STRESSES INDUCED IN A SANDWICH PANEL BY LOAD APPLIED AT AN INSERT

March 1955

This Report is one of a Series
Issued in Cooperation with the
AIR FORCE - NAVY - CIVIL SUBCOMMITTEE
on
AIRCRAFT DESIGN CRITERIA
Under the Supervision of the
AIRCRAFT COMMITTEE
of the
MUNITIONS BOARD

No. 1845

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

STRESSES INDUCED IN A SANDWICH PANEL BY LOAD APPLIED AT AN INSERT[1]

By

W. G. YOUNGQUIST, Engineer
and
EDWARD W. KUENZI, Engineer

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Summary

This report presents the results of tests conducted to determine the stresses induced in the core and facings of a flat sandwich panel by a concentrated load applied at an insert. Test stresses are compared with stresses computed by using theoretical analyses previously developed for the bending of a circular sandwich panel under normal load.[3] It is concluded that the theoretical analysis is fairly well confirmed by the tests and therefore may be used to develop proper design criteria for stresses caused by a loaded insert.

---

[1] This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics Order No. NAer 01628 and U. S. Air Force No. USAF 18-(600)-102. Results here reported are preliminary and may be revised as additional data become available.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Ericksen, W. S. The Bending of a Circular Sandwich Plate Under Normal Load. Forest Products Laboratory Report No. 1828. Revised 1953.

Introduction

In the use of structural sandwich construction, particularly for aircraft structures, it is often necessary to carry loads into the sandwich through fittings that allow loads to be applied in a direction normal or inclined to the plane of the sandwich. The fittings are usually fastened to the sandwich by attachment to a small insert that locally replaces the sandwich core. This insert may be of metal or of denser core, and it is bonded between the facings at the time the sandwich is manufactured.

The experimental work was conducted on relatively large, circular sandwich panels that had a small, circular insert at their centers. Loads were applied at the insert in a direction normal to the sandwich panel. In order to measure core strains (hence stresses) the work was limited to continuous cores, one of end-grain balsa wood representing a core of moderate shear modulus and one of cork board representing a core of low shear modulus.

After tests had been conducted to determine the stresses induced by loading at the insert, test specimens were cut from the sandwich panel. These specimens were subsequently tested, and the values obtained were used in the theoretical analysis to compute core and facing stresses.

Experimental Procedure

The experimental procedure involved the fabrication of circular sandwich panels of cores in which strain gages had been embedded at different points. The sandwich was tested by loading through an aluminum insert, and shear strains in the core were measured so as to obtain their radial distribution. The sandwich was then carefully cut, and shear tests were conducted on the core pieces that contained the strain gages. These tests then gave the relationship between the strain-gage readings and the shear stress, regardless as to whether the strain gages read proper shear strain or as to the exact shear modulus of the core. Thus, the shear stress in the panel could be determined by proportioning the shear stress of the shear test according to strain-gage readings.

Strains were also measured on some of the facings. Since the facings were of aluminum alloy, however, the stresses could be calculated directly.

Materials Tested

Five test panels, as described in table 1, were fabricated for test.

The balsa cores were made from wood having a density of about 9 to 10 pounds per cubic foot. The wood was conditioned to a moisture content (5 to 7 percent) substantially in equilibrium with the workroom conditions. The individual boards were surfaced on four sides and then cut across the grain into slices that were glued edge to edge to form the cores. In each case, the material obtained from one board was sufficient for one panel, thus insuring close matching of material.

The cork core was made from two edge-glued sheets of granulated cork having a protein binder. The core was reduced to proper thickness in a planer.

The facings were of 24ST clad aluminum alloy conforming to Federal Specification QQ-A-362A. The aluminum inserts used were turned from solid bar stock.

Fabrication of Test Panels

The installation of SR-4 strain gages at various points within the core proved to be extremely exacting and largely determined the panel sizes and the techniques required for fabrication of the panels. The panel dimensions and gage locations are shown in figure 1. For calibration purposes, gages were located in a pattern which permitted the cutting of 2-inch-wide and 6-inch-long sections of the panel, each containing one gage as shown.

The SR-4 gages had 1/4-inch gage lengths and were mounted in the core as follows: Two gages were mounted at the selected locations at the center of the depth of the core and were oriented at 90 degrees to each other and at 45 degrees to the selected radial line of the core. Lead wires were carried to the outside edge of each core segment. Two gages mounted as described above are shown in place on a balsa core segment in figure 2.

The actual steps used in the fabrication of the panels were as follows:

(1) The core material was fabricated into octagon-shaped mats 20 inches

wide across the flats. A room-temperature-setting resorcinol adhesive was used for edge gluing the blocks.

(2) Mats were cut into eight equal pie-shaped sections as shown in figure 1.

(3) SR-4 gages were mounted on the edges of these sections, as previously described. The pieces were then reglued into the original shape with adequate glue pressure being applied by means of wedges placed against the flats of the octagon.

(4) A 2-inch-diameter hole was drilled in the center of the mat into which an aluminum insert (containing a 1/4-inch central hole), which was machined to fit for both diameter and thickness, was carefully glued.

(5) The aluminum faces, which also had 1/4-inch central holes, were next glued in place using EPON 8, a formulation of epoxy resins. A 1/4-inch steel pin was used to secure accurate alinement of the core and faces.

Method of Test

The test method used in testing the panels is illustrated in figure 3. The 20 -inch-diameter panels were accurately centered over an 18-inch-diameter hole in a heavy base of densified laminated wood mounted on the lower platen of a testing machine. In all cases, the test panels were simply supported and not clamped to the base block. Load was transmitted to the panel insert through a 1-1/2-inch-diameter steel ball resting in the 1/4-inch central hole in the panel. Simultaneous readings of load and strain gages in the core at two gage locations were obtained at uniform load increments until a previously determined load, which was well within the elastic limit of the panel, was reached. This procedure was repeated until values had been obtained at all eight gage locations. A plot of the data showed that an excellent linear relation existed between strain-gage readings and applied load.

After all gages in the core had been read, SR-4 gages of 1/8-inch gage length were glued to the top faces of panels 4, 5, 6, and 8. The gages were glued on in pairs, with the gages in each pair placed on diametrically opposite sides of the central insert and at distances of 1/16, 1/4, 1/2, and 1 inch from the rim of the insert. Facing strains were measured at each of the previously used increments of load. A plot of the data showed that an excellent linear relation also existed between the strain-gage readings and applied loads.

Following the completion of the panel test, eight shear-test specimens 2 inches wide and 6 inches long and each containing one set of the gages in the core, were cut from each panel. Figure 1 shows the general cutting pattern used. It will be noted that many of the gages were thus located near the ends of the shear specimens. To avoid possible end effects, each specimen was cut off at a point 3 inches from the gage, and sufficient stock cut from a nearby location in the panel was then butt joined to the other end of the specimen to insure a central location for the gage. It was assumed that the discontinuity of the specimen would not affect the results, since for test purposes the specimens were glued between heavy steel plates, 1/2 inch thick.

The shear tests of the specimens containing the gages were made in accordance with the method outlined in ASTM Designation C273-51T[4] and as illustrated in figure 4. Simultaneous readings of the dial gage, the SR-4 gages in the core, and load were made at various load increments until a total load of 2, 000 pounds for the balsa cores and 100 pounds for the cork cores had been reached.

