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TECHNICAL NOTE 3991

INTERFACE THERMAL CONDUCTANCE OF TWENTY-SEVEN RIVETED AIRCRAFT JOINTS

By Martin E. Barzelay and George F. Holloway

Syracuse University

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SUMMARY

Twenty-seven structural joint specimens of 2024-T3 and 2024-T4 aluminum alloy consisting of a T-stringer riveted to a 10- by 10-inch skin surface were tested under simulated aerodynamic heating with no external loading applied. Interface thermal conductance was determined from local transient-temperature records.

Rivet size and pitch were found to influence the conductance but the rivet materials tested had no observable effect. It was also found that the thickness of the skin had an influence on the value of the conductance. The dimensions of the T-stringer (thickness and length of flange and of web) were found to have no consistent influence. During transient heating a random time variation of conductance was observed in any given specimen.

A considerable scatter in interface-conductance values partly obscured the main trends. Such scatter also existed between comparable locations on the same specimen. The scatter was found to be the largest in the thin-skin configurations. Interface-conductance values ranged from approximately 100 to 3,500 Btu/(sq ft)(hr)(°F).

The heat input to the specimen was held constant during any given tests at values which ranged from approximately 10,000 to 75,000 Btu/(sq ft)(hr). The duration of heating, determined by a maximum allowed temperature rise of 450° F, was from 15 to 50 seconds.

INTRODUCTION

The experience gathered in the course of the work of references 1, 2, and 3 demonstrated that the value of thermal conductance across joint interfaces involves many physical variables which form complicated and usually nonlinear relationships. Thus, realistic and practically applicable interface-conductance values must be found from experiments with actual joint samples.

The necessity of knowing the interface-conductance value for the determination of the temperature and stress distribution was discussed in detail in reference 1; therefore, the present report is limited to supplying additional experimental data and to assessing the importance of the variables studied.

The test specimens were furnished by Northrop Aircraft, Inc., Hawthorne, California. This investigation at Syracuse University was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics. The authors wish to thank Mr. John W. Schaefer and Mr. Robert C. Limburg for their assistance in conducting the test program.

SYMBOLS

A	cross-sectional area of stringer, sq in.
c	specific heat of joint material, Btu/(lb)(°F)
d	rivet diameter, in.
h	interface thermal conductance, Btu/(sq ft)(hr)(°F)
l_f	length of flange in cross section, in.
l_w	length of web in cross section, in.
P	rivet pitch, in.
Q	heat flow into specimen, Btu/(sq ft)(hr)
q	heat flow across interface, Btu/(sq ft)(hr)
s	distance of rivet from center line in cross section, in.
T	temperature, °F
ΔT	temperature drop across interface, °F
t_f	thickness of flange, in.
t_s	skin thickness, in.
t_w	thickness of web, in.

w	specific weight of joint material, lb/cu ft
x,y,z	coordinate axes (fig. 2)
θ	time, sec

THEORETICAL BASIS

Thermal conductance of the boundary plane between two objects is defined as the quantity of heat flowing across the interface per unit time divided by the temperature difference existing across the interface while heat is flowing. Interface conductance across a joint is measurable indirectly under these conditions by measuring the quantity of heat flow and the temperature difference separately.

The aerodynamic heating of an aircraft skin causes heat to flow into the cooler regions of the structure. In general, the heat flow is variable with time depending on the boundary conditions (adiabatic wall temperature and heat-transfer coefficient) associated with a high-speed flight mission, and on the configuration, material, and instantaneous temperature distribution of the structure. For known boundary conditions and continuous heat path the temperature distribution can be predicted for design requirements. When the heat path contains a contact joint the thermal conductance of this joint also plays an important part in the overall temperature distribution. Since interface conductance depends on a large number of material and manufacturing variables, its value can best be determined by testing samples of composite joints under actual heat-flow conditions.

Aerodynamic heating usually imposes a complex time-dependent temperature distribution on the structure. To evaluate interface conductance experimentally, however, it is not necessary to create all possible expected temperature distributions because it may be assumed that the resulting stress distribution has a negligible effect on the interface conductance. It is believed admissible to simulate the aerodynamic heating of the outside skin by energy sources such as radiant heating.

In the present tests the boundary conditions were the same as in reference 1 and are repeated here:

(1) The specimens were at a uniform room temperature at the beginning of each test and only the temperature rise was recorded.

(2) Heat input was approximately constant with time.

(3) Faces of the structure not subjected to heating were regarded as insulated and did not lose heat by convection or radiation.

(4) There was two-dimensional heat flow, that is, no heat flow along the stringer.

The experimental technique as described in reference 1 permitted a reasonable adherence to the above boundary conditions.

From the available temperature-time record of each heating test the heat passing through a unit area of the interface per unit time q was first determined at several time intervals by reading the $\partial T/\partial \theta$ values. Likewise, an average interface temperature drop ΔT was computed from the record at the same intervals. Consequently, the continuous record permitted an arbitrarily large number of values to be determined during any heating cycle. Due to time limitations, however, only three or four values from each transient test were computed.

DESCRIPTION OF SPECIMENS AND TEST APPARATUS

The specimens, consisting of aluminum-alloy skin-stringer combinations riveted according to aircraft practice, are described in figure 1 and table 1. The skin thickness varied from 1/16 to 1/2 inch, while the flange and web of the extruded T-section had a thickness range of 1/16 to 1/4 inch. The width of the flange facing the skin was $1\frac{1}{4}$ inches for all specimens.

The two rows of standard countersunk rivets attaching the T-section to the skin were of the AD-3, AD-5, and DD-6 type. The rivet pitch varied from 3/4 inch to $1\frac{1}{2}$ inches, but in most of the specimens it was 1 inch. The material of the extrusions and plates was 2024-T3 or 2024-T4 aluminum alloy, and some had cladding.

The thermocouple technique was the same as that described in reference 1.

In general, four cross sections in each specimen were investigated at two locations close to the rivets (B and D) and two other locations midway between the rivets (A and C) as shown in figure 2. This arrangement permitted study of the local effect of the rivet and of uniformity of contact along the extrusion.

The apparatus used in this investigation was the same as that used in reference 1. Its main features are repeated here:

(1) Uniformly spaced parallel graphite rods with a radiating area of 12 by 10 inches supplied heat to the specimen. The maximum power drawn from the 3-phase, 110-volt supply was 125 kilowatts. A reflector made of 3/8-inch-thick 6061-T4 polished aluminum-alloy plate helped to minimize losses.

