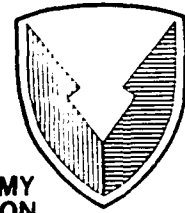


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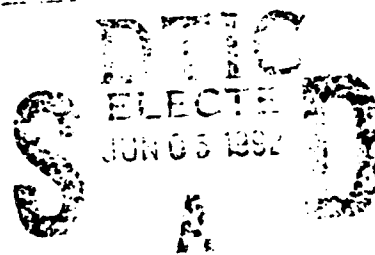
**US ARMY
AVIATION
SYSTEMS COMMAND**

**ORGANIC MATRIX COMPOSITE HELICOPTER INTERNAL/
EXTERNAL CARGO PALLET SYSTEM (OMC INTEX)**

Rob J. Sjostedt and Donna K. Dawson

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April 1992



Final Report for Period July 1986 - June 1990

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Prepared for

**AVIATION APPLIED TECHNOLOGY DIRECTORATE
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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report presents the design and development of a cargo carrying Helicopter Internal/External (INTEX) Cargo Pallet System (to include pallet, restraint net, and associated tiedown provisions). The system must be capable of supporting loads up to 10,000 pounds when airlifted externally from UH-60 and CH-47 helicopters and internally on C-130, C-141, and C-5 aircraft, as well as CH-47 helicopters with the Helicopter Internal Cargo Handling System. The design phase consisted of conducting a preliminary analysis to determine the material and manufacturing processes needed to meet the structural requirements for testing. Trade-offs were conducted to determine the final design for testing. Testing was conducted and the initial two pallets failed the lift tests. A redesign was conducted and a third pallet was manufactured that did pass all the required tests. The results presented in this report acknowledge that a pallet can be constructed from organic matrix composite material and pass all the tests specified in the contract. This information will contribute to the advanced development and production of an INTEX pallet system.

Paul Pantelis of the Reliability, Maintainability, and Mission Technology Division served as project engineer for this effort.

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1.0 INTRODUCTION

The Army has a need for a new, durable cargo handling platform suitable for both helicopter and fixed-wing aircraft movement throughout the entire airlift system, including a field environment. The current aluminum/balsa core primary cargo pallet is not designed for external helicopter transport and is not rugged enough for field use.

This program was conducted to develop a Helicopter Internal/External (INTEX) Cargo Pallet System from organic matrix composites (OMC) to meet stated objectives and design and performance requirements.

Primary system objectives call for the pallets to be durable, universal (usable throughout the airlift system), compatible with existing roller/rail systems, compatible with use of a cargo restraint net, stackable, and reusable, as well as have forklift provisions. They must be capable of supporting loads up to 10,000 pounds under airlift conditions. The target design weight was 300 pounds.

To meet these objectives for an OMC part, the contractor faced challenges in performance, cost, and technical risk. While OMC structural parts had been fabricated by touch-labor, production economics required a combined automated pultrusion and molding approach. Use of standard OMC manufacturing processes (pultrusion and molding) and a modular assembly approach reduced the technical and manufacturing risks that often occur in developing new composite products. However, while pultrusion has long been an established commercial process for manufacture of nonstructural parts, processing parameters were still in development for pultruding structural shapes. Pultrusion is a basic composite raw material processing system that is analogous to aluminum extrusion. It converts raw composite materials, such as fiberglass reinforcements and epoxy resin, into finished product stock in an automated, continuous process.

The original scope of work comprised •design and fabrication of experimental pallet systems, •test, •fabrication of prototype pallet systems, and •cost estimate of 1000 production units. Due to technical problems, the program was descoped to reflect a deletion of all tasks associated with the fabrication of prototype pallet systems and the cost estimate of 1000 production units.

This final report discusses the approach to meeting the OMC INTEX system requirements, including design assumptions and investigations, fabrication methods and procedures, tests and test results.

2.0 DESIGN OF EXPERIMENTAL PALLETS

Design and performance requirements were evaluated for the OMC INTEX Cargo Pallet System, and a preliminary stress analysis was performed. The design process that was used is illustrated by the flowchart in Figure 1. Results yielded a selected baseline and preliminary design and manufacturing plan for the experimental pallets.

The following system requirements dictated the approach. Design flexibility was limited by weight, height, and tunnel restraints.

Overall dimensions	108 long X 88 side X 5.75 in. deep
Weight range	300-330 lb per unit
Loads	Capable of supporting a load up to 10,000 lb when airlifted externally from Army helicopters or as an internal pallet
Cargo restraint net	22 cargo net restraint rings (equally spaced around edge)
Sling lifting eyes	4 pallet sling lifting eyes (1 per corner)
Forklift accommodation	12X4 through-intersecting forklift tunnels, all sides
Cargo handling	Compatible with roller-rail systems found in C-130, C-141, & C-5 aircraft, and CH-47 Helicopter Internal Cargo Handling System (HICHS)

Other design and performance requirements are summarized in the Summary of Design Criteria (see Appendix).

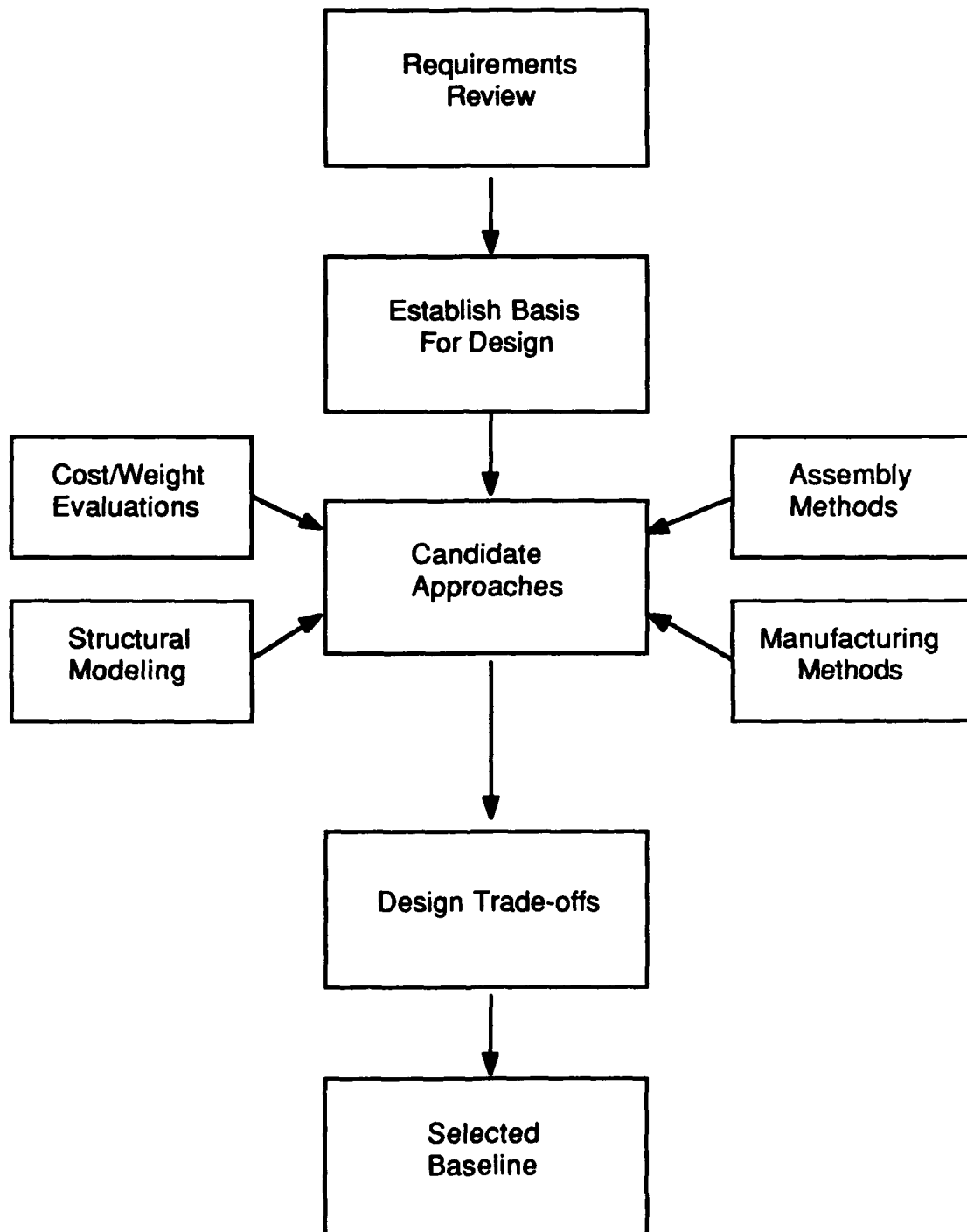


Figure 1. Design process flowchart.

2.1. PRELIMINARY DESIGN ANALYSIS

The preliminary design phase of the pallet program included computer modeling of pallet structural failure modes and an analysis of load conditions using structural response models. In addition, tests of material samples and a finite element analysis were performed before the design was finalized.

2.1.1 Preliminary Design and Manufacturing Plan

The preliminary design and manufacturing plan called for construction of outer panels consisting of face sheets with an aluminum honeycomb "sandwich" core, with an inner low density foam core. This proposed pallet structure consisted of six major components (illustrated by Figure 2), to be manufactured according to the following basic plan :

Outer panels	
Outer face sheets	Molded glass/epoxy
Inner face sheets	Molded glass/epoxy
Outer core (sandwich)	Aluminum honeycomb
Inner core	Low density PVC foam
Forklift tunnel	Molded glass/epoxy roof and floor
	Pultruded glass/epoxy walls
Edge member	Pultruded glass/epoxy

The initial design was purposely very general in order to accommodate any changes in the final design parameters. It was defined in terms of subareas for design planning purposes. Any subarea could be revised or eliminated in order to improve the final design, within the limits of the pallet structural model.

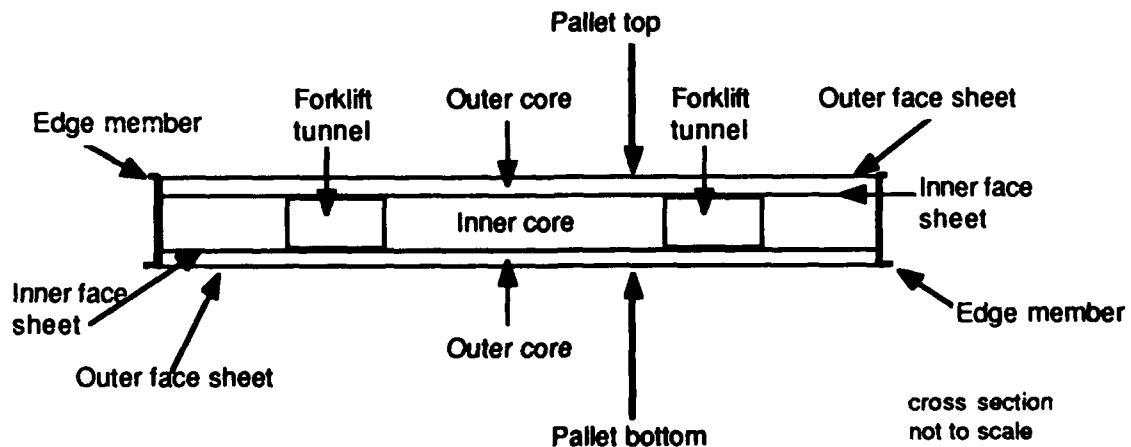


Figure 2. Major components of proposed pallet structure.

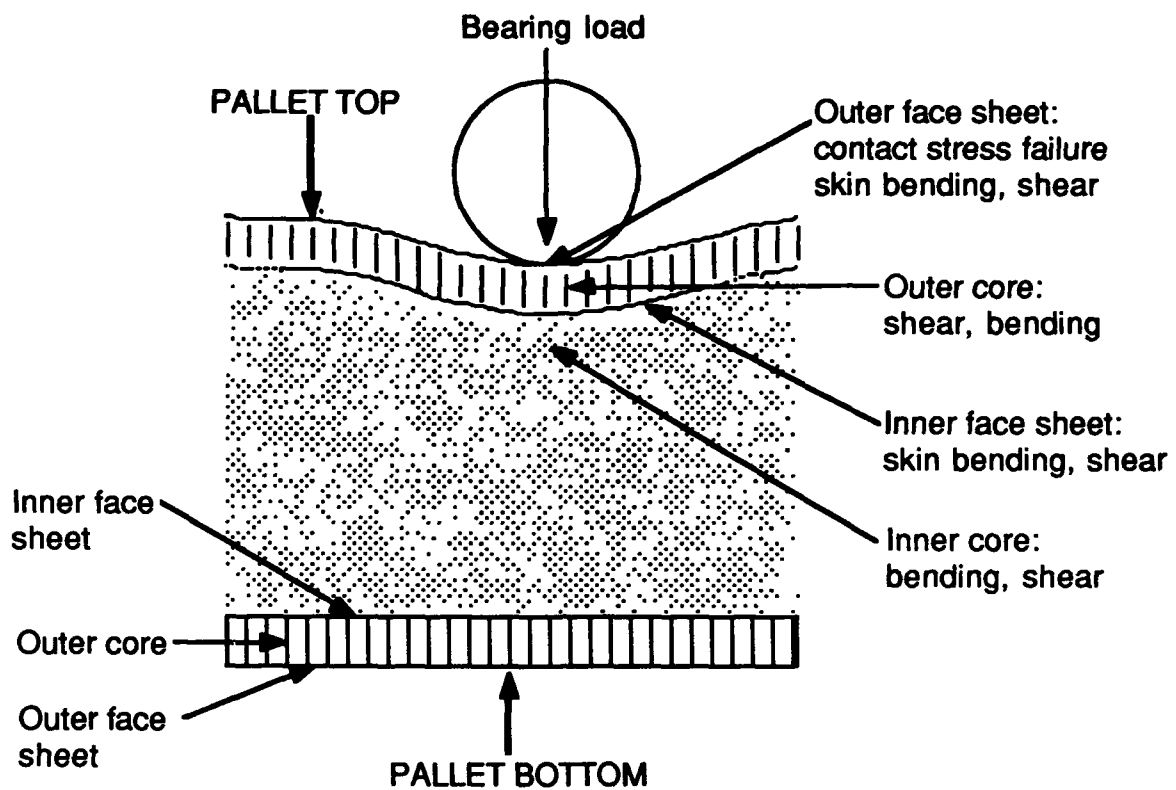
2.1.2 Pallet Structural Model Failure Modes

An appropriate pallet structural model required response evaluation for many failure modes, as illustrated by Figures 3, 4, and 5. Analytical models for the structural response of the pallet to various load conditions were based on various strength of materials theories, including:

1. Contact stress theory--Predicts stresses on a plate at the point of contact when it is subjected to a bearing load from a roller. This theory was used to estimate the point-of-contact stress from bearing loads that would be applied to the pallet by the INTEX roller conveyor system.
2. Plate theory--Predicts bending moments on a rectangular plate that is supported at four corners when it is subjected to uniform loads. It was used to estimate the overall bending of the loaded cargo pallet.
3. Beams and plates on an elastic foundation theory¹--Predicts bending stresses on beams and plates supported on an elastic foundation, such as a concrete slab laid on the ground. This theory was used to estimate pallet surface bending when it is subject to the loads applied by the roller conveyor system. The upper sandwich panel was modeled as a beam and the inner foam core as the elastic foundation. The data obtained enabled prediction of upper sandwich panel deformation from various shear stresses and stresses applied by the roller conveyor system.
4. Composite beam theory--Predicts how stresses are distributed through a composite beam; that is, a beam in which the elements of the cross section are different materials, such as steel-reinforced concrete. The theory assumes that plane sections will remain plane. It was used to determine how stresses would be distributed and allocated through the pallet cross section, and to estimate bending of the pallet elements that might take place due to overall flexure of the pallet.

A Spreadsheet Pallet Design Model was used to estimate stress margins by comparing predicted key stresses and failure modes with material allowables. The spreadsheet model allowed quick variations in pallet geometry and materials, with evaluation of a new design accomplished in 30 seconds of microcomputer time.

¹Hetyeny, M., Beam On Elastic Foundation Theory, Sixth Edition, University of Michigan Press, 1961.

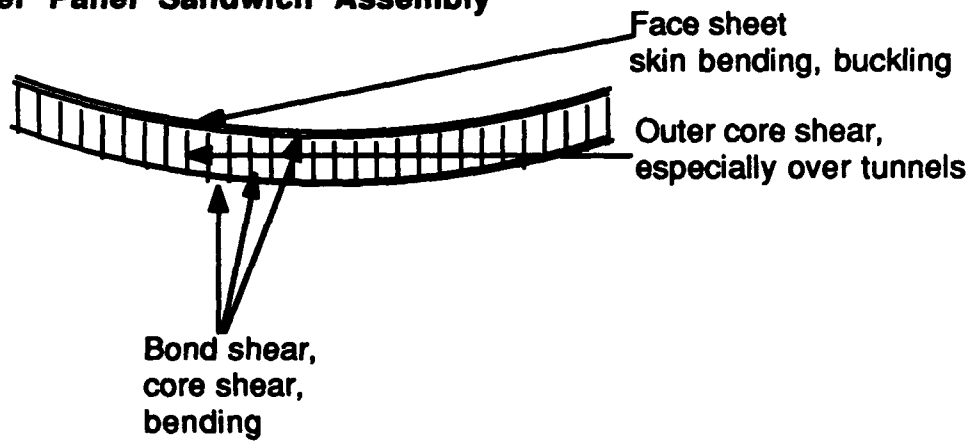


Notes

1. Top face sheet bearing load is by 1-in. mandrel on typical pallet areas and above tunnels
2. Bottom face sheet bearing failure modes are defined correspondingly

Figure 3. Pallet structural model, bearing failure modes.

Upper Panel Sandwich Assembly



Inner Core



Lower Panel Sandwich Assembly

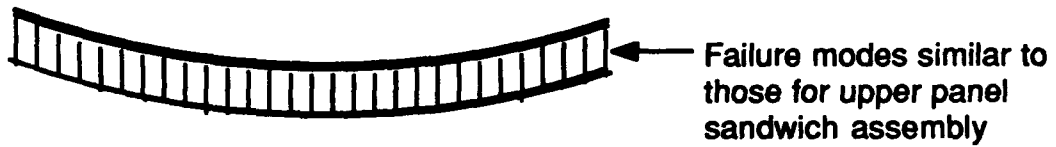


Figure 4. Pallet structural model, bending failure modes.

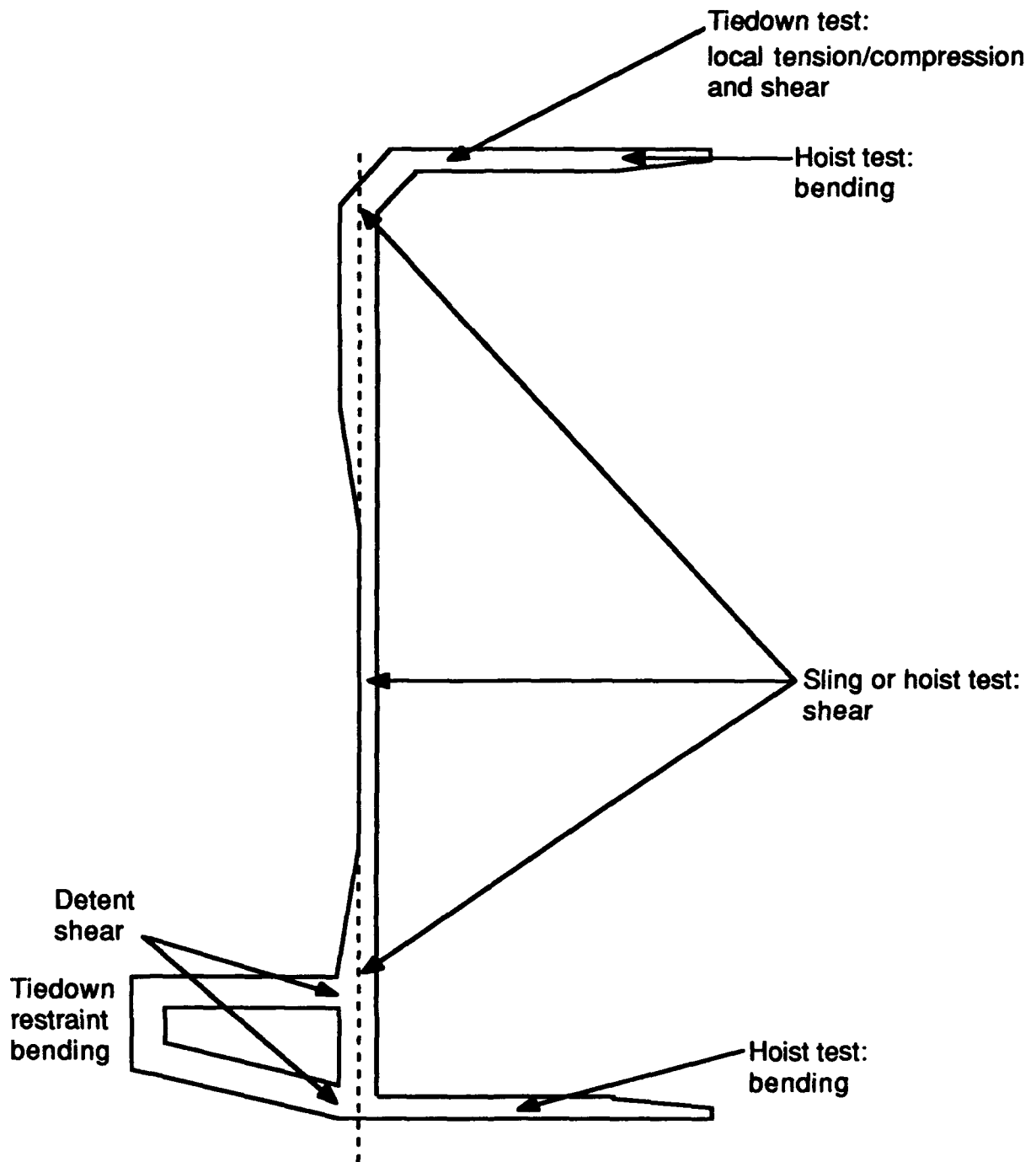


Figure 5. Pallet structural model, edge member failure modes.

