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TESTS OF AEROPLANE FIREWALLS

REPORT NO. MM-28

BY

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Addendum to Report No. MM-28
"Tests of Aeroplane Firewalls"

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Approved (Sgd.) J. H. Parkin
Director

Discrepancies between the results of penetration resistance tests of certain types of aeroplane firewalls as described in Report No. MM-28 and those obtained by another laboratory have led to the discovery that the spike used for the tests in the National Research Laboratories had a conical point having a half-angle of 45° (i.e. an included angle of 90°), whereas the specifications of the British Air Ministry which it was intended to follow call for an included angle of 45°.

As the four samples of constructions 1 to 4 of the report, page 9, to which the penetrations had previously applied were still on hand, tests were repeated using a spike of 45° included angle. The points of impact were not at the centre of the panel as specified, but were removed a few inches from the centre to avoid the indentations produced by the previous test. This is not considered likely to affect the results to any extent. Whereas no penetration was obtained with the 90° spike, the following results were obtained with the 45° spike:

Construction I	Single sheet terne plate 0.030" Penetration 5 out of 5 drops, holes approx. 1/8" diameter.
Construction II	Aluminum sandwich with asbestos paper spacer Penetration 3 out of 5 drops, holes minute.

Construction III Single sheet stainless steel 0.020" Penetration 5 out of 5 drops, holes approx. 1/16" diameter.

Construction IV Aluminum sandwich with medium asbestos millboard spacer, Penetration 2 out of 5 drops, holes minute.

It will be noted that so far as this test is concerned there is little to choose between the two sandwiches both of which are superior to the single sheet constructions. This is apparently due to the fact that most of the energy of the spike has been absorbed in forming and enlarging a hole in the first sheet before the point has reached the second sheet, so that with a slight increase in thickness of the filler the second sheet might not be penetrated at all.

The difference between the terne plate and stainless steel panel is probably due more to the difference in gauges than in materials.

By comparison with a steel scale, the points of both the 90° and 45° spikes were judged to have a radius of approximately 1/64" after the tests.

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REPORT

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Introduction

These tests were performed in the Fire Hazard Testing Laboratory at the request of the Associate Committee of Aeronautical Research with the purpose of comparing the relative effectiveness of various types of construction of fireproof bulkheads as required by the existing United States Civil Air Regulations and the British Air Ministry Civil Aircraft Regulations; to investigate other types of construction which might prove more effective and satisfactory than the present accepted designs and to permit a performance specification for firewall construction to be prepared.

When the tests described in this report were first undertaken by the Fire Hazard Testing Laboratory, the existing requirements for fireproof bulkheads consisted of construction specifications only stating the materials, thickness and method of arrangement. Moreover, the British and American regulations were not identical and it was not known whether the firewalls so specified were equivalent. It was therefore intended to compare panels meeting the separate requirements by actual test and if possible devise a performance specification on the basis of test results. Accordingly, a furnace in which test panels could be subjected to flame-tests was designed and constructed. However after several tests had been performed with this furnace an amendment to the Regulations of the British Air Ministry in the Airworthiness Handbook for Civil Aircraft Vol. I, Design Section, was issued in February 1938. This Amendment, entitled "Appendix I to Design Leaflet D.1, besides listing approved types of bulkheads, outlined tests for determining resistance to flame penetration, resistance to impact and resistance to mechanical penetration by which bulkheads of other than listed construction might be judged.

Apparatus for performing all the tests in the Air Ministry Specification was made and comparative tests made of samples of panels corresponding to those tested in the Fire

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Hazard Testing Laboratory furnace.

The British Air Ministry Specifications are included in Appendix I to this report, and the drawings Figs. 1, 2 & 3 therefore are included with Fig. 4. The United States Civil Air Regulations for aeroplane firewalls are included in Appendix II.

On the basis of the tests made, the British Air Ministry specification is considered generally adequate as a performance specification, but an alternative suggestion regarding the procedure for conduction of flame penetration tests is submitted.

PART I.

Construction of F.H.T.L. Furnace See Fig. 4

The furnace walls were made of an inner layer of refractory brick 2½" thick, and an outer layer of expanded mica thermal insulating brick 2½" thick, all bonded with refractory cement. The outer corners of the furnace were protected by an angle iron frame which also served to hold the panel clamping frame. The inside dimensions of the combustion chamber were 25" x 25" x 9". The furnace was heated by means of four bunsen-type gas burners, each nominally rated at 35 cu. ft. per hr.

The flames from the burners were directed across the face of the furnace and deflected towards the test panel by a baffle and the bricks forming the flue. In operation a large portion of the heat striking the panel was radiated from the rear surface of the combustion chamber which was heated to a straw heat. The location of the baffles and the outlet for the exhaust gases were chosen by experiment in an effort to obtain even heating without moving the burners from their built-in-positions. The results obtained, while satisfactory, might perhaps be improved on by moving the two upper burners approximately 6" lower.

Extensions of the angle iron framework acted as a support for a second framework of angle iron, the vertical and horizontal angles of which formed a rectangle 28" x 28", slightly larger than the furnace opening. Bosses were welded to these members and threaded to receive machine screws which when tightened, held the test panel against the furnace opening.

The draft in the furnace was controlled by adjustment of a damper in the stack and by the partial or total closure with moistened asbestos pulp of the openings through which the burners were inserted.

Flame Penetration and Temperature Test with F.H.T.L. Furnace

Test Arrangement   See Fig. 10d

All panels tested were of a nominal size, 36" x 36", which permitted a panel overlap of approximately 5" around the edge of the furnace opening.

Groups of chromel-alumel thermocouples were placed at the points on the test panel where the highest temperatures were obtained as determined from preliminary tests. In the case of the Terne Plate panel, the first panel tested, thermocouples were placed at four separate points, but in all succeeding tests this number was reduced to three. Referring to the lower left hand corner of the furnace opening viewed from the front as the origin, the position of each group of thermocouples on the test panel was as follows:

Terne Plate Panel

T.C. #1 - X = 11"	Y = 19"
T.C. #2 - X = 12"	Y = 13"
T.C. #3 - X = 3"	Y = 7½"
T.C. #4 - X = 19"	Y = 9½"

All other panels

T.C. #1 - X = 12½"	Y = 20½"
T.C. #2 - X = 11½"	Y = 12½"
T.C. #3 - X = 8½"	Y = 6½"

Four thermocouples were placed in group Nos. 1 and 2, and three thermocouples in groups Nos. 3 and 4 as follows:

T.C. #1a and 2a - 1" from the inner surface
T.C. #1b, 2b, 3b, and 4b - In contact with inner surface of panel
T.C. #1c, 2c, 3c and 4c - In contact with outer surface of panel
T.C. #1d, 2d, 3d and 4d - 1" from outer surface of panel

Thermocouples Nos. 1a and 2a were connected to a recording potentiometer which gave a continuous record of the flame temperatures at these points. The remainder of the thermocouples were connected to a portable dial type potentiometer.

Where the thermocouple wires passed through the panel, porcelain beads ("fish spines") were used to insulate them from the panel and any small opening that remained was sealed with a fire resisting porcelain cement. This cement was also employed to hold the thermocouples in position both on the inner and outer surfaces of the panel. Unfortunately, in some cases, severe buckling caused by thermal expansion forced the thermocouples out of position. Whenever possible, the thermocouples were relocated in their original position relative to the panel surface. In the case of the thermocouples on the inner surface side, it was extremely difficult in some cases to hold the thermocouples in position due to the melting and breaking away of the panel metal and the softening of the thermocouple wire.

In the initial tests, no attempt was made to subject the panels to vibration, but in later tests this was done.

A vibrator, see Fig. 10f, was made up in the Laboratories which consisted primarily of a steel disc 3" in diameter by 1/2" thick, weight approximately 1 lb, and fastened to a 1/4" diam. shaft by two machine screws. The disc was slotted on the diameter permitting a maximum eccentricity of 1/2" by adjustment of the machine screws. The 1/4" diam. shaft was carried on a steel bracket arm which was free to pivot about a bolt passing through its lower end and held in place by two angle irons fastened securely to a wooden base. A 1/8" H.P. motor turning at 1770 R.P.M. was supported on the same base and connected to the disc shaft by a few inches of thick wall rubber tubing. A 1/4" diam. steel rod, 1 ft. long, was used to transmit the vibrations produced by the rotating eccentric disc to the panel.

The rod was connected to the bracket arm by a clevice and bolt 3-5/8" from the bracket arm pivot and 2-3/8" from the centre of rotation of the disc. Employing the previous notation the vibrator rod was attached to the lower right hand corner of the test panel at a point where X = 21", Y = 5½".

Test Procedure

The panel was firmly fixed in position against the furnace opening by the clamping screws and the outer thermocouples attached to the panel. By preheating the stack before lighting the furnace, the burners were observed to burn more readily at the start. Otherwise some difficulty was experienced in keeping them alight until the furnace was heated up and a proper draft obtained. Usually two or three minutes elapsed before the burners were burning steadily and readings could be taken.

Readings were taken on the portable potentiometer at intervals of approximately 3 minutes for a period of 30 minutes.

By observation of the recording potentiometers, the draft was adjusted with the burners on full until the maximum operating temperature was obtained.

In the tests where the vibrator was used, the amplitude of vibration was adjusted to between approximately 1/8" and 1/4".

<u>Note</u> Where photographs of the outer surface of the panels are shown, these serve to illustrate the buckling or distortion of the panels obtained in all cases.

The following panels were constructed to comply as closely as available gauges of materials would permit with the American and British Specifications for fireproof bulkheads.

Results

Standard Panels

Aluminum Sandwich with Millboard (Soft) "Asbestos Paper" Spacer see Fig. 11b. & 11d.

Panel 36" x 36" Weight 1.15 lb./sq. ft.
Aluminum 0.022" thick
British specification.- 0.022"
American " - not less than 0.02"
Millboard 1/8" thick
British specification 3/32",
American " at least 1/8"

Aluminum Sandwich with Millboard (Medium) Spacer, see Fig. 11f.

Panel - 36" x 36" Weight 1.338 lb./sq. ft.
Aluminum 0.022" thick
British specification 0.022"
American " not less than 0.02"
Millboard 1/8" thick
British specification - 3/32"
American " - at least 1/8"

Single sheet "Staybrite" stainless steel 0.017" thick
American specification - not less than 0.015"
see Fig. 11e.

Panel - 36" x 36" Weight 0.75 lb./sq. in.

Single sheet Terne Plate - 0.030" thick
British and American specification 0.028"
see Fig. 11c.

Panel - 36" x 36" Weight - 1.28 lb./sq. ft.

These panels were not subjected to vibration during test.

The temperatures recorded by each group of thermocouples were plotted on a time base and the relative effectiveness of each panel determined from the resulting curves, see Figs. 5a-f, 6a-c, 8a-d.

In no case did the flame penetrate the outer surface although in the case of the aluminum panels, the inner sheet or surface in contact with the flame was melted and the asbestos millboard spacer charred. It was noted that circular areas of the inner sheet from 1/2" to 1½" in diameter surrounding each rivet remained unmelted.

Results

Experimental Panels

These panels were made up to investigate the possibility of any advantages they might have over the standard panels and were subjected to vibration during test.

Aluminum Asbestos Panels

The two aluminum-asbestos sandwich panels were prepared by spraying one sheet of aluminum with asbestos by a patented process, (sodium silicate was used as the bond) and rivetting a second aluminum sheet to the sprayed sheet. Two such panels were tested each making use of a different density of asbestos which may be described as No. 1 and No. 2.

Aluminum sandwich with No. 1 sprayed asbestos spacer
see Figs. 12a and 12b.

Panel - 36" x 36" Weight 0.894 lb./sq. ft.
Aluminum - 0.020"
Spacer - 1/8" to 3/16" thick

Aluminum sandwich with No. 2 sprayed asbestos spacer
see Figs. 12c and 12d.

Panel - 36" x 36" Weight - 0.764 lb./sq. ft.
Aluminum 0.020" thick
Spacer - 1/8" to 3/16" thick

In testing, the sprayed sheet formed the outer surface, the unsprayed sheet being exposed to the flame. This arrangement was adopted since the sprayed sheet supported the asbestos, and if that sheet were melted, the asbestos might collapse.

