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ACROSS A CYLINDER.

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AIR-WATER SPRAY FLOW HEAT TRANSFER

ACROSS A CYLINDER

APPROVED BY

DISSERTATION COMMITTEE

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ABSTRACT

Forced convection heat transfer from vertical cylinders normal to an air-water spray flow stream was measured over an air velocity range from 60 to 140 ft./sec. and a water spray density range from 0.03 to 0.50 lb_m/(min.)(sq.in.). Local heat transfer coefficients were determined at 15 degree intervals around the circumference of both a 1.5 inch and a 1.0 inch diameter cylinder.

It was found that the addition of 0.426 lb_m/(min.)(sq.in.) of water spray to a 133 ft./sec. air stream raised the stagnation point heat transfer coefficient from 45 to 1650 Btu/(hr.)(sq.ft.)(F). Similar heat transfer intensification was found for other angles around the tube circumference, however, the magnitude decreased with increasing distance from the stagnation point.

Local heat transfer coefficients were normalized with respect to their corresponding stagnation point values and plotted parametrically as a function of angle and air velocity. These profiles showed that the normalized heat transfer coefficients decreased with increasing air velocity at angles other than the stagnation point.

Average cylinder heat transfer coefficients were calculated from the air-water data and correlated by the following equation:

$$Nu_m = 0.44\ (Re_w)^{0.633}\ (Re_a)^{0.264}$$

The fluid properties were calculated for the average film temperatures on the leading half of the cylinder. This correlation, derived from a boundary layer analysis on the cylinder in conjunction with the experimental data, applies over the air velocity and water spray density ranges mentioned above.

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CHAPTER I

INTRODUCTION

In recent years, forced convection heat transfer around submerged bodies has been extensively studied in an attempt to understand its effect in aerodynamic systems and heat exchange equipment. Although heat transfer from a body submerged in a flowing fluid is a complicated process due to such factors as turbulence, body shape and flow regime, it is quite well understood for a wide range of these parameters. In many cases, heat transfer rates can be predicted theoretically.

The addition of a second component and/or a second phase to the flow stream makes the situation extremely complex. In the case of a liquid spray in a gas stream, additional parameters such as droplet size, quality, relative velocities, relative temperatures and relative flow rates may become important. Even with its complexity, such a system merits investigation because of the high heat transfer rates obtainable with relatively small amounts of liquid injected into the gas stream. Information derived from such an investigation can be useful in aerodynamics as well as in cooling equipment design.

Background

Forced convection heat transfer data from submerged bodies are usually reported as a family of curves of local Nusselt number versus angle with the Reynolds number as the parameter. A typical heat transfer curve at one Reynolds number for a circular cylinder normal to the flow stream is shown in Figure 1. Starting at the stagnation point, the local heat transfer coefficient decreases around the cylinder until the vicinity of the separation point is reached. Then it increases again around the back of the cylinder.

On the front portion of the cylinder, the boundary layer can be laminar, turbulent or, sometimes, laminar with a transition into turbulent depending upon the free stream flow characteristics (31). The boundary layer breaks off at the separation point due to the adverse pressure gradient around the rear of the cylinder and forms a vortex pattern as the fluid flows from the separation point downstream. The heat transfer rate reaches a minimum at the separation point due to the flow characteristics.

Many investigators (9,16,17,26,27,32,41) have

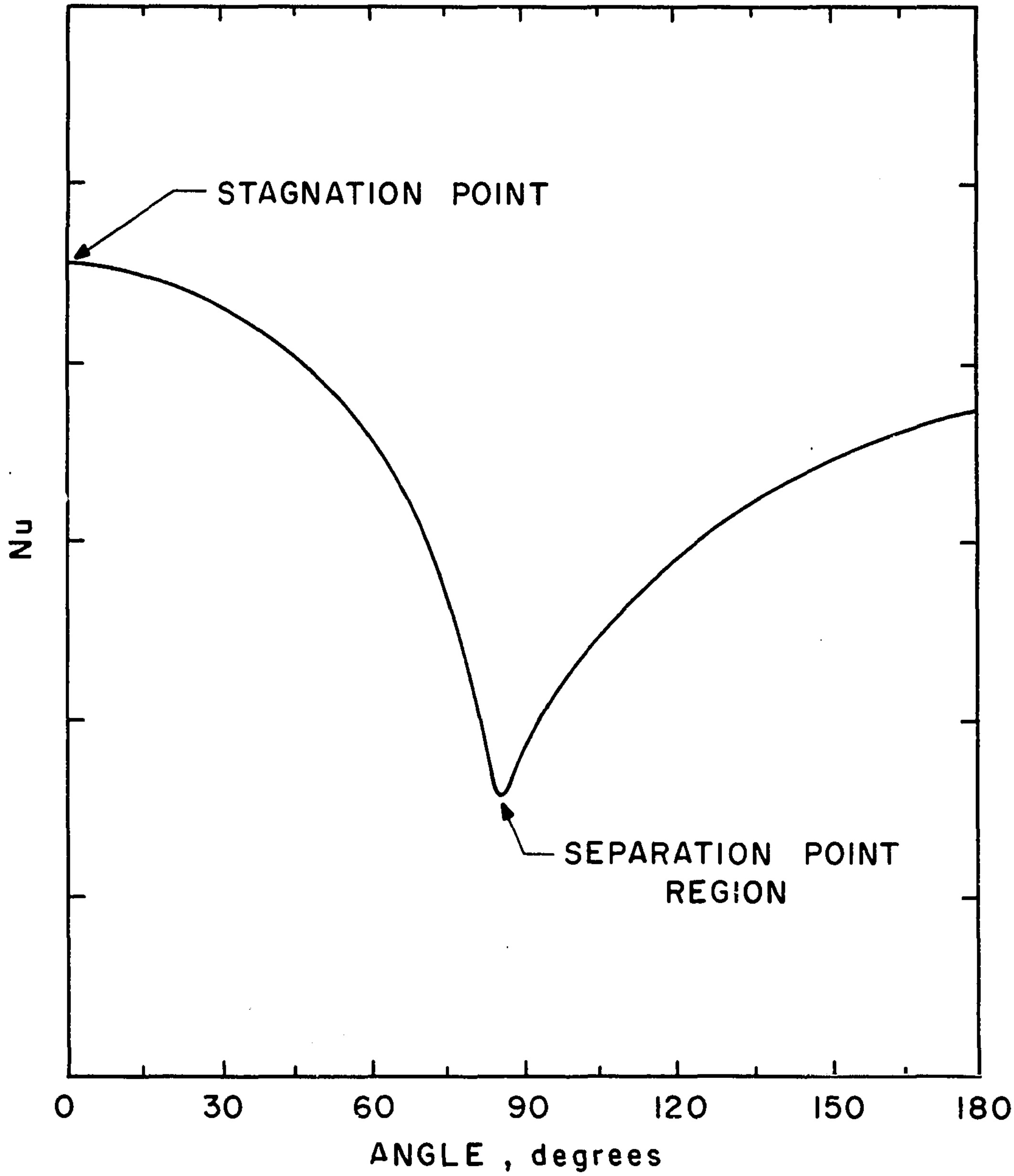

FIGURE I. FORCED CONVECTION HEAT TRANSFER CURVE.

studied the Reynolds number effect on the heat transfer curve for a cylinder normal to an air flow stream. Increasing Reynolds number causes a general increase in the heat transfer rates around the cylinder. The effect of turbulence on heat transfer was studied by several investigators (16,18,21,33,42) for a cylinder in crossflow air. Similar to the Reynolds number effect, increasing free stream turbulence increases the heat transfer rate. Maximum reported heat transfer coefficients for air flow in the subcritical Reynolds number range never exceed 100 Btu/(hr.)(sq.ft.)(F). The critical Reynolds number is defined as the free stream Reynolds number at which the boundary layer flow makes a transition from the laminar to the turbulent regime on the cylinder surface.

Heat transfer to liquid streams from submerged bodies produces considerably higher rates than gases when compared at the same Reynolds numbers. Fand (12), in his study of forced convection around a cylinder, and Brown, Pitts and Leppert (5), in their study of forced convection around a sphere, measured stagnation point heat transfer coefficients of 3000 Btu/(hr.)(sq.ft.)(F) at free stream water velocities of 30 ft./sec.

Theoretical analyses have been applied to the front portion of a cylinder in transverse flow by several investigators. A survey of fifteen such analyses for air flow has been presented by Spalding and Pun (38). They found large differences between various predictions and were unable to make final conclusions due to a lack of enough reliable experimental data. In addition to the analyses mentioned above, many other investigators (2,5,13,14,15,22,26,30,41) have done theoretical work in association with submerged bodies in flowing streams. In many of these analyses, the heat transfer predictions do not accurately predict experimental results since such factors as free stream turbulence and surface characteristics are excluded from the analyses.

Air-Water Spray Flow

As mentioned previously, gas-liquid spray flow heat transfer is considerably more complex than one-phase forced convection. In order to understand its complexity, a diagram of the air-water spray flow pattern around a cylinder is shown in Figure 2. Water spray, flowing toward the cylinder, forms a tangential envelope terminating at the cylinder at an angle less than 90 degrees from the stagnation point. Water spray flowing outside this envelope never impinges the cylinder surface. The tangential angle of intersection with the cylinder is a function of droplet size, droplet velocity and air velocity. Brun and Mergler (6) have theoretically developed local impingement rates over a wide range of the above parameters. Dorsch and his co-workers (10) have generated similar information for spheres.

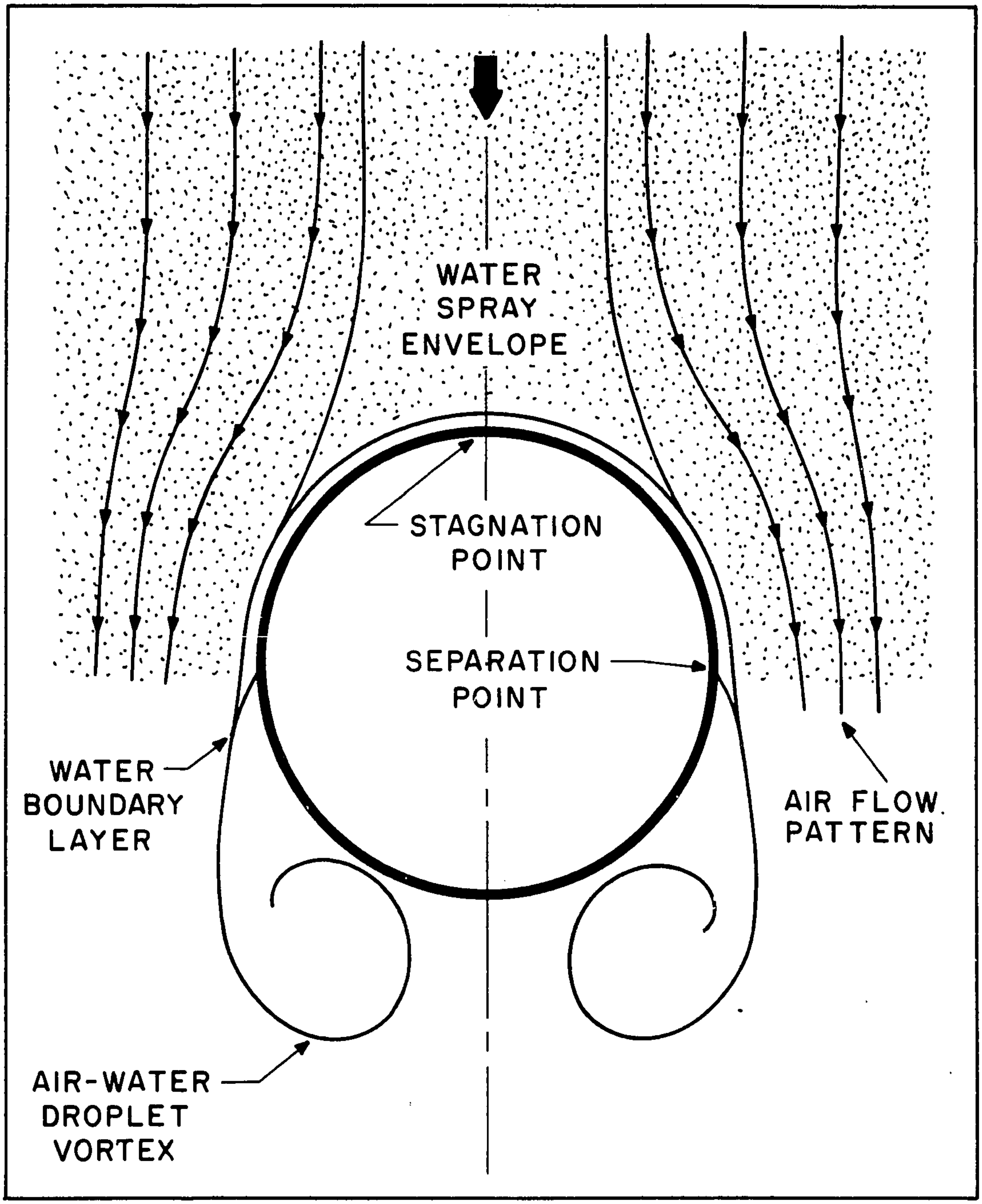

FIGURE 2. AIR-WATER SPRAY FLOW PATTERN AROUND A CYLINDER.

The water spray impinging the cylinder forms a water film or boundary layer on the forward portion of the cylinder. Due to the momentum imparted to the water layer from the incoming spray and the flowing air stream, the fluid within this layer flows around the cylinder to the separation point. Here, much of the water leaves the cylinder and flows downstream in the air-water droplet vortices. Also, if the cylinder is in a vertical position, gravity becomes an important force at the separation point and pulls the remaining water down the cylinder wall. The rear portion of the cylinder does not contain a water film--only occasional droplets splashing back from the vortices. These droplets flow toward the separation point from the rear portion of the cylinder and down the cylinder wall simultaneously. At the separation point, they join with the water film coming from the forward portion of the cylinder and either leave the wall again or flow down the wall.

One of the first heat transfer investigations in spray flow was performed by Tifford (40) in a study which was concerned with the flat plate geometry. At approximately the same time, Acrivos, Ahern and Nagy (1) conducted the first heat transfer investigation from a cylinder in an air-water spray flow environment. Their study was both analytical and experimental. Their experimental equipment consisted of a 1.5 inch diameter cylinder positioned vertically in a horizontal wind tunnel. The cylinder was designed to achieve a constant surface temperature around the circumference. By varying the heat input every 30 degrees around the cylinder, they were able to determine the local heat transfer coefficients. Their results consisted of local heat transfer coefficients at two air velocities and two spray densities. Due to non-homogeneous water spray distribution from the nozzles, their heat transfer information was not symmetric about the stagnation point. Nonetheless, the results showed as much as an eight-fold increase in the local heat transfer coefficients when compared with dry air flow.

Acrivos and his co-workers postulated four analytical models to describe the two-component heat transfer. Of the four, a conduction and convection film model more closely resembled the observed experimental phenomena. This model assumed that the heat produced on the front portion of the cylinder was absorbed in the liquid film as sensible heat. Assuming the film to be at the wall temperature for an upper bound, the maximum heat transfer intensification was predicted to be 45.

Shortly after the conclusion of the Acrivos study, two consecutive studies (19,39) were begun at the Air Force Institute of Technology. The experimental appratus utilized in these studies was essentially the same as the study described above. However, improvements in the water spray system yielded more homogeneous and symmetrical spray distributions than previously achieved.

In the first of these studies, Hoelscher (19) studied the effect of increasing water rate on the heat transfer for a single air velocity. Also, a local heat transfer coefficient profile was determined for an air velocity of 135 ft./sec. and a water-air mass ratio of 0.048. Using the inlet dry air temperature as the reference temperature, Hoelscher calculated a maximum heat transfer coefficient of 650 Btu/(hr.) (sq.ft.)(F) at the stagnation point. However, due to experimental difficulties in achieving a constant surface temperature around the cylinder, his results showed a zero heat transfer coefficient on the rear portion of the cylinder. Even at the minimum condition of no water spray, the rear side heat transfer coefficients are normally significant. The occasional water droplets striking the rear side of the tube as a result of the vortices should have raised his rear side heat transfer to a significant fraction of the front side heat transfer. Part of his difficulty may have been in the choice of a reference temperature since the dry air temperature does not have any connection to the true temperature driving force for heat transfer on the rear side of the cylinder.

Takahara (39) modified the test cylinder somewhat and used a steam injection system to raise the incoming air temperature to match the water droplet temperature. By doing this, he raised the relative humidity within the wind tunnel to 100 per cent and facilitated an easy choice for the reference temperatures in the flow stream since all these temperatures were identical. Takahara's investigation covered three air velocities and three water-air mass ratios for each velocity. A maximum stagnation point heat transfer coefficient of 2480 Btu/(hr.)(sq.ft.)(F) was measured for a Reynolds number of 110,000 and a water-air mass ratio of 0.041. For the same conditions, his average cylinder heat transfer coefficient was 352 Btu/(hr.)(sq.ft.)(F). As in the previous study, local rear side heat transfer coefficients were zero indicating experimental problems existed even with this modified constant surface temperature test cylinder.

Concurrent with Takahara's study, Northern Research and Engineering Corporation began an investigation (35,36) using a vertical wind tunnel and a horizontal cylinder. Due to this orientation, the gravity force acted in conjunction with the flow forces instead of pulling the water down the cylinder as in previous studies. An improved constant surface temperature cylinder design contributed to more accurate heat transfer coefficient profiles as a function of angle. For an air velocity of 63 ft./sec. and a water-air mass ratio of 0.024, the reported stagnation point heat transfer coefficient was 700 Btu/(hr.)(sq.ft.)(F). From there, it dropped to a minimum at 90 degrees and then increased to 140 Btu/(hr.) sq.ft.)(F) at 180 degrees. Data was taken at twelve points around the two inch diameter cylinder for two air velocities and several water spray densities. In conjunction with the experimental work, an analytical study was conducted. The analysis consisted of assuming second order temperature and velocity profiles in the liquid boundary layer around the front portion of the cylinder. The air was assumed incompressible and it was assumed that there was no droplet bouncing phenomena. The necessary mass and momentum balances were set up and solved for the boundary layer thickness and velocity as a function of spray density, air velocity and angle. An energy balance was written and, after taking into account sensible heat in the liquid film and convective and evaporative heat transfer from the film to the air, a solution was obtained for the heat transfer coefficient at the tube wall. The analytical results showed an order of magnitude agreement with the experimental results, but were more dependent upon the air and water droplet velocities than was observed experimentally.

Object of Investigation

The present work was undertaken in an effort to obtain additional heat transfer information over a wide range of air velocities and water spray densities. Included in the study was the use of more than one constant heat flux cylinder to isolate diameter effects. One goal was concerned with finding the reference temperature which yields the best temperature driving force and, thus, the most reproducible heat transfer coefficients. Moreover, by studying the heat transfer at frequent intervals around the cylinder, it was possible to obtain more refined profiles than in previous investigations. This investigation was also concerned with obtaining a correlation of the average cylinder heat transfer coefficients in air-water spray flow from a theoretical boundary layer analysis combined with the experimental data.

CHAPTER II

DESCRIPTION OF EQUIPMENT

Introduction

It was desired to obtain representative heat transfer data for the air-water spray system over an air velocity range from 60 to 140 ft./sec. and over a water spray density range from 0.0 to 0.5 lb_m/(min.)(sq.in.). The equipment had to be designed to handle heat fluxes up to 12,000 Btu/(hr.)(sq.ft.) and temperatures up to about 200 F. Also, to insure steady-state conditions in the bulk flowing fluids, it was imperative that the equipment be housed in a controlled environment where changes in humidity as well as changes in ambient water and air temperatures could be minimized.

The experimental apparatus consisted primarily of an electrically heated heat transfer tube, a wind tunnel and blower, a water spray system, a stainless steel demister and instrumentation.

As a precaution against saturating the air in the laboratory, the heat transfer tube was enclosed in a Plexiglas housing. Thus, the air-water spray flow was contained

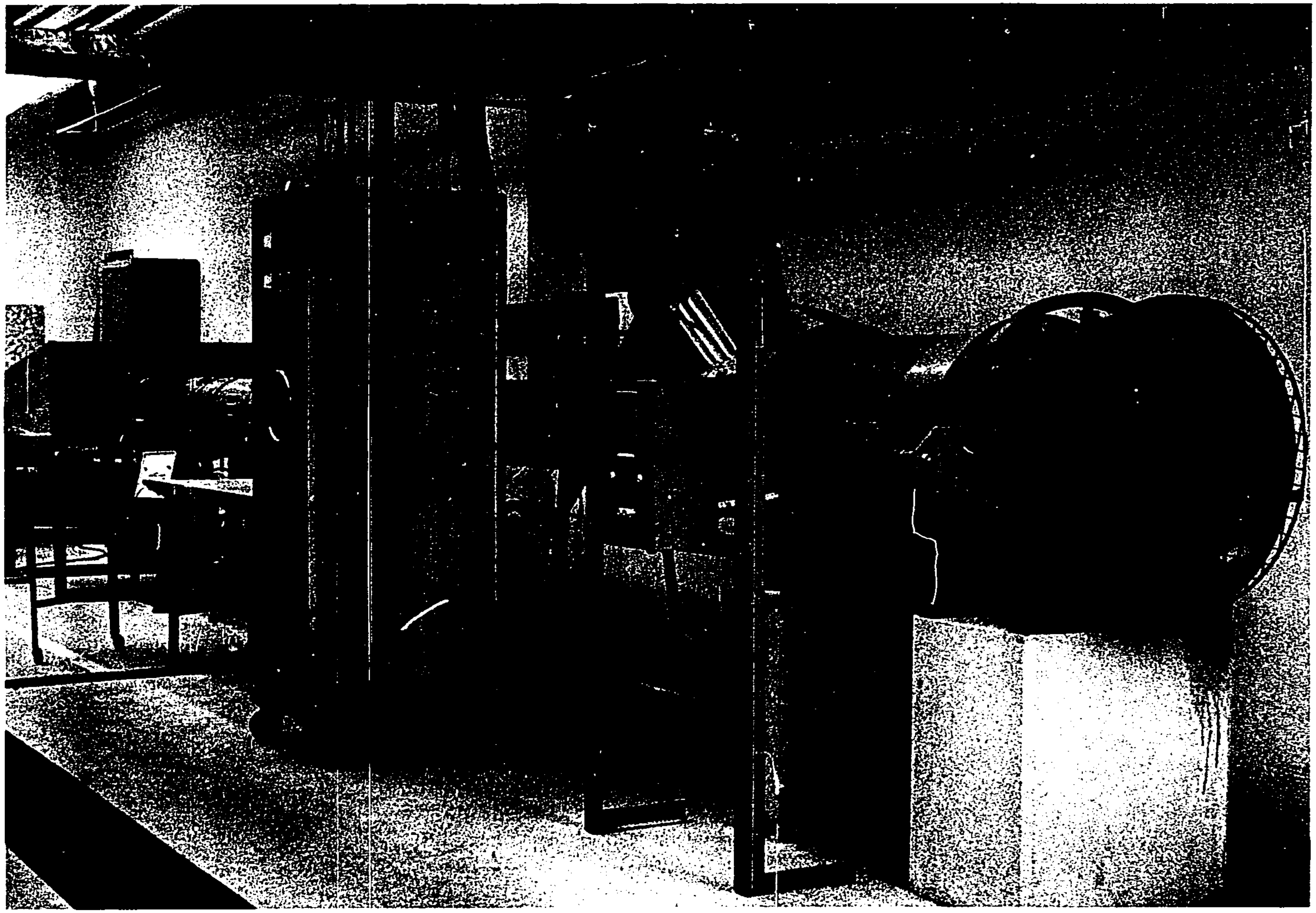

FIGURE 3. EXPERIMENTAL APPARATUS.

in the system until it reached the demister pad. The demister was designed to remove most of the entrained water from the air stream before the air stream left the system. The laboratory central ventilating system maintained a fairly constant humidity and temperature in the room and, thus, gave uniform intake air to the wind tunnel.

Air from the wind tunnel blower passed through a 12 inch diameter air flow straightening section where the water spray was injected into the air stream. The air-water stream then flowed past the heat transfer tube in the test chamber and, finally, into the demister section.

A photograph of most of the experimental equipment and instrumentation is shown in Figure 3. A diagram of the apparatus is shown in Figure 4.

Heat Transfer Tube

Two basic types of cylindrical heaters have been utilized in forced convection heat transfer studies. One type is designed to achieve constant surface temperature around the tube circumference while the other type is designed to achieve constant flux. The constant surface temperature type was utilized by Acrivos, Ahern and Nagy (1), Northern Research (35,36), Hoelscher (19) and Takahara (39), all for air-water spray flow studies. This system basically consists of a solid copper rod with cartridge heaters and thermocouples

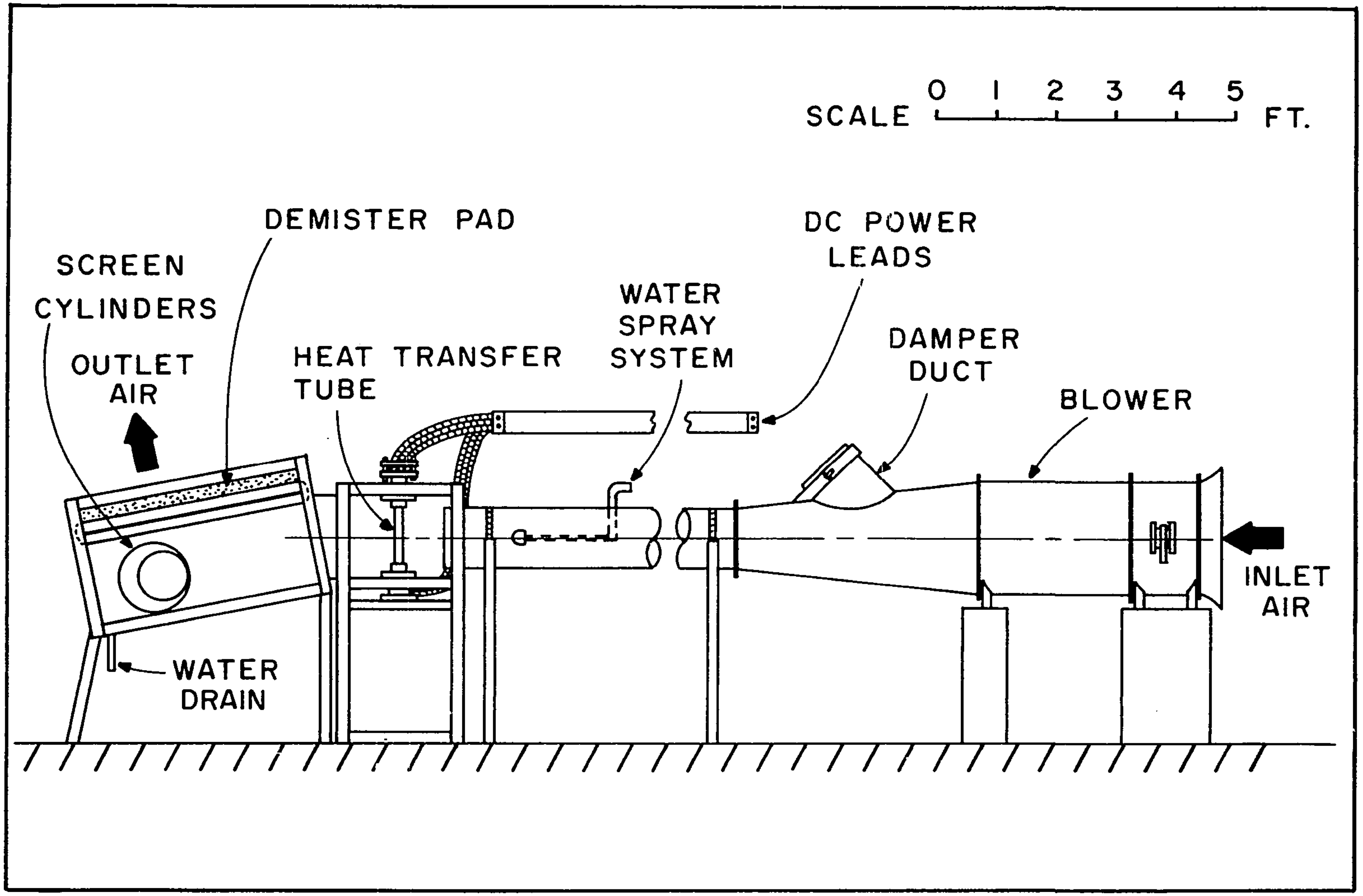

FIGURE 4. DIAGRAM OF EXPERIMENTAL APPARATUS.

spaced at regular intervals around the circumference of the rod. Each heater is individually controlled until all the thermocouples indicate identical temperatures. Local heat transfer coefficients are then calculated from the power requirements of the individual heaters around the rod and one ΔT measurement.

The constant heat flux type heat transfer tube was used by Perkins and Leppert (26,27), Seban (33), Geidt (17,18) and many others for one component forced convection systems. This heater design consists of utilizing an electrically heated thin wall tube or a tube with a strip heater wound around the outside. There are several advantages to this type of heater. It requires fewer thermocouples and auxiliary power facilities since the tube can be rotated to obtain surface temperature information as a function of angle. Also, the tube reaches steady-state conditions rapidly since there is very little material to heat. With this type of heater design, local heat transfer coefficients are calculated from one heat flux measurement and a series of temperature measurements around the cylinder circumference. Because of its ease of fabrication and its simplicity of operation, the constant flux heater design was chosen for this study.

Two heat transfer tubes were constructed during the course of this study. Tube "A" had an outside diameter of 1.5 inches and a wall thickness of 0.028 inches. Tube "B" had a 1.0 inch outside diameter and a 0.025 inch wall thickness. Both tubes were 11 inches long and were constructed of type 304 stainless steel.

Three surface thermocouples were installed on each tube. One was located midway along the length; the other two were spaced 1.5 inches on either side of the middle thermocouple. The thermocouple design chosen for this application was similar to those first used by Moore and Mesler (25). It was designed, fabricated and installed in tube "B" by Moeller (24) at Mo-re, Inc., Bonner Springs, Kansas. Identical thermocouples were installed in tube "A" at the Heat Technology Laboratory, Inc., Huntsville, Alabama. The installations consisted of 0.015 inch diameter coaxial Chromel-Alumel surface thermocouples, silver soldered into the tube wall. The thermocouple junctions were created on the outside surface by abrading with number 160 abrasive paper to carry slivers of the Chromel tubing over to the center Alumel wire. A cutout view of an installed surface thermocouple is shown in Figure 5.