(2) A movable heat-insulating curtain intercepted the radiant heat to the specimen during the warmup period and provided a step heat input.

(3) The specimen was simply supported at the four corners.

(4) The temperature-recording instrumentation consisted of a Century, Model 408, multichannel recording oscillograph working in conjunction with a thermocouple-galvanometer calibrator.

(5) An electric timer to record heating-element life and a microswitch to define the limits of the step heat input with respect to the temperature traces completed the instrumentation.

CONDUCT OF TESTS

Each specimen was exposed to four separate heating runs. Because of the limited number of galvanometer channels available the heating history of only two cross-sectional stations could be followed simultaneously. The sequence of test runs was the following:

(1) First run: stations B and C

(2) Second run: stations A and D

(3) Third run: stations B and C (retested)

(4) Fourth run: stations A and D (retested)

Thus, while the entire specimen was heated four times the temperature distribution at stations B and C was available in the first and third runs only, and that of stations A and D, from the second and fourth runs only.

The rate of heat flow into the specimens Q ranged from 10,000 to 75,000 Btu/(sq ft)(hr). For any test run this heating rate was approximately constant, although differences between test runs on a given specimen of up to ±30 percent were possible, mainly because of the loss of material from the surface of the graphite heating elements.

The duration of the tests, limited by an arbitrarily selected maximum temperature rise of 450° F, was from 15 to 50 seconds.

The specimens were supported loosely at the four corners so that they were free to expand and bend as heating progressed. Bending of the skin toward the heated face was visually observed in each test but no permanent deformation or buckling was apparent after cooling to room temperature.

EVALUATION OF DATA

Since the duration of the heating period and the maximum temperature were limited it can be assumed that the heat losses from the unheated back surface of the specimen by convection and radiation are negligible. Thus, during the short transient heating period all the heat absorbed by the specimen at the front face can be considered to be stored energy. The correctness of this assumption was confirmed by calculation and also by the recorded temperature history of the free skin. During the entire heating period the temperature rise in the free skin away from the stringer was a nearly linear function of time, with only a slight tendency to level off toward the end of the heating period.

The heat input was found to vary over the exposed surface. There are two reasons for the nonuniformity of heating. One is that the end effects at the outer boundaries of the heating bank result in a concentrically decreasing heat delivery to the specimen. The other is that along the center line of the specimen (i.e., where the stringer is attached) there is a larger sink effect than in the free skin; therefore, in this region the heat flow is always higher.

The above type of heating does not necessarily correspond to aerodynamic heating with respect to time and space, but it is adequate for the evaluation of a practical interface-conductance value. All that are necessary for the determination of this value are the instantaneous heat flow across the interface plane and the temperature drop between two points on either side of the interface some small distance away from it.

The measurement of the temperature drop is a relatively simple matter under any heat-flow condition. The representative ΔT value was arrived at by taking the average difference of the readings of thermocouples located at opposite sides of the interface. Corrections were made for the small temperature drop over the distance between the thermocouples and the interface.

Heat flow was determined by taking an average value of $\partial T/\partial\theta$ for the structural mass "downstream" from the interface (i.e., the stringer). This was permissible because in the short-time heating limited to 450° F the heat losses from this mass were negligible. During this period the heat flow across the interface is directly proportional to $\partial T/\partial\theta$.

The $\partial T/\partial\theta$ value representative of the heat flow across the interface was the weighted average of the $\partial T/\partial\theta$ values at all thermocouple locations downstream of the interface.

With the two basic variables ΔT and $\partial T/\partial\theta$ determined, the interface conductance was found from the relationship

$$h = \frac{cwA\,\frac{\partial T}{\partial\theta}}{l_f \Delta T}$$

where c and w are, respectively, the specific heat and specific weight of the structure downstream of the interface, A is the cross-sectional area of this structure, and l_f is the length of contact in the cross section.

Continuous temperature records were taken in each test during the entire transient heating period. The interface conductance was evaluated at a number of equally spaced time intervals to detect any possible variation in its value with time.

It must be remarked that the interface conductance of joints with a finite contact area has a somewhat arbitrary definition. For complete temperature- and stress-distribution calculations the thermal conductance of every point in the interface should be known. If the conductance throughout a practical joint is uniform then little problem is involved in its computation and utilization. In this case, and in this case only, the joint possesses a true "overall" interface-conductance value, which can be determined at a single interface point and is independent of temperature distribution and cross-section geometry.

Completely uniform contact conditions, however, are generally impossible to attain in riveted joints. It will be shown below that interface conductance at different stations along the stringer varied with distance from the rivets. It is certain that variation of a similar nature occurs along the line of contact at any cross section normal to the stringer direction. The experimental technique adopted, however, places a limit on the determination of local conductances along the line of contact. Of the two required quantities, the local temperature drop can be measured without difficulty, but the value of transient heat flow over a small area cannot readily be determined. Because of this limitation the tests were conducted and the data evaluated in such a way as to

yield a single conductance value for each stringer station. The transient heat flow q was determined from the total heat-content increase of the downstream mass. The interface temperature drop ΔT was found by averaging a number of thermocouple readings (two or three) on both sides of the interface and taking the difference of these two averages. The experiments thus automatically gave an arbitrary definition to the joint interface conductance by overlooking local variations.

One disadvantage of the above method is that the average value obtained by its application is not independent of temperature distribution and thus of joint cross-sectional geometry (as local conductances are in the absence of warping); thus, the existing local conductances over an interface area are not weighted in a consistent manner. For instance, because of this geometrical effect, inadvertently included in the averaging process, two joints of different configuration but of the same conductance distribution (assuming this to be possible) may yield slightly different averages.

In spite of difficulties in the above interpretation of an "average" interface conductance and the obvious shortcoming of any other arbitrary definition, in practice a single overall joint conductance at any given stringer cross section is desirable. For design purposes it may be worthwhile to go one step further and consolidate the varying interface-conductance values along the stringer into a single average value.

PRECISION OF DATA

In general, the same considerations as to precision of data apply as in reference 1.

Several cross sections were under study simultaneously because it was found that as few as eight thermocouples at each cross section yielded sufficient information for the computation work. Complete temperature distribution patterns were not sought in the present series of tests.