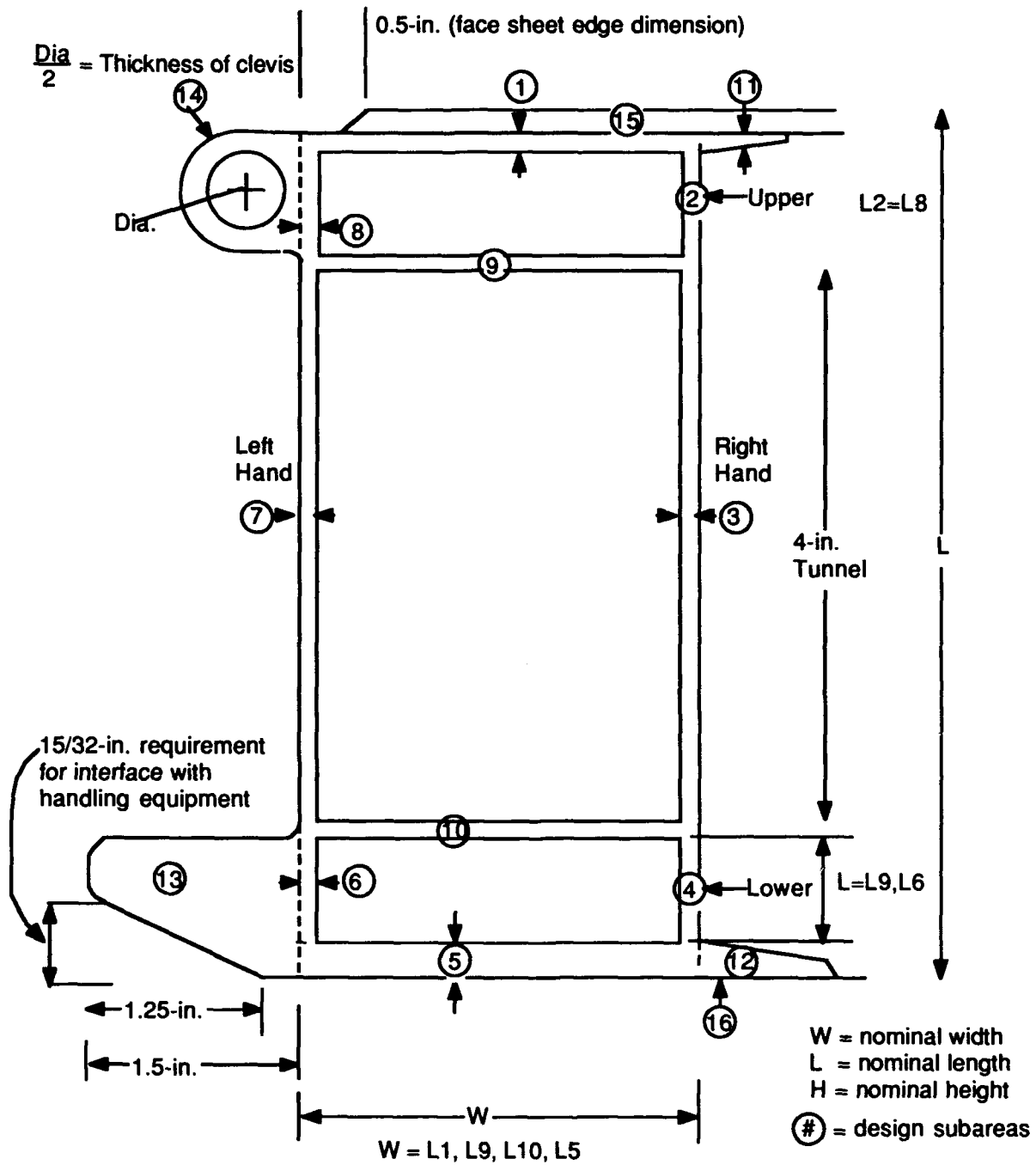
2.1.3 Structural Response Models

In order to determine the optimum design and minimum weight for the least cost, structural response models included consideration of weight and materials costs, as well as flexural strength, shear properties, and loads and stresses during hoist test.

Through numerous design iterations, the spreadsheet model mathematically predicted pallet performance for a wide variety of design parameters. The models illustrated by Figures 6 and 7 were combined with models of other aspects of the design, including:

1. System geometry parameters for edge members, face sheet/sandwich assembly, tunnel and core
2. Candidate materials data for laminates and core materials
3. Area and stiffness properties of pallet components for the pallet typical cross section (1-in. width), edge members, tunnel cross section, tunnel top and tunnel bottom (unit width).

A summary of failure modes, margins, and other key results is given in Table 1.



Note: The design was defined in terms of subareas. Subarea parameters such as thickness and materials were varied through numerous design iterations to arrive at the optimum weight vs. cost. The edge member was simplified in the final design.

Figure 6. System geometry parameters--edge members, outer panels, tunnel and core.

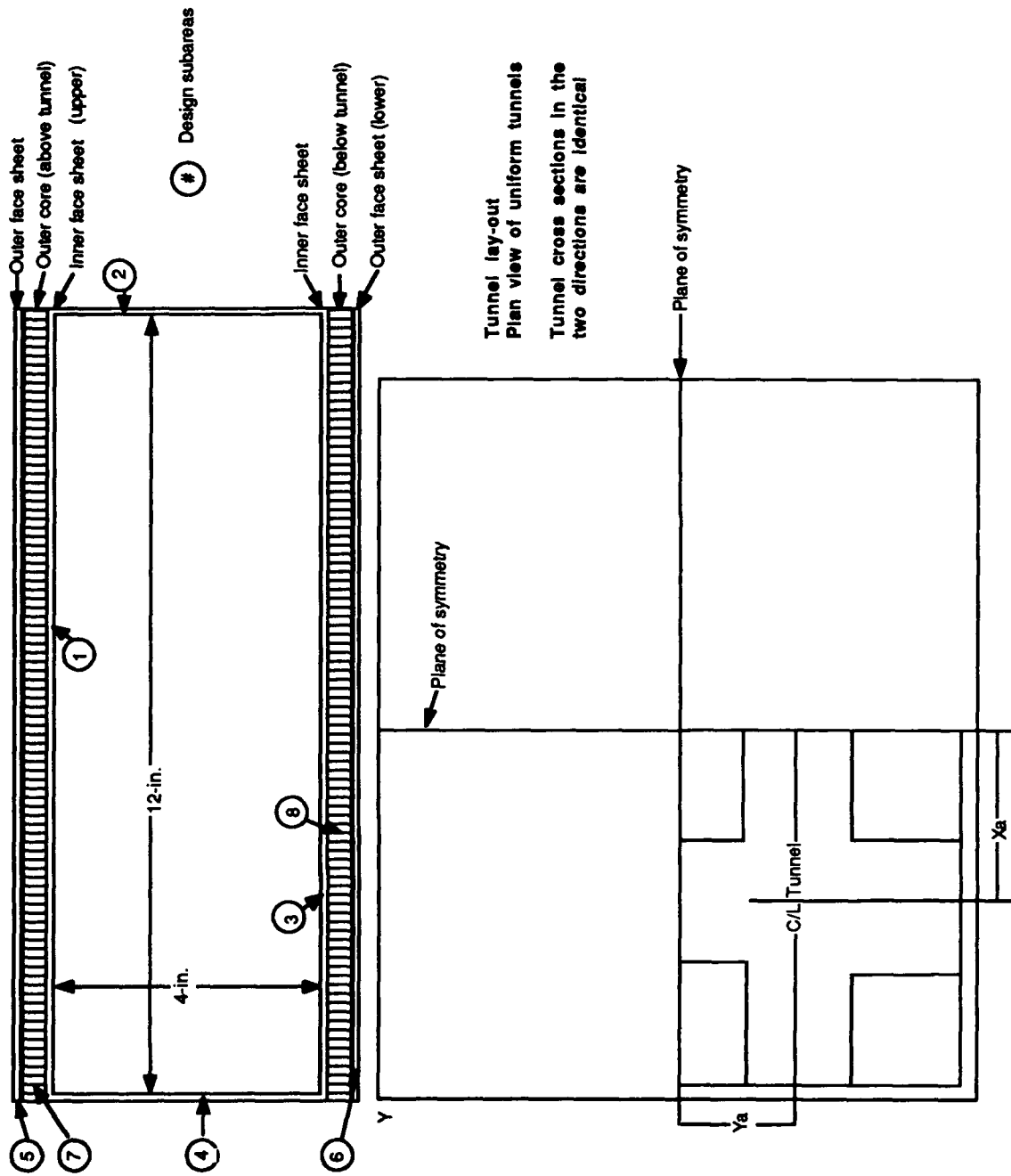


Figure 7. System geometry parameters for tunnels at intersection with edge members.

TABLE 1. SUMMARY OF FAILURE MODES, MARGINS,
AND OTHER KEY RESULTS

Part	Load Source	Failure Mode	Factor of Safety	Margin of Safety
Edge members	Hoist	Longitudinal stress	1.5	0.71
		Shear with upper box	1.5	0.620
		Shear with lower box	1.5	0.465
		Shear at mid-height	1.5	0.605
Tunnel*	Hoist	Cross section bending	1.5	0.602
		Upper face shear/core shear	1.5	0.942
		Upper core/tunnel top shear	1.5	0.942
		Side mid-height shear	1.5	0.512
Tunnel top	Hoist	Upper face sheet bending	1.5	0.720
		Core bending	1.5	0.161
		Lower face sheet bending	1.5	0.412
		Upper face sheet/core shear	1.5	0.945
		Core mid-height shear	1.5	0.939
		Bottom face sheet/core shear	1.5	0.942
Tunnel top	Mandrel	Upper face sheet/core shear	1.2	0.263
		Core mid-height shear	1.2	0.182
		Bottom face sheet/core shear	1.2	0.217
Tunnel top	Forklift	Core bearing stress	1.8	0.157
		Lower face sheet bending	1.8	0.945
		Lower face sheet shear	1.8	0.684
Tunnel bottom**	Roller	Upper face sheet/core shear	2.5	0.352
		Core mid-height shear	2.5	0.318
		Bottom face sheet/core shear	2.5	0.458
Tunnel bottom**	Hoist	Upper face sheet bending	1.5	0.397
		Core bending	1.5	0.478
		Lower face sheet bending	1.5	0.747
		Upper face sheet/core shear	1.5	0.623
		Core at mid-height shear	1.5	0.603
		Bottom face sheet/core shear	1.5	0.685

*Bending about transverse axis

**Cross section warp

TABLE 1. SUMMARY OF FAILURE MODES, MARGINS,
AND OTHER KEY RESULTS (Continued)

Part	Load source	Failure mode	Factor of safety	Margin of safety
Pallet typical cross section	Caster	Contact deflection, yield	4.0	0.77
		Skin bending at caster	2.5	0.50
		Core bearing stress	2.5	1.43
Pallet typical cross section	Roller	Contact deflection, yield	4.0	0.94
		Skin bending at roller	2.5	0.77
		Core bearing stress	2.5	0.00
Pallet typical cross section	Mandrel	Contact deflection	1.2	-
		Skin bending at mandrel	1.2	1.00
		Skin shear at mandrel	1.2	0.80
		Core bearing stress	1.2	0.49
Pallet typical cross section	Hoist	Upper skin bending	1.5	0.83
		Lower skin bending	1.5	0.84
		Upper core bending	1.5	0.63
		Mid-core bending	1.5	0.69
		Upper face sheet/core shear	1.5	0.94
		Upper core/mid-core shear	1.5	0.33
		Mid-plane shear	1.5	0.31
		Mid-core/lower core shear	1.5	0.32
		Lower core/face sheet shear	1.5	0.94

2.1.4 Sample Tests

In order to further validate the design and minimize potential redesign efforts, preliminary tests were conducted on sample outer panels and inner and outer core specimens. Testing of the fiberglass/epoxy panel samples produced interlaminar shear and bearing strength data for the face sheet materials. This data was not otherwise available. Testing eliminated numerous failure modes as possible mechanisms of pallet failure. Tests included:

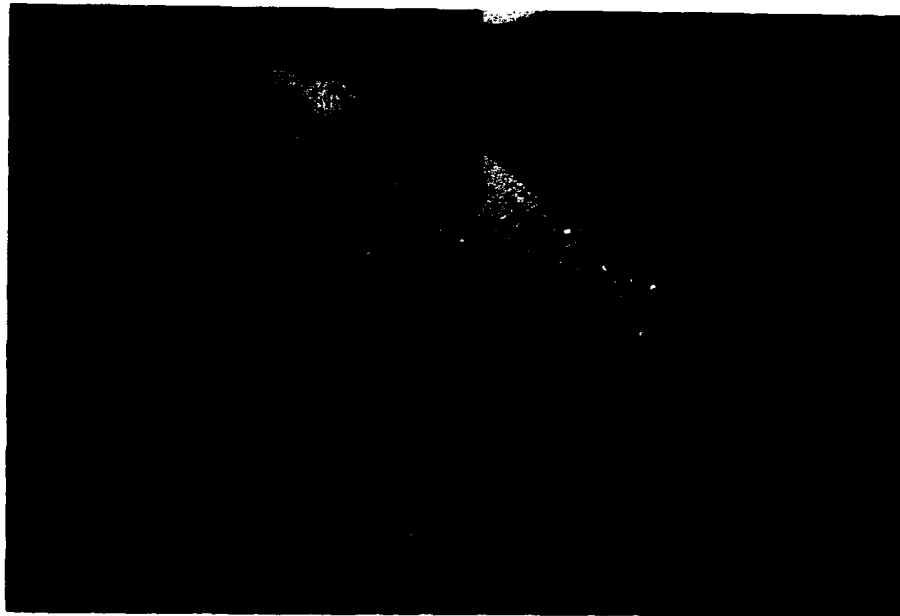
- Mandrel test for deflection under bearing force
- Roller test for deflection and ultimate strength under bearing load
- Short beam test for ultimate shear strength
- Beam bending test for ultimate bending strength
- Tiedown pull test for pull strength

1. **Mandrel test (Figures 8, 9, and 10)**--The purpose of this test was to test the ability of the upper surface of the pallet to take up to 900 lb concentrated load on 1 square inch without damage. A mandrel fixture 1-in. square was placed on the upper surface of an outer panel sample and loaded with weights. A strain gauge was used to measure deflection under the applied load. No observable permanent deformation resulted at the 900-lb load. The sample experienced ultimate failure with permanent deformation at 2,260 lb. The honeycomb outer core failed first, and then the PVC foam inner core.
2. **Roller tests (Figure 11)**--The purpose of these tests was to demonstrate that the pallet lower surface can withstand the highest loads applied by the roller conveyor system. An applied load of 2,500 lb simulates worst case; that is, it simulates a pallet with a full load of 10,000 lb riding over the crest of a ramp in the roller conveyor system. A roller fixture 5-in. long by 2-in. diameter was loaded into the surface of a lower panel sample. No permanent deformation occurred under a 2,500-lb applied load. The sample failed under a 5,700-lb applied load, with permanent deformation of the PVC foam inner core.
3. **Short beam test (Figures 12, 13, and 14)**--The purpose of this test was to demonstrate that the pallet is capable of carrying the necessary levels of shear strain without failure. To meet the criterion for success, a 6-in.-wide simulated pallet sample was required to carry a 3,711-lb load without failure. The sample was supported in a fixture so as to provide a 27-in. span. Loads were applied in the center of the sample. Shear failure and permanent deformation of the inner foam core occurred under a load of 4,915 lb.
4. **Beam bending test (Figures 15 and 16)**--The purpose of this test was to determine the ultimate bending strength of the pallet. To pass this test, the sample was required to support a load of 350 lb without failure. A 6-in.-wide by 60-in.-long simulated pallet sample was extended to 120-in. long by bonding a steel extension to one end. The other end of the composite was attached in a cantilever fashion to a rigid mount. Load was applied to the steel extension in an upward direction and was measured with a load cell. The upper cap of the beam failed in compression at 855 lb. The deflection at failure was 4 in. at a distance of 48 in. from the cantilever support. This is almost three times the required load.
5. **Tiedown pull test (Figures 17, 18, and 19)**--The purpose of this test was to demonstrate the ability of the pallet to carry the load applied by the tiedown fittings, when loaded to 7,500 lb at angles of 0° and 90°. Tiedown fittings were bonded and fastened to simulated pallet samples. Loads at the required angles were applied to the samples by a special fixture prepared for this purpose. No permanent deformation of the composite pallet sample occurred under the 7,500-lb loads. The PVC foam inner core cracked just inside of the edge-member bond, but this did not affect the structural integrity of the pallet. The tiedown fittings did sustain some permanent deformation.

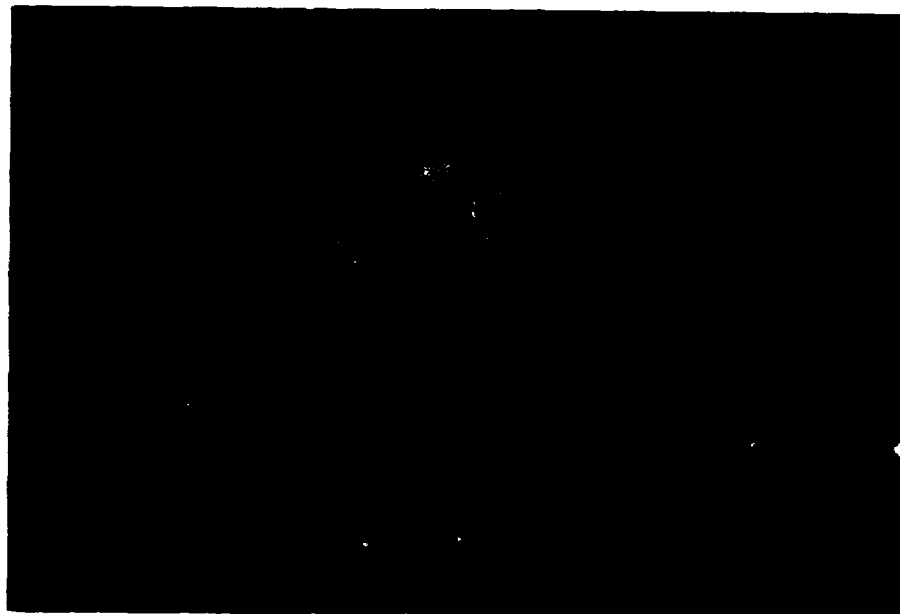
The test conditions and results are summarized in Table 2, Summary of Sample Tests.



Figure 8. Mandrel test setup for sample specimen.