Although the inner sheet in each case was melted, and the asbestos charred, in neither case did the flame penetrate the outer surface. As in the previous cases, buckling or distortion of the panel occurred and the asbestos sprayed on the aluminum sheet separated from it where the exposed sheet had been melted away, but in both cases the asbestos remained intact to present an unbroken surface.

The temperatures obtained are shown graphically in Figs. 7a - 7f.

Aluminum-Stainless Steel Panel

It was originally planned to test a wall composed of two sheets of aluminum separated by an air space which would replace asbestos as a thermal insulating medium. However, upon reconsideration, it was evident that once the exposed panel melted, the air space would cease to have an insulating value and the outer panel would possibly be heated to melting point. It was then decided to use stainless steel for the exposed face. The combination would be heavier than the stainless steel alone, but this might be compensated for if a panel were obtained which would combine the strength of the single sheet steel panel with the thermal resistance of the sandwich type.

The test panel was constructed as follows:

Horizontal transite spacers 3/8" wide and 1/4" thick were placed at intervals of 6" and securely rivetted in position between the aluminum and steel sheet. The ends of each duct or air space formed by the spacers were closed by a second group of transite strips 1/4" thick at a distance of 6" from the edge of the panel.

Aluminum "Staybrite" stainless steel sandwich
see Figs. 12e and 12f.

Panel - 36" x 36" Weight 1.289 lb./sq. ft.

Aluminum - 0.020" thick
Stainless Steel - 0.017"
1/4" Air space - Transite spacers

The panel was held in position in the furnace by lengths of angle iron placed under the clamping screws. The steel sheet was exposed to the flame.

Severe distortion of the panel occurred and was sufficient to bring the steel sheet in contact with the outer aluminum sheet at one point. Towards the end of the 30 minute test period, the aluminum sheet reached a red heat at this point and by the end of the test a section of approximately 2½ sq. in. had melted.

The observed temperatures are shown on Figs. 6d-f.

PART II.

Construction of British Air Ministry Furnace   see Fig. 1

The details of the furnace shown in Fig. 1 are those issued by the British Air Ministry, and this design was closely followed in the construction of a similar furnace in the Laboratories - see Fig. 10a and 10b. However, for ease of construction minor alterations were made as follows: A light angle iron frame was provided to carry the walls of the furnace which were made of 1/8" transite. The remainder of the furnace was constructed in accordance with the specifications shown in Fig. 1.

Flame Penetration and Temperature Test with British Air Ministry Furnace

Test Arrangement

Although not included in the method of test outlined for determining the resistance to flame penetration (see Appendix I of this report) it was considered that valuable information regarding the conditions of test as compared with the F.H.T.L. furnace would be obtained by placing at least one group of thermocouples at a point on the test panel, similar to those used in the preceding tests, i.e.:

T.C. #1 - 1" from inner surface of panel
T.C. #2 - In contact with inner surface
T.C. #3 - In contact with outer surface
T.C. #4 - 1" from outer surface

Such a group was located directly above one of the burners, and the 1" spacing brought T.C. #1 into the tip of the flame. Again some difficulty was experienced in holding these thermocouples in their correct position relative to the panel owing to the distortion of the panel.

Test Procedure   see also Appendix I section (ii) and 3.

Readings were taken at 3-minute intervals during the 30-minute test using the portable potentiometer.

Results

The following panels, duplicates of the panels tested in the F.H.T.L. furnace but with a smaller area, 18" x 18" were tested in the British Air Ministry furnace. Panels 1-4 inclusive, were not made at the same time as the corresponding larger ones, and weight per unit area of the materials used differ somewhat from the values for the latter. Panels 5 and 6 were prepared at the same time as the corresponding larger ones from the same batch of aluminum plates, so it appears that the difference between the weight per unit area of the small and large panels is caused by variation in the spraying process.

No. 1 Single sheet Terne Plate - 0.030" thick
British & American Specifications - 0.028"
see Fig. 12j
Weight - 1.255 lb./sq. ft.
Temperature curves - Fig. 8e.

No. 2 Aluminum sandwich with millboard (soft) "asbestos Paper" Spacer see Fig. 12j

Weight - 1.29 lb./sq. ft.
Aluminum - 0.020" thick
British specification - 0.022"
American " - not less than 0.02"
Millboard - 1/8" thick
British specification - 3/32"
American " at least 1/8"

Temperature curves - Fig. 8f.

No. 3 Single sheet "Staybrite" stainless steel - 0.017" thick
American specification not less than 0.015"
see Fig. 12j.
Weight - 0.717 lb./sq. ft.
Temperature curves Figs. 9a & 9b.

No. 4 Aluminum sandwich with millboard (medium) spacer
see Fig. 12j.
Weight - 1.22 lb./sq. ft.
Aluminum - 0.020" thick
British specification - 0.022"
American " - not less than 0.02"
Millboard - 1/8" thick
British specification 3/32"
American " at least 1/8"
Temperature curves - Figs. 9c and 9d.

No. 5 Aluminum sandwich with No. 1 sprayed asbestos spacer
see Fig. 12i.

Weight - 0.794 lb./sq. ft.
Aluminum - 0.020" thick
Spacer - 1/8" to 3/16" thick
Temperature curves - Fig. 9e.

No. 6 Aluminum sandwich with No. 2 sprayed asbestos spacer
see Figs. 12g. and 12h.

Weight - 0.705 lb./sq. ft.
Aluminum - 0.020" thick
Spacer - 1/8" to 3/16" thick
Temperature curves Fig. 9f.

A 1½" flame as specified by the British Air Ministry was used in all tests except panel No. 5. Otherwise the test procedure was followed as outlined in the specifications and described previously.

In an attempt to regulate the flame height during the testing of panel No. 5, the flame was inadvertently allowed to become much higher than prescribed, approximately 3½". This resulted in the melting of almost all of the inner surface of the panel, whereas the other aluminum panels did not melt except locally where the aluminum buckled and came in contact with the flame.

In no case did the flame penetrate the upper surface of any of the panels.

PART III.

Mechanical Penetration and Impact Tests According to British Air Ministry Specifications

Construction of Apparatus see also Appendix I.

An impact test frame and penetration spike together with suitable guides for the latter were made up in the Laboratories according to the details shown in Figs. 2 and 3.

Test Arrangement

Impact test - see Fig 10c.
Mechanical Penetration Test - see Fig. 10e.

Test Procedure See also Appendix I.

Impact Test

As specified in Appendix I.

Mechanical Penetration Test

As specified in Appendix I.

Results

Tests were conducted on duplicates of panel Nos. 1, 2, 3 and 4, as described under Part II Results.

It was considered unnecessary to apply these tests also to panels 5, 6 and 7 since the results could be predicted from the preceding.

After testing the "Staybrite" stainless steel panel, one 1/4" diam. bolt hole where the panel was bolted to the frame was found to have been enlarged to 5/16" in the direction of the applied force. Otherwise this and all the other panels successfully passed the Impact and Mechanical Penetration Tests. See Fig. 12k and 12m.

Conclusions Part I and II

Resistance to Flame Penetration

All panels except the Aluminum-Stainless Steel Sandwich with 1/4" air-space were deemed to pass the flame penetration tests conducted in the F.H.T.L. and British Air Ministry furnaces. In the case of the exception mentioned the outer or aluminum sheet had melted when the steel sheet had come in contact with it.

Distortion or Buckling

The distortion of the aluminum panels was more pronounced than that of the single sheet stainless steel or terne plate; in the former case, a maximum of approximately 1" to 1½" from the original surface plane as compared with 1/2" to 3/4" in latter case. In the case of the Aluminum-Stainless Steel Sandwich with 1/4" air space, the distortion definitely impaired the rigidity of the panel and caused melting of the aluminum surface.

Relative Effectiveness

The performance of the different types of panels in one group (aluminum-asbestos-sandwich group or single-sheet group) were approximately the same.

Although each panel was not subjected to the same temperatures, their relative effectiveness or resistance to the conduction of heat may be estimated from the relative position of the temperature curves for each group of thermocouples.

Temperatures at outer surface of the aluminum-asbestos sandwich panels increased gradually to a maximum drop through panel of 700°F to 800°F. 1" from the surface of the panel, the temperatures did not rise much above 200°F and were usually around 150°F.

T.C. #1c for the aluminum sprayed asbestos panels indicated temperatures greater than those obtained with the aluminum millboard panels. This increase was caused by forcing the thermocouple against the outer surface to form a positive metal to metal contact.

Temperatures at the outer surface and 1" from the outer surface of the single sheet panels increased rapidly during the first 10 minutes to a maximum of 600°F to 800°F and 200°F to 300°F respectively. The temperature drop through these panels at the end of test was considerably less than with the aluminum panels, being approximately 300°F to 500°F.

The manner in which the aluminum in the vicinity of the rivets was protected from melting suggested that the conduction through rivets was fairly high. Apparatus was not available to test this effect directly. However, calculations based on the values of conductivity for aluminum and asbestos taken from handbooks indicated that a cylinder of aluminum 1/8" diameter and 0.165" long (corresponding to the shank of the aluminum rivets used in constructing the panels) might have a conductivity approximately 11% of that of a square foot of sandwich composed of 1/8" asbestos between two sheets of aluminum 0.020" thick without any rivets.

Thus in the case of such a panel having, say, six rivets per square foot, the no-rivet conductivity would be increased by 66%. In making the above calculations, no allowance was made for the resistance of the air film on each side of the panel. Were this considered the contribution of a rivet to the overall conductivity would be less than indicated above.

Comparison of Results obtained from British Air Ministry and F.H.T.L. Furnaces

The temperatures 1" from the inner surface of the panels tested in the British Air Ministry furnace ranged in the neighbourhood of 1700°F. Temperatures of 1700°F and more were obtained in the F.H.T.L. furnace. In spite of this fact, the temperatures at the inner panel surface were in nearly all cases 100°F or more cooler in the former case.

The temperatures at the outer surface were approximately the same in both cases, but at 1" from the outer panel surface, the temperatures obtained with the British Air Ministry furnace were considerably higher, being approximately 500°F to 600°F. These temperatures were produced by covering the furnace with a lid so as to enclose the panel.

Where consistent readings were obtained the results did not show such marked differences between the different panels as was indicated by the results from the F.H.T.L. furnace.

Impact and Mechanical Penetration Tests

The one slightly enlarged bolt hole in the stainless steel panel was not deemed sufficiently serious to cause the panel to fail to pass the impact test.

All the panels with this one exception readily passed both the impact and mechanical penetration tests. These tests specified by the British Air Ministry were considered sufficiently severe and exacting.

General Comparison of Panels

1. The stainless steel aluminum combination was unsatisfactory.

2. The metal single sheet panels are usually of more rugged construction than the combination panels. Those tested did not permit penetration of flame, but apparently were much less resistant to the passage of heat than the aluminum-asbestos sandwiches. The single sheets showed less distortion than the combination panels and their effectiveness was apparently unimpaired by the fire.

3. The aluminum-asbestos sandwich appears to be the best method for obtaining a reasonable thermal insulating value combined with resistance to flame penetration and durability. The amount of protection may be increased by using a thicker asbestos spacer, providing the increase in weight is permissible. One disadvantage to the aluminum-asbestos sandwich is that the firewall might have to be replaced if a severe fire occurred.

The panels with the sprayed-asbestos spacer behaved under the flame test similarly to those using millboard. The weight per unit area of the lighter of the two sprayed panels tested compared favourably with that of the single-sheet stainless steel panel.

The effect of rivets in increasing the thermal conductivity of aluminum-asbestos sandwich panels is considered sufficiently great to justify careful design of firewalls to reduce the number of rivets to the minumum consistent with the distortion permissible and, of course, structural strength.

Performance Test Specifications for Firewalls

On the basis of the tests made, the British Air Ministry Appendix I to Design Leaflet D.1 is considered generally adequate as a performance specification for firewall construction. The tests for resistance to impact and mechanical penetration are considered quite satisfactory.

It is considered that the following criticisms might be made regarding the flame penetration test in the British Air Ministry specifications.

(a) The flame temperature for a flame height of 1½" at inner surface of panel is too low.

(b) The flame should extend over entire surface and not be confined to local points.

(c) The horizontal position of the panel in the furnace is not considered satisfactory since if molten or charred fragments are produced, these may fall on the burners and interfere with their action.

(d) The horizontal position does not approximate the average position of service installation as well as the vertical position.

(e) Panel should be held firmly in position in the furnace.

(f) Panel should not be enclosed in furnace.

(g) Flame penetration alone is considered; some indication of thermal conductivity is desirable.

