NATIONAL BUREAU OF STANDARDS REPORT

9571

CAPACITY TESTS OF FOUR REMOTE FORCED CIRCULATION REFRIGERATION EVAPORATORS

Manufactured by

Dunham–Bush, Incorporated
West Hartford, Connecticut

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
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NBS REPORT
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CAPACITY TESTS OF FOUR REMOTE FORCED CIRCULATION REFRIGERATION EVAPORATORS

Manufactured by

Dunham-Bush, Incorporated
West Hartford, Connecticut

by
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Environmental Engineering Section
Building Research Division IAT
National Bureau of Standards

IMPORTANT NOTICE

U.S. DEPARTMENT OF COMMERCE

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1.0 Introduction

This report presents results of capacity tests of four remote, forced circulation, refrigeration evaporators, of the same class and of four different sizes listed in QMR&E IP/DES S-9-8, "Interim Purchase Description, Refrigeration Evaporators, Forced Circulation, for Use with Dichlorodifluoromethane (F-12)", dated January 31, 1958. All four were manufactured by Dunham-Bush, Inc., West Hartford, Connecticut.

The four evaporators were:

1. Class A Size 1
   Copper Tubes, Aluminum Fins
   NBS Specimen No. 184-58

2. Class 2 Size 2
   Copper Tubes, Aluminum Fins
   NBS Specimen No. 185-58

3. Class A Size 3
   Copper Tubes, Aluminum Fins
   NBS Specimen No. 186-58

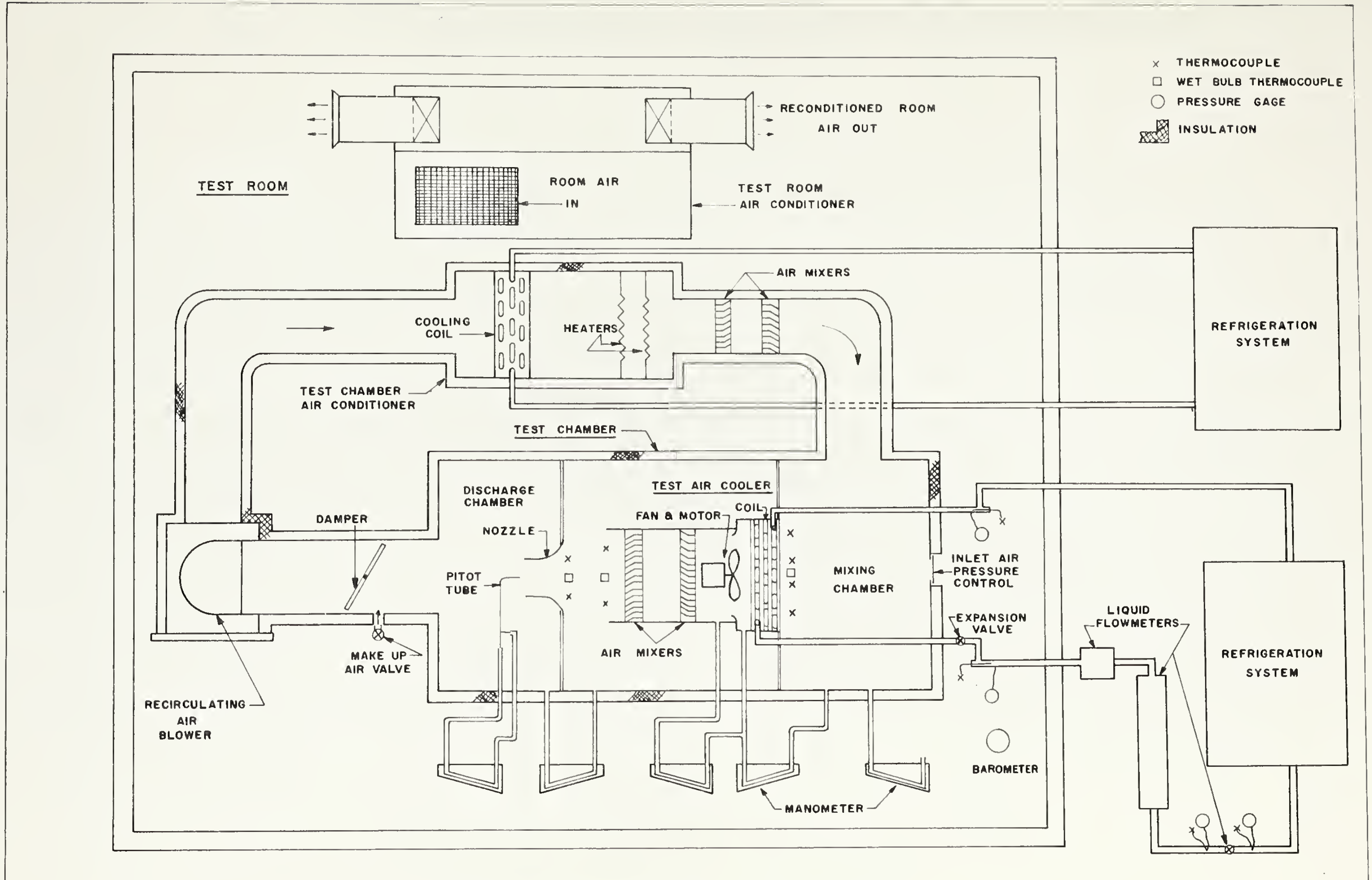
4. Class A Size 4
   Copper Tubes, Aluminum Fins
   NBS Specimen No. 187-58

All specimens were procured under contract No. DA 19-129-QM-1237.

1.1 Background

This report is one of three presenting test data on the performance of forced circulation refrigeration evaporators. Each of the other two reports in this series presents test data on the performance of four evaporators of the same military sizes as this report, but constructed by different manufacturers.

The test apparatus used for this series of tests was constructed by modifying an apparatus previously developed at NBS for U.S. Army Natick Laboratories for the testing of remote air-cooled refrigeration condensers in accordance with ASRE (American Society of Refrigerating Engineers) Standard PS-2.4. The apparatus was modified and developed in two stages to conform to ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) Standard 25-56, "Method of Rating Air Coolers for Refrigeration", between March and October 1962 and between October and December 1964. Tests were run on the twelve coils, four of which are reported here, between December 1964 and August 1966. To accomodate other investigations of higher priority to QMR&E, this project was deferred for approximately one year between the two stages. Subsequent to implementation of the project, a revision of ASHRAE 25-56 has been proposed. The primary change between the original standard and its revision is the elimination of capacity determination using the psychrometric (air side) measurement and substitution of the measurement of the refrigerant flow with two independent flow meters. The apparatus as used is shown schematically in figure 1. Provision was retained for measurement of capacity by air side measurement; however, it was



PSYCHROMETRIC CALORIMETER FOR AIR COOLER TESTS

Figure 1

found necessary to provide air mixers both at the inlet and outlet of the test coil for stable, repeatable air temperature measurements.

ASHRAE Standard 25 was prepared for the testing of entire air cooler units including fans, expansion valves, heat exchangers, casings, etc. For these tests, ASHRAE 25-56 was used as a guide to determine the conformance of the test coils with the requirements of IP/DES S-9-8 which deals primarily with the evaporators. A principal objective of the investigation was to determine the interchangeability (from the standpoint of capacity) of the various manufacturers' evaporators.

The expansion valve supplied with each coil was removed before testing and replaced with a specially selected valve which would permit comparison of the performance of the evaporators without consideration of the performance of different thermostatic expansion valves.

Although IP/DES S-9-8 requires draw-through fans all evaporator coils were supplied with blow-through fans. Fans and motors were packed separately and not attached to the evaporator housing. The fan orifice was of bell-mouth shape and for all four evaporators indicated that they were designed for draw-through air flow. New blades of the draw-through type identical to the original blades except for air flow direction were procured from the Torrington Company, manufacturer of all the original blades. After the correct fan blades were substituted the fan and motor units were then mounted on the downstream side of their coils so that the air flow over the coil surfaces was not reversed in direction from the manufacturer's original design.

Each of the four Dunham-Bush evaporators was equipped with an integral liquid-suction refrigerant heat exchanger, and in each of these evaporators, the refrigerant leaving the suction header passed through several of the bottom tubes of the coil before entering the heat exchanger. The number of tubes used in this fashion ranged from three for the Size I evaporator to eight for the Size IV evaporator.

The Interim Purchase Description, S-9-8, set forth the following capacity requirements. At a refrigerant saturation temperature of -10 °F, corresponding to the pressure at the suction outlet of the evaporator, and an inlet air dry bulb temperature of 0 °F, the minimum capacities for the four sizes of evaporators are:

Size I	4500 Btu/hr
Size II	6500 Btu/hr
Size III	10,000 Btu/hr
Size IV	13,000 Btu/hr

Capacities have been determined at these conditions and also at the following conditions as suggested in ASHRAE 25-56:

Dry Bulb Temp. °F	Wet Bulb Temp. °F	Nominal RH, %	Refrigerant Temp. °F
50	45	70	35
30	-	-	18
-10	-	-	-22

ASHRAE 25-56 suggests a fourth rating condition at -30 °F dry bulb temperature and -40 °F refrigerant temperature. The refrigeration capacity of the test apparatus was not adequate to pull the test chamber temperature down to the level this test requires.

2.0 Test Apparatus and Procedures

Tests were run in general conformance with requirements of ASHRAE Standard 25-56, "Method of Testing for Rating Air Coolers for Refrigeration."

Because ASHRAE Standard 25-56 is intended primarily for testing of entire air coolers whereas these tests were primarily concerned with comparative evaporator performance, and for other reasons, certain deviations were made from the standard in conducting tests. A few points of non-conformance are discussed below.

1) The requirement in Section 4.1.2 of ±0.1 deg F accuracy of absolute temperature measurements is unrealistic. For normal laboratory quality measuring systems ±0.2 deg F is more realistic, and test results reported were based on measurements approaching this degree of accuracy.

2) The thermostatic expansion valves which were supplied with the coils were replaced with specially selected thermostatic expansion valves with a changeable maximum coil pressure setting. Two of these valves, of 1 and 1 1/2 ton nominal sizes, were used to cover the range of coil sizes tested. The same valve was used for all coils of appropriate size.

ASHRAE Standard 25-56 describes a test procedure for air cooler units incorporating fans and expansion valves as well as evaporators. It was desired in the series of tests to compare evaporators (principally) with the variability of valve performance removed from the test. It was also found that some normal expansion valves were not sufficiently stable in performance to enable easy maintenance of steady-state test conditions.

3) In the ASHRAE Standard 25-56 test method, the air flow rate over the coil is established by the fan and motor as supplied with the assembled air cooler. IP/DES S-9-8 specifies minimum air flow rates for the different size

coils for the 0 °F entering air -10 °F refrigerant test as follows:

Mil. Std. Evap. Size	Minimum Air Quantity, CFM
I	750
II	1100
III	1500
IV	2200

As described earlier the units were fitted and tested with draw-through fans identical otherwise to the blow-through fan supplied and selected by the evaporator manufacturer to provide the required minimum air flow capacity. With the fan running, the minimum required air flow rate was obtained for each test by adjusting the dampers on the auxiliary blower in the psychrometric calorimeter to produce a suitable pressure downstream from the fan in the test unit.

4) ASHRAE Standard 25-56 specifies a superheat of 5 to 8 deg F in the refrigerant leaving the air cooler under test. This is not a practical requirement for a unit with an integral liquid-suction refrigerant heat exchanger when a thermal expansion valve is used for refrigerant flow control and the expansion valve bulb is mounted on the suction line ahead of the heat exchanger. Even though the actual refrigerant superheat is held quite low at the thermal expansion valve bulb the superheat in the refrigerant leaving the heat exchanger (and the air cooler assembly) is likely to be in excess of 8 deg F. All of the capacity tests covered in this report were made with the refrigerant leaving the evaporator (entering the heat exchanger) saturated or at a low superheat condition but with a positive superheat in excess of 3 deg F at the outlet of the heat exchanger. This was done to obtain higest cooling capacity for a coil equipped with an integral heat exchanger.

