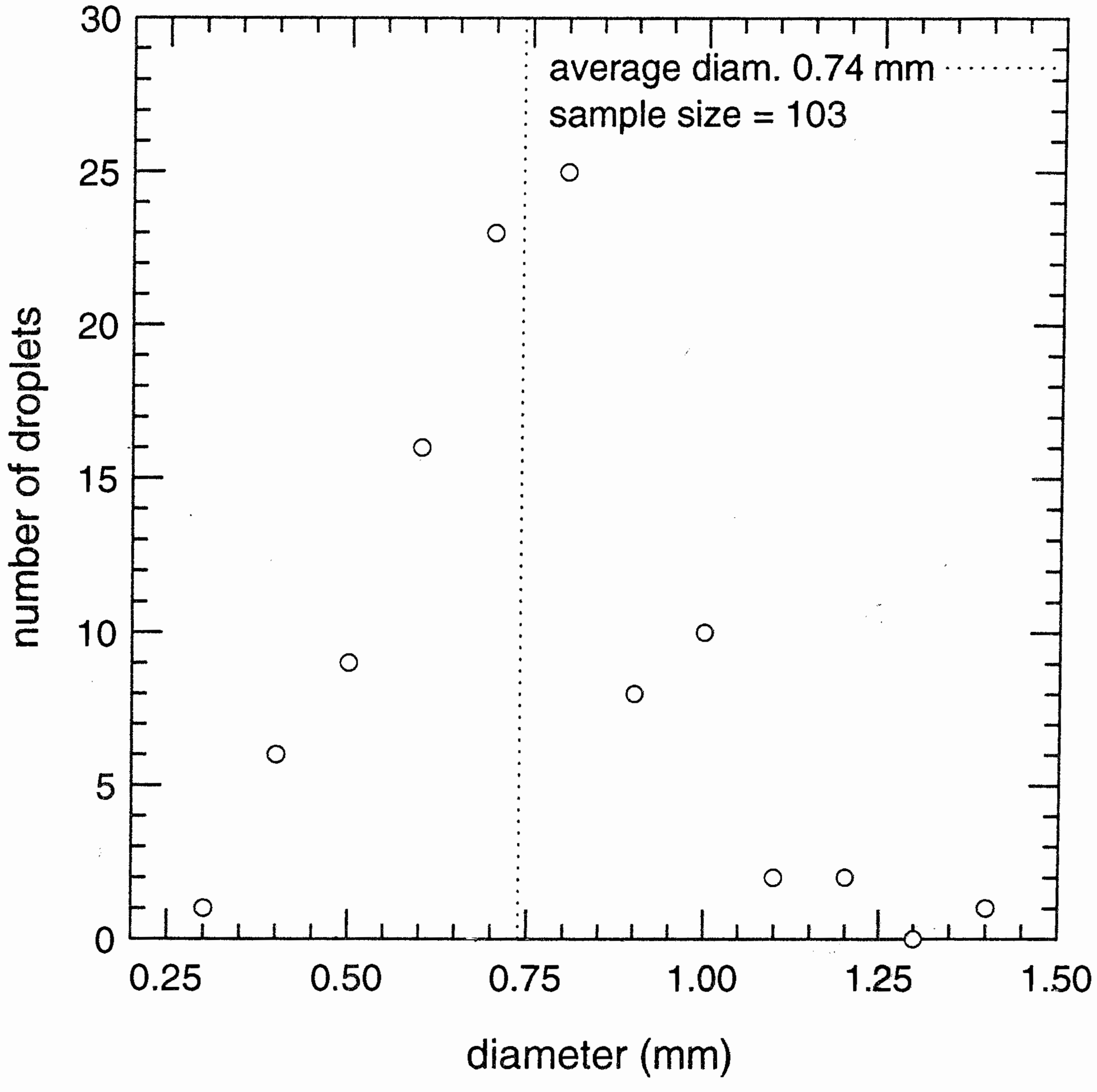

Figure 10: Frequency distribution of the droplet size for the four experiments using lamb's blood.