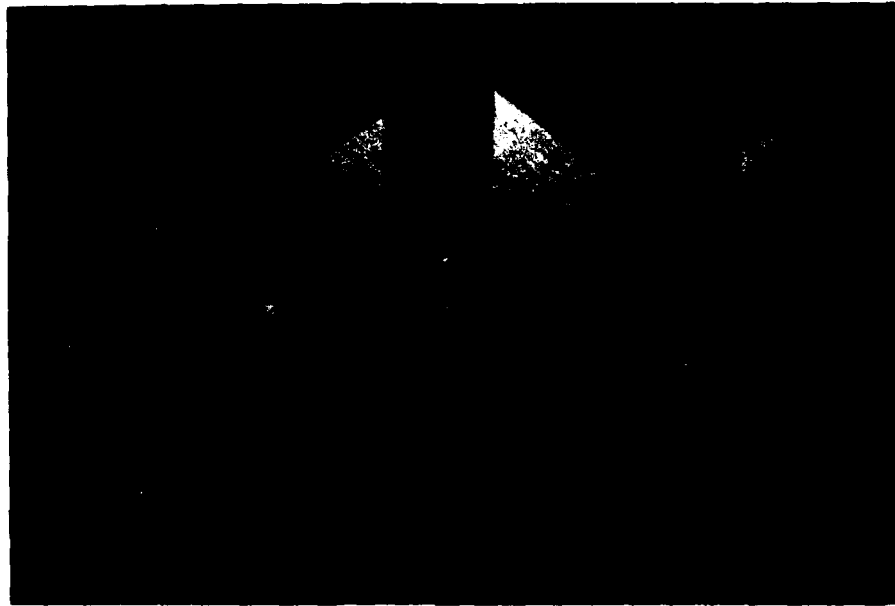


After 900 lb: No permanent deformation



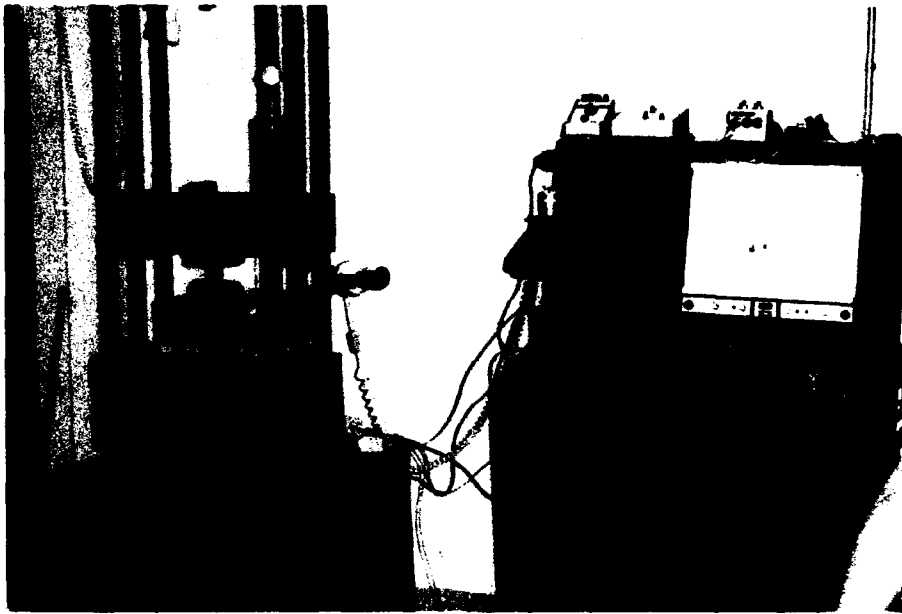
After 2,260 lb: 0.02-in. permanent deformation

Figure 9. Mandrel test results for sample specimen, 900-lb and 2,260-lb loads.

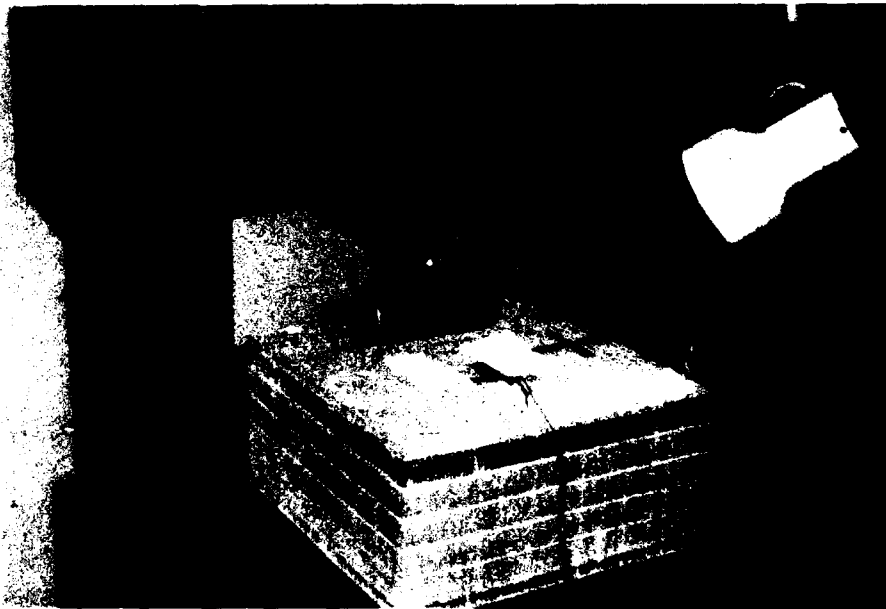


After 2,430 lb: 0.04-in. permanent deformation

Figure 10. Mandrel test results for sample specimen, 2,430-lb load.

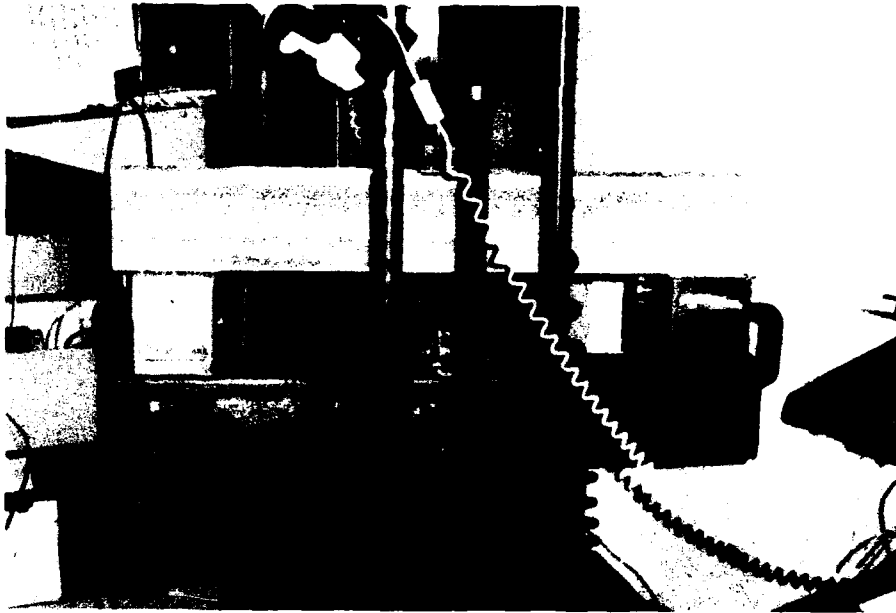


Setup



After 5,700 lb: 0.203-in. deflection under load
0.005-in. permanent deformation

Figure 11. Roller test for sample specimen.



Setup with 2-in.-wide load bar



Local failure at edge of load bar

Figure 12. Short beam shear test setup for sample specimen, 2-in.-wide load bar.

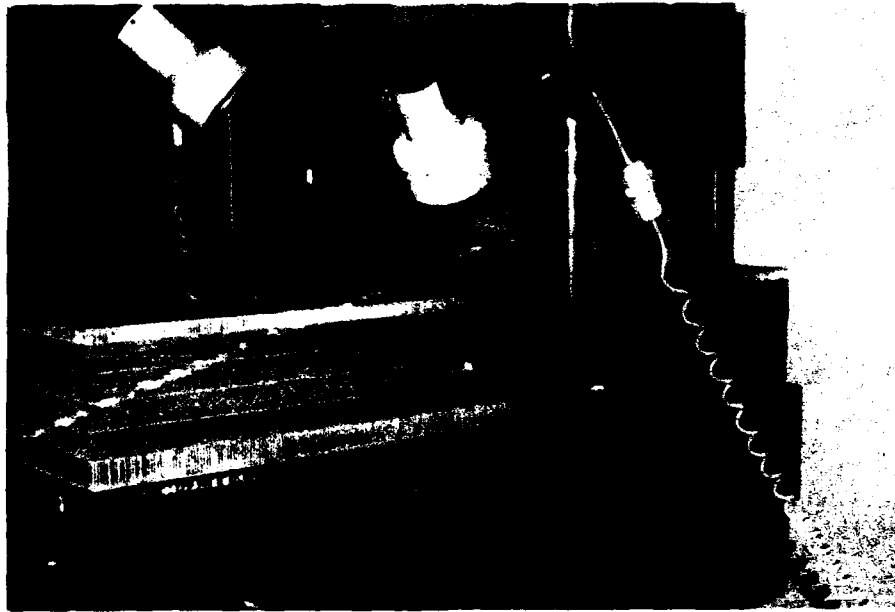
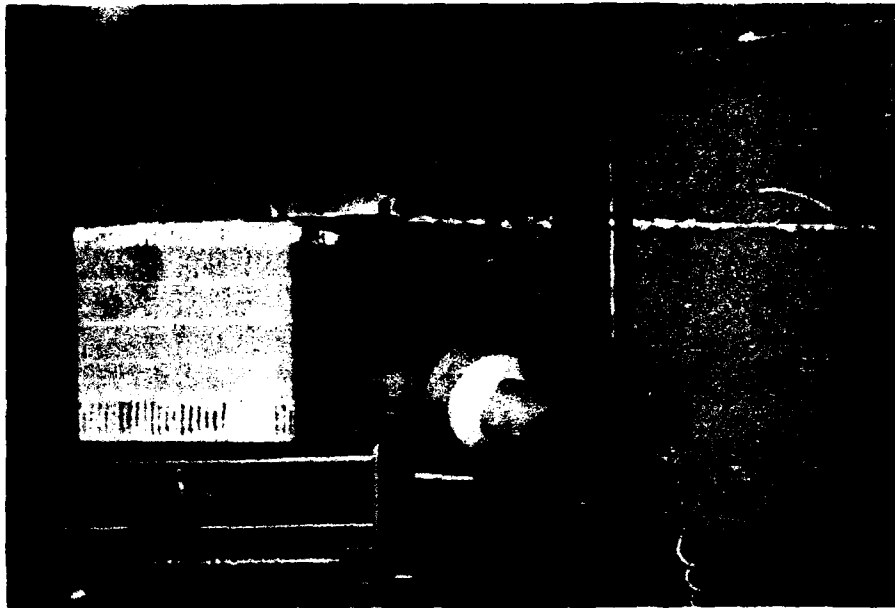
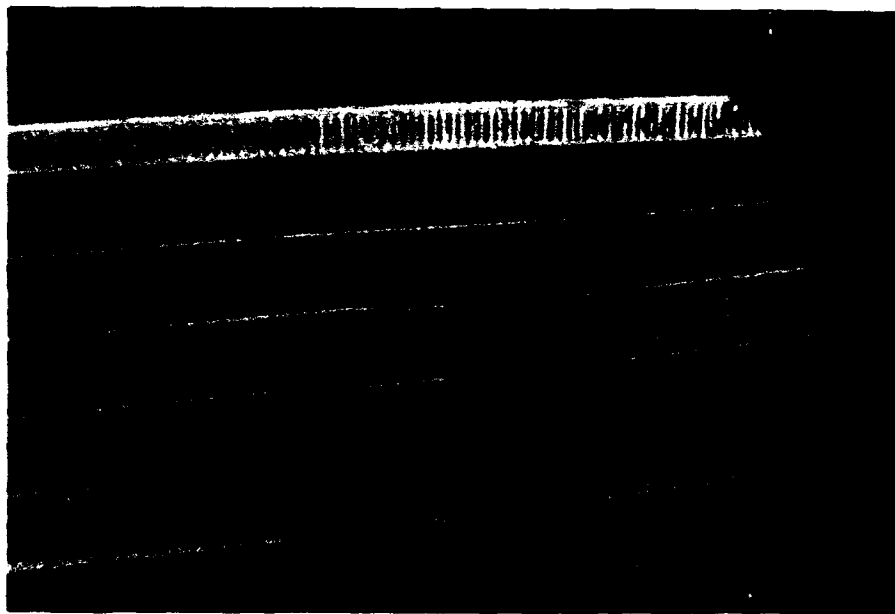


Figure 13. Short beam shear test setup for sample specimen, 5.5-in.-wide load bar.

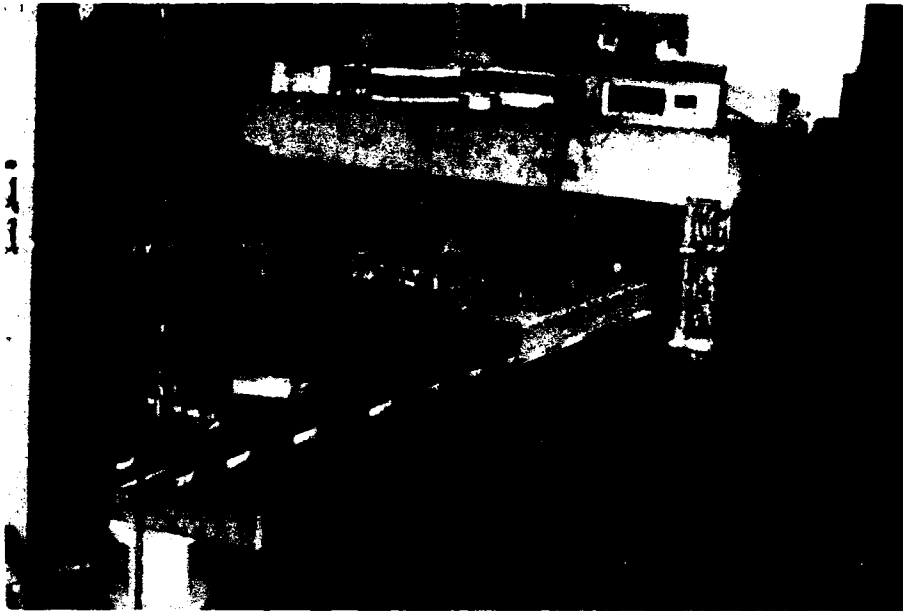


Beam at 4,130 lb

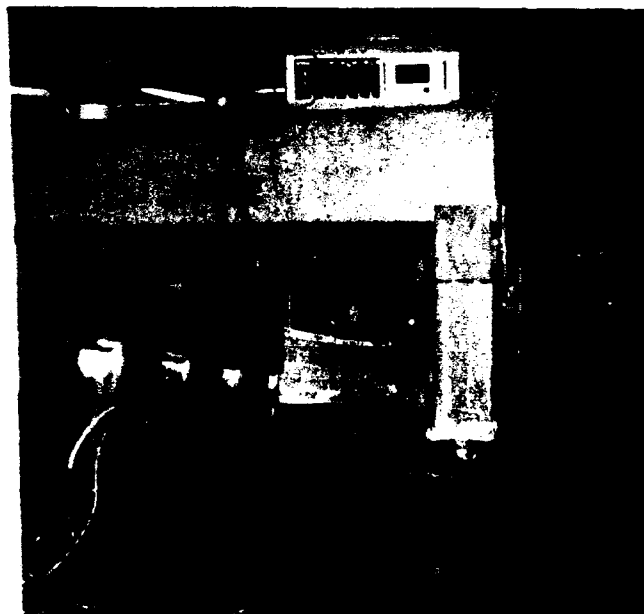


At 4,915 lb: Shear failure in PVC foam
0.305-in. deflection at failure

**Figure 14. Short beam shear test results, sample specimen,
5.5-in.-wide load bar--4,130-lb and 4,915-lb loads.**

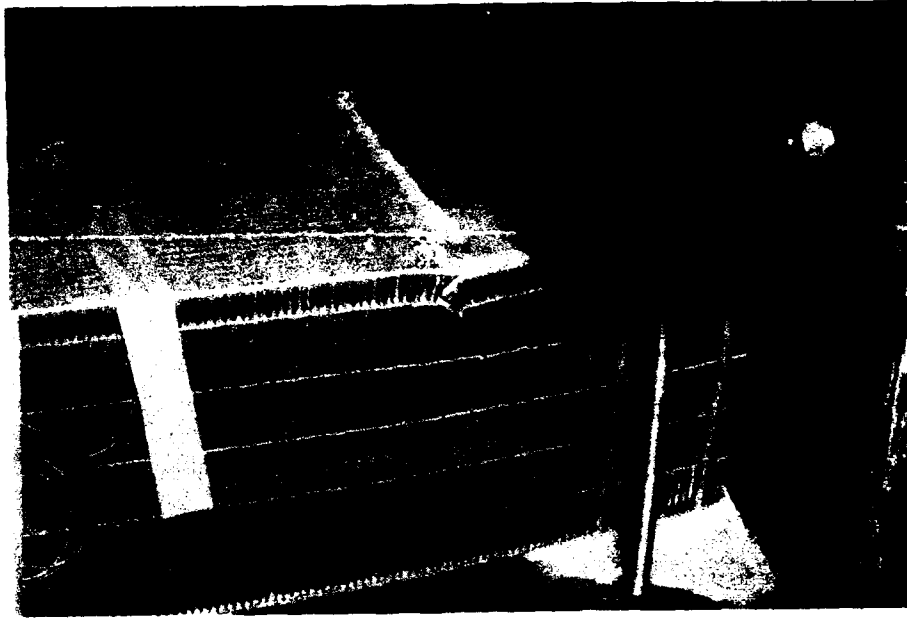


Setup showing load cell and chain hoist used to apply the load

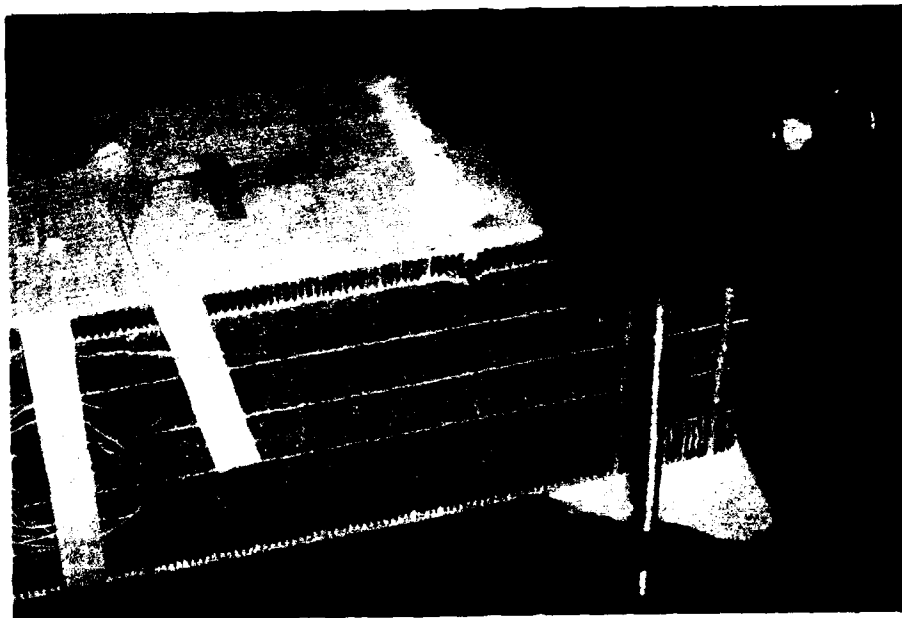


Beam at 572-lb applied load

Figure 15. Beam bending test setup for sample specimen.

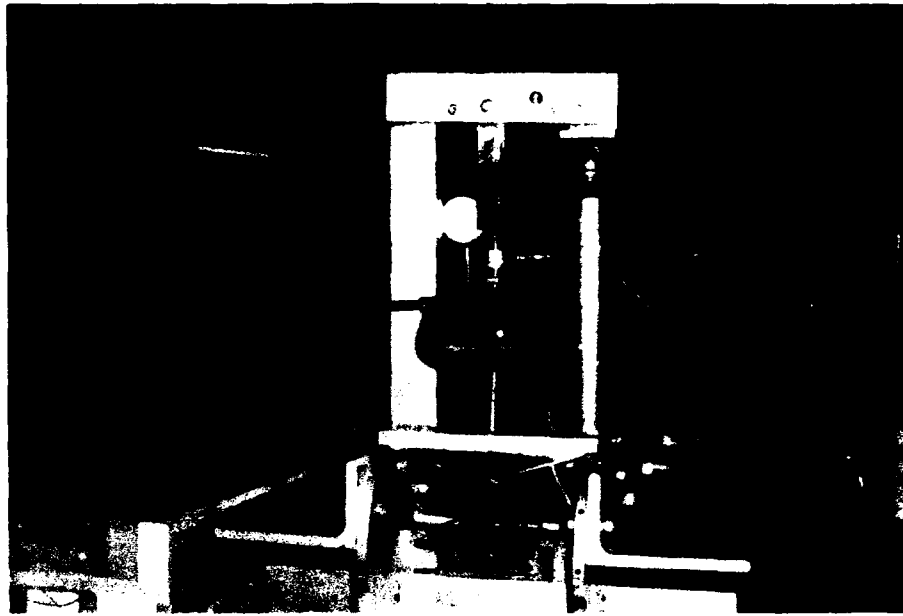


At 855 lb: Bending failure



Failure with load removed

Figure 16. Beam bending test results, sample specimen, 855-lb load.