(h) Furnace temperature should be specified in preference to flame height and design of burners. Even if construction specifications are followed exactly and the flame height (difficult to determine) accurately adjusted, differences in the heating value of various gases used might produce different results. Moreover, if the temperature were specified, any burners available, similar but not identical with those specified might be used.

For this reason the following is suggested as an alternative to paragraph 3 of Appendix I to Design Leaflet D.1.

A test specimen large enough to overlap the opening of the test furnace by at least 1" all round shall be cut from the firewall. In selecting the test panel, care should be taken to include a representative rivetted section and to avoid if possible openings cut for the passage of controls or for any other reason. If the specimen consists of more than one sheet, the component test sheets of the test specimen shall be rivetted together at each corner and along the sides at intervals not greater than 6" with rivets similar to those used in construction. The specimen shall be clamped along the edges in a vertical plane against a suitable opening in a gas-fired furnace. The opening should not be less than 18" square but may be larger if desired. The gas burners shall be so arranged that uniform heating of the test panel results.

At least three bare-junction thermocouples shall be located at a distance of one inch from the heated face of the panel and so disposed as a result of preliminary tests of the furnace to give values representative of the temperatures throughout the furnace. Bare-junction thermocouples shall be placed outside the furnace one inch from the outer face of the panel directly opposite each of the inner ones. The temperature of the furnace shall be raised continuously at such a rate that the average of the temperatures indicated by the thermocouples inside is 1325°F. 10 minutes after start; 1500°F. 20 minutes after start, and 1550°F. 30 minutes after start. (End of test).

While the test is proceeding, the panel shall be vibrated by the apparatus prescribed (vibrator as used in F.H.T.L. tests to be prescribed, eccentricity of disc shall be 3/16", operated at 1750 R.P.M.) The vibrator shall be attached to the panel at a point on the diagonal of the furnace opening at a distance of 1/6 of the length of the diagonal from one end of the diagonal.

The test shall continue for thirty minutes during which time no penetration by flame shall occur; the highest temperature recorded by any of the outer thermocouples shall not exceed room temperature by more than 250°F.

Notes

1. In drafting the above, besides arranging for testing the panel in a vertical position, every effort has been made to permit the tests to be made with any furnace that may be available. It is felt that the difficulties encountered in controlling furnace temperatures in most tests of this kind make it inadvisable to specify exact construction details for the furnace.

2. Thermocouple locations a short distance from the panel have been specified in preference to the inner and outer surfaces of the panel because of the variation of temperature indication in the latter positions depending upon the intimacy of contact between the thermocouple and the surface.

3. The test temperatures suggested for the interior of the furnace and the time schedule therefor are purely arbitrary. The maximum temperature of 250°F. above room temperature for the outer thermocouples specified as a condition the test panel must pass was chosen so that the metal single sheet panels at present accepted would pass the test. It would be preferable to specify this temperature on the basis of safety considerations, having regard to the nature of the parts to be protected, possibly requiring different degrees of protection according to the location in which the firewall is to be used.

4. It is considered likely that eventually it will be found necessary to specify methods of installation of firewalls and minimum distances of vulnerable parts therefrom. Also performance tests of grommets and bushings for the passage of controls through firewalls may be found necessary.

APPENDIX I.

British Air Ministry Civil Aircraft Regulations

Appendix I to Design Leaflet D.1

Fireproof bulkhead requirements

1. Summary of requirements.-(i) Construction.-The bulkhead shall consist of a single sheet or of more than one sheet of similar or dissimilar materials securely riveted together.

(ii) Resistance to flame penetration.-The bulkhead shall resist penetration by flame for a period of not less than thirty minutes when tested as described in para. 3.

(iii) Resistance to impact.-The bulkhead shall withstand impact by a steel ball when tested as described in para. 4 without showing signs of rupture or tearing at the supports.

(iv) Resistance to mechanical penetration.-The bulkhead shall resist penetration by a hardened steel spike when tested as described in para. 5.

2. Approved types of bulkheads.-The following are approved, and no further tests need be made on these bulkheads:-

(a) A sandwich of best quality asbestos millboard 3/32". thick, held between 0.022" aluminum or duralumin sheets, the whole being securely riveted together.

(b) 0.028" or thicker ferrous metal sheet.

3. Method of determining the resistance to flame penetration.-(i) A test specimen 18 in. square shall be cut from the bulkhead. If the bulkhead consists of more than one sheet, the component sheets of the test specimen shall be bolted together at each corner and at the centre of each side. The specimen shall be supported horizontally $2\frac{1}{2}$ in. above the orifices (each orifice being 5/16" diameter) of 16 uniformly distributed lighted Bunsen burners with flames $1\frac{1}{2}$ in. long. The whole shall be enclosed within a suitable furnace. The furnace shall be heated up for 15 minutes with the lid on before the test specimen is inserted. During the test the lid shall be on. During the test the specimen shall be tapped at 15-second intervals by dropping on to it from a height of 4 in. a steel ball weighing 4 oz. through a 2 in. diameter hole in the lid. The purpose of this is to detach molten and charred fragments. The specimen shall be deemed to pass this test if, at the end of 30 minutes, no flame has penetrated the upper surface.

(ii) Furnace.-Details of a suitable furnace are given in fig. 1.

4. Method of determining the resistance to ball impact.- (i) A test specimen 18 in. square shall be cut from the bulkhead. This shall be bolted to a suitable frame by 1/4-in. bolts at each corner and at the centre of each side, the centre of the bolts being 1 in. from the edges of the specimen. A steel ball 3 in. in diameter, weighing 4 lb. shall be dropped on to the centre of the specimen from a height of 15 ft. The specimen shall be deemed to pass this test if it shows no signs of rupture or tearing at the supports.

(ii) Frame.-Details of a suitable frame are given in fig. 2. It consists of a rectangular box with a 15-in. square opening cut in the top, the material being 1/4-in. thick steel with welded corners.

5. Method of determining the resistance to penetration by a steel spike.-(i) The test specimen, frame, and method of mounting are as described in para. 4. The spike shown in fig. 3 shall be dropped through suitable guides on to the centre of the specimen from a height of 6 in., measured from the surface of the specimen to the point of the spike. The specimen shall be deemed to pass this test if it is not pierced by the spike, as judged by holding the specimen up against a light.

(ii) Spike.-The point of the spike shall be made of hardened steel. The whole spike shall be adjusted to weigh 7 lb.

Note.-The requirements of this Appendix are applicable to all new Type bulkheads approved after 1st February, 1938. (537172/36).

Design leaflet D.1 to which the above is an Appendix includes the following material regarding firewalls.

(i) Engine in nose of fuselage - A fireproof bulkhead complying with Appendix I of this leaflet is to be fitted aft of the engine. This bulkhead must completely fill the cross section of the fuselage. Additional fireproof screens may also be required (see Design Leaflet D.2, sub. para. 7(iv).

(ii) Engine in, above, or below the wings - If fuel tanks are placed in the nacelle aft of the engine, a fireproof bulkhead complying with Appendix I of this leaflet must be fitted between the engine and the tank. Additional fireproof screens may also be required (see Design Leaflet D.2, sub. para. 7 (iv).

APPENDIX II.

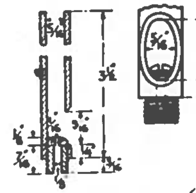
U.S. Dept. of Commerce,
Bureau of Air Commerce
Civil Air Regulations
Part 04.664, 04.6640
Page 53 (Page 79)

Firewall:
04.664 A firewall shall be provided unless the engine is mounted in an isolated nacelle with no fuel tanks. Such fire bulkhead shall be constructed in either of the following approved manners.

(a) A single sheet of terne-plate not less than 0.028" thick
(b) A single sheet of stainless steel not less than 0.015" thick
(c) Two sheets of aluminum or aluminum alloy not less than 0.02" thick fastened together and having between them an asbestos paper or asbestos fabric sheet at least 1/8" thick.

04.6640 The firewall shall completely isolate the engine compartment and shall have all necessary openings fitted with close-fitting grommets or bushings. Adjacent inflammable structural members shall be protected by asbestos or an equivalent insulating material and provision shall be made for preventing fuel and oil from permeating it.

DESIGN LEAFLET D.I. A.P. 1208



Details of burner tube

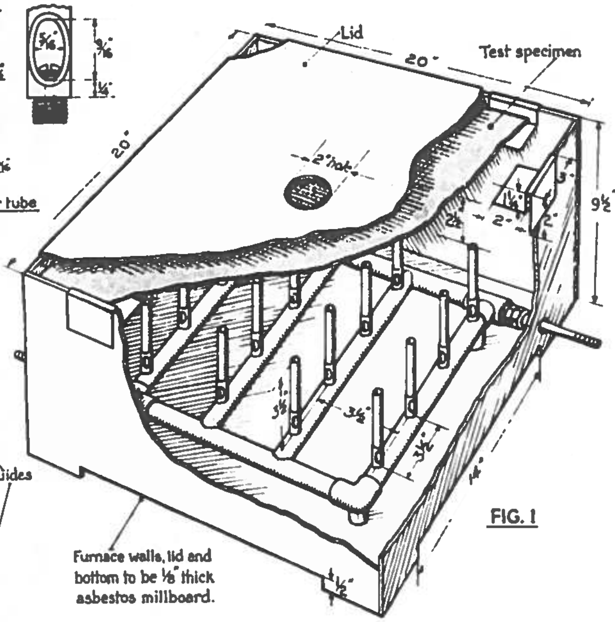


FIG. 1

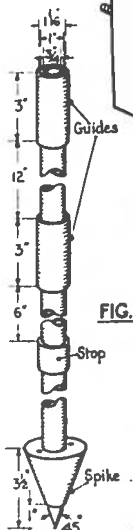


FIG. 3

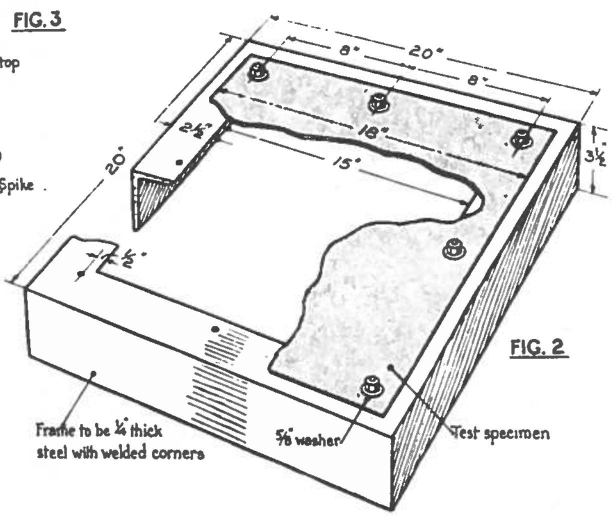
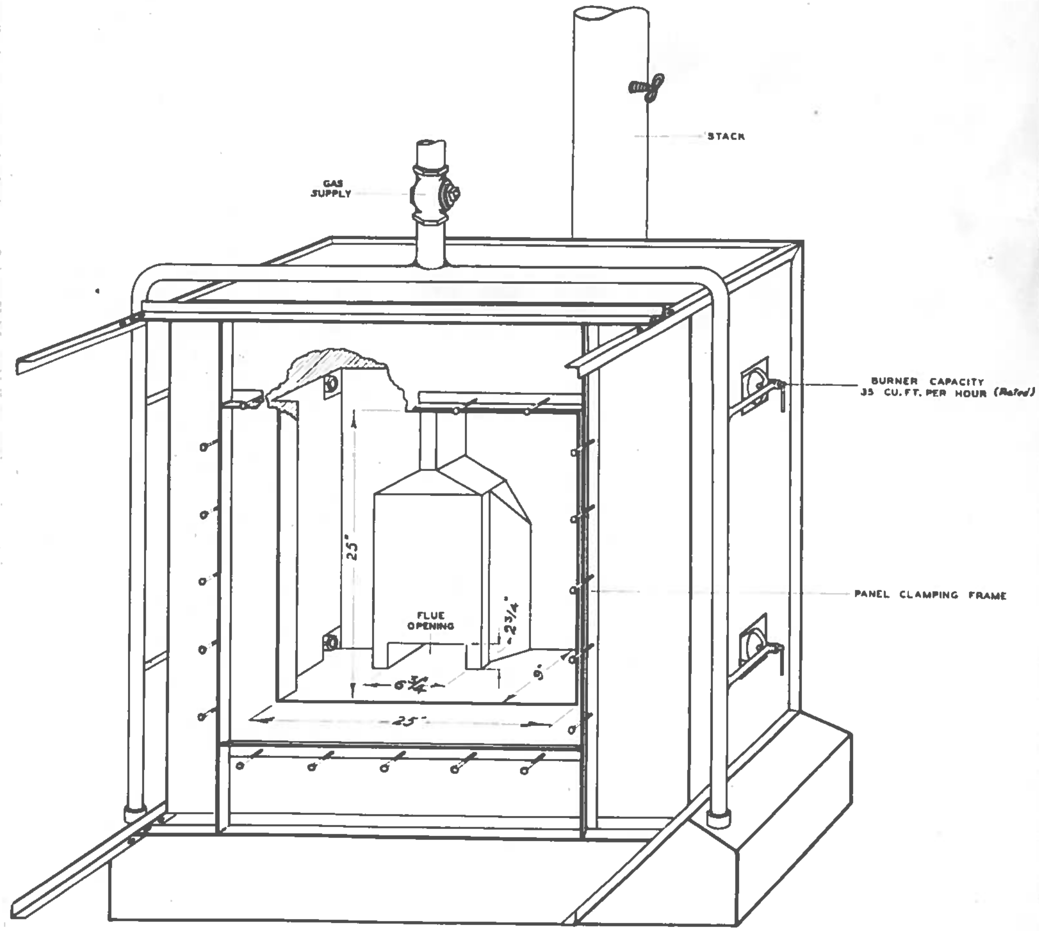