Table 2: Results from experiment 970303b (blood substitute)

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
1	79.1	12.6	3.2	2.0	0.6
2	78.9	17.7	22.3	2.9	1.0
3	78.4	18.6	20.0	3.7	0.7
4	80.1	54.2	53.8	5.1	0.8
5	83.8	-2.7	-7.2	3.8	1.1
6	85.2	0.4	15.1	2.8	0.5
7	83.3	9.4	23.7	2.8	0.6
8	83.3	10.7	17.3	3.0	0.6
9	81.8	11.8	10.2	2.3	0.6
10	82.2	13.5	13.6	3.1	0.7
11	84.7	57.2	54.3	5.4	0.8
12	88.7	-3.0	3.9	3.4	0.6
13	89.1	8.1	-7.5	2.7	0.6
14	86.5	14.6	8.9	3.4	0.7
15	86.9	22.5	32.6	3.9	0.8
16	89.6	25.2	29.8	5.0	0.7
17	85.7	27.1	45.6	3.6	0.8
18	93.6	7.8	10.7	4.4	0.6
19	91.2	10.9	8.8	4.9	0.6
20	95.3	12.3	11.1	5.2	0.8
21	94.7	14.7	16.1	4.4	0.8
22	95.9	45.8	40.7	5.7	0.8
23	111.4	2.0	-3.7	6.6	0.7

Table 3: Results from experiment 970303c (blood substitute)

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
1	77.5	1.0	-1.2	4.4	0.5
2	80.4	-2.9	-9.6	4.4	0.7
3	83.2	-0.9	-0.7	3.5	0.7
4	82.7	12.3	9.7	3.3	0.6
5	86.0	10.1	2.4	2.5	0.5
6	88.1	-2.7	-3.9	5.6	0.6
7	91.5	-3.7	-7.6	6.3	0.6
8	88.3	16.3	24.4	3.4	0.7
9	92.3	14.8	6.1	4.8	1.5
10	97.0	-2.2	-7.2	6.3	0.8
11	97.3	1.7	9.0	3.5	0.5
12	97.3	12.1	2.4	3.7	0.6
13	97.4	16.6	2.2	4.1	0.7
14	95.8	18.5	17.0	4.1	0.6
15	97.5	77.0	42.8	7.0	0.4
16	101.3	-3.3	-3.1	5.4	0.6
17	101.4	13.4	1.4	4.4	0.3
18	106.8	-3.5	-0.4	5.6	0.7
19	109.8	3.3	-6.6	6.9	0.5
20	106.7	12.1	4.5	4.6	0.6
21	107.8	14.5	2.4	6.2	0.7
22	108.2	15.1	0.1	5.5	0.7
23	111.8	16.5	7.2	5.3	0.6
24	112.0	17.6	-0.9	5.7	0.6
25	116.7	-2.7	-4.9	5.7	0.5
26	117.9	-0.5	-3.4	5.7	0.7
27	117.3	15.6	8.3	6.3	0.5
28	122.6	16.3	7.4	7.0	0.6
29	129.3	20.9	13.3	8.3	0.5
30	130.8	26.3	20.0	7.6	0.6
31	141.2	20.0	8.1	7.8	0.8

Table 4: Results from experiment 970310a (lamb's blood)

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
1	76.8	9.2	-28.5	3.6	1.0
2	81.9	5.0	-28.0	1.5	0.5
3	85.3	5.4	-28.2	1.8	0.5
4	83.7	11.2	16.1	1.7	0.9
5	82.6	14.1	15.5	1.5	0.6
6	94.9	15.6	6.4	3.6	0.7
7	102.9	9.5	-16.6	3.4	0.8
8	114.5	6.1	-11.2	4.2	0.7
9	109.7	22.3	7.5	6.2	0.7
10	105.7	32.8	15.8	5.9	0.8
11	114.9	27.3	15.4	5.2	0.4
12	118.3	47.4	15.5	6.8	0.9
13	123.1	90.3	34.4	9.8	0.8
14	136.3	26.7	6.9	8.7	0.8
15	134.5	44.2	14.7	9.9	0.8
16	134.7	46.2	18.7	9.3	1.1
17	128.0	71.5	26.3	8.8	0.8
18	128.6	77.0	29.2	9.5	0.7
19	130.1	93.3	34.8	11.0	1.0
20	138.3	80.1	30.4	10.2	0.6
21	154.3	57.5	12.2	9.1	0.9
22	152.2	63.7	16.9	10.3	1.0
23	150.9	85.9	30.5	11.5	0.8
24	162.0	69.4	6.0	8.9	0.7
25	161.4	70.3	9.1	9.8	0.8
26	157.8	72.7	18.4	11.1	1.0
27	163.7	77.0	32.0	11.2	1.0
28	170.1	42.2	8.4	10.7	0.9
29	170.7	43.9	10.9	11.3	1.0
30	181.6	31.8	6.5	12.4	0.8

