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TECHNIQUE FOR BURNING SINGLE FUEL DROPLETS

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FOREWORD

This report was prepared by the Engineering Research Institute of the University of Michigan on U. S. A. F. Contract No. AF 33(600)5057. The work was sponsored by the Powerplant Laboratory, with Lt. C. B. Shepherd acting as project coordinator. This work was initiated at the University of Michigan under Project M988, and the following report is the second of several to be prepared on the several phases of this project. Others will be published as the work progresses.

ABSTRACT

A proposed technique for the investigation of the burning of a single droplet of liquid fuel in free flight is outlined. The preliminary designs of a microdropper for producing small drops of uniform size and of a low-turbulence wind tunnel for controlling the flight of the drop during the burning process are illustrated and described. A brief outline of the proposed experimental procedure is discussed.

TECHNIQUE FOR BURNING SINGLE FUEL DROPLETS

INTRODUCTION

A preliminary investigation of the literature indicates that very little work has been done on the production and burning of single droplets of liquid fuel in free flight. The closest approach to this problem that has come to the attention of the writer has been the study of the evaporation of droplets in free flight in which the rate of evaporation was obtained from the change in size of a drop while falling through a heated vertical furnace[9]. No attempt was made, however, to observe the drop during any part of the flight, so that the results are based entirely upon the initial and final drop-size measurements. Other works pertaining to this subject[4,5] relate to the evaporation and burning of droplets suspended from very fine wires, making it impossible to study the completion of the burning process or the burning of very small droplets.

In setting up the present program for the study of the burning of a single droplet of liquid fuel in free flight, it was considered desirable to develop a method whereby the burning droplet could be observed and photographed continuously during the entire burning process. Not only would this method lend itself to straight photographic studies, but it would also be easily adaptable to studies by shadowgraph, schlieren, or interferometer techniques if these methods should become desirable. Present efforts are therefore directed towards the design and construction of such a system.

DISCUSSION

1. Preliminary Considerations

Two techniques for obtaining photographs of a burning liquid drop of fuel in free flight were considered, and a selection was made on the basis of the type of photographic record obtainable, the amount and type of equipment involved, and the ease of operation and maintenance.

The first of these methods involved photographing the burning drop at about three of four stations during its descent in a low-turbulence vertical wind tunnel. At each station two photographs of the drop would be taken in quick succession on a single film using the method described by Professor J. L. York[10]. The distance between the two images on the film would be proportional to the velocity of the drop, which can easily be computed when the time interval between the two exposures is known. Negatives from each of these stations would combine to form a short history of the burning process.

Photoelectric control of the camera and high-speed flash-lamps would be triggered by the light of the burning drop, thereby insuring exposure at the correct time, and a fixed time delay incorporated in the electrical control circuit would provide the necessary delay for getting the second image on the film.

While this technique seems quite feasible for producing the desired results, the amount of photographic and electronic equipment required stands as the main drawback. A complete photographic setup of photoelectric tube, electronic amplifying and timing equipment, camera, and two high-speed flash-lamps would be required for each station. When multiplied by three or four stations, the amount of equipment becomes objectionable.

Because of lower equipment requirements and because of the possibility of obtaining a continuous photographic record of the burning process from start to finish, the second method was chosen for a first attampt in preference to the one just described.

2. Description of Method for Studying Burning Droplets

In the second method proposed for photographing burning droplets, the drop is suspended on a column of air rising through a low-turbulence vertical wind tunnel, so that the drop stays in the field of view of a motion-picture or still camera placed near the wind tunnel. This method would provide a complete photographic history of the burning drop from drop formation and ignition to completion of the burning process. Elimination of all the photoelectric controls and electronic timing circuits required for the first method described, and of all but one camera and possibly one high-speed flashlamp, are additional factors favoring the selection of this second method.

The method of suspending a drop of liquid on a rising column of air is based on the method used by Blanchard[1] in his study of rain-drop formation. His report gives a brief description of the construction of the wind tunnel and the use of window screen and drag plates to obtain the desired pressure profile across the mouth of the tunnel. It is stated that a great deal of experimentation was involved before a wind tunnel design was obtained which actually held the drop suspended in space. In view of this fact, it is felt that considerable time will be saved by starting out with a wind tunnel of similar design. This is being done, and the design of the first model is shown in Fig. 1.