Testing at 90° to the pallet surface

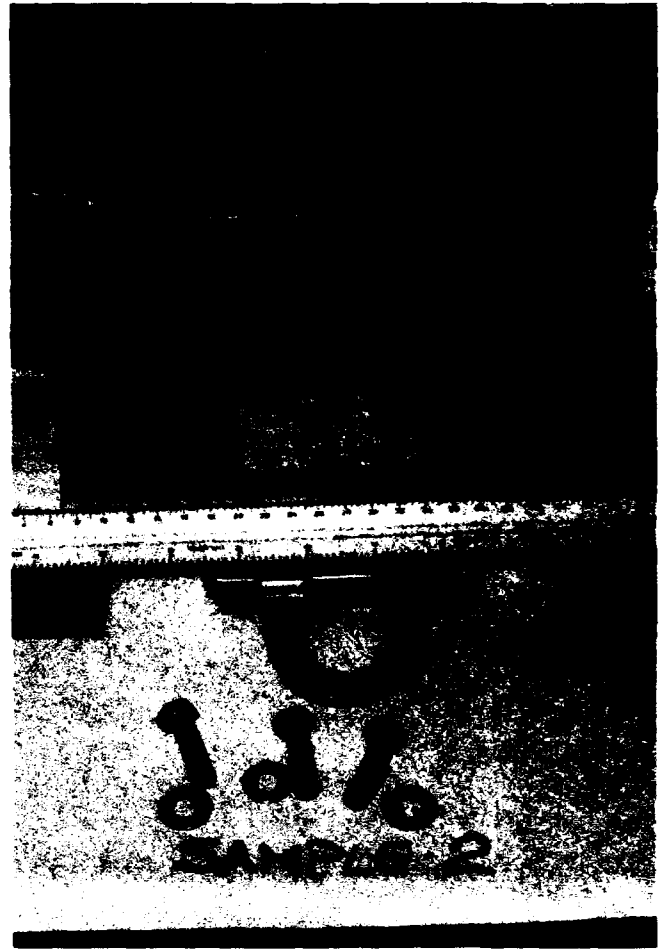


Testing at 0° to the pallet surface

Figure 17. Tiedown pull test setup for sample specimen.



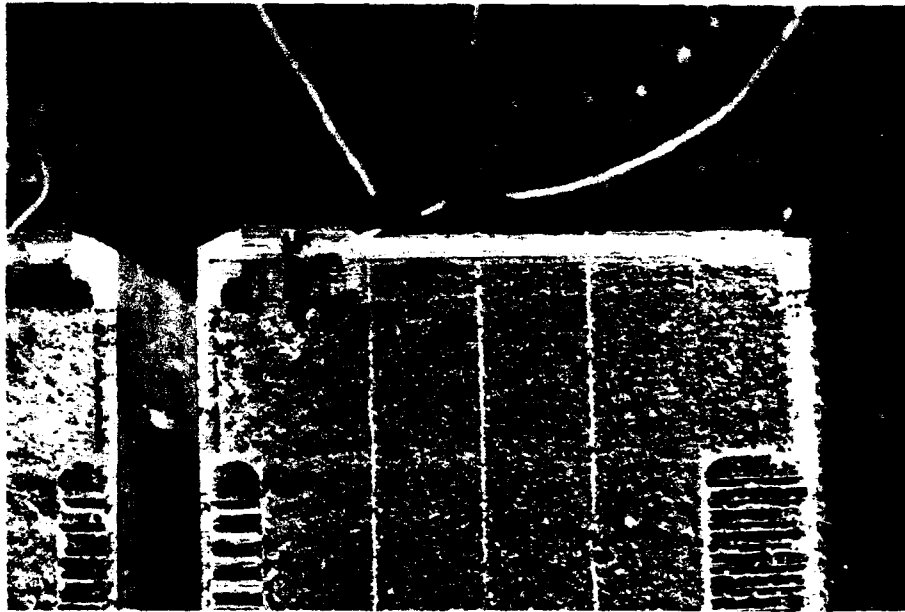
Sample 1--0.5-in. steel
tiedown gusset



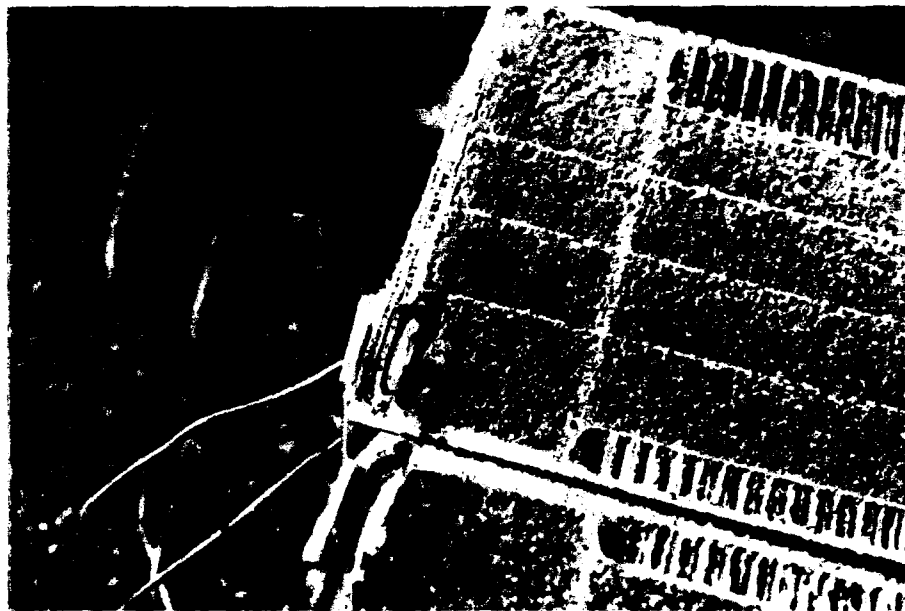
Sample 2--0.125-in. aluminum
tiedown gusset

Hardware deformation of both samples
Composite structure still intact

Figure 18. Tiedown pull test results for sample specimen hardware, 7,500-lb load.



Sample #1--0.5-in. steel tiedown gusset
Crack in PVC foam did not damage composite structural integrity



Sample #2--0.125-in. aluminum tiedown gusset
Gusset dis-bond and crack in PVC foam did not damage composite structural integrity

Figure 19. Tiedown pull test results, sample specimen composite structure, 7,500-lb load.

The test results were compared to the failure modes that had been predicted for the pallet preliminary design. While the performance of the components was in all cases within the specified load requirements, the panel shear and bending strengths were 15% below the predicted failure values. The results of the sample tests demonstrated that the preliminary design met all pallet structural requirements and provided clear indicators of potential material failure modes.

TABLE 2. SUMMARY OF SAMPLE TESTS

Test	Condition	Observed Result	Failure Mode Predicted
Tiedown pull	7,500 lb at 90°	No cracking in edge member. Localized cracking of PVC foam.	Edge member would not crack. Foam would crack.
Tiedown pull	7,500 lb at 0°	No cracking in edge member. Localized cracking of PVC foam.	Edge member would not crack. Foam would crack.
Mandrel	900 lb on 1-in. mandrel	No observable permanent deformation of the face sheet	No permanent deformation
Mandrel	Loaded to material rupture	Rupture at 2,300 psi. Yielding at lower stresses.	1,688 lb ultimate load, with bearing failure of honey-comb then PVC foam core
Roller	2-in. and 5-in. roller loaded to 2,500 lb	No permanent deformation	No permanent deformation
Roller	2-in. and 5-in. roller loaded to 6,050 lb	Permanent surface deformation 0.030-in. at 6,050 lb	3,817 lb ultimate load with failure of PVC foam
Short beam test for ultimate shear	6-in.X27-in. span loaded in center to 4,915 lb	Shear failure through PVC foam core at 4,915 lb	6,160 lb shear failure of PVC foam
Beam test for ultimate bending	Cantilevered 6-in.X120-in. beam loaded to 855 lb	Compression failure of upper face panel	1,043 lb compression failure of upper face sheet

2.1.5 Finite Element Analysis

A preliminary finite element analysis (FEA) was performed to establish overall internal load distributions under hoist loads, and to confirm the adequacy of the design at tunnel intersections and at the joints between edge members and tunnels. It was limited to the following efforts, which were considered appropriate for the development task: hoist analysis, tiedown pull analysis, corner lift analysis, tunnel intersection analysis.

2.2 FINAL DESIGN AND MANUFACTURING PLAN

Based on data from the foregoing tests and analysis, the design was finalized and a manufacturing plan was written for the experimental pallets. The data indicated that the basic sandwich configuration design would meet the functional requirements.

Certain manufacturing, tooling and materials plans were revised from the original plan, primarily for cost advantages. For example, the pultruded edge member final design was simplified, reducing both cost and weight.. Also, the tunnel sides were molded rather than pultruded for the two experimental pallets, as molding was a more cost effective approach for the small quantities required. (However, pultrusion will be more cost effective for production quantities.)

Additionally, the film adhesive originally planned for the face sheets (Newport Adhesive NB-101) would have required high pressure processing in a full-size press (108X88 in.), which was only available on the East Coast. A material change was therefore made, substituting Shell EPON 828/TETA for the film adhesive, enabling fabrication at Goldsworthy's Torrance plant. Another adhesive change was substitution of Shell EPON 8238/Versamid 140 for the Bostik 7087 epoxy/polyamide adhesive originally planned for all adhesive bonding. This change resulted in both reduced cost and improved availability.

Two other material changes addressed difficulties that were encountered during early fabrication efforts. To improve fiber wet-out, Shell EPON 9310 epoxy resin was used for pallet 001 and Dow Derakane 411 vinyl ester resin was used for pallet 002. To reduce the intermediate face sheet thickness, a 6-ounce unidirectional cloth was used in place of E-glass 7781 weave cloth.

The manufacturing, tooling, and materials plans for the two experimental pallets, as-built, are summarized in Tables 3 through 6.

TABLE 3. EXPERIMENTAL PALLET MANUFACTURING PLAN

Subassembly	Component	Fabrication
Edge member frame	Edge members	Pultruded glass/epoxy (pallet 001) Pultruded glass/vinyl ester (pallet 002)
Face sheet/sandwich assy	Face sheets/honeycomb sandwich assy (pallet top and bottom)	Press-molded with honeycomb sandwiched between outer and inner face sheets
Tunnel	Tunnel top and bottom	Vacuum bagged and bonded to face sheet/sandwich assembly at room temperature
Tunnel	Tunnel sides (stiffener)	Vacuum molded and cut to dimensions
Core block assy	Inner foam core	4-in.-thick PVC blocks saw-cut to template shape and details machined

TABLE 4. EXPERIMENTAL PALLET TOOLING PLAN

Tool type	Component	Fabrication
Molding tools	Edge members	Pultrusion die
Molding tools	Tunnel sides	Molding mandrel
Molding tools	Sandwich assy	Platen press with sacrificial caul sheet
Shaping tools	Inner core PVC foam	Table saw for cutting PVC foam blanks to template shape. Router table for machining details.
Assembly tools	Surface plate	Flat square steel plate
Assembly tools	Bonding fixtures	Fixtures for joining edge members and gussets and clamping tunnel sides to core blocks
Assembly tools	Bonding weights	Heavy weights
Assembly tools	Final assy table	Flat precision steel table

TABLE 5. EXPERIMENTAL PALLET ASSEMBLY PLAN

Subassembly	Assembly Method
Edge member frame	Edge members and corner gussets rigged for joining on flat square plate
Face sheets/sandwich assy with tunnel top and bottom	Vacuum bagged, bonded and cured on flat surface
Core block assy	PVC foam core and tunnel sides bonded and cured in fixture
Final assy	Pallet subassemblies rigged on flat precision table for final assembly and bonding operations

TABLE 6. EXPERIMENTAL PALLET MATERIALS PLAN

Component	Material type	Material Specified
Pultruded edge members	Fiber reinforcement and resin (OMC)	<u>Reinforcement:</u> E-glass grade of fiberglass. Stitched fabrics were used in a quasi-isotropic laminate (0,90,+45,-45 orientation) <u>Resin:</u> Pallet 001--Shell EPON epoxy resin system Pallet 002--Dow DERA KANE 411 vinyl ester resin system
Molded face sheets	Fiber reinforcement and resin (OMC)	<u>Reinforcement:</u> Same as for pultruded edge members <u>Resin:</u> Shell EPON 828/TETA
Molded tunnel sides	Fiber reinforcement and resin (OMC)	<u>Reinforcement:</u> E-glass <u>Resin:</u> Shell EPON 9310
Molded tunnel top and bottom	Fiber reinforcement and resin (OMC)	<u>Reinforcement:</u> E-glass <u>Resin:</u> Shell EPON 828/TETA
Outer core (sandwich assembly)	Aluminum	CR-3, 1/8, 5052, 0.002, 8.12 lb/ft ³ aluminum honeycomb (minimum compressive strength 1,100 psi)
Inner core	PVC foam	Termanto C70.55, 3.5 lb/ft ³
Bonding agents	Adhesives	Shell EPON 828/Versamid 140 used for all adhesive bonding

TABLE 6. EXPERIMENTAL PALLET MATERIALS PLAN (Continued)

Component	Material type	Material Specified
Tunnel opening reinforcement	Aluminum	Aluminum fabrication (4 pieces)
Tiedowns	Steel	Eastern Rotorcraft SP-2804-2
Tiedown inserts	Steel	Steel fabrication
Slinging eye	Steel	Steel fabrication
Corner gusset	Aluminum	Aluminum fabrication
Nuts	-	Self-clinching Kwik-Thread, CNS-518-3

Two experimental OMC INTEX pallet systems were released for fabrication in accordance with the approved final detail design.

3.0 FABRICATION OF EXPERIMENTAL PALLETS

The experimental pallets fabricated from the foregoing plan consist of multiple parts in a bonded assembly. Fabrication methods would change somewhat for pallets built in production quantities. For example, wherever possible, detail components would be "net molded" (molded in one piece) to reduce the part count, thereby also reducing labor and assembly time.

In this section, the methods and procedures are described and illustrated that were used for fabrication of two experimental pallets. They are presented in the following order:

- Fabrication of detail components
- Fabrication of subassemblies and hardware
- Final assembly

3.1 FABRICATION OF DETAIL COMPONENTS

The following detail components comprise the experimental pallets:

- Sandwich assembly
- Tunnel top and bottom
- Tunnel sides
- Inner core
- Edge members

3.1.1 Sandwich Assembly (Figure 20)

Two sandwich assemblies were fabricated for each pallet. They make up the pallet's outer panels; that is, its top and bottom surfaces. Each sandwich assembly consists of molded inner and outer face sheets, with an aluminum honeycomb core captured between these sheets.

The face sheets were press molded, as this was considered the most efficient fabrication method with the least cycle time and material waste for the experimental pallets. The face sheets would be net molded as a complete part in production, thereby reducing both molding time and a secondary labor operation.

Fabrication of the experimental pallet sandwich assembly proceeded as follows:

1. The prepreg cloth was laid into a "caul sheet" mold to form the inner face sheet.¹
2. The aluminum honeycomb was prepared by application of a foaming film adhesive around its perimeter. It was then placed on top of the cloth in the mold.

¹E-glass stitched reinforcing fabric preimpregnated with EPON 828/TETA epoxy resin

3. Another layer of prepreg cloth was laid on top of the honeycomb to form the outer face sheet, with film adhesive interwoven between the plies of the cloth.
4. The upper caul sheet was then installed over the laminate lay-up. The entire package was put into a press and molded at 275°F for 60 minutes under 25 to 50 psi pressure.
5. When the part had cured and cooled, the sandwich assemblies were bonded to the tunnel top and bottom sheets.

3.1.2 Tunnel Top and Bottom (Figure 21)

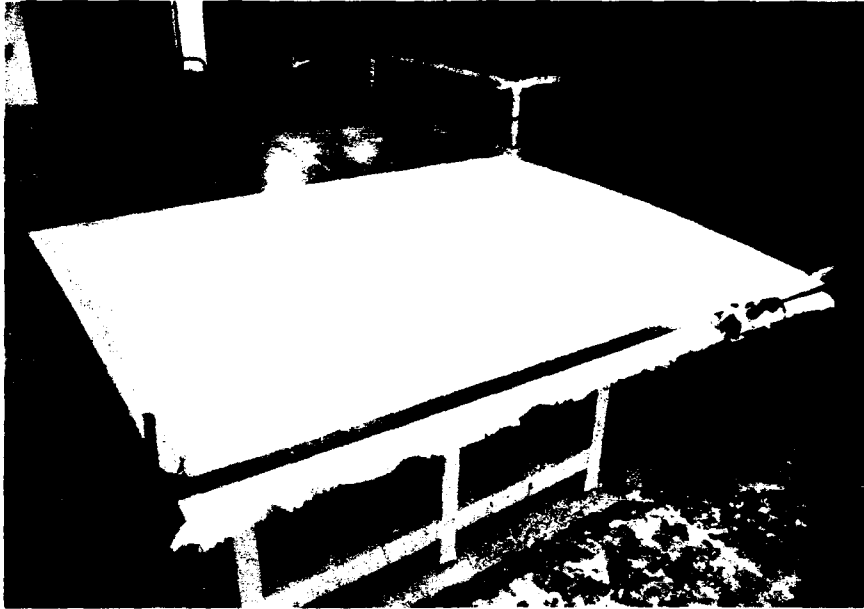
Each pallet incorporates two full-width and two full-length tunnels for forklift access. The tunnels cross the width and the length of the pallet, passing between the PVC foam blocks comprising the pallet's inner core. The tunnels were reinforced on the top and the bottom by an additional molded sheet that was bonded to the inner face sheets of the sandwich assemblies. Fabrication of the tunnel top and bottom sheets proceeded as follows:

1. A template was prepared conforming to the pallet's interior design. The tunnels crossed the width and the length of the pallet, passing between the PVC blocks in the pallet's inner core.
2. Prepreg cloth was laid onto a flat caul sheet, covered with a vacuum bag, and cured under vacuum pressure. The molding cycle was the same as for the face sheets.
3. Following cure, the template was used to cut the sheet to the correct size and shape.
4. The tunnel top and bottom were positioned on the upper and lower face sheets, respectively. Two locating holes were drilled through each tunnel sheet and into, but not through, the outer panels. The mating surfaces were then prepared for bonding.
5. Adhesive was applied to the contact surfaces, the parts placed together, positioning pins installed, and a vacuum bag installed.
6. A vacuum of 14 psi was drawn and held until the bond cured.

The design called for the tunnel side reinforcements to be separately fabricated.

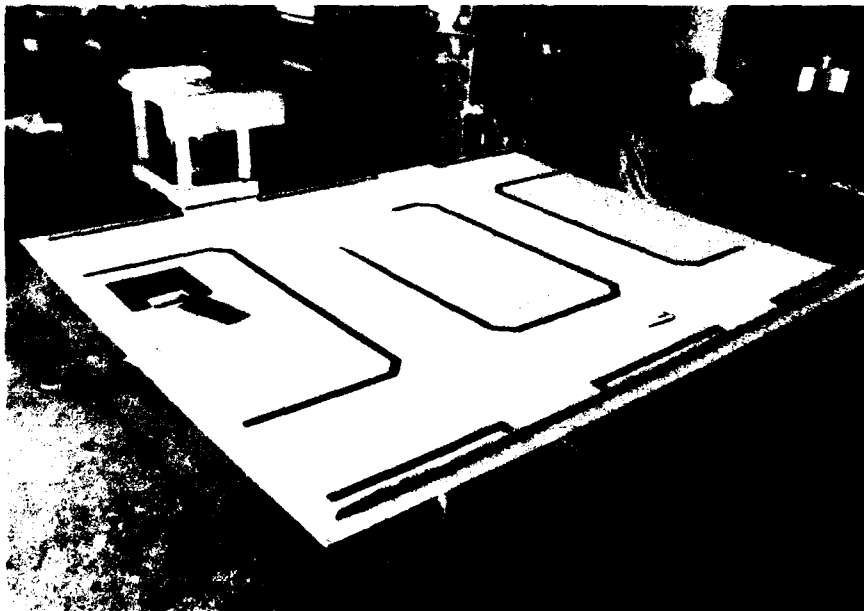
3.1.3 Tunnel Sides (Figure 22)

Two molded channels reinforce the sides of each tunnel. The tunnel sides were molded. In production quantities, pultrusion would produce parts of better quality and tolerance, with less labor invested. However, molding was more cost effective for the smaller numbers of parts required for the two experimental pallets. Each channel was bonded to its adjacent core block during subassembly (see Section 3.2).



