INVESTIGATION OF METHODS OF INSPECTING BONDS BETWEEN CORES AND FACES OF SANDWICH PANELS OF THE AIRCRAFT TYPE

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INVESTIGATION OF METHODS OF INSPECTING BONDS BETWEEN CORES AND FACES OF SANDWICH PANELS OF THE AIRCRAFT TYPE[1]

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Introduction

Sandwich construction is finding limited use at present in the aircraft industry, and plans are being made for its more extensive application to structural parts. Manufacturing processes involving recently developed (and often unproven) adhesives and assembly techniques are presently used for bonding various core and face materials. It is therefore highly desirable to have, as a working tool, a dependable quality-inspection method or nondestructive test to insure the detection and subsequent rejection of inferior bonds between the cores and faces.

The ANC Subcommittee on Wood Aircraft Structures requested that, along with other research on sandwich construction, the Forest Products Laboratory evaluate the various inspection methods that have been proposed and also attempt to develop and evaluate other inspection and nondestructive test procedures. It is the purpose of this report to present the results of this work covering the period from late in 1945 to May 1947.

Summary and Conclusions

The following 10 methods, which appeared to offer promise of determining the quality of joints between cores and faces of sandwich panels without relying upon destructive tests, were investigated:

1. Visual inspection
2. Special lighting
3. Tapping
4. Supersonic inspection
5. Exposure to vacuum

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[1]This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

6. Vacuum-cup test
7. Internal-pressure test
8. Heating complete panel
9. Local heating
10. Button-tension test

All of the methods had some merit and under certain limited conditions were capable of detecting actual voids or unglued areas between the face and core. The tapping test, performed by a specially trained person, appeared to be the most practicable and dependable.

A careful visual inspection immediately after the panel was removed from the hot press or bag often revealed blistered areas that disappeared after the panel cooled. On special combinations of materials, such as translucent glass-cloth faces on an expanded rubber core, these blisters could be made visible again by special lighting, but on combinations involving opaque faces, such as aluminum, special lighting effects had no merit.

Scanning by supersonic vibrations revealed voids, but was sensitive to varying density. Weak bonds between the face and a balsa core could not be isolated, as their attenuation of supersonic vibrations was found to be essentially the same as that of strong bonds. Because panels having honeycomb cores contain essentially complete voids between the faces, it is probable that an unbonded area between the face and core could not be detected.

Vacuum-induced air pressure exerted a slight tensile force upon the bond between the face and the core that extended an existing blister when the face was impervious and core material slightly pervious to air. The same force could be applied locally by means of a vacuum cup, but both methods were found to be ineffective and unreliable.

The magnitude of the forces tending to separate the faces from the core could be greatly increased by quickly releasing an externally applied air pressure after several hours of exposure. This test was capable of extending unbonded areas as small as 1/2 inch in diameter so that they could be easily detected. The range of this test could be further increased by conducting it at an elevated temperature so that the glue bonds were stressed while hot. Tests revealed, however, that poorly bonded areas could withstand this test.

Heating, applied either to the complete panel or locally, proved to be ineffective and unreliable as an inspection method.

Tension exerted through a button glued to the face of the panel was found to be the only method used that would detect poorly glued areas. Since this test was time-consuming and involved, however, it was considered impractical for use over a complete panel, but it appeared to have application for "spot" tests.

None of the tests investigated presented practical and dependable means of inspecting sandwich panels for quality of joints, and it appeared that combinations of the test methods would offer little promise of improvements. For the present, therefore, it is considered that carefully controlled process specifications, substantiated by sufficient destructive tests and supplemented by rigid inspection, must be relied upon to insure uniformly high-quality joints in sandwich panels.

Test Procedures and Discussion of Results

Visual Inspection

Visual examinations were made immediately after the sandwich panels were removed from the press or bag. In each of these processes, the panels were cured with heat and pressure, and upon removal of the pressure, the face of an unbonded area often rose to form a blister. These blisters were extended for a short interval only or until the drop in panel temperature reduced the internal pressure of the panel. During this short interval the blisters were outlined with a wax crayon line for future identification. Such blisters were visible on aluminum- and glass-cloth-faced panels, but could not be seen so readily in plywood-faced panels. On glass-cloth-faced panels, a blister could sometimes be seen by the variation in color or transparency of the face, but this was not always true, because many times such a variation appeared to be perfectly sound when the tapping method was used.

The visual inspection method appeared to have only limited possibilities. If a panel has blisters when removed from the press or bag, the presence of defective areas is demonstrated and the panel can be rejected immediately. If no blisters are visible, however, the absence of defective areas is not proved and the panel must be subjected to further tests by more dependable methods.

Special Lighting

The use of lights was tried for determining faulty areas or blisters in various types of sandwich construction, but mainly in panels with glass-cloth faces. Various light arrangements were used in an attempt to bring out the defects, such as lighting from the edges of the panel and passing light through the panel. By these arrangements and other variations of light angles, some blistered areas could be detected, but not with any degree of reliability. Poorly bonded areas could not be located. The possibilities of successful detection of faults and blisters by this method appeared to be less promising than those of other methods, and therefore efforts to use lighting were discontinued.

Tapping

Tapping is one of the simplest methods that has been used for testing for voids in the glue bond between the faces and core material of sandwich construction. The only equipment necessary for this test was a small piece of metal, such as a coin or a small light hammer. A special hammer was used for most of the tapping tests herein reported. It consisted of an aluminum ball about 3/4 inch in diameter attached to a 6-inch handle. The panels (usually 1/2 by 36 by 36 inches) were supported near two opposite edges to intensify the tone produced by tapping and thus to make it easier to determine the faulty areas. A well-bonded area produced a clear tone, while an unglued area usually produced a lower tone or dull thud.

This method proved reasonably satisfactory for detecting areas where the faces of the sandwich were not firmly attached to the core. It was found that if there was intimate contact between the face and core, however, no difference in tone quality could be detected. Poorly bonded areas, therefore, could not be differentiated from well-bonded areas. It was also evident that very light tapping was more selective than heavy blows. Considerable experience was required consistently to locate defective areas because panels of different construction gave off different tones and the tones on a single panel varied with the position of the spot tapped on the panel. The variation in tone was especially noticeable within a few inches of the edges of a panel.

Supersonic Inspection

Metal products, such as steel castings, forgings, and tin plate, are sometimes inspected by the use of supersonic vibrations. Hidden flaws, voids, and other defects are located by their attenuating effect upon these high-frequency vibrations. It was thought that by proper adjustment for density these devices might be adapted for use on sandwich constructions. Several panels, containing known defective areas, as shown in figure 1, were subjected to supersonic inspection under laboratory conditions. In these tests the transmitter and receiver units were entirely submerged in water and mounted so that they could be made to contact the panel at directly opposite points on the faces. Each unit covered an area of about 1 square inch. The panel was passed between these two units while the transmitter was operating at a frequency of 440 kilocycles. Observations during these tests revealed considerable variation in attenuation as the aluminum-balsa panels were passed between the heads of the instrument. This variation was attributed to the variations in density of the balsa. It was found from repeated trials that poorly bonded areas could not be located, but that areas having actual voids between the face and the core were consistently detected.

While it is possible that tests made at a higher frequency might be more selective, it is improbable that a differentiation could be made between poorly glued and well-bonded areas by supersonic methods alone.

Although no tests were made, this method would appear to be quite ineffective when used on sandwich panels with honeycomb cores. The voids in the honeycomb cores are continuous from face to face, so that the presence of voids in the joints between the faces and coresundoubtedly could not be detected.

Exposure to Vacuum

The force exerted by vacuum-induced air pressure may be used to apply a moderate load to completed sandwich panels provided the face and core materials are relatively impervious to air. The magnitude of this load is dependent entirely upon the rate of air flow through the face and core of the panel, but under ideal conditions cannot exceed atmospheric pressure, or about 14 pounds per square inch.

Tests made by this method were conducted upon small aluminum-faced panels in an autoclave having a window in its door through which the immediate effect of quickly drawing a high vacuum upon the completed panels could be observed. It was found that areas having poor bonds could not be detected, and areas having no bond whatsoever were difficult to locate unless the area was large and the face very thin. Defects of this type could be located more easily and with greater accuracy by tapping. The vacuum-test method, therefore, appeared to have little value.

