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COMBUSTION OF A LIQUID-FUEL SPRAY

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FOREWORD

This report was prepared by the Engineering Research Institute of The University of Michigan on U.S. Air Force Contract No. AF 33(616)-2436, Change Order No. Ca(55-792). The work was sponsored by the Wright Air Development Center, with Jack W. Fulton acting as project coordinator. The work was conducted at The University of Michigan under Projects 1988 and 2253-3.

ABSTRACT

A six-flash photographic technique used to obtain pictures of burning fuel droplets proved unsuccessful because the droplets moved out of the camera's field. However, high-speed motion pictures gave an insight into the burning process.

The development of a small vertical-duct furnace aided in stabilizing the flame.

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INTRODUCTION

The work on this project was a continuation of the work done under Air Force Contract 33(600)-5057 with the purpose of determining the burning rate of different fuels. These included kerosene, pure hydrocarbons, and fuels such as JP-4 which are commonly used in gas turbines.

Previous work[1,2] had been done with single drops suspended on filaments, but it was felt that it would be valuable to get data under actual spray conditions, where the droplets would be influenced by their neighbors but not by artificial constraints. A spinning-disc spray generator was developed that gave droplets of a uniform size. Photographs of the spray were taken at two successive times with a known interval; this gave, by a statistical analysis, both the drop size and velocity.

Discrepancies between photographs taken with the camera axis vertical and horizontal, and between different photographs in the same plane, pointed out a need for following a single droplet throughout the whole combustion process. This led to the development of the six-flash technique.

EARLY FLASH WORK

The early work was done with the fuel burning in the open air. The experimental setup is shown in Fig. 1. The photographs of a nonburning spray clearly showed many droplets in their characteristic strings of six, (see Fig. 2). However, when there was burning present, only a few strays were indicated by strings of six and these showed no apparent reduction in size. Occasionally, a droplet would appear once on the photograph and not be seen again. Frequently, strings of two or three would be seen with no sign of what happened to the others. In those cases where strings of six were noted, quite often three were out of focus. On all the photographs of the burning spray, the number of droplets photographed was always considerably less than the number when no burning was present.

At this point it was felt that one of the following two phenomena caused these difficulties:

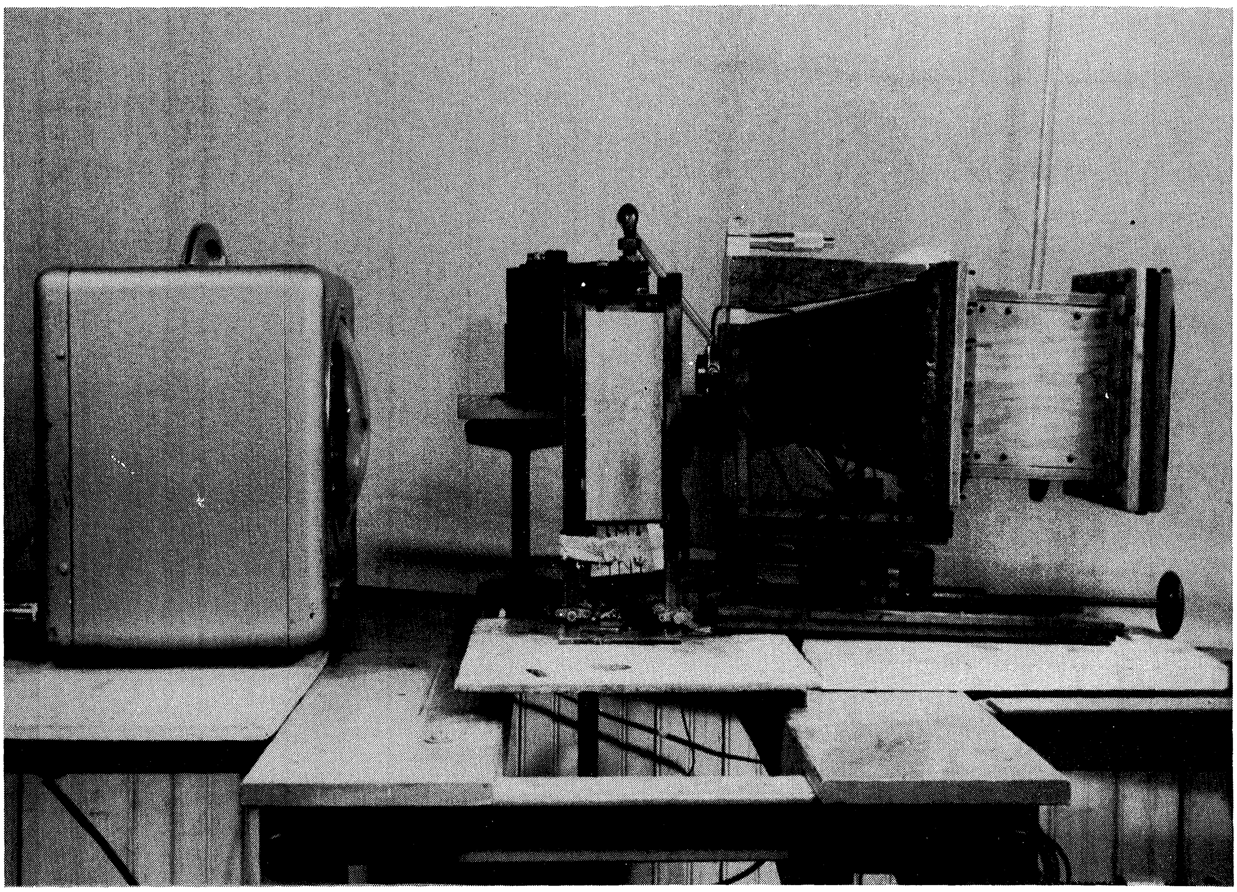

Fig. 1. Picture of six-flash setup with furnace.