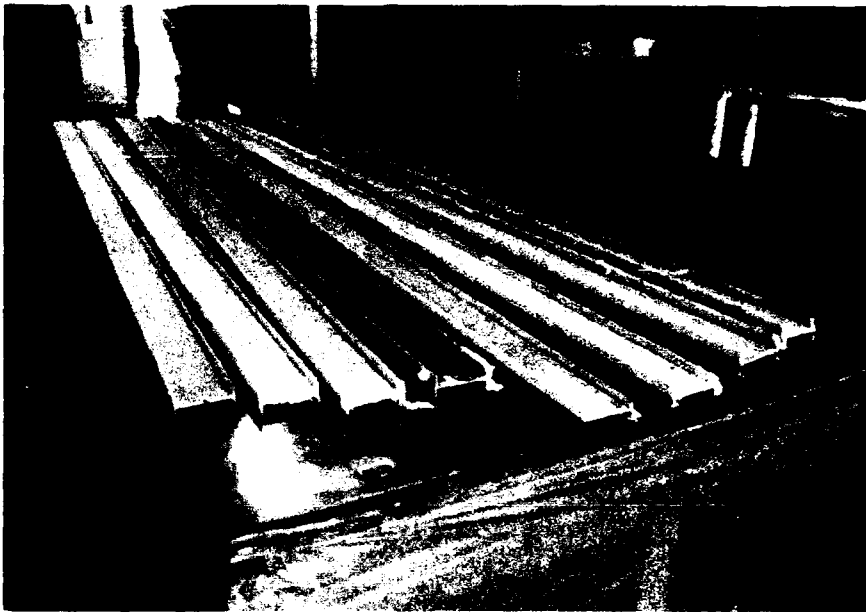
Part rigged on flat surface

Figure 20. Sandwich assembly fabrication, experimental pallet.



Vacuum molded tunnel bottom ready for bonding with sandwich assembly

Figure 21. Fabrication of tunnel top and bottom, experimental pallet.



Molded tunnel side channels



Corner joint layup

Figure 22. Fabrication of tunnel sides, experimental pallet.

A bonding gusset was used to join the adjacent tunnel side members. Two styles of corner gussets were used: one 90°, the other 135°. As with the tunnel sides, this gusset would be pultruded in production quantities. However, for small quantities, it was less costly to mold the corner gussets.

3.1.4 Inner Core (Figure 23)

Each pallet consists of an inner core of three PVC foam blocks. The foam core blocks were bonded to the tunnel top, bottom, and sides. Fabrication of the inner core proceeded as follows:

1. PVC foam was purchased in pre-bonded 4-in.-thick billets.
2. The foam blocks were cut to the shape of the template by means of a table saw.
3. Details were machined into the blocks by a router table and appropriate guides.

The inner core required external closure; pultruded edge members met this requirement.

3.1.5 Edge Members (Figures 24 and 25)

Four edge members enclose the perimeter of each pallet. Each edge member was fabricated to fit one side of the pallet.

The edge members were fabricated by means of the pultrusion process and filled with a foam core. The pultrusion process begins by pulling the reinforcements through a resin tank to thoroughly saturate them with the resin system, and through bushings to pre-form the part shape and squeeze out excess resin from the wet package. The wet package is then pulled through a heated, part-shaped die, where it is cured into finished product stock. The puller/gripper system pulls the cured stock out of the die and downstream into an automated cut-off saw, where it is cut to length. Pultrusion is a high volume production system that produces simple or complex monolithic parts with repeatable properties. The basic pultrusion process is illustrated by Figure 24.

Pultrusion fabrication of the edge members proceeded as follows (see Figure 25):

1. The material was set up and the pultrusion machine prepared for start-up:
 - a. Rolls of stitched E-glass reinforcements were arranged on material infeed racks.
 - b. The reinforcement material was fed through the resin wet-out tank, forming bushings, die, and puller/gripper system.
 - c. Processing speed controls and die temperature controls were set for machine start-up.



PVC foam core



Core block configuration

Figure 23. Inner core fabrication, experimental pallet.

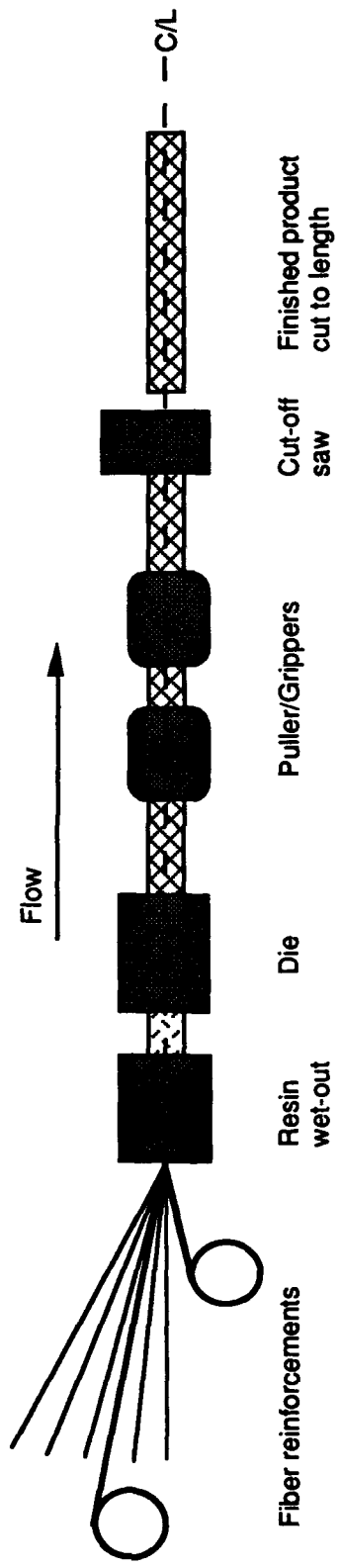
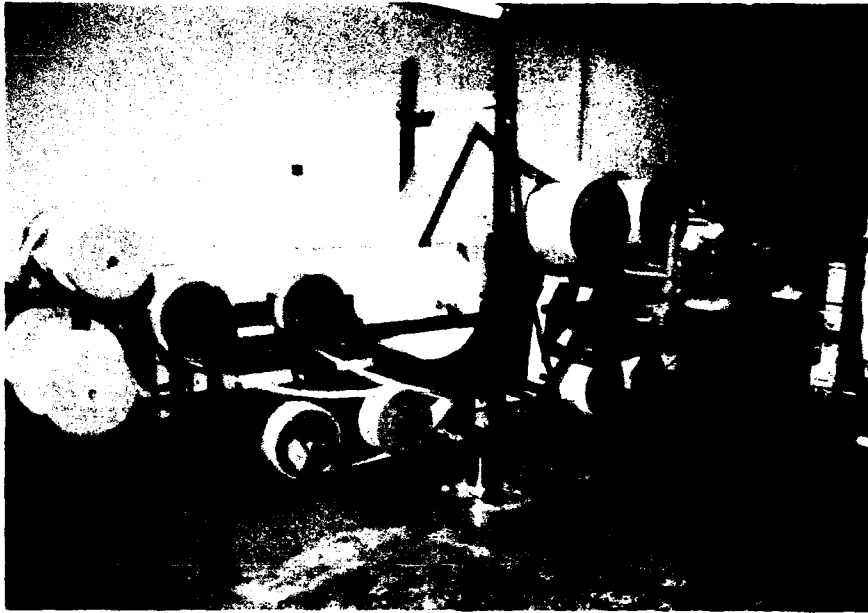
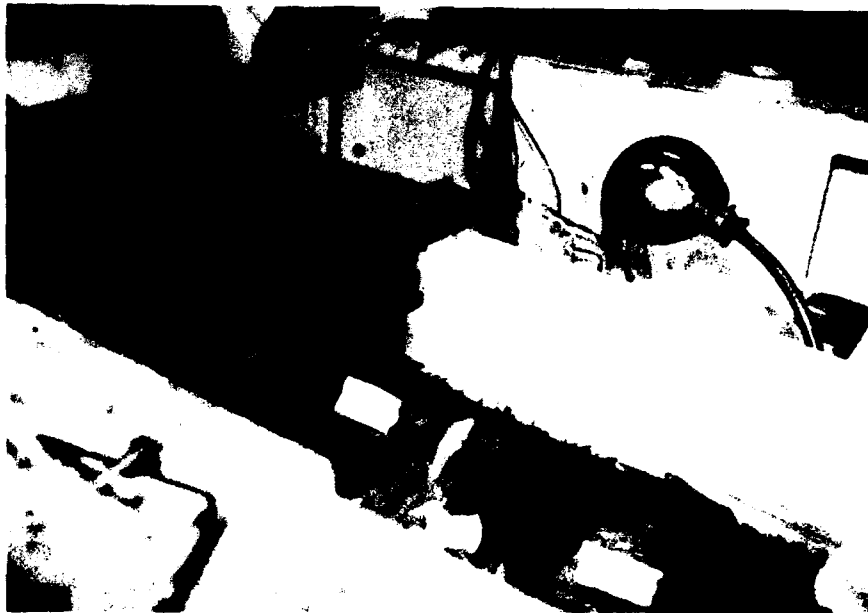


Figure 24. Basic pultrusion process.



Pultrusion infeed racks loaded with E-glass fabric rolls



Edge member at pultrusion die exit

Figure 25. Pultrusion fabrication of edge members, experimental pallet.

2. The pultrusion machine was started up to produce the desired lengths of edge member stock.
3. The edge members were finished by machining details in the pultruded stock to fit the pallet configuration.
4. Tiedown inserts were bonded to the edge members.

3.2 FABRICATION OF SUBASSEMBLIES AND HARDWARE

The fabrication procedures for the following subassemblies will be described in this section:

- Edge member frame
- Inner core block subassembly
- Hardware

3.2.1 Edge Member Frame Subassembly (Figure 26)

The edge member frame for each pallet consisted of four finished edge members with a foam core and fastening hardware. Frame assembly was accomplished by fastening the edge members into an assembly fixture and bonding them together at the corners. The edge member foam core was cut to shape and details machined with a router table for installation during final assembly.

3.2.2 Inner Core Block Subassembly (Figure 27)

The inner core block subassembly for each pallet consisted of three PVC foam blocks and the tunnel sides. These parts were rigged for bonding, and bonded together. The subassembly was then arranged in the fixture for final assembly.

3.2.3 Hardware (Figure 28)

The hardware used in the pallet consisted of the following parts:

Sling eye and tiedowns on all four corners (steel fabrication)

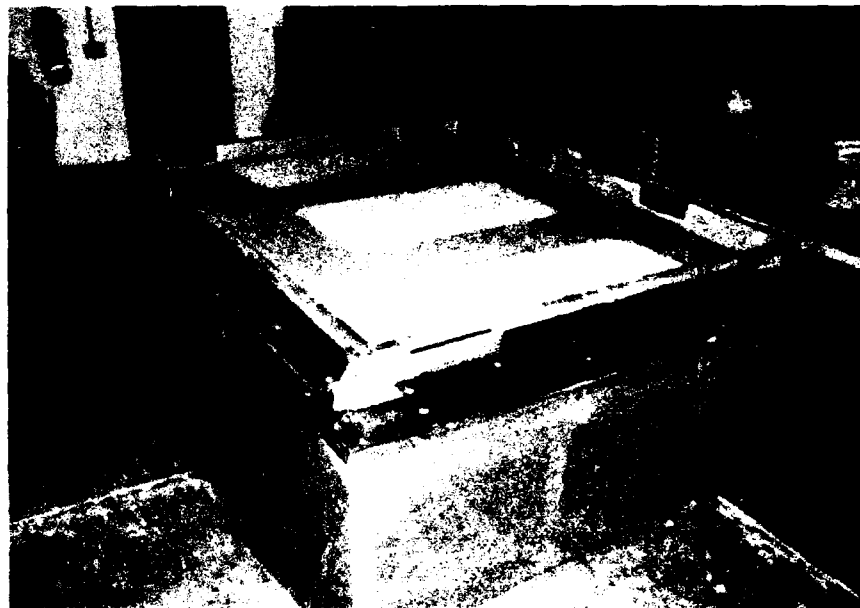
Corner gussets, nuts, and tiedown inserts (aluminum)

Tunnel opening reinforcement on all tunnels (aluminum fabrication). Consists of four pieces that both reinforce the tunnel opening for bending loads and provide a damage-tolerant scuff guard to protect this critical section of the pallet from damage caused by the forklift.

These parts were mechanically fastened to the pallet subassemblies, as illustrated in Figure 28.

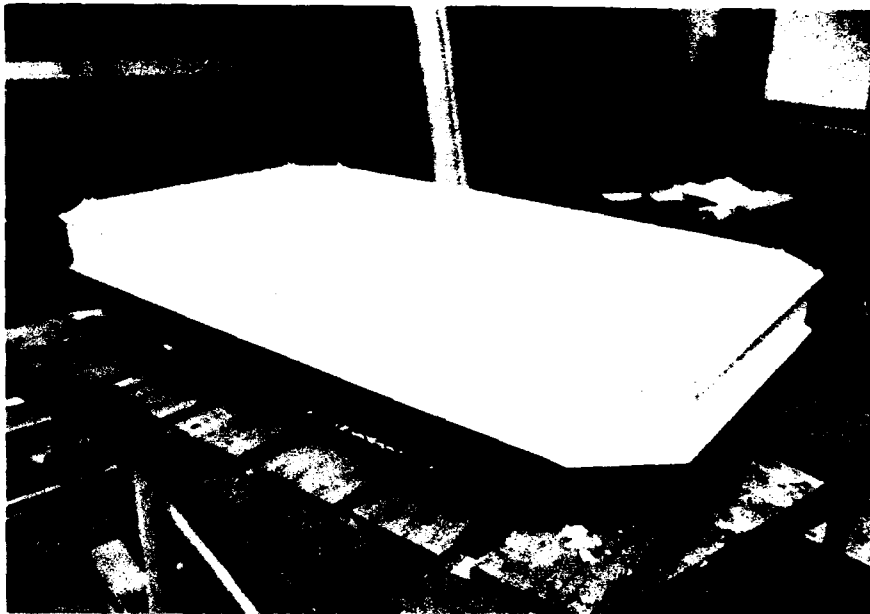


Pultruded edge members with details machined, ready for frame subassembly

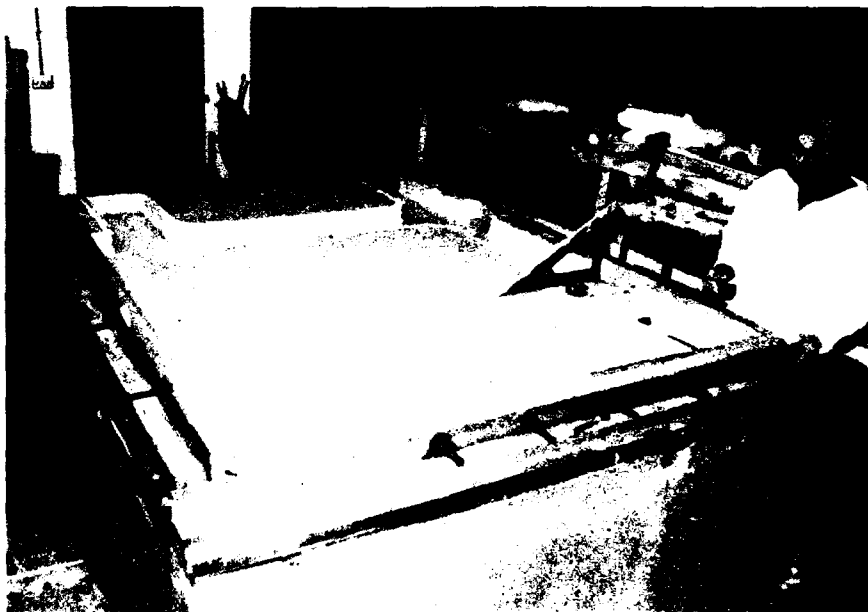


Frame subassembly fastened into fixture for pallet final assembly and bonding

Figure 26. Edge member frame subassembly, experimental pallet.

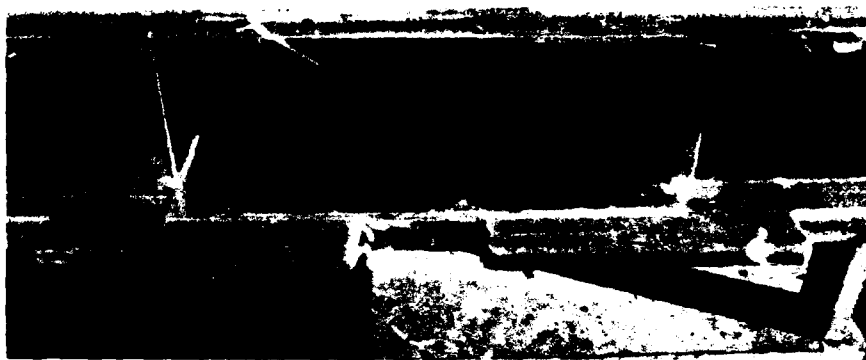


Completed inner core subassembly



Three inner core subassemblies ready for pallet final assembly

Figure 27. Inner core subassembly, experimental pallet.



Aluminum reinforcement for tunnel opening,
with steel sling eye and tie-downs



Aluminum corner gusset, nuts, tie-down inserts (interior view)

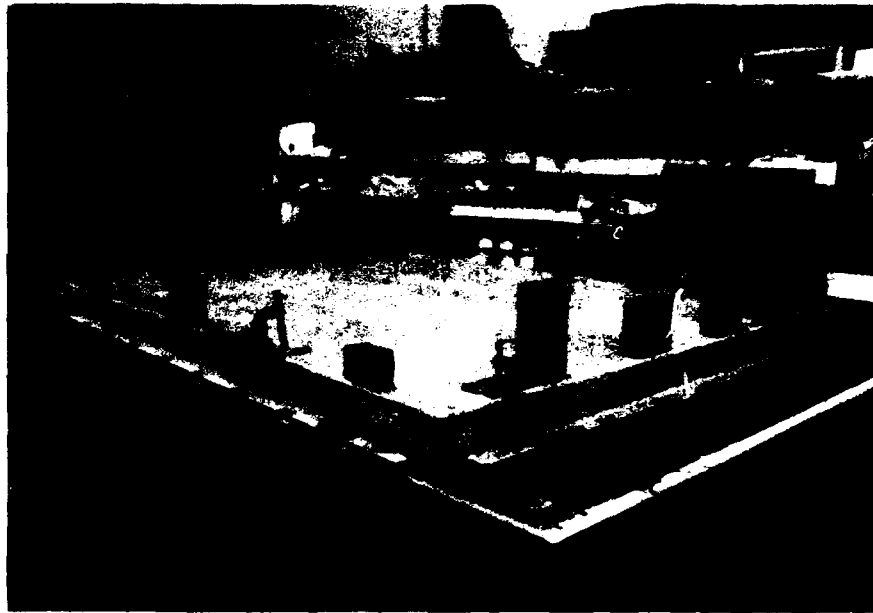
Figure 28. Hardware, experimental pallet.

3.3 FINAL ASSEMBLY (Figures 29 and 30)

Final assembly of the pallet subassemblies took place on a flat precision table. To complete fabrication of the two experimental pallets, the subassemblies were both mechanically fastened and adhesively bonded together. Final assembly proceeded as follows:

1. Edge member frame assembled to the bottom panel of the pallet
 - a. Mating surfaces of the lower face sheet and edge member subassembly were prepared for bonding
 - b. The bottom panel was placed on the assembly table and epoxy adhesive applied to the prepared mating surface
 - c. The edge frame subassembly was laid on the lower face sheet
 - d. A vacuum bag was installed and the assembly bond was cured under 14 psi vacuum pressure
2. Detail assembly parts installed
 - a. Adhesive was applied to the inside of the edge members and the edge member foam core installed
 - b. Foam adhesive was applied at the tunnel openings and the tunnel opening reinforcements were installed
 - c. Vacuum pressure was applied and the bonds were allowed to cure
3. Inner core block subassemblies were coated with adhesive and installed in the proper positions. The bonds were cured under 14 psi vacuum pressure.
4. Upper panel installed
 - a. Mating surfaces were prepared for bonding
 - b. The edge member frame and core block subassemblies were coated with adhesive
 - c. The upper panel was laid over the edge member frame and core block subassemblies, with the lower face sheet down
 - d. A vacuum bag was installed and the bonds were cured under 14 psi vacuum pressure
5. Hardware details installed. Tiedown rings, inserts, and slinging eye were bonded and mechanically fastened to the assembly

One completed experimental pallet is shown in Figure 30.



