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USAAVLABS TECHNICAL REPORT 68-71

DESIGN, DEVELOPMENT, FABRICATION, AND TESTING OF SMALL AND LARGE LOAD-BEARING PALLETS FOR THE CH-54 "FLYING CRANE" HELICOPTER

By

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U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-67-C-0052

BROOKS & PERKINS, INC.
DETROIT, MICHIGAN

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This report was prepared by Brooks & Perkins, Inc., under the terms of Contract DAAJ02-68-C-0052. It presents the stress analysis used in the load-bearing pallet design, as well as work performed to develop, design, fabricate, and test six small and ten large load-bearing cargo pallets to be used with the CH-54 "Flying Crane" helicopter.

The object of this contractual effort was to achieve a lightweight load-bearing cargo pallet that is compatible with the four-point external load handling system of the CH-54 helicopter and that can withstand the forces imposed in flight and during ground handling.

In general, the design used in this program is sound and reasonable.

The conclusions contained herein are concurred in by this Command.

Project 1X131901D332
Contract DAAJ02-67-C-0052
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DESIGN, DEVELOPMENT, FABRICATION, AND TESTING OF SMALL AND LARGE LOAD-BEARING PALLETS FOR THE CH-54 "FLYING CRANE" HELICOPTER

Final Report

by

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Prepared by

Brooks & Perkins, Inc.
Detroit, Michigan

for

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FORT EUSTIS, VIRGINIA

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SUMMARY

The purpose of this engineering effort was to provide the CH-54 "Flying Crane" helicopter with a significant improvement in the capability of transporting a variety of external cargo loads (in fair as well as inclement weather) which do not have the structural integrity to be supported by slings or which are too bulky to be carried in a cargo pod.

This improvement in capability was achieved by the design, development, fabrication, and testing of load-bearing pallets of two sizes; namely, 88 inches wide by 120 inches long and 88 inches wide by 240 inches long. These pallets can be suspended underneath the helicopter, and they have a design load of 20,000 pounds x 2.5g, uniformly distributed.

The positive results obtained from the testing of the load-bearing pallets, in which the small and large load-bearing pallets were loaded with a uniform load of 80,000 pounds and with a variety of cargo such as engine containers, 105-mm guns, etc., without failure, indicate that the design load and purpose have been met.

The load-bearing pallet's design and configuration allow a variety of cargo, such as helicopter replacement blades, engine pods, ammunition boxes, etc., to be preloaded at the depot, transported with a forklift truck, and attached to the helicopter as a module. Cargo that is too bulky or too heavy, such as trucks, can be loaded and tied down to the load-bearing pallet while it is tied to the helicopter. The use of the load-bearing pallets decreases load instability, especially in inclement weather, thereby extending the inclement weather capability of the helicopter.

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LIST OF SYMBOLS

A	area, $inch^2$
a, l	span, length, inches
b	width, inches
d	total depth, thickness, inches
E	modulus of elasticity, psi
F_{c_y}	compressive yield stress, psi
F_{t_y}	tensile yield stress, psi
F_{s_y}	shear yield stress, psi
F_{br_y}	bearing yield stress, psi
h	distance between sandwich panel skin centroids, inches
I	moment of inertia, $inch^4$
M	bending moment, inch-pounds/inch width
T	sandwich thickness, inches
T_c	sandwich panel core thickness, inches
T_s	sandwich panel skin thickness, inches
w	uniformly distributed load per unit length, pounds/inch
Z	section modulus of cross section, $inch^3$
R_1	load reaction, pounds
R_2	load reaction, pounds
D	diameter roller, inches
P	load/inch, pounds/inch of roller
R	load reaction, pounds/inch

INTRODUCTION

The concept of using lightweight load-bearing pallets to increase the load carrying capacity and capability of the CH-54A helicopter originated with the Project Management Office of the Heavy Lift Helicopter Systems, U.S. Army Materiel Command, St. Louis, Missouri.

In order to test the concept, Brooks & Perkins, Inc. was awarded research and development Contract DAAJ02-67-C-0052 by the U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, to develop, design, fabricate, and test six small and ten large load-bearing pallets to be used with the CH-54A helicopter.

This report presents the stress analysis used in the load-bearing pallet design, the design description, the test results, and the work performed in each of the three phases of the contract.

DISCUSSION

BACKGROUND

The configuration of the CH-54A helicopter does not allow loads to be carried internally; the vehicle frame is used as a support to carry loads suspended underneath it.

The standard procedure for carrying loads was either to attach slings to the load or to place the load in a cargo net, which was then attached to the helicopter. Large and bulky loads, and loads without the necessary structural integrity, either could not be carried or severely limited the operational capability of the helicopter.

Load-bearing pallets, attached to the CH-54A helicopter, were required to fully utilize this load capability. These load-bearing pallets would serve as a tiedown and support for the load. They also would allow carrying of large and bulky loads and loads without the necessary structural integrity for self-support. In addition, this arrangement would decrease the c.g. movement of the load and thus increase the stability and operational capability of the helicopter.

BASIC REQUIREMENTS AND DESIGN CRITERIA

The basic requirements for the design of the load-bearing pallets were that they be as light as possible, uncomplicated, compatible with the external load handling system (winch, hoist, and suspension lines) of the CH-54A helicopter, and adequate to withstand the forces imposed in flight and during ground handling.

In conjunction with the basic requirements, the following specific design criteria were also part of the contractual requirement:

1. The load-bearing pallets (small and large) shall be adequate to support a 20,000-pound uniformly distributed load, while sustaining a 2.5g load factor and aerodynamic loads due to a 100-knot rotor downwash.

2. The lifting eyebolts of the load-bearing pallets shall be compatible with the CH-54A helicopter hoist system hooks.

3. The load restraint fittings of the load-bearing pallets shall be compatible with standard restraint devices and shall meet the following restraint criteria:

Forward	2.0g's
Aft	2.0g's
Vertical (up)	2.0g's
Side	1.5g's

4. The ground handling provisions (forklift tunnels) of the load-bearing pallets (small and large) shall be compatible with standard military forklift trucks with a 10,000-pound capacity.

5. The bottom face of the load-bearing pallets shall be capable of withstanding concentrated loadings due to operation over the "Skate Wheel" and "Dual Rail" type conveyors.

6. The load-bearing pallets shall have 17-inch-wide treadways, 30 inches apart and equidistant from the edges. The carrying capacity of the treadways shall be 950 pounds/ft^2 x 2.5g's.

7. The load-bearing pallets' lifting eyebolts shall be adequate to support the load-bearing pallets under loadings specified in paragraph 1.

8. The small load-bearing pallet shall be suspended from the four corners. The large load-bearing pallet shall be suspended from six points: four at the corners and two in the middle.

9. The small load-bearing pallets shall be so designed that two of them can be connected together to form one large load-bearing pallet.

10. The full capabilities of the load-bearing pallets shall not be degraded by ambient temperatures in the range from +125°F to -65°F.

In addition to the contractual requirements, Brooks & Perkins, Inc. endeavored to make the load-bearing pallet as simple as possible and to use as many standard parts as possible.

DESIGN AND DESIGN DESCRIPTION

Preliminary analysis and previous experience indicated that the best design approach to be followed was to use bonded balsa wood core as the load-carrying medium in the load-bearing pallet. This approach posed several interrelated factors having a direct bearing on the load-bearing pallet's design. Two of the most important factors were the height of the load-bearing pallet (which was limited by the bonding equipment and determined the strength and weight of the load-bearing pallet) and the type of material used (which determined the strength and weight of the load-bearing pallet and the ease of manufacture, as well as delivery dates).

The design of the load-bearing pallets, based upon the stress analysis, has taken these factors into consideration and evolved into the final designs described below:

Small Load-Bearing Pallet (see Figure 1)

The small load-bearing pallet is 5.5 inches high, 120 inches long, and 88 inches wide; it weights 600 pounds. It can be suspended from the helicopter by a sling with either one or four attaching points on the helicopter. The load-bearing pallet is constructed of an 8 pounds/ft^3 average balsa wood core sandwiched between two 7075-T6 0.06-inch-thick aluminum skins and surrounded by structural edge members extruded from 6061-T6 aluminum.

The balsa wood core consists of random-sized balsa wood glued together with urea glue, with the grain of the wood perpendicular to the top and bottom skins of the pallet. The upper and lower skins are bonded to the balsa wood core and the structural edge members with FM-47 adhesive.

The four lifting eyebolts are screwed into 4130 steel castings which form the four corners of the load-bearing pallet and to which the ends of the structural edge members are riveted, thus forming a rigid frame. The balsa wood core is bonded to the frame on the inside.

Eighteen cargo tiedown rings (with 7500 pounds capacity each), five on each of the longer sides and four on each of the shorter sides, spaced approximately 20 inches apart, are located on top of the structural edge members. These tiedown rings can be placed flush against the side of the load-bearing pallet or flat on top of the load-bearing pallet.