After the thermocouples were installed, each tube was packed lightly with glass wool insulation to minimize interior convection. Machined copper bus bars containing voltage taps were then press fitted into both ends of each tube. Set screws were installed in insure that the tube-bus bar connections would always remain solid. The bottom bus bars con-

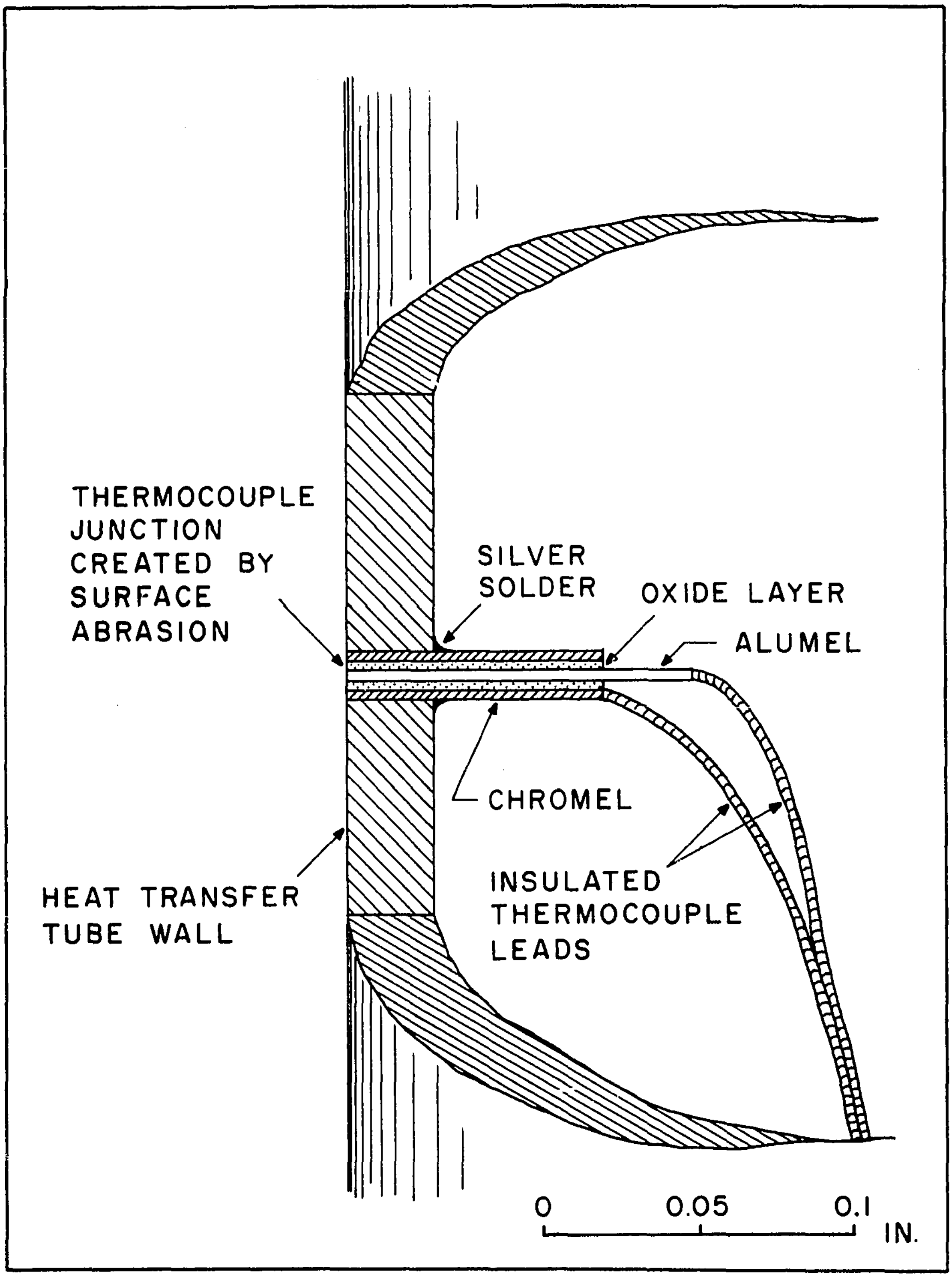

FIGURE 5. SURFACE THERMOCOUPLE INSTALLATION.

tained a ¼ inch hole for the thermocouple wires and voltage tap wires to pass through.

The tubes were designed to rotate on their axes so that the surface thermocouples could be rotated circumferentially relative to the stagnation point. In order to accomplish this, the tube bus bars and the stationary leads from the DC power source were machined in such a manner as to allow electrical contact to be made through amalgamated mercury connections.

A drawing of the heat transfer tube and its supports is shown in Figure 6.

Test Chamber

The enclosed test chamber contained the heat transfer tube with its supports and a traversing system to measure air velocities and water spray densities. A photograph showing the test chamber is presented in Figure 8.

The completed heat transfer tube was mounted within the test chamber in a vertical position five inches downstream from the end of the wind tunnel duct. At both ends of the tube, ¼ inch thick supporting plates held the tube in place within the test chamber. Teflon spacing rings separated the bus bars at both ends from the supporting plates. Thus, the test stand was effectively electrically insulated from the heat transfer tube and the tube could rotate easily because of the Teflon bushings.

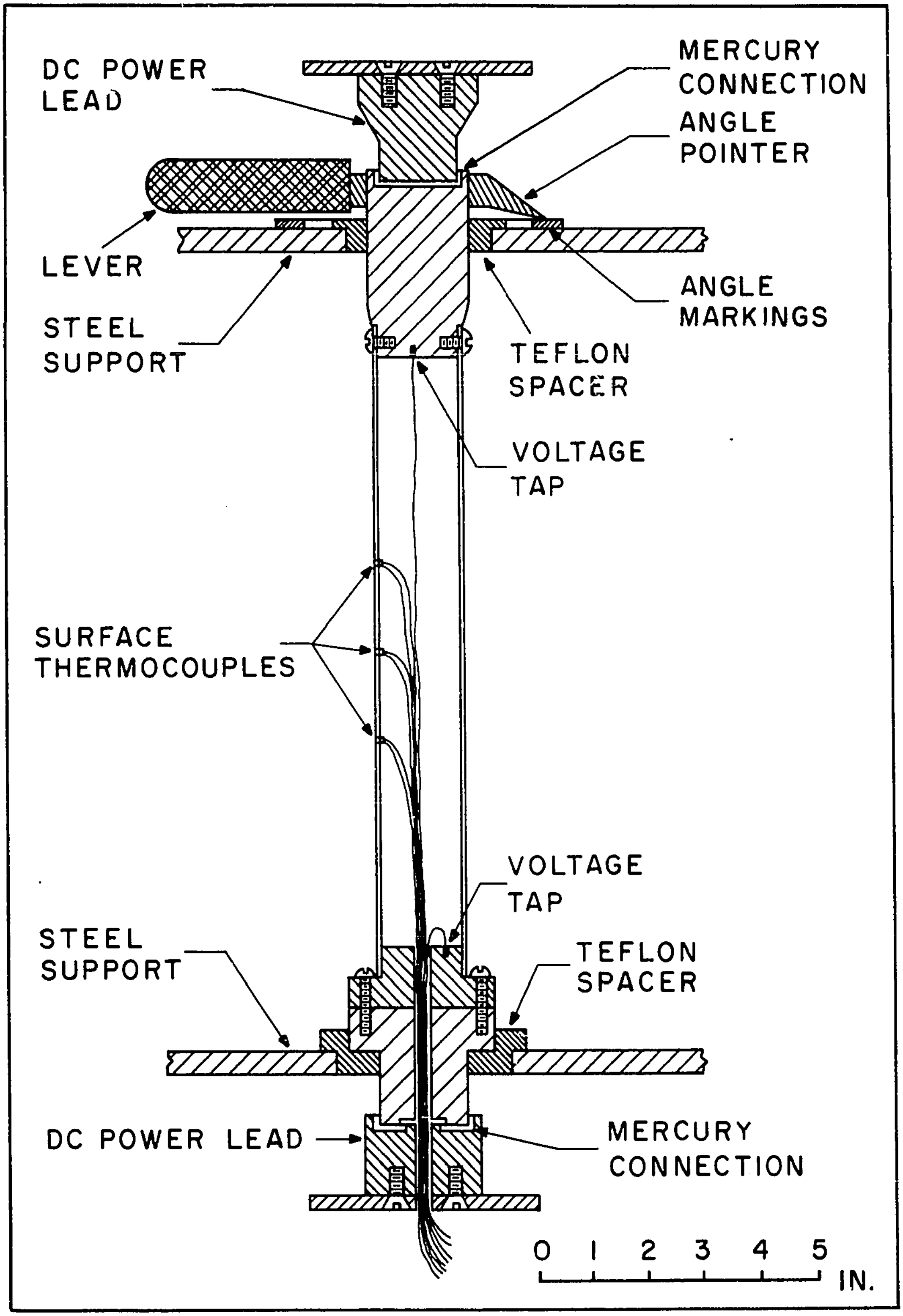

FIGURE 6. HEAT TRANSFER TUBE AND ASSEMBLY SECTION VIEW.

The test section was enclosed in Plexiglas to form a rectangular channel 16 inches wide by 16 inches high by 21 inches from the end of the wind tunnel duct to the demister section. A lever for rotating the cylinder and a pointer were connected to the heat transfer tube top bus bar outside the test chamber. Angle markings were put on the top steel support. Thus, from outside the test chamber it was possible to rotate the tube and its surface thermocouples to any desired position relative to the stagnation point. Simple design of the test chamber made it possible to install either tube "A" or "B" easily and to remove them quickly for inspection or repairs as necessary.

An externally controlled traversing system was built into the test chamber two inches upstream from the heat transfer tube. This made it possible to measure free stream flow properties throughout the plane normal to the flow stream. The traversing system consisted of two vertical rods and one horizontal rod, each calibrated with half inch incremental markings. An adaptor was affixed to the horizontal rod which held either a water spray collection system or a pitot tube for measuring air velocities. The spray collection system consisted of five 0.209 inch ID stainless steel tubes spaced ½ inch apart. The five collection tubes were mounted on a brass rod and 3/8 inch copper tubing carried the collected water from the tubes to 25 ml. graduated cylinders located outside the test chamber. This arrangement made it possible to measure the water spray density at five locations simultaneously in a plane perpendicular to the air flow and located two inches upstream from the front of the heat transfer tube. The spray collection system was designed to be removed during heat transfer runs. A photograph of the test chamber with the heat transfer tube, traversing mechanism and water spray collection system in place is shown in Figure 7. Air velocities were measured with a Dwyer 167-12CF pocket pitot tube manufactured by the F. W. Dwyer Manufacturing Co., Michigan City, Indiana.

Wind Tunnel and Blower

The wind tunnel consisted of a blower, a converging section and a straightening section fifteen feet long. Most wind tunnels pull air through the test chamber instead of pushing the air from the blower into the test chamber. Since it was undesirable to have the water spray enter the blower because of corrosion, the wind tunnel design utilizing air flow from the blower to the test chamber was chosen. This design had the disadvantage of more turbulent air flow. A diagram of the wind tunnel is shown in Figure 4.

The air was supplied by a Buffalo size 22A, type "S" Adjustax Axial Fan Blower with variable inlet vanes purchased from the Buffalo Forge Company, Buffalo, New York. The

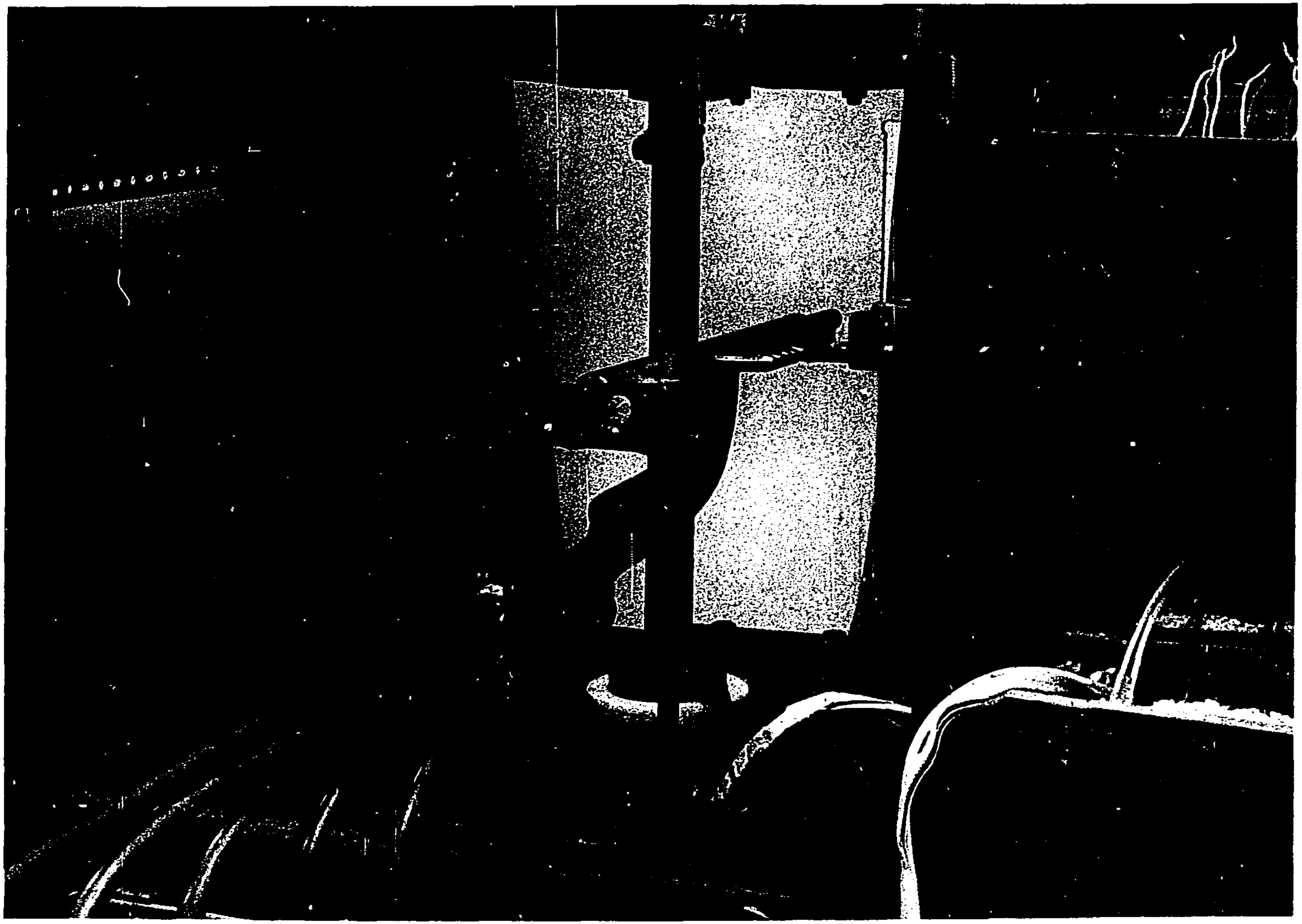

FIGURE 7. WATER SPRAY COLLECTION SYSTEM IN TEST SECTION.

blower contains a 220 volt, three phase, 3500 rpm, 35 horsepower motor located axially to the fan blades within the blower housing. The blower capacity was 10,000 CFM at an eleven inch total pressure drop. A Nema I, size 3 motor starter was used to complete the electrical connections to the blower.

A converging section made it possible to attain velocities up to 140 ft./sec. at the test chamber by narrowing the tunnel diameter from 22 inches at the blower outlet bell to 12 inches. This four foot long section contained a 12 inch diameter damper duct to assist in attaining low air velocities at the test chamber by allowing some air to be vented to the atmosphere. By opening the damper duct and closing the inlet vanes to the blower, velocities as low as 60 ft./sec. were obtained.

The twelve inch diameter straightening section contained straightening vanes, honeycomb and 1/16 inch mesh screen. This section as well as the converging section were constructed from 16 gauge galvanized sheet steel. Four six inch wide straightening vanes were located horizontally two inches apart and five feet upstream from the test chamber. Two 1/4 inch pitch stainless steel honeycomb sections with a screen sandwiched between them were located two feet upstream from the test chamber. Each honeycomb section was one inch thick. The total effect of the vanes, honeycomb and screen was to minimize swirling effects in the air stream and flatten the velocity profile.

The blower was mounted on a 27 inch high concrete block which raised the wind tunnel centerline to a height of 40 inches off the floor. The wind tunnel duct was mounted on angle iron A-frames.

Water Spray System

The spray system consisted of one solid cone spray nozzle located two feet upstream from the heat transfer tube and pointed directly downstream. The water line, constructed of 3/8 inch copper tubing, entered the wind tunnel five feet upstream from the test section and ran along the wind tunnel centerline through the honeycomb to a point two feet in front of the heat transfer tube. At this position, a brass Full-jet solid cone spray nozzle was attached. To vary water spray density, eleven different capacity nozzles, sizes 1/8-G1 through 1/2-G32, were purchased from Spraying Systems Co., Bellwood, Illinois. The system was designed to allow easy interchange of the eleven nozzles. Since these nozzles had flatter spray distributions with higher water line pressure, interchanging nozzles was the best method of varying water spray density.

The nozzle was held in place within the wind tunnel duct by horizontal and vertical guide wires. These wires were fastened outside the duct and made it possible to move the spray nozzle both horizontally and vertically to obtain the best possible spray distribution within the test chamber.

Water was supplied to the spray nozzle from an Electrifugal Pump, size 2X1-1/2, type SS-L manufactured by Allis Chalmers, Milwaukee, Wisconsin. The pump was capable of supplying water to the spray nozzles over the designed water spray density range while maintaining a steady 43 psig line pressure. The pump was used because the laboratory water line pressure fluctuated more than 10 per cent, making it impossible to obtain steady spray density conditions. A bleed line was inserted in the pump water line so that the water spray density could be regulated either by interchanging nozzles or by reducing line pressure.

Demister Section

A type 304 stainless steel demister pad was utilized to remove entrained liquid water from the air-water spray stream before venting into the laboratory. The demister pad, four feet by four feet by four inches thick, was donated by Otto H. York Company, Inc., West Orange, New Jersey. As shown in Figure 4, the demister pad was mounted on top of a Plexiglas enclosed stand at a 15 degree angle downward from the side nearest the test chamber. A drain was located along the low end of the enclosed stand to allow the collected water to flow out of the demister section.

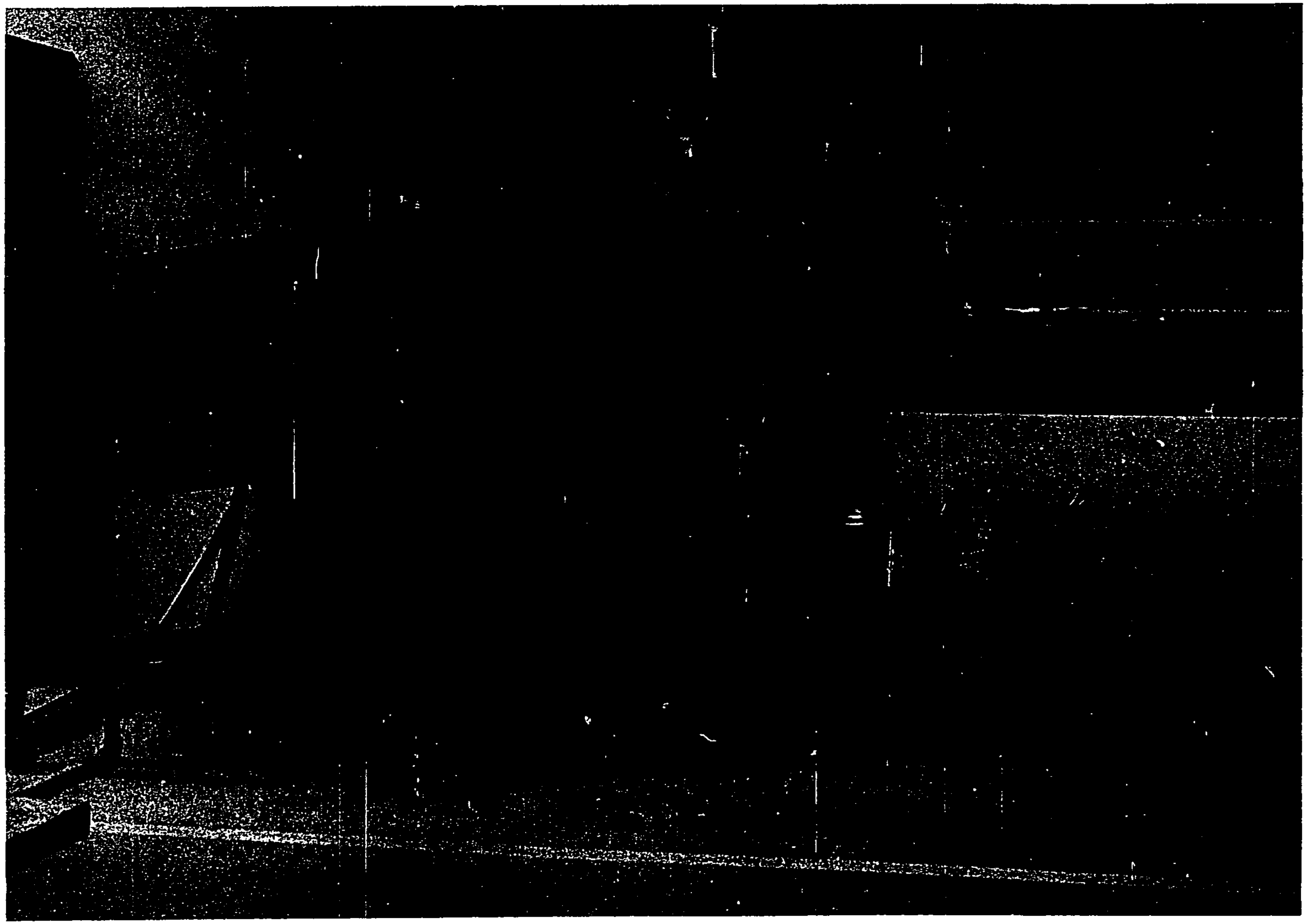

FIGURE 8. DEMISTER, TEST CHAMBER, AND WIND TUNNEL DUCT.

Two 1/4 inch mesh screen cylinders, three feet long, were inserted into the demister section to break up the high velocity flow pattern as the air entered the enclosure. This forced the air to flow uniformly through the entire 16 square foot demister pad and minimized the impact of the high velocity air against the rear wall of the demister section. A photograph of the demister section is shown in Figure 8.

Power and Instrumentation

Power to the heat transfer tube was furnished by an Ultrasil 2-IP2-10-01 silicon rectifier purchased from the Udylite Corporation, Detroit, Michigan. The DC rectifier had a maximum rated output of 2000 amps at 10 volts or 1000 amps at 20 volts, each with a five per cent ripple. Maximum required power in the heat transfer tube was about 800 amps at four volts DC. The rectifier required an 85 amp, three phase, 220 volt power line.

Two 1/4 inch by four inch copper bus bars carried the direct current to the heat transfer tube and back to the rectifier. Three strands of 1/2 inch diameter copper cable were used to connect the bus bars to the rectifier and to the heat transfer tube connections since these points needed flexible connections. The DC line was grounded to eliminate stray AC from the heat transfer tube.

Temperature measurements in the system were made with Chromel-Alumel thermocouples. Three were located on the heat transfer tube surface, one in the air-water stream, one in the dry air stream and one in the water line. The three auxiliary thermocouples were made from 28 gauge Hoskins Chromel and Alumel wire, grade 3-G-178. Fabrication of these thermocouple junctions was accomplished by using the standard gas welding technique recommended by the manufacturer. The thermocouple leads were attached to a Leeds and Northrup 1508662 eleven point selector switch. The thermocouple measurements were made with a Leeds and Northrup K-3 universal potentiometer system. The system included a Leeds and Northrup 9834 D-C null detector, a 099034 constant voltage supply manufactured by Dynage, Inc., Hartford, Connecticut and a standard cell manufactured by the Eppley Laboratory, Inc., Newport, Rhode Island. Surface temperature fluctuations were recorded on a 7701-A direct writing oscillographic recorder with an 8803A high gain DC amplifier manufactured by the Sanborn Division of Hewlett Packard Company, Waltham, Massachussetts.

The DC voltage drop across the heat transfer tube was monitored with a Westinghouse 423282"A" voltmeter with ranges of 0-2.5 and 0-10 volts. This meter was calibrated against the K-3 potentiometer. The DC amperage was measured across a 50 millivolt shunt supplied with the rectifier on a General Electric 8DP9ABH1 ammeter.

The test section pitot tube as well as an auxiliary pitot tube in the wind tunnel duct and a pressure tap in the blower were connected to Meriam 15 inch U-tube manometers. The blower pressure tap and the auxiliary pitot tube were utilized to monitor wind tunnel operating conditions.

Line pressure in the water spray system was monitored by two Ashcroft pressure gauges, one with a range of 0-60 psig and the other with a 0-160 psig range. Water flow rates were measured with a Fischer-Porter flowrator.

CHAPTER III

EXPERIMENTAL METHODS AND PROCEDURES

Initial Preparations

After the equipment installation was completed, instrumentation was calibrated as discussed in Appendix A. It was then necessary to check air flow patterns and attempt to eliminate any swirling motion in the test chamber as detected by a yaw tube. Straightening vanes, honeycomb and wire screen were placed in the wind tunnel duct to create straight flow and to produce a flat velocity profile. Air flow uniformity was further checked by making initial temperature measurements around the heat transfer tube. The air flow was considered satisfactory when the surface temperatures around the tube were symmetrical about the stagnation point.

By making extensive spray distribution tests with several types of spray nozzles, the best nozzle type, nozzle orientation and line pressure were determined. The spray system described in Chapter II was found to be the most effective. Several methods of collecting water spray for the determination of spray density as a function of position in the test chamber were tried. Once it was determined that the spray density measurements were not affected by collection tube diameter, the five tube collection system was chosen. This made it possible to save considerable time in making the spray density measurements.

Bulk temperatures measured in the air-water spray stream varied considerably from one point to another in the flow stream. This was due to nonuniform evaporative cooling within the air-water spray stream. Unless the incoming air was presaturated, tests showed that it was impossible to obtain reproducible data from a bulk temperature measurement made in this stream. To produce consistent local heat transfer coefficients, it became necessary to measure a reference temperature in the proximity of the surface thermocouple. This was verified when the adiabatic surface temperature was measured. Adiabatic surface temperature is here defined as the surface temperature present without heat flow from the tube. Tests disclosed that the adiabatic surface temperature varied as much as 5 F from the upstream to the downstream stagnation points. It was found that, utilizing this local adiabatic surface temperature as the reference temperature in the local ΔT determination yielded highly reproducible heat transfer information at all angles around the tube. Also, by using the adiabatic surface temperature instead of one measured in the air-water spray stream, it was possible to conduct this investigation without presaturating incoming air and without preheating input water or air streams as previous investigators (19,35,36,39) have done.

Occasionally during preliminary testing, continuity at a surface thermocouple junction was lost. The thermocouple junctions were re-established by abrading the tube surface in the vicinity of the junctions until continuity was established in the thermocouples. Tests showed that this process did not change the thermocouple calibrations. By carefully re-establishing the thermocouple junctions in this manner, the junctions were substantial enough to remain in position through all the final runs.

Since the surface thermocouples were homogeneous with the tube surface, the electricity flowing in the tube induced a voltage in the thermocouples. This induced voltage was measured in two ways. First, as described by Bobst (4), by taking a thermocouple reading with the current directed through the tube in one direction and averaging it with one taken with the current reversed, the induced voltage was calculated as the difference between the average reading and one of the unaveraged readings. A second method utilized the Sanborn recorder. As described by Davenport, Magee and Leppert (8), by quickly turning the power off and on, the induced voltage was measured as the amplitude difference of the thermocouple readings. For each thermocouple, these corrections were found to be a function of power only. When the thermocouple junctions had to be re-established during the initial runs, these corrections had to be measured again. The induced voltage corrections, in equation form, are presented in Appendix A for the middle thermocouple in both heat transfer tubes.

On tube "A", initial tests showed that the top and bottom thermocouples were incorrectly installed and the Chromel and Alumel wires were in contact in places other than the tube surface. On tube "B", all three thermocouples worked properly. However, once initial runs were made on all three to determine whether there was any axial heat conduction, only the middle thermocouple was used for the final runs.

Experimental Procedure

Before each run, the heat transfer tube was cleaned with soap and thoroughly rinsed with water and acetone. The desired spray density was achieved by installing the proper size spray nozzle. The variable inlet blower vanes and the damper duct were set to obtain the desired air velocity.

After installing and aligning the pitot tube on the test chamber traversing mechanism, the blower was turned on. Room barometric readings and the dry bulb temperature within the test chamber were recorded. The air velocity was then measured over the plane in front of the heat transfer tube normal to the flow stream at half inch intervals.

Upon completion of the velocity measurements, the blower was turned off and the pitot tube replaced with the water spray collection system. The blower and water spray were turned on and water collected over a timed period at five locations simultaneously. After completion of the spray density data for the entire plane in front of the tube, the spray and blower were turned off, the spray collection system removed and, then, the blower and spray were turned on again. The power supply was turned on and set to achieve the desired heat flux level. The heat transfer tube orientation was set so that the surface thermocouples were located at the upstream stagnation point. Fifteen minutes were allowed for the entire system to reach steady-state. During this period and at several other times during the run, auxiliary measurements were recorded. These included wet and dry-bulb air temperatures in the wind tunnel, water line temperature and air-water spray temperature. Also, the power supply amperage and voltage levels were measured.

Once steady conditions were reached, the surface thermocouple readings were taken and the tube was rotated 15 degrees. After a minute wait to allow the system to reach steady-state again, the surface thermocouple readings were again recorded. This procedure was repeated until measurements had been taken completely around the tube. The power supply was then turned off and the system allowed to come to steady-state. The surface temperatures were again recorded every 15 degrees around the tube. These temperatures were the local adiabatic surface temperatures.

If additional data were desired for the same air velocity and water spray density, but at a different heat flux, the power supply was set to the new level and the entire set of temperature measurements was repeated. For the runs without water spray, the procedure was identical except that the water spray collection step was eliminated.

The entire process was done repeatedly until the desired air velocity and spray density ranges were fully covered. Tube "A" was then replaced by tube "B" and representative heat transfer data were taken for the desired velocity and spray density ranges.

The complete experimental data are given in Appendix B in converted form. The calibration data and treatment of the raw experimental data are presented in Appendix A.

CHAPTER IV

RESULTS AND DISCUSSION

Sixty sets of local heat transfer data are presented in tabular form in Appendix B. These data cover a range of several spray densities for each of four air velocities from 63 to 133 ft./sec. Data for both the 1.5 inch and the 1.0 inch diameter cylinders are included. Also included are the water spray and air velocity distributions for each set of data.