The two independent measuring systems are shown schematically in figure 1 and can be described briefly.

1) Air-side or Psychrometric. The test evaporator was mounted in an insulated, closed-loop, air duct apparatus with temperature and humidity controlled at the specified evaporator entering air conditions.

Figure 2 shows a test coil during installation in the psychrometric calorimeter. The discharge test duct and air mixer can be seen in the foreground. The apparatus was enclosed in a test room with controlled ambient conditions. The air was drawn through the evaporator by its fan mounted directly on the unit and by a large auxiliary blower with an adjustable damper which was used to control the air flow rate and system pressure at the specified values. Evaporator heat absorption capacity was determined by measuring air quantity and enthalpy change and correcting for fan motor energy input. Air quantity was measured with an ASME long radius nozzle.

2) Liquid refrigerant flowmeter. The subcooled condensed liquid refrigerant was metered by means of a totalizing (integrating) piston-type positive displacement flowmeter, and heat absorption capacities were determined from refrigerant mass flow and enthalpy change. A variable head meter was read and used as a flow check during steady state periods. A cylindrical tank, built and instrumented by the NBS Fluid Meters Section, which showed the quantity of refrigerant contained by the position of a piston which formed one of its ends was installed in the system and used as a calibration device.

The required conditions of inlet air temperature were determined by a multiple grid arrangement of calibrated thermocouples and a precision potentiometer. Inlet humidity (for the 50 °F test) was measured with calibrated

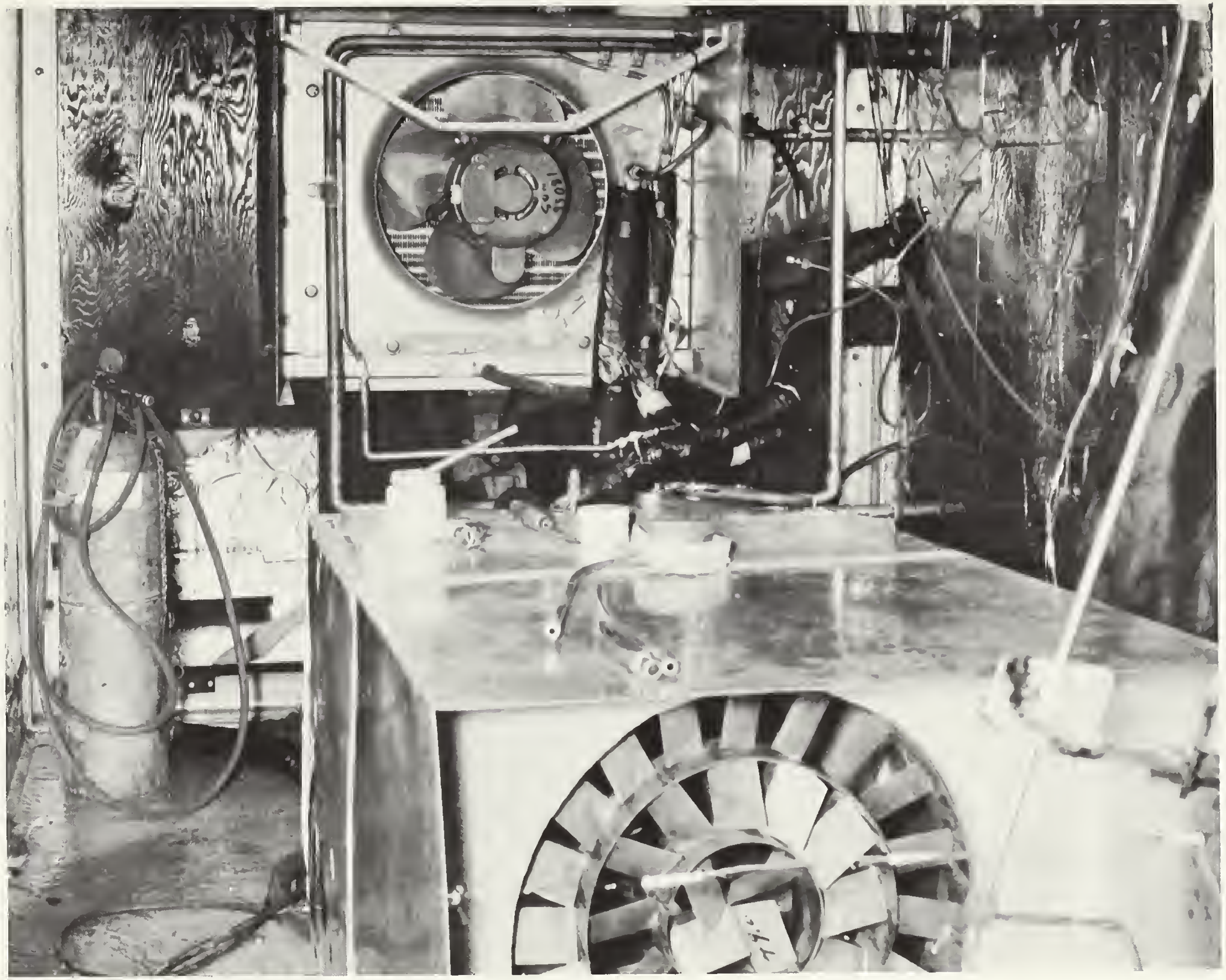


Figure 2. Test coil during installation in psychrometric calorimeter. Note discharge test duct and air mixer in foreground.

thermocouple psychrometers. The absolute suction pressure, from which the required refrigerant temperature was determined, was measured with a calibrated, precision grade, aneroid absolute pressure gage. Other temperatures were read using calibrated thermocouples and an electronic potentiometer. Air pressures in the fan circuit were measured with calibrated slope gages referenced to a calibrated aneroid barometer.

3.0 Test Specimens

Four Dunham-Bush forced circulation refrigeration evaporators were tested. As furnished each was mounted in a metal casing with a draw-through bell mouth fan orifice. A blow-through fan, fan motor and thermal expansion valve for each was packaged separately. No supporting frame work was provided for the fan motor. For the tests an otherwise identical draw-through fan was used and the coils were mounted for test to provide the direction of air flow indicated by the fan orifice. An integral liquid-suction refrigerant heat exchanger was incorporated as a part of each evaporator. Table 1 gives related physical data for the four units.

The aluminum fin and copper tube assembly was similar for all units (except for numbers of tubes and rows) and is shown in figures 3 and 4. Figure 3 is a section of one coil. Note that the bottom four tubes do not have the patented, "Inner-Fin" construction common to the other tubes in the coil. In this coil these four tubes were series connected and used to carry suction vapor from the suction header to the coil outlet and heat exchanger. Figure 4 shows the "Inner-Fin" construction in more detail. The accordion-pleated inner fin was spirally wound and formed from 1-in. wide aluminum strip and the center aluminum tube was blocked to prevent refrigerant passage except through the inner fin. The irregular appearance of the inner fin in figure 4 is due to the sectioning operation. Note the cut raised sections in the external plate fin. The external fins were bonded by mechanical expansion of the tubes and the final expanded diameter of the tubes was approximately 0.76 in. The inner fin assembly was bonded by mechanical expansion of the interior tube. All coils had tubes in adjacent rows staggered in the direction of air flow.

TABLE 1. PHYSICAL CHARACTERISTICS

DUNHAM - BUSH AIR COOLERS

QMR & E Size		I	II	III	IV
QMR & E Class		A	A	A	A
NBS Specimen No.		184-58	185-58	186-58	187-58
COIL TUBE CHARACTERISTICS					
Material		Copper	Copper	Copper	Copper
Number of Rows Deep		3	4	4	3
Number of Tubes High		9	10	12	20
Number of Circuits In Parallel		2 [Suction header feeds	3 [Suction header feeds	5 [Suction header feeds	6 [Suction header feeds
Number of Tubes Per Circuit		12 bottom three tubes]	12 bottom four tubes]	8 bottom eight tubes]	9 bottom six tubes]
Tube Diameter, O.D., in.		0.760	0.760	0.760	0.760
Tube Diameter, I.D., in.		----- "Inner-Fin" Construction	----- "Inner-Fin" Construction	-----"Inner-Fin" Construction	----- "Inner-Fin" Construction
Tube Wall Thickenss, in.		----- "Inner-Fin" Construction	----- "Inner-Fin" Construction	-----"Inner-Fin" Construction	----- "Inner-Fin" Construction
Tube Return Bend Diameter, O.D., in.		5/8	5/8	5/8	5/8
Vapor Outlet Diameter, O.D., in.		7/8	7/8	1 1/8	1 1/8
Liquid Inlet Diameter, O.D., in.		1/2	3/8	5/8	5/8
Vertical Spacing of Tubes, in S		2 Tubes staggered	2 Tubes staggered	2 Tubes staggered	2 Tubes staggered
Horizontal Spacing of Rows, in.		1 1/2 Horizontally	1 1/2 Horizontally	1 1/2 Horizontally	1 1/2 Horizontally
Integral Heat Exchanger		Yes	Yes	Yes	Yes
COIL FIN CHARACTERISTICS					
Material		Aluminum	Aluminum	Aluminum	Aluminum
Type of Fin		Plate Cut raised sections	Plate Cut raised sections	Plate Cut raised sections	Plate Cut raised sections
Fin Spacing, Fins per in.		6 119 Fins(front),127(back)	6 120 Fins(front),119(back)	6 166 Fins(front),168(back)	6 159 Fins(front top),157(front botto
Fin Thickness, in.		0.011	0.011	0.011	0.011 159 Fins(back top),169(back bottom)
COIL DIMENSIONS					
Finned Height, in.	K	18	20	24 1/16	40
Finned Width, in.	F	19 1/4	19 1/2	27 3/8	26
Finned Depth, in.	V	4 1/2	6	6 1/16	4 1/2
Coil Height, in.	H	17	19	23	39 1/4
Coil Width, in.	W	22 11/16	22 1/2	31 1/8	29 1/4
Coil Depth, in.	D	3	4 1/2	4 1/2	3
Face Area, sq. ft.		2.40 (17 1/2" x 19 3/4")	2.57 (19" x 19 1/2")	4.48 (27 5/8" x 23 3/8")	7.10 (26 1/16" x 39 1/4")
SURFACE AREAS					
Primary Area, sq. ft.		0.68	1.02	1.71	2.03
Secondary Area, sq. ft.		9.75	14.02	23.89	28.34
Total Area, sq. ft.		10.43	15.04	25.60	30.37
OVERALL DIMENSIONS					
Width, in.	A	26 1/2	26 3/4	34 1/2	34 3/8
Width, Shroud, in.	B	19 1/4	19 1/2	27 5/8	26 1/16
Height, in.	C	21	21 1/4	26	44 1/2
Depth, in.	E	9	9	9	9 7/8
Fan Orifice Diameter, in	X	14 7/8	16 1/4	18 1/4	22 5/16
Fan Orifice Radius, in.	R	------ Orifice type similar to NBS 185	9/16	5/8	7/8