Two forklift tunnels, running the entire width of the load-bearing pallet, permit the handling of the load-bearing pallets with standard 10,000-pound-capacity Army forklift trucks. The tunnels are spaced 64 inches apart, center to center, are 10.16 inches wide by 2.90 inches high, and are fabricated from 6060-T6 aluminum.

One short side of the small load-bearing pallet is male; the opposite side is female. Two small load-bearing pallets are joined by connecting the male end of one load-bearing pallet with the female end of another load-bearing pallet and inserting the six quick-release pins attached to the female end into the common holes.

Two black strips locating the treadways, each 15 inches wide and 17 inches from the long edge, are painted on top of the load-bearing pallet. Black station lines, 3 feet apart, are painted on top of the load-bearing pallet, perpendicular to the long side. "F.S.N. 1670-H23-0178", "Maximum Load Capacity 20,000 pounds", and "Maximum Vehicle or Load Contact Pressure: 300 psi" legends are painted in the lower right-hand corner of the load-bearing pallet.

Commercial and Military Standard hardware used in the load-bearing pallet comprises nuts, bolts, rivets, cargo tiedown rings, snap rings, adhesives, chains, quick-release pins, and lifting eyebolts.

Figure 1. Small Load-Bearing Pallet With Spare Engine Containers.

Large Load-Bearing Pallet (see Figure 2)

The large load-bearing pallet is 5.5 inches high, 240 inches long, and 88 inches wide; it weights approximately 1100 pounds. Six lifting eyebolts, one in each corner and two at approximately the 120-inch station, are provided. This arrangement requires a lifting sling with four suspension points for the helicopter and six for the load-bearing pallet.

The construction and the density of the balsa wood core are the same as those of the small load-bearing pallet. Structural edge members form a frame around the core, with the top and bottom skins bonded to the balsa wood core and the structural edge members with FM-47 adhesive.

The corners of the load-bearing pallet are formed by riveting the two ends of the structural edge members to the corner castings, into which the lifting eyebolts are screwed.

The large load-bearing pallet is divided in the middle by a 6061-T6 aluminum I-beam which is riveted at each end to an angle and a corner casting; each end, in turn, is then riveted to the structural edge members. Twenty-eight cargo tiedown rings, ten on each of the longer sides and four each on the shorter sides (spaced approximately 20 inches apart) are located on top of the structural edge members. Two forklift truck tunnels, spaced 83 inches center to center, run the entire width of the load-bearing pallet. Two 0.09-inch-thick 7075-T6 aluminum plates, one on the top and the other at the bottom side of the load-bearing pallet, are each fastened at the center to skins and I-beam by 72 MS20601-AD5W6 rivets, spaced 2 inches apart.

Commercial and MS hardware used is represented by the same parts as those used on the small load-bearing pallet, with the exception of the quick-release pin, which is unique to the small load-bearing pallet.

The color, dimensions, and spacings of the treadways and station lines are the same as those used on the small load-bearing pallet. The information regarding the maximum load capacity and maximum vehicle or load contact pressure is the same as that of the small load-bearing pallet, with the exception of the Federal Stock Number (F.S.N. 1670-H23-0177 in this case).

TEST FIXTURE DESIGN AND TESTING

Test Fixture

The test fixture, shown in Figures 3 and 4, consisted of interconnected I-beams upon which a 2-inch-thick layer of plywood was placed. Four air bags were placed on the plywood (to induce the pressure to the load-bearing pallets), with the air lines from each of the air bags interconnected to a common manifold, which is connected to a single air supply line. The supply of air to the air bags was regulated with an air

Figure 2. Large Load-Bearing Pallet With Spare Rotor Blades.

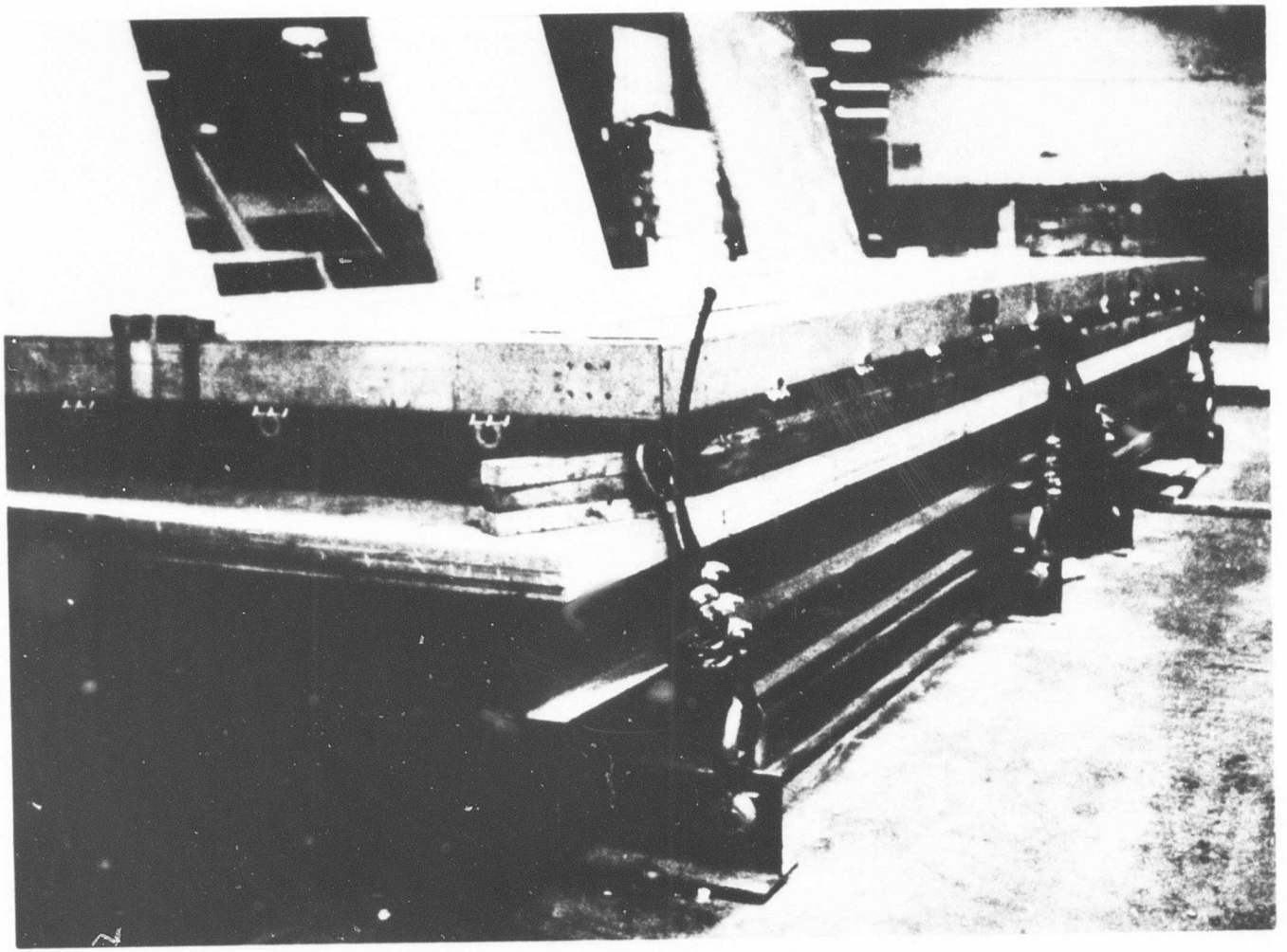


Figure 3. Test Fixture With Large Load-Bearing Pallet.