FIG. 2

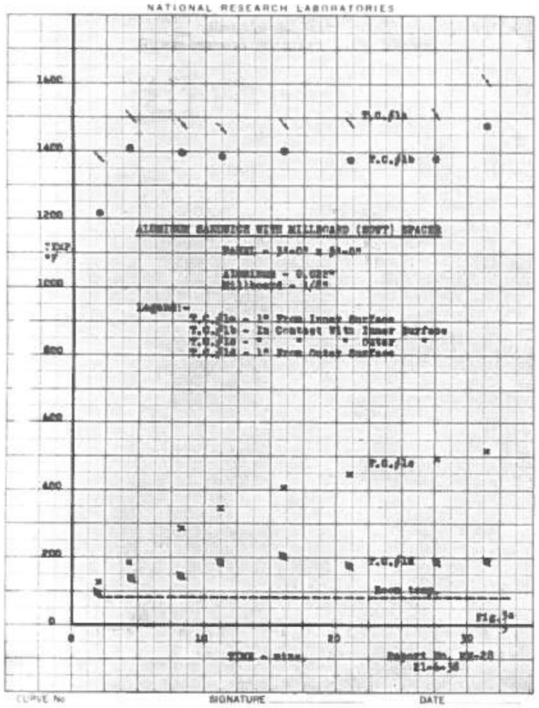
BRITISH AIR MINISTRY TEST FURNACE
IMPACT TEST FRAME & PENETRATION TEST SPIKE

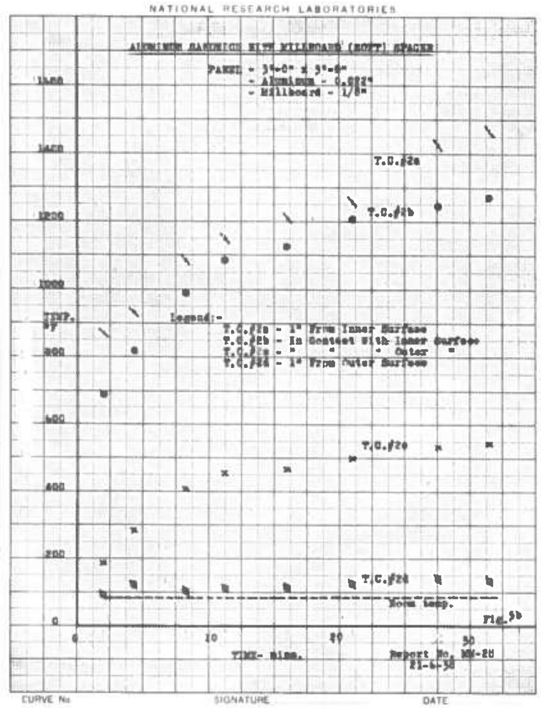


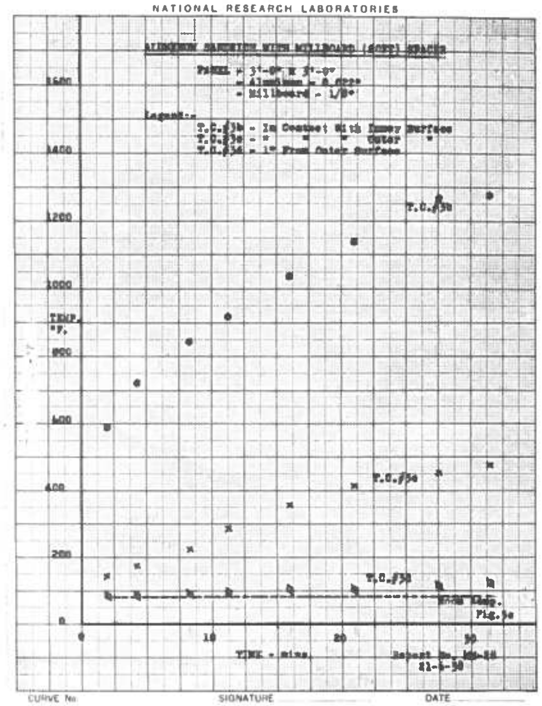
FHTL TEST FURNACE FOR AEROPLANE FIRE WALLS

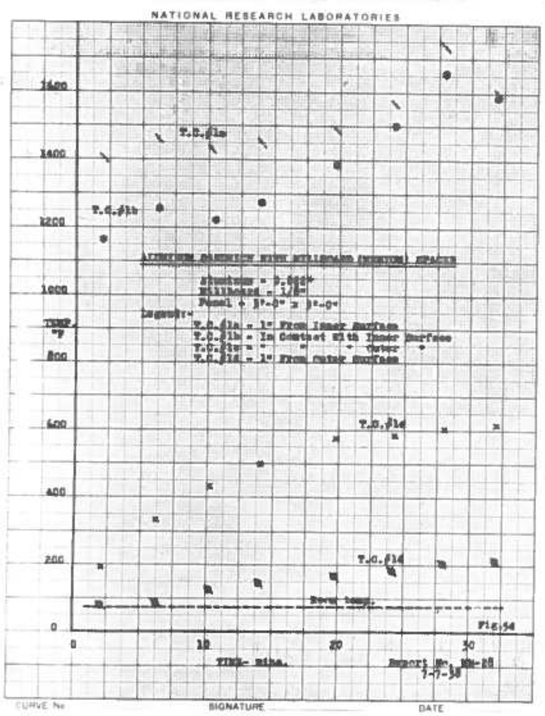
FIG.4

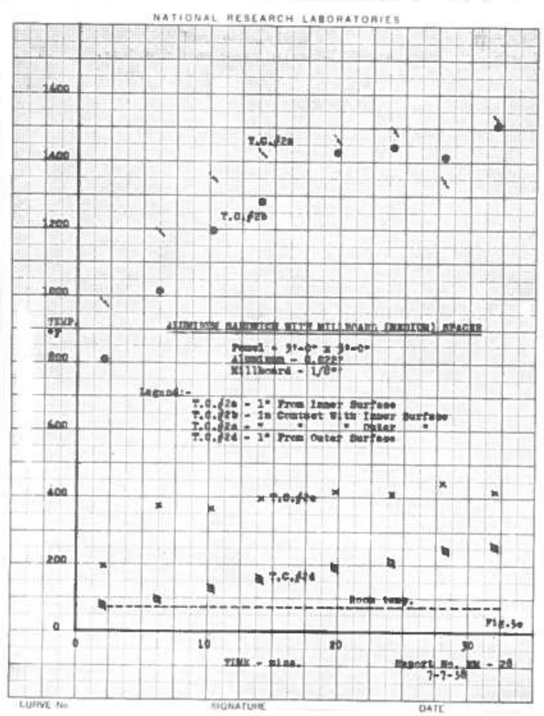
REPORT MM-28
25/4/39

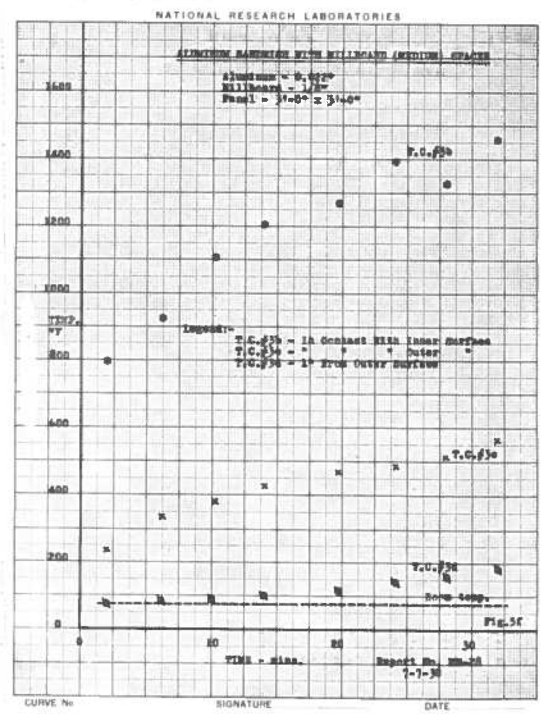

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER
PANEL - 3'-0" x 3'-0"
Aluminum - 0.022"
Millboard - 1/8"
Legend:-
T.C.#1a - 1" From Inner Surface
T.C.#1b - In Contact With Inner Surface
T.C.#1c - " " " Outer "
T.C.#1d - 1" From Outer Surface
T.C.#1a
T.C.#1b
T.C.#1c
T.C.#1d
Room temp.
TEMP. °F
TIME - mins.
Fig.5a
Report No. MM-28
21-6-58
CURVE No
SIGNATURE
DATE