Local heat transfer coefficients around the cylinder circumference were calculated from the equation,

$$h = \frac{\frac{Q}{A} + kt\left(\frac{360}{\Pi D}\right)^2 \left(\frac{\partial^2 T_W}{\partial \theta^2}\right)}{T_W - T_O} . \qquad (1)$$

The local adiabatic surface temperature, T_O, was used as the reference temperature in order to obtain heat transfer coefficients which were reproducible and independent of the heat flux level at all angles around the cylinder. The stainless steel thermal conductivity in Equation (1) was represented by the following expression determined from the experimental data of Lyman (23):

$$k = 8.60 + 0.00425\, T_w \qquad (2)$$

The second derivative term in Equation (1) is a correction for angular conduction in the tube wall. The maximum value of this correction, which amounted to about five per cent of the total heat flux, occurred near the separation point, and was due to the inflections of the temperature profile in this region. A further description of the heat transfer calculation procedure is presented in Appendix A.

Stagnation Point Heat Transfer Coefficients

A plot of the stagnation point heat transfer coefficients for the 1.5 inch diameter cylinder is presented in Figure 9. Similar information for the 1.0 inch diameter cylinder is shown in Figure 10. The curves consist of heat transfer coefficients plotted with respect to the water spray density as measured two inches upstream from the stagnation point. Data for each of the four experimental air velocities were curve fitted individually.

As seen from Figures 9 and 10, the stagnation point heat transfer coefficient increases with increasing water spray density and with increasing air velocity. The curves originate at their respective dry air heat transfer coef-

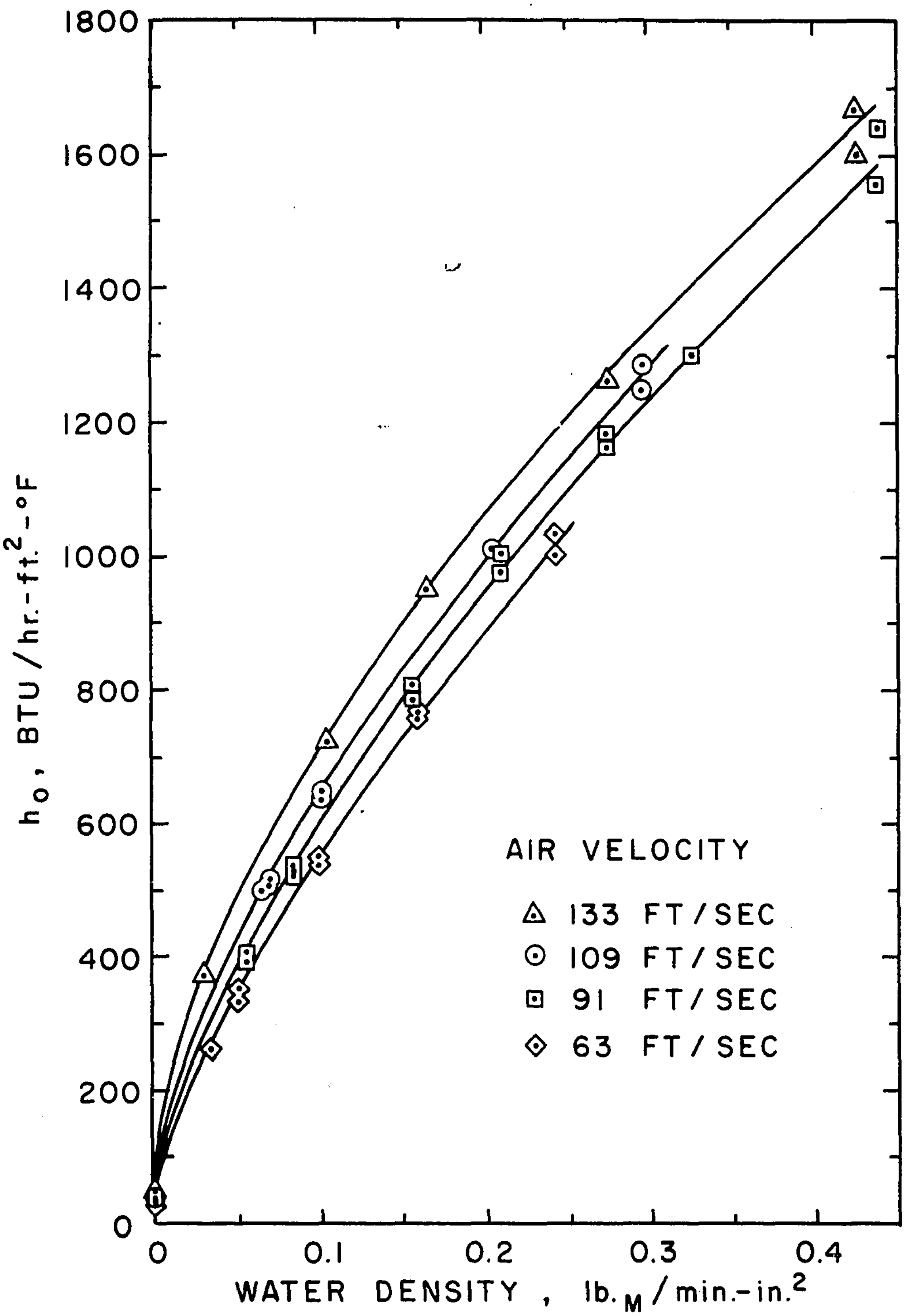

FIGURE 9. STAGNATION POINT HEAT TRANSFER COEFFICIENTS FOR 1.5 INCH DIAMETER TUBE.

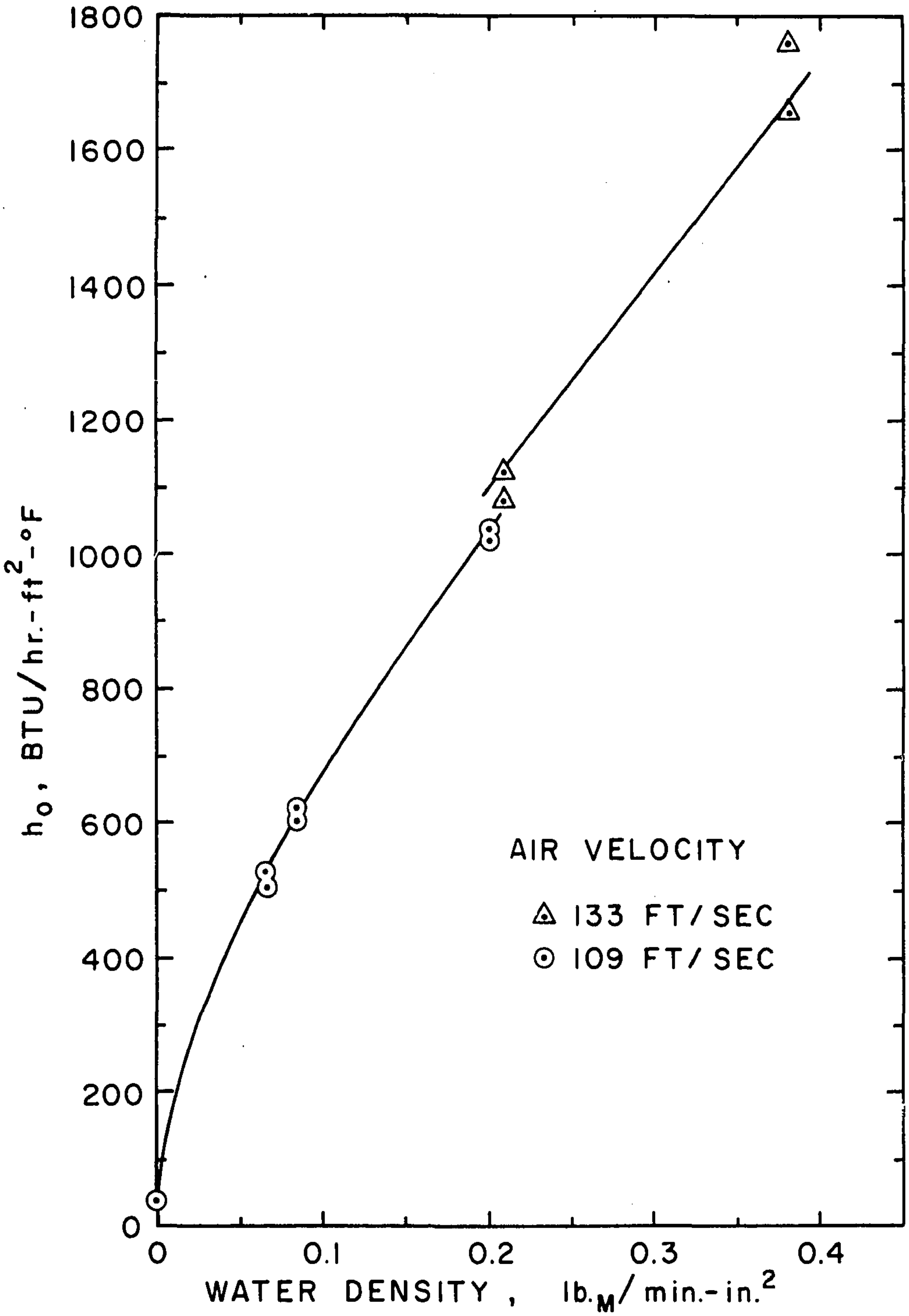

FIGURE 10. STAGNATION POINT HEAT TRANSFER COEFFICIENTS FOR 1.0 INCH DIAMETER TUBE.

ficient values, increase rapidly through the low water spray density range and then level off to a fairly linear increase at higher water spray densities. The maximum measured heat transfer coefficient was 1760 Btu/(hr.)(sq.ft.)(F) at an air velocity of 133 ft./sec. and a water spray density of 0.38 lb_m/(min.)(sq.in.) on the 1.0 inch diameter cylinder At most water spray density and air velocity settings, data were taken for two heat fluxes; the resulting stagnation point heat transfer coefficients agreed within seven per cent.

Local Cylinder Temperatures

For a given setting of air velocity, water spray density and heat flux, the local surface temperature increased as the cylinder was rotated from the stagnation point. In the region from 90 to 135 degrees, the surface temperature reached a maximum. From there, it decreased slightly as the cylinder was rotated toward 180 degrees.

The adiabatic surface temperature profile was relatively constant from the stagnation point to about 90 degrees. From there to 180 degrees, the temperature dropped as much as 5 F. On the forward portion of the cylinder, the adiabatic surface temperature closely matched the water spray droplet temperature near the tube. Finely dispersed water droplets on the rear side of the tube greatly enhanced water evaporation, resulting in an adiabatic wall temperature approaching the wet-bulb air temperature.

During the experimental runs, the surface temperature fluctuations on the front portion of the tube were small. However, on the rear side the local surface temperature fluctuated considerably. Figure 11 shows the steady-state local surface temperature fluctuations as a function of angle around the cylinder during run number A-48. During this run, the air velocity was 63 ft./sec. and the water spray density was 0.245 lb_m/(min.)(sq.in.). The observed fluctuations of greater than 10 F on the rear portion of the cylinder were attributed to rapid temperature variations in the air and droplet flow eddies (see previous discussion in Chapter I). In spite of these large fluctuations, it was possible to obtain reliable information from time mean average temperature readings. In comparison, the fluctuations at the stagnation point were less that 1 F.

Normalized Heat Transfer Coefficient Profiles

Figure 12 shows a normalized heat transfer coefficient profile for an air velocity of 91 ft./sec. on the 1.5 inch diameter tube. Fourteen individual sets of data for different water spray densities are incorporated in this curve. The normalized profiles at other velocities for both tube diameters are similar to that shown in Figure 12 and are presented in Appendix B.

Local heat transfer coefficients used in determining the normalized plots were values which were averaged point-

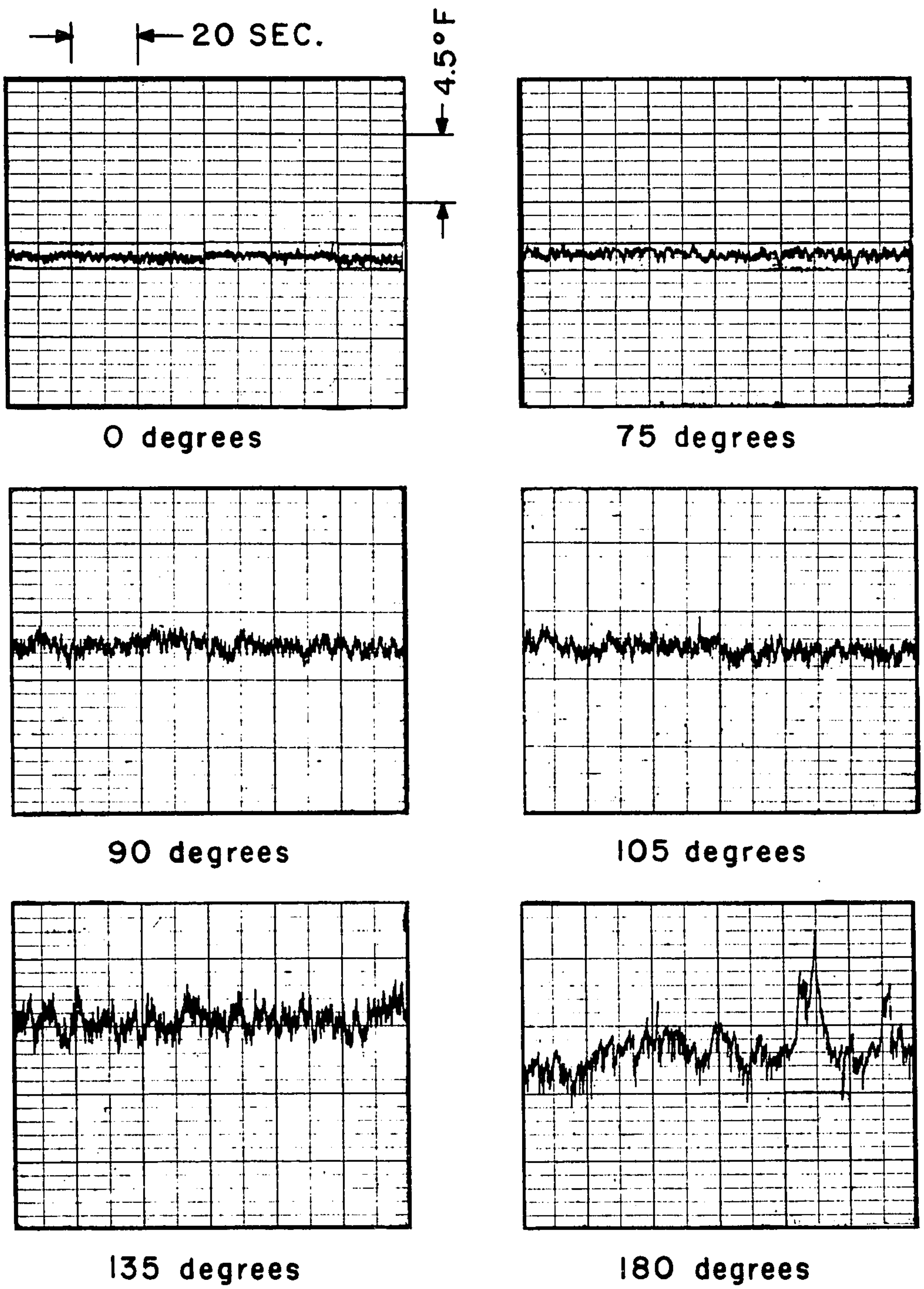

FIGURE II. TEMPERATURE FLUCTUATIONS WITH ANGLE.

wise about the stagnation point for a given run, that is, the coefficient at 15 degrees was averaged with the coefficient at 345 degrees. Then each of the resulting 0 to 180 degree profiles was normalized with respect to its stagnation point heat transfer coefficient. For each air velocity, it was found that the normalized profiles were identical over the entire measured water spray density range. All of the normalized profiles determined for a single air velocity are, therefore, fitted with one curve.

As seen from Figure 12, the normalized heat transfer coefficient profile rapidly decreases from the stagnation point to about 90 degrees where it has a value of approximately 40 per cent that of its stagnation point. In the region from 0 to 90 degrees, a flowing water film existed on the tube surface and, consequently, the heat transfer coefficients were high. Since the thermal boundary layer progressively developed within the water film as the film flowed from the stagnation point to 90 degrees, the heat transfer coefficient decreased accordingly. Recall that the heat transfer coefficient is inversely proportional to the thermal boundary layer thickness. From 90 degrees the heat transfer coefficient continues to decrease, but not as rapidly as before. The effect of the separating water film in the region from 90 to 135 degrees caused the intermediate heat transfer coefficients in this range. At 135 degrees, the profile

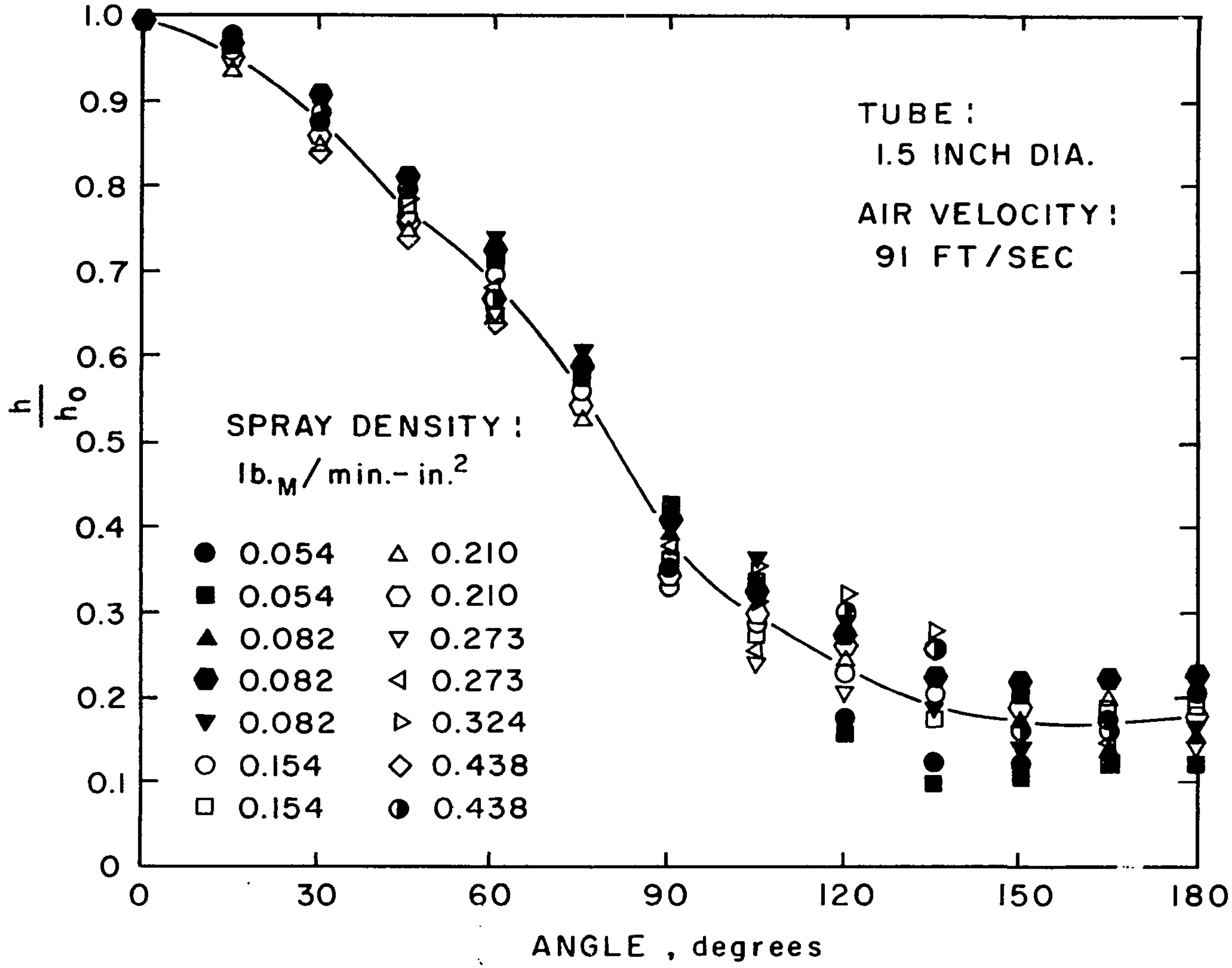

FIGURE 12. NORMALIZED HEAT TRANSFER PROFILE.

essentially levels out. The region from 135 to 180 degrees was the driest portion of the cylinder and, naturally, yielded the lowest heat transfer coefficients.

Although it can not be clearly seen in Figure 12, similar plots in Appendix B show a slight inflection in the heat transfer coefficient profile near 45 degrees. Since temperature and flow measurements were not made within the water boundary layer in this investigation, it was impossible to isolate the exact nature of these observed inflections. However, as discussed in Chapter I, Brun and Mergler (6) have theoretically shown that in the region from 45 to 75 degrees the flow lines of the water spray become tangent to the cylinder and the liquid film. It is possible that the cessation of water droplet impingement upon the water boundary layer effected a change in the flow characteristics which, in turn, slightly altered the local heat transfer characteristics. Since the inflections are similar to that caused by a laminar to turbulent transition in boundary layer flow, it is possible that such a transition took place in the water film in the region near 45 degrees.

Four normalized heat transfer curves representing all the data taken on the 1.5 inch diameter tube for the four air velocities are shown in Figure 13. Similar information for the 1.0 inch diameter tube is presented in Figure 14. These plots show the effect of increasing air velocity on

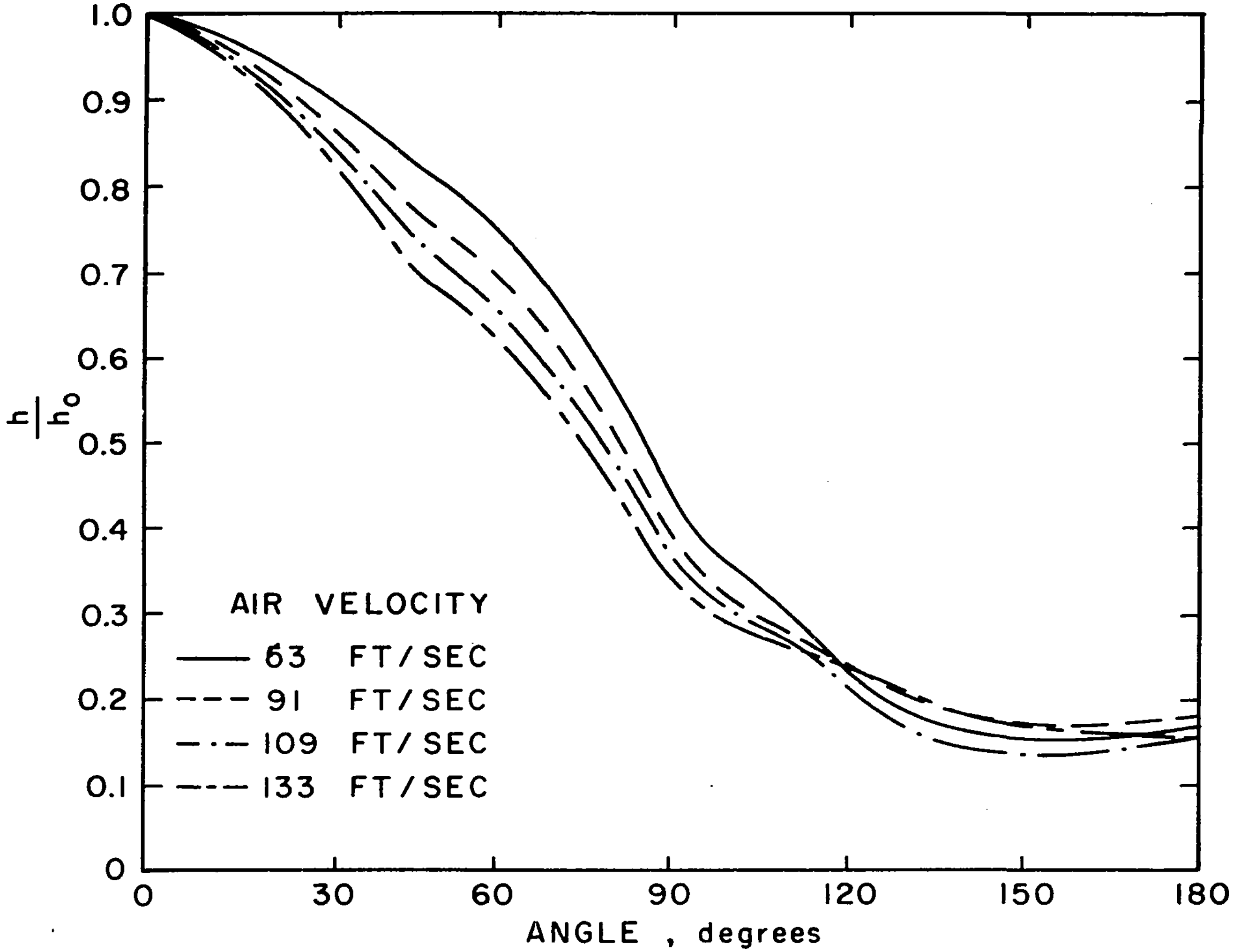

FIGURE 13. NORMALIZED PROFILES FOR 1.5 INCH DIAMETER TUBE.

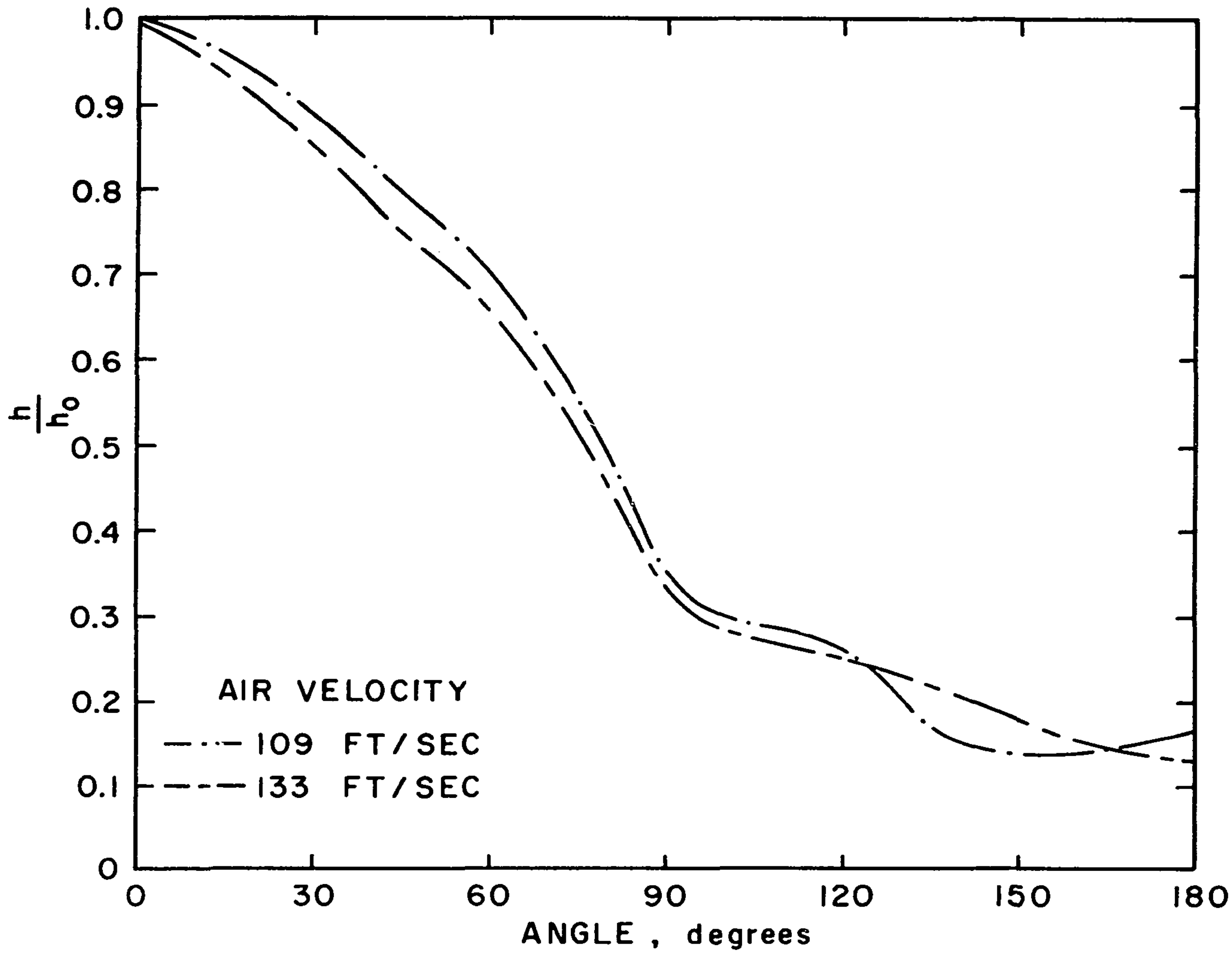

FIGURE 14. NORMALIZED PROFILES FOR 1.0 INCH DIAMETER TUBE.

the heat transfer coefficient profiles. It can be observed that, as the air velocity increases, the normalized profiles decrease more rapidly from the stagnation point. The constant velocity curves parallel each other up to about 120 degrees, but from 120 to 180 degrees, the profiles show no definite pattern due to the erratic behavior of the vortices in this region. The curves show that the inflection at 45 degrees becomes slightly more pronounced with increasing air velocity. Also, the three regions of heat transfer on the cylinder circumference, as described above, show up clearly on all the curves. A comparison of the data for the two tubes shows that increasing the tube diameter has the same effect on the normalized heat transfer coefficient profiles as does increasing air velocity.

Theoretical Boundary Layer Analysis

A boundary layer analysis was performed in an attempt to theoretically predict heat transfer coefficients on the forward portion of a cylinder positioned normal to an air-water spray flow stream. The details of this analysis are presented in Appendix D.

Briefly, the analysis consisted of assuming that a laminar water layer existed adjacent to the cylinder. A laminar air boundary layer existed outside the water layer and water spray flowed into the water layer at a rate which was dependent upon the angle from the stagnation point.

The appropriate integral mass, momentum and energy balances were formulated. Using a Pohlhausen technique (31), linear velocity profiles were assumed for the water layer and the air layer; a cubic expression was chosen for the temperature profile. The three profiles were then inserted into the integral equations and, at the stagnation point, a series of three third order algebraic expressions resulted. These simultaneous equations were solved numerically. The results were of the right order of magnitude, but the heat transfer coefficients varied little with increasing water spray density.

The procedure was repeated using a second order velocity profile in the air boundary layer and keeping everything else identical with the previous case. Again, the results were of the right order of magnitude, but they decreased with increasing water spray density.

Finally, an analysis was made using third order velocity profiles in both boundary layers. This derivation is presented in Appendix D and includes the resulting implicit algebraic expressions for the boundary layer thicknesses and the heat transfer coefficient. The resulting set of high order equations in this case was not solved due to its inaccessibility to standard root finding techniques.