Vacuum-cup Test

The vacuum-cup method of inspection was similar in principle to exposure of the entire panel to a vacuum. A portion of the face was covered by an inverted container in which a vacuum was drawn. Vacuum-induced air pressure within the portion of the panel under the container exerted a force tending to push the face off, provided that the face was impervious to air. In this type of test the most severe load was applied when the face was airtight and the core was not. Under these conditions the ultimate load was equal to about atmospheric pressure.

Original tests at the Laboratory were made by using a glass funnel for the vacuum cup. Its open end, which was in contact with the panel, was coated with rubber to provide an airtight joint. If a blister appeared under the glass funnel when a high vacuum was drawn, it could be observed by reflected light.

The results resembled those obtained when the complete panel was tested under vacuum. Areas containing weak bonds could not be located, but large areas containing open joints could sometimes be detected.

Later, an instrument operating upon the same principle but incorporating a dial indicator for actual measurement of the face movement was tried. This device is shown in figure 2. For accurate deflection readings the rubber gasket, as used on the funnel, had to be omitted, and therefore, considerable leakage developed under the aluminum cup, especially on panels that were not perfectly plane and smooth.

The results obtained with this instrument were similar to those with the inverted glass funnel except that, because of the reduced degree of vacuum, areas having no bond would often be undetected.

Internal-pressure Test

After exposure to air pressure for several hours, a sandwich panel having airtight faces and a core that is slightly pervious to air tends to develop an air pressure within the core (and in any voids between the face and the core) equal to the external pressure. If this external pressure is suddenly released the air entrapped within the voids exerts a temporary force on the face that may cause a blister. The void, or unbonded area, can then be easily located by visual inspection.

Tests by this method of inspection were conducted on small (12-inch) and large (36-inch) square sandwich panels of various constructions.

Tests on small panels.--The small panels had aluminum faces 0.012, 0.020, or 0.032 inch thick glued to 1/4-inch end-grain balsa cores. The gluing process involved a primary cement cured on the aluminum and a secondary phenolic glue between the primed aluminum and the balsa core. These panels were carefully prepared to include unbonded areas (no glue) and areas of poor bond (secondary glue only) at certain points that could be located by means of a template. Tension tests on similar areas of poor bond yielded erratic tensile values ranging from 0 to 220 pounds per square inch as compared to a normal tensile strength of 800 to 1,000 pounds per square inch for well-glued areas. The location and size of these defective areas are shown in figure 1.

These panels were first thoroughly inspected by tapping, and a record was made of the defective areas thus located. This inspection was followed by a test consisting of exposure for 16 hours to air pressure of about 75 pounds per square inch, succeeded by a quick release of pressure. The defects detected by visual inspection after this test were again recorded. Later an additional test for 24 hours at a pressure of 80 pounds per square inch, followed by quick release of pressure, was performed, and the results were again recorded. It was thought that a pressure test at elevated temperature (not exceeding the fabrication temperature) might be more effective in locating poorly bonded areas. The panels, therefore, were exposed to an air pressure of 75 pounds per square inch at a temperature of 230° F. for periods of 3 and 20 hours. The results of inspections following each of these tests are presented in table 1.

None of the poorly bonded areas could be located by any of the tests, and only the larger unbonded areas were detected in most cases. It appeared also that the detection of unbonded areas became more difficult with an increase in face thickness.

Air-transmission tests.--To determine the relative air-transmission rates of two types of cores, 3/4-inch buttons were glued to the outer face of two panels in various positions as shown in figure 3. A 1/8-inch hole was drilled through the button and face of the panel and a 1/8-inch copper tube soldered in place. The joints between the button, panel, and copper tube were tested for leakage by submerging the panel in water and applying a low air pressure to the loose end of the copper tubes. The panels were then placed one at a time in an autoclave and exposed to an air pressure of 75 pounds per square inch. The copper tubes were threaded through a sealed fitting in the autoclave walls and mounted so that the end of each was directly under an inverted water-filled container as shown in figure 4.

The air passing through the core to the various points at which the copper tubes were attached, was forced out and collected in the inverted containers. Two panels, 1/2 by 12 by 12 inches in size, one with aluminum faces glued to an end-grain balsa core and one with aluminum faces glued to a paper honeycomb core, were subjected to this test. The results, recorded in table 2, show that the paper honeycomb core is far more pervious to air than the balsa core. There also appears to be no relation between rate of flow and distance to the nearest edge. The variations within one panel are probably due to nonuniformities in the core materials, or to open-edge glue joints between individual pieces of core.

Some core materials, such as cellular hard rubber and cellular cellulose acetate, have "closed bubble" constructions, which are undoubtedly almost impervious to air. Such core materials would require long exposure to air pressure before the air would penetrate any existing voids for an adequate test. Other core materials, such as glass cloth and cotton honeycomb, have open or "screenlike" weaves that offer little resistance to the flow of air and consequently produce little force on the core-to-face bond when the external pressure is quickly released.

Tests on large panels.--The tests on large panels by this inspection method were made in a steel autoclave 40 inches in diameter. The panels were first thoroughly tested by tapping on both faces to determine any areas having voids before they were pressure-tested. Such areas were outlined with a wax-crayon line. The panels were then piled on a small car, with stickers placed between the panels to allow for air circulation and free expansion of the faces, and wheeled into the autoclave. Air was supplied from a line that maintained a pressure of between 60 and 75 pounds per square inch. For the stronger core materials, such as paper honeycomb and glass-cloth honeycomb, the pressure was applied as fast as the line would allow, but for the low-strength cores, such as cotton-cloth honeycomb, the pressure was brought up to 75 pounds per square inch in three equal steps at about 20-minute intervals. Pressure was maintained in the autoclave for 15 hours, which was assumed to be sufficient time for the pressure in the core (and possible voids) to become approximately equal to the line pressure. The exhaust valves were then opened wide, and the autoclave pressure was reduced to atmospheric pressure within 2 minutes.

Of the 57 panels pressure-tested in this manner, 6 were found to be defective. One of these 6 had a hard-rubber core that crushed in several spots, presumably because the application of air pressure was too rapid. In the further testing of panels with hard-rubber cores, therefore, the three-step procedure of applying pressure was used. All the others that failed were panels with aluminum faces bonded to paper honeycomb cores with various adhesives. The failure in all cases was primarily in the glue line rather than in the core. This inspection method apparently applied higher stresses on panels having paper honeycomb cores than those having glass-cloth honeycomb or cotton-cloth honeycomb cores that were made with the same adhesives and methods of fabrication. The glass-cloth and cotton-cloth honeycomb are more pervious to air and therefore allow the entrapped air to escape very rapidly without exerting appreciable pressure on the face. Figure 5 shows one of the panels having paper honeycomb core and aluminum faces that exploded in the pressure test.

One panel, made with 0.020-inch aluminum faces bonded to paper honeycomb core with an adhesive composed of a thermosetting liquid and a thermoplastic powder, had an unbonded area in the middle, which was located by tapping (fig. 6). The panel was later subjected to the pressure test previously discussed, and a large blister (also outlined in fig. 6) was formed. From the shape of the blister it can be seen that the air pressure tore the faces from the core to form a channel to the edge of the panel, which allowed the air to escape.

The air-pressure method has an advantage over the tapping method because of the possibility that a very poorly glued area may fail when subjected to the stresses developed by the air pressure. No determinations were made as to the exact pressure that existed on the inside of the panels, but it undoubtedly varied according to the various types of construction. The loss of air under pressure in panels having aluminum faces is entirely through the core material, while in those having glass-cloth faces impregnated with a laminating resin and likely to be porous the loss occurs through both the core and the faces. From the air-transmission tests it was found that the rate of air transmission through different core materials varied considerably (table 2). The resultant pressure when a panel is pressure-tested will vary accordingly, and panels made of different materials will be subjected to different internal pressures, although the autoclave pressure is the same.

Heating Complete Panel

Heating a complete panel involved the use of heat to produce air pressure within a panel by the expansion of the air in the cells of the core and in any possible voids. Six glass-cloth-faced panels in a stickered pile were heated for 1 hour in a steam-heated oven equipped with a temperature recorder and a fan for circulating the air. Since the temperature for this inspection method (250° F.) was the same as the curing temperature used in fabricating the panels, the temperature alone should have had no damaging effect upon the panels.