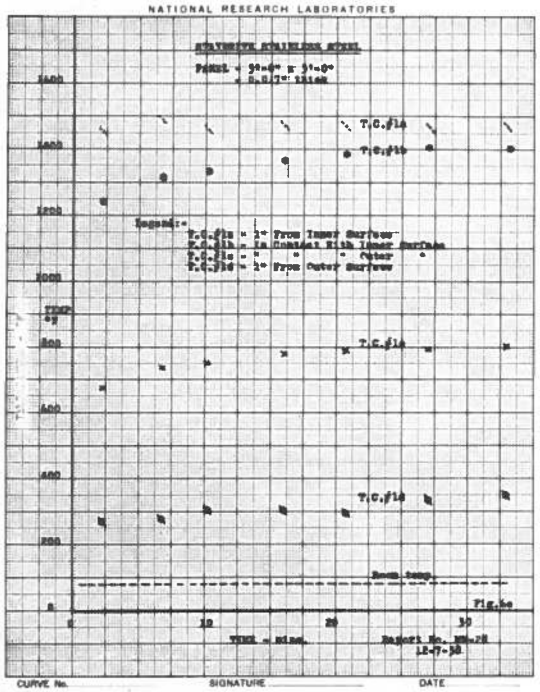

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER
PANEL - 3'-0" x 3'-0"
- Aluminum - 0.022"
- Millboard - 1/8"
Legend:-
T.C.#2a - 1" From Inner Surface
T.C.#2b - In Contact With Inner Surface
T.C.#2c - " " " Outer "
T.C.#2d - 1" From Outer Surface
T.C.#2a
T.C.#2b
T.C.#2c
T.C.#2d
Room temp.
TEMP. °F
TIME- mins.
Fig.5b
Report No. MM-28
21-6-58
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER
PANEL - 3'-0" x 3'-0"
- Aluminum - 0.022"
- Millboard - 1/8"
Legend:-
T.C.#3b - In Contact With Inner Surface
T.C.#3c - " " " Outer "
T.C.#3d - 1" From Outer Surface
T.C.#3b
T.C.#3c
T.C.#3d
Room temp.
TEMP. °F.
TIME - mins.
Fig.5c
Report No. MM-28
21-6-58
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER
Aluminum - 0.022"
Millboard - 1/8"
Panel - 3'-0" x 3'-0"
Legend:-
T.C.#1a - 1" From Inner Surface
T.C.#1b - In Contact With Inner Surface
T.C.#1c - " " " Outer "
T.C.#1d - 1" From Outer Surface
T.C.#1a
T.C.#1b
T.C.#1c
T.C.#1d
Room temp.
TEMP. °F
TIME- mins.
Fig.5d
Report No. MM-28
7-7-58
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER
Panel - 3'-0" x 3'-0"
Aluminum - 0.022"
Millboard - 1/8"
Legend:-
T.C.#2a - 1" From Inner Surface
T.C.#2b - In Contact With Inner Surface
T.C.#2c - " " " Outer "
T.C.#2d - 1" From Outer Surface
T.C.#2a
T.C.#2b
T.C.#2c
T.C.#2d
Room temp.
TEMP. °F
TIME - mins.
Fig.5e
Report No. MM - 28
7-7-58
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER
Aluminum - 0.022"
Millboard - 1/8"
Panel - 3'-0" x 3'-0"
Legend:-
T.C.#3b - In Contact With Inner Surface
T.C.#3c - " " " Outer "
T.C.#3d - 1" From Outer Surface
T.C.#3b
T.C.#3c
T.C.#3d
Room temp.
TEMP. °F
TIME - mins.
Fig.5f
Report No. MM-28
7-7-58
CURVE No
SIGNATURE
DATE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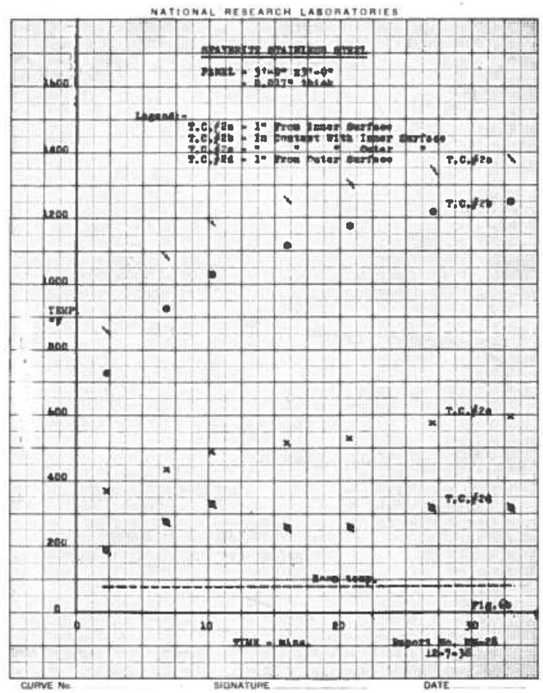
TEMP. °F
TIME - Mins.
Room temp.
CURVE No.
SIGNATURE
DATE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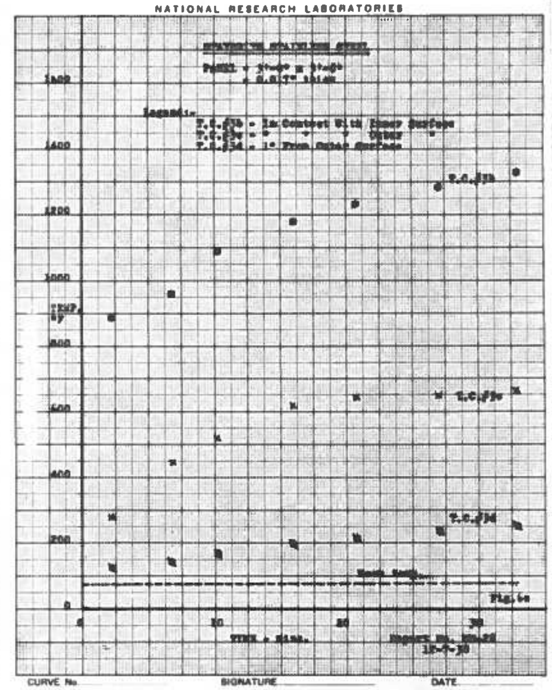
TEMP. °F
TIME - Mins.
Room temp.
CURVE No.
SIGNATURE
DATE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TIME - Mins.
CURVE No.
SIGNATURE
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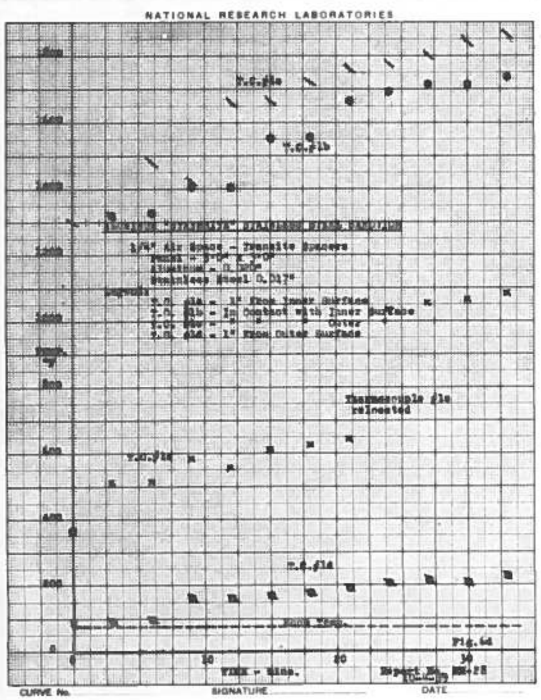
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TIME - Mins.
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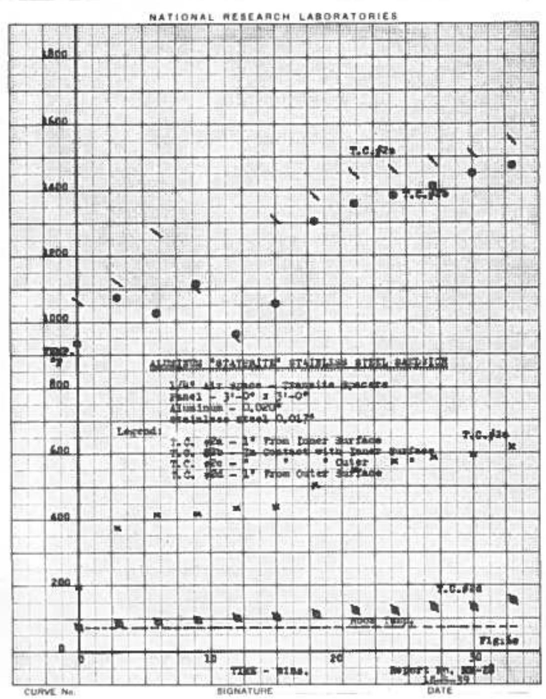
SIGNATURE
DATE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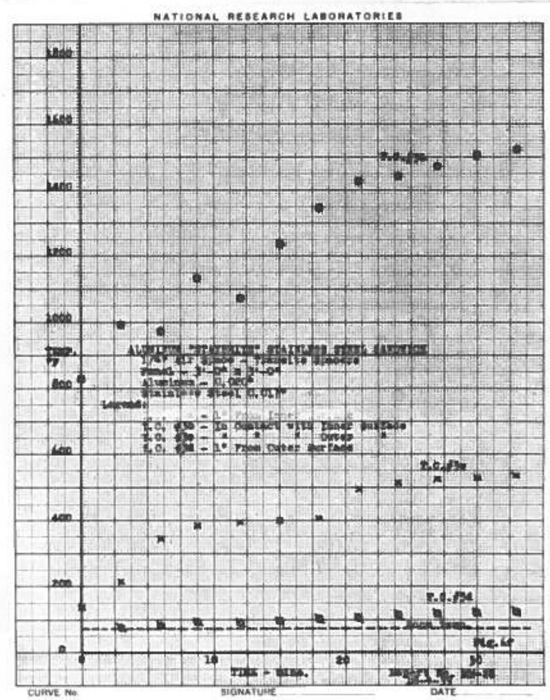
TIME - Mins.
CURVE No.
SIGNATURE
DATE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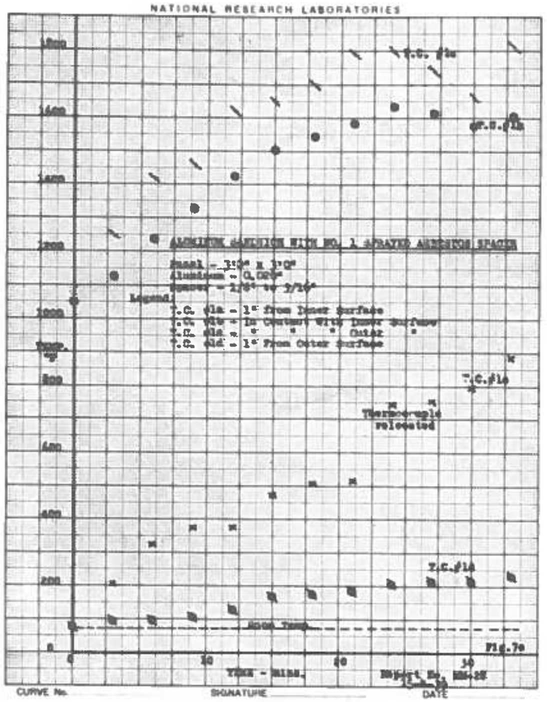
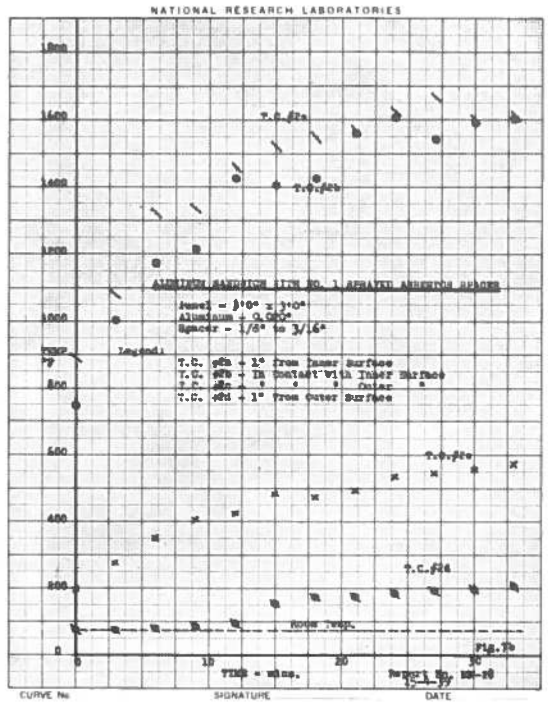
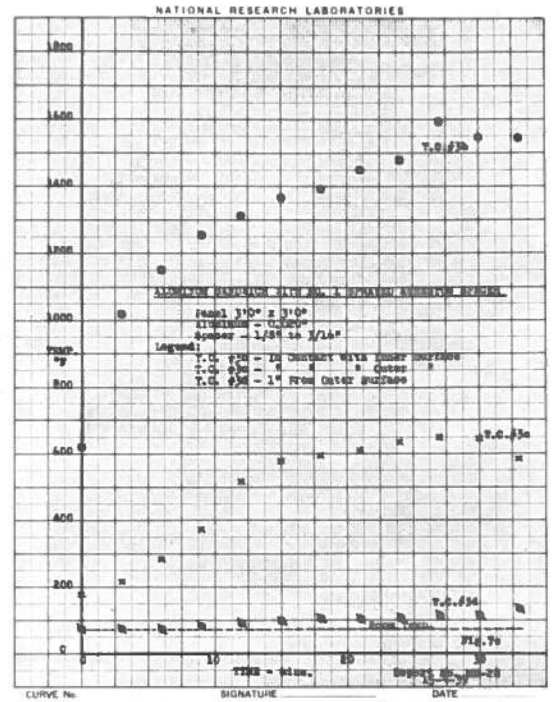
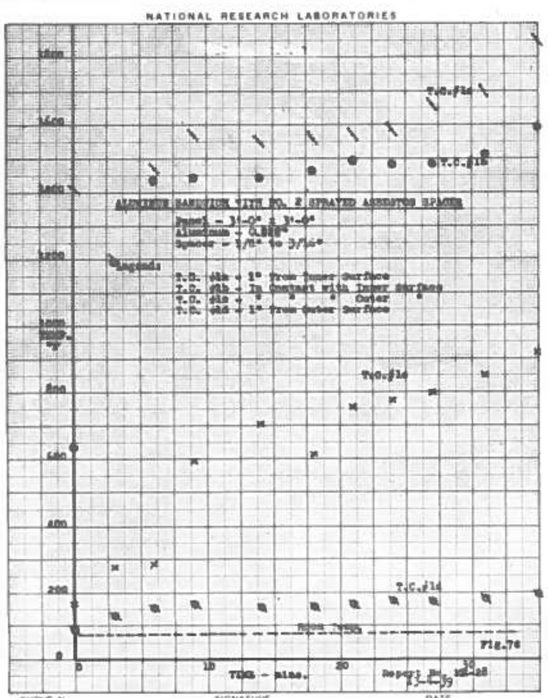
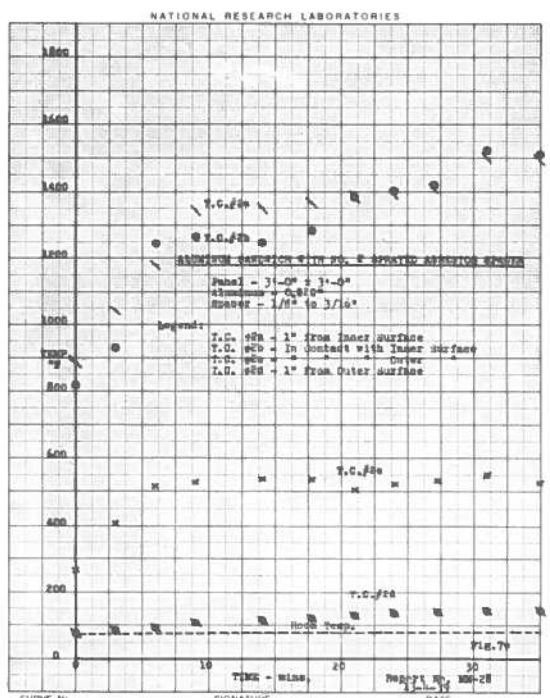
TEMP. °F
TIME - Mins.
CURVE No.
SIGNATURE
DATE