3. Drop Formation

Some work has been carried out in an attampt to obtain single droplets of uniform size in the general size range of 1000 microns and lower. The method which gives greatest promise of success is that employing a capillary dropper, containing fuel at atmospheric pressure, which is surrounded by a concentric nozzle housing through which air is pulsed by the capillary outlet. The size of the liquid droplet, considering only the effect of the design of the microdropper and disregarding those of the liquid properties, is largely dependent upon the diameter of the capillary outlet, the velocity of the pulsed air passing the capillary outlet, the distance that the capillary outlet protrudes beyond the end of the nozzle, and the velocity of the column of air rising from the wind tunnel.

Fig. 2 shows the construction of the microdropper. The two main parts consist of the glass capillary dropper and the concentric nozzle housing made of brass. The capillary dropper is made by drawing standard glass tubing into a fine capillary and breaking off the capillary at the desired diameter.

The microdropper housing is made in two main sections, the main body and the detachable nozzle. This is done so that nozzles of various sizes and shapes can be used if this should prove necessary for proper drop formation. The nozzle contains three centering screws for centering the capillary in the nozzle opening. The body is closed off at one end by a neoprene stopper, which serves primarily as a means for holding the glass dropper. A short length of brass tubing attached to the main body serves as the air inlet.

In order to obtain a high-velocity air pulse through the microdropper, the air inlet tube is connected to a supply of high-pressure air. Opening a valve in the connecting line momentarily will allow a pulse of the high-pressure air to pass through the microdropper body and out through the nozzle. As the air pulse passes the capillary outlet, it wipes off the liquid droplet suspended from its end.

4. Ignition of Drop

To date little has been done in investigating the various methods for igniting the drop. A few tests have indicated that dropping the drop very close to a small flame at the end of a hypodermic-sized bunsen burner would work quite well, but the effect of the flame on the air stream is not as yet known. Whether this will have any effect on the stability of the suspended drop will have to be determined by further tests.

5. Vertical Wind Tunnel (Preliminary Design)

The purpose of the wind tunnel is to provide a rising column of air of such characteristics that it will support a drop of burning fuel within the field of view of a stationary camera during the entire burning process. It is conceivable that the tunnel may have to respond to slow transient motions such as might arise from the gradual decrease in droplet mass as it burns, but no provisions are contemplated for transients having high frequencies and large amplitudes such as might arise from turbulent flow.

The wind tunnel, Fig. 1, consists of three sections, the slightly modified standard commercial blower set, the section for filtering out large turbulent flows, and the observation section.

A standard American Blower Utility Set, having a 9-inch diameter blower and driven by a 1/2-hp a-c motor has been procured for moving the air through the tunnel. Referring to Fig. 1, a short duct containing a butterfly valve is attached to the inlet, providing a means for regulating the air flow. Gauze placed over the intake opening is used to filter out most of the dirt which would otherwise be trapped by the screens in the flow-control section of the wind tunnel. The blower outlet is altered slightly to provide a constant cross-sectional passageway between the blower outlet and the entrance to the wind tunnel.

The first section of the wind tunnel acts to decrease the turbulence level of the blower discharge air and to bring about a more nearly laminar flow. This is accomplished by passing the air through several layers of screens, each layer being placed about thirty mesh lengths downstream of the preceding layer. Two plates, crossing in the center of the tunnel at ninety degrees, are placed over the final layer of screen. These plates introduce drag to the center of the air column and help bring about the desired pressure profile across the tunnel. A screen disc, 2 inches in diameter, suspended by fine wires in the center of the tunnel directly above the drag plates, smooths out the low-velocity flow coming off the drag plates and provides the low-pressure well in which the liquid drop is suspended. The type of pressure profile across the tunnel above the disc is shown in Fig. 3.

An observation section is built around the region where the drop is to be suspended and is merely an extension of the wind tunnel having two opposite sides made of glass. This section protects the suspended drop from stray external air currents and allows both visual and photographic observations to be made of the burning droplet.