Theoretical Analysis

The theoretical analysis of a clamped circular sandwich panel under normal load[3] has shown that the shear stress in the core of a sandwich having a solid, clamped insert under normal load is given by the formula:

$$\tau(r) = \frac{PI_m}{\pi(h + c)\,I}\left\{\frac{1}{r} - \frac{I_1(\alpha r)}{ab}\left[\frac{bK_1(\alpha b) - aK_1(\alpha a)}{I_1(\alpha a)K_1(\alpha b) - I_1(\alpha b)K_1(\alpha a)}\right]\right. \qquad (1)$$

$$\left.\frac{K_1(\alpha r)}{ab}\left[\frac{aI_1(\alpha a) - bI_1(\alpha b)}{I_1(\alpha a)K_1(\alpha b) - I_1(\alpha b)K_1(\alpha a)}\right]\right\}$$

where $\tau(r)$ -- shear stress in the core at radius r
P -- applied load at insert
c -- core thickness
h -- total sandwich thickness
r -- radius measured from center of insert
a -- outer radius of sandwich plate
b -- radius of insert

[4] American Society for Testing Materials, 1952 Standards, Part IV.

$$I_m = \frac{ff' (h + c)^2}{4 (h - c)}$$

f, f' -- facing thicknesses; equal or unequal

$$I = I_m + I_f$$

$$I_f = \frac{f^3 + f'^3}{12}$$

$$\alpha = \sqrt{\frac{G(h - c) I}{Ecff' I_f}}$$

G -- shear modulus of the core

$$E = \frac{E_f}{1 - \nu^2}$$

E_f -- Young's modulus of facings

ν -- Poisson's ratio of facings

$I_1(\alpha r)$, $K_1(\alpha r)$ -- modified Bessel functions[5]

The formula for shear stress in the core (formula 1) can be written as

$$\tau(r) = \frac{PI_m}{\pi(h + c) I} K \tag{2}$$

where K represents the entire bracketed quantity involving the modified Bessel functions. Then the variation of K can be examined to determine shear-stress variation. It is rather difficult to determine the variation of K because of the modified Bessel functions involved, but it is possible to begin by examining K for large values of (αr) for which the Bessel functions become the exponentials

$$I_1(\alpha r) = \frac{e^{\alpha r}}{\sqrt{2\pi\alpha r}}$$

$$K_1(\alpha r) = - e^{-\alpha r}\sqrt{\frac{\pi}{2\alpha r}} \tag{3}$$

---

[5] See Forest Products Laboratory Report No. 1828 for details concerning the use of these functions.

The extent to which equations (3) actually represent the modified Bessel functions can be determined by evaluating the expressions for various values of (ar) and obtaining the ratio of the exponential function to the Bessel function. This was done, and the results are shown graphically in figure 5 where the values of the ratios $\dfrac{\dfrac{e^{ar}}{\sqrt{2\pi ar}}}{I_1(ar)}$ and $\dfrac{-e^{-ar}\sqrt{\dfrac{\pi}{2ar}}}{K_1(ar)}$, using actual values of the modified Bessel functions far $I_1(ar)$ and $K_1(ar)$, are plotted against the parameter (ar). The curves of figure 5 show that for values of (ar) as low as 5 there is less than 10 percent difference between the exponential functions and the modified Bessel functions. For values of (ar) larger than 5, the differences between the exponential and Bessel functions become gradually smaller as ar increases. At values of (ar) less than 5, however, the differences increase rapidly as ar becomes smaller. The formula for shear stress in the core has the Bessel functions appearing as products, etc., which may lead one to expect that, even though the exponentials are considerably different from Bessel functions at small (ar) values, the value of K as determined by exponentials may be much nearer the value of K as determined by using modified Bessel functions. Substitution of equations (3) into the bracketed expres sion of formula 1 results in exponential functions which can be written as hyperbolic functions, thus:

$$K = \frac{1}{r}\left[1 - \sqrt{r}\,\frac{\sqrt{b}\sinh a(r - b) + \sqrt{a}\sinh a(a - r)}{\sqrt{ab}\sinh a(a - b)}\right] \qquad (4)$$

In order to investigate the effects on K, values of K were computed using exponential and modified Bessel functions for a value of a as low as 1. 0. Convenient parameters excluding panel size and insert size cannot be formed because of the transcendental form of the expressions involved. Therefore, the problem was solved for a "worst" case--one in which an insert 2 inches in diameter was placed in a sandwich 8 inches in diameter. This seemed to represent one of the smallest panels likely to be used, and a larger panel would result in less differences between values calculated by using exponential functions or modified Bessel functions. Curves representing the radial variation in core shear stress are presented in figure 6. For a = 1 (ab =1; aa = 4) the modified Bessel functions give the maximum shear stress in the core approximately 10 percent greater than the exponential functions. For a = 2. 5 (ab = 2. 5; aa = 10) the maximum shear stress in the core is only about 1 percent greater than that given by the exponential functions, and at larger values of a essentially no difference exists between determination of K by using either exponential functions or modified Bessel functions. As a becomes larger and larger, the value of K finally becomes $\frac{1}{r}$, which is equivalent to saying that the shear stress in the core is given approximately by the load divided by the circumferential core area at a radius r.

If the circular sandwich is large and has a small circular insert, many of the terms of formula 1 can be omitted[6] finally resulting in

$$\tau(r) = \frac{P I_m a T}{\pi(h + c) I}$$

where $$T = \frac{1}{(ar)} - \frac{K_1(ar)}{(ab)\, K_1(ab)}$$

The equation for T can be differentiated and maximized with respect to (ar) so that it will finally result in the determination of the maximum shear stress in the core and its position. The results of this procedure are given graphically in figure 7, where T is plotted against the parameter (ab). As (ab) becomes larger and larger, the value of T approaches $\frac{1}{ab}$. The position of maximum shear stress is given by the parameter $\gamma = \frac{b}{r_{\tau\ max.}}$, and as (ab) becomes large, γ approaches unity. This shows that the point of maximum shear stress approaches the edge of the insert as (ab) increases. Thus, as the position of maximum shear stress approaches the edge of the insert, the value of T approaches $\frac{1}{ab}$. This shows that as the limit stress, as determined by the area around the insert, is approached, the larger the plate or the larger a becomes. It should be noted that a becomes large as the core shear modulus increases, but that a becomes smaller if the facings of the sandwich or. the sandwich core are thickened. This means that the more rigid the core, the higher the core shear stress; or the stiffer the facings and sandwich, the lower the core shear stress.

The facing stresses are maximum at the edge of the insert and are given for a plate with clamped outer rim and clamped insert by the formula[3]

---

[6] This is discussed in more detail in Forest Products Laboratory Report No. 1828.

$$\sigma_r = \frac{P}{2\pi I}\left\{\left[\frac{I_m}{f\ (h + c)} + \frac{f}{4}\right]\left[1 - \frac{2a^2}{a^2 - b^2}\log\frac{a}{b}\right] - \frac{1}{ab}\left[\frac{2I_m}{f\ (h + c)} - \frac{I_m f}{2I_f}\right]\frac{K_o(ab)}{K_1(ab)}\right\} \tag{5}$$

In this formula $K_o(ab)$ and $K_1(ab)$ represent the modified Bessel functions as defined in Forest Products Laboratory Report No. 1828. If (ab) is 5, the ratio $\frac{K_o(ab)}{K_1(ab)} = -1$ with less than 10 percent error. For larger values of (ab), the error decreases, and for smaller values of (ab), the error increases. If the sandwich has facings of equal thickness and the facings are thin so that their individual stiffness can be neglected and (ab) is greater than 5, formula (5) can be rewritten to give the somewhat simpler expression ---

$$\sigma_r = \frac{Ph}{\pi f\ (h + c)^2}\left[1 + \frac{h + c}{h\ (ab)} - \frac{2a^2}{a^2 - b^2}\log\frac{a}{b} - \frac{3\ (h + c)^2}{h\ (h - c)(ab)}\right] \tag{6}$$

The analysis has not been carried out for stresses in a panel simply supported at the outer rim and clamped at the insert. It would be expected that shear stresses in the core would not be greatly affected by type of support at the outer rim. The facing stresses, however, might be considerably greater at the edge of the insert if the outer rim were simply supported rather than clamped. The difference in stress would increase as the panel size decreased. Analyses of homogeneous plates[7] show that bending stresses in a plate twice the size of an insert or hub are about 85 percent greater when the outer rim is simply supported rather than clamped. If the plate is 20 times the size of an insert or hub, the stresses are still about 30 percent greater when the outer rim is simply supported rather than clamped.