The six panels tested consisted of eight-ply glass-cloth faces impregnated with a low-viscosity laminating resin bonded to paper honeycomb, glass-cloth honeycomb, or cotton-cloth honeycomb cores. Two panels of each combination were included in the test. No effect was noticed upon the glass-cloth honeycomb and cotton-cloth honeycomb panels, but one paper honeycomb panel developed a few blisters. The other paper honeycomb panel developed some smaller light-colored areas that appeared the same as blisters, but which could not be detected by tapping.

Very little work was done with this method because the bond was being tested at a temperature higher than that expected in service conditions and the degree of pressure developed in the panels was questionable. The probability that the pressure on the inside of the faces varied with the materials making up the sandwich panel was indicated by the varying air-transmission rates.

Local Heating

The only equipment used for the local-heating inspection method was an electrically heated flatiron. The panels had aluminum faces glued to balsa or paper honeycomb cores and were previously tapped on both faces to determine any questionable areas. Both questionable and well-bonded areas were heated for a short period with the iron and then removed and tapped to determine the condition of the bond. In many cases blisters developed that could be seen by visual examination.

This method was also considered unsatisfactory, however, because the bond was stressed at a high temperature and many of the adhesives were of a thermoplastic nature. Further, no simple way was found to determine the stresses produced on the bond by the pressure developed inside the panel, or by the thermal expansion of the heated portion of the face.

Button-tension Test

A mechanical pulling test for inspecting sandwich panels was developed at the Laboratory. It consisted of gluing an aluminum button to the face of a panel and applying tension to the button by means of a mechanical device operated by air pressure. The panels inspected by this means consisted of various combinations, including aluminum, plywood, and glass-cloth faces and balsa, cellular hard-rubber, cellulose acetate, and paper honeycomb cores. The panels were first inspected by tapping before the buttons were glued in place.

Preparatory to gluing the buttons to the panels, the chosen spots on the panel and the face of each button were sanded with fine emery paper, cleaned with acetone, and coated with two or three applications of a high-temperature-setting thermoplastic resin adhesive. A drying period of about one-half hour elapsed between each coat and 1 to about 3 hours after the final coat. The buttons were glued in position with the aid of a vacuum blanket containing a special adapter (fig. 7). A thermocouple to determine the temperature during the gluing operation was held with a balsa plug against the bottom of the hole in the button. The vacuum blanket was taped to the panel and a vacuum hose attached. The heating element consisted of a metal core surrounded by a coil, which, in turn, was connected in series with a lamp bank for varying the resistance of the circuit and thereby changing the heating capacity. The protruding end of the metal core of the heating element was fitted into a recess in the special adapter of the vacuum blanket directly over the button. Although the metal core was closely fitted in the recess, the thin air film acted as an insulator; but by displacing this air with oil, efficiency was greatly increased. The complete arrangement used for gluing the buttons onto the panels is shown in figure 8. The buttons were glued on the panels at a temperature of 275° F. for 20 minutes.

A pneumatic pulling device was used to apply tension to the buttons as shown in figure 9. It consisted of a cylinder and piston, with a rod leading from the piston for attachment to the buttons. The attachment was made by means of a loose-fitting pin. Air flow was regulated by a valve, and the air pressure in the cylinder was registered on a gage. Frictional resistance was held to a minimum by allowing air to leak past the piston and piston rod. Constant pressure in the cylinder was maintained by adjusting the inlet valve to obtain steady-flow conditions. The area of the button was one-half square inch and the net area of the piston was such that by multiplying the gage pressure by 19.1, the tension under the button could be determined in pounds per square inch.

The ultimate tension values that were obtained at random from various exploratory panels are recorded in table 3 and, in most cases, are in the relative order of tensile strengths of these combinations as determined by normal tension-testing methods, except that the tension values obtained from the aluminum-balsa panel were abnormally low. More comparable values were obtained from buttons used as controls on the panel referred to in table 4.

In addition, two specially constructed aluminum-faced panels, one with a balsa core and the other with a paper honeycomb core, were fabricated with nine defective areas (fig. 10) to which buttons were glued and pulled with the mechanical pulling device. The ultimate tension results obtained on these panels are recorded in tables 4 and 5. In these tests, lower values were obtained for unbonded or poorly bonded areas than for well-bonded areas.

The two types of core yielded different ultimate tensile values, which agreed fairly well with their respective tensile strengths. The maximum tensile stress that can be exerted by the button depends on the bond between the button and the face, but this bond appeared capable of consistently developing stresses in excess of 300 pounds per square inch.

Insufficient tests were made to determine the safe load that might be applied in a nondestructive tension test of this type. Once this value is established, however, for any combination of face and core material, the button-tension test could be used as an acceptance test on flat or nearly flat surfaces. The buttons could later be removed by softening the thermoplastic glue bond with heat or a solvent. Because of the amount of time and equipment required, this test is not practicable for a complete inspection method, but is rather for random tests or for tests on highly stressed areas. The buttons are glued at 275° F., which may be higher than the curing temperatures of certain resins or adhesives and, therefore, on such panels the test is unsafe.

Table 1.--Results of inspection of small defective aluminum-to-balsa panels by tapping, internal pressure, and a combination of internal pressure and heat

Thickness of aluminum face	Character of bond at defective area	Diameters of defective areas[1] located by:				
		Tapping	16 hours at: 75 p.s.i.	24 hours at: 80 p.s.i.	3 hours at 220° F. and 75 p.s.i.	21 hours at 230° F. and 75 p.s.i.
Inch		Inch	Inch	Inch		
0.012	No glue	2, 1-1/4, 3/4 and 1/2	2 and 1-1/4	2, 1-1/4, 3/4 and 1/2	Large blister included 2- and 1-1/4-inch area. 3/4- and 1/2-inch area blistered.	Large blister included 2- and 1-1/4-inch area. 3/4- and 1/2-inch area blistered.
.012	Poor	None	None	None	None	None
.020	No glue	2	2 and 1-1/4	2, 1-1/4, and 3/4	Large blister included 2- and 1-1/4-inch areas on both faces. 3/4-inch area blistered.	Large blister included 2- and 1-1/4-inch areas on both faces. 3/4-inch area blistered.
.020	Poor	None	None	None	None	None
.032	No glue	2	2	2 and 1-1/4	2- and 1-1/4-inch area. Blister also on back side of 2-inch area	2- and 1-1/4-inch area. Large blister on back side covering practically all areas.
.032	Poor	None	None	None	None	None

[1]Each 12- by 12-inch panel had four defective areas as shown in figure 1.

Table 2.--Results of air-transmission tests on sandwich panels with aluminum faces on balsa and paper honeycomb cores

Location	Distance to nearest edge	Autoclave pressure	Air-transmission rate	
			Aluminum to balsa	Aluminum to paper honeycomb
	In.	P.s.i.	Cc. per hr.	Cc. per hr.
1	1-1/2	75	2.8	.........[1]
2	2	75	3.2	16,500
3	4-1/4	75	3.5	10,250
4	1-1/2	75	113.0	5,790

[1]Leak in joint; not tested

Table 3.--Preliminary results of button-tension test on sandwich panels

Panel construction		Ultimate tension on area of button	Type of failure
Face	Core		
		P.s.i.	
Aluminum	End-grain balsa	267	Aluminum pulled from balsa
		363	.............Do
Birch plywood	End-grain balsa	592	Button pulled fibers from plywood
		611	.............Do
Glass cloth	Paper honeycomb	401	Failed in glue line between button and face
		459	Glass-cloth face pulled from paper honeycomb
Aluminum	Cellulose acetate	363	Aluminum pulled from cellulose acetate
		401	.............Do.
Glass cloth	Cellular hard rubber	229	Glass-cloth face pulled from hard rubber
		191	.............Do.