Some experimental error is involved in the reported values. Among these are errors in locating the thermocouple elements precisely, time lag of temperature pickup, heating of the stringer mass by radiation from the adjacent inside skin surfaces, and some loss of heat from the stringer.

In addition, there are probably errors in determining both a representative stringer temperature and interface temperature drop as well as in the reading of the $\partial T/\partial \theta$ values from the original data.

Because of this variety of sources it is difficult to give a fixed estimate of probable errors in the reported values; however, it is believed that these errors do not exceed ±10 percent.

Instrumentation errors were too small to have an appreciable influence on the computed value of interface conductance.

RESULTS

The experimentally determined interface-conductance values for the 27 contact joint specimens are given in table II. Conductance was measured at both near-rivet and midway-between-rivet (1/2 pitch) stations.

The conductance values measured in the entire program ranged from approximately 100 to 3,500 Btu/(sq ft)(hr)(°F). The tabulated values are averages obtained in two test runs at two comparable locations (that is, two near-rivet stations or two midway stations) evaluated at three or four time intervals each.

Figure 3 shows the complete relationship of interface conductance against time in one typical specimen. This time-dependent variation was noted in all test runs but no consistent trend could be detected. The magnitude of these variations was different from specimen to specimen and in a few extreme cases it reached ±40 percent, although in most specimens the fluctuation was much lower.

Interface conductance was found to be higher, by an average of approximately 30 percent, near rivets than midway between rivets in all of the specimens tested. Occasionally the difference between values at the two stations was much lower or higher than the average as seen in table II.

Examination of the interface-conductance data indicates that the local contact conditions were less uniform in the vicinity of a rivet than at a point some distance from the rivet. Though complete data are presented for both locations, attention is focused on the midpoint stations because these points are representative of the relatively largest part of the contact area. The quantitative results and the trends observed were based on midstation conductance values. The difference between the values at near-rivet and midrivet stations was interpreted as a measure of the local effect of rivet clamping.

The configuration of specimens in this program was such that examination of selected individual variables was possible. It was found that:

(1) Conductance increased generally with rivet diameter between 3/32 and 6/32 inch, as shown in figure 4.

(2) Conductance at midrivet stations decreased with increasing pitch distance, as shown in figure 5.

(3) Conductance decreased with increasing skin thickness, as shown in figure 6.

An examination of the data revealed no consistent relationship between the conductance and the dimensions of the T-section, such as the thickness and the length of the flanges.

No significant effect of the difference in the two rivet materials used (2024-T4 and 2117-T4) could be found.

It appears from figures 4, 5, and 6 that the amount of scatter is usually largest in thin-skin specimens (1/16 inch thick) and gradually diminishes for higher values of skin thickness.

Scatter was also observed when comparing conductance values at different stations on the same specimen (i.e., at geometrically identical positions). This is apparent from the values of table II. In this respect it was also found that in thin-skin specimens the scatter was greater than in the thick-skin specimens.

DISCUSSION

Upon assembly of a contact joint, interface conductance can be considered a tangible physical quantity dependent mainly on the surface conditions of the assembled parts and on the contact pressure existing between them (see refs. 2 and 3). The measurement of the quantity in a particular joint is possible, however, only when heat is flowing. But as soon as temperature differences arise, warping of the components occurs, which affects the thermal conductance of composite joints by altering the intimacy of contact on a large scale, as discussed in reference 3.

The time variation of conductance found in all tests (fig. 3) can be traced back to the above cause. From the moment the heat begins to flow a time-dependent temperature distribution is created which sets up thermal stresses in the structure. The resulting time-dependent deformations in the joined parts and rivets cause corresponding changes in interface contact which in turn modify the temperature distribution, resulting in further deformation. In addition, the temperature-dependent modulus of elasticity and coefficient of expansion of the material have a minor effect.

According to the above discussion the rate of heat flow should also influence the conductance. Each specimen in this program was exposed to a range of heating rates in successive tests and such conductance variation was observed. However, no consistent relationship between the rate of heat flow and interface conductance was apparent.

The effect of extremely high heat flows on interface conductance was not investigated because of the limitations of the test apparatus. The maximum value attained was 75,000 Btu/(sq ft)(hr). Furthermore, no destructive testing was carried out because contact conductance does not have a meaning in the usual sense after buckling or failure of the mating parts or after permanent yielding of the connecting rivets.

It is to be noted in figure 3 that the interface conductance is not presented from zero time level. In the first few seconds of heating both the heat flow across the interface and the temperature gradients were so small that the computation of conductance gave unreliable results. However, since in the same period the heat flow across the interface plane is negligibly small, the interface conductance can have only an insignificant effect on the temperature distribution. It is therefore concluded that even if a joint possesses, prior to and in the first few seconds of heating, a substantially different interface conductance from that observed in the latter part of heating, the knowledge of the initial value is relatively unimportant.

Riveting

The increase of thermal conductance with increasing rivet diameter (fig. 4) could be expected because larger rivets assure higher pressure and thus better contact between the assembled parts. The rivet itself serves as a good conduction path between the parts parallel to the contact conductance and tends to increase the experimentally measured thermal conductance of the joint.

The decrease of conductance with increasing rivet pitch (fig. 5) is also intuitively logical for any point in the plane of contact (except very close to the rivet where local effects predominate) since larger rivet spacing is associated with lower contact pressure and consequent lower average conductance.

The experiments yielded sufficient evidence to conclude that interface conductance along the stringer varied from a maximum value near the rivet to a minimum value midway between rivets. The near-rivet stations showed a 30 percent higher conductance value, on the average, than mid-rivet stations. This can also be attributed to variation of local contact pressure inherent in the riveting process.

The structural behavior of the rivets under thermal-load conditions was not specifically investigated. The stresses in the rivets, the amount of elastic deformations, slippage, loss of strength, and plastic yielding at elevated temperatures were outside the range of the present experimental program.

Skin Thickness

The experimental data gave evidence that interface conductance depends on the skin thickness to the extent indicated in figure 6. It is known that the relative flatness of two mating surfaces influences the average conductance of the contact joint formed between them (ref. 3).