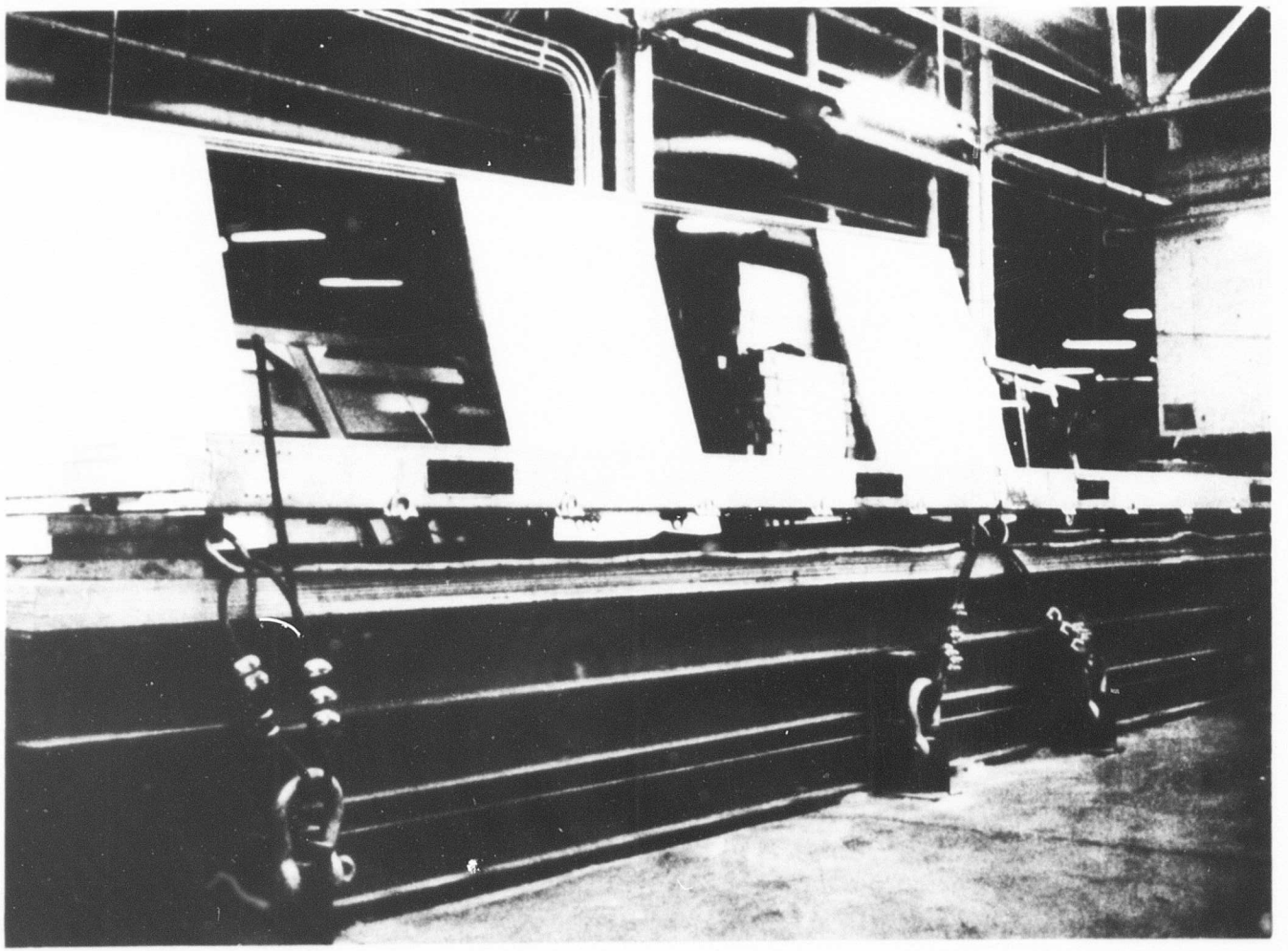


Figure 4. Test Fixture With Two Small Load-Bearing Pallets Joined Together.

regulator and monitored with a 0-psi to 15-psi air gage with a .25-psi graduation. The load-bearing pallets were placed on the air bags, and the load was induced into the load-bearing pallets by inflating the air bags while restraining the load-bearing pallets with cables connected between the load-bearing pallet lifting eyebolts and the tiedown points on the I-beams of the test fixture.

The design of the test fixture allowed the testing of either one small, one large, or two small load-bearing pallets joined, with the tiedown cables oriented at the proper tiedown angles (see Figure 5). These tiedown angles, which were calculated from prints and sketches supplied to Brooks & Perkins, Inc., by the U.S. Army Aviation Materiel Laboratories, represent the angles that the load-bearing slings of the helicopter make with the load-bearing pallets.

Inspection of Load-Bearing Pallets Prior to Testing

All load-bearing pallets were inspected prior to testing. During the inspection of the load-bearing pallets that were to be tested to destruction (two small and one large), it was discovered that a section of one of the shorter sides of the bottom skin of one small and one large load-bearing pallet was not bonded to the extrusion. The length and width of the unbonded skin section were approximately 24 inches and 1.5 inches, respectively.

The repair of the unbonded sections was accomplished by injecting liquid FM-47 adhesive between the skin and the extrusion and by riveting a section of the skin approximately 60 inches long, inclusive of the 24 inches of unbonded section, to the extrusion with 5/32-inch-diameter rivets spaced approximately 1.5 inches apart.

Test of Load-Bearing Pallets

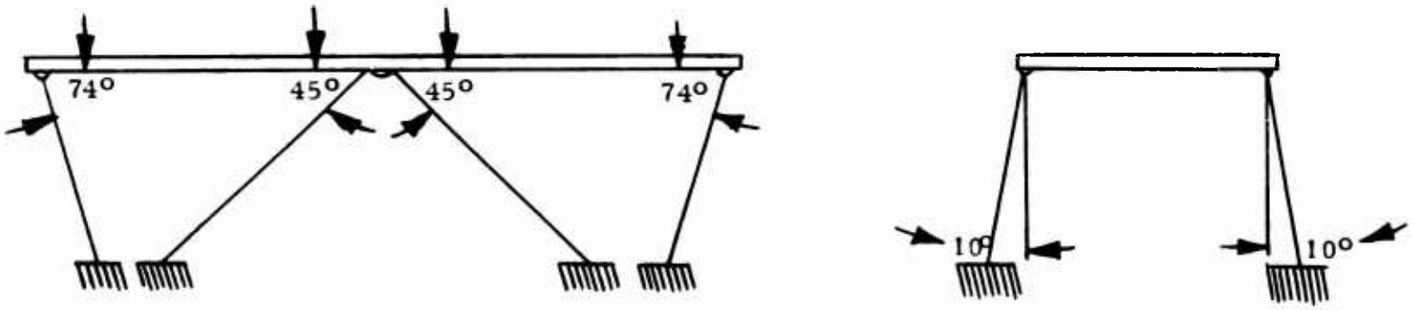
The load-bearing pallets were tested at Brooks & Perkins, Inc., facilities in Cadillac, Michigan.

Two types of tests were performed. The first test was to destruction or an equally distributed load of 80,000 pounds. The second was a proof test which involved loading the pallets with a 50,000-pound load, uniformly distributed.

1. Destructive Testing of Load-Bearing Pallets

The testing involved one large and two small load-bearing pallets, tested in the following sequence: one large load-bearing pallet, two small load-bearing pallets joined together, and one small load-bearing pallet. The procedure used in testing the load-bearing pallets is outlined below:

LARGE LOAD-BEARING PALLET



SMALL LOAD-BEARING PALLET

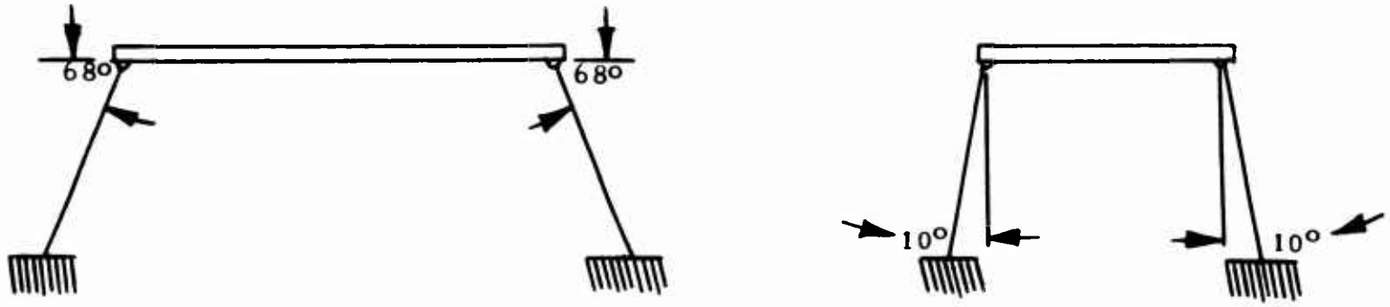


Figure 5. Load-Bearing Pallet Sling Angles.

Large Load-Bearing Pallet

a. The pallet was placed on top of the four air bags, with the top of the pallet facing down, and with the corners supported above the deflated air bags by 3-inch-high wooden blocks. Two air bags were used on the small load-bearing pallet.

b. Steel cables were connected between the pallet lifting eyes (six) and the tiedown points on the bottom test fixture I-beams. Four steel cables were used to tie down the small load-bearing pallet.

c. The air bags were inflated to a pressure of 1 psig, and the cables were adjusted so that the load would be taken by each cable at the same time.

d. The air regulator and air gage were checked for proper functioning by inflating and deflating the air bags twice.

e. The load was applied to the pallet in increments as shown in Table I, with the deflection readings taken in the center of the load-bearing pallet at the 1/4 distance (60 inches), the midpoint (120 inches), and the 3/4 distance (180 inches).