Correlation of Average Heat Transfer Coefficients

Average cylinder heat transfer coefficients were calculated from the local heat transfer data for each setting of air velocity, water spray density and heat flux. This section describes the correlation of these coefficients since a general predicting expression was felt to be of particular importance for cooling tower design calculations. Such a correlation would permit extension to other tube diameters, air velocities and water spray densities.

The boundary layer analysis discussed above was used to obtain the pertinent dimensionless groups. The tube diameter was substituted for the boundary layer thicknesses in these groups and the groups were suitably rearranged to yield the following expression:

$$\frac{h_m D}{k_w} = a \left(\frac{WD}{\mu_w}\right)^b \left(\frac{DV\rho_a}{\mu_a}\right)^c \left(\frac{k_w}{c_{pw}\mu_w}\right)^d \left(\frac{\mu_a}{\mu_w}\right)^e \left(\frac{\rho_a}{\rho_w}\right)^f \qquad (3)$$

Since the data was limited to an air-water flow stream, and since all the data was taken in approximately the same temperature range, it was impossible to isolate the fluid property parameters. Therefore, the last three terms in Equation (3) were incorporated into the constant. The resulting expression can be written as,

$$Nu_m = a \, (Re_w)^b \, (Re_a)^c. \qquad (4)$$

By studying the data in terms of the air and the water spray

Reynolds numbers separately, it was possible to solve for the relative magnitudes of the two exponents. Then, from a log-log plot of Nusselt number versus the product of these two Reynolds numbers raised to their respective powers, it was possible to obtain the best values for each of these exponents. The resulting expression was then plotted in cartesian coordinates to obtain the coefficient from the slope of the straight line best fit through the data. This plot is shown in Figure 15. The data for both cylinders fit the correlation throughout the experimental range.

The correlation of average cylinder heat transfer coefficients can be written in equation form as,

$$\frac{h_m D}{k_w} = 0.44\left(\frac{WD}{\mu_w}\right)^{0.633}\left(\frac{DV\rho_a}{\mu_a}\right)^{0.264} \tag{5}$$

where the fluid properties were determined at the average surface temperature on the leading half of the cylinder. This particular temperature was used because more than 70 per cent of the heat transfer occurred on the leading half of the cylinder. As can be seen from Figure 15, the range of applicability of the correlation was from 100 to 700 on the combined Reynolds numbers raised to their respective powers. Further extension of this range is possible, however, there is no data available for final conformation.

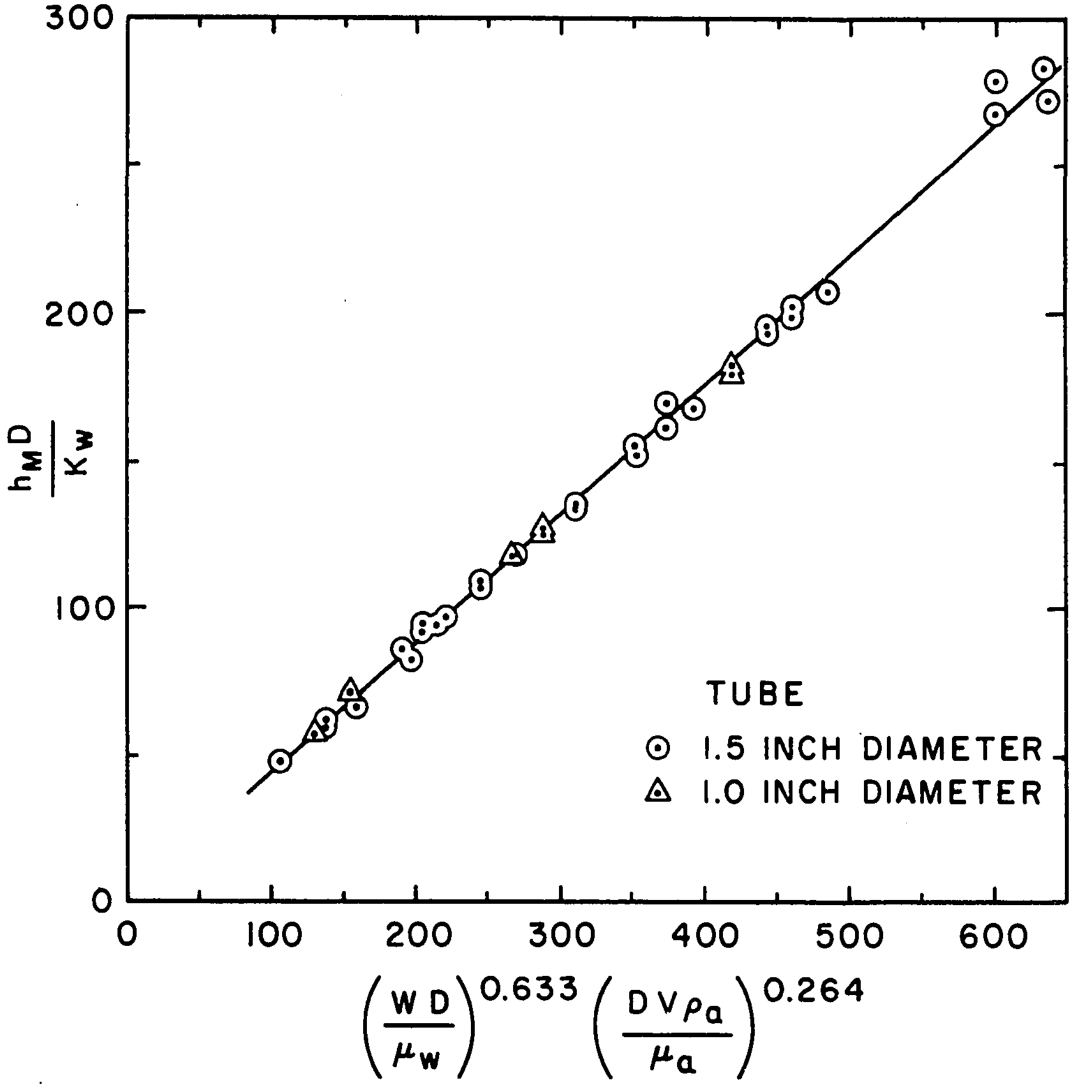

FIGURE 15. CORRELATION OF AVERAGE CYLINDER HEAT TRANSFER COEFFICIENTS.

There is one important limiting case to the above correlation. When the water spray density approaches zero, heat may still be transferred to the dry air flow stream. Equation (5) gives a zero heat transfer coefficient for this limit and, therefore, can not be relied upon for predicting heat transfer coefficients much below the range of experimental spray flow data. However, it was found possible to include terms in the correlation to account for this limit. The air correlation of Douglas and Churchill (11) was chosen to represent the dry air heat transfer in the modified air-water spray flow correlation. From an evaluation procedure similar to that used in obtaining Equation (5), the following average heat transfer coefficient correlation was established.

$$\frac{h_m D}{k_w} = \left(\frac{WD}{\mu_w}\right)^{0.74} \left(\frac{DV\rho_a}{\mu_a}\right)^{0.16} + \frac{k_a}{k_w}\left[0.46\left(\frac{DV\rho_a}{\mu_a}\right)^{0.5} + 0.00128\left(\frac{DV\rho_a}{\mu_a}\right)\right] \qquad (6)$$

The dry air data and the air-water spray data are compared with Equation (6) in Figure 16.

The air-water spray data fit Equation (5) somewhat better than Equation (6), however, Equation (6) correlated the dry air data as well as the air-water spray data.

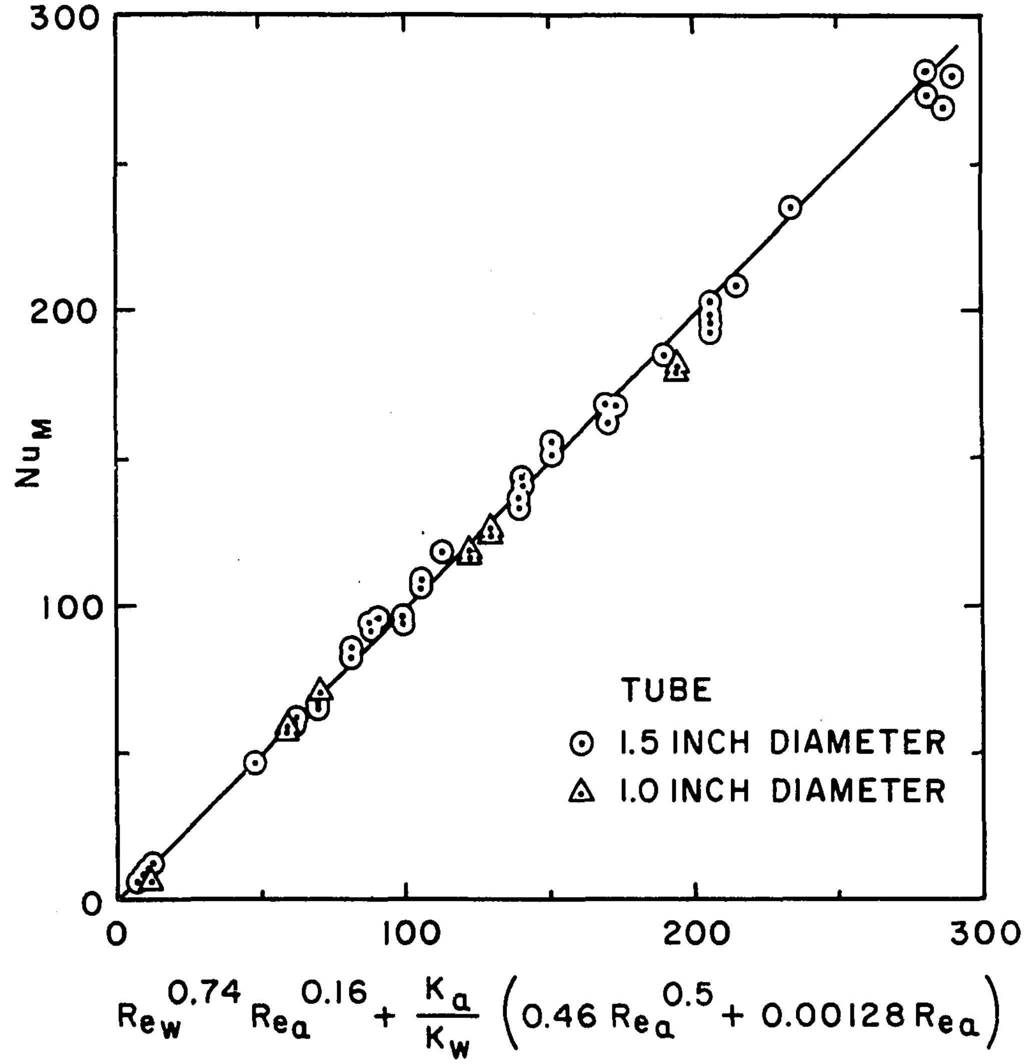

FIGURE 16. CORRELATION OF AVERAGE COEFFICIENTS INCLUDING DRY AIR DATA.

Therefore, each correlation has advantages. Equation (5) is easier to use and it predicts the average heat transfer coefficients more accurately as long as the water spray density is between 0.03 and 0.50 lb_m/(min.)(sq.in.). Equation (6) has the advantage that it applies over the water spray density range from 0.00 to 0.50 lb_m/(min.)(sq.in.). Both correlations apply over the air velocity range from 60 to 140 ft./sec.

CHAPTER V

CONCLUSIONS

1. Local heat transfer data were taken around two cylinder circumferences in an air-water spray flow stream for several water spray densities between 0.00 and 0.50 lb_m/(min.)(sq.in.) for each of four air velocities in the range from 60 to 140 ft./sec.

2. Use of the local adiabatic surface temperature for the reference temperature in calculating heat transfer coefficients resulted in highly reproducible heat transfer information.

3. Normalized profiles representing local heat transfer coefficients around the cylinder circumference were obtained. These profiles were independent of water spray density, but showed the effect of air velocity upon the heat transfer coefficients around the cylinder. They also showed three fairly distinct regions of heat transfer on the cylinder circumference including an inflection in the profile at 45 degrees.

4. Injecting water spray into the air stream increased heat transfer rates as much as forty-fold over rates

obtained for dry air on the forward portion of the cylinder.

5. A theoretical boundary layer analysis was undertaken, but adequate solutions for the heat transfer coefficient were never obtained from the resulting algebraic equations.

6. The average cylinder heat transfer coefficients were correlated in terms of air and water spray Reynolds numbers. Two correlations were obtained. The first correlation included only air-water spray data while the second also correlated dry air data. Both correlations accurately predict average cylinder heat transfer coefficients in an air-water spray flow environment.

CHAPTER VI

RECOMMENDATIONS

The following are some suggestions for further investigations in the area of air-water spray flow heat transfer:

1. Data should be taken at air velocities below 60 ft./sec. and above 150 ft./sec. in order to extend the useful range of the correlations. Additional data should be taken for water spray densities above 0.5 lb_m/(min.)(sq.in.) for the same reason.

2. Data should be taken for other gas-liquid spray systems in order to isolate the Prandtl number, viscosity ratio and density ratio effects in the correlations.

3. Build a thermal probe to measure such parameters as the water film thickness, the temperature profile in the water film, turbulence in the water film and spray droplet impingement. With the use of a thermal probe, it should also be possible to gain further insight into the nature of the inflection in the normalized heat transfer profiles which was observed at an angle of 45 degrees from the stagnation point.

4. An extensive boundary layer analysis should be

undertaken in an attempt to predict the heat transfer rates theoretically.

5. Air-water spray flow heat transfer across other body shapes and other cylinder orientations can be investigated. Some possibilities include horizontal cylinders, spheres, flat plates, wedges and aerofoils.

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APPENDIX A

CALIBRATION AND TREATMENT OF EXPERIMENTAL DATA

Surface Thermocouple Calibration and Corrections

The heat transfer tube surface thermocouples were calibrated against an accurate mercury thermometer by immersion in a constant temperature water bath. Within the accuracy of the measurements made, the surface Chromel-Alumel thermocouples reproduced standard table values over the temperature range from 60 F to 200 F. In measuring heat transfer coefficients, the critical quantity was ΔT--not either of the individual temperatures. Since the same thermocouple was utilized for measurement of both T_W and T_O, and since the temperature range was small, it was possible to use standard table values to convert EMFs to temperatures. Any deviations from standard table values were nullified when T_O was subtracted from T_W after conversion, provided the deviations were consistent.

Induced voltage correction data for the surface thermocouples were reduced to equation form for each thermocouple. This induced voltage, discussed in Chapter III, was found to be a linear function of amperage in the heat transfer tube. For the 1.5 inch diameter tube, the correction which was applied to the middle thermocouple for all the final runs was represented as:

$$(EMF)_{actual} = (EMF)_{measured} + 0.000264\ I \qquad (7)$$

For the 1.0 inch diameter tube, the middle thermocouple correction was:

$$(EMF)_{actual} = (EMF)_{measured} - 0.000081\ I \qquad (8)$$

Heat Flux Measurement

Because of contact resistances in the heat transfer tube bus bar connections, it was decided to measure the voltage drop accurately as a function of amperage initially and use this information to obtain the heat flux in subsequent runs. Two wire straps were wrapped around the tube 6.0 inches apart. The K-3 potentiometer was used to measure the voltage drop across these straps as a function of amperage. These measurements were conducted under average air and water spray flow conditions to eliminate electrical resistance deviations due to erroneous temperatures. Heat flux was then calculated by the following equation:

$$\frac{Q}{A} = 3.415\ \frac{I\ E}{A} \qquad (9)$$

The data obtained in these tests are plotted in Figure 17.

Calculation of Heat Transfer Coefficients

Although the heat transfer tube was designed as a

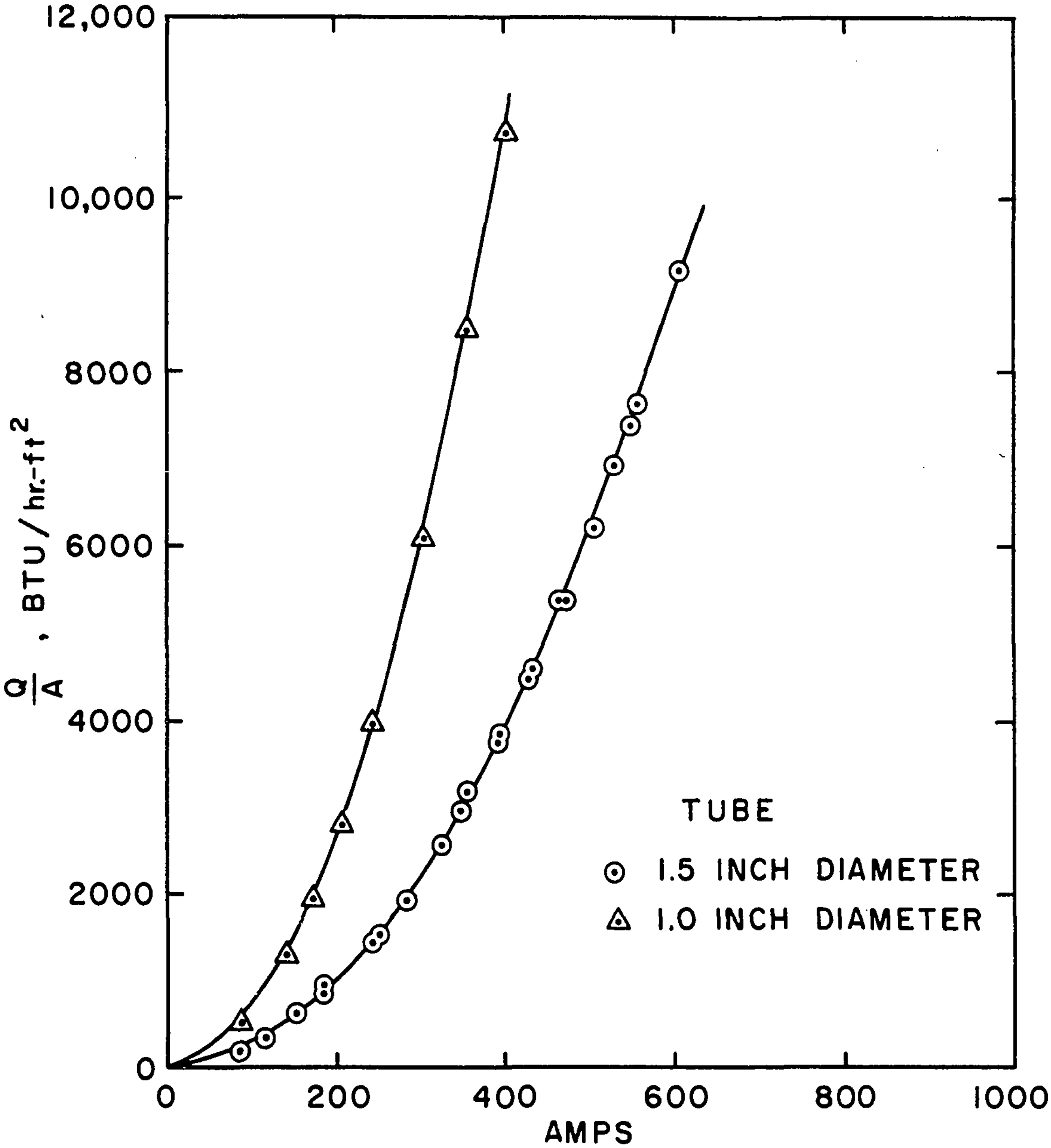

FIGURE 17. HEAT FLUX vs. AMPERAGE CURVES.

constant heat flux system, conduction in the angular direction around the tube wall was significant. Angular conduction was expecially important in the region near the separation point where the temperature was changing rapidly with angle. Equations (1) and (2) were used to calculate local heat transfer coefficients corrected for angular conduction. Equation (1) was derived from a heat balance on the tube wall in a manner similar to that used by Geidt (17). From a theoretical calculation, the maximum predicted temperature drop across the wall thickness for a heat flux of 10,000 Btu/(hr.)(sq.ft.) was about 1 F. Since this was small compared with the temperature change with angle, it was reasonable to neglect the radial temperature change and use the local surface temperature in the angular conduction term. The errors inherent in these assumptions and in Equation (1) are discussed in Appendix C.

Data Reduction Program

Because of the tremendous number of tedious conversions to be made, a computer program was written. Data reduction was carried out on the IBM 1410 computer at the University of Oklahoma Computer Center.

The data input consisted of EMFs for every surface temperature and adiabatic surface temperature at 15 degree intervals around the cylinder circumference. Additional input information consisted of the operating heat flux and the induced voltage corrections for the surface temperatures. These corrections were added to the EMF measurements for the local surface temperatures. Then a LaGrange interpolation formula (3) was utilized to convert these EMFs and the EMFs representing the adiabatic surface temperatures to their corresponding temperatures. From these temperatures, ΔTs were calculated and, from the slopes of the surface temperature profiles, the angular conduction corrections were determined. The local heat transfer coefficients were then calculated. The program also calculated average local heat transfer coefficients by averaging the corresponding points from both sides of the tube. An average cylinder heat transfer coefficient for the entire circumference was the final calculation performed by the computer program.

Water Spray and Air Velocity Distributions

The water spray density was measured by collecting the water passing into a known diameter tube. The data recorded were the number of cubic centimeters of water collected per unit of time. The time interval ranged from 100 to 900 seconds depending upon the accumulation rate of the water spray. This information was then converted to pounds of water per minute per square inch. Using a pitot tube, the air velocities were determined by measuring the dynamic pressure in inches of water and were converted to feet per second by the following equation:

$$V = \sqrt{\frac{g_c R}{6} \left(\frac{\rho_w - \rho_a}{\rho_a}\right)} \qquad (10)$$

In more convenient form, the equation is:

$$V = \sqrt{252 \frac{T_a R}{B}} \qquad (11)$$

APPENDIX B

EXPERIMENTAL DATA AND PLOTS

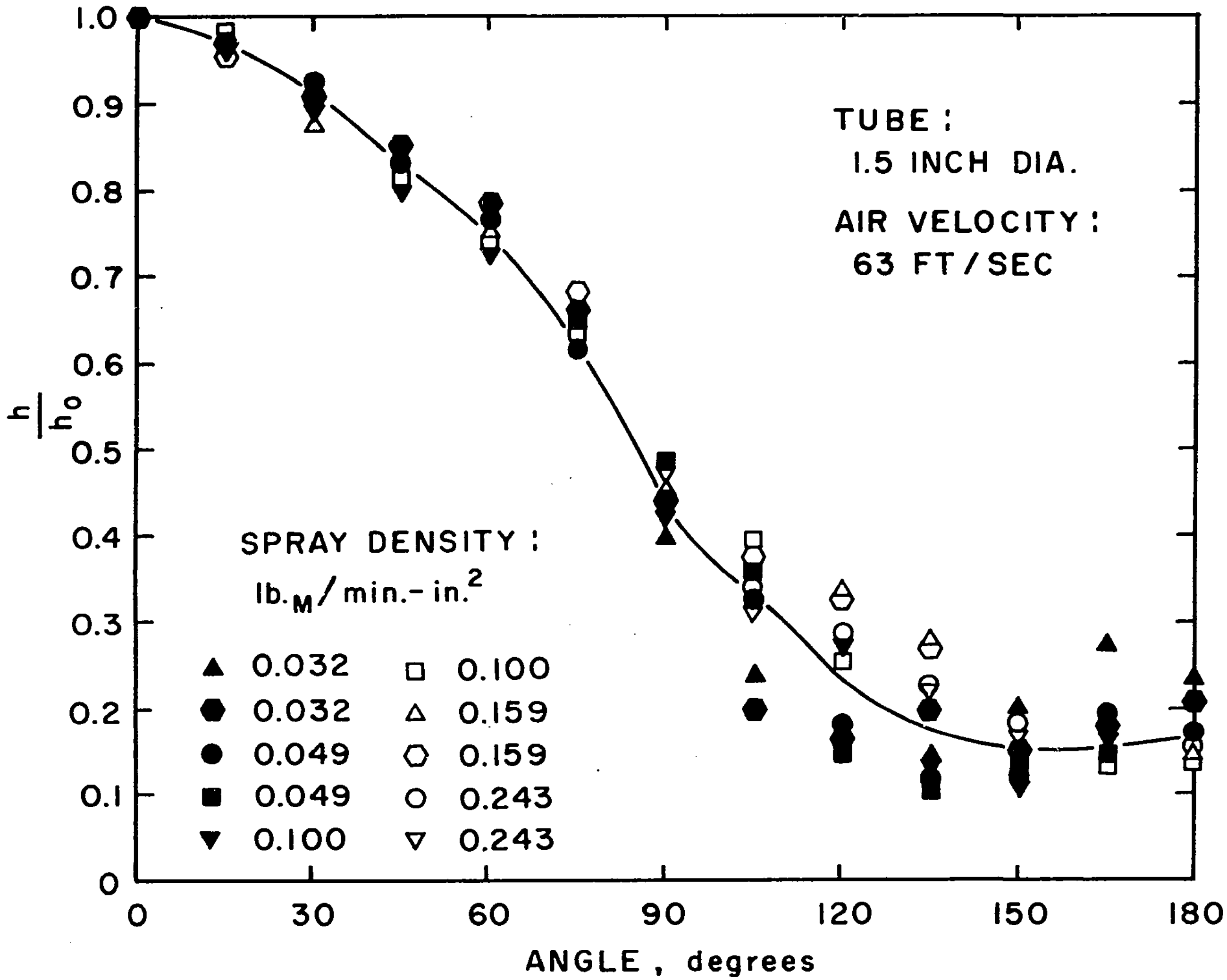

FIGURE 18. NORMALIZED HEAT TRANSFER PROFILE.

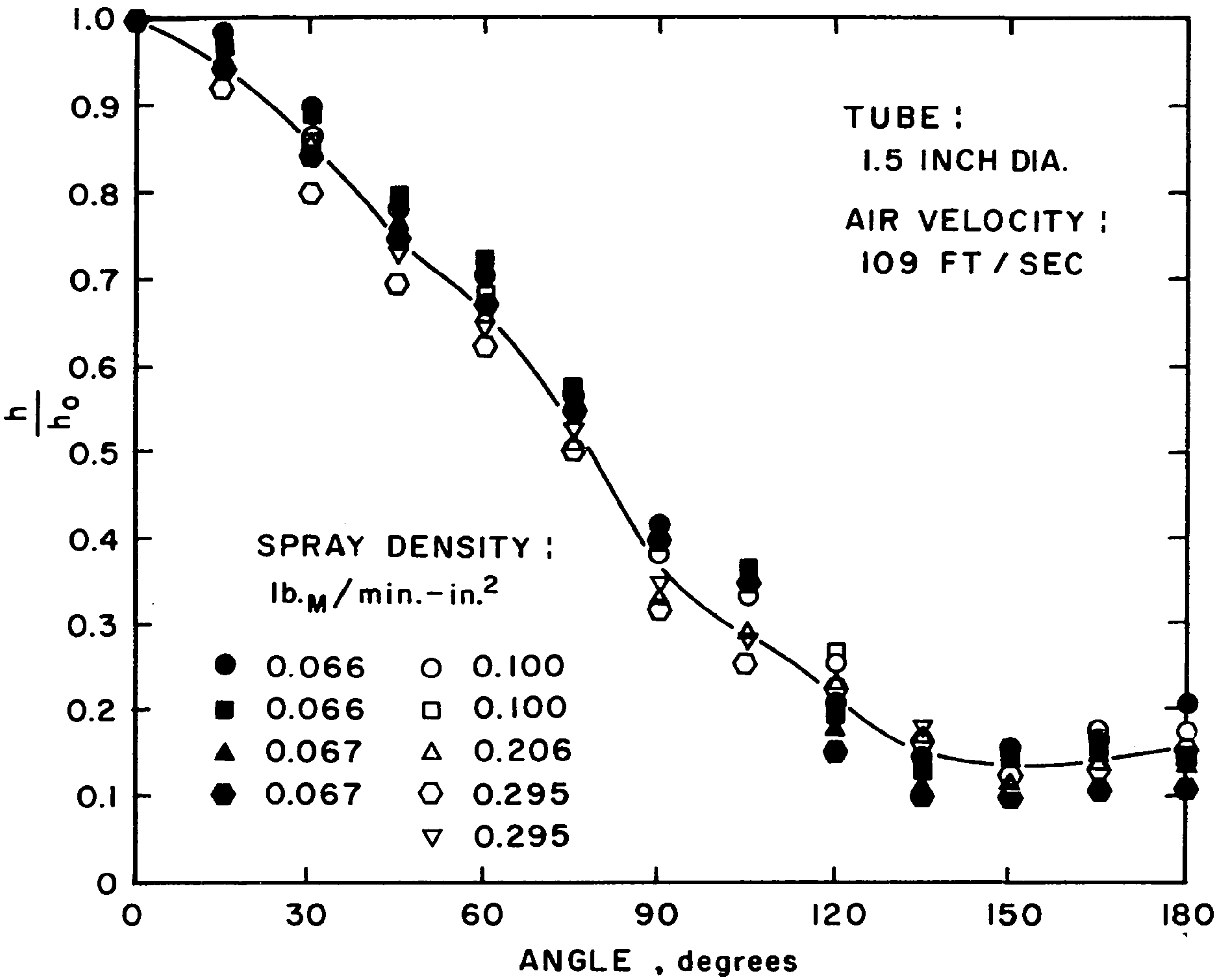

FIGURE 19. NORMALIZED HEAT TRANSFER PROFILE.