Table 4: Results from experiment 970310a con't

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
31	177.9	33.4	4.3	10.9	0.5
32	178.0	34.4	7.1	11.5	0.6
33	179.7	34.9	4.8	12.1	0.7
34	182.1	79.5	27.8	13.0	0.9
35	182.1	82.3	25.4	13.7	0.8
36	191.3	21.1	4.3	12.5	0.7
37	205.4	9.3	-1.9	12.9	0.8
38	208.8	11.4	-4.6	19.9	0.5
39	209.5	21.5	3.4	14.1	0.8
40	204.1	31.5	2.9	13.0	0.7
41	208.9	72.5	20.4	18.3	0.6
42	209.6	74.9	20.2	14.9	0.7
43	213.8	82.1	21.8	15.1	0.7
44	207.1	83.2	17.9	13.4	1.0
45	212.5	89.6	23.4	15.6	0.8

Table 5: Results from experiment 970310b (lamb's blood)

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
1	82.0	11.1	12.1	5.9	0.4
2	82.4	27.6	21.7	4.5	0.4
3	80.7	50.8	38.4	9.7	0.6
4	88.4	68.7	44.6	10.1	0.7
5	101.4	23.7	17.4	7.9	0.7
6	100.0	36.6	37.3	8.9	0.8
7	112.7	24.2	11.7	9.4	0.6
8	110.2	61.9	26.5	13.0	1.4
9	116.8	12.9	3.0	9.6	0.6
10	114.4	32.5	20.4	10.4	1.1
11	118.7	25.3	13.1	9.9	0.7
12	119.5	31.1	20.4	10.4	1.2
13	121.1	29.2	9.6	11.4	0.7
14	127.6	12.1	3.6	11.8	0.3
15	127.8	24.3	11.9	11.6	0.4
16	129.0	31.8	16.3	12.4	0.9
17	135.7	27.5	10.0	12.0	0.6
18	136.8	43.8	22.7	14.1	1.2
19	137.3	48.5	23.3	14.3	1.0
20	154.2	50.7	20.1	15.3	0.7
21	155.3	57.2	21.1	15.7	0.7
22	155.2	67.0	26.8	17.4	0.8
23	151.4	76.1	27.4	17.1	0.8
24	162.0	73.5	23.0	19.2	0.6
25	162.8	50.1	13.4	16.1	0.4
26	163.8	59.0	20.0	16.6	0.8
27	168.3	58.2	18.7	17.3	0.8
28	173.7	86.1	29.0	18.9	0.7

Table 6: Results from experiment 970310c (lamb's blood)

Droplet #	X (mm)	Y (mm)	1^{st} Angle (°)	1^{st} Speed (m/s)	2^{nd} Angle (°)	2^{nd} Speed (m/s)	Diam. (mm)
1	103.8	15.4	17.8	7.6	17.0	8.1	0.5
2	108.8	36.7	27.7	8.6	28.1	9.1	0.6
3	126.8	16.9	9.4	10.7	9.6	11.1	0.8
4	125.8	33.2	18.5	9.9	17.5	9.3	0.5
5	155.0	47.5	19.5	15.2	20.3	14.7	0.8
6	182.1	59.6	19.1	19.7	17.8	19.0	0.8
7	181.3	64.2	20.8	19.7	18.0	18.5	1.0

Table 7: Results from experiment 970310d (lamb's blood)

Droplet #	X (mm)	Y (mm)	Angle (°)	Speed (m/s)	Diam. (mm)
1	79.3	6.4	-9.2	1.6	0.8
2	74.3	16.0	6.2	3.9	0.7
3	76.1	55.2	39.5	8.4	0.7
4	75.1	77.3	56.9	11.0	0.8
5	81.7	8.0	-0.9	5.9	0.7
6	82.2	16.5	50.0	1.8	0.4
7	83.9	35.4	30.6	7.6	0.6
8	94.5	24.7	18.9	8.0	0.5
9	90.5	31.8	18.4	8.8	0.7
10	92.6	60.3	39.1	10.0	0.6
11	116.2	7.2	-7.3	8.5	0.6
12	114.8	9.8	1.8	9.4	0.6
13	138.2	4.7	-6.7	11.3	0.6
14	138.6	17.1	2.3	13.6	0.9
15	151.1	0.9	-2.1	14.3	1.0
16	156.6	3.1	2.2	13.2	0.8
17	161.1	7.5	-0.2	13.4	0.7
18	170.1	33.0	11.5	15.1	0.8
19	171.9	35.1	14.2	15.6	0.7
20	181.0	24.0	8.4	16.4	0.5
21	202.7	25.7	9.9	19.3	0.6
22	202.4	27.1	10.3	18.3	0.5
23	203.0	87.9	26.1	21.6	0.9