Presentation of Data

The results of all tests for the determination of shear stresses in the cores of the five panels tested are tabulated in tables 2 to 6. Column 2 indicates the actual distance of each gage from the center of the panel.

---

[7] Timoshenko, S. Theory of Plates and Shells. New York, 1940.

The readings of the SR-4 gages in the panel cores are tabulated in column 3. Column 4 gives values for shear strains in specimens cut from the core and measured by a dial gage, and column 5 gives the comparable readings of the SR-4 gages in the core. The actual shear stress in each shear specimen is shown in column 6. Since all specimens from one panel were subjected to identical loads, the slight differences shown were actually due to dimensional variations. The modulus of rigidity at eight points in the panel, as determined by the shear-test specimens in which strains were measured by a dial gage, is shown in column 7. The average value shown for each panel was used in all computations. The shear-stress values shown in column 8 for the sandwich panel were obtained by proportioning the shear stress applied on the shear specimen according to the ratios of strain-gage readings for the panel to readings for the shear-test specimens. The computed values tabulated in column 9 were computed using formula (2) with K given by formula (4). The values in column 10 are those obtained in test, while theoretical values computed by formula (4) are tabulated in column 11.

The measured and computed facing strains in panels 4, 5, 6, and 8 are tabulated in table 7 and shown graphically in figure 9. The computed strains shown were computed by means of formula (5). The measured strains in columns 4, 5, 6, and 7 are each the average of two values measured at two directly opposite points on the panels.

Results of Tests

Figure 8 provides a ready means for comparing the observed and computed shear stresses in the panels. The observed values shown and also tabulated in the tables are those obtained at the arbitrarily selected loads applied to the panels. Excellent straight-line relationships were obtained in plotting load increments against measured shear-strain increments, thus indicating that the relationships obtained would apply throughout the elastic range of the panels. Only the computed values for panel 6, which had a balsa core (α = 19.16), and for panel 8, which had a cork core (α = 3.52), are shown in figure 4, since panels 3, 4, and 5 were similar in construction to panel 6 and gave almost identical computed values. The relationships between computed and observed values for panels 3, 4, 5, and 6 are very good both as to the maximum values obtained and as to the indicated trends.

Of interest in design are the maximum values obtained and the point at which these values occur. The practical limitations in the placement of gages and also the limited number of tests made do not permit an accurate determination of these values from the test data. As indicated in figure 8, however, the test data do provide good estimates of these values.

The observed values for panel 8, which had a cork core (a = 3.52), are generally less than the computed values, with the maximum observed value being about 80 percent of the computed value. It is possible that additional tests may have given a better correlation.

Figure 9 shows the observed direct radial strains at various points on the top faces of four of the test panels and the computed strains at the rim of the inserts. The observed values show a rapid increase as the edge of the insert is approached; however, it was not possible to check the strains at the actual rim insert.

Conclusions

Tests of four sandwich panels that had solid end-grain balsa cores, aluminum facings, and solid aluminum central inserts show a good correlation between observed and theoretically computed shear stresses in the cores. Although the tests are limited in number, the close correlation obtained between observed and calculated values indicates that the formulas presented are satisfactory for design purposes. The test of a single panel that had cork-board core gave an observed maximum value about 20 percent less than the computed value.

Observed facing strains in the test panels showed a rapid increase as the insert was approached, to that extent confirming the theoretical analysis; however, the actual maximum strains occurring in the test panels could not be checked by the test method used.

The test methods used in this study necessitated the use of solid cores with substantially uniform properties in the radial and tangential directions. It is recommended that some additional tests of panels with cores of the more commonly used honeycomb, which has nonuniform directional properties, be made to check the applicability of the formulas to this type of construction.

Table 1.--Description of test panels. Panels were 20 inches in diameter with a solid aluminum insert 2 inches in diameter and faces of clad aluminum 0.032 inch thick

Panel No.	Description of core			Average panel thickness	Parameter α
	Type	Density	Shear Modulus		
(1)	(2)	(3)	(4)	(5)	(6)
		Lbs. per cu. ft.	P.s.i.	Inch	
3	End-grain Balsa	9.7	36,160	0.588	20.14
4	..do..	10.1	33,090	.561	18.48
5	..do..	9.3	38,560	.563	19.99
6	..do..	9.4	35,810	.557	19.16
8	Cork board	28.7	1,146	.587	3.52

Table 2.--Results of tests of panel 3 and tests of shear specimens cut therefrom

Gage No.	Distance of gage from center of panel	Panel test	Test of shear specimens		Shear strain at 2,000-pound load	Modulus of rigidity	Shear stress in panel at 400-pound load		K	
		SR-4 strain-gage readings in core	Shear strain in core as determined by dial gage	SR-4 strain-gage readings in core			From test data $\frac{\text{Col. 3}}{\text{Col. 5}}$ x Col. 6	Computed by formula	From test data	Computed by formula 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	In./in.	In./in.	In./in.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1	1.25	0.00260	0.00432	0.00410	177.6	46,350	112.6	90.8	0.985	0.794
3	1.50	.00169	.00445	.00386	166.1	42,050	72.7	76.2	.636	.667
5	1.75	.00212	.00608	.00458	180.5	33,500	83.5	65.4	.730	.572
7	2.00	.00210	.00534	.00448	165.6	35,020	77.6	57.2	.679	.500
8	3.00	.00088	.00584	.00455	168.1	32,500	32.5	38.1	.284	.333
4	4.00	.00093	.00593	.00468	167.2	31,840	33.2	28.6	.291	.250
6	5.00	.00077	.00841	.00600	181.8	24,420	23.3	22.9	.204	.200
2	6.00	.00062	.00434	.00368	167.5	43,580	28.2	19.1	.247	.167
Av.			.00559	.00449		36,160				