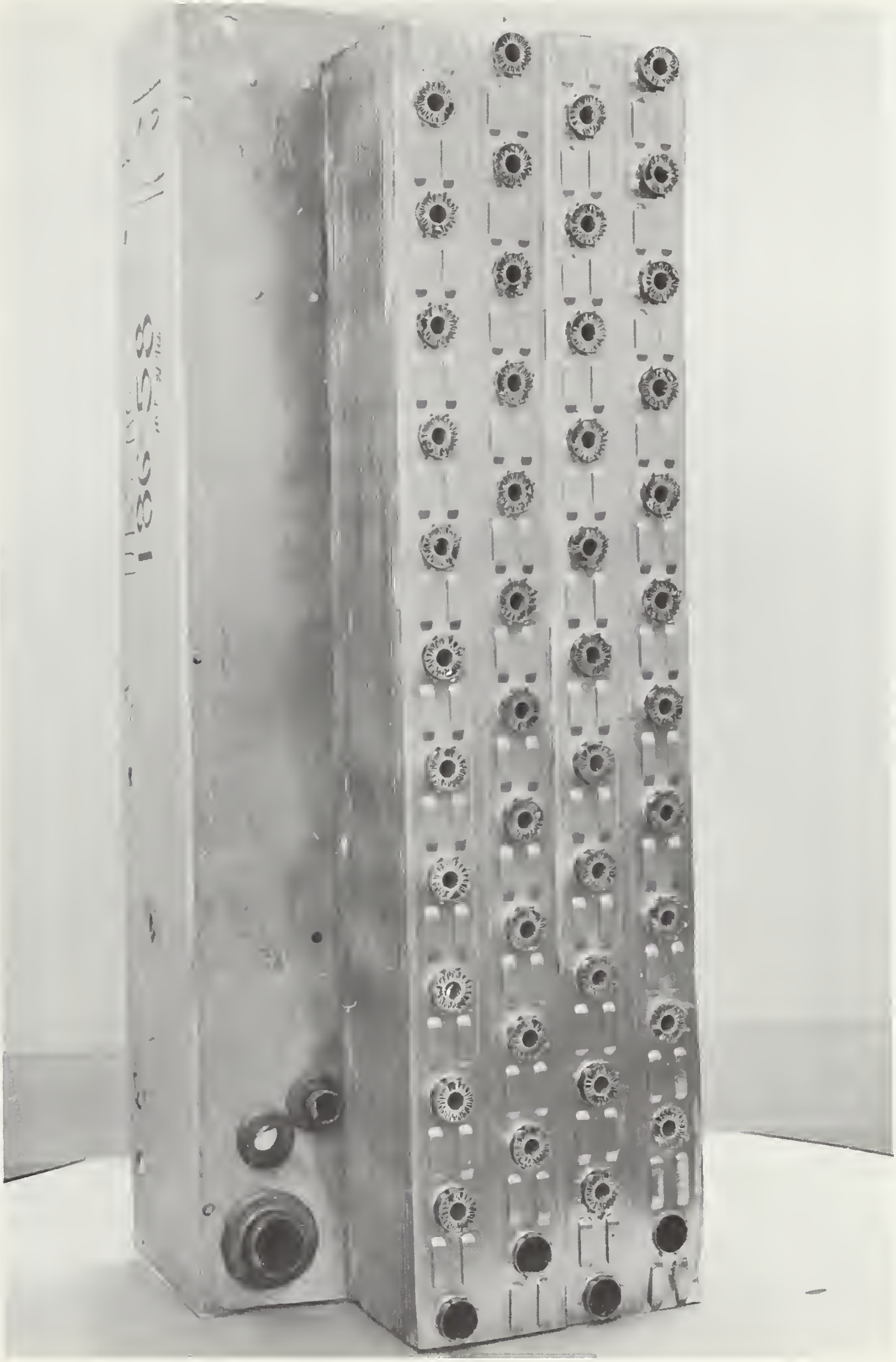


Figure 3. Section of Dunham-Bush coil showing typical fin and tube assembly. Note "Inner-Fin" construction in all except bottom four tubes.

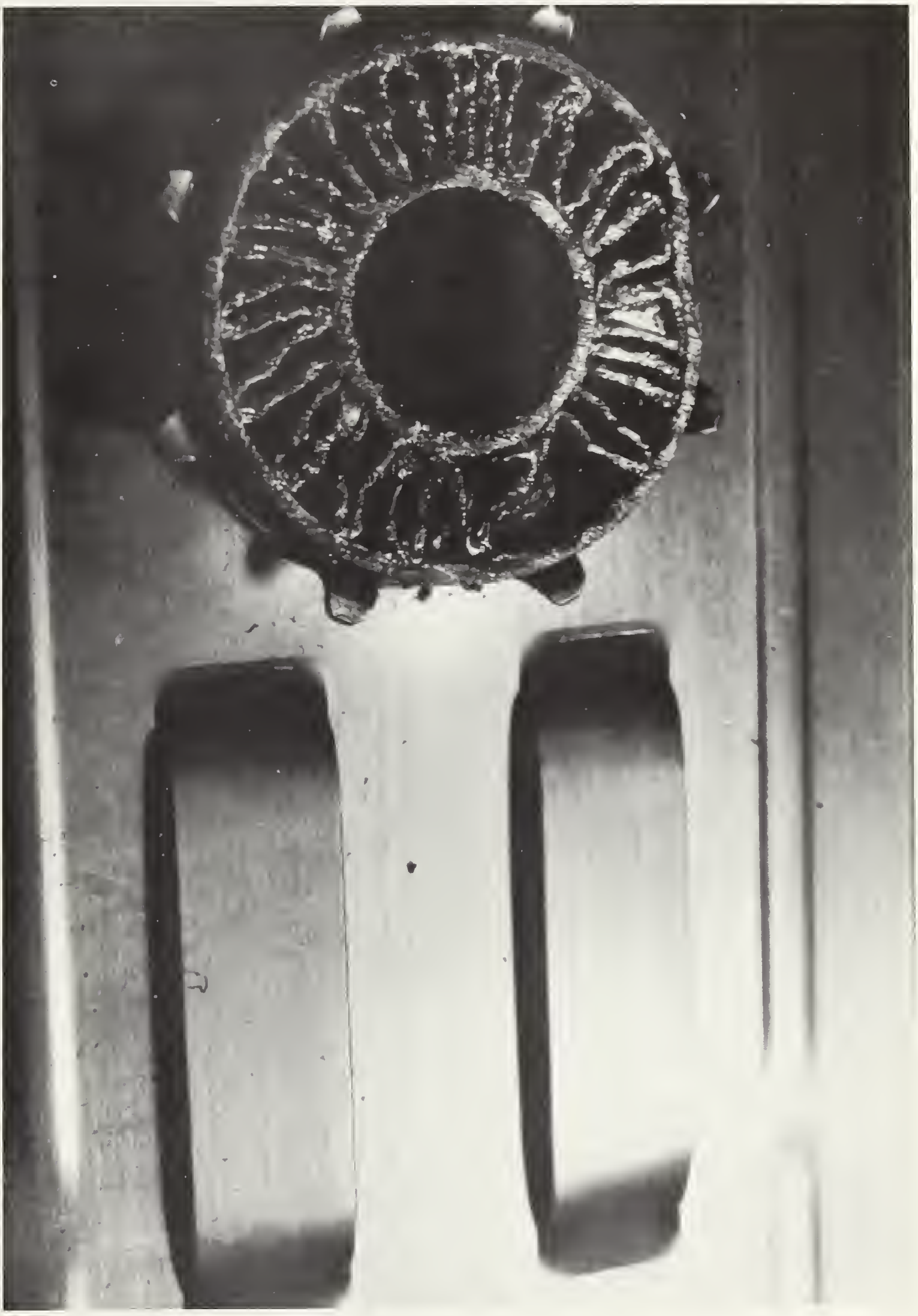


Figure 4. Typical Dunham-Bush fin collar, tube and "Inner-Fin" assembly. Irregular appearance of the inner fin was caused by the sectioning operation.

3.1.1 NBS Specimen No. 184-58 was a Size I Class A evaporator with copper tubes, aluminum exterior fins and aluminum "Inner-Fin" construction. Figure 5 shows the air discharge side and right end of the unit as received. Note the bell mouth fan orifice typical to the four Dunham-Bush units indicating draw-through air flow design. Figure 6 shows the air discharge side and left end of the unit as mounted for test. Note sealing material added at the bottom of the coil end sheet to block undesired air flow from the test chamber into the drain pan during test. Figure 7 is a schematic drawing of the general configuration of this unit and the related physical data are given in Table 1. The bottom three tubes, without the inner fin, were series-connected to conduct refrigerant from the suction header to the heat exchanger.

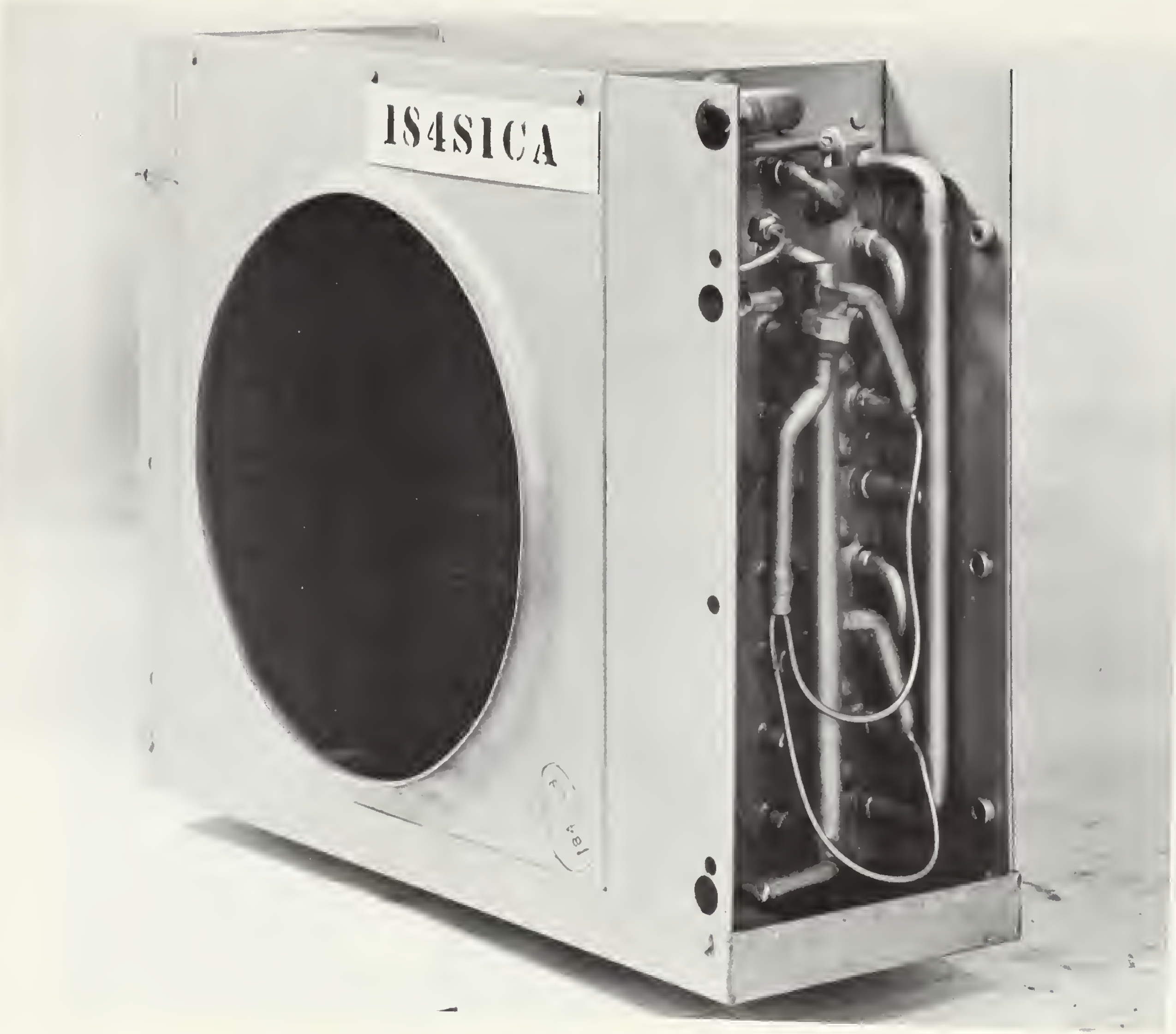


Figure 5. Air discharge side and right end view of
Size I evaporator (NBS No. 184-58) as supplied.

Figure 6. Air discharge side and left end view of Size I evaporator (NBS No. 184-58) as mounted for test.