Pallet rigged for final assembly



Interior view through tunnel

Figure 29. Final assembly of experimental pallet.

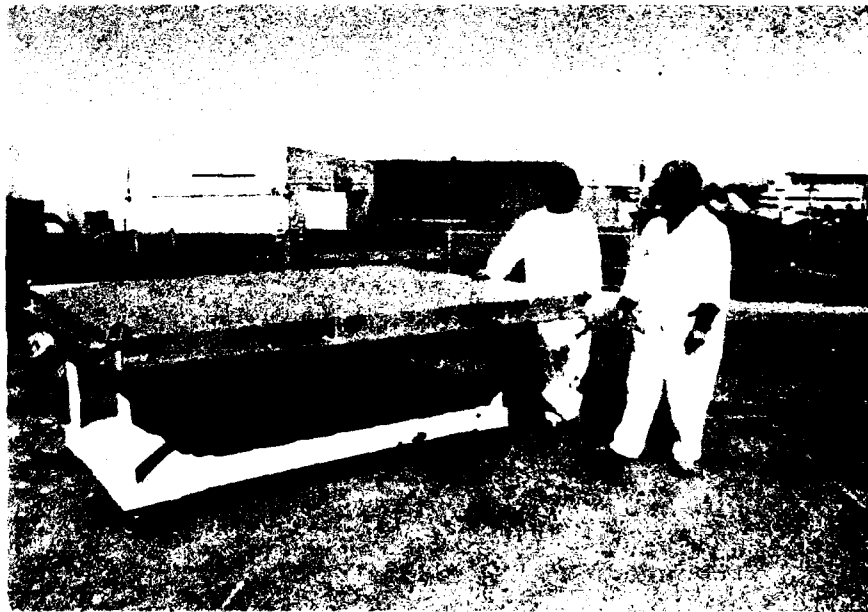
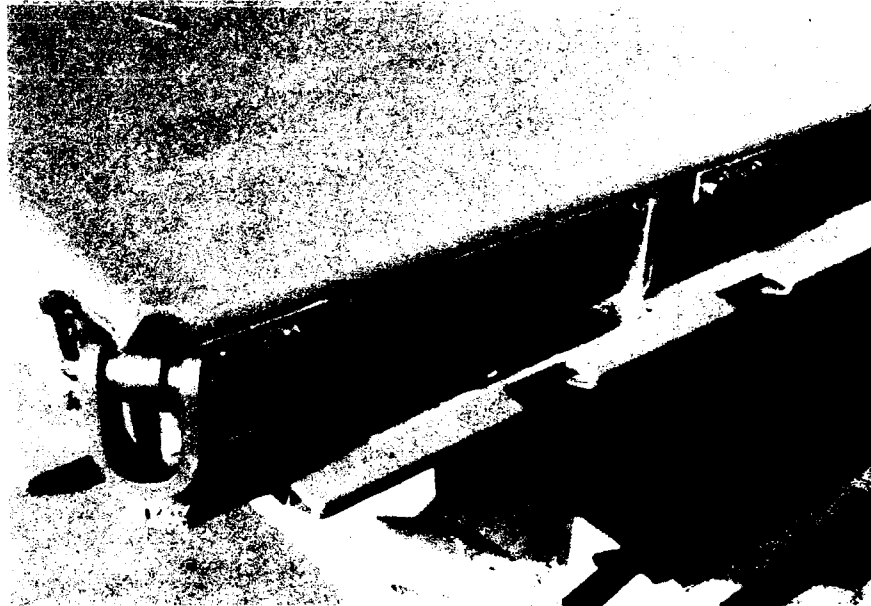


Figure 30. Completed experimental pallet.

4.0 TESTING OF EXPERIMENTAL PALLETS

The tests were designed to show compliance with a severe combination of requirements including compatibility with existing air cargo systems, ground handling equipment, and helicopter slinging. To meet these requirements, the pallets must be able to survive bearing loads applied to them by concentrated loads, and such operations as passage of the loaded pallet over roller or caster systems, and handling of loaded pallets by a cargo net, forklift, and hoisting equipment. At the same time, the pallet weight requirement was a maximum of 330 lb, so that it could be manually lifted by four men, one at each corner of the pallet.

The two experimental pallets subjected to test were identical except for the edge member resin system:

Pallet 001 Epoxy resin pultruded edge members
Pallet 002 Vinyl ester resin pultruded edge members

4.1 DESCRIPTION OF TESTING

This section describes and illustrates the tests that were performed on the experimental pallets. Test results are summarized and evaluated in section 4.2. Table 7 lists the tests, the requirements for which they were designed, and the criteria of success in evaluating test results.

TABLE 7. TESTING OF EXPERIMENTAL PALLETS--REQUIREMENTS, TESTS PERFORMED, AND CRITERIA OF SUCCESS

Requirement of Use	Test	Criterion of Success
Bear concentrated loads	1-in.-square mandrel test	No permanent deformation of the surface*
Passage over roller or caster systems	Ball caster test Dynamic roller test Static roller test	No permanent deformation of the surface
Cargo net loads	Tiedown ring pull test	No permanent deformation of the pallet
Forklift handling	Forklift test	No damage to the pallet
Hoist loads	Hoist test, working load	No rupture or permanent deformation of the pallet that would make it unusable

*Permanent deformation is defined as 0.005 in. or greater.

4.1.1 Ball Caster Test (Figure 31)

Requirement: Pallet must have the ability to roll across a grid of ball casters when fully loaded (net load 10,000 lb)

Description: A fixture with four steel ball casters was loaded with 124 lb. The casters were 1-1/4-in. in diameter, spaced on 5-in. centers. The fixture was reciprocated across the bottom of the pallet to simulate the pallet traversing a grid of steel ball casters with a load of 10,000 lb.

Results: Both pallets met criterion of success.

4.1.2 One-inch-Square Mandrel Test (Figure 32)

Requirement: Withstand load of 900 lb concentrated on 1 square inch of the upper surface.

Description: A fixture was fabricated in such a manner as to allow loading weights on a 1-in.-square mandrel. The edges of the mandrel were radiused slightly (1/16 in. or less). The fixture was loaded to 901 lb on each of three points on each pallet:

point 1	above full depth core, pallet center
point 2	above tunnel
point 3	above tunnel intersection (worst case)

Results: Both pallets met the criterion of success.

The only effect noted from both caster and square mandrel test was a "polishing" of the paint at the point of contact. There was no permanent deformation.

4.1.3 Forklift Test (Figure 33)

Requirement: Ability to be lifted by a forklift from any side when loaded with 10,000 lb.

Description: Fork extensions were fabricated for 10,000 lb capacity forklift. The pallets were loaded with 10,015 lb of lead to prepare them for the designated test cycles. One test cycle consisted of lifting the pallet 1 foot off the ground, holding it up for 1 minute, and setting the pallet down again. Each test consisted of ten cycles. Each loaded pallet was tested by lifting from all four sides.

Results: Both pallets met the criterion of success. Pallet 001 deflected 1/2 in. when lifted from the 88-in. side. Pallet 002 deflected 3/4 in. under this loading. No permanent deformation was noted.

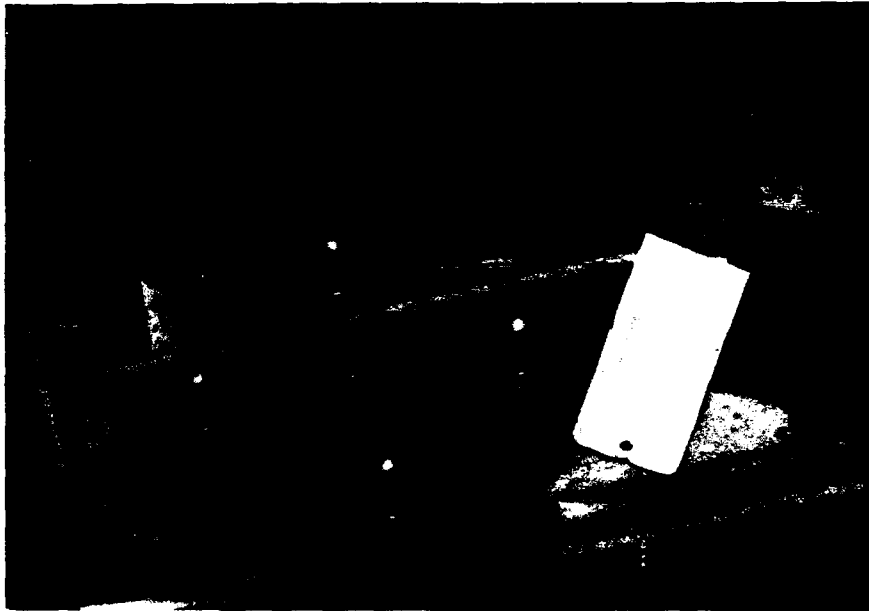


Figure 31. Ball caster test setup, experimental pallet.

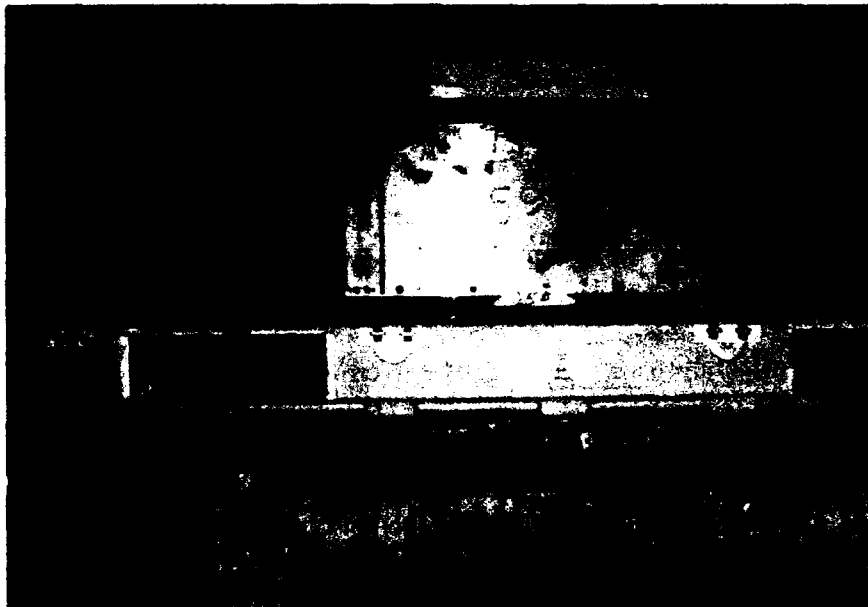
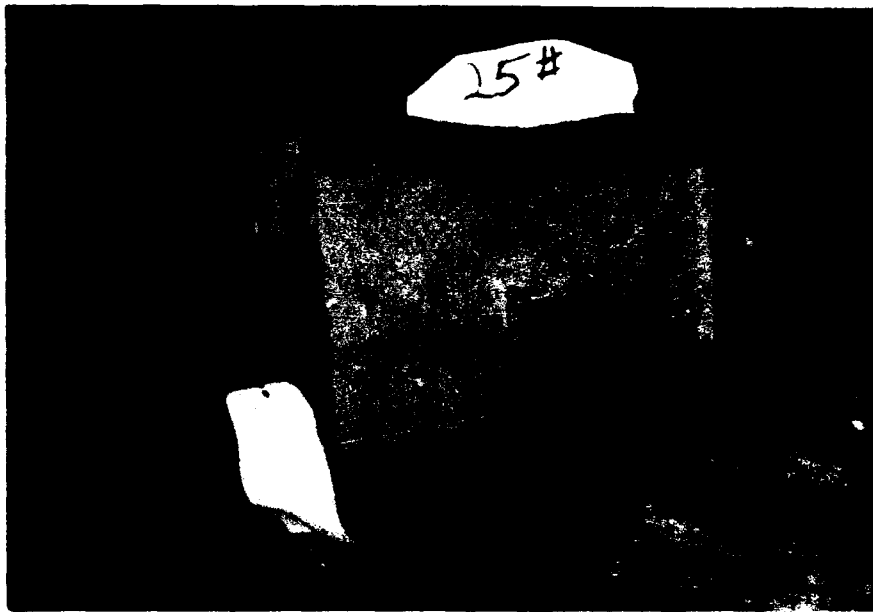


Figure 32. One-inch-square mandrel test setup, experimental pallet.

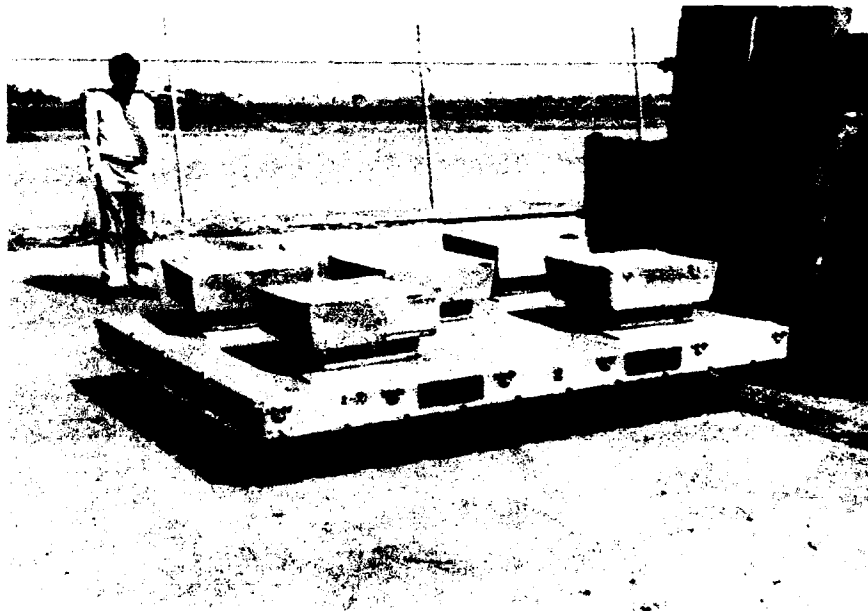
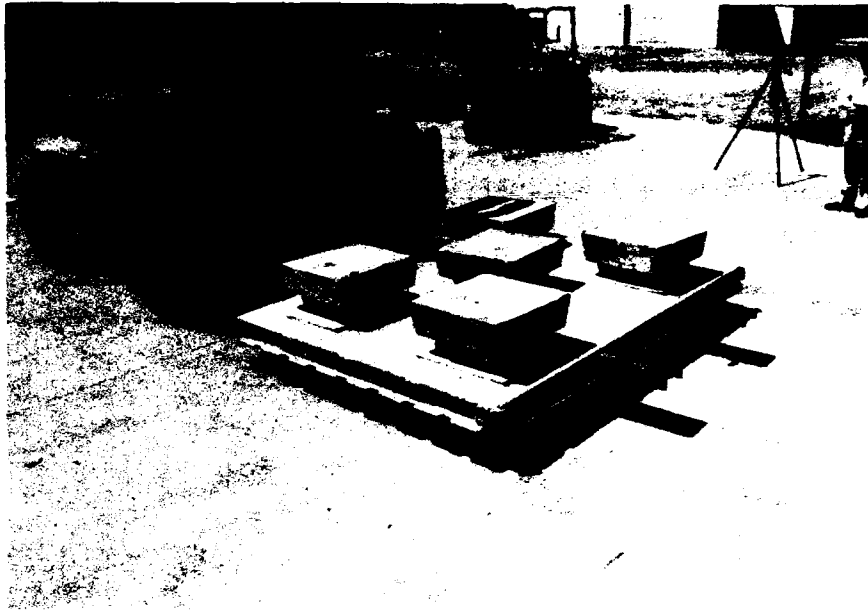


Figure 33. Forklift test, experimental pallet.

4.1.4 Dynamic Roller Test (Figure 34)

Requirement: Ability to roll on aircraft roller systems, fully loaded (10,000 lb net).

Description: A rack of rollers was fabricated consisting of 2-in.-diameter, 5-in.-long rollers on 10-in. centers, aligned in four adjustable rows to simulate system aircraft racks. Rows were aligned symmetrically about the centerline in both the 108-in. direction and the 88-in. direction. The pallets were placed on the rollers, loaded with 10,015 lb, and rolled one pallet length across the rollers and back--first in the 108-in. direction and then in the 88-in. direction.

Results: Both pallets were judged to have met the criterion of success. (Permanent deformation was sustained by both pallets; however, this was attributed to faulty test setup, not to inadequacy of the pallet structure.)

4.1.5 Static Roller Test

Requirement: Withstand 1 hour on rollers when loaded with 45,000 lb.

Description: Each pallet was placed on the rack of rollers that had been fabricated for the dynamic roller test. The pallet was loaded with 46,070 lb and allowed to stand for 1 hour. Then the load was removed.

Results: Both pallets met criterion of success.

4.1.6 Tiedown Ring Pull Test (Figure 35)

Requirement: Withstand 7,500-lb load applied in multiple directions to each of the tiedown rings at 30°, 45°, 90°, 135°, and 180° with the upper pallet surface, and at 45° and 135° in a vertical plane.

Description: A fixture was fabricated to apply a load of 7,500 lb to the tiedown fitting at the following angles:

- perpendicular (90°) to the pallet surface in an upward direction
- parallel (180°) to the pallet surface in an outward direction
- 45° to the pallet surface in an upward direction

The load was measured by load cell and indicated on a digital display.

Results: Pallet 002 met the criterion of success. (Pallet 001 was not tested, since it did not have the necessary internal reinforcements installed.)

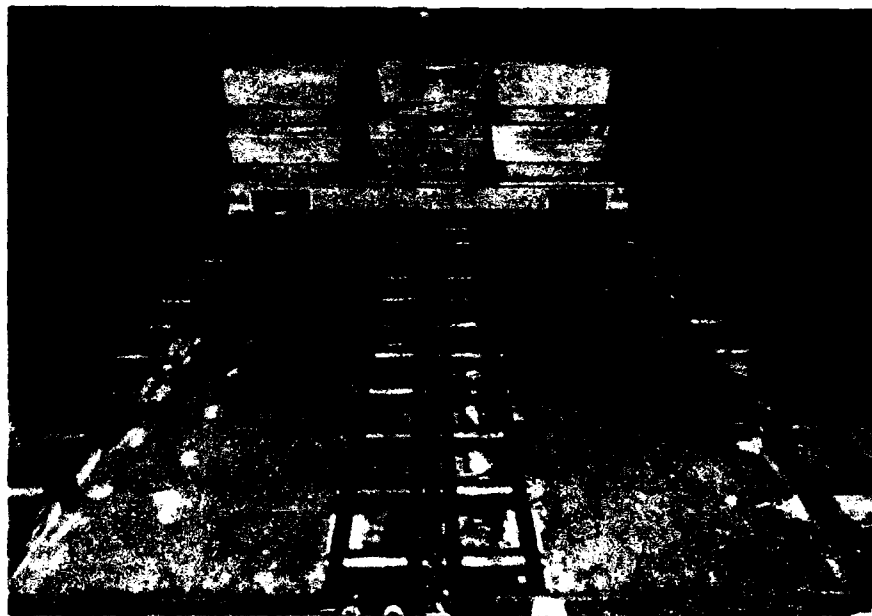
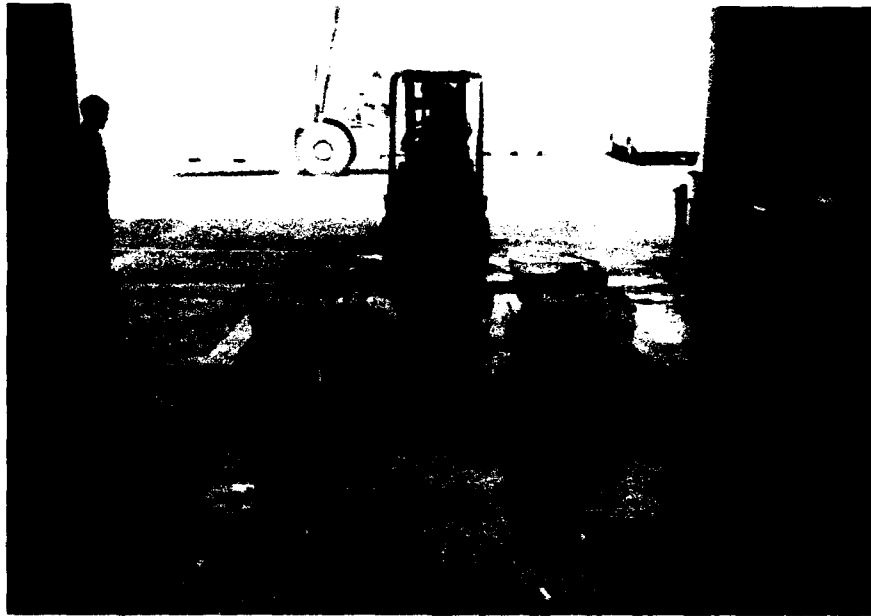


Figure 34. Dynamic roller test, experimental pallet.