Table 4.--Summary of results of button-tension tests on aluminum-balsa sandwich panel

Position[1]	Gluing conditions	Ultimate tension on area of button	Condition of test area (Determined by tapping)	
			Before	After
		P.s.i.		
1	No glue	73	Satisfactory	Aluminum pulled from core
2	.........do.........	535	Satisfactory	Aluminum pulled from core
3	.........do.........	477	Aluminum loose from core	Aluminum loose from core
4	.........do.........	96	Aluminum loose from core	Aluminum loose from core
5	Only secondary adhesive on aluminum faces. (No primary adhesive applied.)	248	Satisfactory	Satisfactory
6	.........do.........	172	Satisfactory	Aluminum pulled from core. (Note - aluminum tore from balsa at 57 p.s.i.)
7	.........do.........	382	Satisfactory	Aluminum pulled from core
8	.........do.........	210	Satisfactory	Aluminum pulled from core
9	.........do.........	401	Satisfactory	Satisfactory

(continued)

Table 4.--Summary of results of button-tension tests on aluminum-balsa sandwich panel (continued)

Position[1]	Gluing conditions	Ultimate tension on area of button	Condition of test area (Determined by tapping): Before	Condition of test area (Determined by tapping): After
		P.s.i.		
Controls				
Between 1 and 2	Primary and secondary adhesives on faces (normal bonding procedure)	764	Satisfactory	Aluminum pulled from core[2]
Between 1 and 2	..........do..........	841	Satisfactory	Satisfactory[3]
Between 1 and 2	..........do..........	994	Satisfactory	Aluminum pulled from core
Between 2 and 3	..........do..........	764	Satisfactory	Satisfactory
Between 2 and 3	..........do..........	898	Satisfactory	Satisfactory
Between 5 and 9	..........do..........	688	Satisfactory	Satisfactory
Between 7 and 8	..........do..........	497	Satisfactory	Satisfactory

[1]"Position" here refers to a defective area of definite size on the panel as shown in figure 10.

[2]First trial reached 898 p.s.i. without fracture.

[3]First pull reached 1,012 p.s.i. without fracture.

Table 5.--Summary of results of button-tension tests on aluminum-paper honeycomb sandwich panel

Position[1]	Gluing condition	Ultimate tension on area of button	Condition of defective area (Determined by tapping)	
			Before	After
		P.s.i.		
1	Secondary adhesive - on core only	191	Aluminum loose from core	Aluminum loose from core
2	.........do..........	134	Satisfactory	Aluminum pulled from core
3	.........do..........	115	Aluminum loose from core	Aluminum loose from core
4	.........do..........	38	Aluminum loose from core	Aluminum loose from core
5	Only secondary adhesive on core and faces. (No primary adhesive applied)	191	Aluminum loose from core	Aluminum loose from core
6	.........do..........	191	Satisfactory	Aluminum pulled from core[2]
7	.........do..........	153	Aluminum loose from core	Aluminum loose from core
8	.........do..........	172	Satisfactory	Aluminum pulled from core
9	.........do..........	96	Satisfactory	Aluminum pulled from core

(continued)

Table 5.--Summary of results of button-tension tests on aluminum-paper honeycomb sandwich panel (continued)

Position[1]	Gluing condition	Ultimate tension on area of button	Condition of defective area (Determined by tapping)	
			Before	After
		P.s.i.		
Controls				
Between 1 and 2	Primary adhesive on faces; secondary adhesive on faces and core (normal bonding procedure)	306	Satisfactory	Satisfactory
Between 1 and 2	..........do..........	306	Satisfactory	Satisfactory
Between 1 and 2	..........do..........	554	Satisfactory	Satisfactory
Between 2 and 3	..........do..........	401	Satisfactory	Aluminum pulled from core
Between 2 and 3	..........do..........	401	Satisfactory	Aluminum pulled from core
Between 2 and 3	..........do..........	497	Satisfactory	Satisfactory
Between 5 and 7	..........do..........	477	Satisfactory	Satisfactory

[1]Position here refers to a defective area of definite size on the panel as shown on diagram (fig. 10).

[2]Aluminum tore from core at 38 p.s.i.

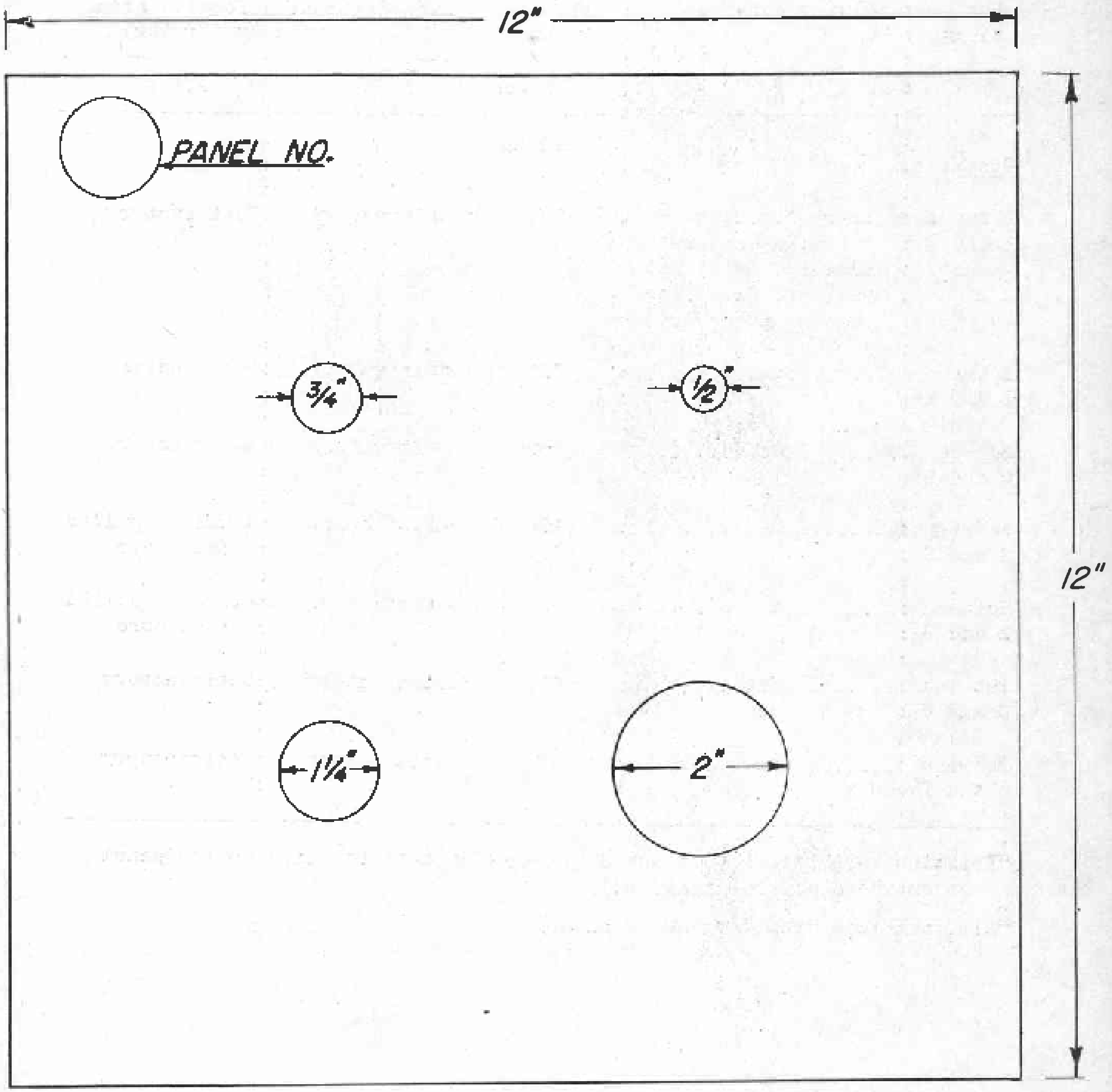

Figure 1.--Location and diameter of defective areas in small test panels.