EVAPORATOR SPECIMEN

DUNHAM-BUSH NBS NO. 184-58 SIZE I CLASS A

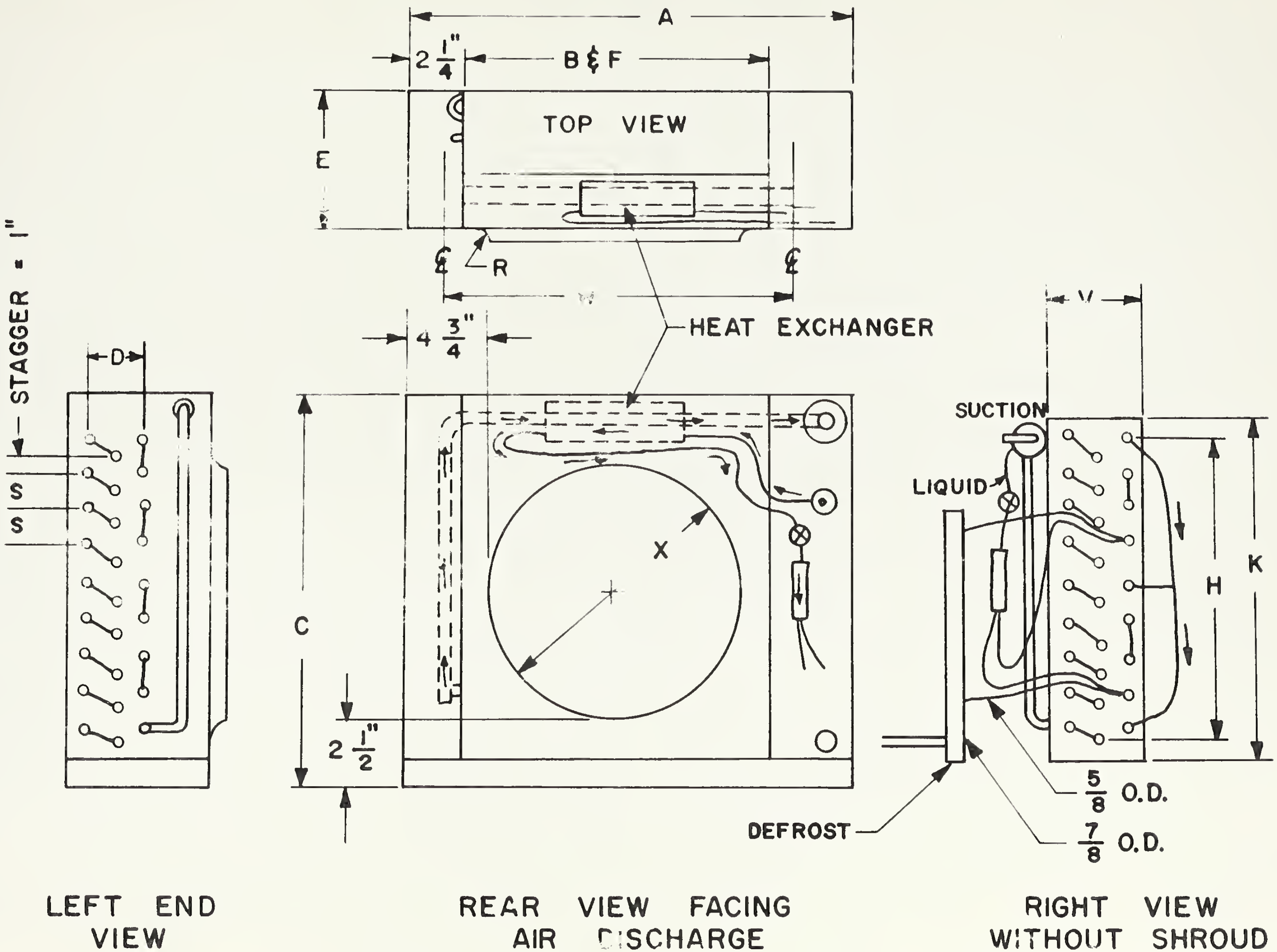


Figure 7

3.1.2 NBS Specimen No. 185-58 was a Size II Class A evaporator with copper tubes, aluminum exterior fins and aluminum "Inner-Fin" construction. Figure 8 shows the left end and air discharge side of the unit as received. The end of the heat exchanger can be seen through the bottom of the fan orifice. The vertical defrost tube header, typical of the four Dunham-Bush evaporators, can be seen in the center of the exposed end of the coil. Note the liquid line and distributor connections for the expansion valve in the center and the suction header on the left. Figure 9 shows the right end and air discharge side of this unit as mounted for test. The plywood backing facilitated mounting of the test coils in the psychrometric calorimeter. Figure 9a is a schematic drawing of this unit and the related physical data are given in Table 1. The bottom four tubes, without the inner fin, were used to conduct refrigerant from the suction header to the heat exchanger.

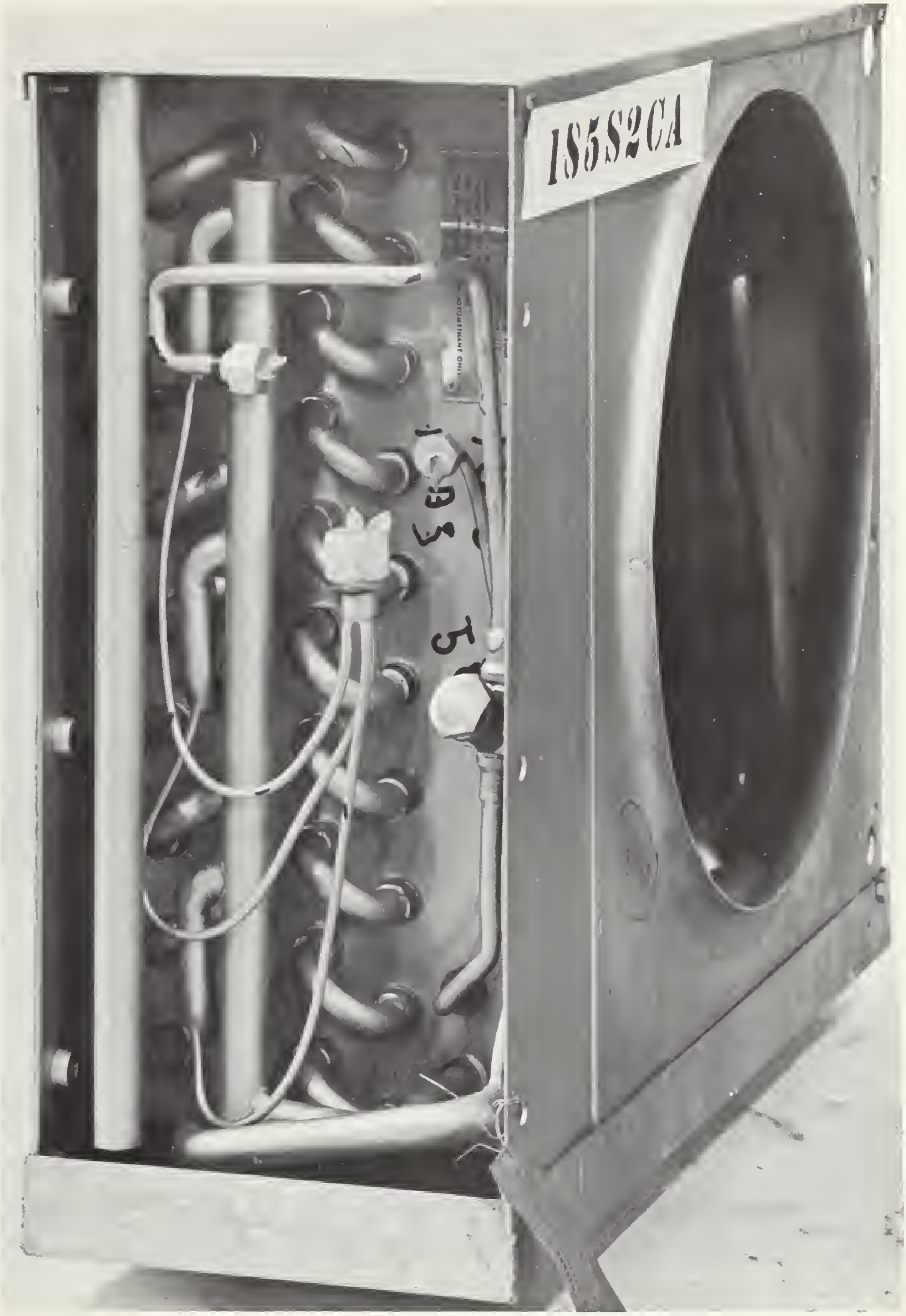


Figure 8. Air discharge side and left end view of Size II evaporator (NBS No. 185-58) as supplied.

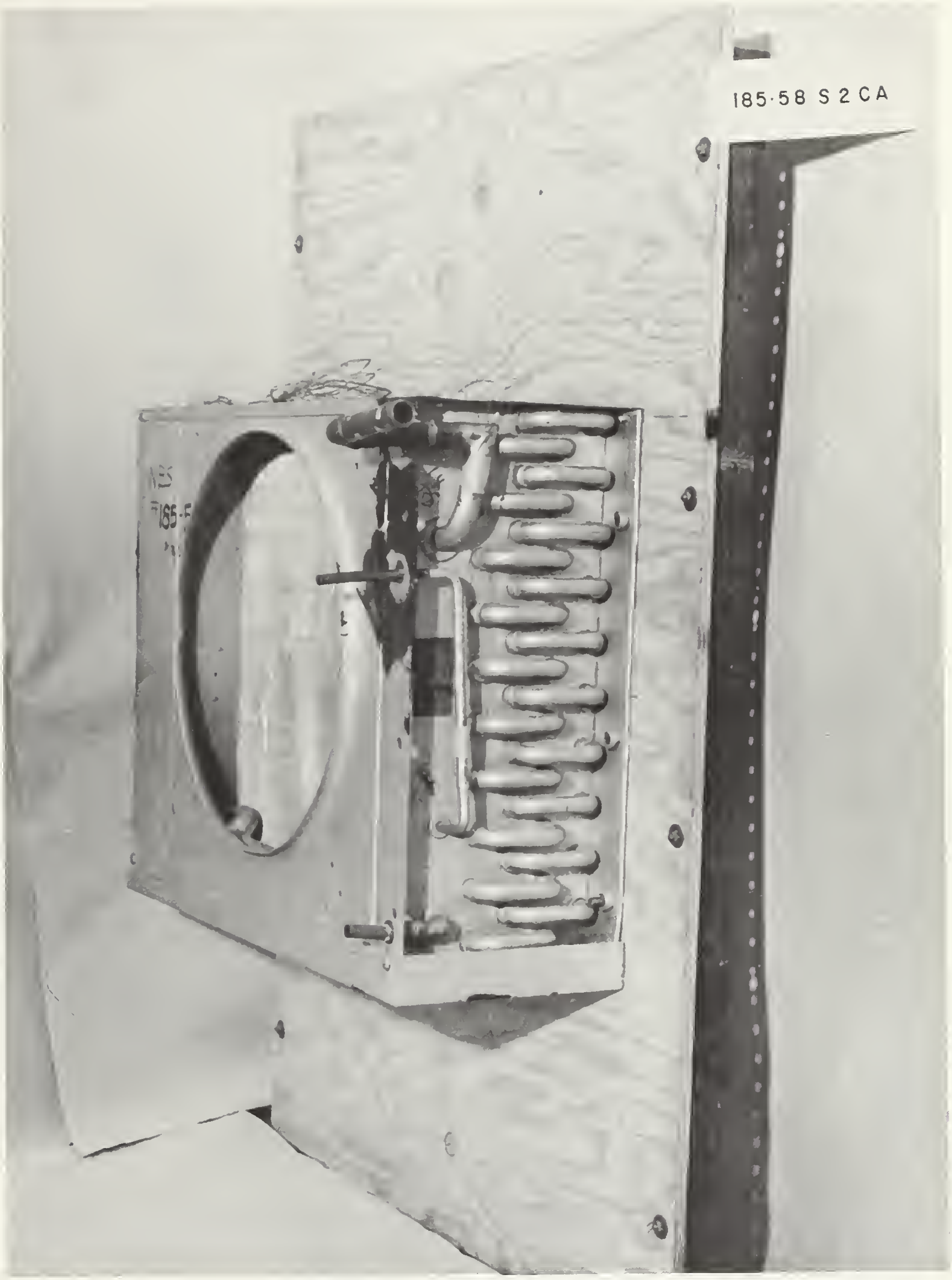


Figure 9. Air discharge side and right end view of Size II evaporator (NBS No. 185-58) as mounted for test.