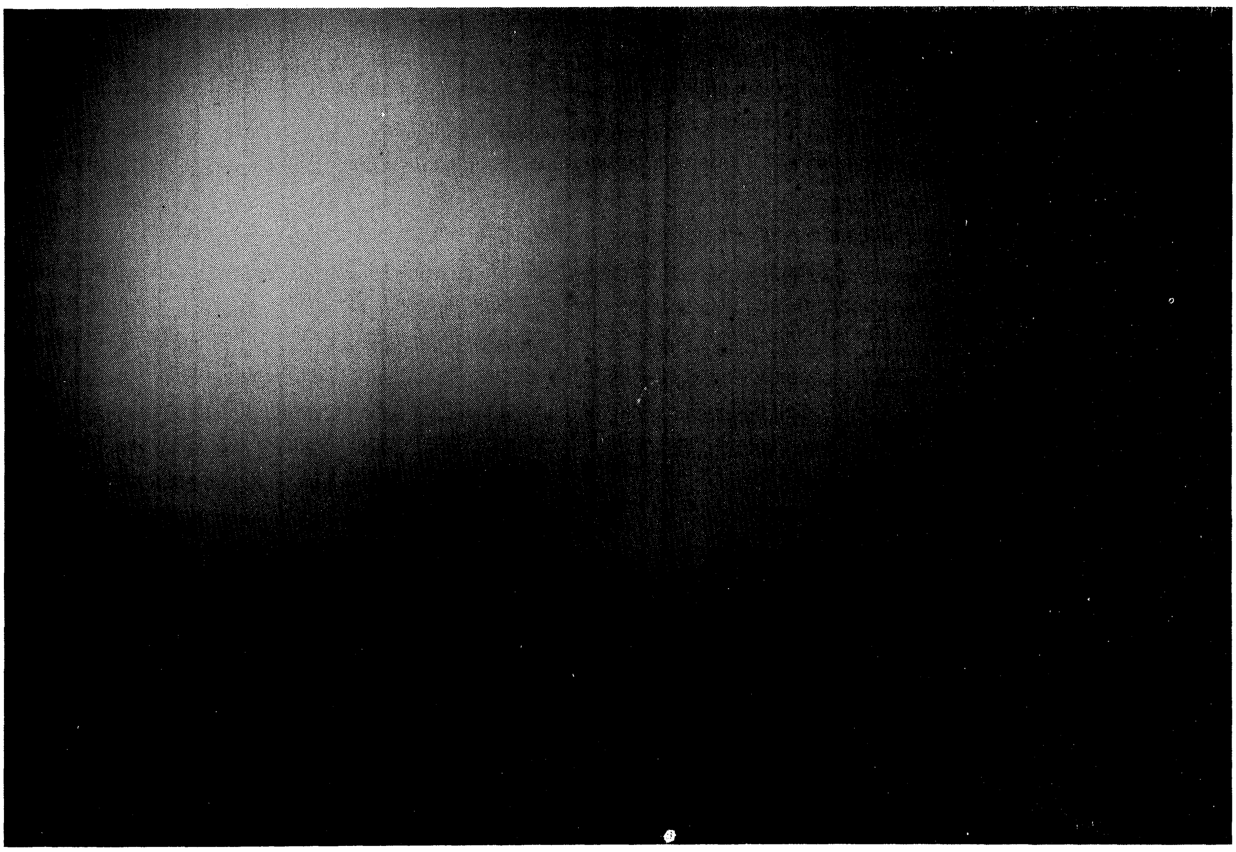

Fig. 2. Six successive pictures of a single droplet

1. The burning rate varied greatly depending upon the location of the droplet with respect to the flame.

2. The action of combustion either moved the droplet out of focus or caused some distortion so that the droplet could not be seen.

A small vertical-duct furnace (Fig. 3) was built in an attempt to solve these problems. By raising the ambient temperature, it was hoped that a more uniform burning rate could be achieved and that the action of combustion would be stabilized.

SIX-FLASH PHOTOGRAPHY WITH THE FURNACE

Six-flash photographs were taken of both burning and nonburning spray with ambient temperatures ranging from room temperature up to 800°F. In every case the phenomena noted above were present, and no satisfactory pictures were obtained. However, the furnace enclosure and the associated flame holder made the pictures much easier to take.

It was seen that little useful information could be obtained unless we had a clearer understanding of what was going on in the burning spray.

THE DEVELOPMENT OF A HIGH-SPEED MOTION-PICTURE TECHNIQUE

Earlier an unsuccessful attempt to take high-speed motion pictures was made; the failure was primarily due to the fact that it was very difficult to hold the flame in one place long enough to take a picture. With the stabilized flame possible in the furnace, this difficulty was eliminated. A high-speed motion picture is valuable since it allows a drop to be followed, with little or no loss in continuity, until it disappears.

Experimental motion pictures were taken of burning n-heptane spray at 1000 and 3000 frames per second (see Figs. 4 and 5). Those at 1000 frames were unsatisfactory for two reasons:

1. Continuity was still not maintained, i.e., individual drops were lost among the mass of others.

2. The shutter speed was so slow that the droplets looked like lines instead of spheres.

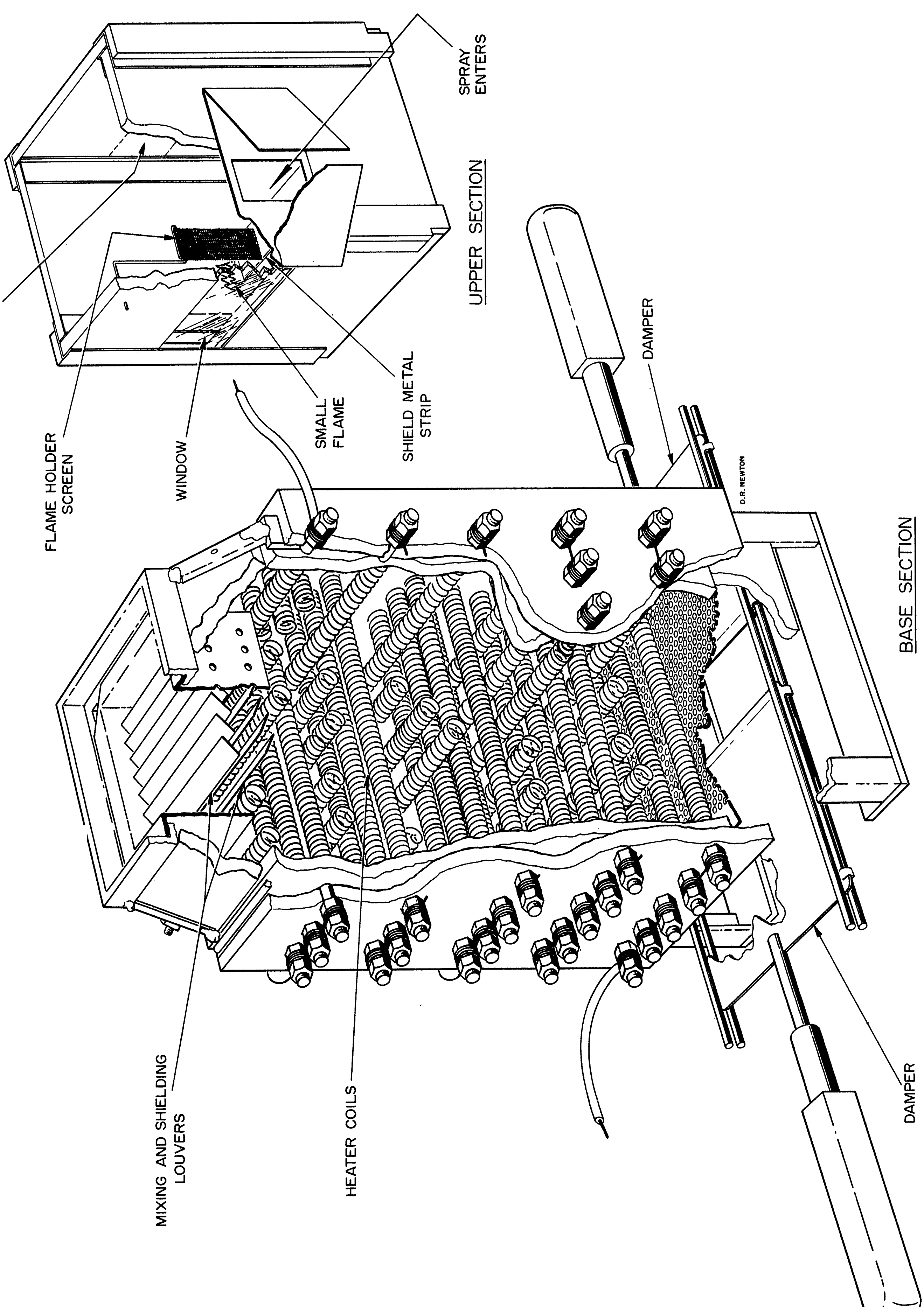

Fig. 3. Sketch of furnace base and combustion chamber.

Fig. 4 Picture of motion-picture setup.