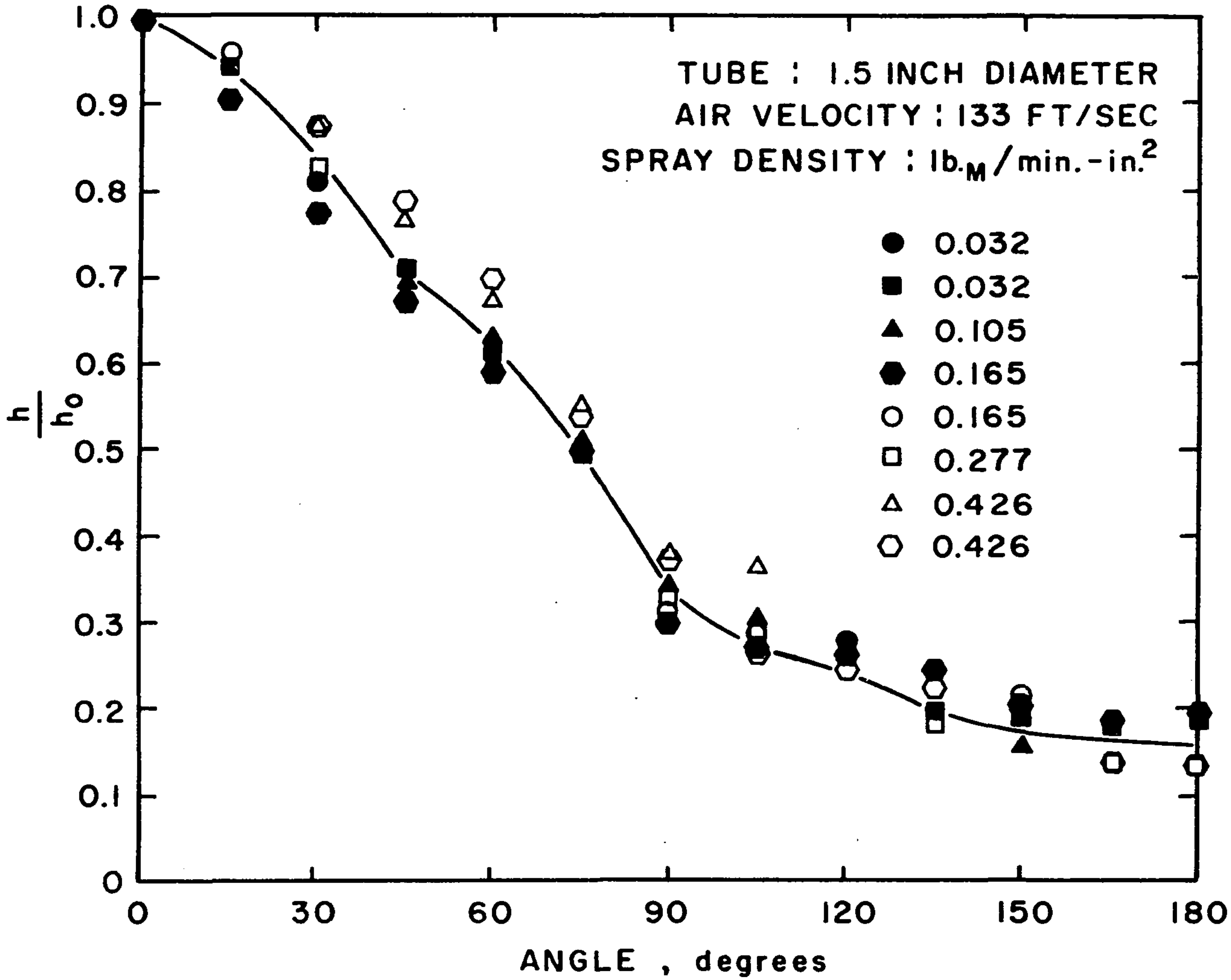

FIGURE 20. NORMALIZED HEAT TRANSFER PROFILE.

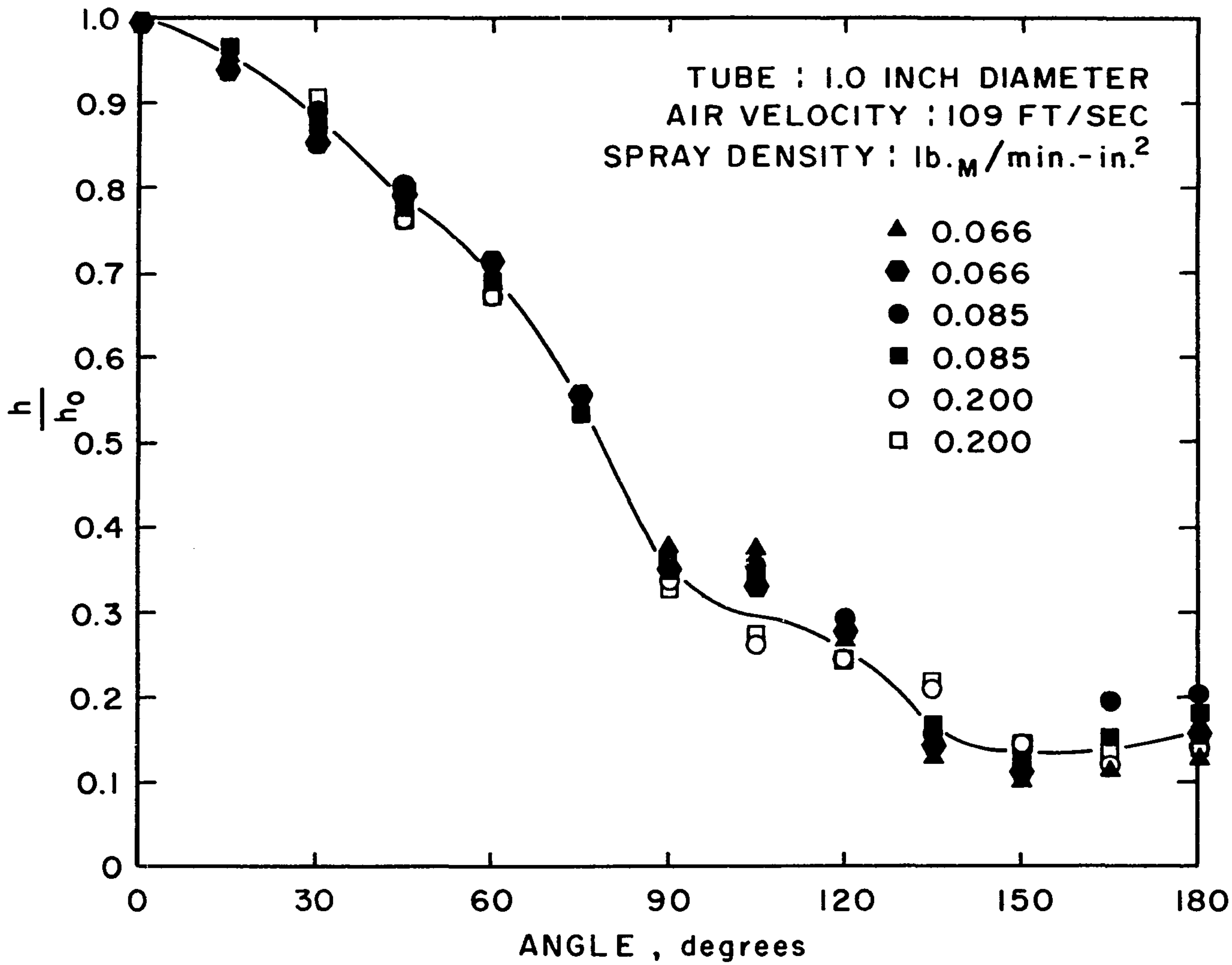

FIGURE 21. NORMALIZED HEAT TRANSFER PROFILE.

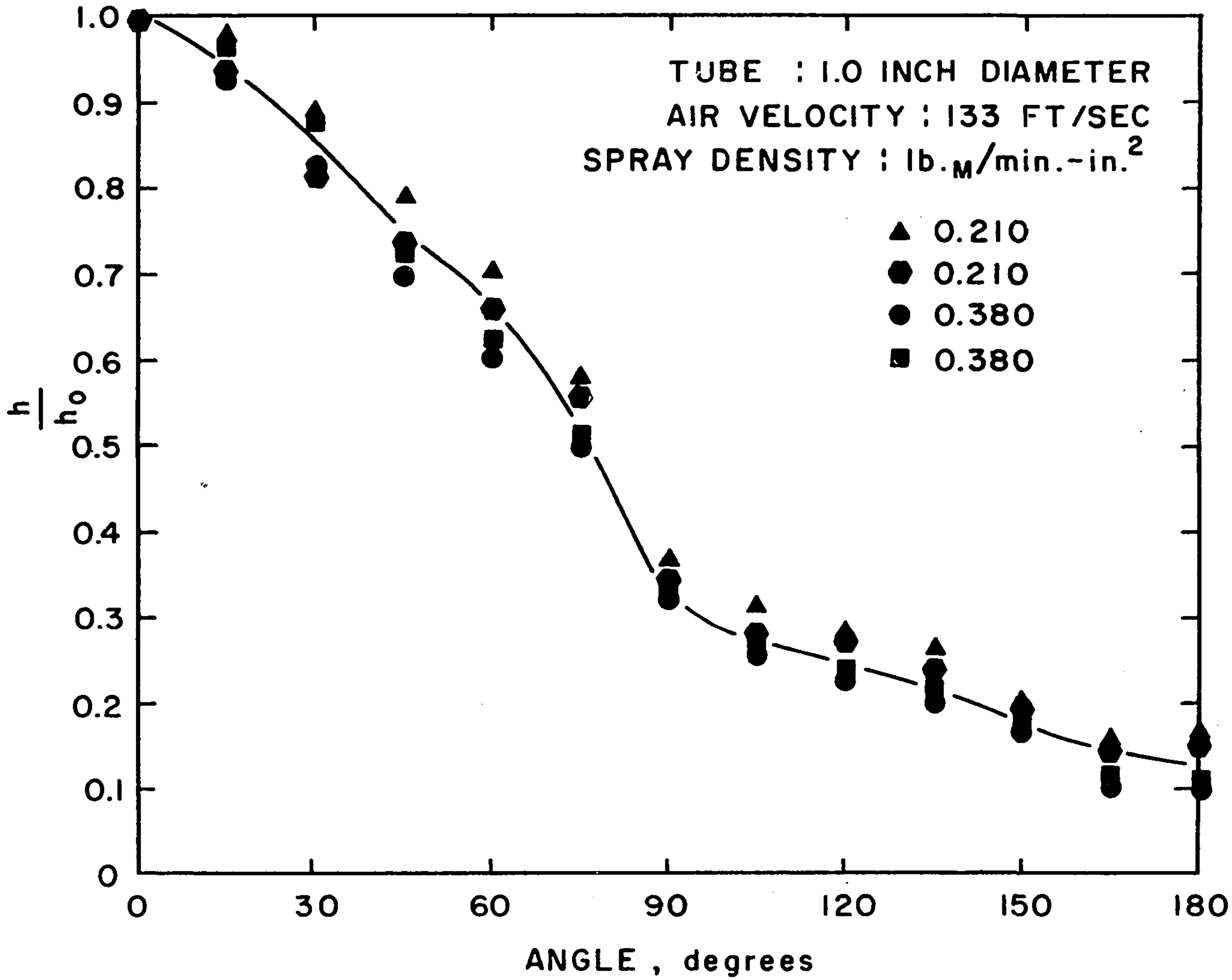

FIGURE 22. NORMALIZED HEAT TRANSFER PROFILE.

Experimental Data

Local heat transfer coefficients were calculated from surface temperature data at a number of water spray rates and air velocities. These data are presented in this appendix. The letter "A" in the run number stands for the 1.5 inch diameter heat transfer tube and "B" for the 1.0 inch tube. All temperatures are in F, heat flux in Btu/(hr.)(sq.ft.) and the local heat transfer coefficient, h, in Btu/(hr.)(sq.ft.)(F). The data are presented as a function of angle beginning at the stagnation point. The air temperature was measured in the tunnel upstream from the point of water spray injection while the water temperature was measured in the water line.

The spray distribution is reported in lb_m/(1000 min.)(sq.in.) and the air velocity is in ft./sec. These measurements were taken two inches upstream from the heat transfer tube stagnation point in a plane perpendicular to the direction of air flow. The data point locations, measured in inches, originate at the point in the plane which is directly in front of the middle thermocouple. The left hand side of each table corresponds to positions in the plane in front of the low angle side of the heat transfer tube. Upper sections of these tables correspond to positions in the plane in front of the upper half of the tube.

TABLE I

EXPERIMENTAL DATA--1.5 IN. DIA. TUBE

RUN NUMBER A-1 AIR TEMPERATURE 81.0 F

DATE 12/18/66 HEAT FLUX 840.0

ANGLE	T_w	T_o	ΔT	h
0	99.8	80.3	19.5	44.7
15	100.2	80.2	20.0	44.0
30	100.9	80.2	20.7	43.3
45	102.1	80.0	22.2	41.1
60	104.5	79.8	24.8	33.8
75	107.7	79.6	28.1	25.8
90	108.1	79.6	28.6	26.0
105	107.5	79.5	28.0	30.3
120	106.9	79.4	27.5	32.1
135	107.8	79.4	28.5	28.8
150	107.9	79.4	28.5	28.2
165	107.3	79.4	27.9	30.4
180	107.0	79.4	27.7	30.4
195	108.0	79.4	28.7	29.8
210	108.4	79.4	29.1	27.8
225	108.8	79.4	29.4	27.2
240	108.3	79.4	28.9	29.2
255	107.6	79.5	28.1	31.0
270	108.3	79.6	28.8	26.6
285	108.2	79.8	28.4	25.0
300	104.8	79.9	24.9	33.4
315	102.1	80.0	22.1	41.7
330	100.7	80.1	20.6	44.0
345	100.0	80.2	19.8	44.8
360	99.8	80.3	19.5	44.7

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

Spray: -1.0	-0.5	0.0	0.5	1.0	LOCATION	Velocity: -1.0	-0.5	0.0	0.5	1.0
					1.5	146	143	139	141	144
					1.0	147	144	139	142	144
					0.5	147	141	137	142	147
		0			0.0	146	141	138	143	152
					-0.5	148	139	139	146	152
					-1.0	151	150	145	149	152
					-1.5	155	152	148	155	156

TABLE I -- (continued)

RUN NUMBER A-2 AIR TEMPERATURE 81.0 F

DATE 12/18/66 HEAT FLUX 1570.0

ANGLE	T_W	T_O	ΔT	h
0	116.4	80.3	36.1	45.3
15	117.2	80.2	37.0	44.9
30	118.7	80.2	38.5	43.7
45	121.7	80.0	41.7	40.7
60	126.4	79.8	46.6	33.8
75	132.6	79.6	53.0	25.7
90	134.5	79.6	54.9	25.0
105	133.1	79.5	53.7	29.4
120	132.8	79.4	53.4	30.4
135	134.3	79.4	54.9	27.7
150	134.0	79.4	54.6	27.4
165	133.0	79.4	53.6	29.7
180	131.5	79.4	52.2	30.1
195	132.3	79.4	52.9	30.1
210	132.6	79.4	53.2	29.0
225	133.5	79.4	54.1	28.1
240	132.4	79.4	53.0	29.9
255	132.2	79.5	52.7	30.2
270	133.0	79.6	53.5	26.1
285	132.3	79.8	52.5	25.4
300	125.1	79.9	45.2	34.9
315	120.3	80.0	40.3	43.1
330	117.6	80.1	37.4	45.3
345	116.7	80.2	36.4	45.2
360	116.4	80.3	36.1	45.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	146	143	139	141	144
					1.0	147	144	139	142	144
					0.5	147	141	137	142	147
		0			0.0	146	141	138	143	152
					-0.5	148	139	139	146	152
					-1.0	151	150	145	149	152
					-1.5	155	152	148	155	156

TABLE I -- (continued)

RUN NUMBER A-3

DATE 1/21/57

AIR TEMPERATURE 81.0 F
WATER TEMPERATURE 74.5 F
HEAT FLUX 4940.0

ANGLE	T_W	T_O	ΔT	h
0	78.2	65.0	13.2	376.0
15	78.8	65.0	13.8	361.7
30	79.7	65.0	14.7	337.1
45	80.9	64.7	16.2	307.4
60	82.2	64.7	17.4	287.9
75	81.2	64.6	20.6	240.0
90	88.9	64.6	24.3	204.2
105	89.0	64.5	24.5	214.6
120	96.1	64.0	32.0	163.4
135	108.9	63.5	45.4	99.7
150	117.6	62.8	54.8	77.0
165	108.0	62.7	45.3	109.1
180	104.0	62.7	41.3	119.7
195	109.3	63.1	46.2	112.7
210	115.9	63.2	52.7	84.9
225	122.9	63.4	59.4	67.2
240	104.5	63.9	40.6	119.4
255	89.6	64.8	24.9	221.5
270	89.1	65.2	23.9	214.5
285	84.6	65.3	19.3	257.7
300	81.9	65.4	16.5	306.4
315	80.7	65.3	15.5	321.5
330	79.5	65.2	14.3	346.3
345	78.6	65.1	13.5	369.5
360	78.2	65.0	13.2	376.0

SPRAY DISTRIBUTION						VELOCITY DISTRIBUTION				
-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
64	64	50	51	53	1.5	141	132	136	138	142
84	77	74	68	77	1.0	139	132	135	139	142
60	57	67	72	90	0.5	136	131	132	136	142
48	32	32	46	66	0.0	139	132	129	137	147
25	31	31	35	53	-0.5	142	136	134	136	143
20	22	23	30	40	-1.0	147	144	144	144	148
18	21	22	20	26	-1.5	151	145	149	150	151

TABLE I -- (continued)

RUN NUMBER A-4

DATE 1/21/67

AIR TEMPERATURE 81.0 F
WATER TEMPERATURE 74.5 F
HEAT FLUX 6080.0

ANGLE	T_W	T_O	ΔT	h
0	82.2	65.8	16.4	373.0
15	83.0	65.8	17.2	356.8
30	84.0	65.8	18.2	334.5
45	85.3	65.5	19.8	309.2
60	86.9	65.5	21.4	288.2
75	90.2	65.4	24.7	246.2
90	94.6	65.4	29.1	211.1
105	95.3	65.3	30.1	222.9
120	105.1	64.9	40.2	164.3
135	131.8	64.3	67.5	79.1
150	141.7	63.6	78.1	65.2
165	130.9	63.5	67.4	90.3
180	130.5	63.6	66.9	90.9
195	130.5	64.0	66.5	94.3
210	138.7	64.0	74.7	74.8
225	140.4	64.3	76.2	65.4
240	122.6	64.7	57.9	100.6
255	96.4	65.6	30.8	221.5
270	94.4	66.0	28.4	228.4
285	89.5	66.2	23.3	263.2
300	86.0	66.2	19.7	314.9
315	84.7	66.1	18.6	328.7
330	83.6	66.0	17.6	346.9
345	82.5	65.9	16.6	369.6
360	82.2	65.8	16.4	373.0

SPRAY DISTRIBUTION

VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
64	64	50	51	53	1.5	141	132	136	138	142
84	77	74	68	77	1.0	139	132	135	139	142
60	57	67	72	90	0.5	136	131	132	136	142
48	32	32	46	66	0.0	139	132	129	137	147
25	31	31	35	53	-0.5	142	136	134	136	143
20	22	23	30	40	-1.0	147	144	144	144	148
18	21	22	20	26	-1.5	151	146	149	150	151

TABLE I -- (continued)

RUN NUMBER A-5

DATE 12/11/66

AIR TEMPERATURE 78.2 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 5500.0

ANGLE	T_w	T_o	ΔT	h
0	71.6	63.9	7.7	722.0
15	72.0	63.8	8.2	675.8
30	73.4	63.6	9.8	563.1
45	74.8	63.2	11.6	476.1
60	75.9	63.1	12.9	437.2
75	78.8	63.1	15.8	355.2
90	84.9	62.2	22.7	237.7
105	86.7	61.4	25.4	218.1
120	88.8	61.3	27.5	209.3
135	96.8	60.4	36.4	147.8
150	104.7	59.1	45.7	109.4
165	99.9	58.7	41.2	131.1
180	96.8	58.6	38.2	143.8
195	98.1	58.4	39.7	140.4
210	102.1	58.7	43.4	119.7
225	103.4	59.6	43.9	115.1
240	93.8	60.9	33.0	166.4
255	86.6	61.6	25.0	227.3
270	84.8	62.9	21.9	252.2
285	78.4	63.6	14.8	379.5
300	75.9	63.6	12.3	459.3
315	74.5	63.9	10.6	524.3
330	73.1	63.9	9.2	602.9
345	72.0	63.9	8.1	684.8
360	71.6	63.9	7.7	722.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
91	105	106	100	78	1.5	141	140	135	135	140
66	91	97	95	70	1.0	141	138	135	136	142
62	88	107	97	75	0.5	145	141	133	131	141
68	75	105	111	101	0.0	145	141	133	134	141
73	87	108	114	102	-0.5	145	143	136	141	148
72	80	95	100	99	-1.0	149	146	147	149	149
68	68	81	87	80	-1.5	152	151	152	153	154

TABLE I -- (continued)

RUN NUMBER A-6

DATE 11/15/66

AIR TEMPERATURE 78.2 F
WATER TEMPERATURE 76.0 F
HEAT FLUX 5270.0

ANGLE	T_w	T_o	ΔT	h
0	73.9	68.3	5.6	948.0
15	74.4	68.2	6.2	855.5
30	75.4	67.9	7.5	702.8
45	76.4	67.9	8.5	623.0
60	77.4	67.7	9.7	551.8
75	79.5	67.8	11.7	458.7
90	84.3	67.0	17.3	301.1
105	86.4	66.6	19.8	261.4
120	87.7	66.6	21.1	252.2
135	89.6	66.6	23.0	232.0
150	93.4	66.0	27.4	189.7
165	94.8	64.8	30.1	170.8
180	93.9	64.1	29.8	176.9
195	94.6	64.8	29.9	172.4
210	93.5	65.7	27.8	186.1
225	90.2	66.5	23.7	224.3
240	87.7	66.5	21.2	252.6
255	86.4	66.5	19.9	259.8
270	85.4	66.8	18.6	277.4
285	79.4	67.9	11.4	470.1
300	77.5	67.9	9.6	561.6
315	76.5	68.3	8.2	644.1
330	75.2	68.2	7.0	759.5
345	74.5	68.3	6.3	848.4
360	73.9	68.3	5.6	948.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
145	162	132	127	115	1.5	142	138	135	137	141
144	153	156	133	120	1.0	141	135	135	140	142
142	129	161	157	135	0.5	144	138	128	132	143
126	150	165	150	171	0.0	145	140	133	133	142
154	145	181	141	156	-0.5	145	140	137	137	143
115	168	144	157	142	-1.0	149	143	147	149	149
122	164	125	144	148	-1.5	152	148	149	154	154

TABLE I -- (continued)

RUN NUMBER A-7

DATE 11/15/66

AIR TEMPERATURE 78.2 F
WATER TEMPERATURE 76.0 F
HEAT FLUX 7430.0

ANGLE	T_w	T_o	ΔT	h
0	76.1	68.3	7.8	955.1
15	76.5	68.2	8.3	901.2
30	77.8	67.9	9.9	755.3
45	79.2	67.9	11.3	660.7
60	80.9	67.7	13.2	573.1
75	83.7	67.7	16.0	473.0
90	90.8	67.0	23.8	307.6
105	93.6	66.6	27.0	270.6
120	95.2	66.6	28.5	263.1
135	97.9	66.6	31.3	240.2
150	103.2	66.0	37.1	197.3
165	105.1	64.8	40.3	180.0
180	104.7	64.1	40.6	182.9
195	104.9	64.7	40.2	181.6
210	103.8	65.7	38.1	191.4
225	99.6	66.5	33.1	225.1
240	95.3	66.5	28.7	262.5
255	93.8	66.5	27.3	267.9
270	92.1	66.8	25.3	286.9
285	84.0	67.9	16.1	469.0
300	80.9	67.9	12.9	587.5
315	79.4	68.3	11.1	672.0
330	77.7	68.2	9.5	784.7
345	76.4	68.3	8.2	915.9
360	76.1	68.3	7.8	955.1

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
145	162	132	127	115	1.5	142	138	135	137	141
144	153	156	133	120	1.0	141	135	135	140	142
142	129	161	157	135	0.5	144	138	128	132	143
126	150	165	150	171	0.0	145	140	133	133	142
154	145	181	141	156	-0.5	145	140	137	137	143
115	168	144	157	142	-1.0	149	143	147	149	149
122	164	125	144	148	-1.5	152	148	149	154	154

TABLE I -- (continued)

RUN NUMBER A-8

DATE 1/25/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 9170.0

ANGLE	T_W	T_O	ΔT	h
0	74.1	66.8	7.3	1263.0
15	74.4	66.8	7.6	1205.2
30	75.3	66.8	8.5	1077.7
45	76.6	66.7	9.8	936.3
60	78.0	66.7	11.3	818.8
75	80.4	66.6	13.8	675.9
90	86.9	66.6	20.3	448.6
105	90.4	66.3	24.1	376.3
120	93.1	66.3	26.8	344.5
135	95.7	66.4	29.3	315.8
150	101.9	66.2	35.7	254.0
165	105.0	65.8	39.2	229.2
180	105.0	65.8	39.2	234.1
195	105.4	65.5	40.0	226.2
210	103.7	65.7	37.9	237.4
225	99.3	65.9	33.4	274.7
240	94.4	66.0	28.4	324.8
255	93.1	66.0	27.1	335.2
270	88.7	66.1	22.6	403.2
285	82.1	66.3	15.8	586.4
300	79.1	66.4	12.7	732.7
315	77.4	66.5	10.9	848.3
330	75.7	66.5	9.2	1004.3
345	74.5	66.6	7.9	1166.1
360	74.1	66.8	7.3	1263.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
207	215	211	183	171	1.5	144	139	135	137	140
247	247	247	219	199	1.0	144	138	133	135	141
258	262	274	243	223	0.5	144	138	132	135	143
262	270	277	268	243	0.0	143	138	133	135	144
227	231	259	259	243	-0.5	146	141	135	136	148
183	207	223	219	231	-1.0	149	145	144	140	150
167	191	199	191	215	-1.5	155	149	152	153	156

TABLE I -- (continued)

RUN NUMBER A-9

DATE 1/12/67

AIR TEMPERATURE 78.2 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 6200.0

ANGLE	T_W	T_O	ΔT	h
0	72.0	68.1	3.9	1600.2
15	72.2	68.2	4.0	1545.5
30	72.6	68.2	4.4	1403.9
45	73.2	68.2	5.0	1241.5
60	73.8	68.2	5.7	1101.3
75	75.0	68.2	6.8	924.7
90	77.4	67.9	9.6	648.5
105	80.1	67.4	12.7	481.2
120	80.3	67.0	13.3	466.7
135	81.6	67.0	14.7	433.6
150	85.2	66.5	18.7	336.0
165	90.5	65.3	25.2	237.7
180	92.7	64.6	28.1	220.6
195	93.2	64.5	28.7	209.2
210	88.3	65.3	23.0	268.6
225	84.8	65.8	19.0	333.6
240	83.4	65.8	17.6	351.5
255	82.1	66.4	15.7	389.6
270	78.3	67.2	11.1	562.3
285	74.8	67.4	7.4	851.3
300	73.7	67.7	6.0	1046.9
315	73.0	67.8	5.1	1210.5
330	72.4	67.9	4.6	1362.7
345	72.1	68.0	4.1	1528.9
360	72.0	68.1	3.9	1600.2

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

Spray -1.0	Spray -0.5	Spray 0.0	Spray 0.5	Spray 1.0	LOCATION	Velocity -1.0	Velocity -0.5	Velocity 0.0	Velocity 0.5	Velocity 1.0
233	298	269	300	256	1.5	144	136	133	136	141
239	302	318	306	275	1.0	144	135	135	140	143
269	350	402	342	291	0.5	141	135	136	141	146
322	430	426	448	276	0.0	142	132	131	134	145
446	430	283	322	386	-0.5	142	138	137	137	137
342	287	215	282	334	-1.0	146	143	145	142	141
257	231	207	265	255	-1.5	151	148	151	151	151

TABLE I -- (continued)

RUN NUMBER A-10

DATE 1/12/67

AIR TEMPERATURE 78.2 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 8870.0

ANGLE	T_W	T_O	ΔT	h
0	72.7	67.4	5.3	1675.0
15	73.0	67.5	5.6	1591.0
30	73.6	67.5	6.1	1451.1
45	74.2	67.5	6.7	1327.7
60	75.3	67.5	7.8	1143.2
75	76.9	67.5	9.5	947.5
90	80.3	67.1	13.1	676.9
105	84.2	66.6	15.6	499.4
120	85.4	66.2	19.2	463.6
135	87.2	66.2	21.0	433.6
150	92.1	65.8	26.3	341.9
165	100.0	64.6	35.4	242.2
180	103.1	63.9	39.2	226.2
195	103.1	63.7	39.4	219.3
210	96.1	64.5	31.5	282.0
225	92.5	65.1	27.4	328.1
240	89.9	65.1	24.7	356.7
255	88.0	65.7	22.3	391.2
270	82.0	66.5	15.5	573.5
285	77.1	66.7	10.4	867.6
300	75.2	66.9	8.2	1090.9
315	73.9	67.1	6.8	1303.5
330	73.3	67.1	6.1	1452.2
345	73.0	67.3	5.6	1578.6
360	72.7	67.4	5.3	1675.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
233	298	269	300	256	1.5	144	136	133	136	141
239	302	318	306	275	1.0	144	135	135	140	143
269	350	402	342	291	0.5	141	135	136	141	146
322	430	426	448	276	0.0	142	132	131	134	145
446	430	283	322	386	-0.5	142	138	137	137	137
342	287	215	282	334	-1.0	146	143	145	142	141
257	231	207	265	255	-1.5	151	148	151	151	151

TABLE I -- (continued)

RUN NUMBER A-11 AIR TEMPERATURE 83.0 F

DATE 12/27/66 HEAT FLUX 970.0

ANGLE	T_w	T_o	ΔT	h
0	109.5	81.9	27.6	37.9
15	109.7	81.9	27.8	37.8
30	111.0	81.8	29.2	37.0
45	113.7	81.8	31.9	34.6
60	118.1	81.6	36.5	28.1
75	124.4	81.5	42.9	19.3
90	128.1	81.4	46.7	15.8
105	128.0	81.3	46.6	18.2
120	126.4	81.2	45.1	21.0
135	125.6	81.3	44.2	21.3
150	123.8	81.3	42.4	22.9
165	121.7	81.3	40.4	25.9
180	121.2	81.3	39.9	24.3
195	122.3	81.3	41.0	25.1
210	123.7	81.3	42.4	23.2
225	125.4	81.4	44.0	21.8
240	127.1	81.5	45.6	20.3
255	127.9	81.5	46.5	18.7
270	128.1	81.6	46.5	16.9
285	125.5	81.7	43.8	18.1
300	119.8	81.8	38.1	25.5
315	114.0	81.8	32.2	34.6
330	111.4	81.8	29.6	37.1
345	109.9	81.8	28.1	37.4
360	109.5	81.9	27.6	37.9

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	106	106	106	105	106
					1.0	107	108	107	106	107
					0.5	111	108	108	106	108
		0			0.0	111	111	110	108	108
					-0.5	110	109	110	106	108
					-1.0	110	110	110	110	110
					-1.5	114	115	114	114	115

TABLE I -- (continued)

RUN NUMBER A-12 | AIR TEMPERATURE 83.0 F

DATE 12/27/66 | HEAT FLUX 1580.0

ANGLE	T_W	T_O	ΔT	h
0	126.0	81.9	44.1	39.2
15	126.1	81.9	44.3	39.1
30	128.7	81.8	46.9	37.5
45	133.6	81.8	51.8	33.6
60	140.4	81.6	58.8	27.8
75	148.9	81.5	67.4	20.7
90	154.8	81.4	73.4	17.1
105	155.0	81.3	73.7	18.9
120	153.2	81.3	71.9	21.3
135	151.7	81.3	70.4	21.8
150	149.5	81.3	68.1	22.9
165	146.0	81.3	64.7	26.2
180	144.6	81.3	63.3	24.9
195	145.5	81.3	64.2	26.4
210	147.8	81.3	66.5	24.6
225	151.4	81.4	70.0	21.8
240	153.8	81.4	72.5	20.6
255	154.7	81.5	73.3	20.1
270	155.6	81.5	74.1	17.3
285	152.6	81.6	71.0	17.7
300	142.5	81.7	60.8	25.8
315	134.4	81.8	52.6	34.1
330	128.8	81.8	47.0	38.2
345	126.6	81.8	44.8	38.7
360	126.0	81.9	44.1	39.2