This relative flatness between mating surfaces is obviously influenced in the course of riveting skin and stringer assemblies by the geometry, or more specifically the relative stiffness, of the assembled parts. For a given rivet pattern more intimate contact (in the sense of closeness of surfaces to each other as well as actual metal-to-metal contact) may be achieved on assembly when the skin is relatively flexible compared with the stringer. In the combinations tested the ratio of moment of inertia of the largest stringer to that of the thinnest skin was approximately 1,600 to 1. As the other extreme, the ratio of moment of inertia of the smallest stringer to that of the thickest skin was approximately 1.6 to 1. Exact values of this ratio depend on the assumption made regarding effective skin width.

The geometry of the system not only influences the interface conductance in the above sense but also plays a part during heating since the temperature and stress distribution depend on the configuration. However, it appears from an examination of the experimental data that only the skin thickness has a consistent influence on the interface conductance; the stringer dimensions appear to be relatively unimportant.

Although the effects of riveting and skin thickness on joint conductance have apparently been well established, attention must be directed to the experimental scatter which tends to obscure the significance of the above-mentioned trends. The nature of the scatter may be sought in the randomness of the process by which ordinary joints are made in an aircraft shop. Manufacturing variability may enter through a number of factors which are not feasible to control closely in production. Surface roughness, flatness, cleanness, rivet-hole tolerance, and driving of the individual rivets are bound to vary in a more or less random fashion and the resulting contact is sensitive to any or all of these variations. The presence of manufacturing variability as a factor in masking and obscuring trends can be demonstrated by observing the variation of conductance between comparable stations in the same specimen.

It is noted that all types of scatter are more apparent on specimens with thin skin. As noted above the highest conductance values were also found in such specimens. It is believed that the two tendencies are interrelated. For a relatively thick-skin combination the influence of riveting variability can have little effect on scatter since ordinary riveting does not create sufficient joint pressure upon original assembly to deform the thick skin. A thin skin, on the other hand, may be pulled into good contact with a stringer and thus give high conductance values, but any variability in the riveting, say a loose rivet in the extreme case, will obviously have a much larger effect on the closeness of contact than in the thick-skin joints.

In figure 6 variation of conductance due to rivet diameter is not indicated since its presence does not alter the main trend attributed to skin thickness alone. With the exception of specimen 34 all specimens with 1-inch pitch are located within the scatter band. Specimen 34 had an exceptionally poor joint contact (visible air gap) while in specimens 24 and 29 an unusually good contact was apparent. As it was pointed out before, such large fluctuations can be expected only in joints with thin skin.

The conductance values of the 21 specimens of figure 6 are replotted in figure 4 with rivet diameter as abscissa. In this figure the influence of rivet diameter is obvious, but it should be noted that the width of the band is due to skin-thickness variation (which is not shown by separate curves) as well as to scatter. On the basis of figure 6 it may seem that the upper region of the band in figure 4 is associated with thin-skin and the lower region, with thick-skin configurations.

In the section entitled "Results" it was indicated that the effect of pitch variation was also ascertained. There were six specimens (specimens 37 to 42) with a pitch distance different from 1 inch. The resulting three groups of specimens where only the pitch varied were specimens 41, 29, and 42, specimens 39, 12, and 40, and specimens 37, 20, and 38. The corresponding conductance values are plotted in figure 5 and again, instead of individual curves, a scatter band is shown. Since in this plot skin thickness is an included variable, the top region of the scatter band can again be considered to correspond to thin skin and the bottom region, to thick skin.

CONCLUDING REMARKS

The experimental data for interface conductance were obtained from joint configurations and conditions which were thought to be fairly typical of current problems. It is to be realized, however, that actual aerodynamically heated aircraft joints differ in several respects from

those tested under laboratory conditions: mainly, in size, manner of restraint, and loading. Nevertheless, the use of the experimentally determined interface-conductance values for design purposes may be recommended when the material and configuration of a proposed joint as well as the expected rate of heat flow are similar to those tested in this program.

Syracuse University,
Syracuse, N. Y., December 15, 1955.

REFERENCES

1. Barzelay, Martin E., and Holloway, George F.: Effect of an Interface on Transient Temperature Distribution in Composite Aircraft Joints. NACA TN 3824, 1957.

2. Barzelay, Martin E., Tong, Kin Nee, and Hollo, George: Thermal Conductance of Contacts in Aircraft Joints. NACA TN 3167, 1954.

3. Barzelay, Martin E., Tong, Kin Nee, and Holloway, George F.: Effect of Pressure on Thermal Conductance of Contact Joints. NACA TN 3295, 1955.

TABLE I

SPECIMEN DIMENSIONS AND RIVETING VARIABLES

Specimen	t_s, in.	l_f, in.	t_f, in.	l_w, in.	t_w, in.	s, in.	P, in.	Rivet type
16	0.063	1.25	0.064	1.25	0.064	0.375	1.00	AD-5
17	.250	1.25	.064	1.25	.064	.375	1.00	AD-5
18	.500	1.25	.064	1.25	.064	.375	1.00	AD-5
19	.063	1.25	.064	1.25	.064	.375	1.00	DD-6
20	.250	1.25	.064	1.25	.064	.375	1.00	DD-6
21	.500	1.25	.064	1.25	.064	.375	1.00	DD-6
22	.250	1.25	.125	1.25	.125	.375	1.00	AD-5
23	.250	1.25	.250	1.25	.250	.375	1.00	AD-5
24	.063	1.25	.125	.50	.125	.375	1.00	DD-6
25	.063	1.25	.125	1.25	.125	.375	1.00	DD-6
26	.063	1.25	.125	2.00	.125	.375	1.00	DD-6
27	.125	1.25	.125	1.25	.125	.375	1.00	DD-6
28	.250	1.25	.125	1.25	.125	.375	1.00	DD-6
29	.063	1.25	.250	1.25	.250	.375	1.00	DD-6
30	.500	1.25	.250	1.25	.250	.375	1.00	DD-6
31	.375	1.25	.125	1.25	.125	.375	1.00	DD-6
32	.500	1.25	.125	1.25	.125	.375	1.00	DD-6
33	.063	1.25	.064	1.25	.064	.375	1.00	AD-3
34	.250	1.25	.250	1.25	.250	.375	1.00	AD-3
35	.250	1.25	.250	1.25	.250	.375	1.00	DD-6
36	.250	1.25	.064	1.25	.064	.375	1.00	AD-3
37	.250	1.25	.064	1.25	.064	.375	.75	DD-6
38	.250	1.25	.064	1.25	.064	.375	1.50	DD-6
39	.063	1.25	.064	1.25	.064	.375	.75	DD-6
40	.063	1.25	.064	1.25	.064	.375	1.50	DD-6
41	.063	1.25	.250	1.25	.250	.375	.75	DD-6
42	.063	1.25	.250	1.25	.250	.375	1.50	DD-6