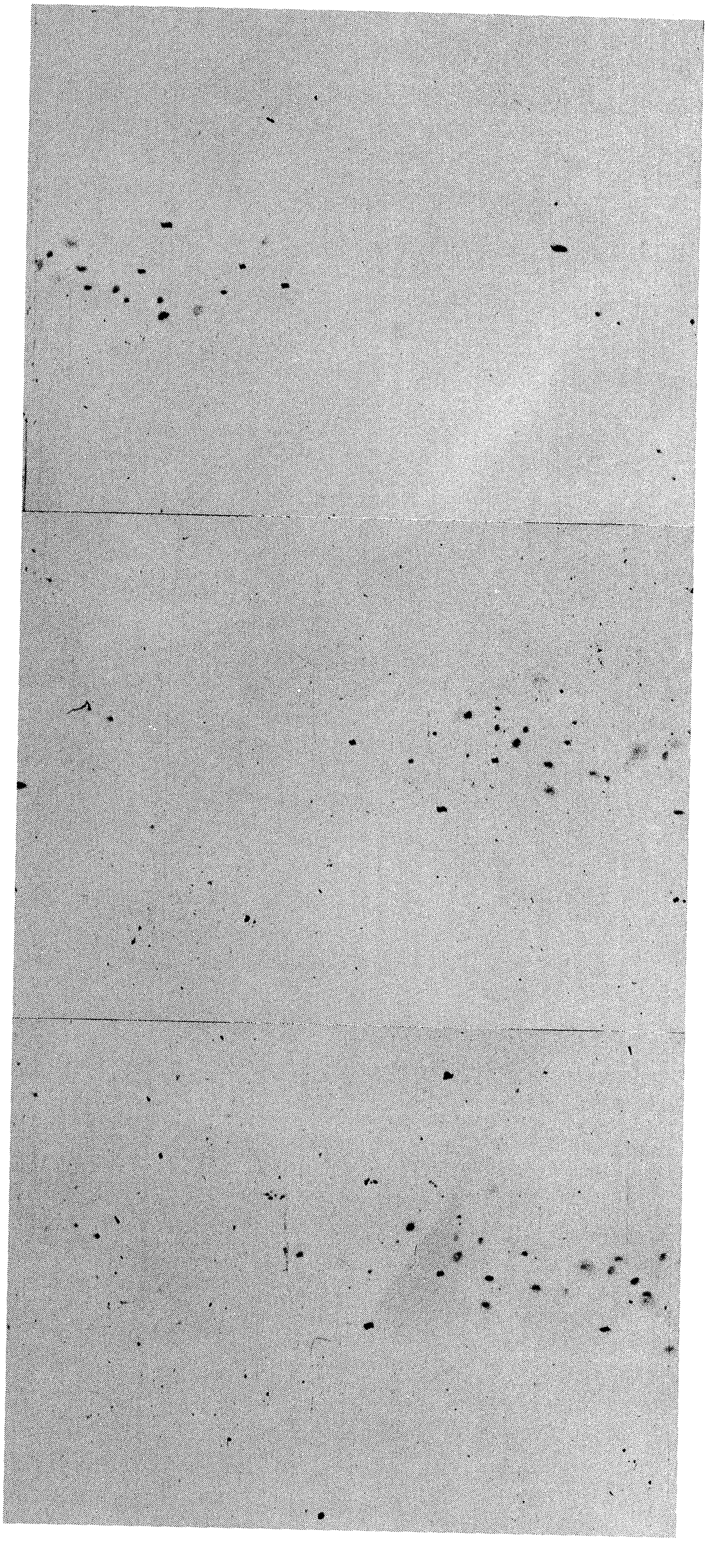

Fig. 5. Three frames of high-speed movies

However, these pictures clearly showed a reduction in droplet size. At 3000 frames the continuity was maintained and the drops looked more like spheres. Lighting problems at the higher rate made it difficult to get distinct pictures. Size reduction was not as evident in these cases.

The movies were taken on 16-mm film with a magnification of approximately one; this prevented the inclusion of the whole flame field on the film. By decreasing the magnification, the whole field could be included; however, this would reduce the droplet image until it would be indistinguishable from the grain of the film.

INTERPRETATION OF THE WORK

Although the lack of image definition on the films made it difficult to get qualitative information, they still gave an insight into the action of combustion in the spray. As expected, the rate of change of drop size is not a constant, but there seem to be no droplets that are consumed instantaneously. It appears that most of them move out of the plane of focus. The increase in depth of field with the movies over the stills makes this particularly clear.

In general, the combustion process should be viewed as an evaporation followed by burning of the vapor. The evaporation depends only on the properties of the fuel and local temperature and vapor concentration, while, in addition, burning requires a supply of oxygen and dissipation of the combustion products. Consequently, the vapor may burn some distance from the drop which was its origin. Therefore, the rate of change of drop size is primarily dependent on the drop's location with respect to the hot flame. It is also to be noted that the faster the drop is moving, the less time it spends in the hot region, hence, it may not be completely consumed.

CONCLUSION

This work has yielded no numerical results; however, it has gained an insight into the action of combustion of a spray. Any continuation of work along these lines should involve a reappraisal of the meaning of terms such as "burning rate." With the new knowledge of the action of combustion, some valuable analytical work could be done. The best experimental approach would probably involve the use of the high-speed camera. The six-flash technique is still good, but modification in the photographic apparatus to get a greater depth of field would be necessary.

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APPENDIX

VERTICAL-DUCT FURNACE

The equipment is essentially the same as that previously used, with the later addition of a vertical-duct furnace. This furnace consists of a base section which houses 50 ohms oh high-capacity heater coils and the upper section which acts as a combustion chamber (see Fig. 3). The transmission of heat from the base section to the upper section is primarily by the chimney effect. The supply of air at the bottom is controlled by a damper, and the current in the heater coils is controlled by a carbon-pile variable resistor.

On opposite sides of the upper section there are two windows through which the photographs are taken. On the third side is a small opening through which the spray enters. Also from this side are two pieces of sheet metal which interrupt the spray that is not desired in the furnace; this is necessary because any spray touching the hot walls of the furnace immediately burns, causing a serious fire hazard.

Above and below the place where the flame burns are two small pieces of stainless-steel sheet. These serve two purposes; they shield the flame from radiation and interrupt the strong vertical convective currents which distort or blow out the flame.

Ignition is accomplished by a spark powered from an ordinary automotive ignition coil. At times a flame holder is used to hold the flame stationary.

SIX-FLASH APPARATUS

The six-flash apparatus consists of a General Electric high-intensity photoflash modified to give six successive flashes instead of one. Power for the flashes is obtained from six two-microfarad capacitors charged to 2000 volts. A six-cylinder automotive distributor driven by an electric motor connects each capacitor in its turn to the lamp. When the camera lens is open, the lamp is triggered by a 6-volt battery at the proper time with the contactor points in the distributor.