Table I. Load and Deflection of Large Load-Bearing Pallet

Reading of Air Gage (psi)	Equivalent Load (pounds)	Length of Time Load Was Held (seconds)	Deflection (inches)		
			1/4	Midpoint	3/4
1	21,120	0	-	-	-
1	-	45	.25	.50	.37
1.6	33,792	60	.62	.62	.37
2.1	44,352	45	.50	.37	.50
2.5	52,800	60	.50	.62	.62
3	63,360	45	.62	.75	.62
3.8	80,000	15	.75	1.00	.75

Result of Test: The pallet was subjected to an equally distributed load of 80,000 pounds without failure or permanent deformation. The deflection at the center of each of the two pallet halves was approximately 0.75 inch, while the deflection at the center of the pallet (cross beam) was approximately 1 inch.

Two Small Load-Bearing Pallets Joined Together

The procedure used for testing the two small pallets joined together was the same as that for the large pallet, except that

the load intervals and, consequently, the air gage readings were different (see Table II). The deflection readings were taken in the center of the load-bearing pallets, at the 1/4 distance (60 inches), at the midpoint (120 inches), and at the 3/4 distance (180 inches).

Table II. Load and Deflection of Two Small Joined Load-Bearing Pallets

Reading of Air Gage (psi)	Equivalent Load (pounds)	Length of Time Load Was Held (seconds)	Deflection (inches)		
			1/4	Midpoint	3/4
1	21,120	7			
1.6	33,792	1.75	Deflection readings		
2	42,240	1.75	were not taken		
2.45	51,744	1.5	during the inter-		
2.6	54,912	1.45	mediate loads on		
2.9	61,248	1.3	this test.		
3.5	73,920	1.3			
3.75	79,200	15			
3.8	80,000	Stop	.75	1.00	.75

Result of Test: The two small load-bearing pallets joined together were subjected to a uniformly distributed load of 80,000 pounds without any failure or permanent deformation. The maximum deflections were approximately 1 inch at the joint of the two pallets and 0.75 inch at the center of each of the two pallets.

One Small Load-Bearing Pallet

The small load-bearing pallet was loaded with a uniformly distributed load of approximately 30,000 pounds. At this load, two eyebolts failed in bending and tension, with the failures occurring in the threads approximately 0.10 inch below the grip of the eyebolt. The failures of these two eyebolts, located at the corner of one of the short edges, did not occur simultaneously, but were spaced approximately one second apart. Examination of the load-bearing pallet and the failed eyebolts indicated the following:

a. The load-bearing pallet did not appear to be damaged.

b. The failure of the eyebolts was due to a loose fit, approximately 0.12 inch between the eyebolt grip O.D. and the corner casting eyebolt I.D., which created a moment arm of 2.5 inches which resulted in a bending moment which induced a tensile stress exceeding the ultimate stress of the eyebolt.

c. The hardness of the two failed specimens was checked, and consistent readings of C50-51 were obtained. The C50 reading indicates a tensile strength of 243,000 psi.

Modification and Retest of the Small Pallet

The modification of the pallet consisted of inserting a close-toleranced sleeve made from S.A.E.5210 steel between the eyebolt grip and the corner casting eyebolt hole, thereby, in effect, cutting the moment arm from 2.5 inches to 1.0 inch and reducing the bending moment correspondingly. Also, the tensile stress was reduced to a level of the ultimate stress of the lifting eyebolt.

The retest of the modified small load-bearing pallet was performed, applying the same testing procedure as used previously, with the following results:

a. The modified small load-bearing pallet was loaded with a uniformly distributed load of 80,000 pounds without failure or permanent deformation.

b. The maximum deflection of the load-bearing pallet resulting from the 80,000 pounds was approximately 0.75 inch in the center of the pallet. The load increments and the corresponding psi readings to which the load-bearing pallet was subjected are shown in Table III.

Table III. Load and Deflection of Small Load-Bearing Pallet

Reading of Air Gage (psi)	Equivalent Load (pounds)	Deflection at Midpoint (inches)
0	0	
0.94	10,000	
1.9	20,000	Deflection readings
2.8	30,000	were not taken during
3.7	40,000	the intermediate
4.7	50,000	loads on this test.
5.6	60,000	
6.6	70,000	
7.6	80,000	.75

c. At a load of approximately 60,000 pounds, it was noticed that one short side of the load-bearing pallet was higher than the opposite side. At 80,000 pounds, the difference in height was approximately 5 inches, which was caused by slippage in the tiedown cables. This condition was not considered to

be detrimental because the loading on the pallet and eyebolt under the above condition was more severe than would normally be encountered; therefore, the test was considered to be valid.

As a result of the two tests performed on the small load-bearing pallet, the design configuration was changed to reflect the tight fit between the eyebolt O.D. and the corner casting eyebolt hole I.D.

2. Proof Testing of Load-Bearing Pallets

Nine large and four small load-bearing pallets were proof tested. The test procedure was the same as that used in the destructive testing, except that the loading was held to 50,000 pounds, equally distributed. No failure or permanent deformation was encountered.

In addition to the proof testing performed at Brooks & Perkins, Inc., in Cadillac, Michigan, two small and two large load-bearing pallets were shipped to Fort Sill, Oklahoma, for testing by the Army. This testing lasted approximately two weeks and involved checking the compatibility of the load-bearing pallets with slings and helicopter hoisting and load-carrying systems.

Some of the variety of loads that were carried by the load-bearing pallets included: 105-mm guns with ammunition, spare engine containers, spare helicopter blades in 36-foot-long boxes, and 3/4-ton trucks. No failure or permanent deformation was encountered.

CONCLUSIONS

The destructive and proof tests of the small and large load-bearing pallets performed by Brooks & Perkins, Inc., and the service tests performed by the Army at Fort Sill, Oklahoma, confirmed the structural adequacy and compatibility of the load-bearing pallets as set forth in the design criteria.

Specifically, the capabilities of the small and large load-bearing pallets and their components are:

1. The load-bearing pallets will support a load of 20,000 pounds x 2.5g and loading due to a 100-knot downwash.

2. The four lifting eyebolts of the small load-bearing pallet are compatible with the hoist system hooks and are capable of supporting the small load-bearing pallet when it is suspended from four points on the helicopter.

3. The six lifting eyebolts of the large load-bearing pallet are capable of providing support from four points on the helicopter and are also compatible with the hoist system hooks.

4. The load-bearing pallets will withstand the loads due to the difference (1 inch) in sling leg or suspension leg length.

5. The load-bearing pallet's treadways are adequate to support vehicles that fall within the load and size limitations of the load-bearing pallet. The treadway load limitation is 950 pounds x 2.5g.

6. The bottom skins of the load-bearing pallets are capable of withstanding loadings due to operation over the "Skate Wheel" and "Dual Rail" type conveyors.

7. The load-bearing pallets can be handled by standard Army forklift trucks of 10,000 pounds capacity.

8. The cargo tiedown rings are compatible with standard restraint devices (nets) and are capable of withstanding the cargo restraint factors listed under "Basic Requirements and Design Criteria."

9. Two small load-bearing pallets can be joined together and used as one large load-bearing pallet.

LITERATURE CITED

1. Hexcel Products, Inc., "Honeycomb Sandwich Design", Brochure "E".

2. Balsa Ecuador Lumber Corporation "Mechanical Properties of BelcoBalsa", Data Sheet.

3. Roark, Raymond J., "Formulas for Stress and Strain", Third Edition, New York, McGraw-Hill Book Company, Inc. 1954 P. 288, Case 4, Table XIV.

APPENDIX I

STRESS ANALYSIS

In performing the stress analysis for the design of the load-bearing pallet, the following assumptions and criteria have been used:

1. A load of 50,000 pounds (20,000 pounds x 2.5g) is equally distributed on the small and large load-bearing pallets.

2. A wind load of 100 mph, due to rotor downdraft on the unshielded portion of the load-bearing pallet, is contributing 33 pounds/ft^2 to the loading.

3. A load of 950 pounds/ft^2 x 2.5g is distributed on two 17-inch-wide treadways on the small and large load-bearing pallets.

4. The forklift tunnels have to accept a standard Army forklift truck with a 10,000-pound capacity.

5. The analysis of the large load-bearing pallet is not included because the load that has to be carried by the large load-bearing pallet is the same as that for the small, but the area is double; therefore, the stresses are not as high as for the small load-bearing pallet.