TABLE II

EXPERIMENTAL INTERFACE-CONDUCTANCE DATA

[Station locations shown in figure 2]

Specimen	Interface conductance, h, Btu/(sq ft)(hr)(°F),					
	Station A	Station B	Station C	Station D	Average of stations A and C	Average of stations B and D
16	620	570	800	870	710	720
17	410	470	420	620	410	540
18	320	290	310	370	310	330
19	580	1,130	820	1,220	700	1,170
20	720	690	490	570	600	630
21	290	470	320	590	300	530
22	330	480	440	400	390	440
23	200	240	290	330	240	290
24	1,890	2,710	1,670	1,710	1,780	2,210
25	1,250	1,200	790	1,000	1,020	1,100
26	1,180	1,120	720	1,550	950	1,330
27	310	710	610	560	460	640
28	360	530	410	420	390	480
29	1,900	4,840	2,040	2,290	1,970	3,560
30	300	320	310	430	300	380
31	450	520	610	770	530	640
32	300	370	590	780	450	570
33	580	520	500	1,580	540	1,050
34	110	110	100	110	110	110
35	350	350	350	390	350	370
36	380	380	230	250	310	310
37	640	890	670	810	660	850
38	370	540	450	940	410	740
39	1,630	1,460	1,160	2,640	1,390	2,050
40	540	630	460	760	500	690
41	3,310	3,050	2,820	2,970	3,070	3,010
42	1,230	2,370	730	860	980	1,620

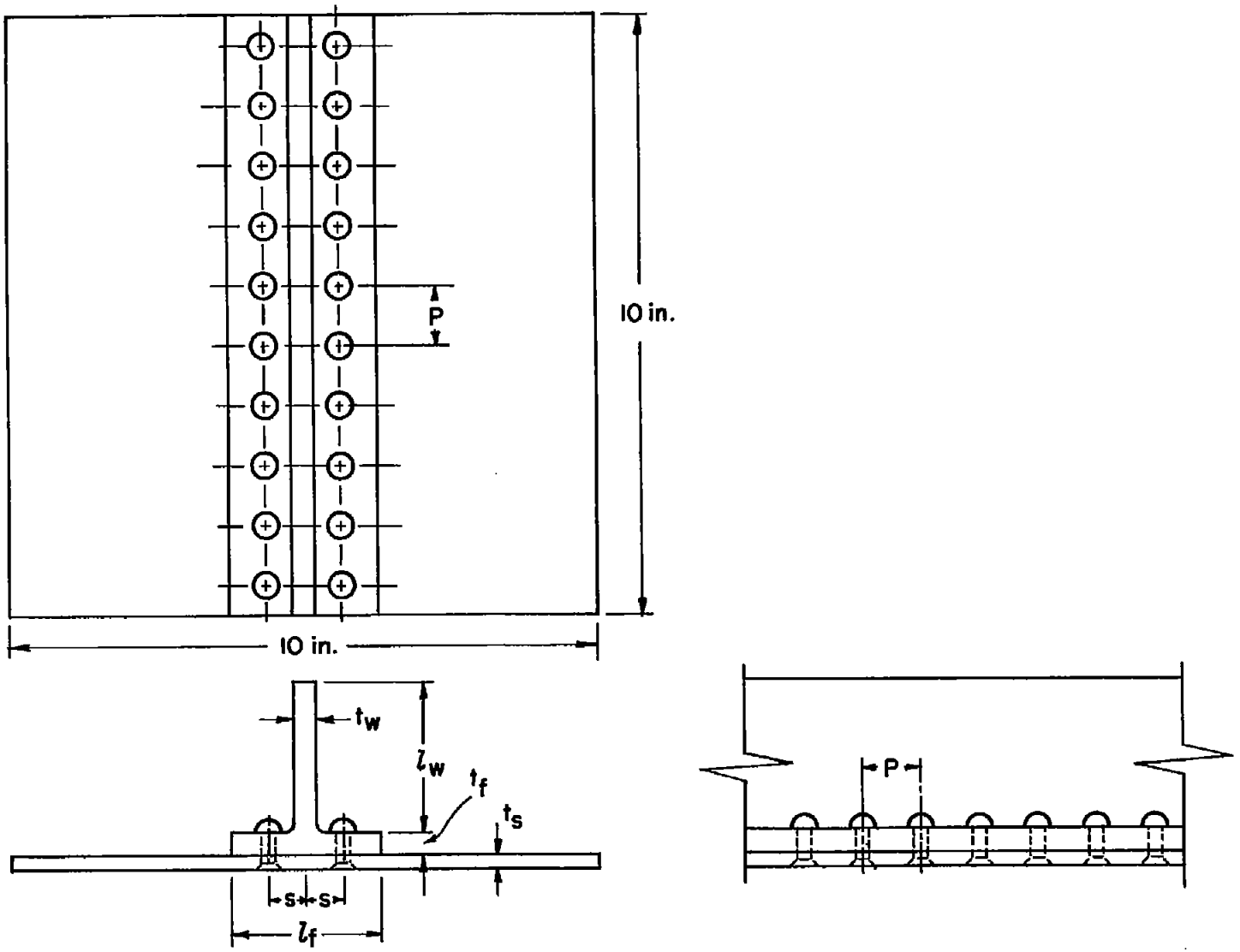

Figure 1.- Specimen configuration. (Dimensions and riveting variables are given in table I.)