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	106	106	106	105	106
					1.0	107	108	107	106	107
					0.5	111	108	108	106	108
		0			0.0	111	111	110	108	108
					-0.5	110	104	110	106	108
					-1.0	110	110	110	110	110
					-1.5	114	115	114	114	115

TABLE I -- (continued)

RUN NUMBER	A-13	AIR TEMPERATURE	78.0 F
		WATER TEMPERATURE	71.0 F
DATE	2/13/67	HEAT FLUX	4930.0

ANGLE	T_w	T_o	ΔT	h
0	73.0	62.9	10.0	494.0
15	73.1	63.0	10.1	490.6
30	73.9	63.1	10.8	457.9
45	74.7	62.9	11.8	423.5
60	75.9	62.8	13.1	391.6
75	78.9	62.8	16.1	317.1
90	87.4	61.6	25.8	193.7
105	90.8	60.7	30.1	173.7
120	101.8	59.9	41.9	118.0
135	117.7	58.3	59.4	73.4
150	116.8	57.9	58.8	74.5
165	117.7	58.0	59.6	82.6
180	106.2	58.1	48.2	102.3
195	117.7	57.9	59.8	83.2
210	119.4	58.5	60.9	74.9
225	120.7	58.7	62.0	68.9
240	114.6	59.5	55.1	81.8
255	91.7	60.7	31.0	172.1
270	89.2	61.2	28.1	186.5
285	82.9	62.3	20.6	242.8
300	78.9	62.3	16.6	305.0
315	77.1	62.7	14.4	344.3
330	74.8	63.1	11.7	425.9
345	73.4	63.0	10.5	478.2
360	73.0	62.9	10.0	494.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
66	73	66	66	58	0.5	116	107	106	106	107
86	82	66	53	57	0.0	119	114	110	110	114
97	73	71	64	56	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

RUN NUMBER A-14

DATE 2/13/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 71.0 F
HEAT FLUX 6210.0

ANGLE	T_w	T_o	ΔT	h
0	75.7	63.2	12.5	499.0
15	76.2	63.2	12.9	483.3
30	77.0	63.3	13.7	455.9
45	78.0	63.2	14.8	424.1
60	79.3	63.1	16.2	397.2
75	83.1	63.1	20.0	320.7
90	92.6	61.8	30.8	208.8
105	96.7	61.0	35.8	188.8
120	117.0	60.2	56.8	110.3
135	137.9	58.6	79.3	68.5
150	143.5	58.2	85.3	66.1
165	142.2	58.3	83.9	72.9
180	143.5	58.3	85.2	72.9
195	143.1	58.1	85.0	74.2
210	148.7	58.8	90.0	63.6
225	148.7	59.0	89.7	57.1
240	130.1	59.7	70.3	83.6
255	101.1	51.0	40.2	171.5
270	95.4	61.4	33.9	195.9
285	87.9	62.5	25.3	250.3
300	82.7	62.6	20.1	317.1
315	80.3	63.0	17.3	362.3
330	77.9	63.3	14.6	429.3
345	76.2	63.2	13.0	485.4
360	75.7	63.2	12.5	499.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
66	73	66	66	58	0.5	116	107	106	106	107
86	82	66	53	57	0.0	119	114	110	110	114
97	73	71	64	56	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE I -- (continued)

RUN NUMBER A-15

DATE 12/4/66

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 4830.0

ANGLE	T_w	T_o	ΔT	h
0	74.8	65.2	9.6	504.0
15	75.2	65.2	10.1	485.5
30	76.7	65.1	11.5	421.3
45	77.8	65.0	12.8	382.0
60	80.0	65.0	14.9	334.7
75	84.0	64.8	19.2	259.2
90	91.0	64.3	26.7	191.7
105	96.5	63.5	33.0	161.3
120	115.6	12.3	53.3	87.7
135	133.6	61.7	71.9	55.1
150	133.2	61.4	71.7	62.1
165	128.5	61.4	67.1	73.4
180	132.9	61.5	71.4	67.6
195	134.0	61.4	72.5	67.0
210	136.8	61.7	75.2	57.5
225	136.1	62.1	74.0	53.1
240	115.6	62.3	53.3	88.5
255	93.9	63.8	30.2	180.6
270	89.9	64.5	25.4	203.2
285	82.9	65.0	17.9	277.5
300	79.6	65.1	14.6	341.9
315	77.9	65.2	12.7	384.8
330	76.6	65.2	11.4	427.9
345	75.4	65.2	10.2	478.6
360	74.8	65.2	9.6	504.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
56	58	62	66	58	1.5	109	108	106	106	109
56	63	64	65	66	1.0	111	110	109	110	110
53	63	60	68	68	0.5	114	109	108	110	112
50	63	68	68	68	0.0	117	112	109	110	112
57	66	63	66	66	-0.5	112	112	111	111	112
50	52	60	60	58	-1.0	112	112	112	112	112
46	48	53	51	53	-1.5	114	113	111	113	115

TABLE I -- (continued)

RUN NUMBER A-16

DATE 12/4/66

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 6750.0

ANGLE	T_W	T_O	ΔT	h
0	78.4	65.2	13.2	514.0
15	79.3	65.2	14.1	483.9
30	81.0	65.1	15.9	428.4
45	83.3	65.0	18.3	373.3
60	86.6	65.0	20.6	337.9
75	91.5	66.8	26.7	261.2
90	100.7	64.3	36.4	202.6
105	109.9	63.5	46.4	164.9
120	146.7	62.3	84.3	76.6
135	174.0	61.7	112.3	49.7
150	179.0	61.4	117.6	52.2
165	181.7	61.4	120.3	54.8
180	181.7	61.5	120.2	56.1
195	181.4	61.4	120.0	54.8
210	186.5	61.7	124.8	46.6
225	173.2	62.1	111.1	49.8
240	146.4	62.3	84.0	78.1
255	125.9	63.8	42.2	183.5
270	98.3	64.5	33.8	220.8
285	88.5	65.0	23.5	298.4
300	84.7	65.1	19.6	353.8
315	82.7	65.2	17.5	388.5
330	80.8	65.2	15.5	436.5
345	79.2	65.1	14.0	486.0
360	78.4	65.2	13.2	514.0

SPRAY DISTRIBUTION — VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
56	58	62	66	58	1.5	109	108	106	106	109
56	63	64	65	66	1.0	111	110	109	110	110
53	63	60	68	68	0.5	114	109	108	110	112
50	63	68	68	68	0.0	117	112	109	110	112
57	66	63	66	66	-0.5	112	112	111	111	112
50	52	60	60	58	-1.0	112	112	112	112	112
46	48	53	51	53	-1.5	114	113	111	113	115

TABLE I -- (continued)

RUN NUMBER A-17

DATE 2/13/67

AIR TEMPERATURE 78.9 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 6080.0

ANGLE	T_W	T_O	ΔT	h
0	73.2	63.6	9.5	638.0
15	73.8	63.5	10.3	595.2
30	74.6	63.4	11.3	541.0
45	75.9	63.2	12.6	485.6
60	77.1	63.1	13.9	447.8
75	80.1	62.9	17.2	362.7
90	87.6	62.3	25.3	240.8
105	91.8	61.8	30.0	210.9
120	98.0	61.4	36.6	172.5
135	115.6	59.6	56.0	99.4
150	117.7	58.4	59.4	93.1
165	113.8	57.9	55.9	108.7
180	111.7	57.7	53.9	112.7
195	113.8	58.1	55.7	109.0
210	116.9	58.3	58.6	96.3
225	114.7	59.2	55.5	100.5
240	101.9	60.7	41.2	148.3
255	91.7	61.7	30.0	211.6
270	88.0	62.3	25.8	239.4
285	81.9	63.1	18.8	328.1
300	78.4	63.3	15.1	412.5
315	76.4	63.4	13.1	469.6
330	74.6	63.4	11.2	547.6
345	73.4	63.5	9.9	618.2
360	73.2	63.6	9.5	638.0

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
109	116	134	114	109	0.5	116	107	106	106	107
85	98	100	85	94	0.0	119	114	110	110	114
100	80	85	81	90	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE I -- (continued)

RUN NUMBER A-18

DATE 2/13/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 7010.0

ANGLE	T_w	T_o	ΔT	h
0	74.6	63.6	10.9	645.0
15	75.4	63.5	11.9	591.7
30	76.7	63.4	13.4	525.2
45	78.1	63.2	14.8	474.7
60	79.6	63.1	16.4	436.5
75	82.5	62.9	19.6	367.1
90	90.6	62.3	28.2	248.1
105	94.9	61.8	33.1	220.9
120	101.0	61.4	39.6	185.9
135	121.7	59.6	62.1	105.6
150	127.4	58.4	68.9	93.5
165	126.0	57.9	68.2	101.1
180	127.4	57.7	69.6	100.7
195	127.4	58.1	69.2	100.2
210	126.9	58.3	68.6	95.9
225	124.7	59.2	65.5	98.2
240	106.8	60.7	46.0	154.6
255	94.4	61.7	32.7	226.3
270	91.3	62.3	29.1	244.3
285	83.6	63.1	20.5	348.1
300	80.0	63.3	16.7	429.4
315	78.0	63.4	14.7	481.2
330	76.3	63.4	12.9	545.1
345	74.6	63.5	11.1	635.5
360	74.6	63.6	10.9	645.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
109	116	134	114	109	0.5	116	107	106	106	107
85	98	100	85	94	0.0	119	114	110	110	114
100	80	85	81	90	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE I -- (continued)

RUN NUMBER A-19

DATE 1/28/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 8830.0

ANGLE	T_W	T_O	ΔT	h
0	77.3	68.6	8.7	1017.0
15	77.6	68.6	9.0	984.2
30	78.4	68.6	9.9	899.0
45	80.0	68.6	11.5	774.3
60	81.7	68.6	13.1	685.7
75	85.0	68.4	16.5	544.9
90	72.5	67.7	24.8	355.9
105	97.8	66.8	31.0	286.2
120	102.2	66.0	36.2	246.5
135	112.8	65.2	47.6	180.4
150	115.4	61.8	52.6	160.5
165	114.5	62.4	52.2	167.6
180	111.5	62.2	49.3	179.1
195	117.2	62.1	55.1	159.0
210	116.3	62.7	53.6	158.0
225	115.0	63.9	51.1	166.5
240	125.3	65.7	39.6	223.4
255	97.8	66.7	31.1	288.0
270	93.8	67.[illegible]	26.7	331.2
285	86.4	68.3	18.1	495.2
300	82.2	68.4	13.8	654.1
315	80.4	68.6	11.8	752.8
330	79.1	68.6	10.5	840.8
345	77.9	68.6	9.3	951.4
360	77.3	68.6	8.7	1017.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
147	165	163	157	151	1.5	110	107	107	108	108
167	181	189	185	171	1.0	111	111	110	111	112
179	199	205	199	189	0.5	114	113	114	116	118
187	200	206	201	183	0.0	114	114	114	114	114
167	185	189	187	177	-0.5	113	112	112	113	114
147	163	159	155	153	-1.0	113	113	113	112	113
135	145	139	133	137	-1.5	114	113	114	115	115

TABLE I -- (continued)

RUN NUMBER A-20

DATE 1/13/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 71.0 F
HEAT FLUX 7420.0

ANGLE	T_W	T_O	ΔT	h
0	72.9	67.1	5.8	1292.0
15	73.5	67.2	6.3	1183.4
30	74.6	66.9	7.6	970.4
45	75.3	66.9	8.4	890.2
60	76.3	67.0	9.4	805.0
75	78.4	67.0	11.4	663.7
90	84.4	66.3	18.0	412.2
105	88.7	65.5	23.2	318.8
120	92.4	65.3	27.1	280.3
135	98.1	64.7	33.4	222.9
150	107.8	62.9	44.9	156.5
165	106.4	61.9	45.0	159.8
180	105.2	62.0	43.2	171.7
195	105.2	62.1	43.1	169.0
210	105.6	63.4	42.2	168.2
225	100.8	64.9	35.9	202.9
240	90.6	65.6	25.0	305.3
255	88.1	66.0	22.1	339.5
270	85.1	66.4	18.6	395.1
285	78.6	66.7	11.9	635.4
300	76.5	66.9	9.6	789.1
315	75.2	66.9	8.4	891.3
330	73.9	67.0	6.9	1074.9
345	73.3	67.0	6.3	1174.8
360	72.9	67.1	5.8	1292.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
149	175	223	225	207	1.5	111	110	107	109	113
194	196	239	265	228	1.0	111	110	110	113	115
223	247	265	281	199	0.5	111	110	109	109	119
247	250	295	271	228	0.0	109	109	107	114	117
199	247	289	239	199	-0.5	109	109	109	112	115
199	220	249	202	175	-1.0	113	113	111	117	117
183	178	210	170	178	-1.5	113	113	112	115	117

TABLE I -- (continued)

RUN NUMBER A-21

DATE 1/13/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 71.0 F
HEAT FLUX 8870.0

ANGLE	T_W	T_O	ΔT	h
0	74.1	67.0	7.1	1253.0
15	74.5	67.1	7.4	1201.2
30	75.5	66.8	8.7	1019.3
45	76.5	66.8	9.7	921.9
60	77.9	66.8	11.0	819.8
75	80.2	66.9	13.3	680.2
90	86.6	66.2	20.4	435.5
105	91.6	65.4	26.2	339.2
120	95.2	65.2	30.0	304.0
135	105.3	64.6	40.7	217.7
150	114.5	62.8	51.8	162.2
165	116.3	61.8	54.5	157.9
180	111.5	61.9	49.6	178.9
195	112.4	62.0	50.3	171.6
210	111.5	63.3	48.1	176.7
225	103.1	64.8	38.4	230.2
240	93.8	65.5	28.3	322.1
255	90.3	65.9	24.4	367.1
270	87.7	66.3	21.4	411.9
285	80.9	66.6	14.3	626.5
300	78.4	66.8	11.6	774.6
315	76.6	66.8	9.8	906.3
330	75.2	66.9	8.3	1077.9
345	74.2	66.9	7.3	1216.5
360	74.1	67.0	7.1	1253.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
149	175	223	225	207	1.5	111	110	107	109	113
194	196	239	265	228	1.0	111	110	110	113	115
223	247	265	281	199	0.5	111	110	109	109	119
247	260	295	271	228	0.0	109	109	107	114	117
199	247	289	239	199	-0.5	109	109	109	112	115
199	220	249	202	175	-1.0	113	113	111	117	117
183	178	210	170	178	-1.5	113	113	112	115	117

TABLE I -- (continued)

RUN NUMBER A-22 AIR TEMPERATURE 83.7 F

DATE 12/28/66 HEAT FLUX 700.0

ANGLE	T_W	T_O	ΔT	h
0	102.8	82.7	20.1	37.3
15	103.0	82.7	20.4	36.7
30	104.1	82.6	21.6	35.9
45	105.9	82.4	23.5	34.4
60	109.2	82.5	26.7	28.4
75	114.6	82.5	32.1	18.4
90	117.4	82.4	35.0	14.7
105	117.6	82.4	35.2	17.0
120	116.2	82.4	33.9	20.1
135	115.5	82.4	33.1	20.9
150	114.1	82.4	31.8	22.6
165	112.9	82.4	30.6	24.5
180	112.9	82.4	30.5	22.9
195	113.9	82.4	31.5	23.4
210	114.8	82.4	32.5	21.9
225	115.8	82.4	33.4	21.0
240	117.3	82.4	35.0	18.9
255	117.9	82.5	35.4	17.4
270	118.1	82.5	35.5	15.5
285	115.8	82.5	33.3	17.0
300	111.1	82.5	28.5	24.8
315	107.0	82.6	24.4	32.7
330	104.7	82.7	22.0	36.0
345	103.2	82.7	20.5	37.3
360	102.8	82.7	20.1	37.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	89	89	88	88	89
					1.0	89	89	89	89	89
					0.5	92	90	90	89	89
		0			0.0	92	92	92	88	90
					-0.5	92	92	93	90	90
					-1.0	93	93	93	93	93
					-1.5	95	95	95	95	95

TABLE I -- (continued)

RUN NUMBER A-23 AIR TEMPERATURE 83.7 F

DATE 12/28/66 HEAT FLUX 1290.0

ANGLE	T_w	T_o	ΔT	h
0	121.9	82.7	39.2	36.1
15	122.2	82.7	39.5	35.7
30	124.1	82.6	41.5	35.0
45	128.1	82.4	45.7	32.6
60	134.6	82.5	52.1	26.7
75	144.6	82.5	62.0	17.4
90	150.1	82.4	67.7	13.9
105	150.2	82.4	67.8	16.3
120	148.2	82.4	65.9	19.0
135	146.8	82.4	64.4	19.7
150	144.4	82.4	62.0	21.0
165	142.2	82.4	59.9	23.1
180	141.2	82.4	58.8	21.9
195	141.7	82.4	59.3	23.4
210	143.3	82.4	61.0	22.2
225	146.5	82.4	64.1	19.6
240	148.7	82.4	66.3	18.2
255	150.0	82.5	67.5	16.8
270	150.0	82.5	67.5	14.7
285	145.5	82.5	63.0	16.8
300	136.4	82.5	53.9	24.6
315	129.6	82.6	47.0	31.2
330	124.9	82.7	42.2	34.6
345	122.5	82.7	39.8	35.9
360	121.9	82.7	39.2	36.1

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	89	89	88	88	89
					1.0	89	89	89	89	89
					0.5	92	90	90	89	89
		0			0.0	92	92	92	88	90
					-0.5	92	92	93	90	90
					-1.0	93	93	93	93	93
					-1.5	95	95	95	95	95

TABLE I -- (continued)

RUN NUMBER A-24

DATE 12/6/66

AIR TEMPERATURE 80.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 4970.0

ANGLE	T_w	T_o	ΔT	h
0	79.1	66.3	12.8	391.0
15	79.5	66.2	13.2	380.8
30	80.9	66.2	14.7	340.1
45	82.6	66.2	16.5	305.8
60	84.9	66.2	18.8	276.3
75	90.0	66.0	23.9	218.0
90	99.9	65.8	34.1	156.9
105	109.0	64.9	43.9	119.3
120	133.2	64.2	69.0	68.7
135	141.9	63.9	78.0	53.7
150	156.2	63.8	92.4	46.7
165	137.2	64.1	73.1	69.4
180	147.6	64.1	83.5	59.5
195	143.0	64.1	78.8	65.2
210	151.6	63.7	87.9	51.1
225	150.9	63.8	87.2	45.0
240	132.6	64.3	68.3	68.2
255	108.0	65.0	43.1	126.1
270	98.8	65.7	33.2	161.6
285	88.5	66.2	22.4	234.7
300	84.2	66.2	18.0	289.2
315	82.4	66.3	16.1	312.5
330	80.9	66.3	14.6	342.5
345	79.6	66.3	13.2	380.2
360	79.1	66.3	12.8	391.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
40	43	48	51	49	1.5	92	89	88	86	89
40	47	51	54	58	1.0	92	90	92	92	92
39	46	49	55	59	0.5	95	92	90	92	92
36	42	54	55	60	0.0	97	92	89	90	92
38	44	48	53	55	-0.5	94	93	92	93	94
32	36	42	47	50	-1.0	94	94	94	94	94
30	33	38	41	47	-1.5	95	95	94	95	97

TABLE I -- (continued)

RUN NUMBER A-25

DATE 12/6/66

AIR TEMPERATURE 80.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 6820.0

ANGLE	T_w	T_o	ΔT	h
0	83.2	66.3	16.9	405.0
15	83.9	66.2	17.7	390.8
30	85.8	66.2	19.6	351.0
45	88.2	66.2	22.0	315.0
60	91.1	66.2	24.9	284.9
75	98.4	66.0	32.4	221.1
90	110.8	65.8	45.0	168.0
105	125.0	64.9	60.0	129.1
120	166.7	64.2	102.5	63.1
135	198.3	63.9	134.4	39.6
150	206.4	63.8	142.7	41.0
165	200.0	64.1	135.8	50.0
180	199.5	64.1	135.4	50.4
195	198.2	64.1	134.1	50.4
210	197.3	63.7	133.7	46.1
225	194.5	63.8	130.7	41.2
240	163.8	64.3	99.5	64.0
255	122.3	65.0	57.3	135.2
270	108.6	65.7	42.9	176.1
285	96.6	66.2	30.4	235.5
300	90.2	66.2	23.9	296.8
315	87.6	66.3	21.4	324.3
330	85.7	66.3	19.4	354.5
345	84.0	66.3	17.6	391.1
360	83.2	66.3	16.9	405.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
40	43	48	51	49	1.5	92	89	88	86	89
40	47	51	54	58	1.0	92	90	92	92	92
39	46	49	55	59	0.5	95	92	90	92	92
36	42	54	55	60	0.0	97	92	89	90	92
38	44	48	53	55	-0.5	94	93	92	93	94
32	36	42	47	50	-1.0	94	94	94	94	94
30	33	38	41	47	-1.5	95	95	94	95	97

TABLE I -- (continued)

RUN NUMBER A-26

DATE 10/22/66

AIR TEMPERATURE 79.2 F
WATER TEMPERATURE 77.5 F
HEAT FLUX 7150.0

ANGLE	T_w	T_o	ΔT	h
0	81.3	67.8	13.5	531.1
15	81.9	67.7	14.1	509.5
30	83.0	67.7	15.3	469.9
45	84.8	67.7	17.1	422.3
60	86.6	67.4	19.2	386.5
75	90.7	67.5	23.2	317.8
90	102.7	66.3	36.3	193.6
105	106.6	65.8	40.8	176.5
120	112.8	65.0	47.8	157.5
135	125.4	63.9	61.5	112.7
150	140.6	62.4	78.2	80.1
165	133.2	62.2	71.0	98.0
180	126.2	62.1	64.1	111.5
195	128.3	62.2	66.2	107.0
210	128.7	62.1	66.5	102.1
225	125.5	62.8	62.6	108.9
240	115.1	64.1	51.0	191.2
255	108.0	65.4	42.6	168.5
270	104.0	66.1	37.9	185.7
285	91.9	67.8	24.0	306.8
300	87.2	67.8	19.4	382.2
315	84.9	67.9	17.0	423.9
330	83.1	67.9	15.1	476.1
345	81.6	67.9	13.7	528.5
360	81.2	67.8	13.4	537.2

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
62	59	61	62	57	1.5	94	89	88	91	92
64	70	65	65	64	1.0	93	90	91	92	92
69	70	74	66	64	0.5	93	92	95	97	97
69	75	82	77	76	0.0	95	93	93	94	99
68	69	76	76	77	-0.5	94	94	94	95	98
65	73	77	81	74	-1.0	98	97	96	98	98
69	76	75	85	84	-1.5	99	99	99	99	100

TABLE I -- (continued)

RUN NUMBER A-27

DATE 10/24/67

AIR TEMPERATURE 80.0 F
WATER TEMPERATURE 78.0 F
HEAT FLUX 5270.0

ANGLE	T_W	T_O	ΔT	h
0	77.8	67.9	9.9	536.3
15	78.1	67.9	10.2	521.4
30	78.9	67.9	11.0	482.6
45	80.0	67.9	12.2	436.9
60	81.3	67.6	13.7	399.1
75	84.7	67.7	17.0	320.2
90	93.1	67.6	26.6	194.8
105	96.3	65.7	30.6	169.3
120	99.9	65.2	34.8	152.0
135	103.3	64.0	39.3	131.7
150	106.6	62.8	43.8	116.2
165	105.8	62.3	43.5	119.4
180	105.5	62.3	43.2	121.9
195	106.0	61.9	44.0	120.1
210	106.2	62.3	43.9	117.0
225	108.0	63.0	45.1	110.6
240	101.6	64.2	37.4	139.4
255	97.1	65.5	31.6	166.6
270	94.4	66.0	28.4	182.6
285	85.6	67.9	17.8	305.6
300	82.4	67.8	14.6	373.6
315	80.4	67.9	12.5	425.0
330	79.0	67.9	11.0	482.2
345	78.3	67.9	10.4	510.5
360	77.8	67.9	9.9	536.3

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
62	59	61	62	57	1.5	94	89	88	91	92
64	70	65	65	64	1.0	93	90	91	92	92
69	70	74	66	64	0.5	93	92	95	97	97
69	75	82	77	76	0.0	95	93	93	94	99
68	69	76	76	77	-0.5	94	94	94	95	98
65	73	77	81	74	-1.0	98	97	96	98	98
69	76	75	85	84	-1.5	99	99	99	99	100

TABLE I -- (continued)

RUN NUMBER A-28

DATE 10/30/66

AIR TEMPERATURE 79.9 F
WATER TEMPERATURE 77.8 F
HEAT FLUX 8600.0

ANGLE	T_w	T_o	ΔT	h
0	85.1	68.9	16.2	531.9
15	85.7	68.8	16.9	511.6
30	87.2	68.8	18.4	470.6
45	89.0	68.7	20.3	426.2
60	91.1	68.6	22.5	393.3
75	95.1	68.5	26.6	333.8
90	107.5	67.5	40.0	214.6
105	113.1	66.7	46.4	189.9
120	123.4	66.4	57.0	159.9
135	142.0	65.4	76.6	111.5
150	163.9	64.5	99.5	78.0
165	168.0	64.2	103.8	77.6
180	164.3	64.0	100.4	85.7
195	172.9	64.0	108.9	79.4
210	168.9	64.3	104.6	73.4
225	159.8	64.8	95.0	83.4
240	128.6	65.7	62.9	143.7
255	114.1	66.5	47.6	192.6
270	110.3	67.3	43.0	199.9
285	97.8	68.7	29.1	302.8
300	92.0	68.7	23.3	382.2
315	89.6	68.7	20.9	415.8
330	87.6	68.9	18.8	460.7
345	85.9	68.9	17.0	509.5
360	85.3	68.9	16.4	527.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
62	59	61	62	57	1.5	94	89	88	91	92
64	70	65	65	64	1.0	93	90	91	92	92
69	70	74	66	64	0.5	93	92	95	97	97
69	75	82	77	76	0.0	95	93	93	94	99
68	69	76	76	77	-0.5	94	94	94	95	98
65	73	77	81	74	-1.0	98	97	96	98	98
69	76	75	85	84	-1.5	99	99	99	99	100

TABLE I -- (continued)

RUN NUMBER A-29

DATE 1/28/67

AIR TEMPERATURE 79.5 F
WATER TEMPERATURE 73.7 F
HEAT FLUX 8830.0

ANGLE	T_W	T_O	ΔT	h
0	79.5	68.2	11.3	786.1
15	79.9	68.1	11.8	753.3
30	80.9	68.1	12.8	692.9
45	82.2	68.0	14.2	627.0
60	84.6	67.9	16.6	544.9
75	88.0	67.9	20.0	454.1
90	99.1	66.7	32.5	270.7
105	104.9	65.9	39.0	224.2
120	111.5	65.5	46.0	190.2
135	117.2	64.2	53.0	163.2
150	118.1	62.7	55.4	155.7
165	119.4	62.0	57.4	152.4
180	116.3	61.8	54.5	161.9
195	118.9	62.2	56.8	155.6
210	123.7	62.2	61.5	137.9
225	120.2	63.3	57.0	149.0
240	115.9	64.9	51.0	170.9
255	105.8	65.9	39.8	221.4
270	101.4	66.6	34.7	253.6
285	89.8	67.7	22.0	410.6
300	84.8	67.9	16.9	537.4
315	83.7	68.0	15.7	564.0
330	81.5	68.1	13.4	661.7
345	80.1	68.1	12.0	741.5
360	79.5	68.2	11.3	786.1

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
119	127	133	129	125	1.5	91	89	88	89	90
133	143	147	149	139	1.0	93	93	91	93	95
141	151	159	157	153	0.5	94	94	93	95	98
139	150	154	154	146	0.0	95	95	95	94	95
133	143	145	145	141	-0.5	95	94	94	93	95
115	127	129	125	125	-1.0	95	93	94	95	96
107	113	113	113	113	-1.5	96	95	95	96	96

TABLE I -- (continued)

RUN NUMBER A-30

DATE 1/28/67

AIR TEMPERATURE 79.5 F
WATER TEMPERATURE 73.7 F
HEAT FLUX 7010.0

ANGLE	T_W	T_O	ΔT	h
0	76.6	67.9	8.7	808.0
15	77.0	67.9	9.2	770.3
30	77.7	67.8	9.9	711.0
45	79.1	67.7	11.4	619.9
60	80.8	67.7	13.2	545.6
75	83.7	67.7	16.1	449.0
90	91.8	66.4	25.3	275.7
105	96.6	65.7	31.0	225.8
120	101.5	65.2	36.3	195.5
135	109.0	64.0	45.0	149.6
150	113.8	62.4	51.4	128.7
165	106.8	61.7	45.1	155.6
180	108.1	61.5	46.6	150.4
195	109.0	61.9	47.1	150.1
210	109.9	61.9	47.9	142.2
225	112.9	63.0	49.9	132.6
240	103.7	64.6	39.1	177.0
255	98.4	65.7	32.7	215.1
270	92.2	66.4	25.8	272.6
285	84.7	67.5	17.3	417.8
300	81.7	67.6	14.1	506.6
315	79.8	67.7	12.1	583.0
330	78.3	67.8	10.5	671.5
345	77.0	67.9	9.2	771.8
360	76.6	67.9	8.7	808.0

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
119	127	133	129	125	1.5	91	89	88	89	90
133	143	147	149	139	1.0	93	93	91	93	95
141	151	159	157	153	0.5	94	94	93	95	98
139	150	154	154	146	0.0	95	95	95	94	95
133	143	145	145	141	-0.5	95	94	94	93	95
115	127	129	125	125	-1.0	95	93	94	95	96
107	113	113	113	113	-1.5	96	95	95	96	96

TABLE I -- (continued)

RUN NUMBER A-31

DATE 1/15/67

AIR TEMPERATURE 79.5 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 6610.0