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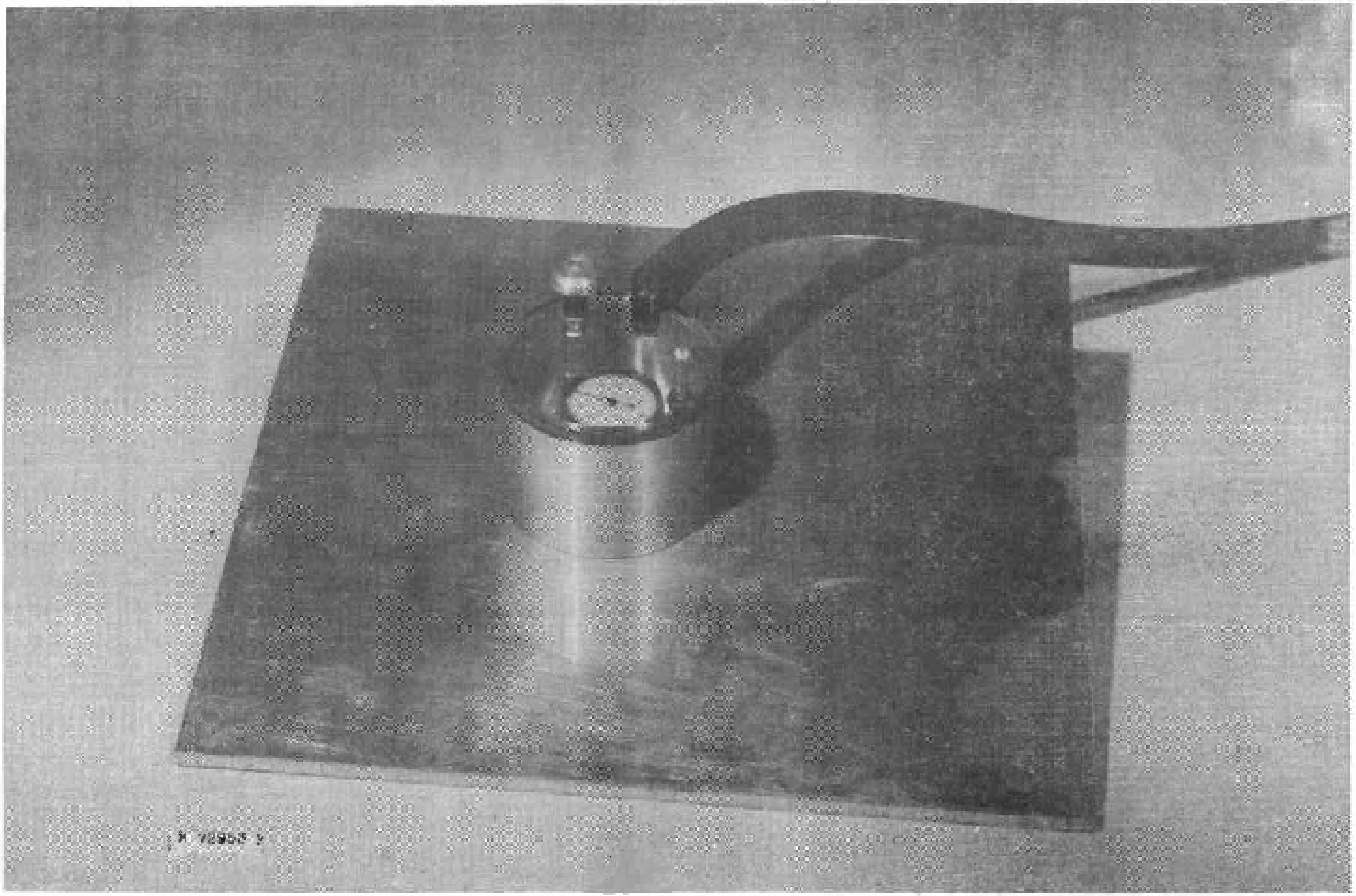


Figure 2.--The Detectometer in position on an aluminum-faced panel.

Z M 74719 F

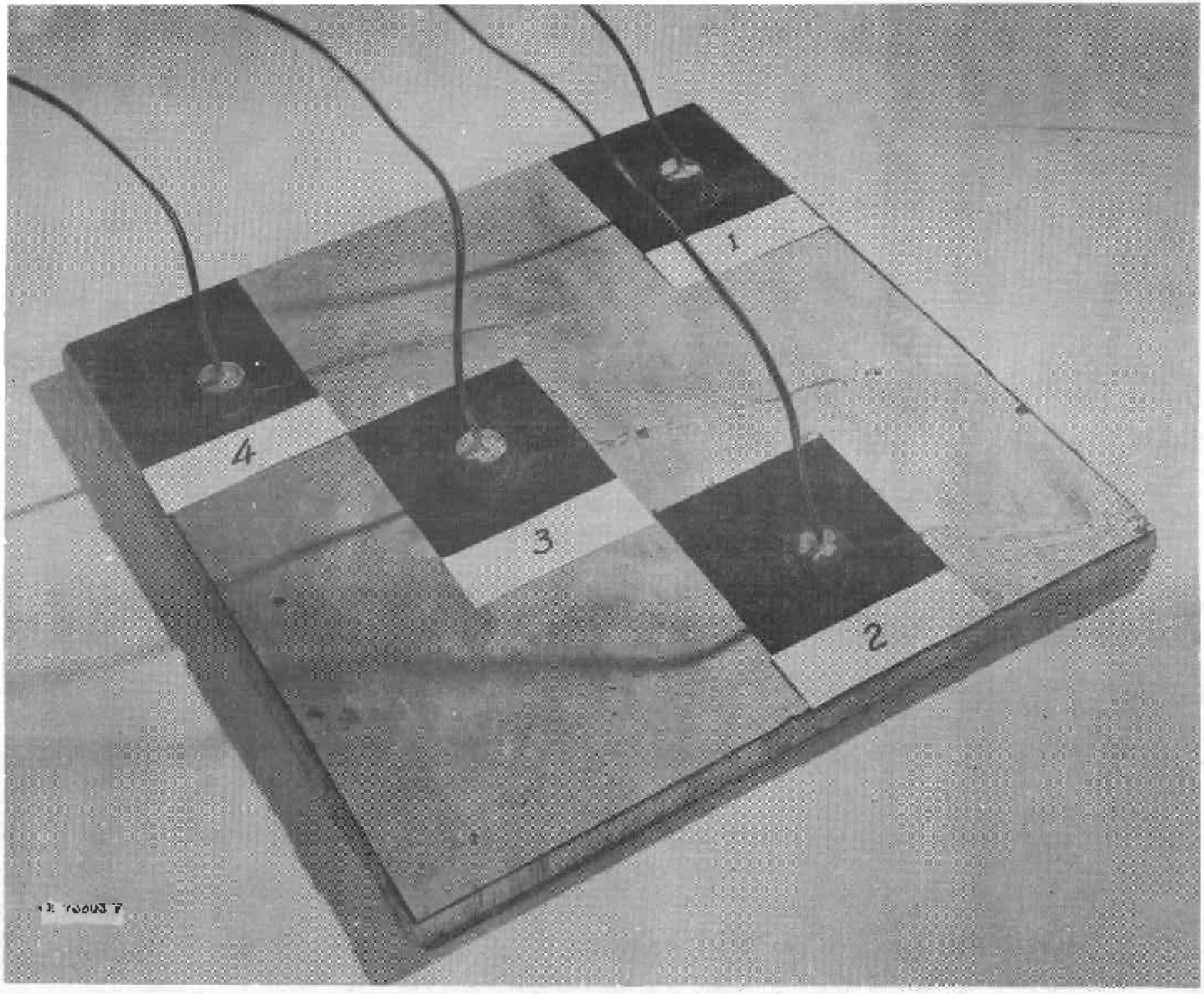


Figure 3.--Aluminum-to-balsa panel (12 by 12 inches) showing button positions used for determining air-transmission rate.