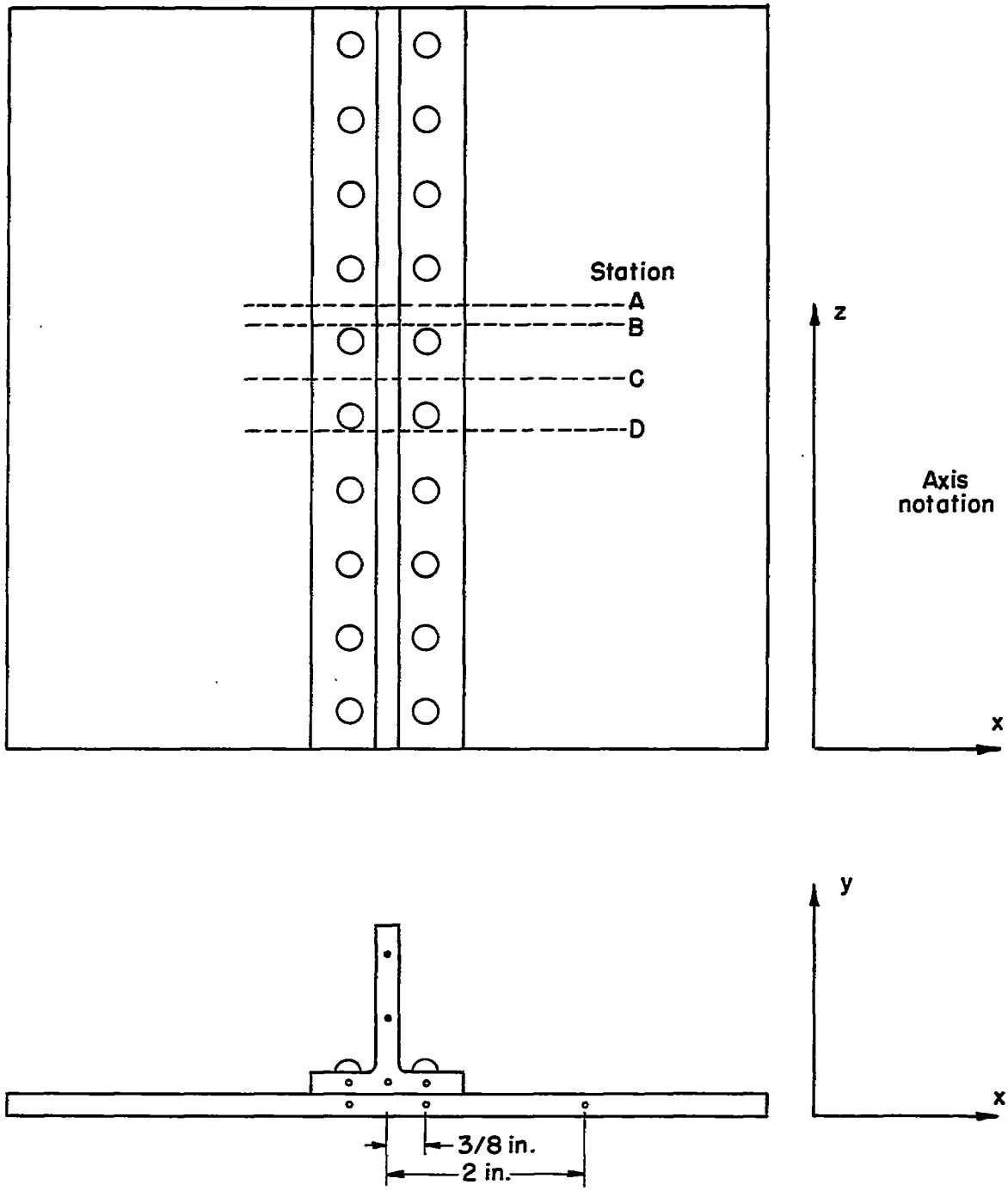

Figure 2.- Thermocouple locations in specimens.

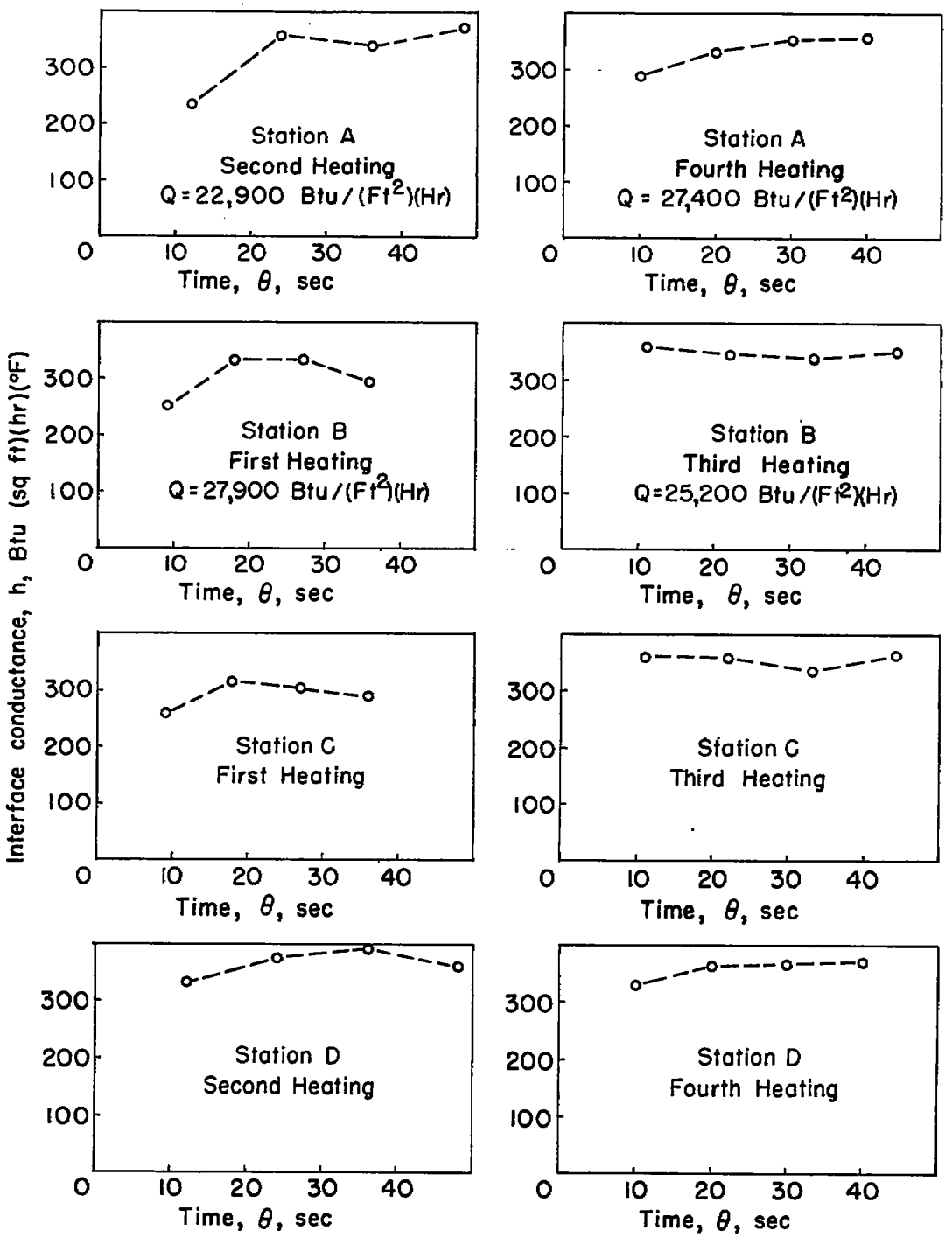

Figure 3.- Typical experimental values of interface conductance. (Specimen 35.)