EVAPORATOR SPECIMEN

DUNHAM - BUSH 185 - 58 SIZE II CLASS A

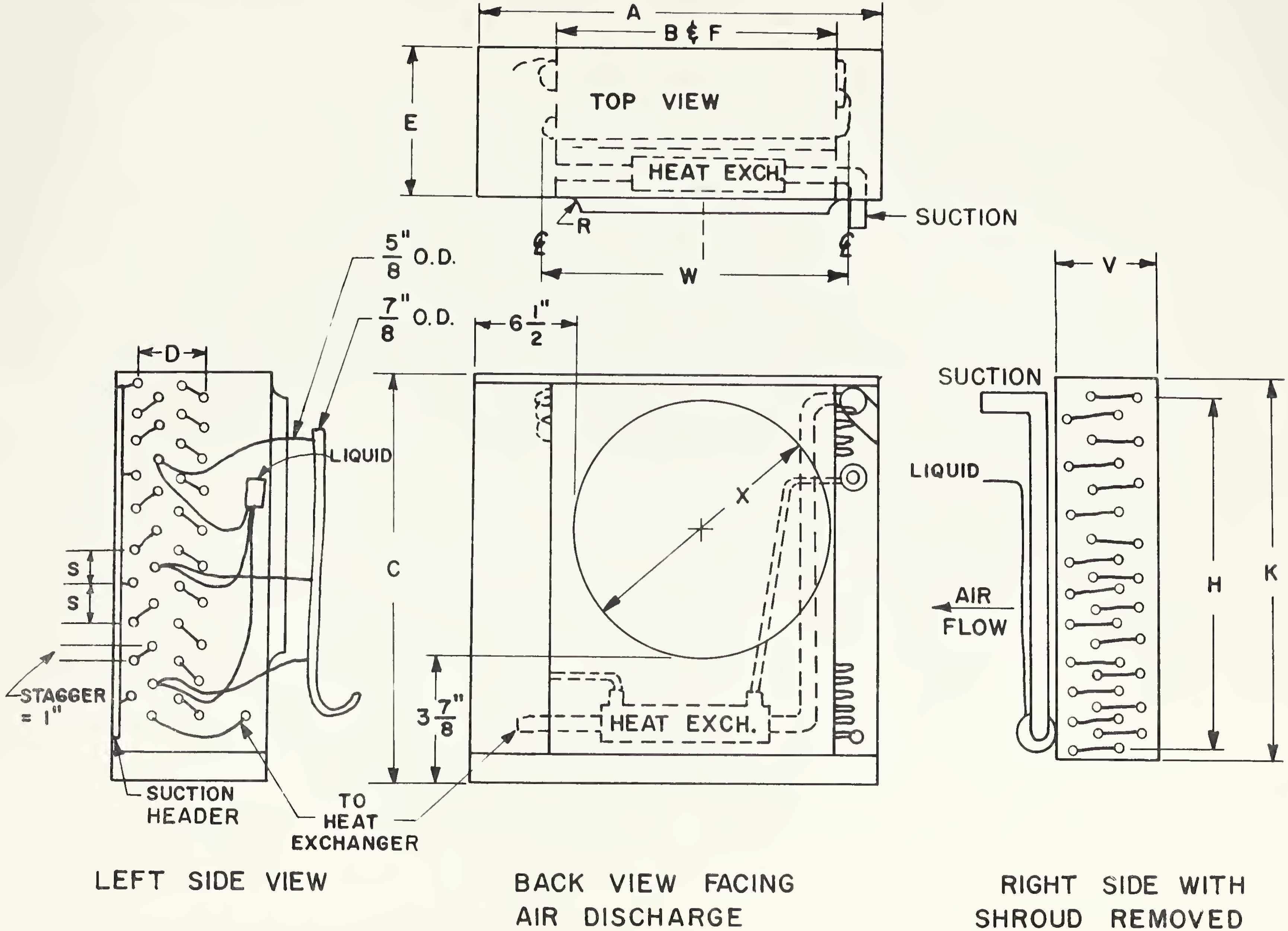


Figure 9a

3.1.3 NBS Specimen No. 186-58 was a Size III Class A evaporator with copper tubes, aluminum exterior fins, and aluminum "Inner-Fin" construction. Figure 10 shows the left end and air discharge side of this unit as supplied. The bottom eight tubes (without the inner fin) used to conduct refrigerant from the suction header were connected in two parallel circuits of four tubes each joined to the short vertical header shown in the lower right corner of the exposed end of the coil. The tube from the center of this header connected to the heat exchanger, one end of which can be seen through the bottom of the fan orifice. Figure 11 is a view of the right end and air discharge side of the Size III unit as mounted for test. The thermocouples attached to the return bends at the end of each coil circuit were used to determine if any circuits were not receiving sufficient refrigerant. The angle strips around the fan orifice were used to attach the air mixer duct after the fan and motor were installed. Figure 12 is a view of the air discharge side of this unit with the fan orifice removed to show the type of heat exchanger used in the four Dunham-Bush evaporators. Figure 13 is a schematic drawing of this unit and the related physical data are given in Table 1.

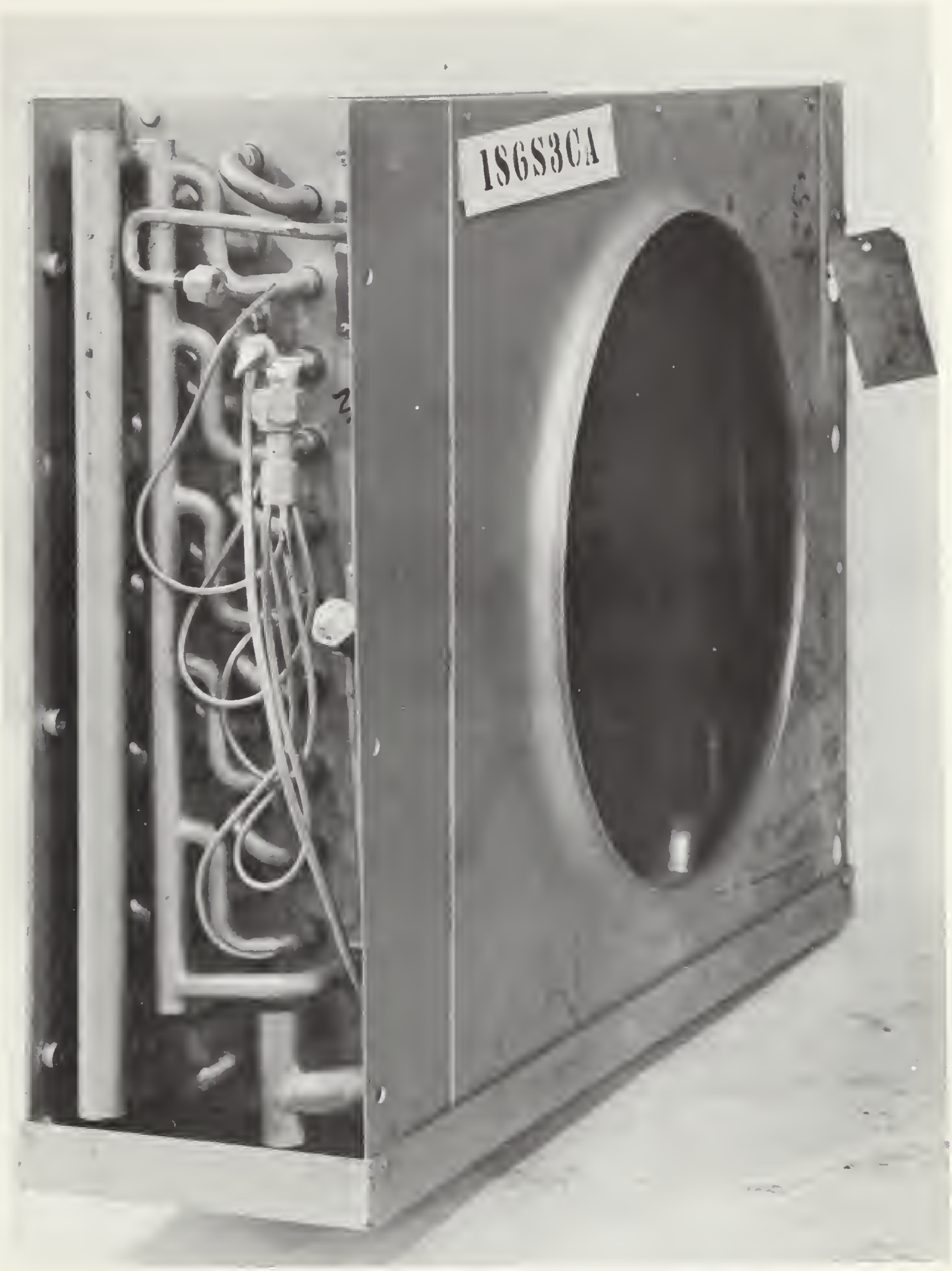


Figure 10. Air discharge side and left end view of Size III evaporator (NBS No. 186-58) as supplied.

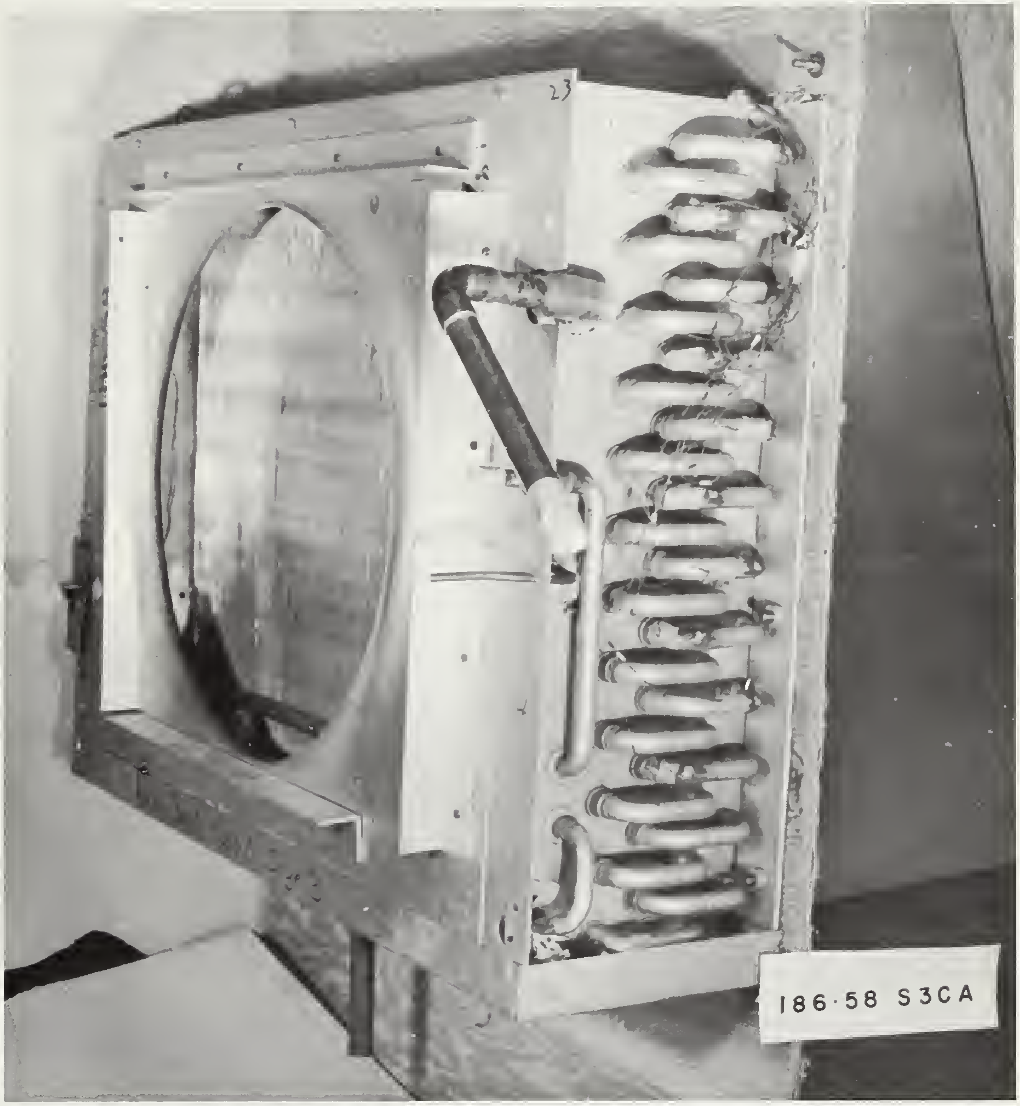


Figure 11. Air discharge side and right end view of Size III evaporator (NBS No. 186-58) as mounted for test.