Z M 74720 F

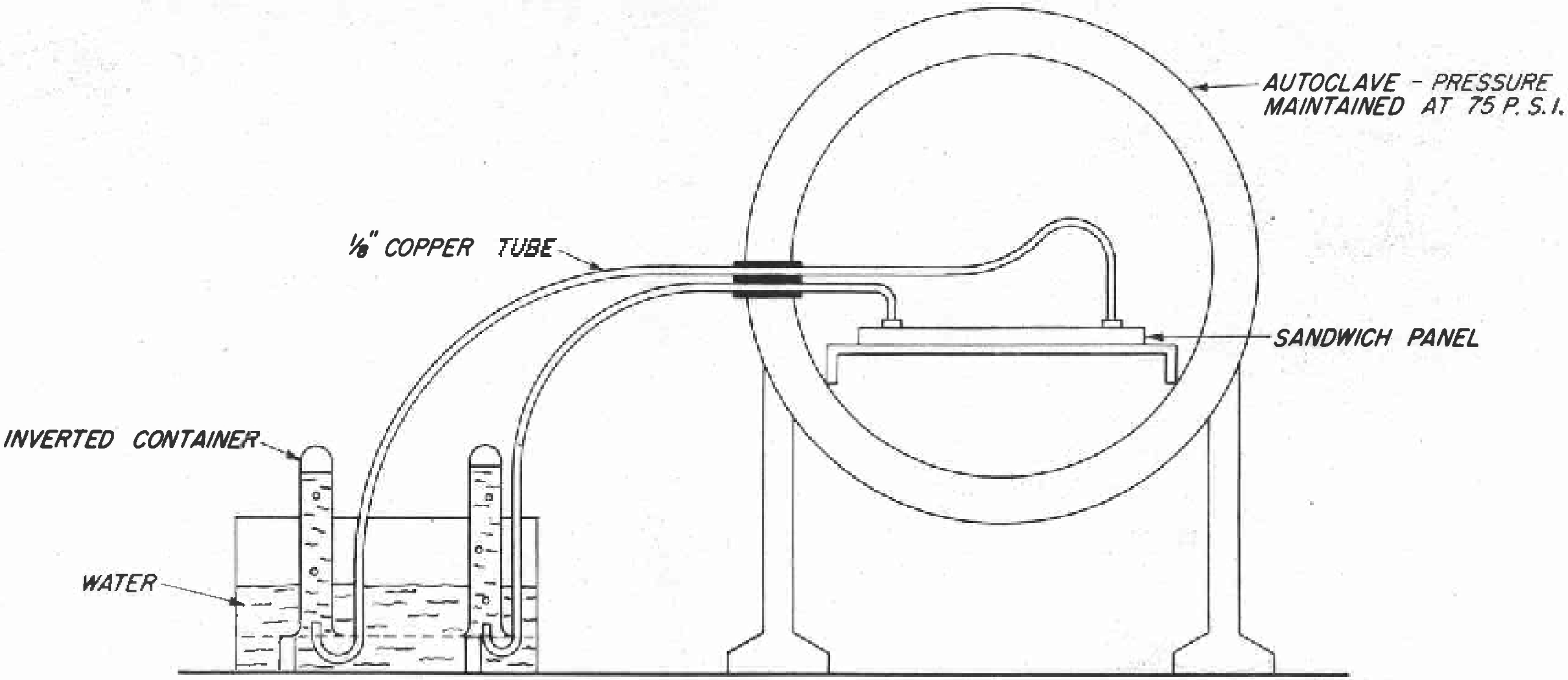


Figure 4.--Diagrammatic sketch of apparatus used for determining the air-transmission rates of sandwich panels.

Z M 73958 F

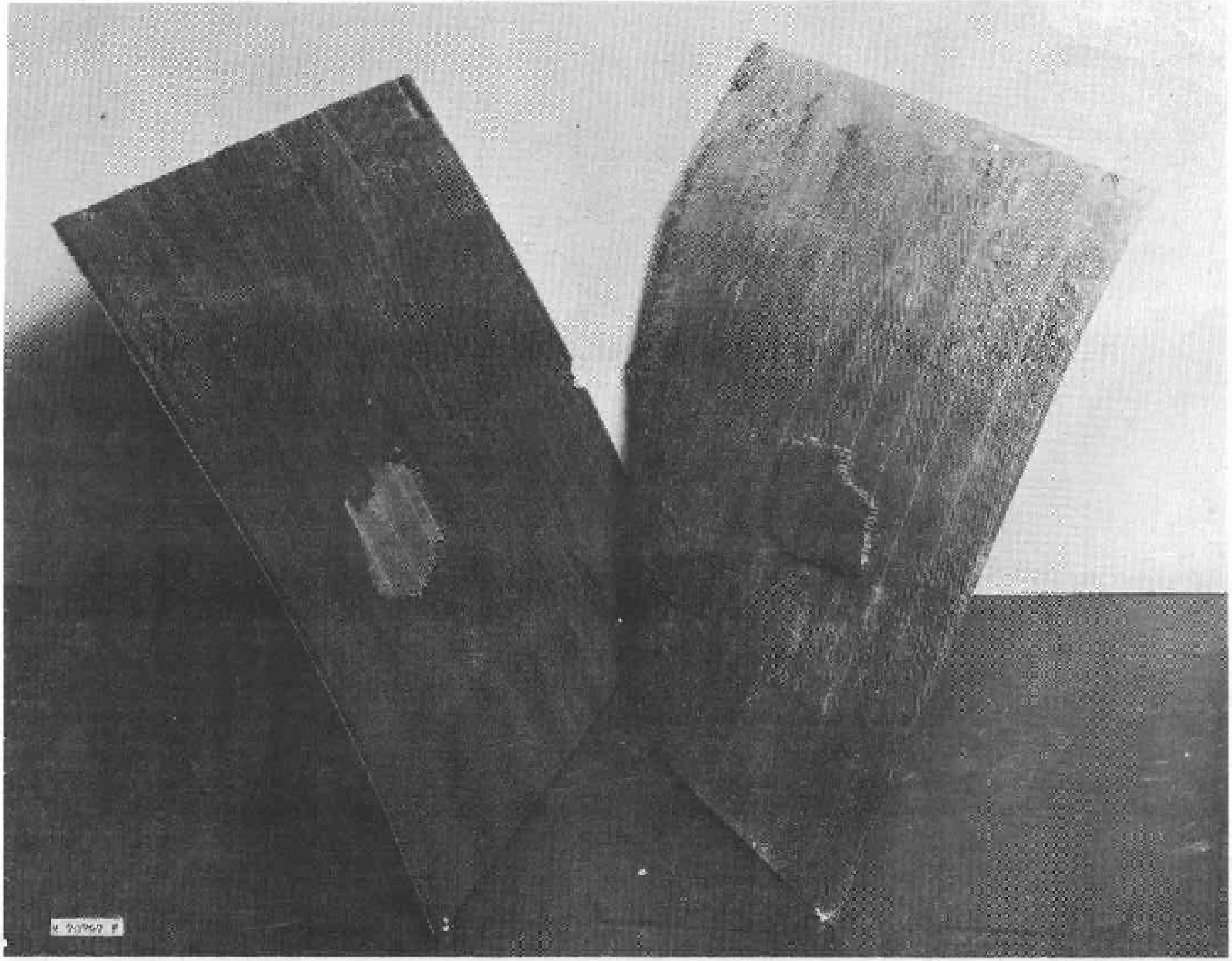


Figure 5.--Exploded sandwich panel of aluminum-to-paper honeycomb caused by internal-pressure test.