6. Proposed Experimental Procedure

Drops of the liquid fuel which are formed by the microdropper can be varied in size by using droppers of different capillary diameters and by varying the velocity of the pulsed air jet. The drops thus formed are made to pass very close to a small bunsen flame, where they are ignited. Since the flame is in the field of view of the camera, the diameter of the drop before ignition can be obtained from the photographic film. After being ignited, the drop falls into the low-pressure well in the rising air column and continues to burn at this spot until the entire drop of fuel is consumed. The entire process of ignition and complete burning is photographed by a high-speed motion-picture camera, and the resulting record can be studied to get a better understanding of the process of burning single droplets of liquid fuel in free flight.

CONCLUDING REMARKS

The outlined technique proposed for burning single fuel droplets in free flight is the result of a rather extensive literature survey but of only a small number of preliminary tests that have been made up to the present time. The apparatus described was designed to meet the need for a piece of working apparatus which can lend itself quite readily to various preliminary tests that are still to be carried out. Some of these are concerned with drop formation, ignition, photographic measurements of drop size, illumination for best photographic image, measurements of drop velocities relative to the air column, obtaining stabilized drop suspension for all drop sizes, and effects of variations in ambient conditions such as pressure and temperature.

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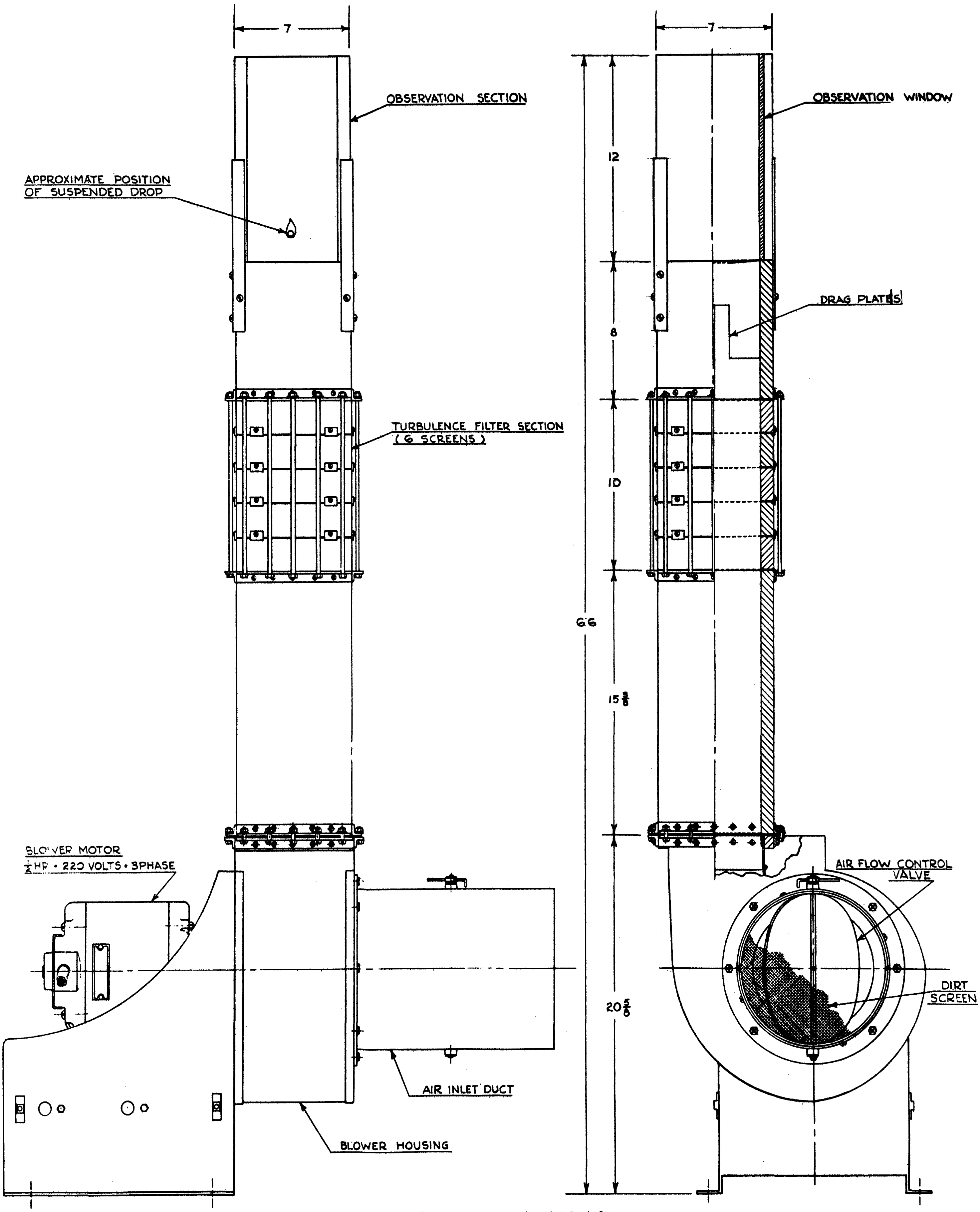