Test setup



45° pull test

Figure 35. Tiedown ring pull test, experimental pallet.

The loads were increased at each angle until the part failed, with the following results:

- 90° pull : Failed at 9,000 lb. Failure of the edge member was gradual, not catastrophic.
- 180° pull : Failed at 10,500 lb. Failure of tiedown fitting and forged part was catastrophic. Nut insert and center bolt pulled through edge member, causing distortion but no catastrophic failure.
- 45° pull : Failed at 10,500 lb. Failure of fixture and distortion of tiedown eye, but no significant damage to edge member.

4.1.7 Hoist Test, Working Load (Figures 36, 37 and 38)

Requirement: Withstand hoisting with a lifting sling and lifting net with a working load of 32,000 lb (ten times) and ultimate load of 54,000 lb (ten times).

Description: Pallets were loaded with 32,010 lb in the form of 20-in. X 20-in. X 12-in. concrete blocks. The load was stacked so that the sling legs were clear of obstruction. The sling legs were set to intersect the pallet surface at 64°. A crane hoisted the loaded pallet with the sling set for ten cycles. One cycle consisted of lifting the pallet 1 foot off the ground, holding it for 1 minute, then setting it down. (The test was conducted by an independent testing firm.)

Results: Both pallets failed criterion of success.

Pallet 001 was lifted three times. Two adjacent corners pulled out of the pallet on the fourth lift.

Pallet 002 failed on the first lift. Two adjacent corners pulled out.

4.2 EVALUATION OF TESTING

Both experimental pallets met the criteria of success in all tests with the exception of the hoist test. Both pallets failed in the hoist test at the 32,000-lb load level. Table 8 summarizes the experimental pallet test results.

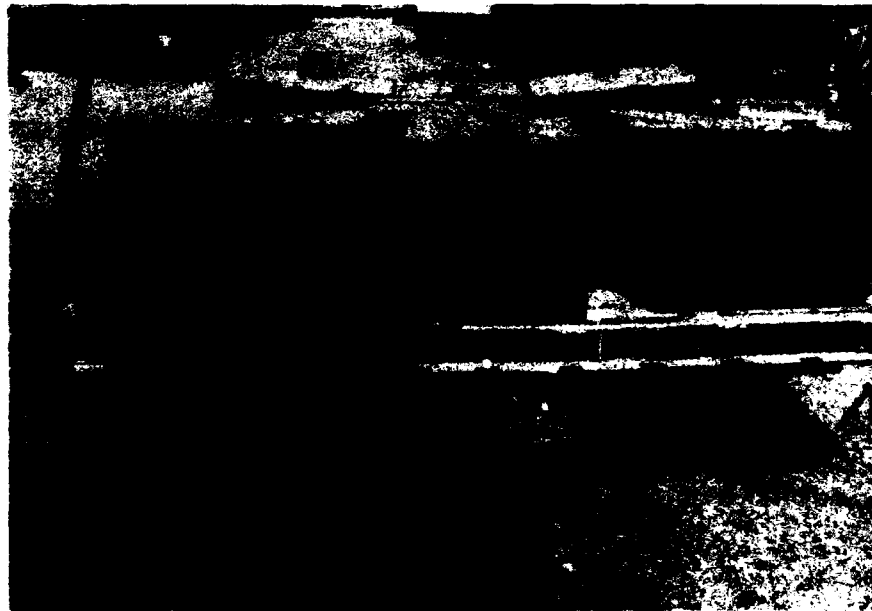
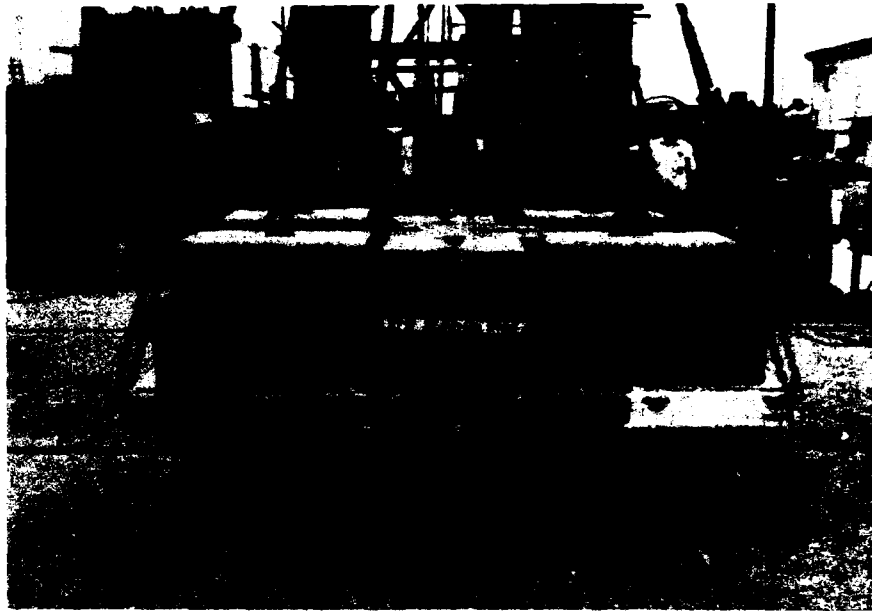
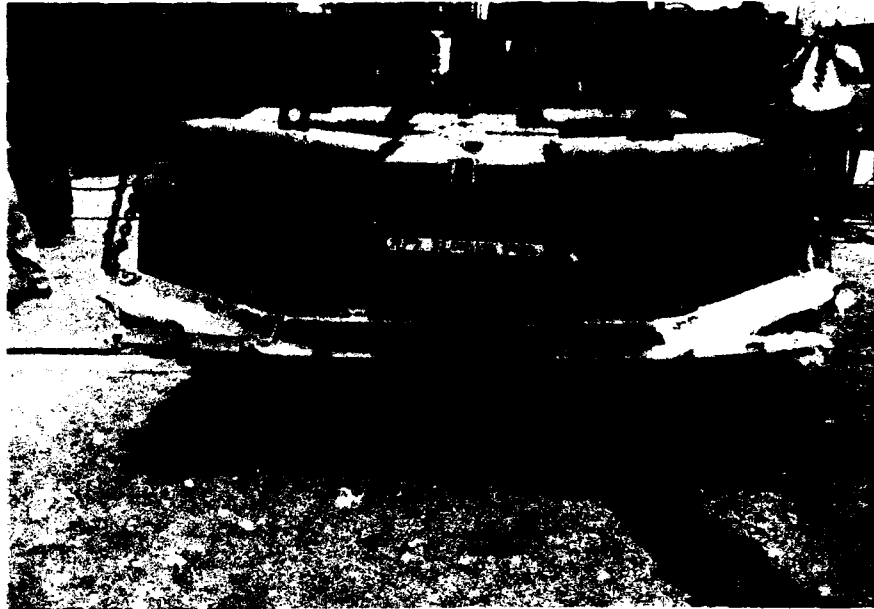


Figure 36. Hoist test preparations, experimental pallet.



Figure 37. Hoist test, experimental pallet, 32,000-lb load.



At 32,010-lb load: Corner failure

Figure 38. Holst test results, experimental pallet, 32,010-lb load.

TABLE 8. SUMMARY OF EXPERIMENTAL PALLET TESTS

Test	Condition	Result
Ball Caster Test	124-lb load on 4 ball casters reciprocated across bottom of pallet	No permanent deformation
1-in.-Square Mandrel Test	901-lb load on three 1-in.-square mandrels concentrated on 3 pallet points	No permanent deformation
Forklift test	Pallet with 10,015-lb load subjected to ten lift cycles	No damage to the pallet
Dynamic Roller Test	Pallet with 10,015-lb load rolled across rack of rollers	Permanent deformation sustained by pallets was attributed to faulty test set-up
Static Roller Test	Pallet with 46,070-lb load placed on rack of rollers for 1 hour	No permanent deformation
Tiedown Ring Pull Test	7,500-lb load applied to tiedown fitting at 90°, 180° and 45° to pallet surface	No permanent deformation of Pallet 002 (Pallet 001 not tested)
Hoist Test, Working Load	Pallet with 32,010-lb load hoisted by crane	Corners ruptured and permanent deformation resulted, making the pallets unusable

The hoist test failure mode for both pallets was the same: failure of the corners where tunnels are closest to the corners (Figure 38). This failure was viewed to be the result of a localized problem: i.e., poor integration of the corner with the tunnel opening reinforcement. Although the composite INTEX pallets were designed to carry a maximum weight of 10,000 lb, loads significantly greater than this can be experienced due to sudden acceleration during helicopter slinging. In this mode of loading, an amplification by a factor of 5.4, or 54,000 lb, is possible. Slinging lines are attached at lifting lugs at the pallet corners; they are not vertical, but are oriented inward at about 23°. Thus, nominally each corner of the pallet must carry an inward directed load of 14,670 lb. This load must be carried by the lifting lug, then the clevis, the corner reinforcement plate, and finally the edge members, which include the tunnel openings. In the tests, the load transition at the 32,000-lb level was successfully handled up to the point of transitioning the load into the tunnel openings closest to the corner. First, the aluminum tunnel opening reinforcement

de-bonded and then the lower corner of the tunnel opening failed in shear. Failure rapidly propagated from this point along the edge member and to the corner. Once failure was initiated, loads along this edge reduced and loads on the second edge increased, thus inducing failure at the tunnel openings on the second edge.

Since the failure was localized, the problem was believed to be solvable. The structural solution involved both the design of the tunnel opening reinforcement and the transition from the corner to the closest tunnel opening. A redesign program was initiated.

5.0 PALLET REDESIGN, FABRICATION, AND TESTING

The contractor developed a Redesign and Revised Program Plan of analysis and test, leading to fabrication of a modified prototype pallet. The plan included four work tasks, which were undertaken to overcome the pallet design deficiencies shown in the hoist test. The first two tasks called for modification of the corner component only. The third and fourth tasks called for redesign, fabrication and test of the full-scale pallet. The following four work tasks are described and illustrated in this section:

Task 1 Corner component modification--Simulate structure of the modified design on an undamaged corner of Pallet 002.

Task 2 Corner component modification test--Test modified corner under simulated 54,000+ load using dynamometer to measure load applied.

Task 3 Redesign of pallet for full-scale lift test--Redesign pallet using existing hardware and composite parts wherever possible.

Task 4 Fabricate and test full-scale test article--Fabricate Pallet 003 to meet new design specifications, and test it. Testing to consist of hoist tests only, as all other structural requirements were shown to be adequate during testing of Pallets 001 and 002. Hoist tests to be conducted at independent testing facility and include both working load lift (32,000 lb) and ultimate load lift (54,000 lb).

5.1 CORNER COMPONENT MODIFICATION (TASK 1)

A preliminary design session was held to review the original design methods and the approach to solving the corner failure. Agreement was reached on a method of redesign and test. The contractor initiated a detailed design effort based on the results of this preliminary session.

The detailed design included two corner reinforcement strategies under Task 1, illustrated by the preliminary sketches in Figure 39, Corner Configuration 1, and Figure 40, Corner Configuration 2. Configuration 1 models an all-aluminum reinforcement with the C-sections extending beyond the short-side tunnel opening. The other tunnel openings, on the long side of the pallet, would be reinforced with an integral aluminum frame. Configuration 2 models E-glass as the reinforcement, with a protective layer of polyurethane.

Fabrication of the two corner reinforcement components and their installation in Pallet 002 proceeded as follows:

1. Both configurations: A portion of the lip in the corner area was cut away to accommodate the width of the strap.
2. Configuration 1: (a) Aluminum parts were made to conform to an undamaged corner and adjacent tunnel openings of Pallet 002. (b) After the weld line was determined, the parts were removed and welded together.

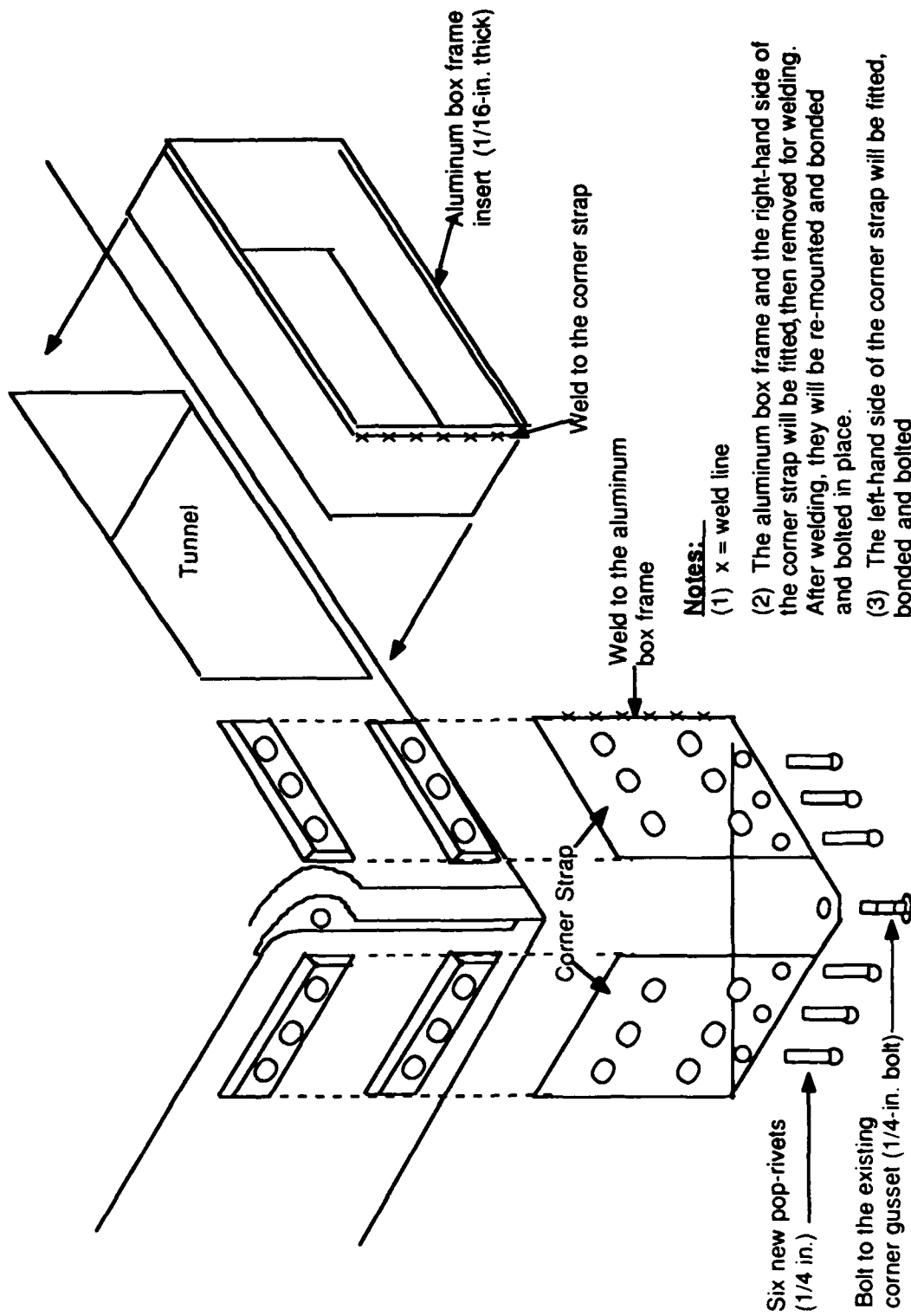


Figure 39. Redesigned corner configuration (#1).

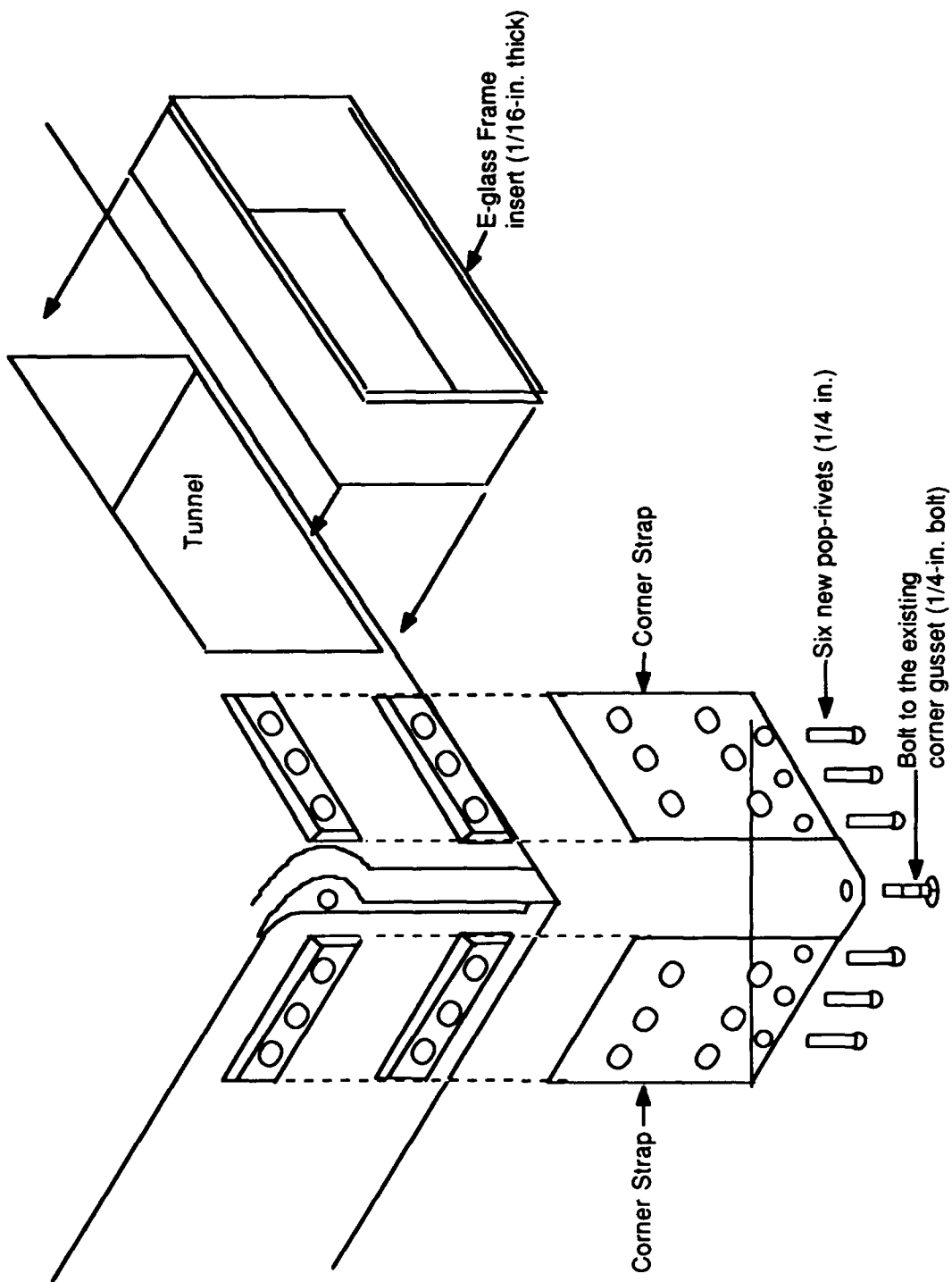


Figure 40. Redesigned corner configuration (#2).

3. Configuration 2: (a) An aluminum corner strap was made and fitted onto a corner of Pallet 002. (b) An E-glass reinforcement was laid-up and bonded into the tunnel opening.
4. The corner straps were fastened down by pop rivets and corner screws.

Note: Task 1 modifications were purposely external to avoid weakening the existing Pallet 002 structure. However, production pallets would not have external plates outside the pallet lower surface. Corner reinforcements can be designed to be flush with the lower surface of the pallet.

5.2 CORNER COMPONENT TEST (TASK 2)

After the composite tunnel and the aluminum tunnel configurations were installed on Pallet 002, they were tested at an independent testing facility, as follows:

1. Test plan--Load modified pallet with 54,000 lb of ballast, applying load to reinforced corner and using stops to prevent lateral skidding of the mass. Load corner to maximum allowable to assess corner strength. Concentrate weights on the pallet to reach projected load with 64° lifting angle.
2. Test description--Enough weights could not be loaded onto the pallet to reach the required weight with the correct 64° lifting angle. The decision was therefore made to lift the pallet straight up.
3. Test results--Both configurations failed. The composite tunnel collapsed at 12,500 lb, lifting straight up. However, the corner mount held. The aluminum tunnel failed at 9,200 lb.