Z M 74721 F

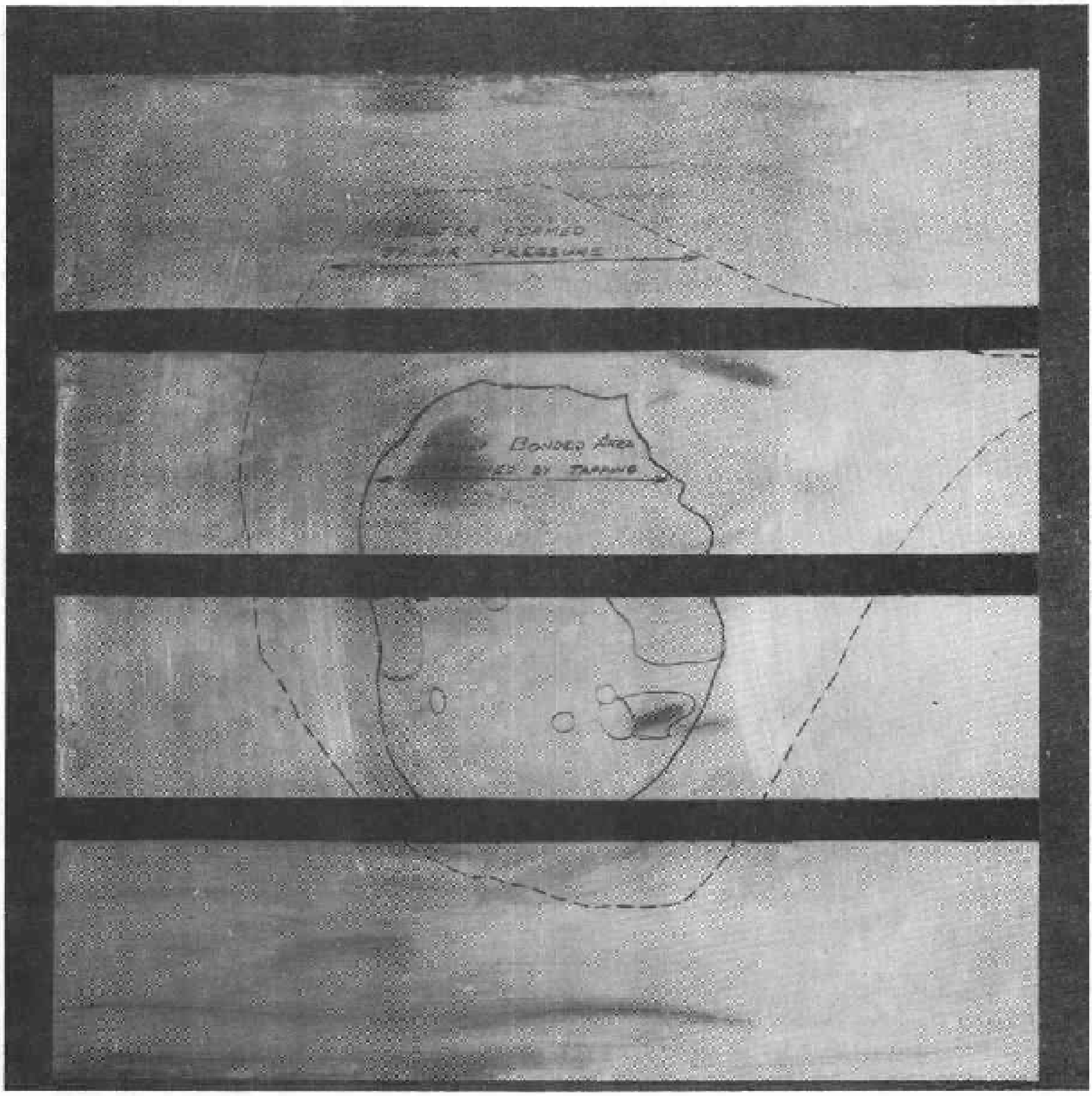


Figure 6.--Sandwich panel of aluminum-to-paper honeycomb with an outlined defective area determined by tapping, and the blister formed after subjecting the panel to the internal-pressure test. (The black bands are stripes of a metal-to-metal glue applied to the aluminum before the panel was fabricated.)

Z M 74722 F

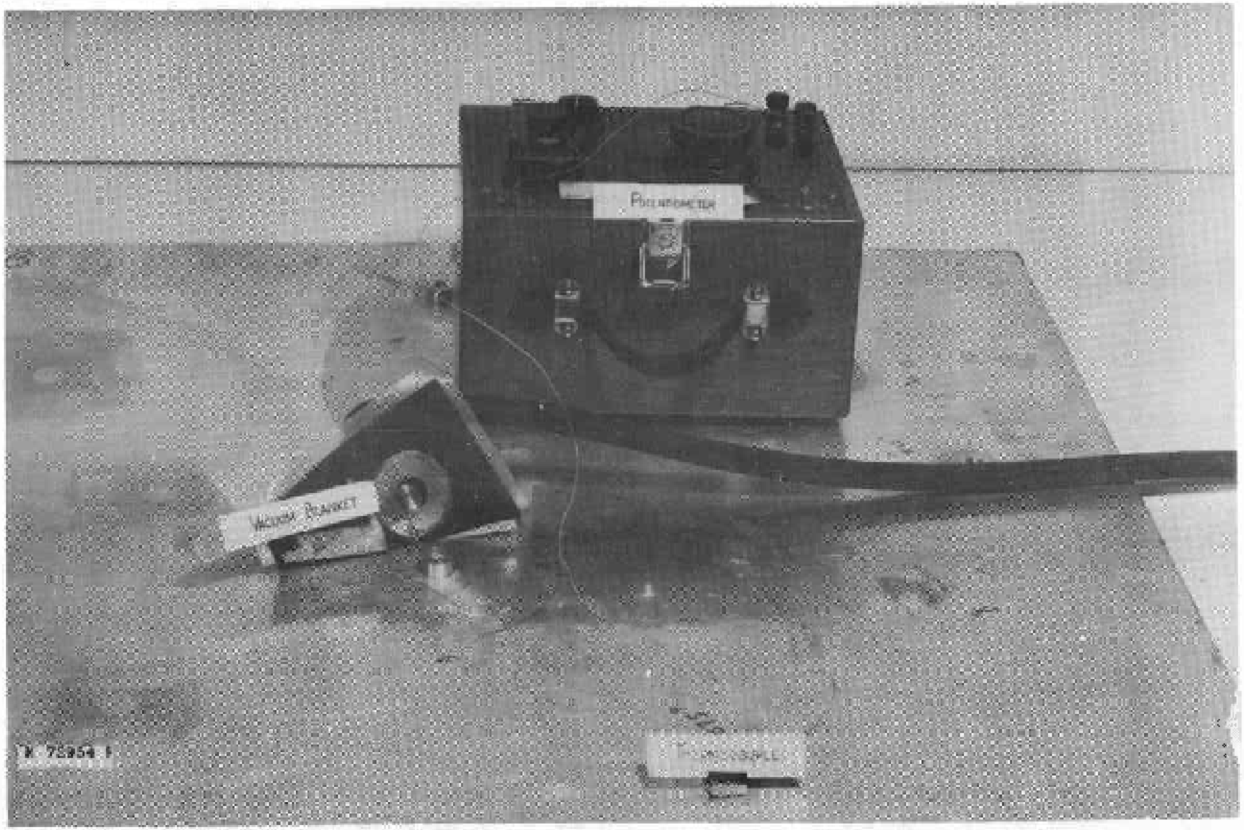


Figure 7.--Tension button ready for gluing to panel, showing thermocouple for determining the temperature and bottom side of vacuum blanket.