ANGLE	T_w	T_o	ΔT	h
0	75.4	68.7	6.7	984.0
15	76.0	68.7	7.4	900.9
30	76.7	68.7	7.9	834.4
45	77.7	68.7	8.9	744.6
60	79.1	68.7	10.4	650.4
75	81.1	68.5	12.5	539.0
90	86.8	67.6	19.3	342.8
105	90.3	66.5	23.8	277.0
120	93.8	66.2	27.6	243.7
135	99.5	65.5	34.0	193.9
150	105.3	62.7	42.6	147.1
165	104.8	61.2	43.6	147.2
180	100.9	61.0	39.9	165.8
195	102.6	61.4	41.3	157.2
210	105.3	62.8	42.4	148.2
225	100.0	64.8	35.2	184.6
240	94.7	66.0	28.7	234.5
255	89.8	66.6	23.2	286.7
270	87.9	67.4	20.6	318.8
285	81.6	68.0	13.5	496.6
300	79.1	68.2	10.9	616.3
315	77.7	68.5	9.2	723.3
330	76.5	68.5	8.0	830.8
345	75.8	68.7	7.1	936.3
360	75.4	68.7	6.7	984.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
138	155	175	175	165	1.5	91	90	88	91	94
169	171	185	199	179	1.0	91	91	91	94	96
177	189	199	203	163	0.5	93	91	90	93	97
179	189	210	189	173	0.0	93	91	90	93	97
161	183	199	179	149	-0.5	94	93	93	95	96
157	165	179	155	143	-1.0	95	96	93	95	95
143	139	163	137	141	-1.5	96	96	94	99	99

TABLE I -- (continued)

RUN NUMBER A-32

DATE 1/15/67

AIR TEMPERATURE	79.5 F
WATER TEMPERATURE	75.0 F
HEAT FLUX	8580.0

ANGLE	T_W	T_O	ΔT	h
0	76.9	68.3	8.6	1001.0
15	77.4	68.3	9.1	944.0
30	78.3	68.3	10.0	861.4
45	79.7	68.4	11.3	764.9
60	81.1	68.4	12.7	687.4
75	83.7	68.2	15.5	563.7
90	90.2	67.2	23.0	373.7
105	95.3	66.1	29.2	294.0
120	99.0	65.8	33.2	263.7
135	107.9	65.2	42.7	199.4
150	115.3	62.3	53.0	152.6
165	117.9	65.3	52.6	159.4
180	112.7	65.1	47.6	180.4
195	114.4	65.5	49.0	173.5
210	115.3	67.0	48.4	171.5
225	109.2	64.5	44.7	186.9
240	100.4	65.7	34.7	249.7
255	95.5	66.2	29.3	295.2
270	92.4	67.0	25.4	335.8
285	84.4	67.7	16.7	522.2
300	81.3	67.8	13.5	647.5
315	79.6	68.1	11.5	754.1
330	78.0	68.1	9.9	872.0
345	77.3	68.3	9.0	958.7
360	76.9	68.3	8.6	1001.0

SPRAY DISTRIBUTION						VELOCITY DISTRIBUTION				
-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
138	155	175	175	165	1.5	91	90	88	91	94
169	171	185	199	179	1.0	91	91	91	94	96
177	189	199	203	163	0.5	93	91	90	93	97
179	189	210	189	173	0.0	93	91	90	93	97
161	183	199	179	149	-0.5	94	93	93	95	96
157	165	179	155	143	-1.0	95	96	93	95	95
143	139	163	137	141	-1.5	96	96	94	99	99

TABLE I -- (continued)

RUN NUMBER A-33

DATE 2/11/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 6120.0

ANGLE	T_W	T_O	ΔT	h
0	71.5	66.3	5.2	1180.3
15	71.9	66.3	5.6	1094.7
30	72.6	66.4	6.2	982.7
45	73.3	66.4	6.9	889.4
60	74.2	66.4	7.8	792.1
75	75.7	66.2	9.5	664.1
90	80.2	65.8	14.4	431.7
105	86.1	64.3	21.7	275.4
120	88.7	63.9	24.9	243.0
135	90.9	63.6	27.3	225.1
150	94.0	62.8	31.3	195.1
165	96.7	61.9	34.8	171.9
180	97.1	60.7	36.5	167.9
195	98.5	61.3	37.2	161.8
210	98.5	61.9	36.5	161.5
225	95.4	63.3	32.1	187.2
240	89.2	63.8	25.3	242.2
255	85.6	64.5	21.2	288.6
270	80.8	65.7	15.1	408.9
285	76.0	66.3	9.7	646.8
300	74.3	66.3	8.0	779.4
315	73.2	66.3	6.9	889.7
330	72.4	66.3	6.0	1021.1
345	71.8	66.3	5.5	1121.9
360	71.5	66.3	5.2	1180.3

SPRAY DISTRIBUTION

VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	106	106	101	106	106
					1.0	106	99	100	104	106
250	206	226	214	154	0.5	102	97	97	99	105
246	254	273	240	198	0.0	97	90	90	94	101
233	254	262	250	190	-0.5	97	92	92	104	108
					-1.0	97	97	92	99	108
					-1.5	102	99	97	106	110

TABLE I -- (continued)

RUN NUMBER A-34

DATE 2/11/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 7690.0

ANGLE	T_W	T_O	ΔT	h
0	73.0	66.4	6.6	1168.0
15	73.6	66.5	7.1	1086.0
30	74.3	66.5	7.8	985.1
45	75.2	66.5	8.7	885.6
60	76.4	66.5	9.9	787.0
75	78.1	66.3	11.8	670.8
90	84.0	65.9	18.1	430.4
105	90.7	64.5	26.2	287.3
120	94.7	64.0	30.7	248.1
135	96.9	63.7	33.2	233.2
150	102.2	62.9	39.3	193.7
165	104.4	62.1	42.3	177.5
180	104.4	60.8	43.6	176.5
195	106.6	61.4	45.2	165.6
210	104.0	62.1	41.9	179.2
225	98.2	63.4	34.8	221.2
240	94.7	64.0	30.7	248.9
255	89.4	64.6	24.8	308.1
270	83.2	65.8	17.4	447.1
285	78.4	66.4	12.0	657.8
300	76.3	66.4	9.9	785.2
315	75.1	66.5	8.7	890.1
330	74.0	66.5	7.5	1027.7
345	73.3	66.4	6.8	1129.2
360	73.0	66.4	6.6	1168.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	106	106	101	106	106
					1.0	106	99	100	104	106
250	206	226	214	254	0.5	102	97	97	99	105
246	254	273	240	198	0.0	97	90	90	94	101
233	254	262	250	190	-0.5	97	92	92	104	108
					-1.0	97	97	92	99	108
					-1.5	102	99	97	106	110

TABLE I -- (continued)

RUN NUMBER A-35

DATE 2/5/57

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 8670.0

ANGLE	T_W	T_O	ΔT	h
0	74.7	68.1	6.7	1308.0
15	75.0	68.1	7.0	1249.0
30	75.8	68.1	7.7	1131.5
45	76.9	68.1	8.8	982.9
60	77.9	67.9	10.0	873.8
75	79.8	67.9	11.9	734.2
90	83.7	67.8	16.0	543.8
105	86.7	67.5	19.2	451.3
120	89.8	67.1	22.6	386.2
135	92.4	67.0	25.4	345.5
150	99.5	66.6	32.9	261.1
165	103.5	65.9	37.5	224.6
180	104.8	65.0	39.8	217.8
195	100.4	66.1	34.3	246.3
210	95.5	66.9	28.7	304.7
225	90.7	67.4	23.3	376.8
240	88.0	67.4	20.6	423.3
255	85.3	67.5	17.8	486.4
270	83.9	67.9	15.9	542.8
285	79.7	68.2	11.5	760.9
300	77.9	68.2	9.8	894.6
315	76.3	68.1	8.2	1065.2
330	75.8	68.1	7.7	1130.9
345	74.9	68.1	6.8	1271.9
360	74.7	68.1	6.7	1308.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
298	278	278	227	247	1.5	107	104	101	104	105
267	274	267	247	243	1.0	106	101	88	89	98
235	235	253	251	247	0.5	105	97	88	86	94
251	276	324	280	259	0.0	104	101	88	90	94
275	286	330	278	290	-0.5	106	100	89	95	98
266	334	354	318	318	-1.0	108	106	105	108	108
282	326	302	278	282	-1.5	110	109	109	111	113

TABLE I -- (continued)

RUN NUMBER A-36

DATE 2/5/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 8670.0

ANGLE	T_w	T_o	ΔT	h
0	73.0	67.8	5.3	1651.2
15	73.4	67.7	5.7	1533.4
30	74.3	67.7	6.6	1313.0
45	75.1	67.6	7.5	1156.8
60	76.2	67.5	8.8	996.6
75	77.6	67.5	10.1	869.3
90	81.3	67.5	13.8	629.5
105	85.3	67.2	18.1	475.7
120	88.0	67.1	20.9	418.6
135	90.2	67.0	23.2	382.3
150	98.2	66.2	32.0	265.6
165	103.0	65.3	37.8	221.9
180	100.4	65.6	34.8	249.4
195	97.7	66.2	31.6	267.2
210	94.2	66.8	27.4	314.3
225	87.1	67.3	19.8	445.1
240	84.9	67.5	17.3	506.2
255	82.7	67.5	15.2	570.3
270	80.4	67.5	12.9	668.9
285	77.1	67.5	9.6	912.8
300	75.6	67.7	8.0	1097.5
315	74.6	67.7	6.8	1271.6
330	73.8	67.8	6.0	1451.5
345	73.2	67.8	5.4	1607.9
360	73.0	67.8	5.3	1651.2

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
310	306	310	235	243	1.5	107	104	101	104	105
295	354	374	298	275	1.0	106	101	88	89	98
255	279	354	342	287	0.5	104	97	88	86	94
291	302	438	346	334	0.0	104	101	88	90	94
334	370	482	362	370	-0.5	106	100	89	95	98
319	438	458	358	346	-1.0	108	106	105	108	108
279	398	310	298	302	-1.5	110	109	109	111	112

TABLE I -- (continued)

RUN NUMBER A-37

DATE 2/5/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 7010.0

ANGLE	T_W	T_O	ΔT	h
0	72.2	67.7	4.5	1561.1
15	72.4	67.7	4.7	1398.6
30	73.0	67.6	5.3	1320.8
45	73.6	67.5	6.0	1164.7
60	74.4	67.4	7.0	1006.8
75	75.8	67.5	8.4	847.5
90	79.0	67.4	11.6	607.9
105	81.6	67.2	14.4	486.5
120	84.2	67.0	17.2	411.0
135	86.4	67.0	19.4	368.0
150	91.3	66.1	25.2	276.3
165	97.1	65.2	31.9	212.4
180	96.6	65.6	31.1	225.7
195	94.0	66.1	27.9	243.9
210	89.1	66.7	22.4	313.7
225	84.2	67.3	16.9	421.8
240	81.6	67.5	14.1	505.3
255	80.7	67.5	13.2	529.2
270	78.0	67.5	10.5	664.8
285	76.0	67.5	8.5	826.4
300	74.5	67.6	6.9	1023.4
315	73.7	67.7	6.0	1165.4
330	72.7	67.8	5.0	1418.3
345	72.4	67.7	4.7	1498.6
360	72.2	67.7	4.5	1561.1

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
310	306	310	235	243	1.5	107	104	101	104	105
295	354	374	398	375	1.0	106	101	88	89	98
255	279	354	342	287	0.5	104	97	88	86	94
291	302	438	346	334	0.0	104	101	88	90	94
334	370	482	362	370	-0.5	106	100	89	95	98
319	438	458	358	346	-1.0	108	106	105	108	108
279	398	310	298	302	-1.5	110	109	109	111	112

TABLE I -- (continued)

RUN NUMBER A-38 AIR TEMPERATURE 80.0 F

DATE 1/9/67 HEAT FLUX 550.0

ANGLE	T_W	T_O	ΔT	h
0	98.7	79.1	19.6	30.3
15	99.3	79.1	20.2	29.9
30	100.5	79.1	21.5	28.4
45	102.2	79.0	23.3	28.4
60	105.4	79.0	26.4	23.5
75	110.8	78.9	31.9	14.2
90	113.8	78.9	34.9	11.1
105	114.5	78.9	35.7	12.4
120	113.9	78.9	35.0	14.2
135	112.9	78.9	34.0	15.8
150	111.3	78.9	32.5	17.8
165	110.5	78.9	31.6	18.9
180	110.2	78.9	31.4	17.5
195	111.8	78.9	32.9	17.8
210	112.5	78.9	33.6	16.4
225	113.7	78.9	34.8	15.9
240	115.0	78.9	36.1	13.7
255	115.7	78.9	36.8	11.9
270	114.7	78.9	35.8	11.5
285	112.2	78.9	33.3	13.4
300	107.3	78.9	28.4	19.9
315	103.3	78.9	24.4	26.2
330	100.6	79.0	21.6	29.7
345	99.2	79.1	20.1	30.6
360	98.7	79.1	19.6	30.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0 -0.5 0.0 0.5 1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
	1.5	63	62	61	61	63
	1.0	63	63	63	63	63
	0.5	64	63	64	62	63
0	0.0	65	64	64	61	63
	-0.5	65	65	65	62	62
	-1.0	65	65	65	65	65
	-1.5	66	67	66	66	67

TABLE I -- (continued)

RUN NUMBER A-39 AIR TEMPERATURE 80.0 F

DATE 1/1/67 HEAT FLUX 1025.0

ANGLE	T_W	T_O	ΔT	h
0	117.1	79.1	38.0	30.3
15	117.5	79.1	38.4	30.0
30	119.8	79.1	40.7	29.4
45	123.8	79.0	44.8	27.4
60	131.2	79.0	52.2	21.3
75	140.4	78.9	61.5	14.1
90	146.9	78.9	68.0	10.4
105	149.0	78.9	70.1	10.7
120	146.9	78.9	68.0	13.4
135	143.9	78.9	65.0	15.9
150	141.0	78.9	62.2	17.7
165	139.3	78.9	60.4	18.5
180	138.9	78.9	60.0	17.1
195	140.8	78.9	61.9	17.9
210	143.0	78.9	64.2	16.0
225	145.0	78.9	66.1	15.3
240	147.3	78.9	68.4	13.8
255	148.5	78.9	69.6	11.8
270	147.4	78.9	68.4	10.6
285	142.0	78.9	63.1	13.0
300	132.5	78.9	53.6	20.2
315	125.3	78.9	46.3	26.1
330	120.5	79.0	41.5	28.7
345	118.0	79.1	38.9	30.1
360	117.1	79.1	38.0	30.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

Spray -1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5	63	62	61	61	63
					1.0	63	63	63	63	63
					0.5	64	63	64	62	63
		0			0.0	65	64	64	61	63
					-0.5	65	65	65	62	62
					-1.0	65	65	65	65	65
					-1.5	66	67	66	66	67

TABLE I -- (continued)

RUN NUMBER A-40

DATE 12/8/66

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 74.0 F
HEAT FLUX 3690.0

ANGLE	T_w	T_o	ΔT	h
0	77.4	63.2	14.2	261.0
15	77.9	63.1	14.9	251.8
30	79.0	63.1	16.0	234.0
45	80.7	62.8	17.9	211.9
60	82.7	62.7	20.0	199.1
75	88.5	62.7	25.8	159.2
90	100.9	62.3	38.6	103.0
105	117.0	61.5	55.5	67.5
120	131.8	60.1	71.7	40.5
135	147.4	59.5	87.9	26.6
150	125.7	60.6	65.1	57.2
165	112.6	59.6	52.9	82.8
180	119.0	58.7	60.3	61.2
195	122.6	59.9	62.7	61.2
210	130.1	59.3	70.7	47.0
225	130.5	60.2	70.3	47.1
240	122.6	59.9	62.7	53.2
255	119.6	60.9	58.7	55.3
270	99.2	62.4	36.8	104.4
285	88.0	63.2	24.8	169.2
300	82.0	63.1	18.9	209.8
315	79.9	63.1	16.8	225.7
330	78.7	63.1	15.6	239.0
345	78.8	63.1	14.7	254.5
360	77.4	63.2	14.2	261.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
23	31	34	36	39	1.5	62	60	60	60	62
27	30	34	38	41	1.0	62	62	62	62	64
26	29	34	38	41	0.5	64	62	62	62	64
24	27	32	36	40	0.0	65	64	62	64	65
23	27	31	35	39	-0.5	65	64	62	64	65
21	23	27	31	35	-1.0	65	65	65	65	65
20	22	25	29	32	-1.5	65	65	65	65	65

TABLE I -- (continued)

RUN NUMBER A-41

DATE 12/8/66

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 74.0 F
HEAT FLUX 4825.0

ANGLE	T_W	T_O	ΔT	h
0	81.7	63.2	18.5	262.0
15	82.5	63.1	19.5	251.3
30	84.2	63.1	21.1	230.7
45	85.7	62.8	22.9	216.8
60	88.9	62.7	26.1	198.6
75	96.7	62.7	34.0	162.2
90	112.3	62.3	50.0	104.1
105	142.0	61.5	80.5	52.6
120	153.2	60.1	93.0	46.0
135	156.6	59.5	97.2	48.0
150	169.6	60.6	109.0	37.7
165	165.3	59.6	105.6	44.1
180	148.0	58.7	89.3	54.0
195	154.5	59.9	94.6	49.6
210	169.6	59.3	110.2	38.6
225	148.0	60.2	87.8	54.9
240	163.1	59.9	103.2	36.7
255	142.0	60.9	81.1	48.9
270	107.0	62.4	44.6	124.9
285	94.4	63.2	31.2	179.8
300	87.5	63.1	24.4	210.6
315	84.8	63.1	21.7	228.0
330	83.4	63.1	20.3	239.7
345	82.1	63.1	19.0	257.0
360	81.7	63.2	18.5	262.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
23	31	34	36	39	1.5	62	60	60	60	62
27	30	34	38	41	1.0	62	62	62	62	64
26	29	34	38	41	0.5	64	62	62	62	64
24	27	32	36	40	0.0	65	64	62	64	65
23	27	31	35	39	-0.5	65	64	62	64	65
21	23	27	31	35	-1.0	65	65	65	65	65
20	22	25	29	32	-1.5	65	65	65	65	65

TABLE I -- (continued)

RUN NUMBER A-42

DATE 11/13/66

AIR TEMPERATURE 78.3 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 5600.0

ANGLE	T_W	T_O	ΔT	h
0	82.0	65.8	16.2	346.6
15	82.4	65.8	16.6	340.8
30	83.6	65.6	18.0	312.7
45	85.5	65.8	19.6	289.9
60	87.5	65.7	21.8	269.3
75	93.0	65.7	27.3	217.2
90	104.4	64.9	39.5	155.3
105	115.9	64.1	51.8	125.0
120	147.2	62.8	48.4	62.5
135	182.3	61.9	120.4	30.4
150	174.8	61.6	113.1	40.9
165	154.9	61.4	93.5	65.7
180	155.3	61.4	94.0	59.6
195	146.8	61.4	85.4	67.6
210	166.3	61.5	104.8	46.8
225	155.9	61.7	94.2	49.8
240	143.6	62.4	81.1	65.0
255	120.9	63.3	57.5	99.8
270	105.7	64.5	41.2	146.1
285	93.9	65.8	28.1	214.0
300	88.3	65.9	22.3	263.4
315	85.8	66.0	19.8	288.6
330	84.0	66.0	17.9	314.9
345	82.7	66.1	16.6	340.0
360	82.1	66.2	16.0	350.5

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
37	36	37	37	33	1.5	62	61	60	60	62
40	40	41	41	37	1.0	62	60	59	59	63
41	41	43	44	40	0.5	63	61	60	60	63
41	42	49	46	44	0.0	63	63	63	63	65
42	44	44	41	44	-0.5	64	64	63	63	65
40	41	44	41	44	-1.0	65	65	64	65	65
38	40	43	45	44	-1.5	66	65	64	66	66

TABLE I -- (continued)

RUN NUMBER A-43

DATE 11/13/66

AIR TEMPERATURE 78.3 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 7300.0

ANGLE	T_W	T_O	ΔT	h
0	88.0	65.8	22.2	329.5
15	88.5	65.8	22.7	324.1
30	90.0	65.6	24.4	301.3
45	92.1	65.8	26.2	282.0
60	94.6	65.7	28.8	265.0
75	100.4	65.7	34.7	223.2
90	115.7	64.9	50.9	165.5
105	130.3	64.1	66.2	130.7
120	192.5	62.8	129.7	48.7
135	227.4	61.9	165.6	33.2
150	222.1	61.6	160.4	38.9
165	239.4	61.4	178.0	39.5
180	201.2	61.4	139.8	52.2
195	194.0	61.4	132.6	57.3
210	186.9	61.5	125.4	59.6
225	208.6	61.7	146.9	37.5
240	182.0	62.4	119.6	50.5
255	137.5	63.3	74.2	108.0
270	116.4	64.5	51.9	158.0
285	103.3	65.8	37.5	208.3
300	95.6	65.9	29.6	257.4
315	92.4	66.0	26.4	282.3
330	90.3	66.0	24.2	303.6
345	88.6	66.1	22.6	327.0
360	88.0	66.2	21.8	334.2

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
37	36	37	37	33	1.5	62	61	60	60	62
40	40	41	41	37	1.0	62	60	59	59	63
41	41	43	44	40	0.5	63	61	60	60	63
41	42	49	46	44	0.0	63	63	63	63	65
42	44	44	41	44	-0.5	64	64	63	63	65
40	41	44	41	44	-1.0	65	65	64	65	65
38	40	43	45	44	-1.5	66	65	64	66	66

TABLE I -- (continued)

RUN NUMBER A-44

DATE 1/16/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 6210.0

ANGLE	T_W	T_O	ΔT	h
0	77.3	65.8	11.4	545.6
15	77.7	65.7	12.0	522.3
30	78.6	65.7	12.8	486.8
45	79.9	65.7	14.2	438.9
60	81.6	65.8	15.8	400.4
75	84.4	65.7	18.7	340.2
90	89.2	64.3	24.9	256.5
105	95.0	63.2	31.7	212.6
120	105.1	62.4	42.7	158.3
135	133.1	61.3	71.8	78.8
150	147.8	59.2	86.6	58.5
165	143.5	59.0	84.5	70.5
180	141.8	58.5	83.3	74.5
195	133.5	58.7	74.8	84.2
210	150.9	59.3	91.6	57.4
225	140.0	60.6	79.5	66.3
240	114.8	62.3	52.4	124.5
255	100.3	63.3	36.9	181.7
270	93.2	63.8	29.4	217.6
285	85.3	65.4	19.9	323.8
300	82.0	65.4	16.6	384.9
315	80.5	65.7	14.8	422.1
330	78.8	65.7	13.1	475.5
345	77.8	65.6	12.2	513.3
360	77.3	65.8	11.4	545.6

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
93	97	102	99	97	1.5	64	63	61	64	66
103	99	102	102	99	1.0	64	63	63	65	67
101	101	103	102	94	0.5	65	63	63	66	67
98	97	101	99	95	0.0	63	63	62	65	67
97	98	102	99	90	-0.5	64	64	63	67	67
93	93	95	92	86	-1.0	67	67	65	67	67
86	85	89	85	82	-1.5	67	67	65	67	67

TABLE I -- (continued)

RUN NUMBER A-45

DATE 1/16/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 7420.0

ANGLE	T_W	T_O	ΔT	h
0	79.6	65.8	13.8	542.0
15	80.1	65.7	14.4	517.8
30	81.1	65.7	15.4	485.5
45	82.6	65.7	17.0	440.5
60	84.6	65.8	18.8	402.4
75	87.9	65.7	22.2	341.1
90	94.6	64.3	30.3	250.8
105	97.7	63.2	34.5	239.0
120	113.1	62.4	50.7	159.5
135	149.7	61.3	88.4	73.7
150	164.3	59.2	105.1	60.1
165	156.1	59.0	97.1	74.6
180	163.0	58.5	104.5	71.0
195	165.2	58.7	106.5	68.4
210	160.4	59.3	101.1	66.6
225	160.4	60.6	99.8	64.3
240	126.2	62.3	63.9	118.3
255	106.9	63.3	43.6	186.1
270	97.2	63.8	33.5	231.3
285	88.4	65.4	23.0	335.6
300	85.0	65.4	19.6	388.7
315	82.6	65.7	16.9	443.8
330	81.3	65.7	15.6	478.9
345	79.9	65.6	14.2	524.4
360	79.6	65.8	13.8	542.0

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
93	97	102	99	97	1.5	64	63	61	64	66
103	99	102	102	99	1.0	64	63	63	65	67
101	101	103	102	94	0.5	65	63	63	66	67
98	97	101	99	95	0.0	63	63	62	65	67
97	98	102	99	90	-0.5	64	64	63	67	67
93	93	95	92	86	-1.0	67	67	65	67	67
86	85	89	85	82	-1.5	67	67	65	67	67

TABLE I -- (continued)

RUN NUMBER A-46

DATE 2/9/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 6030.0

ANGLE	T_w	T_o	ΔT	h
0	74.4	66.4	8.0	757.1
15	74.7	66.3	8.4	721.1
30	75.5	66.2	9.3	649.2
45	76.2	66.2	10.0	607.1
60	77.1	66.2	10.9	561.4
75	78.8	66.2	12.6	488.7
90	82.0	66.2	15.8	384.4
105	86.9	65.2	21.7	275.6
120	87.8	64.8	23.0	267.1
135	92.2	64.3	27.9	223.6
150	99.3	63.1	36.2	165.3
165	105.9	61.2	44.7	127.6
180	108.1	60.8	47.3	127.4
195	112.5	61.3	51.2	110.9
210	102.4	62.6	39.8	148.5
225	97.1	63.6	33.4	184.8
240	90.9	64.7	26.2	234.9
255	88.7	65.4	23.3	258.6
270	88.9	65.9	19.0	317.1
285	78.9	66.4	12.5	494.7
300	77.2	66.4	10.8	569.3
315	76.2	66.4	9.8	615.7
330	75.5	66.4	9.1	662.6
345	74.7	66.4	8.4	724.7
360	74.4	66.4	8.0	757.1

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
162	154	159	143	159	1.5	75	75	68	71	73
164	154	154	143	164	1.0	75	71	65	65	73
151	138	149	146	156	0.5	75	71	63	63	66
154	146	159	156	164	0.0	73	68	63	65	66
146	156	159	165	183	-0.5	75	66	63	66	71
170	178	186	175	186	-1.0	75	70	69	71	75
167	175	193	172	193	-1.5	76	75	75	78	78

TABLE I -- (continued)

RUN NUMBER A-47

DATE 2/9/67

AIR TEMPERATURE 78.0 F
WATER TEMPERATURE 72.0 F
HEAT FLUX 7690.0

ANGLE	T_W	T_O	ΔT	h
0	76.4	66.3	10.1	762.7
15	76.7	66.2	10.5	738.7
30	77.3	66.2	11.1	693.3
45	78.4	66.2	12.2	630.7
60	79.5	66.2	13.3	585.3
75	81.7	66.2	15.5	504.6
90	86.7	66.1	20.6	374.9
105	91.6	65.1	26.5	290.4
120	94.2	64.7	29.6	265.8
135	101.3	64.2	37.1	218.4
150	110.1	63.0	47.1	162.4
165	129.8	61.1	68.7	102.9
180	123.7	60.7	63.0	122.0
195	121.9	61.2	60.8	119.8
210	110.6	62.5	48.1	160.0
225	103.5	63.6	40.0	196.8
240	97.8	64.6	33.2	233.4
255	93.4	65.3	28.1	273.3
270	87.2	65.8	21.3	364.5
285	81.3	66.3	15.0	524.5
300	79.8	66.3	13.5	578.2
315	78.7	66.3	12.4	623.1
330	77.5	66.3	11.2	690.7
345	77.0	66.3	10.7	723.2
360	76.4	66.3	10.1	762.7

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
162	154	159	143	159	1.5	75	75	68	71	73
164	154	154	143	164	1.0	75	71	65	65	73
151	138	149	146	156	0.5	75	71	63	63	66
154	146	159	156	164	0.0	73	68	63	65	66
146	156	159	165	183	-0.5	75	66	63	66	71
170	178	186	175	186	-1.0	75	70	69	71	75
167	175	193	172	193	-1.5	76	75	75	78	78

TABLE I -- (continued)

RUN NUMBER A-48

DATE 2/9/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 7690.0

ANGLE	T_W	T_O	ΔT	h
0	74.3	66.6	7.7	1006.8
15	74.5	66.6	7.9	980.8
30	75.1	66.6	8.6	898.6
45	75.8	66.6	9.3	834.0
60	77.1	66.5	10.6	731.3
75	78.4	66.5	11.9	656.2
90	81.8	66.5	15.4	507.4
105	87.2	65.6	21.6	357.2
120	90.3	64.9	25.3	307.9
135	96.9	64.6	32.3	241.9
150	104.4	63.8	40.6	185.9
165	111.4	62.7	48.8	151.0
180	109.7	61.4	48.3	159.1
195	110.1	61.7	48.4	154.1
210	105.7	62.7	43.0	175.1
225	100.4	63.9	36.6	210.1
240	94.2	64.5	29.7	259.1
255	89.4	65.1	24.3	316.5
270	83.6	66.1	17.4	446.7
285	78.5	66.6	12.0	658.3
300	77.0	66.6	10.5	744.9
315	76.0	66.6	9.4	817.7
330	75.1	66.6	8.5	908.1
345	74.6	66.6	8.0	970.0
360	74.3	66.6	7.7	1006.8

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
203	191	207	159	179	1.5	75	75	68	71	73
223	219	211	179	207	1.0	75	71	65	65	73
219	219	219	207	223	0.5	75	71	63	63	66
203	211	243	239	251	0.0	73	68	63	65	66
215	231	259	247	263	-0.5	75	66	63	66	71
231	266	282	239	247	-1.0	75	70	69	71	75
219	239	247	207	219	-1.5	76	75	75	78	78

TABLE I -- (continued)

RUN NUMBER A-49

DATE 2/9/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 70.0 F
HEAT FLUX 6120.0

ANGLE	T_W	T_O	ΔT	h
0	71.8	65.9	5.9	1033.4
15	72.1	65.9	6.2	988.0
30	72.5	65.8	6.2	927.1
45	73.3	65.8	7.4	826.4
60	74.0	65.8	8.2	756.2
75	75.2	65.8	9.4	662.5
90	79.0	65.7	13.3	464.5
105	83.0	64.9	18.1	335.6
120	84.8	64.2	20.5	302.4
135	88.7	63.9	24.8	251.7
150	95.4	63.1	32.3	188.5
165	100.3	61.9	38.3	152.8
180	102.9	60.6	42.3	144.8
195	104.7	61.0	43.7	134.2
210	99.8	62.0	38.8	157.0
225	93.6	63.1	30.5	202.3
240	87.9	63.8	24.1	256.4
255	83.9	64.4	19.5	314.7
270	78.5	65.4	13.1	474.9
285	75.3	65.8	9.5	662.2
300	74.1	65.8	8.2	751.8
315	73.4	65.9	7.5	821.6
330	72.6	65.9	6.7	914.4
345	72.2	65.9	6.3	973.9
360	71.8	65.9	5.9	1033.4