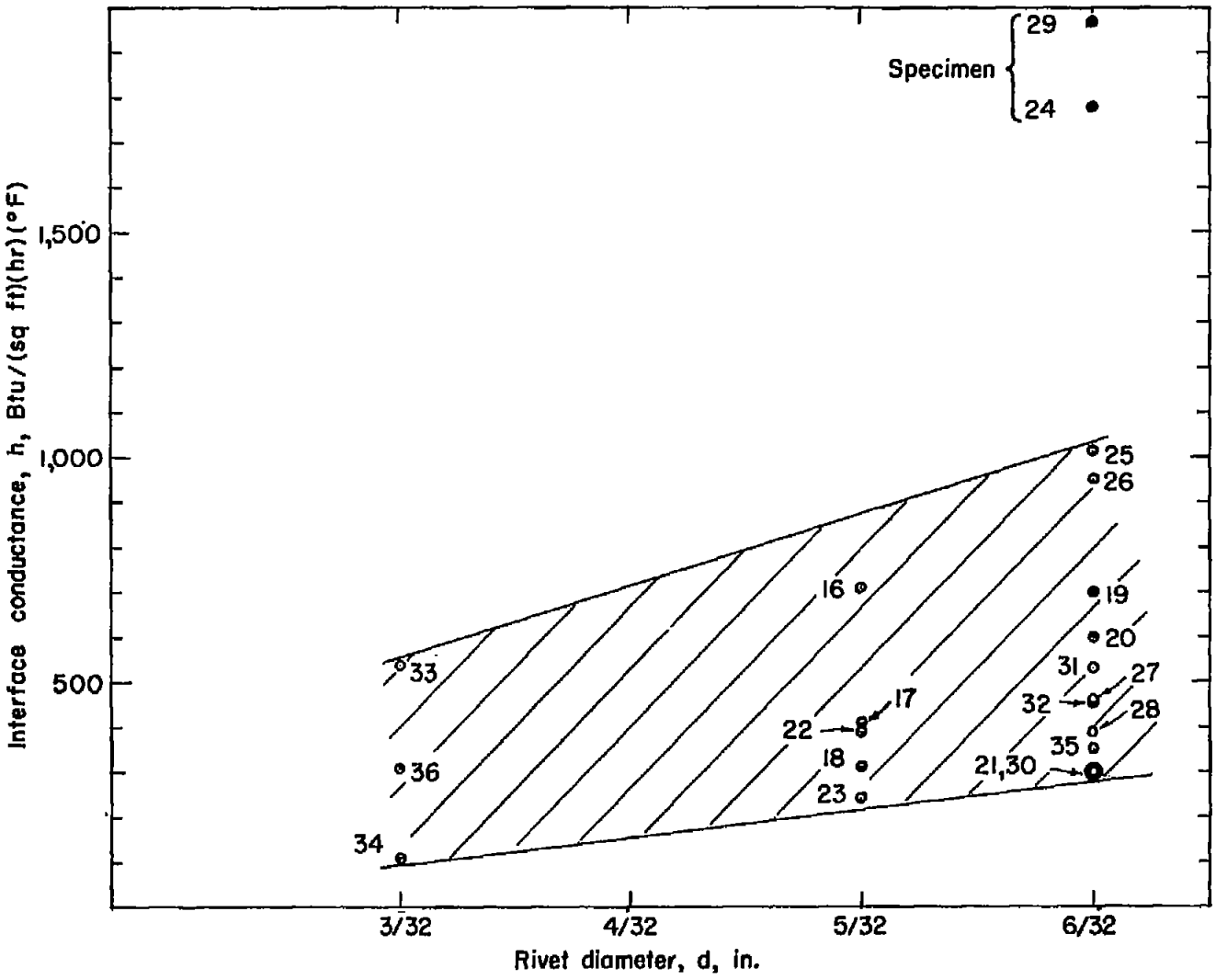

Figure 4.- Variation of interface conductance at midrivet stations with rivet diameter. Rivet pitch, 1 inch; AD and DD rivets.