All tests were fully documented.

5.3 REDESIGN OF PALLET FOR FULL-SCALE LIFT TEST (TASK 3)

The corner component tests helped to point out weaknesses in the corner modifications. Both internal (Alcoa) and outside (independent) consultants were engaged for concentrated computer finite analyses of the loads encountered by the corners. As a result of these analyses, the following structural changes were proposed:

1. Core material--A higher density foam core material was proposed for the corner areas to meet the loads introduced in the ultimate lift test. Core material selected was Divinacell R80 (5 lb/ft³), replacing Termano R7.5 at 4.6 lb/ft³.
2. Tunnel sides--Flanges were widened to 2 in. and laminate thickness was increased to 0.080 in. to help minimize torsional distortion around the tunnel openings.
3. Tunnel opening--A composite tunnel was selected instead of an aluminum tunnel. The composite version more closely matches the edge member's flexural characteristics, and provides a structural tie between the edge member and tunnel faces. Three basic changes were made to the tunnel opening design:
 - a. To help carry torsional as well as bending loads that are encountered by the tunnel area, reinforcements in +45° and -45° orientations were added to the composite tunnel modification.
 - b. The tunnel opening was moved 0.5 in. closer to the centerline on the 88-in. side to help distribute the loads from the corners across the tunnel openings.
 - c. The configuration was lengthened to extend more deeply into the tunnel openings.
4. Corner--The corner design was changed to facilitate mechanically fastening; fasteners selected were 1/4-in. stainless steel countersunk rivets.
5. Edge members--The edge member design was modified to help carry the corner loads across the tunnel openings. A longitudinal reinforcement was added across the top and bottom of the tunnel opening in addition to plies around the tunnel openings, creating a flange around the opening for bonding.

These changes were incorporated into the full-scale test article, Pallet 003.

5.4 FABRICATION AND TEST OF FULL-SCALE ARTICLE. PALLET 003 (PROTOTYPE) (TASK 4)

Pallet 003 was fabricated based on the results of the redesign effort summarized in this section, using hardware and composite parts from the experimental pallets wherever possible. Where new parts needed to be fabricated, the manufacturing plan for the experimental pallets was followed, with three exceptions:

1. Modifications resulting from redesign of the pallet, as discussed herein.
2. The outer panel face sheets were vacuum-cured rather than press molded.
3. All foam machining was done with a table saw.

The pallet was subjected to hoist testing at the independent test facility. See Figures 41 and 42 for photographs taken during testing. The pallet was lifted with both the net and the sling for the following tests:

- Working load--10 lifting cycles at 32,000 lb (1 cycle=90 sec)
- Ultimate load--1 lifting cycle at 54,000 lb (1 cycle=90 sec)

After being subjected to these loads, the pallet retained its original size and shape with no visual permanent deformation. Very close visual inspection revealed a small delamination (0.5X1-in.) in all four of the 88-in. side tunnel openings. This delamination was in the lower, outboard corner of the applied reinforcement around the tunnel opening. As no permanent deformation occurred that would result in loss of load or unsafe operation, the pallet was considered adequate to the task.

During this test, the load was incrementally increased from 32,000 to 54,000 lb. Each increment was lifted 1 cycle. However, the 48,123-lb load was lifted 8 cycles. This lift represented an overload of 16,000 lb. The pallet passed the test with this overload, sustaining no rupture or permanent deformation that would make it unusable. This suggests that the pallet is capable of lifting a load significantly in excess of the design limits.

Additionally, Pallet 003 was flight tested at Fort Rucker, Alabama, in order to establish flight parameters such as speed and angle of flight path. Two flight tests were conducted.

1. The Army's UH-60L Blackhawk helicopter was used to conduct pallet lift tests utilizing three different load weights. Both cargo net and sling lift methods were used, with loads centered and off-center. The following loads were tested:

<u>Weight Loaded on Pallet</u>	<u>Weight of Load Including Handling Devices</u>
2,420 lb	2,500 lb
4,870 lb	5,000 lb
7,256 lb	7,800 lb

Pallet 003 passed all of these tests.



Figure 41. Pallet 003 Hoist Test, 32,000-lb load.

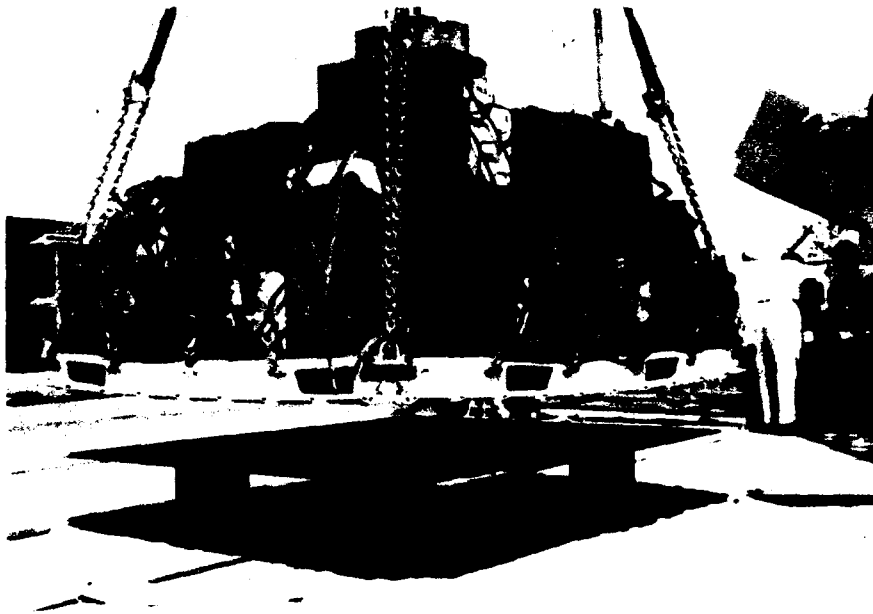


Figure 42. Pallet 003 ultimate load test, 54,000-lb load.

2. The CH-47 two-rotor helicopter was used to test the pallet's ability to handle the above loads, plus a heavier load. Again, both cargo net and sling lift methods were used, with loads centered and off-center. Three types of lift were used:

- Lift with cargo net (one hook)
- Lift with sling single point (sling with one hook)
- Lift with sling dual point (sling with two hooks)

The following loads were tested:

<u>Weight Loaded on Pallet</u>	<u>Weight of Load Including Handling Devices</u>
2,420 lb	2,500 lb
4,870 lb	5,000 lb
7,256 lb	7,800 lb
10,000 lb	10,600 lb

Pallet 003 passed all of these tests.

6.0 CONCLUSIONS

Three full-scale pallets were built during the program, the third of which successfully passed ultimate hoist and flight testing. This represented an important milestone, successfully demonstrating for the first time an organic matrix composite cargo pallet structure that meets stringent INTEX requirements. Furthermore, the pallet was designed for automated pultrusion processing, which will offer cost effective fabrication of pallets in production quantities. Lessons learned can be incorporated into future manufacturing plans for production optimization.

APPENDIX

SUMMARY OF DESIGN CRITERIA INTEX CARGO PALLET

TABLE A-1. GEOMETRY AND INTERFACE REQUIREMENTS

Item	Part	Description	Reference	Comments/Remarks
1.1	Intex pallet	<p>A shipping unit of the 463L cargo handling system.</p> <p>300 lb max. weight excluding all non-permanent equipment.</p> <p>Envelope dimensions 108 in. X 88 in.</p> <p>1-in. X 1.5-in. restraining lip with 2.75-in. notches on 10-in. centers.</p> <p>Forklift entries 4-in. X 12-in. tunnel through pallet, 2 symmetrically placed.</p> <p>Tiedown provisions; 22 positions on 20-in. centers. Class 2 tiedowns.</p> <p>Slinging provision; Class 1 or Class 3</p> <p>Min. clear opening 3-in.</p> <p>Max. dia. cross section 1-in.</p>	DAAJ02-86-C-0009	<p>Prime contract.</p> <p>Max. weight increased to 330 lb to allow use of more cus* effective materials.</p> <p>± 1/8 in.</p> <p>Revise to allow 2.5-in. dia. opening. Ultimate load.</p>
			MIL STD 209F(5.2.1)	

TABLE A-1. GEOMETRY AND INTERFACE REQUIREMENTS (Continued)

Item	Part	Description	Reference	Comments/Remarks
1.2	Cargo net	Restraint net to secure cargo during airlift.	DAAJ02-86-C-0009	Prime contract (contractor supplied)
1.3	Rollers	5-in. long 2-in. dia. on 10-in. centers. 4 rows-- in 108-in. direction: 50.8 in. & 14.8 in. from C/L in 88-in. direction: 37.375 in. & 4.625 in. from C/L.		Not consistent with C-5A or KC-10. Design for worst-case conditions.
1.4	Casters	1-1/4-in. diameter spherical casters spaced on 5-in. centers.		

TABLE A-2. GEOMETRY AND INTERFACE GOALS

Item	Part	Description	Reference	Comments/Remarks
2.1	Intex pallet	Pallet thickness approx. 6 in.	Verbal	Max. allowable.
		Usable surface area 104 in. X 84 in..	MIL-A-8421F (3.3.6.2)	
		Operating temperature range -65°F to +160°F.		Not in contract.
		Tiedown dimensions-- Min. clear opening: 1-1/4 in. Max. cross section: 1/2 in.	MIL-P-27443E (3.4.7)	HCU-6/E Type I Aluminum pallet requirement.
2.2	Cargo net	Restraint system for HCU-6/E pallet-- HCU-7/E side net (2 pieces) HCU-15/E top net (1 piece) Total assy weight 75 lb	MIL-A-8421F (3.3.6.2)	Design to be compatible with existing restraint system.
			MIL-N-27444C	Not included in pallet design weight.
2.3	Cargo strap	CGU-1/B	MIL-T-27260B	

TABLE A-2. GEOMETRY AND INTERFACE GOALS (Continued)

Item	Part	Description	Reference	Comments/Remarks
2.4	Forklifts	All: Fork length 72 in. Fork width 8 in. Thickness 2-3/4 in. Taper assy weight 75 lb S.N. 2000 & below: Fork spread min. inside 9 in. max. outside 68 in. S.N. 2001 & above: Fork spread min. inside 3 in. max. outside 80 in.	TM-10-3930-643- 14&P	Design for worst-case conditions.
2.5	Roller, restraint system, aircraft	Designated A/A32H-4-Rollers, restraint rails--locking detents and ramps for use in aircraft.	MIL-C-27691A	Design for worst-case conditions.

TABLE A-2. GEOMETRY AND INTERFACE GOALS (Continued)

Item	Part	Description	Reference	Comments/Remarks
2.6	Helicopter lifting sling	NSN 1670-01-027-2902	FM 55-450-1	Government furnished.
		10,000 lb. capacity nylon rope and chain assy.	FM 55-450-1	14,400 lb min. breaking strength.
		Max. apex height 24' Max. sling angle from vertical: -45°	MIL STD 209F (4.1.2.2)	Note: Test loads applied 26° from vertical.
		Chain size: 1.375 in. outer dimension	Verbal	Compatible with 2.5-in. dia. clear opening in eye.

TABLE A-3. LOAD REQUIREMENTS

Item	Part	Description	Reference	Comments/Remarks
3.1	Intex pallet	Capacity 10,000 lb. Uniform test load: Blocks, 20-in. X 20-in. X 12-in. high.	DAAJ02-86-C-0009	Prime contract.
3.2	Upper surface	1-in.-square mandrel applies 900 lb on surface; maximum permanent set: 0.005 in.		
3.3	Lower surface	Static load: 45,000 lb on roller system for 1 hour. No permanent deformation.	MIL-P-27443E	Room temperature.
		Must traverse rollers at 10,375 lb in both directions.	DAAJ02-86-C-0009	One pallet length.
		Must traverse steel ball caster at 10,375 lb in both directions.		
3.4	Tiedown eyes	7,500-lb load applied.	DAAJ02-86-C-0009	Restraint to be designed by contractor

TABLE A-3. LOAD REQUIREMENTS (Continued)

Item	Part	Description	Reference	Comments/Remarks
3.5	Lifting rings	32,000 lbs. load on pallet with slow lift.		Ultimate load 54,000 lbs. working load 33,200 lbs.
3.6	Forklift	Forklift must lift 10,375 lbs.		Note: load centered.

TABLE A-4. NON-CONTRACTURAL LOAD INFORMATION

Item	Part	Description	Reference	Comments/Remarks
4.1	Intex pallet	Gross weight 10,375 lb.	MIL-C-27691A (3.5.8.4)	Design requirement (\pm 30 lb).
		Center of gravity limits: 16 in. off center, 108 in. direction 12 in. off center, 88 in. direction	MIL-C-27691A (3.5.8.5)	Information only.
4.2	Lower surface	Dynamic load: 10,375 lbs. on rollers restrained by 4 detents. Subjected to 8 G's for 0.1 sec.	MIL-P-27443E (4.5.9)	Not a requirement.
		10,375 lb over crest of roller ramp at 17° from horizontal and 10-ft. long.	MIL-P-27443E (3.5.7)	Contractor to design pallet to withstand ramp crest loads.
4.3	Tiedown eyes	Tiedown strap-- Max. applied tension when tightening: 300 lb.	MIL-T-27260B (3.4.4.2.1)	Information only.
4.4	Slings	Max. angle from vertical: 45°. Max. apex height: 24 ft.	MIL STD. 209F (4.1.2.2)	Maximum angle from vertical is 26° (design condition)

TABLE A-4. NON-CONTRACTURAL LOAD INFORMATION (Continued)

Item	Part	Description	Reference	Comments/Remarks
4.5	Restraint lip	Restraint force of individual detent, up to 4,000 lb. 10,375-lb pallet-- 2 detents each side, 40-in. apart. 8 G's for 0.1 sec. Must restrain load. Deformation okay.	MIL-C-27691A (3.7.3.3) MIL-P-27443E (4.5.9)	Information only. Information only.
		Lip Bending-- 1/2-in. side section (perpendicular to edge of pallet). 1,250 lb-load applied 1/4 in. in from edge on bottom of lip. Applied perpendicular to bottom surface of pallet.	MIL-P-27443E (4.5.10)	Information only.
4.6	Restraint load criteria, aircraft	Fore: 3.0 G's Aft: 1.5 G's Lateral: 1.5 G's Up: 2.0 G's Down: 4.5 G's	MIL-A-8421F (3.3.4)	Information only.

TABLE A-4. NON-CONTRACTURAL LOAD INFORMATION (Continued)

Item	Part	Description	Reference	Comments/Remarks
4.7	Ultimate load criteria, aircraft	Fore: 8.0 G's Aft: 2.0 G's Lateral: 1.5 G's Up: 2.0 G's Down: 5.1 G's	MIL-C-27691A (3.5.8.3.1.a)	Information only.
4.8	Drop conditions; i.e., load, height, and angle			None defined.

TABLE A-5. TEST REQUIREMENTS

Item	Part	Description	Reference	Comments/Remarks
5.1	Hoisting test	32,000-lb uniform load slings lifting vertically at 90° to pallet surface. Lift, hold for 1 min., lower to floor. Repeat 10 cycles.	DAAJ02-86-C-0009 MIL STD 209F	Delete from contract. Replace with items 5.8 and 5.9.
5.2	Conveyor test	10,375-lb gross weight. Traverse rollers in both 108 in. and 88 in. directions.		Flat surface. One pallet length.
5.3	Forklift test	10,375-lb gross weight. Lift pallet 1 ft. Hold 1 min., return to ground. 10 cycles each side.		Agreed.
5.4	Steel ball caster test	10,375-lb gross weight. Omnidirectionally traverse grid of 1-1/4-in.-dia. steel ball casters spaced on 5-in. centers.		Agreed.
5.5	Tiedown ring test	7,500-lb load applied.	DAAJ02-86-C-0009	Pallet restrained by adjacent lips.

TABLE A-5. TEST REQUIREMENTS (Continued)

Item	Part	Description	Reference	Comments/Remarks
5.6	Static test	45,000-lb static load supported on 4 rows of 5-in.-long, 2-in.-dia. rollers spaced on 10-in. centers for 1 hour. No permanent deformation.		
5.7	Destruction analysis (test)	A 1-in.-square steel mandrel will apply a 900-lb load to the surface of the pallet. Permanent deformation shall not exceed 0.005 in.		Elastic deflection requirement has been waived.
5.8	Working load test	33,200-lb static load uniformly distributed over pallet surface. Sling angle from vertical ~26°. Raise and lower pallet 10 times. After test the pallet shall not exhibit any permanent deformation.		
5.9	Ultimate load test	54,000-lb static load uniformly distributed over pallet surface. Sling angle from vertical ~26°. Raise pallet one time. No overall pallet rupture, including sling eyes, shall be observed.		

TABLE A-6. ALUMINUM PALLET TESTING (TESTS NOT INCLUDED IN CONTRACT)

Item	Part	Description	Reference	Comments/Remarks
6.1	Conveyor test	10,375-lb load. Roller traverse--10,000 ft. at 30 fpm in 25-ft. increments in both 108-in. and 88-in. directions.	MIL-P-27443E (4.5.3)	12,000 cycles. Not a requirement.
6.2	Conveyor ramp test	10,375-lb load. 10-in. ramp of rollers 15-17° between 2 horizontal sections of rollers. 25 cycles up ramp over apex in both 108-in. and 88-in. directions.	MIL-P-27443E (4.5.3.4)	Not a requirement.
6.3	Steel ball caster test	10,375-lb load. 1,500-ft. traverse on steel ball casters in each of 108-in. and 88-in. direction.	MIL-P-27443E (4.5.5)	5-in. centers 3,600 cycles. Not a requirement.
6.4	Tap test	Looking for voids in bond.	MIL-P-27443E (4.5.1.1)	Not a requirement.
6.5	Peel test	Peel skin off core. 100% wood core failure necessary to pass from test panels.	MIL-P-27443E (4.5.1.2)	Not a requirement.

TABLE A-6. ALUMINUM PALLET TESTING (TESTS NOT INCLUDED IN CONTRACT) (Continued)

Item	Part	Description	Reference	Comments/Remarks
6.6	Plug test	Plug-cut from pallet subjected to peel test. 100% wood core failure required.	MIL-P-27443E (4.5.2.1)	Not a requirement.
6.7	Forklift wedge test	Forklift tines wedge under pallet on flat floor. No permanent damage allowed.	MIL-P-27443E (4.5.4.1)	Not a requirement.
6.8	Environmental test	High temp. test: Soak at high temp. Method 501 MIL-STD-810E: A) load to 10,000 lb and B) lift loaded pallet with sling and lower onto 4 in. X 4 in. on floor so it balances. Pallet must take 50 cycles.	MIL-P-27443E (4.5.7.1)	Not a requirement.
		Rain test: Method 506.1 MIL-STD-810E	MIL-P-27443E (4.5.7.2)	Not a requirement.
		Salt spray test: Procedure 1 Method 509 MIL-STD-810E	MIL-P-27443E (4.5.7.3)	Not a requirement.

TABLE A-6. ALUMINUM PALLET TESTING (TESTS NOT INCLUDED IN CONTRACT) (Continued)

Item	Part	Description	Reference	Comments/Remarks
Core resistance and low temp test:	MIL-P-27443E	<ul style="list-style-type: none"> • Drill 5 holes through pallet • Soak at room temp. in water 3 hours • Soak at -65°F 4 hours • Soak 3 hours at room temp. • Soak 4 hours at -65°F • 20 cycles of lift test (4.5.7.1) at -65°F 	(4.5.7.4)	Not a requirement.
6.9 Ultimate load test	MIL-P-27443E	10,000-lb load on a pallet. Restrain pallet by 2 rail slots each side, 40-in. apart. Apply 8 G's forward for 1 sec.	(4.5.9)	Not a requirement.

REFERENCE DOCUMENTS

Designation	Description
DAAJ02-86-C-0009	Prime contract from. Army--source of all requirements.
MIL-P-27443E	Pallets, cargo aircraft, type HCU 6/E. A description and requirements of aluminum pallet.
MIL-STD-209F	Slinging and tiedown provisions for lifting and tying down military equipment.
MIL-N-27444C	Net, cargo tiedown, pallets. HCU 7/E, HCU 15/C.
MIL-T-27260B	Tiedown, cargo, aircraft CGU 1/B.
MIL-C-27691A	Cargo handling system, aircraft A/A 32H-4. Roller and restraint system for aircraft pallet loading.
FM-55-450-1	Helicopter external loads and sling information.
MIL-A-8421F	Air transportability requirements--general specification for.
MIL-STD-810E	Environmental test methods and engineering guidelines.
TM-10-3930-643-14&P	Forklift specifications.