Z M 74723 F

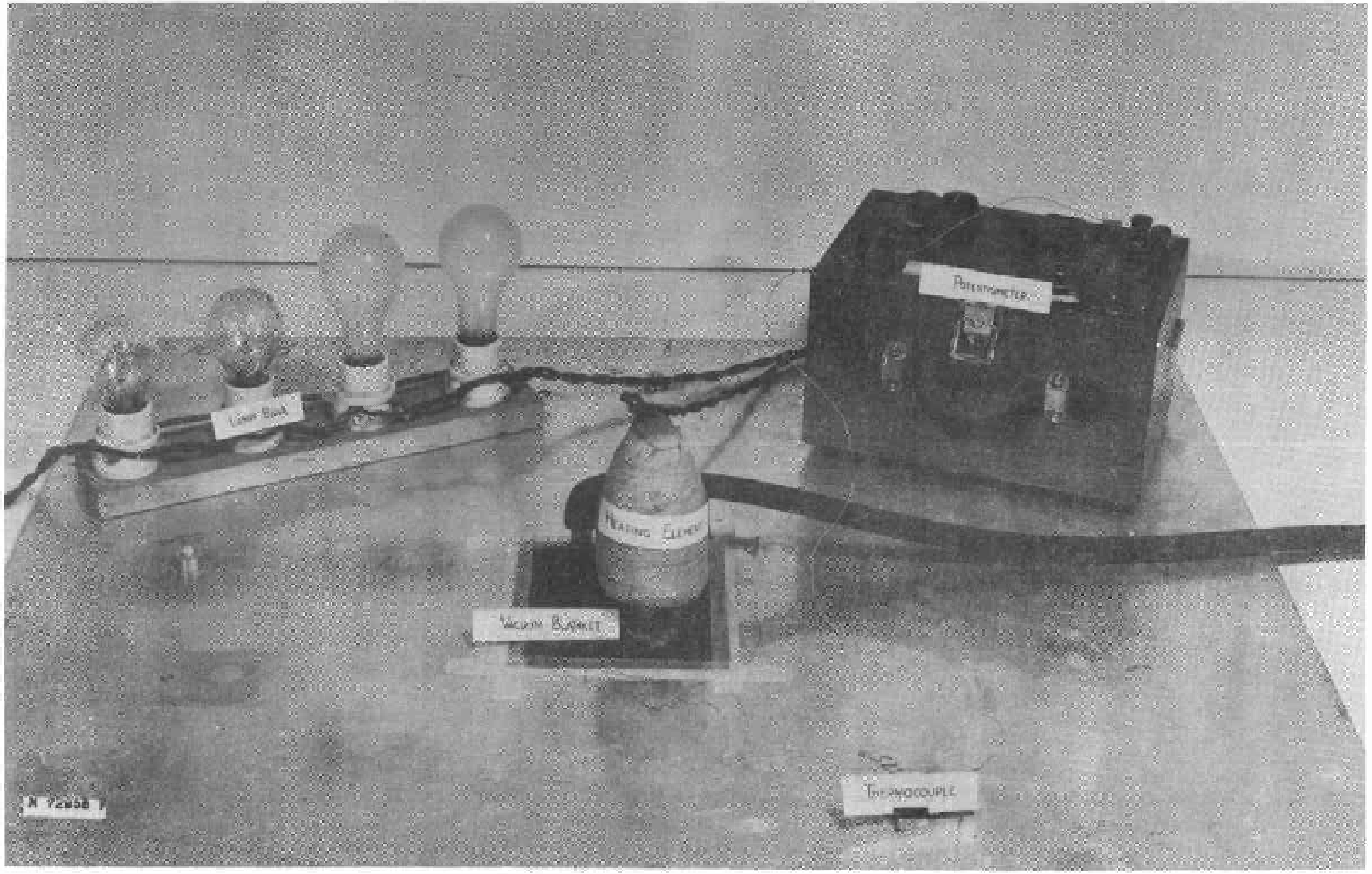
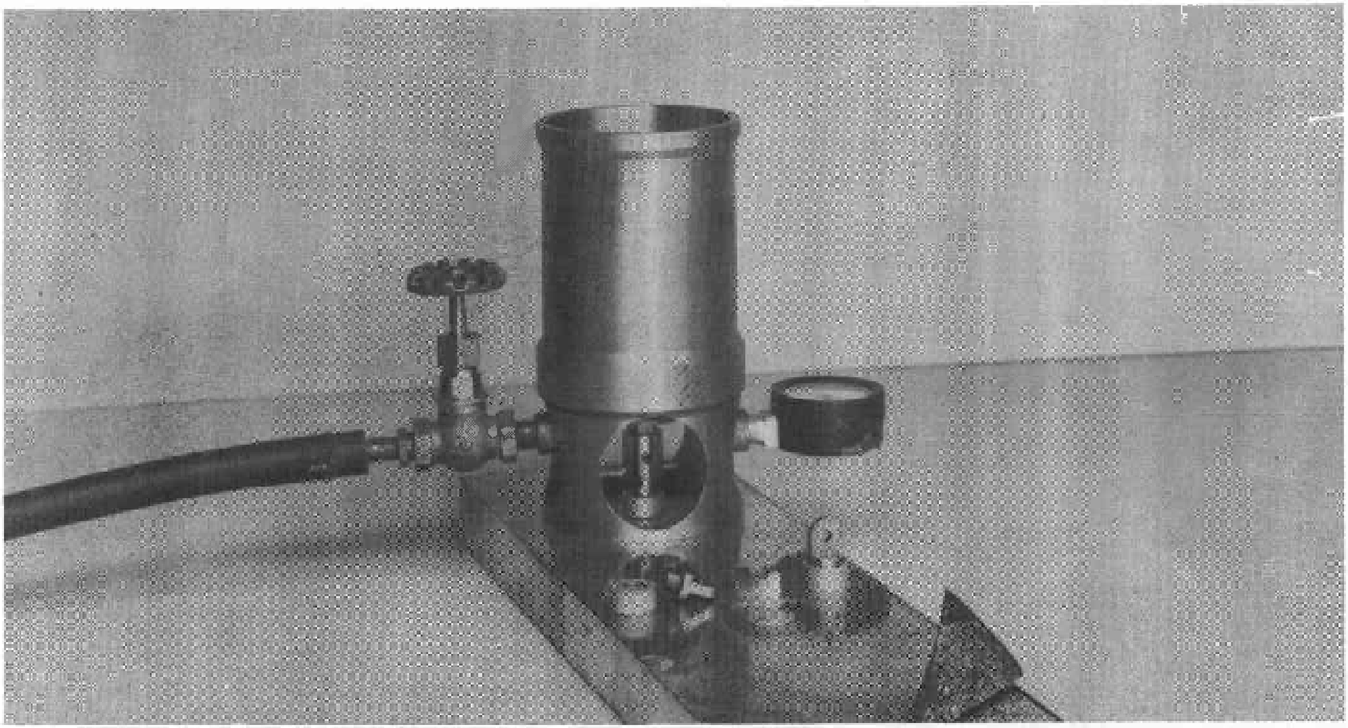


Figure 8.--Complete set-up used for gluing buttons to panels.

Z M 74724 F



Z M 74725 F

Figure 9.--Button tension-pulling device, showing method of attachment to button.

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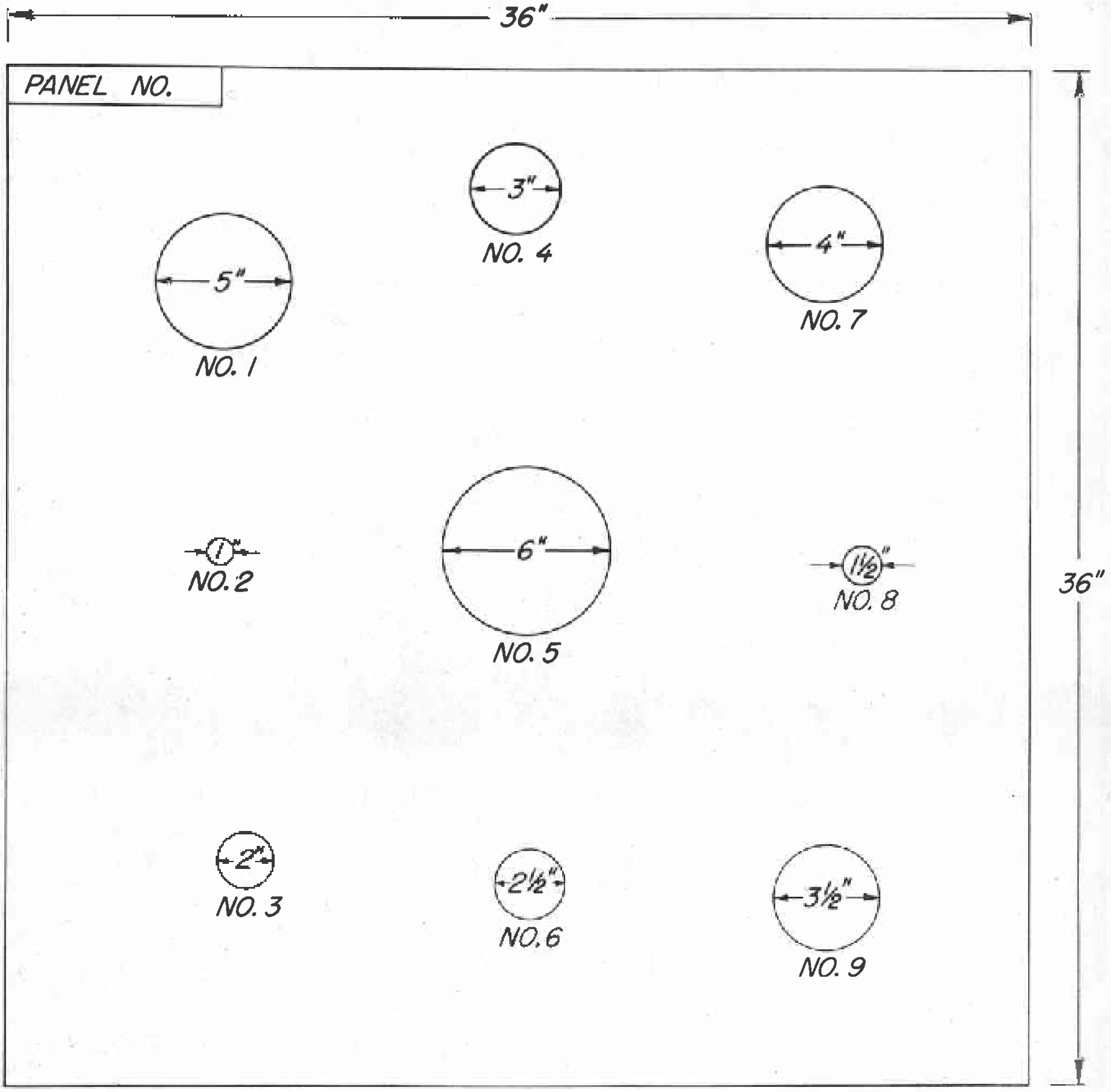

Figure 10.--Location and diameter of defective areas in large test panels.

Z M 73959 F