1. Load Calculation - Small Load-Bearing Pallet: $v = 100$ mph

20,000 pounds x 2.5g + Wind Load

$$\text{Wind Load} = .0033v^2$$
$$= 3.3 \times 10^{-3} \times 1 \times 10^4$$
$$= 3.3 \times 10$$
$$= 33 \text{ pounds/ft}^2$$

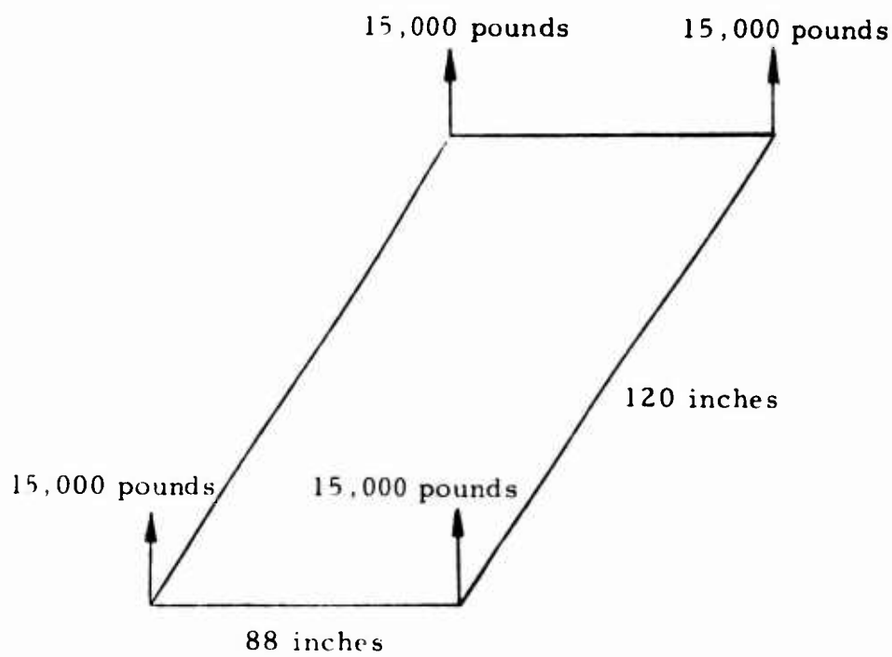
$$\frac{50,000 \text{ pounds}}{73 \text{ ft}^2} + 33 \text{ pounds/ft}^2$$

$$(685 \text{ pounds} + 33 \text{ pounds})\text{ft}^2$$

718 pounds/ft^2

5 psi make it 5.7 = 820.8 pounds/ft^2 = 59,918.4 pounds = 60,000 pounds

2. Bending Moment Calculations - Small Load-Bearing Pallet:



In calculating the maximum bending moment, it was assumed that the shorter side was simply supported first, and then the longer side.

$$M_{width} = \frac{w \times l^2}{8}$$

$$= \frac{5.7 \times 88^2}{8}$$

$$= \frac{5.7 \times 7744}{8}$$

$$= 5500 \text{ inch-pounds/inch width}$$

$$M_{length} = \frac{w \times l^2}{8}$$

$$= \frac{5.7 \times 120^2}{8}$$

$$= \frac{5.7 \times 14400}{8}$$

$$= 10,200 \text{ inch-pounds/inch length}$$

$$M_I = \sqrt{M^2_w + M^2_t}$$

$$= \sqrt{(5500)^2 + (10,200)^2}$$

$$= \sqrt{30,250,000 + 104,040,000}$$

$$= \sqrt{134,290,000}$$

$$= 11,550 \text{ inch-pounds/inch}$$

3. Moment of Inertia and Section Modulus Calculations:

In the sandwich panel design, the upper and lower skins took the tension and compression loads, respectively.

$$\text{Section Modulus} = Z = \frac{b(T^3 - T_c^3)}{6T}$$

$b = 1.00$ inch
$T = 5.625$ inches
$T_c = 5.50$ inches
$T_s = .063$ inch

$$Z = \frac{1\,(5.625^3 - 5.50^3)}{6(5.50)}$$

$Z = .35$ inch^3/inch width

Moment of Inertia $= I = \frac{b(T^3 - Tc^3)}{12}$

$$I = \frac{1\,(5.625^3 - 5.50^3)}{12}$$

$$I = .98 \text{ inch}^4/\text{inch width}$$

4. Required $Z = \frac{M}{F_{t_y}} = \frac{11,550}{66,000} = .175 \text{ inch}^3/\text{inch width for 7075-T6}$

Available $Z = .35 \text{ inch}^3/\text{inch width}$

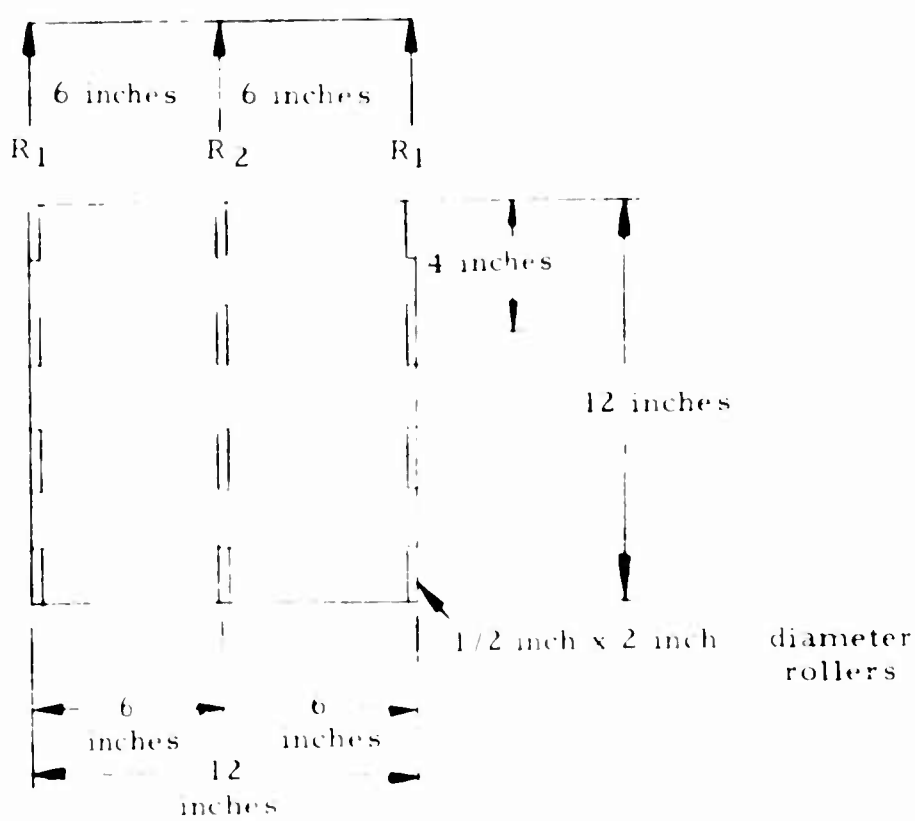
Facing stress $= \frac{M}{T_c T_s} = \frac{11,550}{5.5 \times .063} = \frac{11,550}{.35} = 33,000$ psi (ref. 1)

Allowable facing stress = 66,000 psi using 7075-T6 aluminum.

Core shear stress $= \frac{lw}{T + T_c} = \frac{120 \times 5.7}{5.62 + 5.5} = \frac{6.83}{11.12} = 61$ psi (ref. 2)

Allowable core shear stress = 250 psi using 8 pounds/ft^3 balsa.

5. "Skate Wheel" Conveyor Load Analysis:



Total load (maximum) = 20,000 pounds x 2.5 = 50,000 pounds (on conveyor)

Load per 1 ft^2 = $\frac{50,000 \text{ pounds}}{73 \text{ ft}^2}$ = 685 pounds/ft^2 = 4.75 psi

Load per "Skate Wheel":

$R_1 = \frac{3}{8}$ wl w = 4.75 pounds/inch

$= \frac{3}{8}$ x 4.75 x 6 inches

= 7.6 pounds/inch = 81.2 pounds/ft = 20.3 pounds/wheel

$R_2 = \frac{10}{8}$ wl

$= \frac{5}{4}$ x 4.75 x 6 inches

= 35.6 pounds/inch = 427.2 pounds/ft = 106.5 pounds/wheel

Stress on skin due to roller:

Roller length (width) = 5 inches

Load/inch = 106.5/.5 = 213 pounds/inch

Maximum compression stress:

$$F_{cy} = .798 \sqrt{D \frac{P}{\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2}}}$$