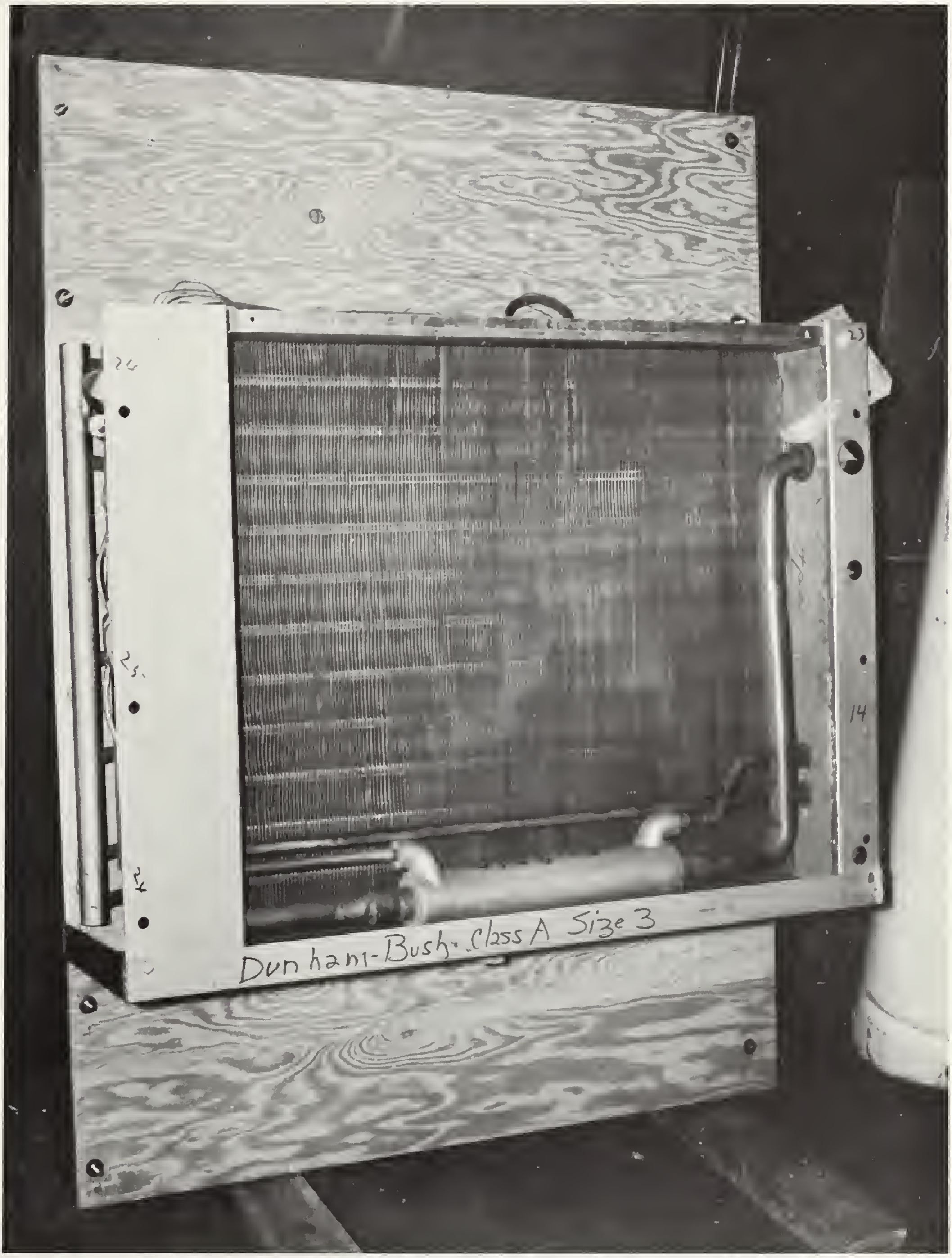


Figure 12. Air discharge side of Size III evaporator
(NBS No. 186-58) with fan orifice removed. Note
liquid-suction heat exchanger.

EVAPORATOR SPECIMEN

DUNHAM-BUSH NBS NO. 186-58 SIZE III CLASS A

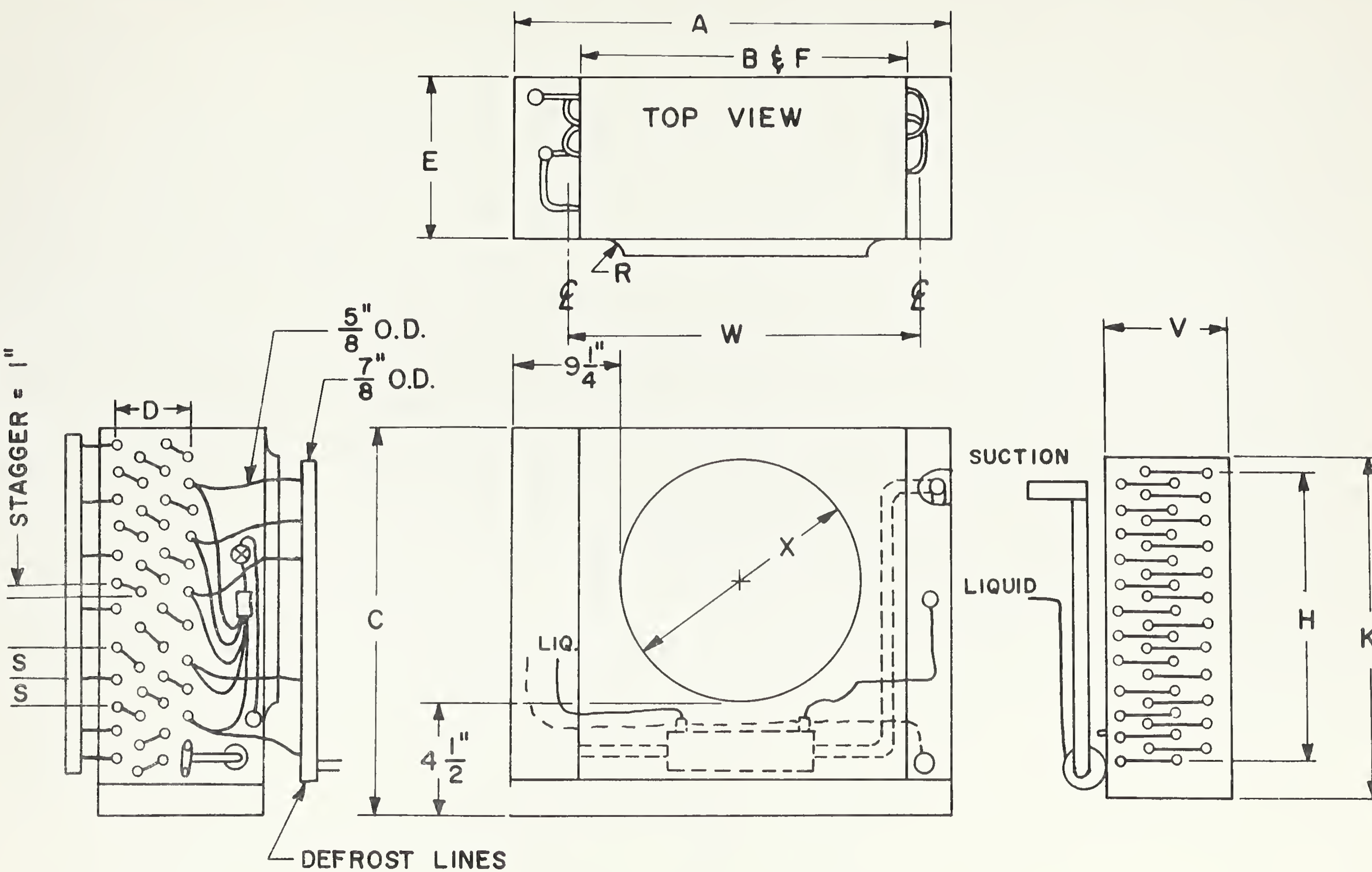


Figure 13

3.1.4 NBS Specimen No. 187-58 was a Size IV Class A evaporator with copper tubes, aluminum exterior fins, and aluminum "Inner-Fin" construction. Figure 14 is a view of the left end and air discharge side of this unit as received. In this unit six parallel circuits, each three tubes high and three tubes deep in direction of air flow are arranged vertically and this grouping is indicated by the positions of the six distributor tubes and defrost tubes. The vertical grouping of rectangular coil arrangement is typical of all four Dunham-Bush evaporators. In figure 14, the short vertical header at the lower left of the exposed end of the coil connects into parallel circuits of three tubes each which carry refrigerant from the suction header to the heat exchanger mounted at the bottom of the coil housing. Figure 15 shows the air discharge and left end of the unit as mounted for test. Thermocouples used to monitor performance were located at the insulated positions. Figure 16 is a view of the right end and air inlet side of the size IV evaporator. The arrangement of the vertical suction header connecting the six parallel coil circuits to the two parallel circuits at the bottom of the coil which connect to the heat exchanger is clearly shown in figure 16. The small tube at mid-height on the left is one of two pressure taps used in measuring the static pressure drop across the coil, as done for all coils tested. Figure 17 is a schematic drawing of this unit and the related physical data are given in Table 1.