Table 3.--Results of tests of panel 4 and tests of shear specimens cut therefrom

Gage No.	Distance of gage from center of panel	Panel test	Test of shear specimens		Shear strain at 2,000-pound load	Modulus of rigidity	Shear stress in panel at 400-pound load		K	
		SR-4 strain-gage readings in core	Shear strain in core as determined by dial gage	SR-4 strain-gage readings in core			From test data $\frac{\text{Col. 3}}{\text{Col. 5}}$ x Col. 6	Computed by formula	From test data	Computed by formula 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	In./in.	In./in.	In./in.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1	1.25	0.00214	0.00415	0.00273	166.9	40,230	130.9	118.9	0.871	0.791
3	1.50	.00225	.00517	.00294	166.9	32,280	127.8	100.2	.850	.667
5	1.75	.00173	.00464	.00280	166.7	35,930	103.0	85.9	.685	.571
7	2.00	.00150	.00569	.00382	168.1	29,580	66.0	75.1	.439	.500
8	3.00	.00087	.00441	.00290	167.2	37,920	50.2	50.1	.334	.333
4	4.00	.00089	.00530	.00318	169.2	31,950	47.3	37.6	.315	.250
6	5.00	.00075	.00629	.00368	167.2	26,580	34.1	30.1	.227	.200
2	6.00	.00057	.00560	.00338	169.5	30,220	28.6	25.0	.190	.167
Av.			.00516	.00318		33,090				

Table 4.--Results of tests of panel 5 and tests of shear specimens cut therefrom

Gage No.	Distance of gage from center of panel	Panel test	Test of shear specimens		Shear strain at 2,000-pound load	Modulus of rigidity	Shear stress in panel at 500-pound load		K	
		SR-4 strain-gage readings in core	Shear strain in core as determined by dial gage	SR-4 strain-gage readings in core			From test data $\frac{\text{Col. 3}}{\text{Col. 5}}$ x Col. 6	Computed by formula	From test data	Computed by formula 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	In./in.	In./in.	In./in.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1	1.25	0.00172	0.00435	0.00230	167.2	38,460	125.1	118.9	0.835	0.794
3	1.50	.00158	.00427	.00260	167.5	39,200	101.8	99.8	.680	.667
5	1.75	Gage dead								
7	2.00	.00119	.00377	.00230	166.7	44,200	86.2	74.8	.576	.500
8	3.00	.00087	.00408	.00254	167.5	41,080	57.4	49.9	.383	.333
4	4.00	.00072	.00456	.00285	166.9	36,600	42.2	37.4	.282	.250
6	5.00	.00050	.00443	.00294	166.7	37,560	28.4	29.9	.189	.200
2	6.00	.00055	.00516	.00288	169.2	32,800	32.3	24.9	.216	.167
Av.			.00437	.00263		38,560				

Table 5.--Results of tests of panel 6 and tests of shear specimens cut therefrom

Gage No.	Distance of gage from center of panel	Panel test	Test of shear specimens		Shear strain at 2,000-pound load	Modulus of rigidity	Shear stress in panel at 400-pound load		K	
		SR-4 strain-gage readings in core	Shear strain in core as determined by dial gage	SR-4 strain-gage readings in core			From test data $\frac{\text{Col. 3}}{\text{Col. 5}}$ x Col. 6	Computed by formula	From test data	Computed by formula 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	In./in.	In./in.	In./in.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1	1.25	0.00173	0.00421	0.00294	167.2	39,730	98.4	120.0	0.650	0.792
3	1.50	.00217	.00525	.00271	167.2	31,860	133.9	100.9	.884	.667
5	1.75	.00158	.00547	.00272	166.7	30,450	96.8	86.5	.640	.571
7	2.00	.00112	.00403	.00250	166.7	41,340	74.7	75.7	.493	.500
8	3.00	.00093	.00404	.00286	167.2	41,400	54.4	50.5	.359	.333
4	4.00	.00092	.00600	.00372	167.2	27,850	41.4	37.9	.273	.250
6	5.00	.00059	.00431	.00330	167.2	38,800	29.9	30.3	.198	.200
2	6.00	.00053	.00477	.00372	167.2	35,050	23.8	25.2	.157	.167
Av.			.00476	.00306		35,810				

Table 6.--Results of tests of panel 8 and tests of shear specimens cut therefrom

Gage No.	Distance of gage from center of panel	Panel test	Test of shear specimens		Shear strain at 100-pound load	Modulus of rigidity	Shear stress in panel at 75-pound load		K	
		SR-4 strain-gage readings in core	Shear strain in core as determined by dial gage	SR-4 strain-gage readings in core			From test data $\frac{\text{Col. 3}}{\text{Col. 5}}$ x Col. 6	Computed by formula	From test data	Computed by formula 4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	In./in.	In./in.	In./in.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
1	1.25	0.00255	0.00618	0.00236[1]	8.32	1,343	9.0	9.2	0.419	0.428
3	1.50	.00192	.00678	.00230	8.29	1,223	6.9	11.3	.322	.526
5	1.75	.00170	.00676	.00199	8.32	1,231	7.1	11.1	.331	.518
7	2.00	.00150	.00723	.00206	8.32	1,151	6.1	10.3	.282	.479
8	3.00	.00142	.00816	.00278	8.38	1,026	4.3	7.2	.199	.333
4	4.00	.00108	.00736	.00253	8.33	1,133	3.6	5.4	.166	.250
6	5.00	.00082	.00780	.00227	8.32	1,067	3.0	4.3	.140	.200
2	6.00	.00089	.00835	.00257	8.33	998	2.9	3.6	.134	.167
Av.			.00733	.00236	8.33	1,146				

[1] Based on average of the other 7 gages.

Table 7.--Observed and computed direct radial strains in facings of panels

Panel No.	Applied center load	Computed facing strains at edge of insert r = 1"	Measured radial facing strains at			
			r = 1-1/16 in.	r = 1-1/4 in.	r = 1-1/2 in.	r = 2 in.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Pounds	In./in.	In./in.	In./in.	In./in.	In./in.
4	500	0.00209	0.00086	0.00051	0.00044	0.00029
5	500	.00200	.00068	.00042	.00038	.00026
6	500	.00206	.00076	.00037	.00032	.00025
7	75	.00096	.00042	.00023	.00007	.00004