FIG. 1 VERTICAL WIND TUNNEL, PRELIMINARY DESIGN

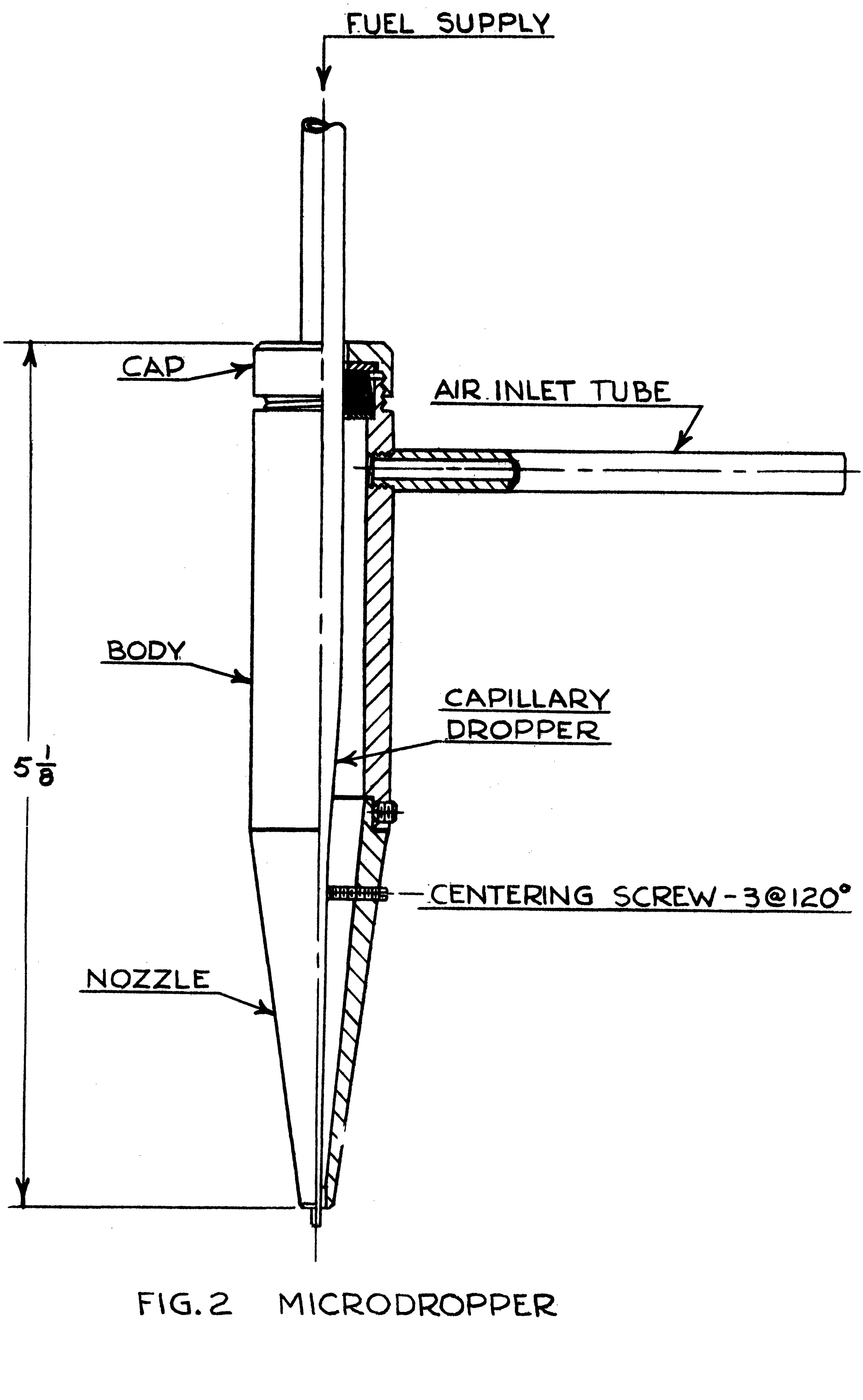

FIG. 2 MICRODROPPER