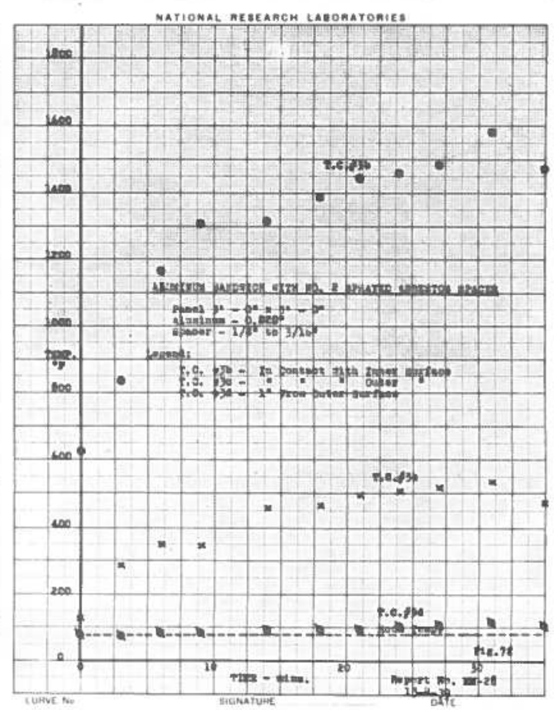

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 1 SPRAYED ASBESTOS SPACER
Legend:
T.C. #1a - 1" from Inner Surface
T.C. #1b - In Contact with Inner Surface
T.C. #1c - " " " Outer "
T.C. #1d - 1" from Outer Surface
Thermocouple relocated
Room Temp.
TEMP. °F
TIME - mins.
Fig. 7a
Report No. MH-28
CURVE No.
SIGNATURE
DATE

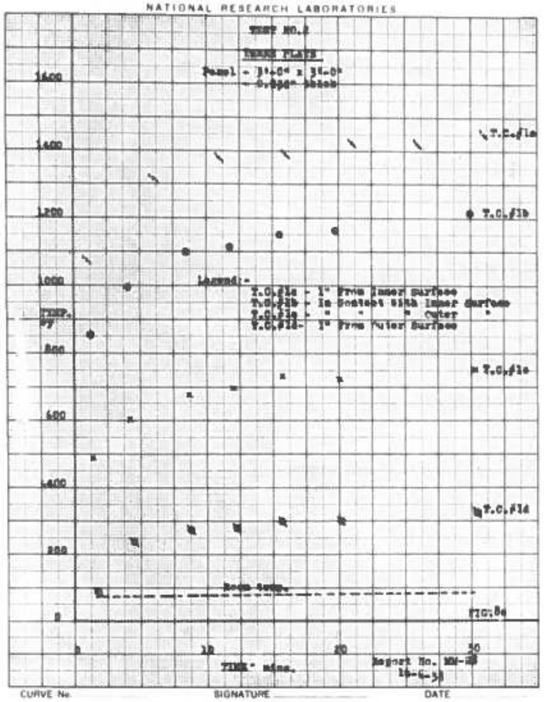

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 1 SPRAYED ASBESTOS SPACER
Legend:
T.C. #2a - 1" from Inner Surface
T.C. #2b - In Contact with Inner Surface
T.C. #2c - " " " Outer "
T.C. #2d - 1" from Outer Surface
Room Temp.
TEMP. °F
TIME - mins.
Fig. 7b
Report No. MH-28
CURVE No.
SIGNATURE
DATE

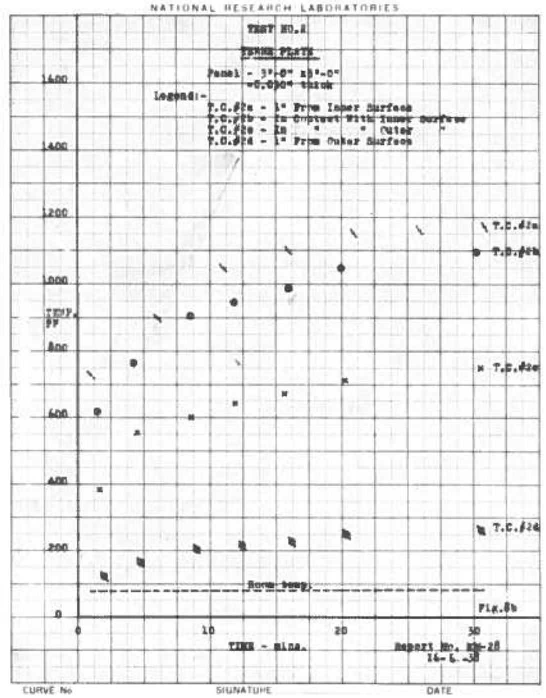

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 1 SPRAYED ASBESTOS SPACER
Legend:
T.C. #3b - In Contact with Inner Surface
T.C. #3c - " " " Outer "
T.C. #3d - 1" from Outer Surface
Room Temp.
TEMP. °F
TIME - mins.
Fig. 7c
Report No. MH-28
CURVE No.
SIGNATURE
DATE

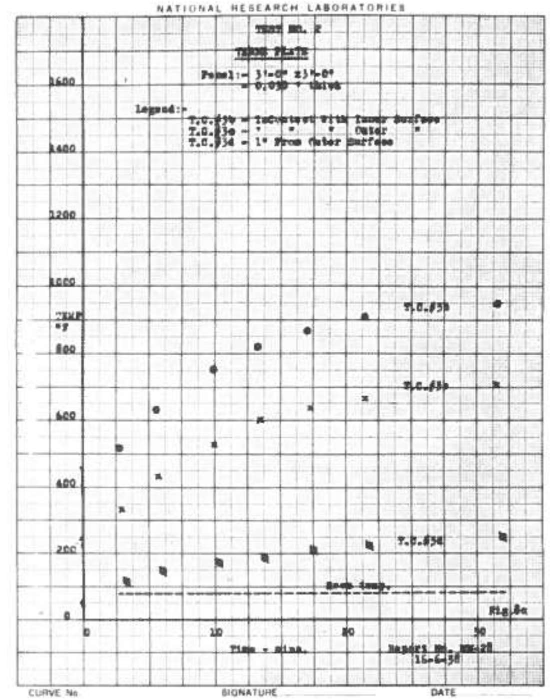

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 2 SPRAYED ASBESTOS SPACER
Legend:
T.C. #4a - 1" from Inner Surface
T.C. #4b - In Contact with Inner Surface
T.C. #4c - " " " Outer "
T.C. #4d - 1" from Outer Surface
Room Temp.
TEMP. °F
TIME - mins.
Fig. 7d
Report No. MH-28
CURVE No.
SIGNATURE
DATE

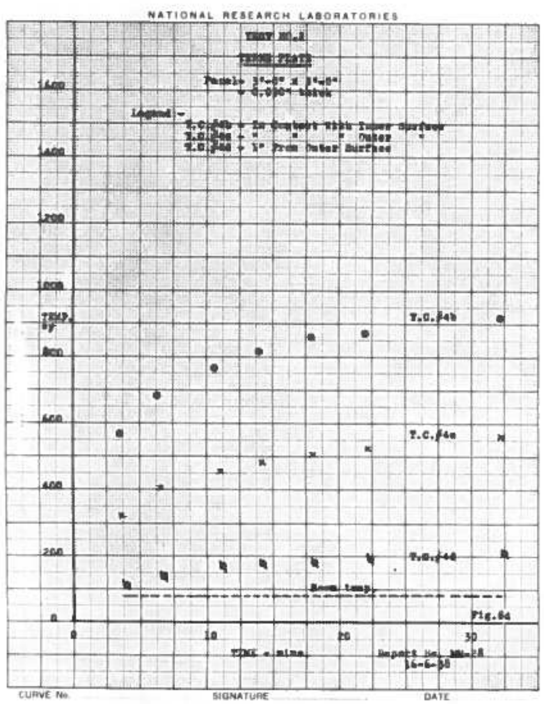

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 2 SPRAYED ASBESTOS SPACER
Legend:
T.C. #2a - 1" from Inner Surface
T.C. #2b - In Contact with Inner Surface
T.C. #2c - " " " Outer "
T.C. #2d - 1" from Outer Surface
Room Temp.
TEMP. °F
TIME - mins.
Report No. MH-28
CURVE No.
SIGNATURE
DATE

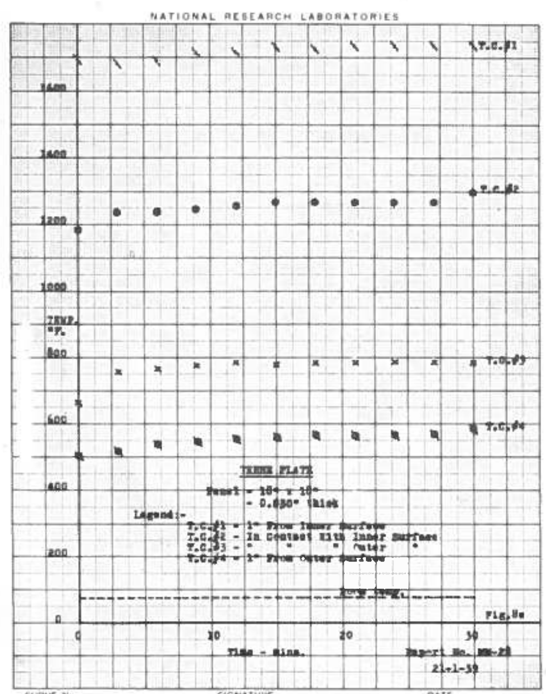

NATIONAL RESEARCH LABORATORIES
ALUMINUM SANDWICH WITH NO. 2 SPRAYED ASBESTOS SPACER
Legend:
T.C. #3b - In Contact with Inner Surface
T.C. #3c - " " " Outer "
T.C. #3d - 1" from Outer Surface
Room Temp.
TEMP. °F
TIME - mins.
Report No. MH-28
CURVE No.
SIGNATURE
DATE