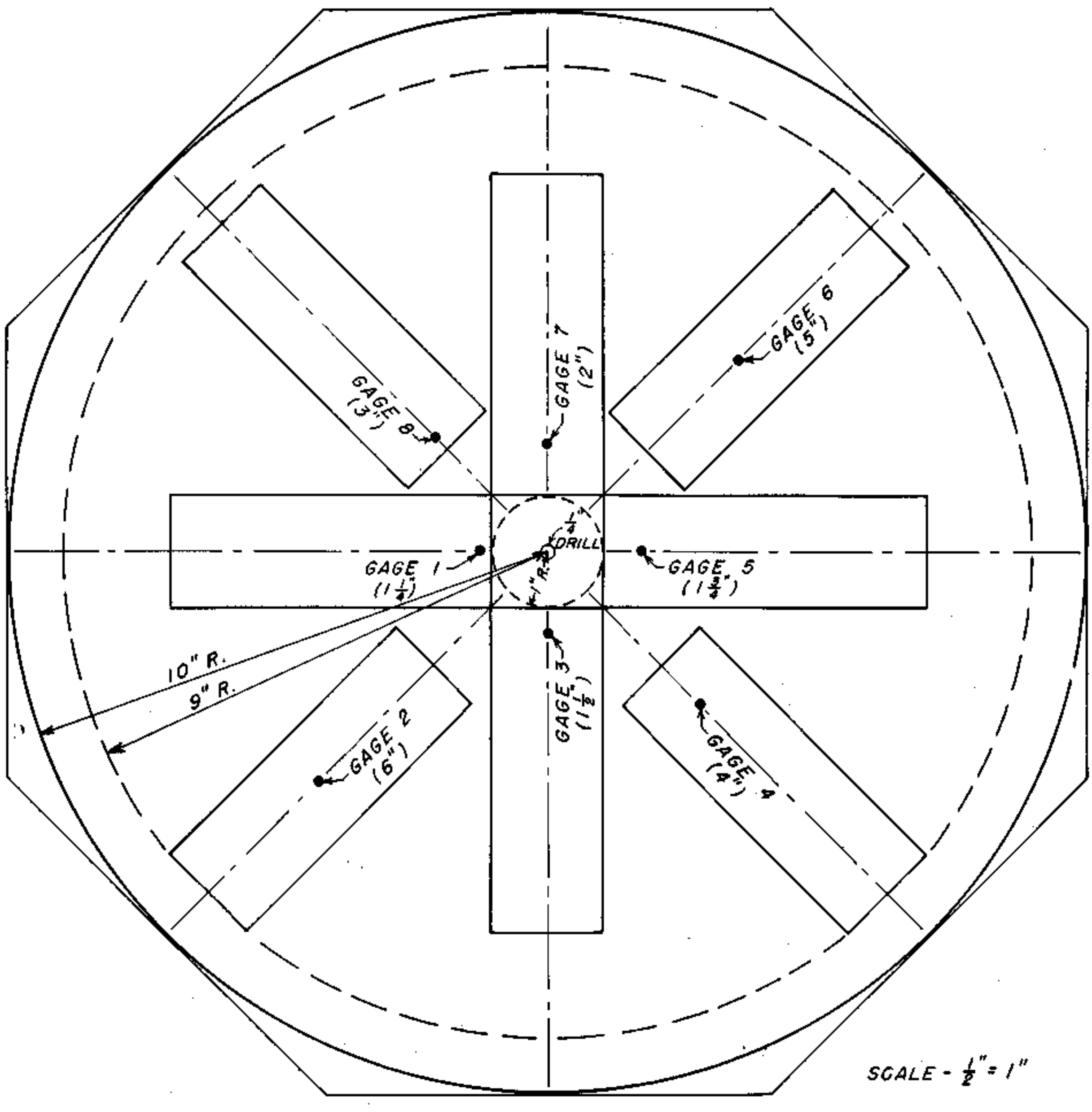

Figure 1. --Details of panel construction, locations of SR-4 gages in core, and the cutting pattern used to obtain shear specimens after the panels were tested.

Z M 97825 F

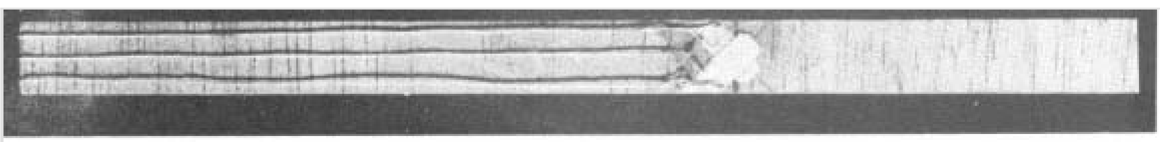

Figure 2. --SR-4 gages in place on one section of balsa core before it was reassembled into the circular panel. Three lead wires were run to the outside edge, with the **central wire being common to both gages.**

Z M 96230 F

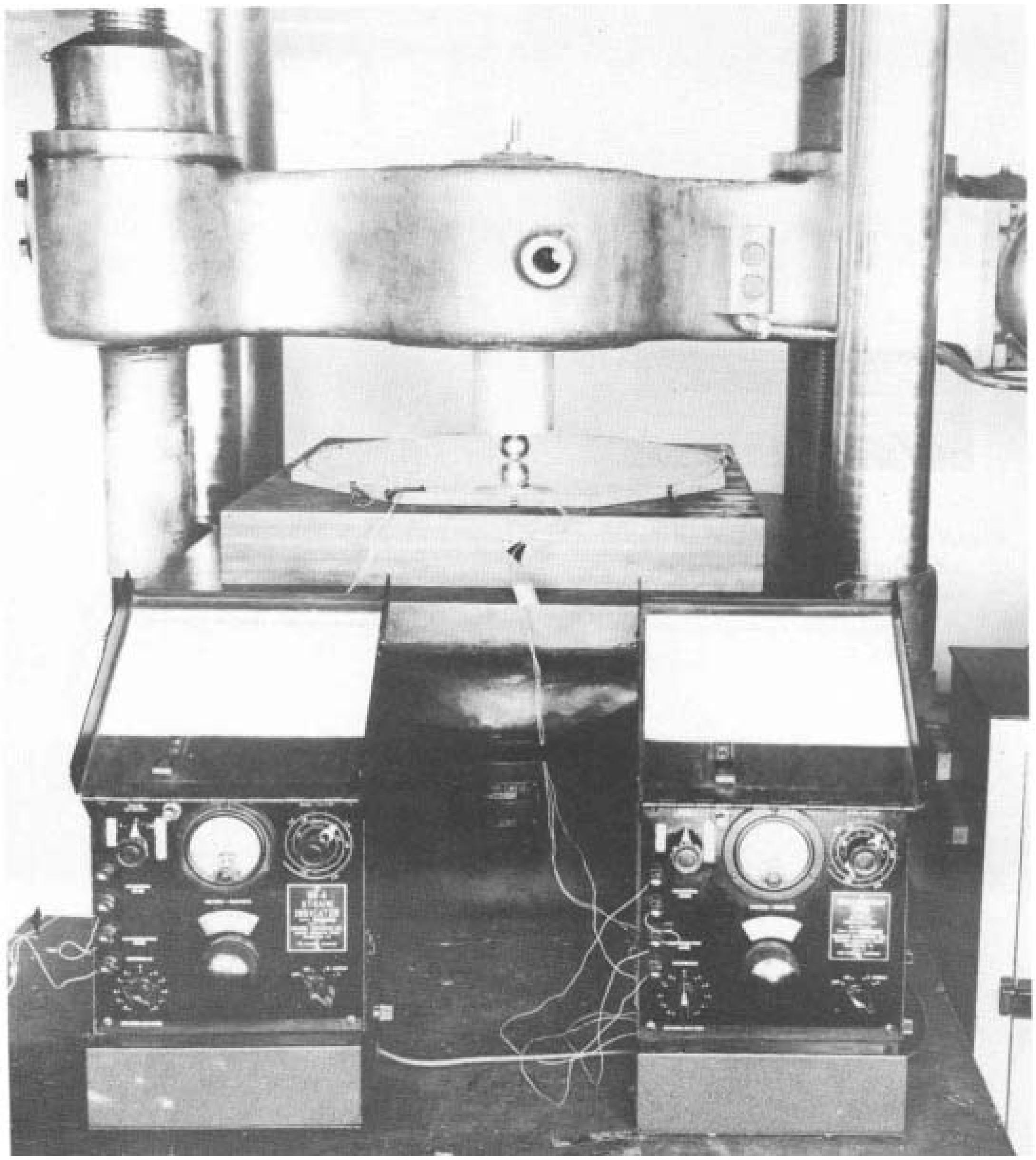

Figure 3. --Cork core panel under test. Load was applied through a steel ball bearing to insure concentric loading of the insert. Two sets of gages were read at one time, and the test was repeated until all gages had been read.