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
203	191	207	159	179	1.5	75	75	68	71	73
223	219	211	179	207	1.0	75	71	65	65	73
219	219	219	207	223	0.5	75	71	63	63	66
203	211	243	239	251	0.0	73	68	63	65	66
215	231	259	247	263	-0.5	75	66	63	66	71
231	266	282	239	247	-1.0	75	70	69	71	75
219	239	247	207	219	-1.5	76	75	75	78	78

TABLE II

EXPERIMENTAL DATA -- 1.0 IN. DIA. TUBE

RUN NUMBER B-1

DATE 2/23/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 8240.0

ANGLE	T_w	T_o	ΔT	h
0	75.7	67.9	7.7	1072.0
15	75.9	67.9	7.9	1049.0
30	76.6	67.9	8.6	961.5
45	77.5	67.9	9.5	872.6
60	78.9	67.9	10.9	772.2
75	80.8	67.9	12.9	657.4
90	86.7	67.5	19.3	424.9
105	89.6	66.4	23.2	346.6
120	92.3	66.4	25.9	321.3
135	94.1	66.1	28.0	309.9
150	100.3	65.1	35.1	235.6
165	108.2	63.2	44.9	170.1
180	107.7	62.3	45.4	181.5
195	108.6	62.5	46.1	168.9
210	106.9	64.7	42.1	187.3
225	98.5	65.4	33.1	254.3
240	95.0	66.0	29.0	291.8
255	91.4	66.2	25.1	324.1
270	88.7	66.7	22.0	368.7
285	81.6	67.3	14.3	590.8
300	78.9	67.4	11.5	738.5
315	77.5	67.5	10.0	831.3
330	76.6	67.8	8.8	942.8
345	75.8	67.9	7.9	1051.1
360	75.7	67.9	7.7	1072.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
152	170	195	207	215	0.5	130	121	126	128	130
176	195	211	215	174	0.0	139	134	133	137	139
215	211	230	262	186	-0.5	141	139	137	139	142
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-2

DATE 2/23/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 5830.0

ANGLE	T_W	T_O	ΔT	h
0	73.5	68.3	5.2	1121.0
15	73.9	68.3	5.6	1043.7
30	74.8	68.3	6.5	900.5
45	75.3	68.3	7.0	835.3
60	76.2	68.3	7.9	763.2
75	77.5	68.3	9.2	653.9
90	82.0	67.8	14.2	406.3
105	84.4	66.7	17.7	320.3
120	85.3	66.7	18.6	319.9
135	88.0	66.4	21.6	283.5
150	92.4	65.5	26.9	214.9
165	97.7	63.6	34.1	158.0
180	96.9	62.7	34.1	170.7
195	96.0	62.9	33.1	166.7
210	93.3	65.1	28.2	204.6
225	89.8	65.7	24.0	248.2
240	87.1	66.3	20.8	285.2
255	85.3	66.6	18.7	305.5
270	83.2	67.1	16.1	356.8
285	78.0	67.7	10.3	583.1
300	76.2	67.7	8.5	709.0
315	75.2	67.9	7.3	806.5
330	74.5	68.1	6.4	917.3
345	73.8	68.2	5.5	1062.7
360	73.5	68.3	5.2	1121.0

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
152	170	195	207	215	0.5	130	121	126	128	130
176	195	211	215	174	0.0	139	134	133	137	139
215	211	230	262	186	-0.5	141	139	137	139	142
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-3

DATE 2/23/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 74.0 F
HEAT FLUX 6030.0

ANGLE	T_W	T_O	ΔT	h
0	70.7	67.3	3.4	1760.9
15	71.1	67.3	3.8	1595.7
30	71.6	67.3	4.3	1406.9
45	72.1	67.2	4.9	1240.2
60	72.6	67.1	5.5	1122.5
75	73.5	67.1	6.4	967.4
90	76.4	67.1	9.3	647.9
105	78.6	66.2	12.4	480.0
120	80.0	66.2	13.8	422.0
135	82.2	65.7	16.4	387.5
150	84.8	64.6	20.3	315.1
165	93.7	63.6	30.2	184.1
180	99.0	62.1	36.9	163.2
195	96.4	62.2	34.2	162.3
210	88.4	64.0	24.3	255.5
225	85.3	64.9	20.4	309.6
240	82.6	65.3	17.3	353.5
255	80.4	65.7	14.7	406.6
270	78.5	66.1	12.4	481.8
285	74.5	66.5	8.0	774.5
300	72.8	66.6	6.2	992.8
315	71.9	66.9	5.1	1203.4
330	71.3	67.2	4.1	1477.3
345	70.9	67.2	3.7	1656.9
360	70.7	67.2	3.4	1760.9

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
231	330	398	429	438	0.5	130	121	126	128	130
269	374	380	338	255	0.0	139	134	133	137	139
318	318	338	426	231	-0.5	141	139	137	139	141
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-4

DATE 2/23/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 74.0 F
HEAT FLUX 8240.0

ANGLE	T_W	T_O	ΔT	h
0	72.5	67.5	5.0	1655.0
15	72.8	67.5	5.3	1559.1
30	73.5	67.5	6.0	1380.4
45	74.4	67.5	6.9	1193.4
60	75.2	67.4	7.8	1070.3
75	76.7	67.4	9.3	901.9
90	80.8	67.4	13.4	613.9
105	83.4	66.4	17.0	480.9
120	85.6	66.4	19.3	432.8
135	88.7	66.0	22.8	375.8
150	92.7	64.8	27.9	305.5
165	101.6	63.8	37.8	204.2
180	107.3	62.3	45.0	182.9
195	107.7	62.4	45.4	167.3
210	95.8	64.3	31.6	266.2
225	91.9	65.1	26.7	323.4
240	88.3	65.6	22.7	366.1
255	85.6	65.9	19.8	413.4
270	82.6	66.3	16.3	501.3
285	77.5	66.7	10.7	785.3
300	75.3	66.8	8.4	995.6
315	74.0	67.1	6.9	1207.2
330	72.9	67.4	5.5	1513.7
345	72.5	67.5	5.1	1628.6
360	72.5	67.5	5.0	1655.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
231	330	398	429	438	0.5	130	121	126	128	130
269	374	380	338	255	0.0	139	134	133	137	139
318	318	338	426	231	-0.5	141	139	137	139	141
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-5 AIR TEMPERATURE 80.0 F

DATE 2/19/67 HEAT FLUX 650.0

ANGLE	T_W	T_O	ΔT	h
0	97.1	79.1	18.0	39.3
15	97.2	79.0	18.1	38.9
30	97.2	79.0	18.2	42.9
45	98.7	78.9	19.7	41.7
60	101.1	78.9	22.3	33.5
75	105.1	78.7	26.3	21.5
90	107.6	78.6	29.0	16.4
105	109.1	78.6	30.4	16.0
120	109.3	78.6	30.7	17.5
135	108.5	78.6	29.9	21.1
150	107.7	78.6	29.2	22.9
165	107.4	78.6	28.8	23.9
180	106.7	78.6	28.2	23.1
195	106.8	78.6	28.2	26.0
210	107.9	78.6	29.3	23.7
225	109.2	78.6	30.6	18.7
240	110.3	78.6	31.7	14.3
255	109.4	78.6	30.8	13.5
270	107.2	78.7	28.5	17.8
285	103.0	78.8	24.2	28.9
300	100.1	78.9	21.2	37.9
315	98.0	78.9	19.1	41.5
330	97.2	79.0	18.3	40.6
345	97.2	79.0	18.1	37.7
360	97.1	79.1	18.0	39.3

SPRAY DISTRIBUTION VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
					0.5	116	107	106	106	107
		0			0.0	119	114	110	110	114
					-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-6

DATE 2/19/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 76.0 F
HEAT FLUX 7040.0

ANGLE	T_W	T_O	ΔT	h
0	79.6	65.8	13.7	517.1
15	80.0	65.7	14.3	501.2
30	81.5	65.5	15.9	447.5
45	83.2	65.3	17.9	406.8
60	86.0	65.2	20.8	359.0
75	92.8	65.0	27.8	259.7
90	102.6	64.2	38.4	188.1
105	106.9	63.7	43.3	193.4
120	124.5	63.2	61.3	129.7
135	159.1	62.5	96.7	56.1
150	172.1	62.2	109.9	46.2
165	166.9	62.2	104.7	64.4
180	166.0	62.1	103.9	67.7
195	163.4	62.2	101.2	62.0
210	158.7	62.7	96.0	59.6
225	142.7	62.9	79.9	79.9
240	114.9	63.5	51.4	156.6
255	103.9	63.9	40.0	196.9
270	100.1	64.5	35.5	197.9
285	89.4	65.7	23.8	310.7
300	85.2	65.7	19.5	383.3
315	83.2	65.8	17.4	411.8
330	81.8	65.8	15.9	444.6
345	80.6	65.8	14.7	484.0
360	79.6	65.8	13.7	517.1

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
66	73	66	66	58	0.5	116	107	106	106	107
86	82	66	53	57	0.0	119	114	110	110	114
97	73	71	64	56	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-7

DATE 2/19/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 76.0 F
HEAT FLUX 5100.0

ANGLE	T_W	T_O	ΔT	h
0	75.6	65.8	9.7	527.3
15	76.2	65.7	10.4	497.8
30	77.2	65.5	11.3	451.5
45	77.9	65.3	12.2	428.1
60	79.4	65.2	13.7	398.5
75	82.6	65.0	16.9	315.7
90	90.6	64.2	26.0	190.6
105	92.6	63.7	28.6	197.6
120	97.9	63.2	34.4	167.2
135	119.4	62.5	56.5	79.3
150	124.2	62.2	61.6	68.1
165	129.0	62.2	66.8	70.9
180	125.1	62.1	63.0	81.0
195	132.1	62.2	69.9	69.7
210	137.7	62.7	75.5	46.8
225	126.0	62.9	63.5	68.6
240	107.1	63.5	43.9	129.4
255	99.6	63.9	35.9	153.3
270	93.2	64.5	29.0	177.5
285	85.2	65.7	20.2	267.9
300	80.6	65.7	15.4	352.8
315	78.5	65.8	13.1	399.8
330	77.1	65.8	11.5	448.6
345	76.2	65.8	10.5	494.2
360	75.6	65.8	9.7	527.3

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
66	73	66	66	58	0.5	116	107	106	106	107
86	82	66	53	57	0.0	119	114	110	110	114
97	73	71	64	56	-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-8

DATE 2/19/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 5650.0

ANGLE	T_W	T_O	ΔT	h
0	75.4	66.0	9.4	605.0
15	76.0	66.0	10.0	571.6
30	76.9	66.1	10.8	527.2
45	78.0	65.9	12.1	473.6
60	79.4	65.7	13.7	432.3
75	82.2	65.6	16.7	352.2
90	89.6	65.0	24.6	224.2
105	92.1	64.7	27.4	214.8
120	96.1	64.0	32.0	186.1
135	108.0	63.1	44.9	114.9
150	110.2	62.0	48.2	104.2
165	109.7	61.4	48.4	114.3
180	107.5	61.3	46.3	122.1
195	109.7	61.8	47.9	123.7
210	122.9	61.6	61.2	70.0
225	118.5	62.9	55.6	79.9
240	101.4	63.9	37.4	162.7
255	93.8	64.8	29.0	213.2
270	91.1	64.8	26.3	212.8
285	83.7	65.7	18.0	322.4
300	79.4	65.5	13.9	428.7
315	77.5	65.7	11.7	495.2
330	76.2	65.9	10.3	558.8
345	78.6	66.0	9.7	592.5
360	75.8	66.0	9.4	605.0

SPRAY DISTRIBUTION / VELOCITY DISTRIBUTION

Spray -1.0	Spray -0.5	Spray 0.0	Spray 0.5	Spray 1.0	LOCATION	Velocity -1.0	Velocity -0.5	Velocity 0.0	Velocity 0.5	Velocity 1.0
					1.5					
					1.0					
					0.5	116	107	106	106	107
100	80	85	81	90	0.0	119	114	110	110	114
					-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-9

DATE 2/19/67

AIR TEMPERATURE 79.0 F
WATER TEMPERATURE 75.0 F
HEAT FLUX 7040.0

ANGLE	T_W	T_O	ΔT	h
0	77.4	66.0	11.3	624.2
15	78.1	66.0	12.1	592.4
30	79.4	66.1	13.3	533.2
45	81.0	65.9	15.1	470.8
60	82.6	65.7	16.9	435.8
75	86.3	65.6	20.7	352.2
90	95.1	65.0	30.1	229.5
105	98.1	64.7	33.5	224.4
120	103.9	64.0	39.8	189.3
135	122.7	63.1	59.7	105.6
150	125.8	62.0	63.8	95.6
165	126.2	61.4	64.9	105.7
180	122.3	61.3	61.0	115.4
195	135.8	61.8	73.9	91.4
210	143.6	61.6	82.0	62.0
225	128.8	62.9	66.0	95.0
240	111.8	63.9	47.9	160.4
255	100.8	64.8	36.0	211.8
270	96.8	64.8	32.0	221.4
285	88.3	65.7	22.6	319.0
300	82.9	65.5	17.4	424.3
315	80.4	65.7	14.6	493.1
330	78.7	65.9	12.8	557.5
345	77.9	66.0	11.9	598.0
360	77.4	66.0	11.3	624.2

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

Spray -1.0	Spray -0.5	Spray 0.0	Spray 0.5	Spray 1.0	LOCATION	Velocity -1.0	Velocity -0.5	Velocity 0.0	Velocity 0.5	Velocity 1.0
					1.5					
					1.0					
					0.5	116	107	106	106	107
100	80	85	81	90	0.0	119	114	110	110	114
					-0.5	116	116	110	112	117
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-10

DATE 2/20/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 8270.0

ANGLE	T_w	T_o	ΔT	h
0	74.1	66.1	8.0	1045.7
15	74.7	66.1	8.6	965.6
30	75.3	66.1	9.2	903.4
45	76.5	66.1	10.4	801.2
60	77.9	66.1	11.9	716.3
75	80.3	66.0	14.3	602.3
90	87.1	65.5	21.6	385.0
105	92.3	64.4	27.9	291.2
120	96.3	63.9	32.4	257.3
135	100.7	63.5	37.2	230.0
150	107.7	62.5	45.3	178.5
165	115.6	61.1	54.6	140.4
180	113.5	60.7	52.7	156.9
195	117.8	60.8	57.0	134.0
210	118.7	62.3	56.4	129.6
225	112.5	63.3	39.1	218.9
240	96.7	63.9	32.8	268.5
255	94.1	64.4	29.7	272.8
270	89.7	64.9	24.7	328.1
285	81.4	65.9	15.5	554.0
300	78.2	66.0	12.2	701.9
315	76.3	66.0	10.3	811.6
330	75.2	66.1	9.1	919.1
345	74.4	66.1	8.3	1008.8
360	74.1	66.1	8.0	1045.7

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
159	163	179	199	199	0.5	113	101	102	106	108
175	183	199	195	179	0.0	116	111	109	112	116
199	199	219	223	183	-0.5	117	116	115	116	118
					-1.0					
					-1.5					

TABLE II -- (continued)

RUN NUMBER B-11

DATE 2/20/67

AIR TEMPERATURE 77.0 F
WATER TEMPERATURE 73.0 F
HEAT FLUX 7250.0

ANGLE	T_W	T_O	ΔT	h
0	73.0	65.9	7.1	1025.1
15	73.3	65.9	7.4	984.0
30	73.8	65.9	7.9	928.3
45	74.9	65.9	9.0	809.3
60	76.2	65.8	10.4	720.6
75	78.1	65.8	12.3	614.3
90	84.6	65.3	19.3	376.8
105	89.2	64.2	25.1	284.6
120	92.8	63.6	29.1	251.4
135	97.6	63.3	34.4	216.1
150	103.4	62.3	41.1	172.1
165	109.5	60.9	48.7	138.6
180	108.7	60.5	48.2	150.5
195	109.5	60.6	49.0	138.8
210	108.7	62.1	46.6	144.0
225	99.0	63.1	35.9	205.2
240	93.2	63.7	29.5	257.6
255	90.1	64.1	26.0	276.1
270	87.5	64.7	22.8	310.7
285	79.7	65.7	14.0	537.3
300	76.9	65.7	11.2	674.6
315	75.3	65.8	9.5	769.6
330	73.8	65.9	7.9	932.3
345	73.2	65.9	7.3	998.7
360	73.0	65.9	7.1	1025.1

SPRAY DISTRIBUTION | VELOCITY DISTRIBUTION

-1.0	-0.5	0.0	0.5	1.0	LOCATION	-1.0	-0.5	0.0	0.5	1.0
					1.5					
					1.0					
159	163	179	199	199	0.5	113	101	102	106	108
175	183	199	195	179	0.0	116	111	109	112	116
199	199	219	223	183	-0.5	117	116	115	116	118
					-1.0					
					-1.5					

APPENDIX C

ESTIMATION OF ERRORS

The experimental accuracy was bounded by possible errors in the temperature measurements, in the heat flux measurements, in the calculation procedure for determining heat transfer coefficients, in the spray density measurements and in the velocity measurements.

Temperature Measurements

On the front portion of the tube, the temperatures were steady enough to read accurately to ± 0.05 F. On the rear side, turbulent fluctuations made it impossible to read temperatures to better than ± 2.0 F. Calibration errors were considered negligible since the same thermocouple was used to obtain both T_W and T_O. Errors in converting from EMFs to temperatures were also negligible. The maximum error in the induced voltage correction was ± 7.0 per cent of the induced voltage. Also, because of the time lag between measurement of T_W and T_O, there was an additional uncertainty of ± 0.05 F in ΔT. Combining these uncertainties, the error in the temperature difference ranged from ± 2 per cent where ΔT was large to ± 16 per cent where ΔT was small such as the stagnation point temperature difference in run number A-9.

Heat Flux Measurements

Since the electrical resistance of stainless steel is a function of temperature, the local heat generation is also a slight function of temperature and, therefore, of angle. However, by assuming constant internal heat generation with angle an error of only ±1.3 per cent of the heat flux is introduced. Additional errors in the heat flux measurements include ammeter reading errors of ±2 amps and an error in measuring the tube length between the voltage taps of ±0.05 inches. The errors in the voltage readings taken on the K-3 potentiometer were negligible. The total error in the heat flux determinations ranged from ±2.5 per cent at high heat fluxes to ±2.9 per cent at low heat fluxes.

Heat Transfer Coeficients

In calculating the heat transfer coefficient from Equation (1), there were errors in the angular conduction term as well as the heat flux and temperature difference errors previously discussed. Radiation and conduction through the insulation within the heat transfer tube were neglected in the derivation of Equation (1). Neglecting internal conduction resulted in an error of ±0.2 per cent and neglecting radiation caused an error of ±0.04 per cent. Combining, the heat transfer coefficient errors ranged from about ±4.6 per cent to a maximum of ±22.4 per cent with a mean of about ±8.0 per cent. Also, checking reproducibility of the heat transfer data showed the maximum deviation to be about 7 per cent. This indicated that the errors mentioned above tend to be somewhat exaggerated.

Spray Density Measurements

Several methods were utilized to determine the effect of collection tube diameter on spray density measurements. These tests indicated that the water density measurements were independent of collection tube diameter and that there was no measurable blockage effect in the final collection system design. Reproducibility studies were conducted on the spray density measurements. They indicated that these measurements had an average deviation of 2.2 per cent from the mean.

Air Velocity Measurements

Velocity measurements were taken with two pitot tubes to check for consistency. There was no measurable difference between the readings of the two instruments. Reproducibility measurements indicated that the velocity measurements had an average deviation of 1.5 per cent from the mean.

APPENDIX D

BOUNDARY LAYER ANALYSIS

Boundary Layer Analysis

A laminar boundary layer analysis was undertaken in an effort to obtain stagnation point heat transfer coefficients corresponding to those obtained experimentally for the air-water spray flow system. The following assumptions were made about the system:

1) There was a continuous laminar water film on the cylinder surface in the region near the stagnation point.

2) There was a laminar air boundary layer outside the water layer.

3) The water spray density was constant through a plane perpendicular to the free stream flow in front of the cylinder.

4) There were no droplets bouncing from the water film surface.

5) The air was incompressible.

6) The thermal boundary layer was fully contained within the water film.

A diagram of the boundary layers and the flow pattern is shown in Figure 23.

An integral mass equation in the form

$$\frac{d}{dx}\int_0^{\delta} \rho_w u \, dy = W \cos\left(\frac{2x}{D}\right) \qquad (12)$$

was derived for the water layer where x represents distance

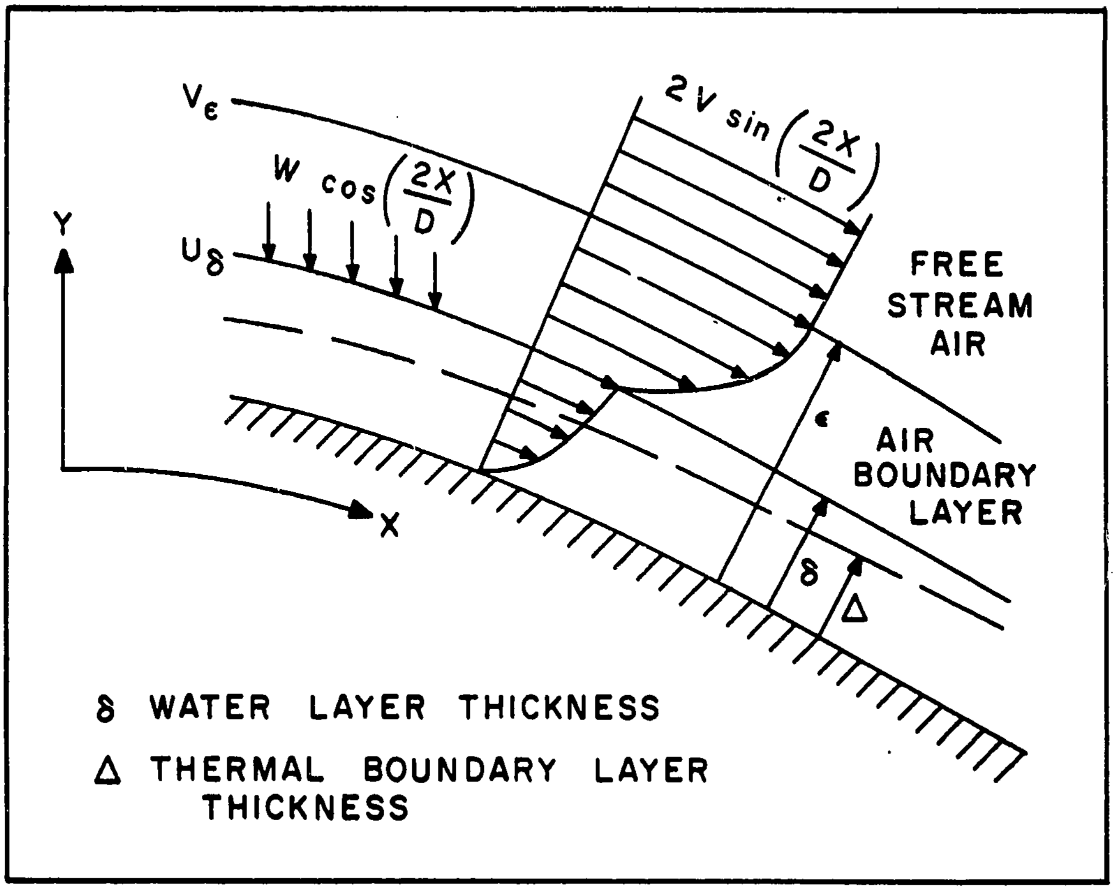

FIGURE 23. DIAGRAM OF BOUNDARY LAYER.

around the cylinder circumference from the stagnation point and y is the distance in the direction normal to the cylinder surface. An integral momentum equation in the form

$$\frac{d}{dx}\left[\int_0^\delta u(u_\delta-u)\,dy + \frac{\rho_a}{\rho_w}\int_\delta^\varepsilon v(v_\varepsilon-v)\,dy\right] + \frac{\rho_a}{\rho_w}\frac{dv}{dx}\left[\frac{v_\varepsilon}{u_\delta}\int_0^\delta (u_\delta-u)\,dy + \int_\delta^\varepsilon (v_\varepsilon-v)\,dy\right] = \nu_w\left(\frac{du}{dy}\right)_o \tag{13}$$

was written for the combined water and air layers.

A third order velocity profile

$$u = a_0 + a_1 y + a_2 y^2 + a_3 y^3 \tag{14}$$

was assumed for the water layer and another third order velocity profile.

$$v = b_1 y + b_2 y^2 + b_3 y^3 \tag{15}$$

was chosen for the air boundary layer. The boundary conditions were

$$y = 0: \quad u = 0, \quad \nu_w \frac{\partial^2 u}{\partial y^2} = \frac{1}{\rho_w}\frac{dP}{dx} = -u_\delta \frac{du_\delta}{dx} \tag{16}$$

$$y = \delta: \quad u = v, \quad \mu_w \frac{\partial u}{\partial y} = \mu_a \frac{\partial v}{\partial y} \tag{17}$$

$$y = \varepsilon: \qquad v = v_\varepsilon, \ \frac{\partial v}{\partial v} = 0, \ \frac{\partial^2 v}{\partial y^2} = 0. \tag{18}$$

With these boundary conditions it was possible to solve for the constants in Equations (14) and (15). The two velocity profiles were then inserted into the integral equations and evaluated at the stagnation point using l'Hospital's rule. The result for the integral mass equation was

$$\frac{\delta^2}{\varepsilon} \left[\frac{a}{2} - \frac{b}{3} + \frac{c}{4}\right] = \frac{WD}{2\rho_w V} \tag{19}$$

and the result for the integral momentum equation was

$$\left(\frac{\delta}{\varepsilon}\right)^3 \left[\frac{a^2}{6} + \frac{2b^2}{15} + \frac{3c^2}{28} - \frac{ab}{3} + \frac{7ac}{20} - \frac{bc}{4}\right] + \frac{\rho_a}{7\rho_w}\left[3 - 42\left(\frac{\delta}{\varepsilon}\right)^2 + 112\left(\frac{\delta}{\varepsilon}\right)^3 - 133\left(\frac{\delta}{\varepsilon}\right)^4 + 84\left(\frac{\delta}{\varepsilon}\right)^5 - 28\left(\frac{\delta}{\varepsilon}\right)^6 + 4\left(\frac{\delta}{\varepsilon}\right)^7\right] + \frac{\rho_a}{\rho_w}$$

$$\left[\frac{1}{6}\left(\frac{\delta}{\varepsilon}\right) \frac{6a-8b+9c}{a-b+c} + \frac{1}{2}\left(1 - \frac{\delta}{\varepsilon}\right)^4\right] = \frac{\mu_w D}{4\rho_w V \varepsilon^2} (a-2b+3c) \tag{20}$$

where

$$a = \left[3 - 3\left(\frac{\delta}{\varepsilon}\right) + \left(\frac{\delta}{\varepsilon}\right)^2\right]\left(\frac{4 + 3\lambda}{1 + \lambda}\right) - 3\,\frac{\mu_a}{\mu_w}\left(1 - \frac{\delta}{\varepsilon}\right)^2$$

$$b = \left[3 - 3\left(\frac{\delta}{\varepsilon}\right) + \left(\frac{\delta}{\varepsilon}\right)^2\right] \left(\frac{2}{1 + \lambda}\right)$$

$$c = 3 \frac{\mu_a}{\mu_w} \left(1 - \frac{\delta}{\varepsilon}\right)^2 - \left[3 - 3\left(\frac{\delta}{\varepsilon}\right) + \left(\frac{\delta}{\varepsilon}\right)^2\right] \left(\frac{\lambda}{1 + \lambda}\right)$$

and

$$\lambda = \frac{\delta^2}{\nu_w} \frac{du}{dx}.$$

Equations (19) and (20) must be solved simultaneously to obtain the two physical boundary layer thicknesses.

A third order temperature profile of the form

$$T - T_o = \frac{2Q}{3Ak_w} \left[1 - \frac{3}{2}\left(\frac{y}{\Delta}\right) + \left(\frac{y}{\Delta}\right)^3\right] \tag{21}$$

was obtained from the following boundary conditions:

$$y = 0: \quad \frac{\partial T}{\partial y} = -\frac{Q}{Ak_w}, \quad \frac{\partial^2 T}{\partial y^2} = 0 \tag{22}$$

$$y = \Delta: \quad T = T_o, \quad \frac{\partial T}{\partial y} = 0 \tag{23}$$

An integral energy equation of the form

$$\frac{d}{dx}\int_{o}^{\Delta} u(T - T_o)\,dy = \frac{Q}{\rho_w A c_{pw}} \tag{24}$$

was written. Then by inserting the water layer velocity profile and the temperature profile into the energy equation, the algebraic expression

$$\frac{a}{30}\left(\frac{\Delta}{\delta}\right)^3 - \frac{b}{72}\left(\frac{\Delta}{\delta}\right)^4 + \frac{c}{140}\left(\frac{\Delta}{\delta}\right)^5 = \frac{k_w D}{4\rho_w c_{pw} V\delta^3} \tag{25}$$

was obtained for the stagnation point. The thermal boundary layer thickness can be extracted from Equation (25) once Equations (19) and (20) have been solved. Then, the stagnation point heat transfer coefficient can be calculated from

$$h_o = \frac{3k_w}{2\Delta}. \tag{26}$$

APPENDIX E

NOMENCLATURE

Nomenclature

A	Tube surface area, sq.ft.
B	Barometric reading, inches of mercury.
c_p	Heat capacity, Btu/(lb_m)(F).
D	Outside diameter of cylinder, ft.
E	Voltage, volts.
EMF	Thermocouple reading, millivolts.
g_c	Universal constant, 32.2 ft-lb_f/lb_msec.
h	Local heat transfer coefficient, Btu/(hr.)(sq.ft.)(F).
I	Amperage, amps.
k	Thermal conductivity, Btu/(hr.) (ft.)(F).
Nu	Nusselt number, hD/k, dimensionless.
Q	Heat flow, Btu/hr.
R	Manometer reading, inches of water.
Re	Reynolds number, $DV\rho/\mu$, dimensionless.
t	Cylinder wall thickness, ft.
T_a	Air temperature in wind tunnel, R.
T_o	Local adiabatic surface temperature, F.
T_w	Local tube surface temperature, F.
ΔT	$T_w - T_o$, F.
u	Velocity in water layer, ft./sec.
v	Velocity in air boundary layer, ft./sec.
V	Free stream air velocity, ft./sec.
W	Water spray density, lb_m/(min.)(sq.in.).
δ	Water layer thickness, ft.

Δ	Thermal boundary layer thickness, ft.
ε	Combined water and air boundary layer thickness, ft.
μ	Viscosity, $lb_m/(ft.)(hr.)$.
ν	Kinematic viscosity, sq.ft./hr.
π	3.14
ρ	Density, $lb_m/(cu.ft.)$.
θ	Angle, degrees.

Subscripts

a	Air.
m	Average over entire cylinder circumference.
o	Stagnation point.
w	Water.