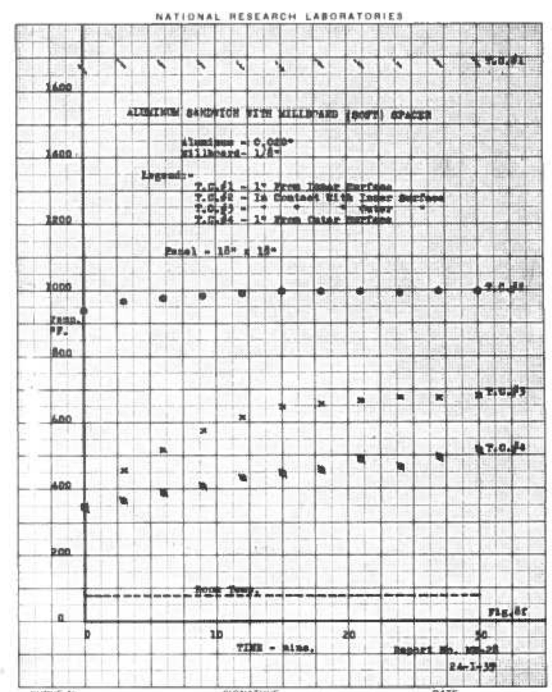

NATIONAL RESEARCH LABORATORIES
TEST NO.2
THREE PLATE
Panel - 3'-0" x 3'-0"
- 0.030" thick
Legend:-
T.C.#1a - 1" From Inner Surface
T.C.#1b - In Contact with Inner Surface
T.C.#1c - " " " Outer "
T.C.#1d - 1" From Outer Surface
T.C.#1a
T.C.#1b
T.C.#1c
T.C.#1d
TEMP. °F
Room temp.
FIG.8a
TIME - mins.
Report No. MM-28
16-6-58
CURVE No.
SIGNATURE
DATE

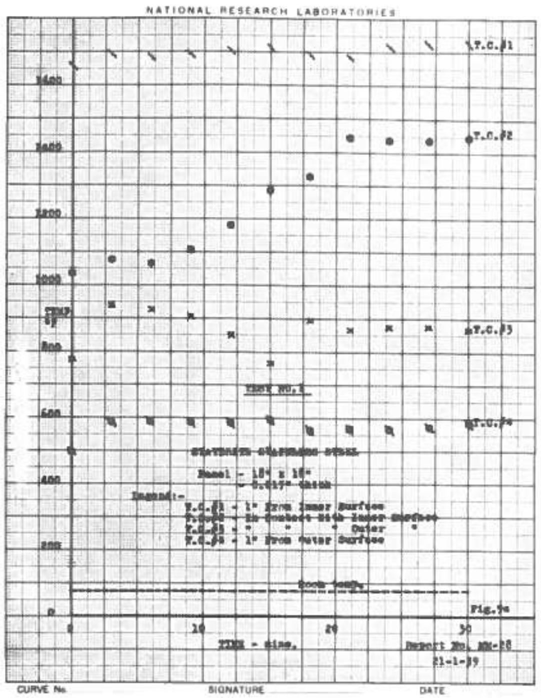

NATIONAL RESEARCH LABORATORIES
TEST NO.2
THREE PLATE
Panel - 3'-0" x 3'-0"
- 0.030" thick
Legend:-
T.C.#2a - 1" From Inner Surface
T.C.#2b - In Contact With Inner Surface
T.C.#2c - In " " Outer "
T.C.#2d - 1" From Outer Surface
T.C.#2a
T.C.#2b
T.C.#2c
T.C.#2d
TEMP. °F
Room temp.
Fig.8b
TIME - mins.
Report No. MM-28
16-6-58
CURVE No.
SIGNATURE
DATE

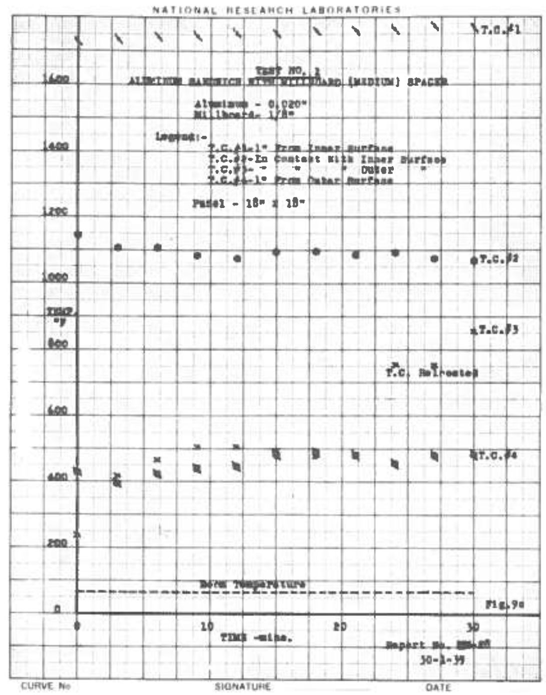

NATIONAL RESEARCH LABORATORIES
TEST NO. 2
THREE PLATE
Panel:- 3'-0" x 3'-0"
= 0.030" thick
Legend:-
T.C.#3b - In Contact With Inner Surface
T.C.#3c - " " " Outer "
T.C.#3d - 1" From Outer Surface
T.C.#3b
T.C.#3c
T.C.#3d
TEMP °F
Room temp.
Fig.8c
Time - mins.
Report No. MM-28
16-6-58
CURVE No.
SIGNATURE
DATE

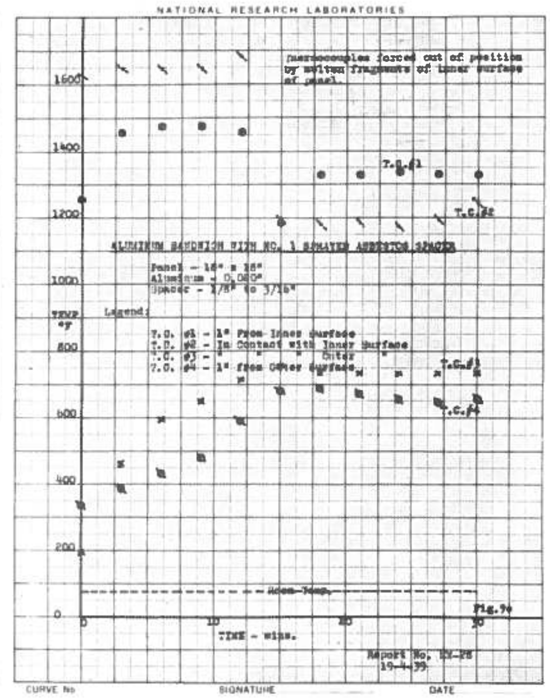

NATIONAL RESEARCH LABORATORIES
TEST NO.2
THREE PLATE
Panel- 3'-0" x 3'-0"
- 0.030" thick
Legend -
T.C.#4b - In Contact With Inner Surface
T.C.#4c - " " " Outer "
T.C.#4d - 1" From Outer Surface
T.C.#4b
T.C.#4c
T.C.#4d
TEMP. °F
Room temp.
Fig.8d
TIME - mins.
Report No. MM-28
16-6-58
CURVE No.
SIGNATURE
DATE

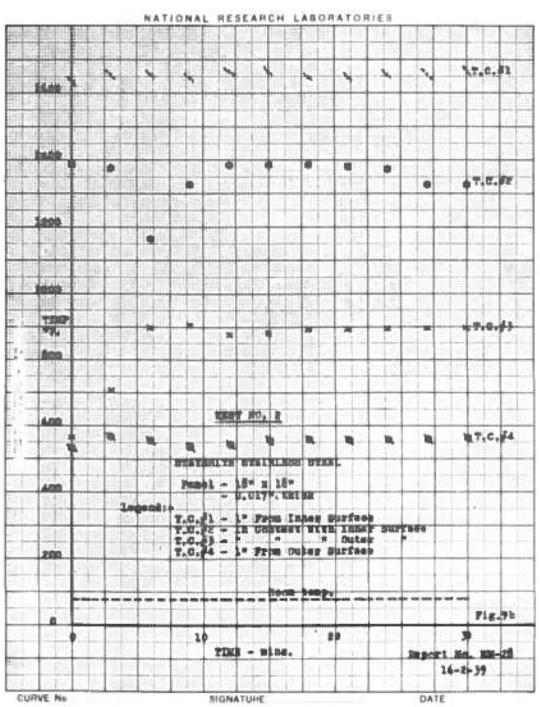

NATIONAL RESEARCH LABORATORIES
T.C.#1
T.C.#2
T.C.#3
T.C.#4
THREE PLATE
Panel - 18" x 18"
- 0.030" thick
Legend:-
T.C.#1 - 1" From Inner Surface
T.C.#2 - In Contact With Inner Surface
T.C.#3 - " " " Outer "
T.C.#4 - 1" From Outer Surface
TEMP. °F.
Room temp.
Fig.8e
TIME - mins.
Report No. MM-28
21-1-59
CURVE No.
SIGNATURE
DATE

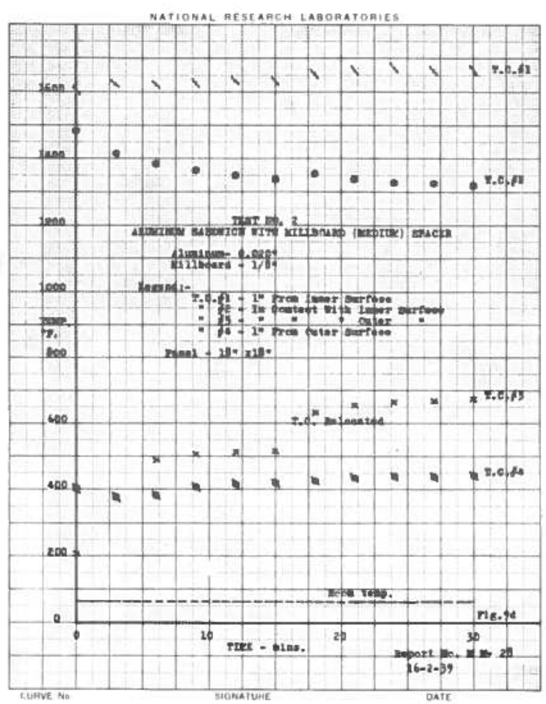

NATIONAL RESEARCH LABORATORIES
T.C.#1
ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER
Aluminum - 0.020"
Millboard - 1/8"
Legend:-
T.C.#1 - 1" From Inner Surface
T.C.#2 - In Contact With Inner Surface
T.C.#3 - " " " Outer "
T.C.#4 - 1" From Outer Surface
Panel - 18" x 18"
T.C.#2
T.C.#3
T.C.#4
Temp. °F.
Room Temp.
Fig.8f
TIME - mins.
Report No. MM-28
24-1-59
CURVE No.
SIGNATURE
DATE