Z M 96661 F

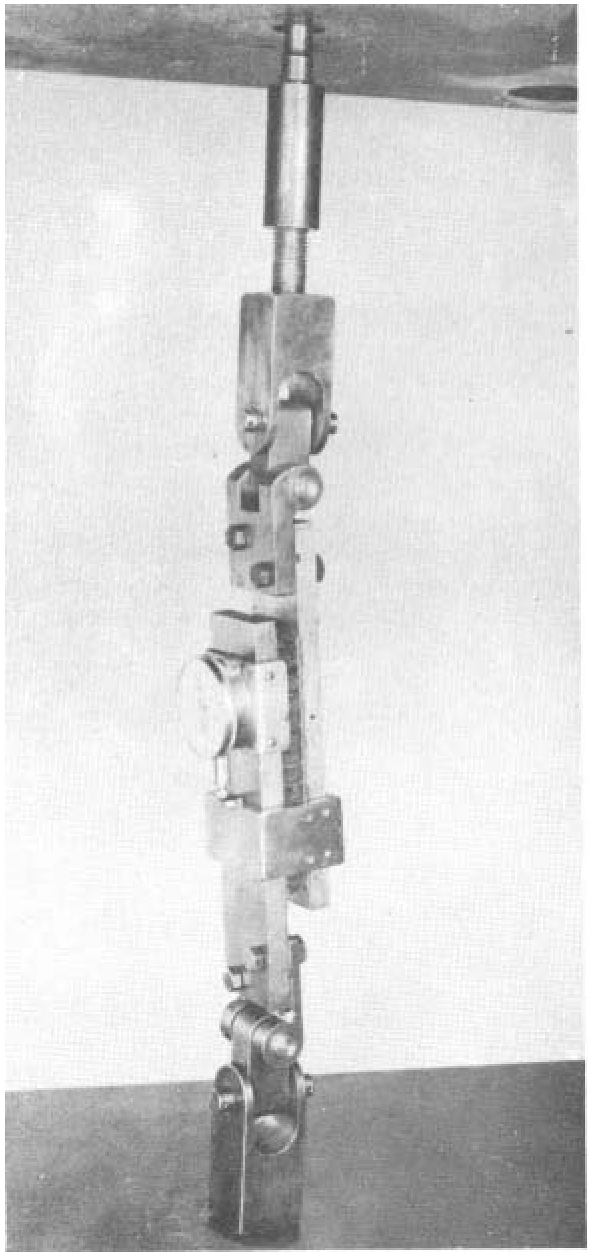

Figure 4. --Apparatus for conducting shear tests of specimens cut from the test panels.

Z M 83718 F

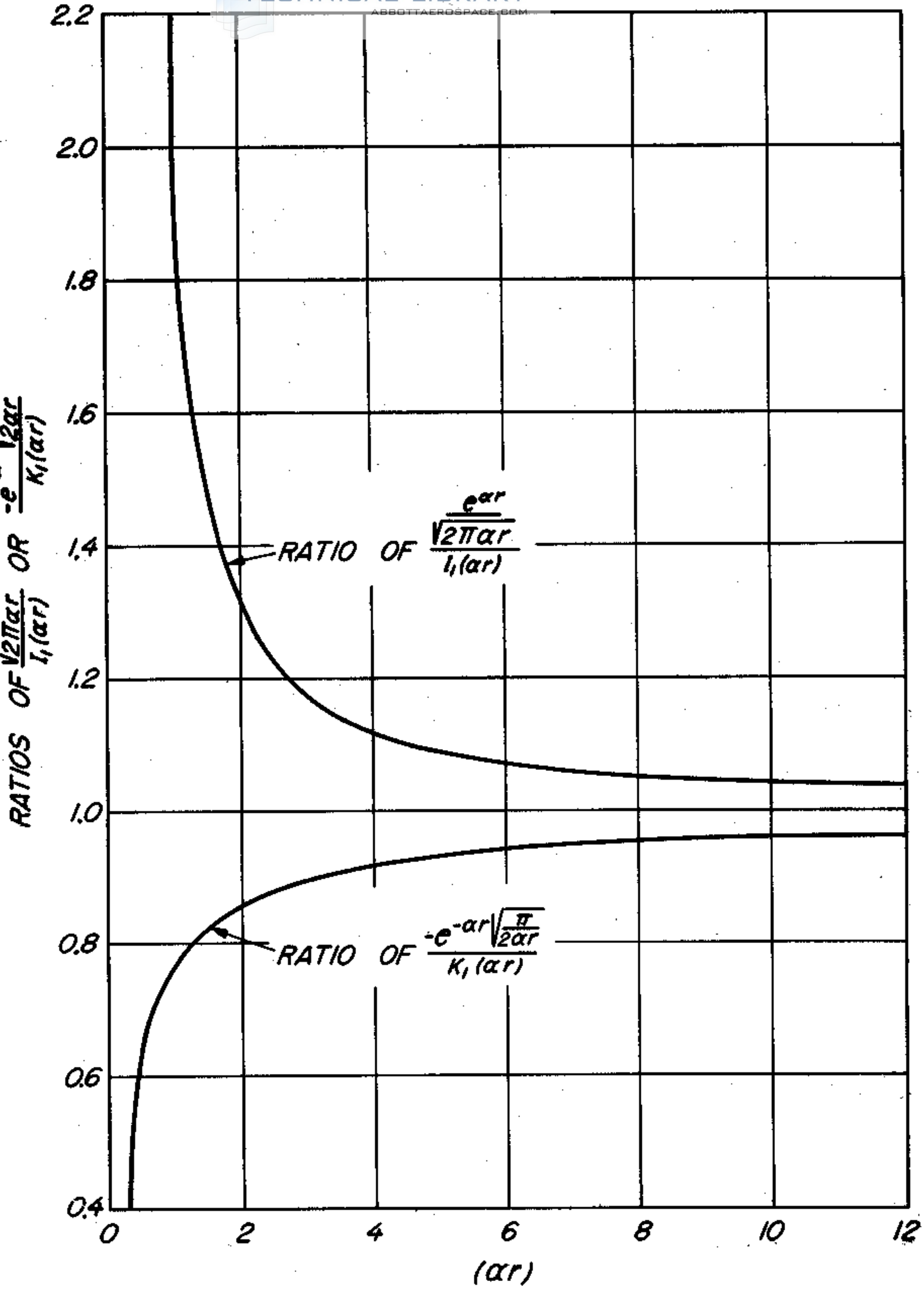

Figure 5. --Relationship between exponential functions and modified Bessel functions.