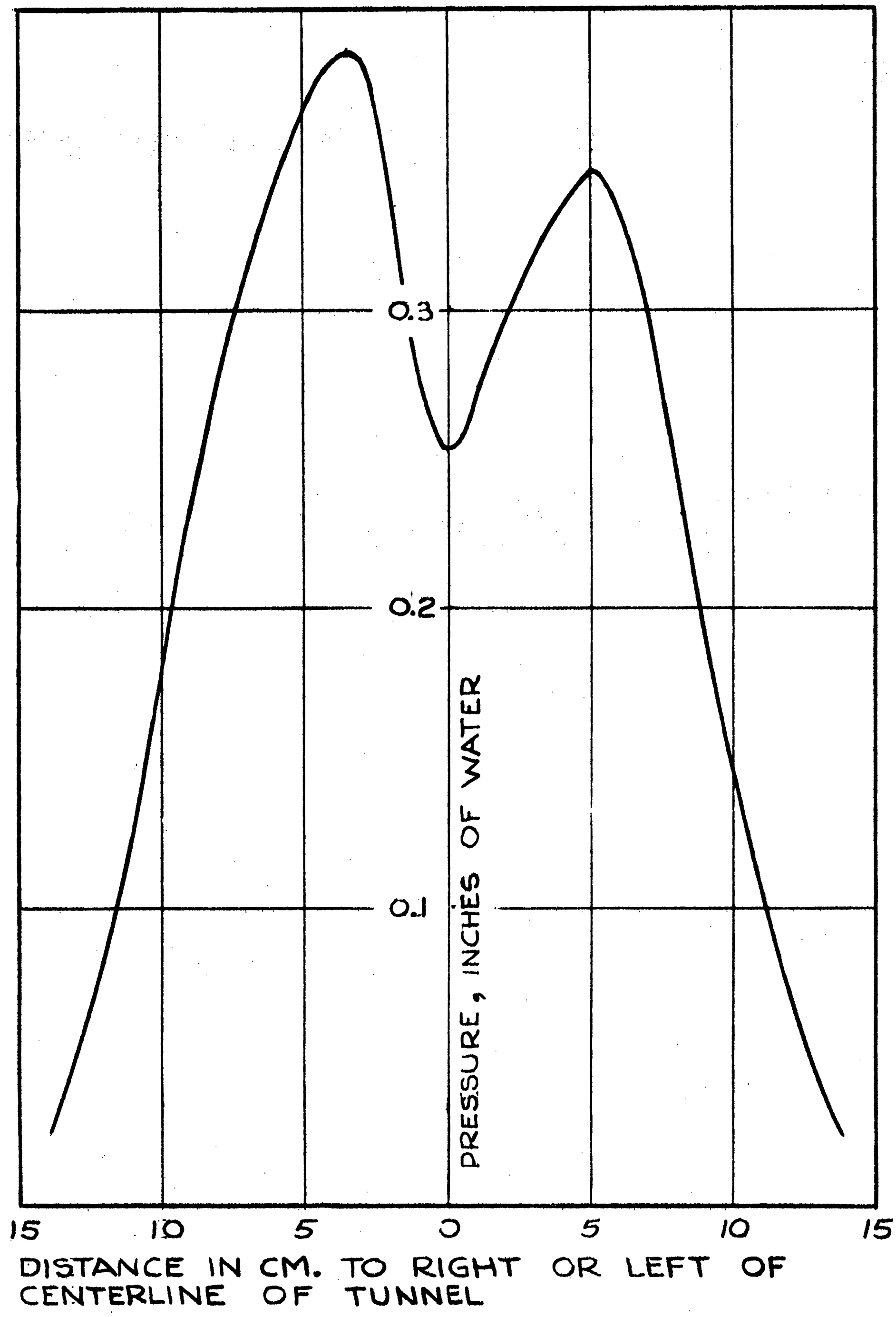

FIG. 3. PRESSURE PROFILE ACROSS AIR STREAM ABOVE TUNNEL - FROM REFERENCE (1)