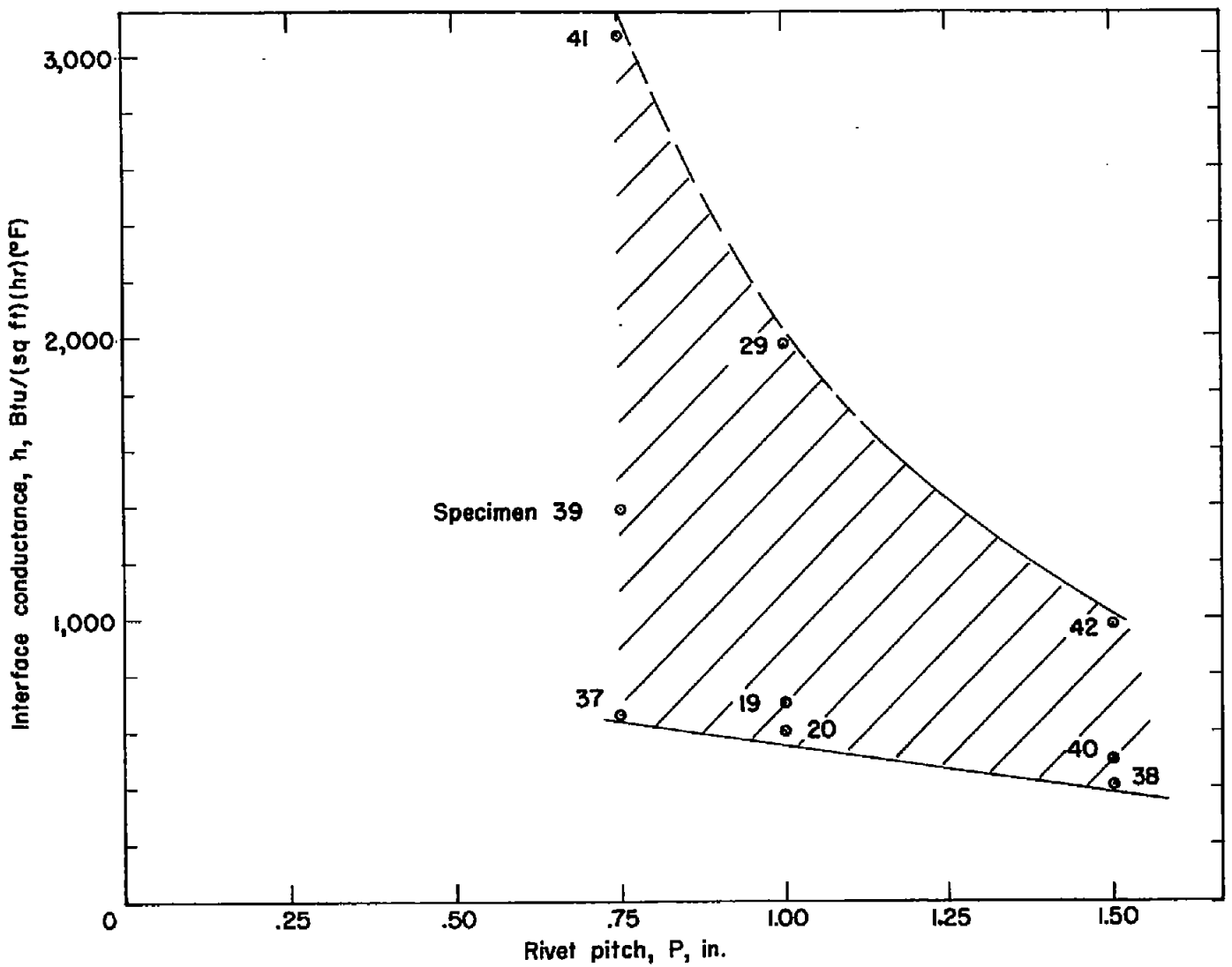

Figure 5.- Variation of interface conductance at midrivet stations with rivet pitch. DD-6 rivets.

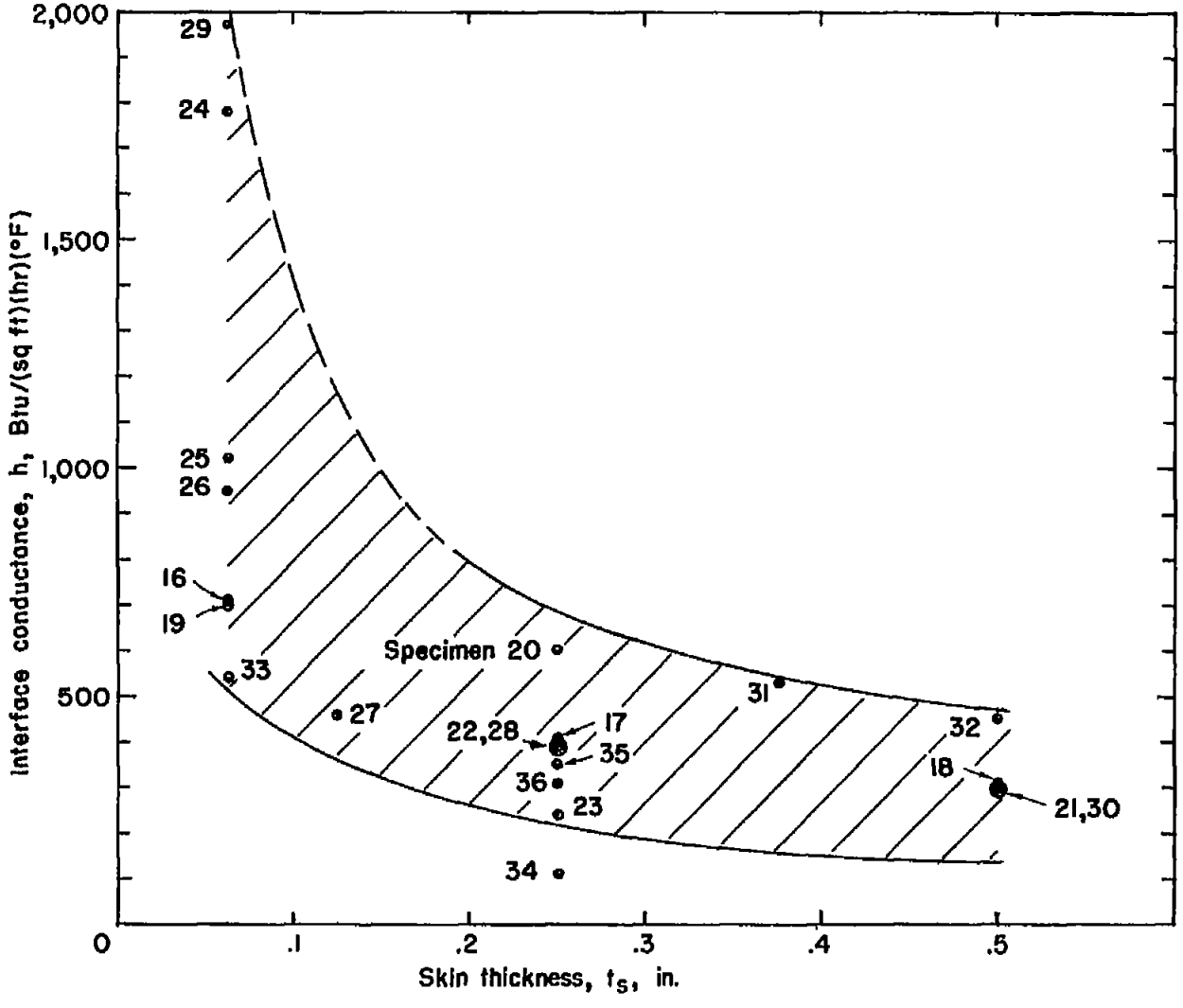

Figure 6.- Variation of interface conductance at midrivet stations with skin thickness. Rivet pitch, 1 inch; AD and DD rivets.

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