Z M 97826 F

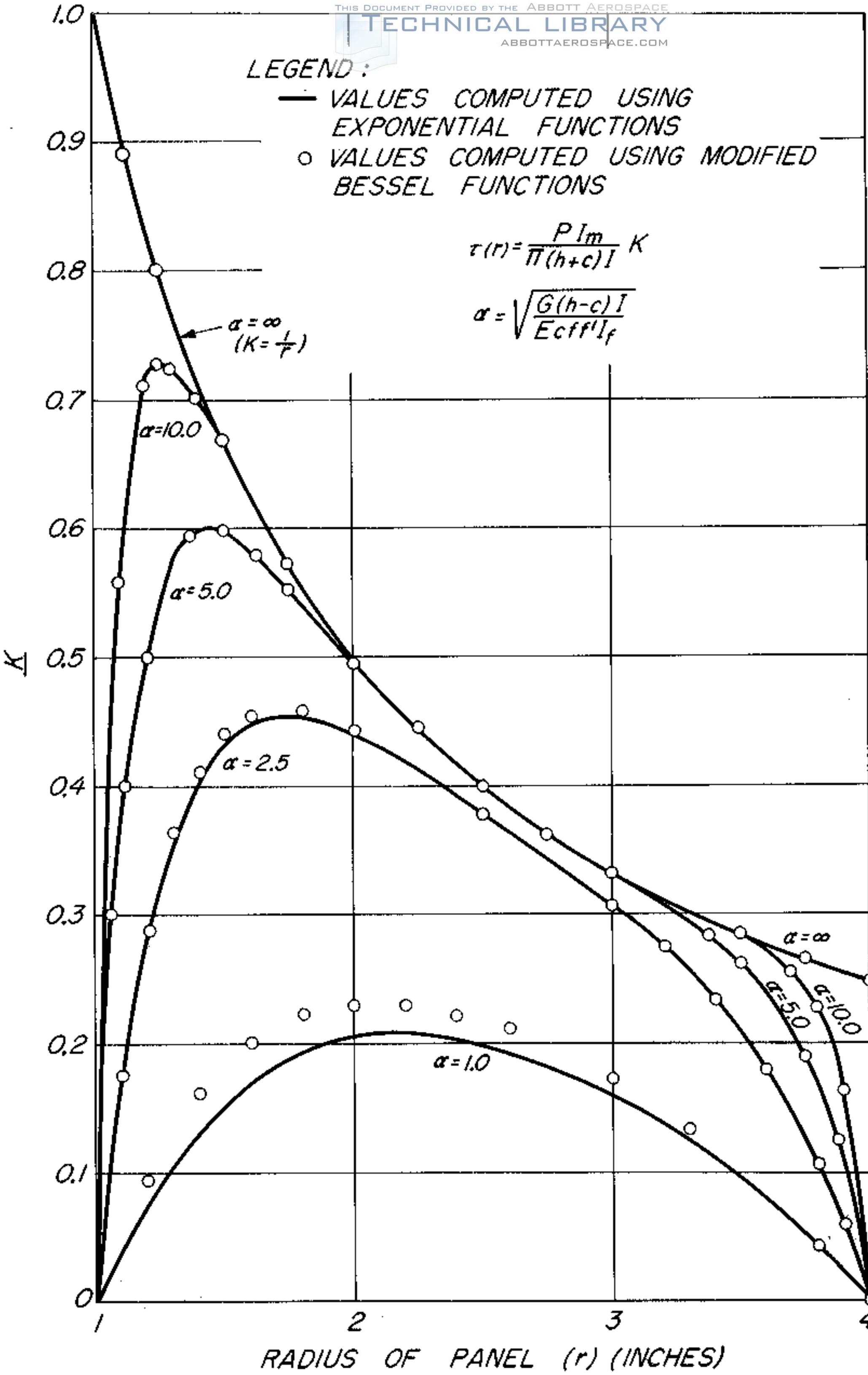

Figure 6. --Radial variation in shear stress in the core of a sandwich panel 8 inches in diameter with a central insert 2 inches in diameter.

Z M 97827 F

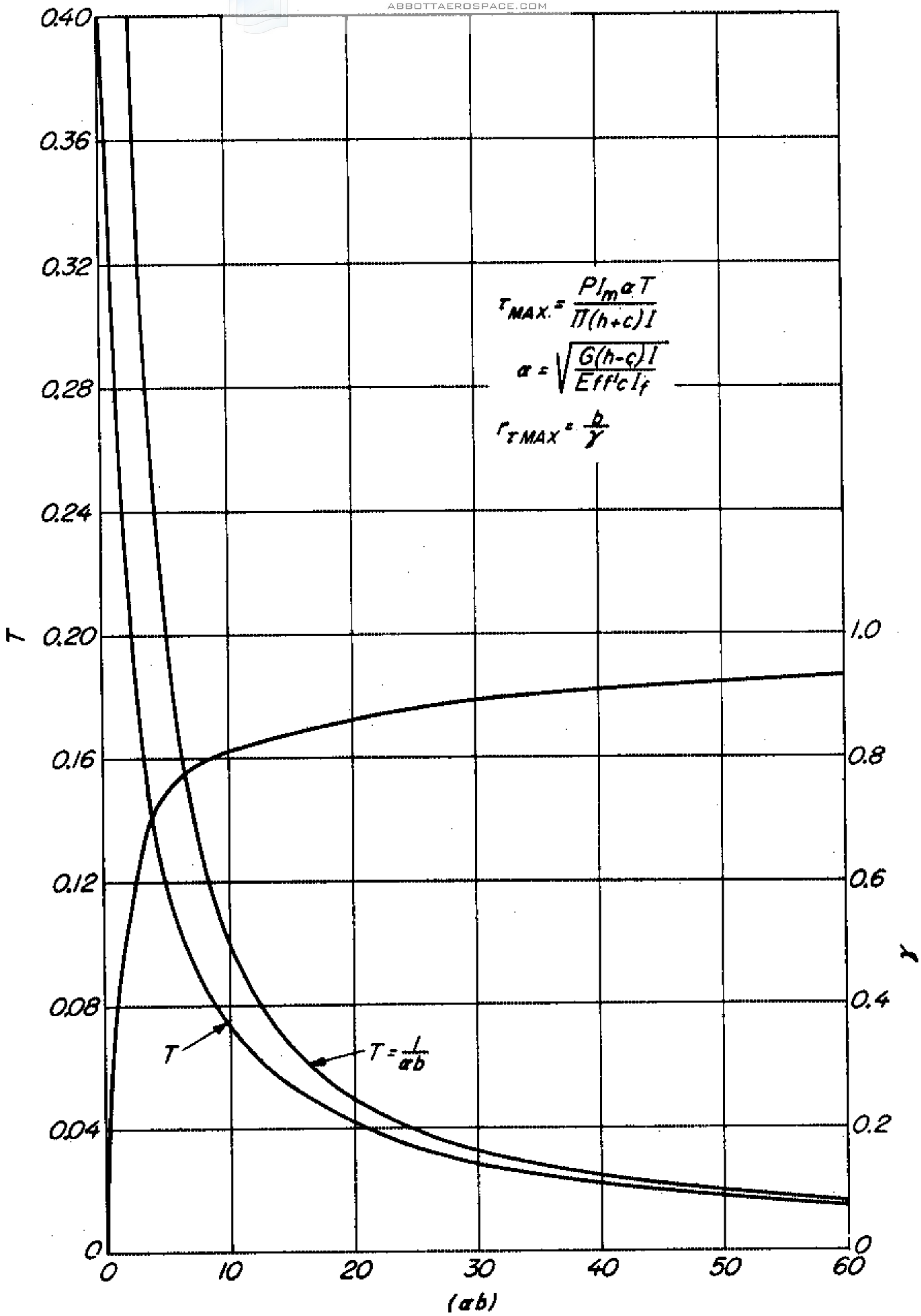

Figure 7.--Maximum shear stress in the core and its radial position for a large, circular sandwich panel with a small, normally loaded, circular insert.