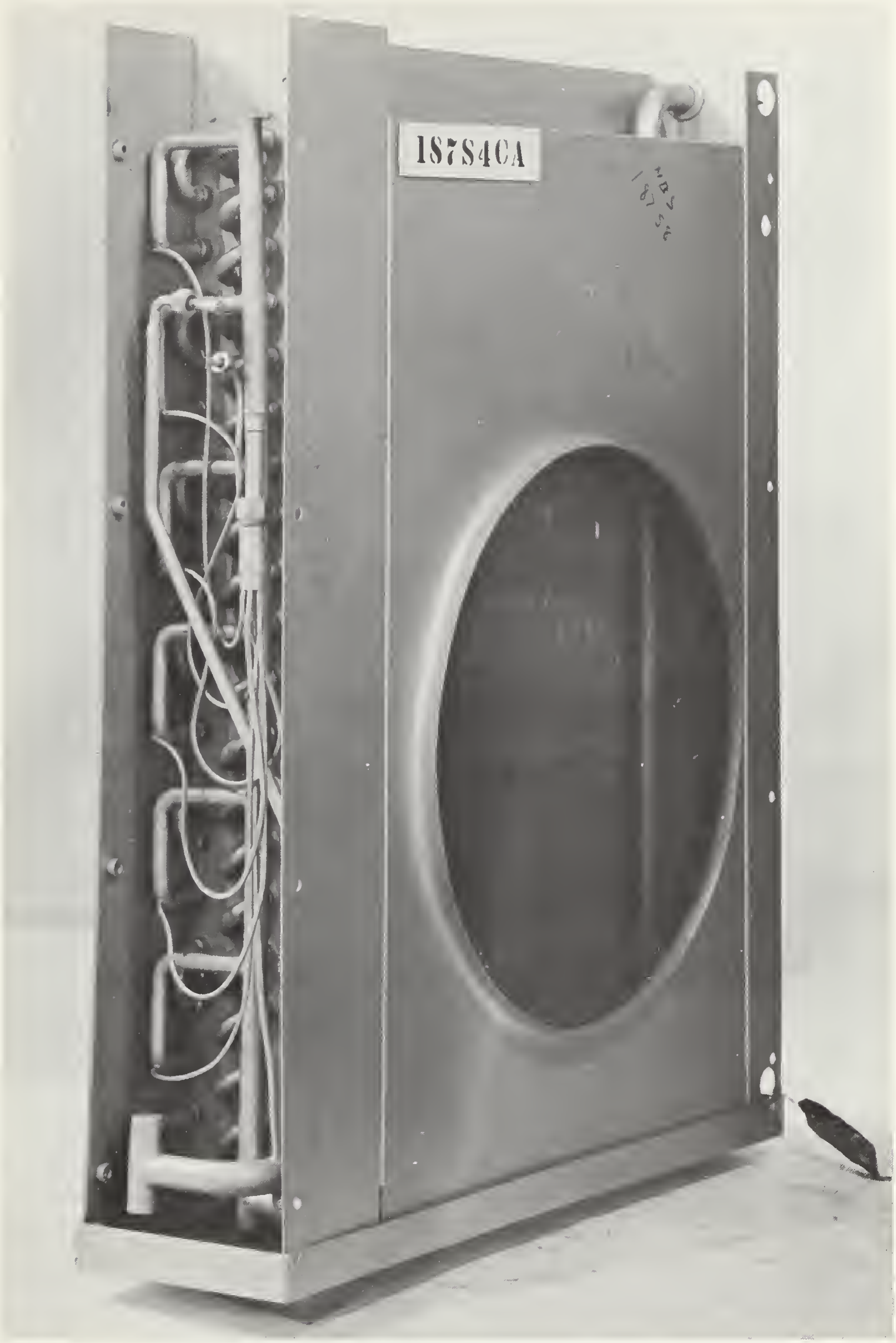


Figure 14. Air discharge side and left end view of Size IV evaporator (NBS No. 187-58) as supplied.

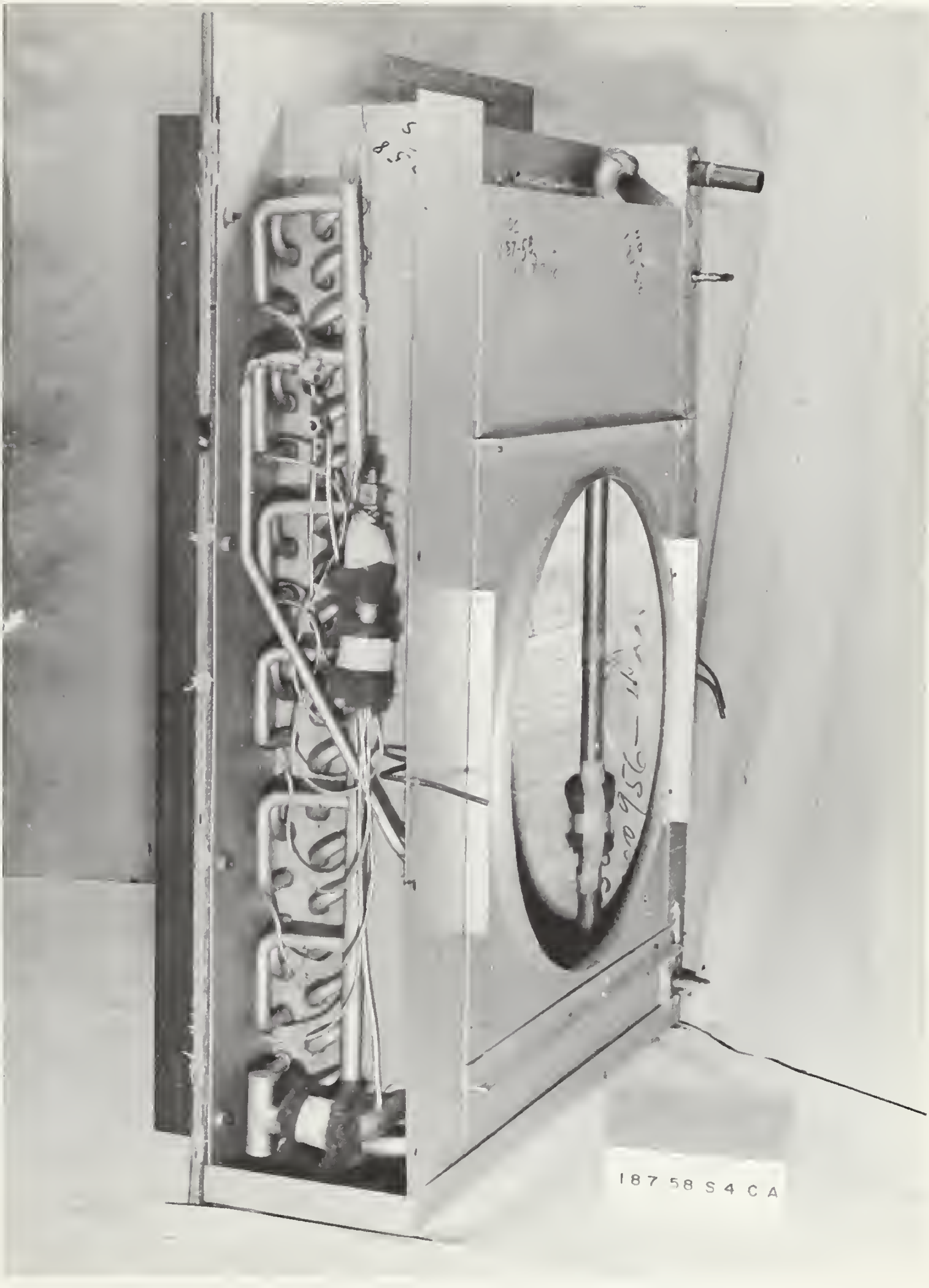


Figure 15. Air discharge side and left end view of Size IV evaporator (NBS No. 187-58) as mounted for test.

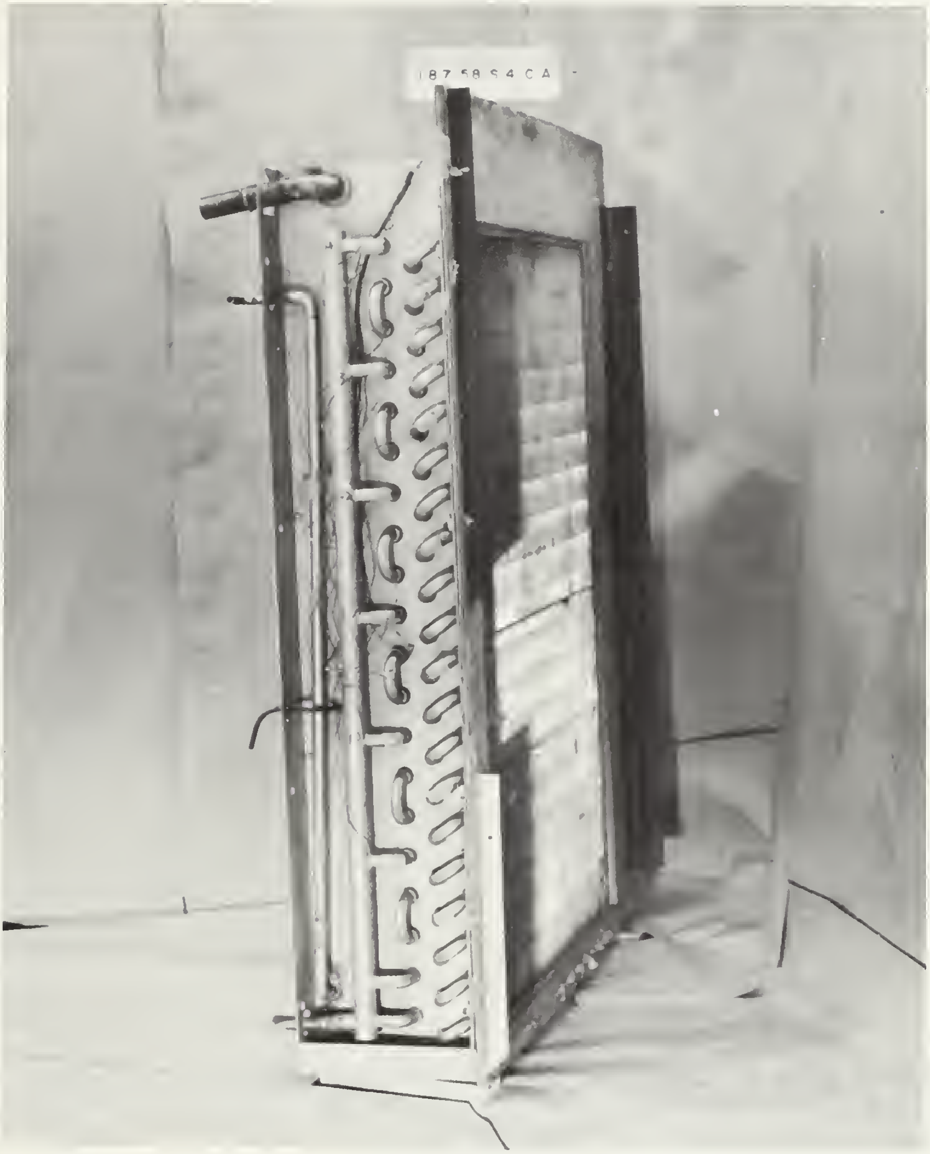


Figure 16. Air inlet side and right end view of Size IV evaporator (NBS No. 187-58) as mounted for test.