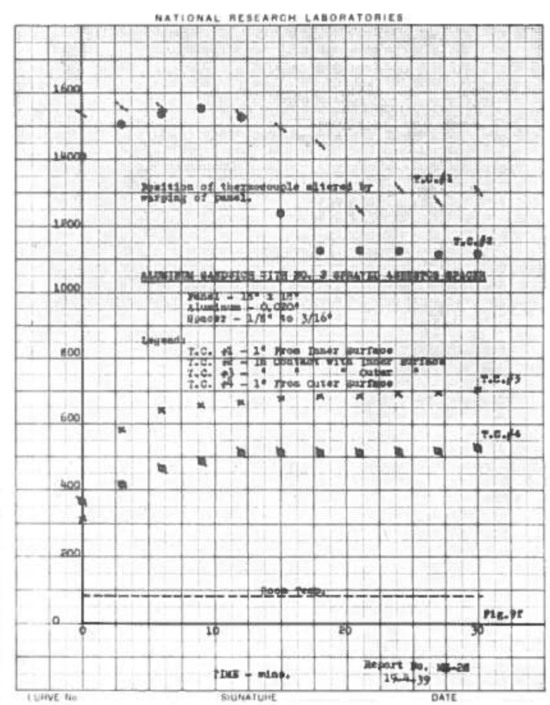

NATIONAL RESEARCH LABORATORIES
T.C.#1
T.C.#2
T.C.#3
T.C.#4
TEMP. °F
TEST NO. 1
Panel - 18" x 18"
Legend:-
T.C.#1 - 1" From Inner Surface
T.C.#2 - In Contact With Inner Surface
T.C.#3 - " " " Outer "
T.C.#4 - 1" From Outer Surface
Room temp.
Fig.9a
TIME - mins.
Report No. MM-28
21-1-39
CURVE No.
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
T.C.#1
TEST NO. 1
ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER
Aluminum - 0.020"
Millboard - 1/8"
Legend:-
T.C.#1-1" From Inner Surface
T.C.#2-In Contact With Inner Surface
T.C.#3- " " " Outer "
T.C.#4-1" From Outer Surface
Panel - 18" x 18"
T.C.#2
T.C.#3
T.C. Relocated
T.C.#4
TEMP. °F
Room Temperature
Fig.9c
TIME -mins.
Report No. MM-28
30-1-39
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
Thermocouples forced out of position by molten fragments of inner surface of panel.
T.C.#1
T.C.#2
ALUMINUM SANDWICH WITH NO. 1 SPRAYED ASBESTOS SPACER
Panel - 18" x 18"
Aluminum - 0.020"
Spacer - 1/8" to 3/16"
TEMP °F
Legend:
T.C. #1 - 1" From Inner Surface
T.C. #2 - In Contact with Inner Surface
T.C. #3 - " " " Outer "
T.C. #4 - 1" from Outer Surface
T.C.#3
T.C.#4
Room Temp.
Fig.9e
TIME - mins.
Report No. MM-28
19-4-39
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
T.C.#1
T.C.#2
T.C.#3
TEMP. °F.
TEST NO. 2
T.C.#4
Panel - 18" x 18"
Legend:-
T.C.#1 - 1" From Inner Surface
T.C.#2 - In Contact With Inner Surface
T.C.#3 - " " " Outer "
T.C.#4 - 1" From Outer Surface
Room temp.
Fig.9b
TIME - mins.
Report No. MM-28
16-2-39
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
T.C.#1
T.C.#2
TEST NO. 2
ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER
Aluminum- 0.020"
Millboard - 1/8"
Legend:-
T.C.#1 - 1" From Inner Surface
" #2 - In Contact With Inner Surface
" #3 - " " " Outer "
" #4 - 1" From Outer Surface
TEMP. °F.
Panel - 18" x18"
T.C.#3
T.C. Relocated
T.C.#4
Room temp.
Fig.9d
TIME - mins.
Report No. MM-28
16-2-39
CURVE No
SIGNATURE
DATE


NATIONAL RESEARCH LABORATORIES
Position of thermocouple altered by warping of panel.
T.C.#1
T.C.#2
Spacer - 1/8" to 3/16"
Legend:
T.C. #1 - 1" From Inner Surface
T.C. #3 - " " " Outer "
T.C. #4 - 1" From Outer Surface
T.C.#3
T.C.#4
Room Temp.
Fig.9f
TIME - mins.
Report No. MM-28
19-4-39
CURVE No
SIGNATURE
DATE

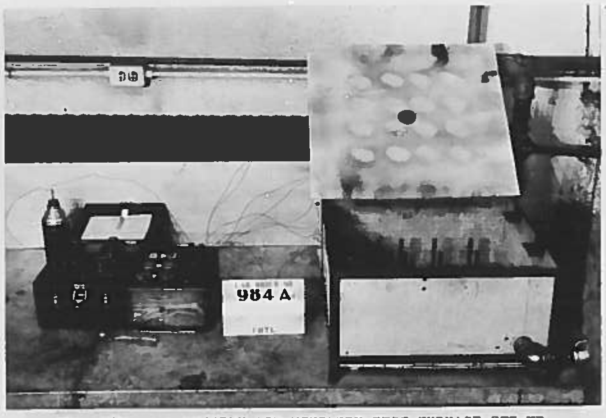


Fig. 10a. - BRITISH AIR MINISTRY TEST FURNACE SET-UP

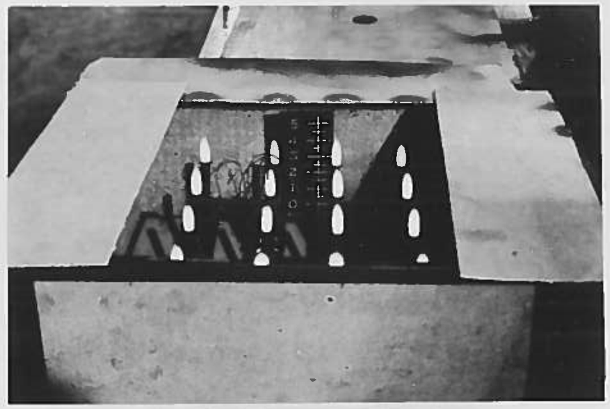


Fig. 10b. - FLAME HEIGHT

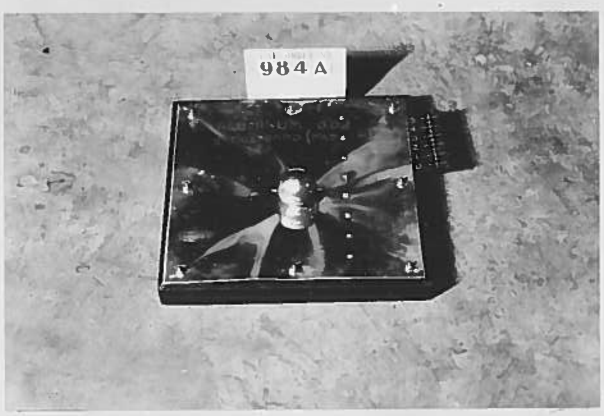


Fig. 10c. - IMPACT TEST SET-UP

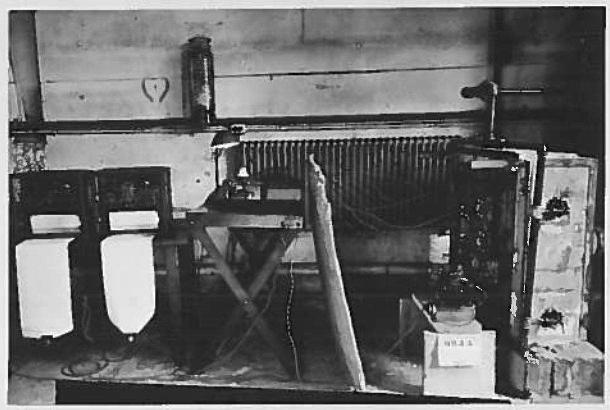


Fig. 10d. - F.H.T.L. TEST FURNACE SET-UP

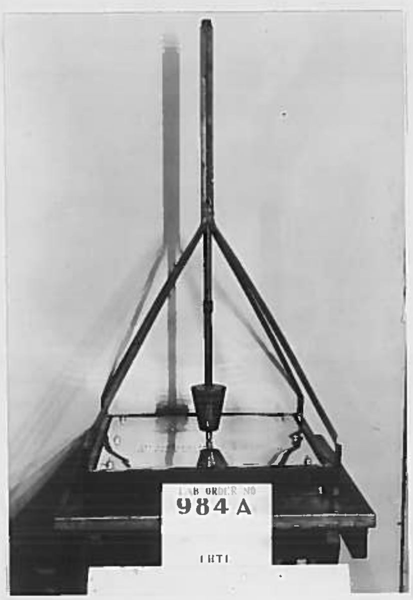


Fig. 10e. - PENETRATION TEST SET-UP

Fig. 10f. - PANEL VIBRATOR

Fig. 10 a-f. - TEST APPARATUS FOR AEROPLANE FIRE WALLS

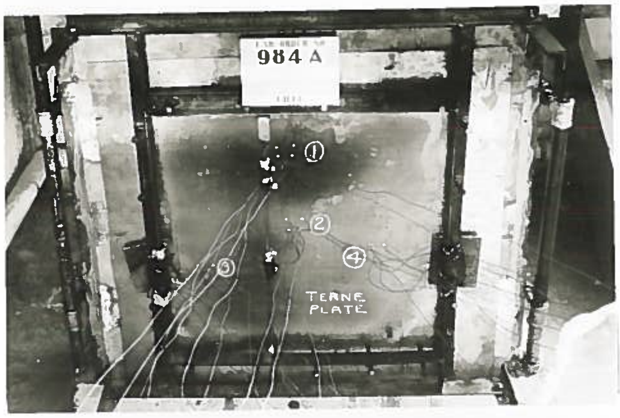


Fig. 11a. - TERNE PLATE PANEL IN FURNACE

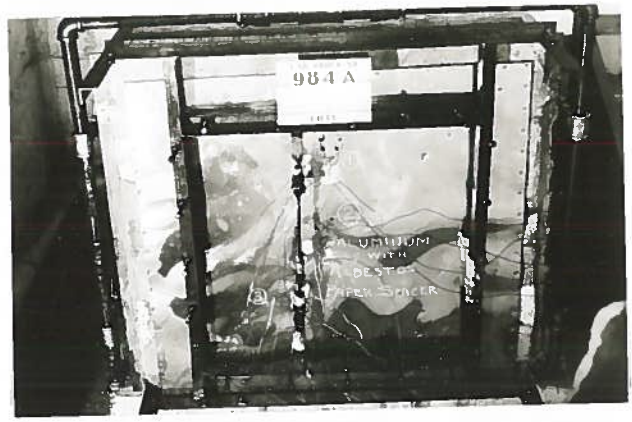


Fig. 11b. -- ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER IN FURNACE

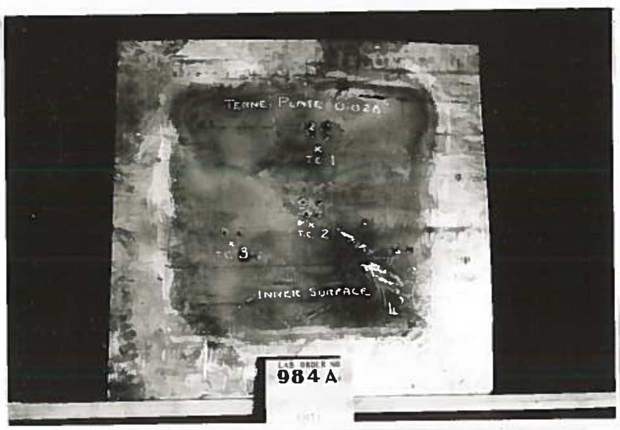


Fig. 11c. - INNER SURFACE OF TERNE PLATE PANEL AFTER TEST

Fig. 11d. - INNER SURFACE OF ALUMINUM SANDWICH WITH MILLBOARD (SOFT) SPACER AFTER TEST

Fig. 11e. - INNER SURFACE OF "STAYBRITE" STAINLESS STEEL PANEL AFTER TEST

Fig. 11f. - INNER SURFACE OF ALUMINUM SANDWICH WITH MILLBOARD (MEDIUM) SPACER AFTER TEST

Fig. 11a-f. - 36" x 36" PANELS TESTED IN F.H.T.L. FURNACE

Fig. 12a.

Fig. 12b.

Fig. 12c.

Fig. 12d.

Fig. 12a-d. - 36" x 36" PANELS TESTED IN F.H.T.L. FURNACE

Fig. 12e.

Fig. 12f

Fig. 12e-f. - 36" x 36" PANEL WITH AIR SPACE TESTED IN F.H.T.L. FURNACE

Fig. 12g.

Fig. 12h.

Fig. 12g-h. - 18" x 18" PANEL TESTED IN BRITISH AIR MINISTRY FURNACE

Fig. 12i.

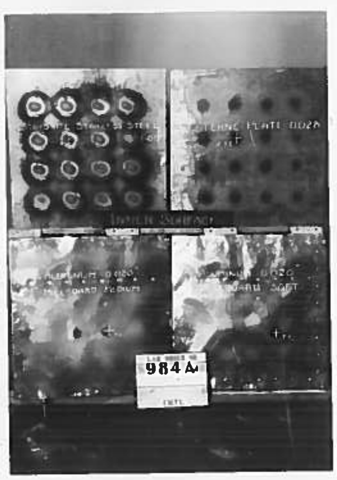


Fig. 12j.

Fig. 12i-j. - 18" x 18" PANELS TESTED IN BRITISH AIR MINISTRY FURNACE

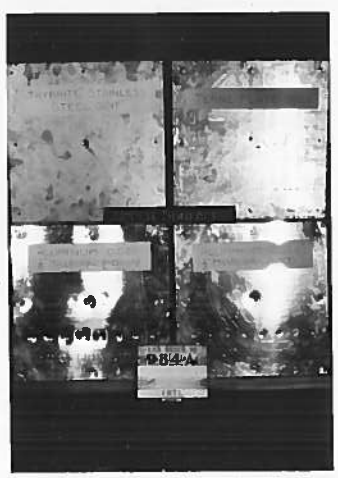


Fig. 12k. - 18"x18" PANELS AFTER PENETRATION TEST

Fig. 12m - 18" x 18" PANELS AFTER IMPACT TEST