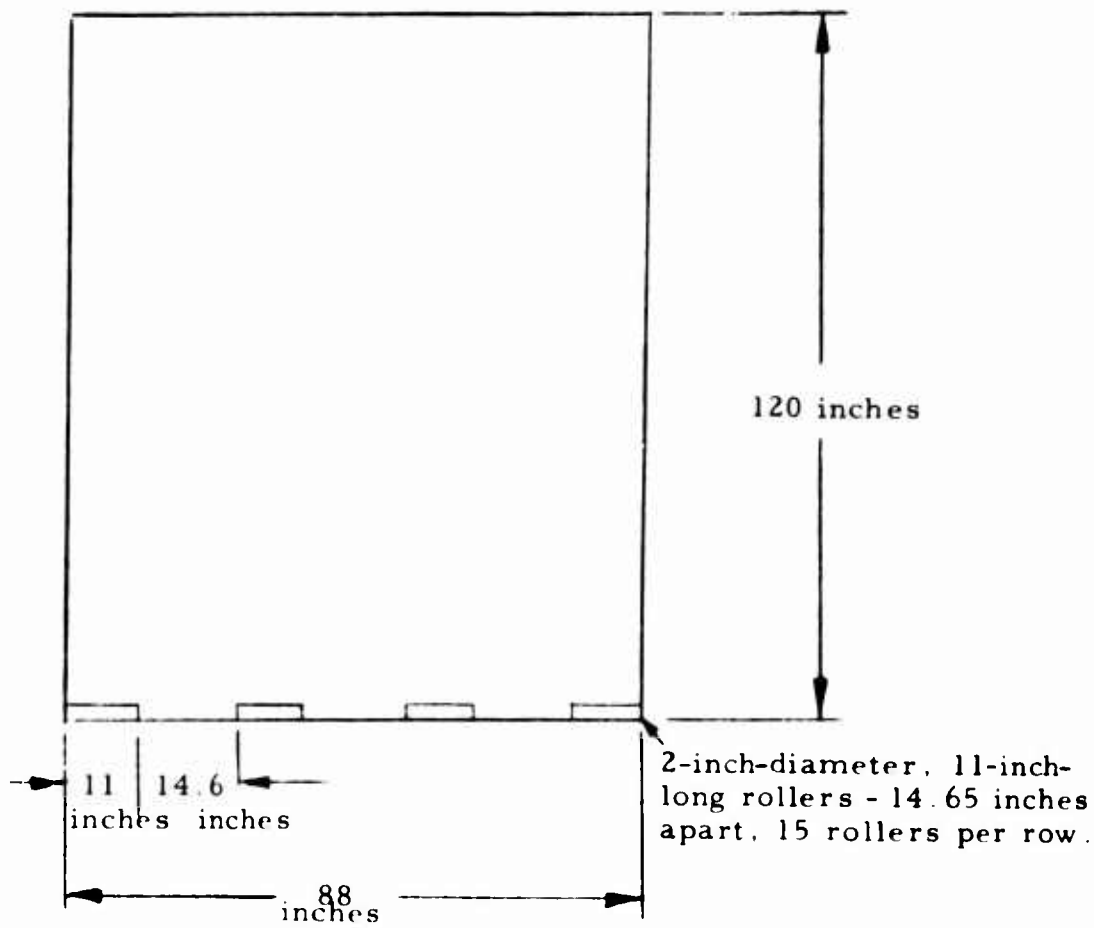
Assume E_1 = 500,000 (ref. 3)
$E_2 = 10^7$
$v_1 - v_2 = 0$
D = 2 inches

$$F_{cy} = .798 \sqrt{2 \frac{213}{\frac{1}{500,000} \quad \frac{1}{10^7}}}$$

$$= .798 \sqrt{\frac{213 \times 10^7}{21}}$$

$$= .798 \times 1000 \sqrt{51}$$
$$= .798 \times 1000 \times 7.12 = 5670 \text{ psi}$$

6. "Dual Rail" Conveyor Load Analysis:



Total number of rollers = 4 x 15 = 60

$$w = \frac{50,000}{88 \text{ inches}} = 568 \text{ pounds/inch}$$

R_1 = 568 x 25.67 x .4 = 6070 pounds = 403 pounds/roller

R_2 = 568 x 25.67 x 1.1 = 1605 pounds = 1070 pounds/roller = worst condition

Roller length = 11 inches

Load/inch = 1070/11 inches = 97 pounds/inch of roller

Maximum Compressive Stress:

$$F_{c_y} = .798 \sqrt{\frac{P}{D\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2}}}$$

$D = 2$ inches (ref. 3)

$P = 97$

$E_1 = 500,000$

$E_2 = 10^7$

$v_1 - v_2 = 0$

$$= .798 \sqrt{\frac{97}{2\frac{1}{500,000} + \frac{1}{10^7}}}$$

$$= .798 \sqrt{\frac{48.5 \times 10^7}{21}}$$

$$= .798 \times 1000 \sqrt{23}$$

$$= 3830 \text{ psi}$$

Summary of loads:

	Max. Load/wheel	Load/inch	Max. Comp. stress
"Skate Wheel" .5 inch wide	106.5 pounds	213 pounds	5670 psi *
"Dual Rail" 11 inches wide	1070 pounds	97 pounds	3830 psi

Note: These calculations are based on a loading of 20,000 pounds x 2.5g, but actually the load is 20,000 pounds; therefore, these figures are high.

Comment: Although the compressive stress indicated is higher than the allowable compressive stress for balsa wood, the combination of core and facing material is capable of supporting the loads encountered as evidenced in the tests performed by Brooks & Perkins, Inc.

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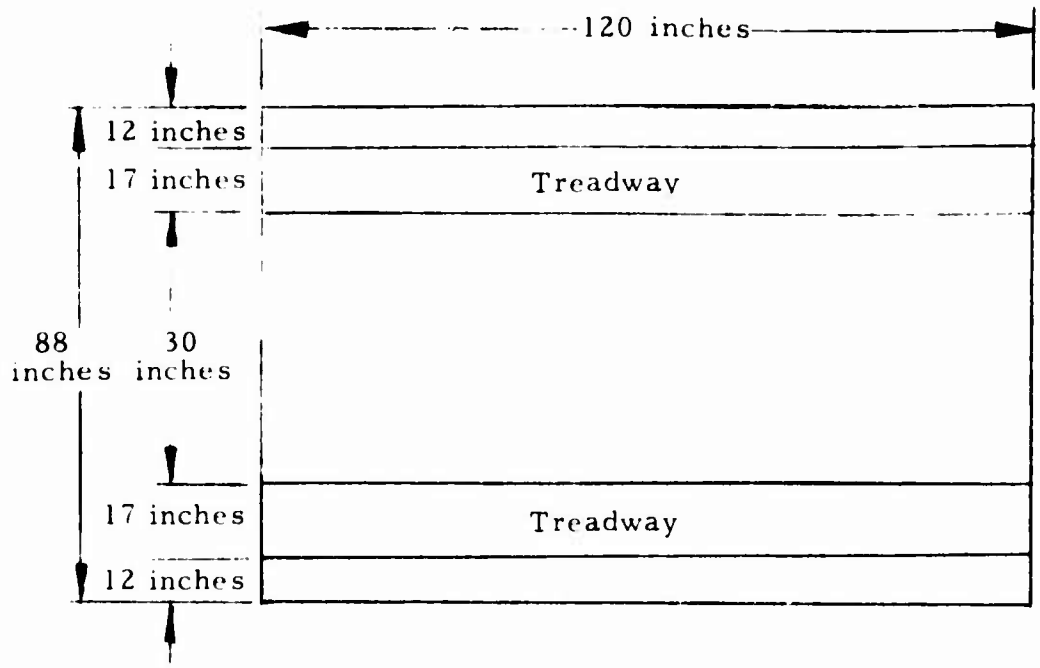
* The "Skate Wheel" induces a higher load on the load-bearing pallet; therefore, this is the design load.

7. Treadway Load Calculations:



Figures 6 and 7 show the maximum bending moment and shear of the small load-bearing pallet.

The following assumptions are made in evaluating this loading condition:

1. The load as imposed upon each treadway is absorbed by one-half (44 inches) of the pallet width.

2. The short edges (88 inches) are simply supported; the long edges (120 inches) are free.

$$M \text{ (maximum)} = \frac{wl^2}{8} \qquad l = 120 \text{ inches}, \quad w = 16.5 \text{ psi}$$

$$= \frac{16.5 \times 120 \times 120}{8}$$

$$= 29,700 \text{ inch-pounds/inch of width}$$

Moment over 17 inches of treadway:

$$= 29,700 \times 17 \text{ inches}$$
$$= 505,000 \text{ inch-pounds}$$

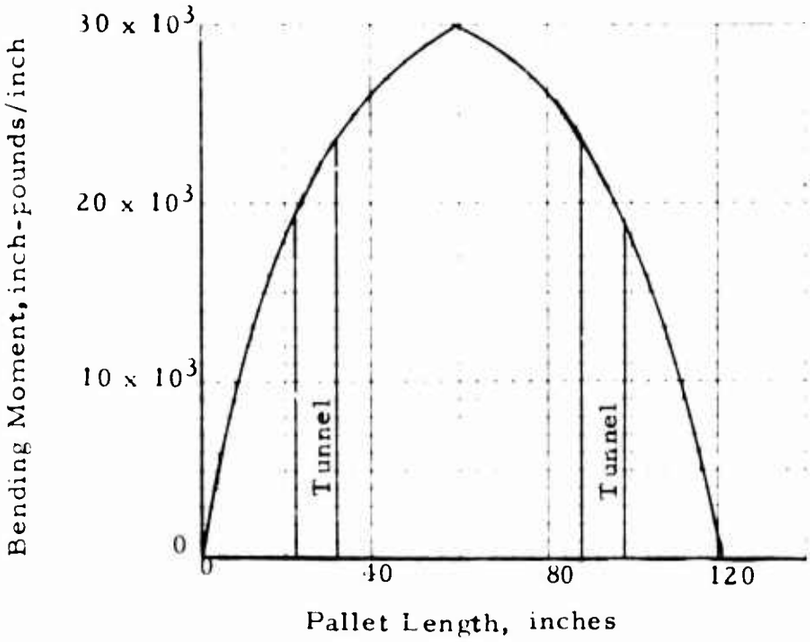


Figure 6. Bending Moment Diagram - Treadway Load 950 Pounds x 2.5g/ft^2 (Small Pallet).