DUNHAM-BUSH

EVAPORATOR SPECIMEN

NBS NO. 187-58

SIZE IV CLASS A

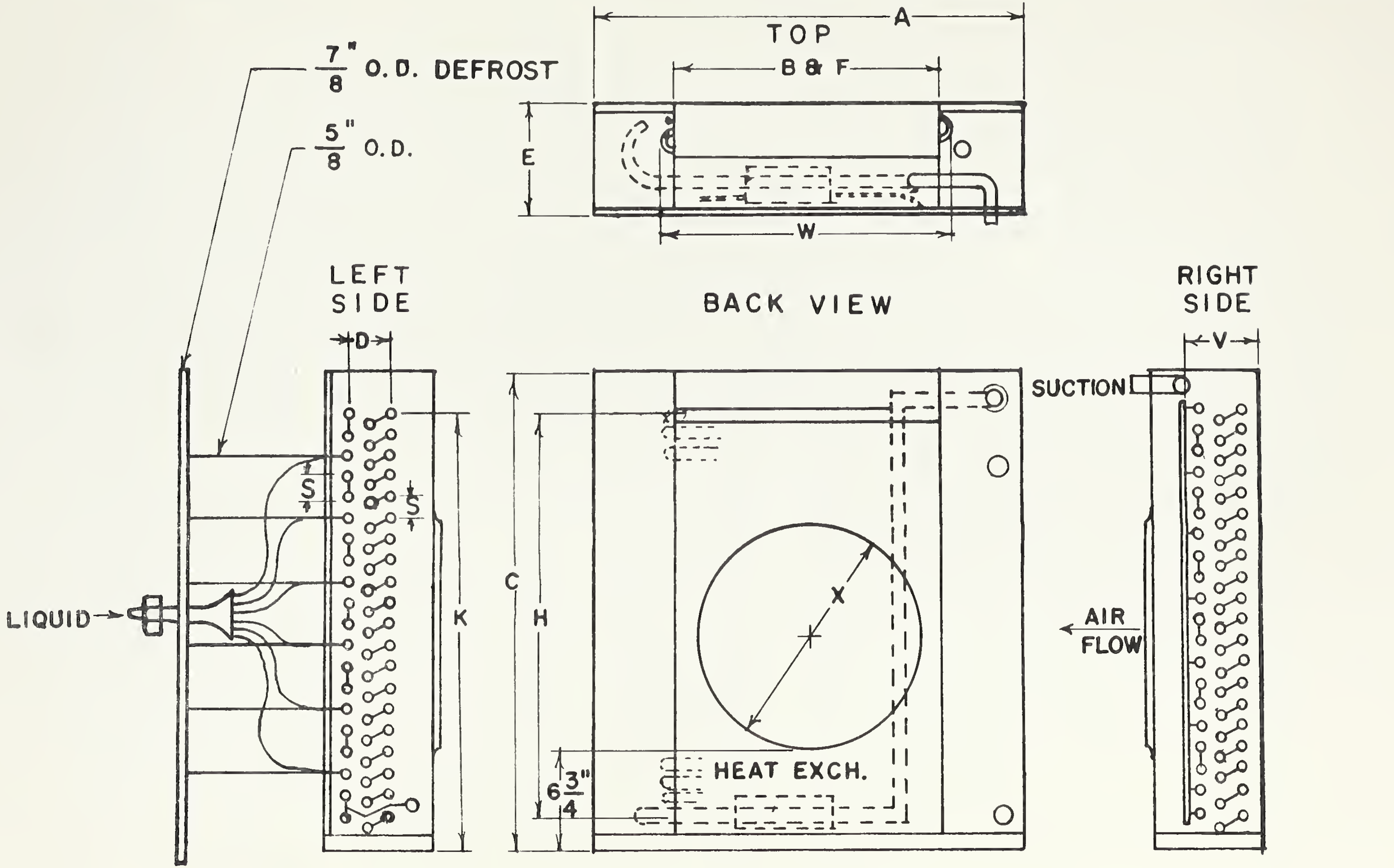


Figure 17

4.0 Data and Results

Each evaporator was studied at four different sets of standard conditions as previously described. Each test required control of refrigerant inlet subcooling and temperature, air inlet temperature and pressure, cubic feet per minute of air flow, and refrigerant outlet pressure and superheat. The variables which fluctuated with capacity were the refrigerant flow rate and the air outlet temperature. Although each evaporator was supplied with its own blow-through fan and fan motor, tests were made using selected draw-through fans identical to those furnished except for the direction of air flow and with an auxiliary blower to adjust the air flow rate to the desired test values. The determination of primary, secondary, and total surface areas were based on the following conditions:

1. Primary area = Number of tubes x length x π x [2/3 measured diameter + 1/3(measured diameter + twice the fin collar thickness)] minus area covered by fins based on fin thickness. Note that fin collars were included as primary area.
2. Area of tube openings was deducted from total fin area, taking into account both surfaces of each fin.
3. End sheets and tube area through and beyond end sheets and exposed fin edges were not included.

At the bottom of figure 2 is shown the air mixing duct which was attached to the downstream side of the coil. It was found to be nearly impossible to obtain consistent satisfactory agreement (to within 6 percent) between air and refrigerant side capacity measurements before this mixer was installed in the apparatus ahead of the downstream temperature measurement

thermocouples.

Table 2 summarizes the test data and results for the four Dunham-Bush air cooler evaporators.

TABLE 2

CAPACITY TEST DATA

DUNHAM-BUSH CLASS A AIR COOLER EVAPORATORS

		Nominal Test Conditions			Actual Test Conditions			Superheat, Deg F[b]		Coil Air	Capacity, BTU/H		Results				Capacity Adjusted
Run No.	Size	Air In, °F	Refr., °F[a]	Air Flow, CFM	Air In, °F	Refr., °F[a]	Air Flow, CFM	Evap. Outlet	Air Cooler Outlet[c]	Pressure Drop, In. W.G.	Air Side	Refr. Side	% Diff.[d]	Air Out °F	Refr. Flow lb./hour	Fan Power Watts[e]	to QMR&E Conditions, BTU/H[f]
309	I	0	-10	750	0.1	-9.9	750	0.7	3.4	0.12	3810	3970	4.0	-3.4	74	142	3940
305	I	50,70% RH	35	750	50.2,69%	34.6	780	1.4	3.1	0.08	6530	6390	-2.2	44.0	119	134	
304	I	30	18	750	30.2	17.9	740	0.6	3.0	0.07	5140	5230	1.7	24.8	97	134	
308	I	-10	-22	750	-9.5	-24.2	750	1.1	25.8	0.22	5100	5270	3.2	-14.3	96	147	
411	II	0	-10	1100	0.0	-9.7	1060	1.1	9.0	0.18	4680	4740	1.3	-3.0	90	194	4860
413	II	50,70% RH	35	1100	49.8,71%	34.9	1070	0.6	14.2	0.18	6390	6490	1.5	45.0	113	183	
410	II	30	18	1100	29.2	17.6	1070	1.1	12.5	0.16	5540	5720	3.1	25.3	105	183	
412	II	-10	-22	1100	-9.7	-21.7	1060	1.5	18.7	0.27	4100	4430	7.4	-12.2	84	195	
705	III	0	-10	1500	0.5	-10.7	1500	0.6	8.5	0.12	8110	8110	0.0	-3.5	157	163	7210
701	III	50,70% RH	35	1500	50.1,68%	35.3	1520	3.7	15.1	0.12	13090	12990	-0.8	42.9	227	163	
702	III	30	18	1500	30.3	18.2	1500	0.8	16.7	0.11	9950	9740	-2.2	25.0	174	161	
704	III	-10	-22	1500	-9.2	-22.5	1500	0.9	7.1	0.22	8520	8890	4.2	-13.3	167	173	
1103	IV	0	-10	2200	0.8	-10.6	2200	0.9	10.3	0.13	10620	10650	0.2	-2.7	217	276	9280
1101	IV	50,70% RH	35	2200	50.0,68%	35.0	2190	0.8	14.2	0.10	15530	15370	1.0	44.2	281	244	
1102	IV	30	18	2200	29.9	17.6	2170	0.8	6.2	0.10	12100	12040	-0.5	25.5	236	249	
1104	IV	-10	-22	2200	-9.2	-23.3	2200	1.0	28.2	0.17	11370	11620	2.2	-13.0	240	267	

a. Refrigerant temperature corresponding to pressure at suction outlet.

b. ASHRAE Standard 25-56 recommends 5 to 8 deg F superheat at the evaporator outlet.

c. Dunham-Bush air coolers equipped with integral heat exchangers.

d. $\frac{\text{REFR. SIDE} - \text{AIR SIDE}}{\text{REFR. SIDE}} \times 100$

e. Air pressure drop across fan adjusted to produce required air flow; power not indicative of free air delivery.

f. Measured capacity adjusted to QMR&E nominal condition = $\frac{0 - (-10)}{T_{air\ in} - T_{refrigerant}} \times$ Measured Capacity

g. Superheat values less than 3 deg F indicate possibility of liquid flooding into heat exchanger.

5.0 Discussion and Conclusions

The tests covered in this report were part of a series intended to provide a comparison of the cooling capacities of refrigeration evaporators produced by three manufacturers for use in military forced circulation air coolers. This report covers results of tests of evaporators manufactured by Dunham-Bush, Inc., purchased under the QMR&E Interim Purchase Description, IP/DES S-9-8, dated January 31, 1958.

To provide a meaningful comparison of coil performance leading to interchangeability of evaporators under conditions where the air flow rate will be a function of the performance of a suitably-selected military standard fan, all coils in this series were tested at the minimum air flow rate specified in IP/DES S-9-8, even though the fans supplied with each evaporator would deliver a different air flow rate under the normal free air delivery conditions. It is likely that the cooling capacities obtained with the minimum air flow rate were less than the capacities which would be obtained if the free air delivery rate were greater than the minimum. As described earlier the minimum air flow rate was obtained by varying the air pressure downstream of the fan.

To remove from the tests the variability of different thermal expansion valves, a specially-selected valve was used to test all coils of the same size. In addition these special test valves were set to maintain essentially steady-state refrigerant flow conditions as opposed to the hunting characteristic of normal thermal expansion valves. It is to be expected that higher cooling capacities are obtained with steady-state operation, other conditions being equal. This was confirmed by a preliminary test of one of the coils in this series.

Use of integral liquid-suction heat exchangers can be a factor when interchangeability is concerned. The Dunham-Bush coils covered in this report were equipped with heat exchangers, as were the coils supplied by one other manufacturer in this series. The coils from the third manufacturer were not so equipped. This should be considered in preparation of the military standard for such units. As discussed under Test Procedures the refrigerant superheat requirement of 5 to 8 deg F specified in ASHRAE Standard 25, the capacity test method prescribed in IP/DES S-9-8, had to be modified for use with the evaporators equipped with integral heat exchangers. It should be noted that ASHRAE Standard 25 describes test methods for fully assembled air coolers whereas the principal interest in these tests was directed to the evaporators in such units.

As shown in Table 2 capacity tests of each coil were made at several conditions in addition to the IP/DES S-9-8 required conditions of -10 ^{o}F refrigerant and 0 ^{o}F entering air. The performance of the four Dunham-Bush evaporators in relation to the QMR&E required capacities was as follows:

	Capacity, Btuh		Percent of
Size	Measured	Required	required capacity
I	3940	4500	88
II	4860	6500	75
III	7210	10000	72
IV	9280	13000	71

The average measured capacities, in Btuh, for the three makes of coils tested, at the QMR&E conditions, were; Size I 3030, Size II 4010, Size III 7620, and Size IV 9710.

Two coefficients related to coil capacity which outline relative performance are:

(1) $\dfrac{\text{Btuh}}{(\text{Face area, ft}^2)\ (\text{deg F})}$ and (2) $\dfrac{\text{Btuh}}{(\text{Total surface area, ft}^2)\ (\text{deg F})}$

For the QMR&E conditions the comparisons of the Dunham-Bush coils with the other makes tested were:

	Btuh / (Face area, ft^2) (deg F)		Btuh / (Total surface area, ft^2) (deg F)	
	Dunham-Bush	Range of three makes	Dunham-Bush	Range of three makes
I	165	76 - 165	38	19 - 38
II	190	106 - 190	32	18 - 32
III	162	157 - 222	28	28 - 38
IV	131	97 - 139	31	26 - 38

One factor which may have had a significant influence on the observed variability of coil performance as indicated by these coefficients was the distribution of refrigerant in proper amounts to the several parallel circuits. In particular the method of connecting the defrost headers should be examined for possible interference with proper distribution.

In view of the fact that the units tested were of a prototype nature they were not examined in rigorous detail for dimensional or material compliance with the purchase description. Table 1 lists the physical data for each unit.

As supplied for test each of the four Dunham-Bush evaporators, contrary to the requirement as shown in sketch 5 of the purchase description, was equipped with a blow-through fan, as were each of the evaporators supplied by the other two manufacturers. The fans were corrected for test purposes as described under Test Procedure.

The change in ASHRAE Standard 25 substituting the use of a second simultaneous independent measurement of the refrigerant-side capacity for the previous psychrometric apparatus air-side measurement emphasizes the importance of valid calibration of the integrating liquid refrigerant flow meters. Experience gained in this series

of tests showed that calibration of these devices using the same fluids as those to be measured is necessary for all instruments affected by pressure, lubricity or viscosity. Air-side measurements were retained in this series inasmuch as the psychrometric apparatus had been constructed prior to the change in ASHRAE Standard 25. Experience gained in this series of tests indicated the necessity for adequate mixing of the air, particularly that leaving the coil (or fan), if the temperature at that point is to be used to obtain a heat balance.

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