Z M 97828 F

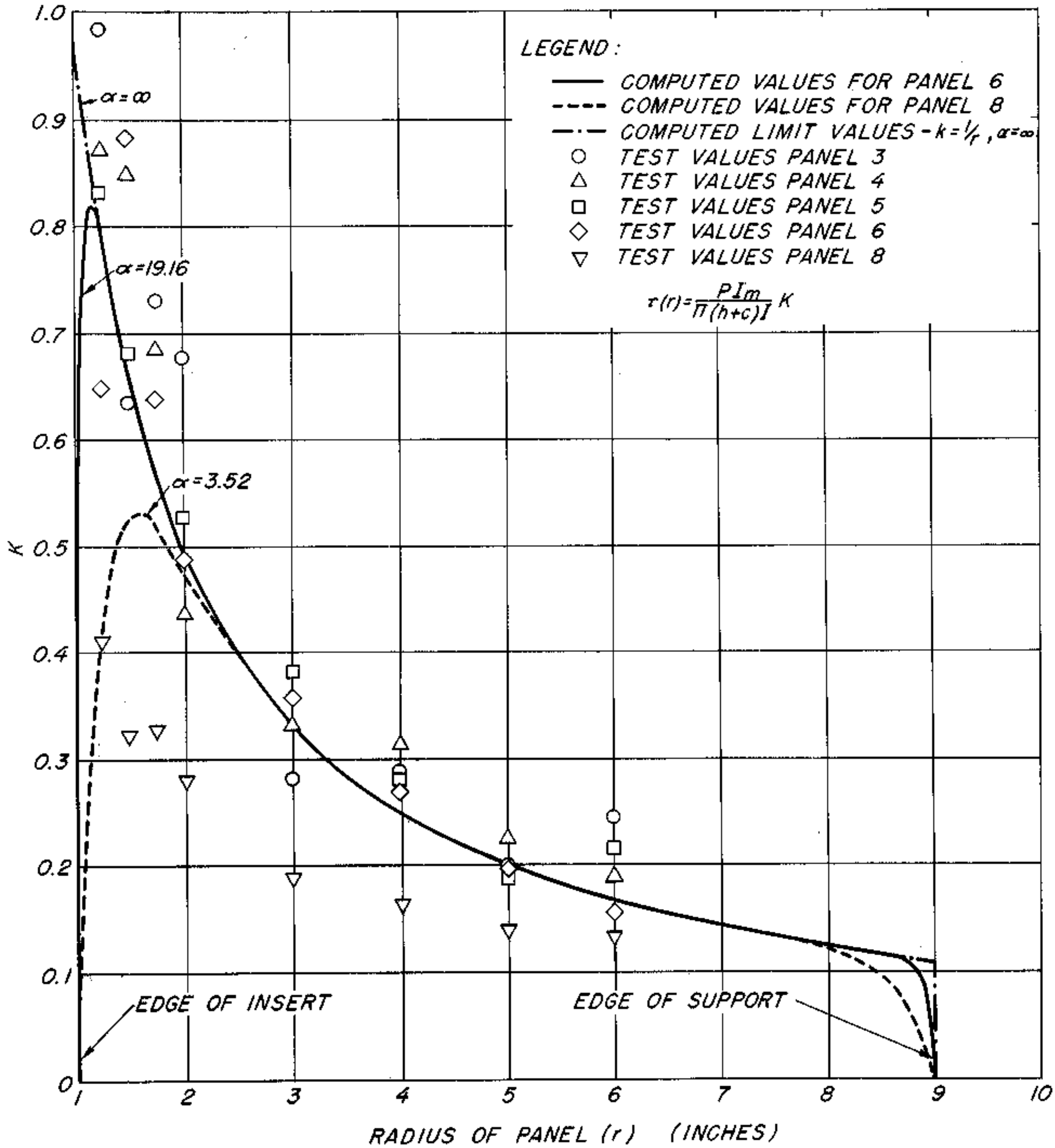

Figure 8.--Computed and observed radial variation in shear stress in the cores. Panels 3, 4, 5, and 6 had balsa cores and aluminum faces; panel 8 had a cork core and aluminum faces.

Z M 97829 F

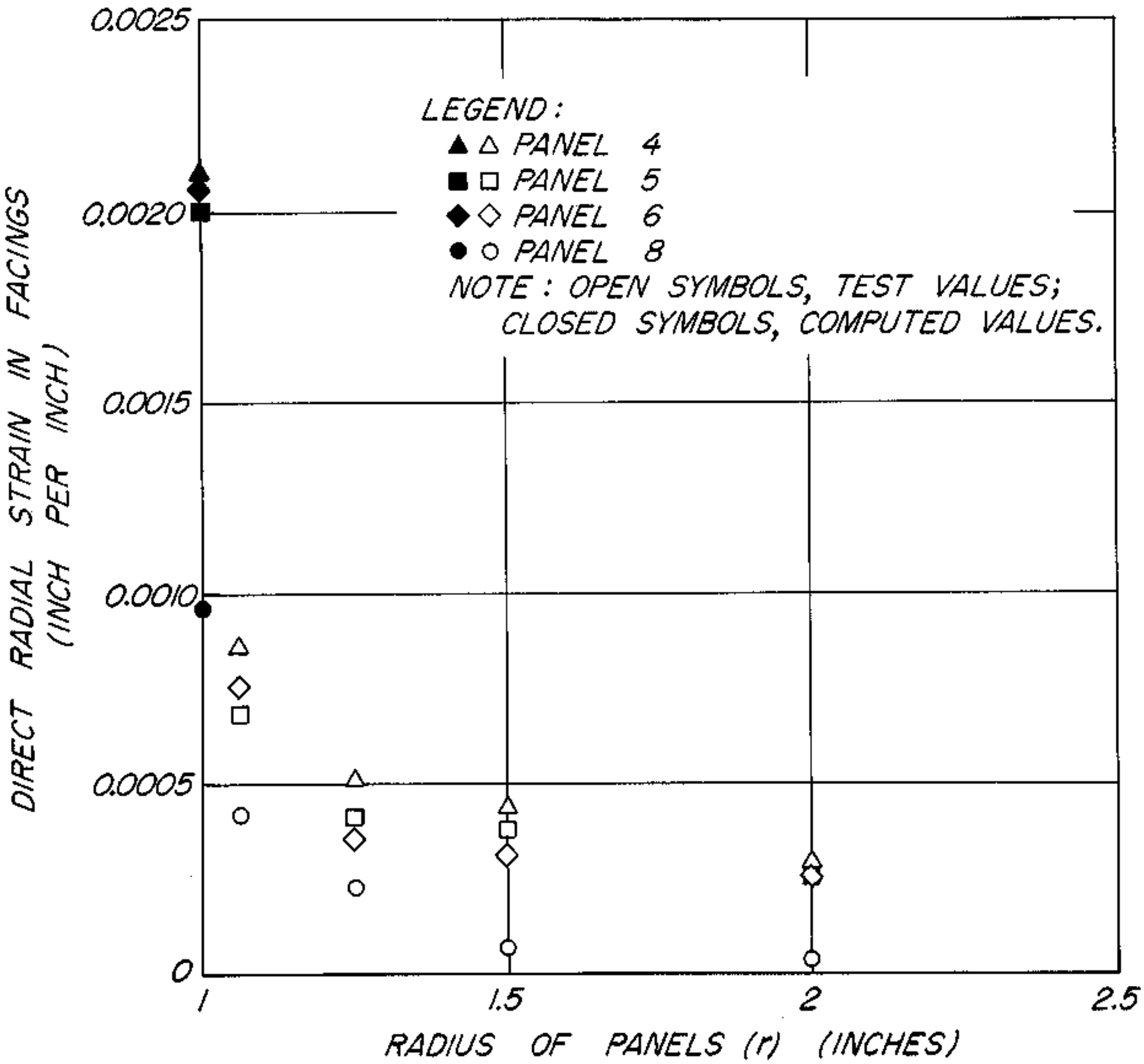

Figure 9.--Relationship between computed radial facing strains at edge of insert and observed facing strains near the insert. All panels had aluminum faces. Panels 4, 5, and 6 had balsa cores; panel 8 had a cork core.

Z M 97830 F