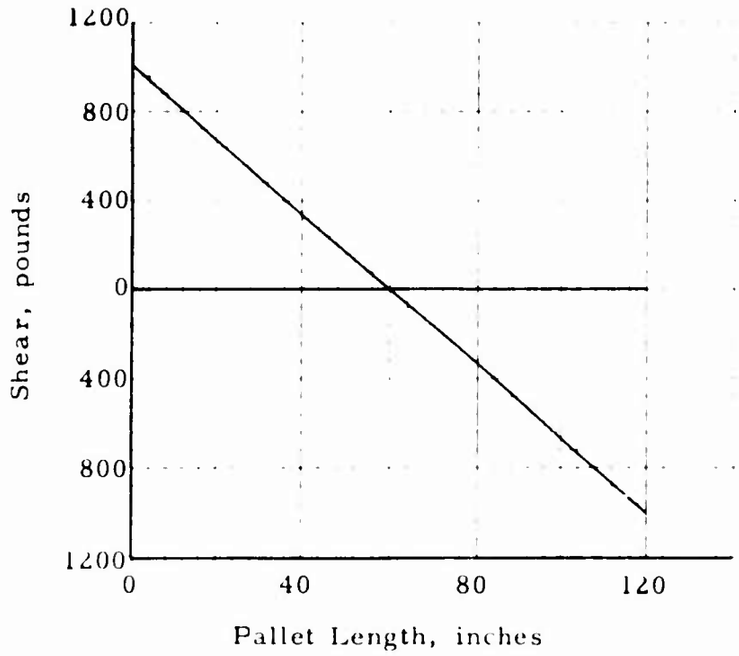


Figure 7. Shear Diagram - Treadway Load 950 Pounds x 2.5g/ft^2 (Small Pallet).

Required "Z" $= \dfrac{505,000}{52,700 \text{ psi}}$ $\qquad F_{t_y} = 66,000$ psi for 7075-T6 aluminum

$= 9.6 \text{ inches}^3$ $\qquad$ F.S. 1.25 = 52,700 psi

a. Facing stress $= \dfrac{2M}{t\,(d+T)\,b}$

$T = 5.5$ inches
$T_s = .063$ inch
$b = 44$ inches
$d = 5.62$ inches

$$= \frac{505,000 \times 2}{.06\,(5.62 + 5.5)\,44}$$

$$= \frac{1,010,000}{29.48}$$

$= 34,000$ psi $\qquad$ F.S. $= 66,000/34,000$

$= \underline{\underline{1.93}}$

b. Core shear stress $= \dfrac{wl}{(d + T)}$

$w = 16.5$ psi
$l = 120$ inches
$d = 5.62$ inches
$T = 5.5$ inches

$$= \frac{16.5 \times 120}{(11.12)}$$

$= 177$ psi

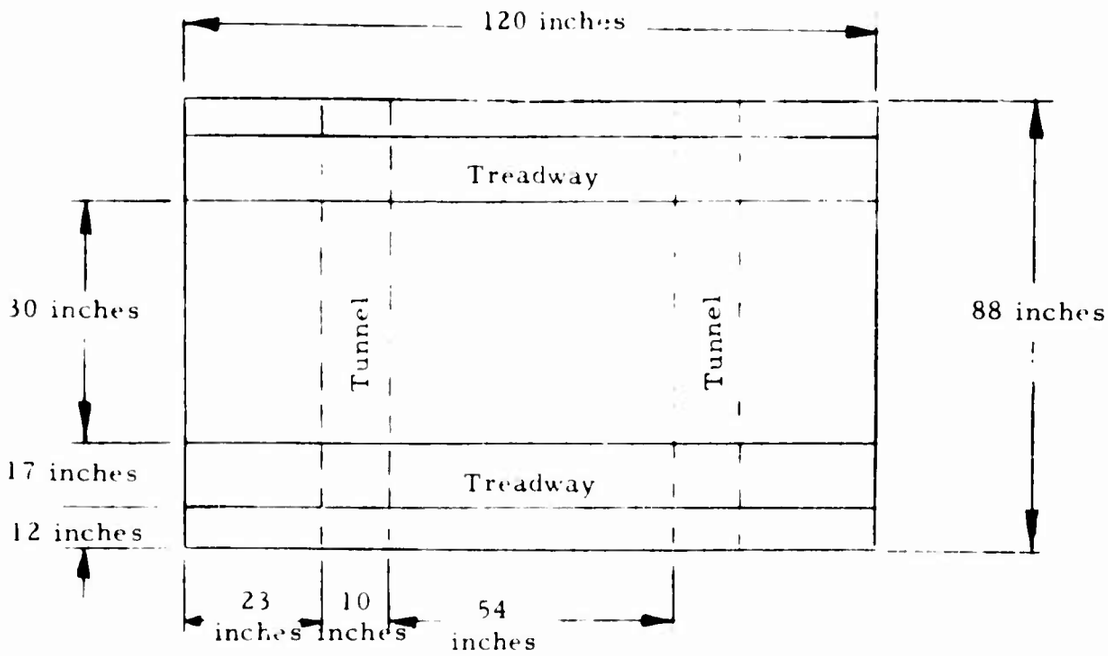
Factor of safety $= \dfrac{250}{177} = 1.4$ for 8 pounds/ft^3 balsa wood.

8. Forklift Tunnel Load Calculations:

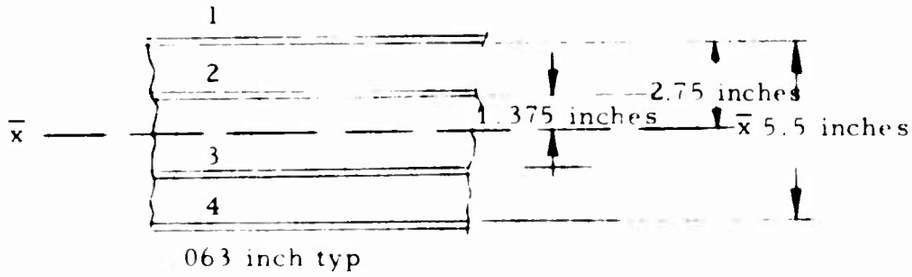
The worst loading condition to which the forklift tunnels are subjected is the treadway loading of 950 pounds x 2.5g/ft^2.

The assumption is made that the two shorter edges are simply supported, while the longer edges are free.

The location of the forklift tunnels is illustrated on the following page.



Moment of inertia and section modulus calculations through a forklift tunnel section 1 inch wide.



No.	Dim. (in.)	Area (in.^{2})	y (in.)	y^2(in.^{2})	Ay^2(in.^{4})	I_o(in.^{4})
1	1 x .063	.063	2.72	7.39	.465	negligible
2	1 x .063	.063	1.34	1.79	.113	
3	1 x .063	.063	1.34	1.79	.113	
4	1 x .063	.063	2.72	7.39	.465	
		.252			1.156	

$I_x = 1.156 \text{ inches}^4$

$M = 23,500$ inch-pounds (see Figure 6)

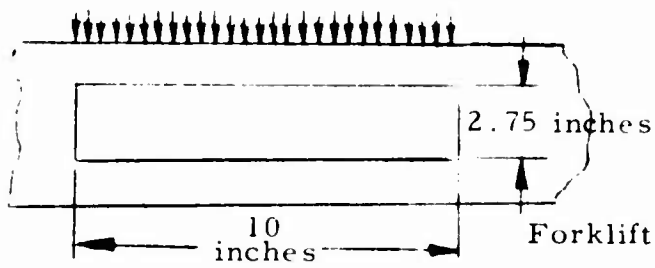
$$Z_x = \frac{1.156 \text{ inches}^4}{2.75 \text{ inches}}$$

$= .42 \text{ inch}^3$ - Available "Z"

$$\text{Required } Z_x = \frac{M}{F_{t_y} F_{c_y}} = \frac{23,500}{66,000} = .357 \text{ inch}^3$$

Local crushing due to a 950 pounds x 2.5g load/ft^2 = 2375 pounds/ft^2 over tunnel.

w = 19.8 psi



Forklift tunnel entrance

$$\text{Crushing load} = \frac{\text{Load}}{\text{Area}}$$

$$= \frac{2375 \text{ pounds/ft}^2}{.830 \text{ ft}^2 \times 144}$$

$= 2850 \text{ pounds/ft}^2$

$= 19.8$ psi

A = 12 inches x 10 inches

$= 120 \text{ inches}^2$

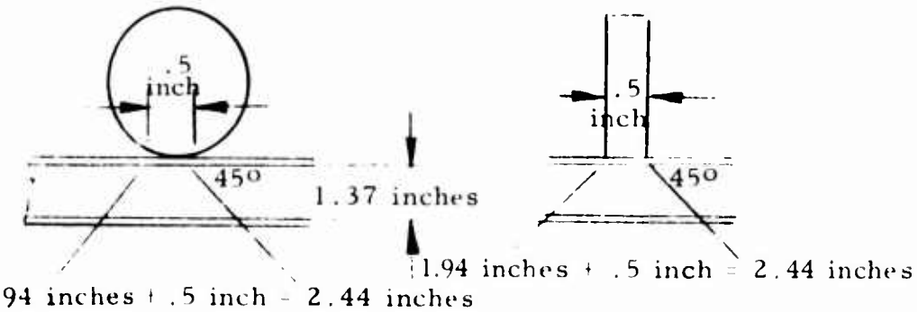
The minimum compressive strength for 8 pounds/ft^3 balsa wood is 75 psi perpendicular to grain and 1400 psi parallel to grain.

9. Core Structural Analysis of "Skate Wheel" Contact Area:

The weakest point of the pallet, with respect to crushing of the core when the pallet is on the conveyor, is the section of the pallet where the two tunnels for forklifts are located.

On the following pages, an approximate stress analysis has been performed, based upon the aforementioned section.

The assumption has also been made that the load is distributed through the core (balsa wood) at an angle of 45°.



1.94 inches + .5 inch = 2.44 inches

"Skate Wheel"

Effective area = 2.44 inches x 2.44 inches

= 5.95 inches^2

Effective area = 12.94 inches x 2.44 inches

For "Dual Rail" = 31.6 inches^2

Load per wheel = 106.5 pounds

$$F_{c_y} = \frac{106.5 \text{ pounds}}{5.95 \text{ inches}^2} = 17.9 \text{ psi for "Skate Wheel"}$$

Load per wheel = 1070 pounds

$$F_{c_y} = \frac{1070 \text{ pounds}}{31.6 \text{ inches}^2} = 34 \text{ psi for "Dual Rail"}$$

Approximate maximum compression stress in core:

It is assumed that the 5670 psi (for "Skate Wheel") and 3830 psi (for "Dual Rail") are transferred into the bottom skin and at 45° through the core, then the compressive stresses (average) through the core are:

For "Skate Wheel": $\frac{5670}{5.95 \times 1} = 952$ psi

For "Dual Rail": $\frac{3830}{31.6} = 121$ psi

For 8 pounds/ft^3 balsa wood, the crushing strength (with end grain) is 1000 psi (minimum).

10. Eyebolt Analysis - Small Load-Bearing Pallet:

The total design load to be carried by the small load-bearing pallet is 20,000 pounds x 2.5g + wind load = 60,000 pounds.

The vertical load on each suspension point (eyebolt) is 60,000/4 = 15,000 pounds.

The assumption is made that the force compound angle acting on the bolt is 30°.

The eyebolts used on the load-bearing pallets are NAS 1251A25 with a capacity of 25,000 pounds, a minimum allowable stress of 160,000 to 180,000 psi, and an ultimate allowable stress of 224,000 to 252,000 psi.

The eyebolt is acted upon by a tensile force "F" and a moment "M". The stress, therefore, is:

$$\text{Stress} = \frac{Mc}{I} + \frac{F}{A}$$

$$= \frac{12,500 \times .5}{.049} + \frac{17,350}{.785}$$

$$= 127,500 + 22,050$$

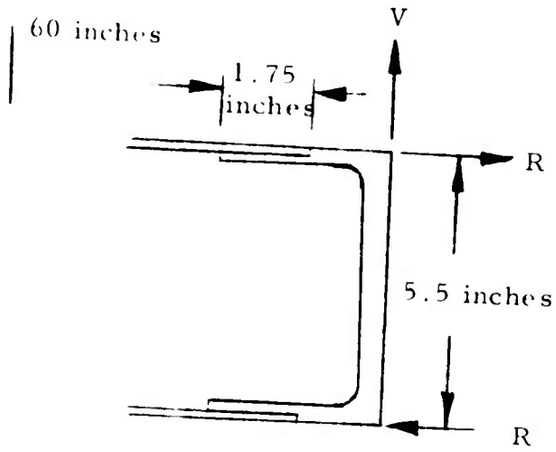
$$= 149,550 \text{ psi}$$

$A = .785 \text{ inch}^2$
$F = 17,350$ pounds
$M = 10,000$ pounds x 1.25 inches
$= 12,500$ inch-pounds
$I = .049 \text{ inch}^4$
$c = .5$ inch

An analysis of the forces acting on the eyebolts of the large load-bearing pallet is not necessary because the loads on the eyebolts of the large load-bearing pallet are lower than those of the small load-bearing pallet.

11. Bond Strength Calculations:

Shear stress in bond (between extrusion and facing). The maximum load that the pallet has to take is 20,000 pounds x 2.5g + wind load = 60,000 pounds. The shear force "V" due to this load is 342 pounds/inch.



$$60 \text{ inches} \times V = R \div 5.5 \text{ inches}$$

$$\frac{60 \text{ inches} \times 342 \text{ pounds}}{5.5 \text{ inches}} = R$$

$$R = 3730 \text{ pounds/inch width}$$

The adhesive FM-47 has a minimum strength of 2500 psi. The joint is good, therefore, for 1.75 inches x 2500 = 4375 pounds.

APPENDIX II

SUPPLEMENTAL TESTS

Two supplemental tests of components were performed.

The first test was a tensile test of the lifting eyebolt, and the second test was an indentation test of the pallet samples.

1. Eyebolt Test:

   a. Purpose. The purpose of the test was to proof test the lifting eyebolt and the insert (MS21209-F1220) which were to be installed into the lifting eyebolt threaded hole of the corner casting.

   b. Procedure. The insert was installed into a piece of 7075-T6 aluminum, and the lifting eyebolt was screwed into it. This assembly was then clamped into a Baldwin tensile testing machine.

   c. Results. The lifting eyebolt was pulled up to a load of 23, 700 pounds, at which point the holding jaw of the testing machine failed. No deformation or yielding occurred.

2. Indentation Test:

   a. Purpose. The purpose of this test was to determine whether the contemplated material (skin and core) to be used in the fabrication of the load-bearing pallet will withstand the loading imposed by the "Skate Wheel" conveyor.

      The "Skate Wheel" type conveyor imposes a greater load on the skin and core of the load-bearing pallet than does the "Dual Rail" system.

   b. Procedure. Four sample balsa wood cores, with top and bottom skins, were made up. Each was 2 inches high, 24 inches long, and 12 inches wide. The "Skate Wheel" was 2 inches in diameter and 1/2 inch thick and was made of 4130 steel.

The "Skate Wheel" was placed on top of each sample pallet, and a compression load of 1000 pounds was applied to the top of the "Skate Wheel" with a Baldwin testing machine. This test was repeated three times for each sample pallet, at different locations on the skin.

c. Results. The results obtained are listed below:

6061-T6 .063-inch thick, .021 inch, .015 inch
7075-T6 .06 -inch thick, .010 inch, .009 inch
6061-T6 .093-inch thick, no indentation, scratches only.
7075-T6 .093-inch thick, no indentation, scratches only.

The results obtained in the tests indicate that the use of the 7075-T6 .063-inch-thick aluminum skin is acceptable.

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13. ABSTRACT

The CH-54A helicopter's load-bearing capability was limited to loads which had the structural integrity to be suspended by slings or could be carried in pods suspended underneath the helicopter. The operation of the helicopter with these loads was limited to fair weather. To increase the load-bearing capability of the helicopter in fair weather and to permit operation in inclement weather, small and large load-bearing pallets which can be suspended from the helicopter were designed and developed.

The results of tests performed indicate that the use of these load-bearing pallets enables the helicopter to carry loads which are bulky and/or do not possess the structural integrity to be suspended by slings from the helicopter.

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Small load-bearing pallet						
Large load-bearing pallet						
Bad weather						
CH-47A						
Flying Crane helicopter						

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