AFAPL-TR-70-25

ADVANCED MODULAR SHELTERS FOR SMALL AND MEDIUM SIZE SHELTER APPLICATIONS

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AIR FORCE AERO PROPULSION LABORATORY
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FOREWORD

This is the final report on Air Force Contract F33615-67-C-1259 "Advanced Modular Shelters for Small and Medium Size Shelter Applications", 15 December 1966 and includes work performed under the following modifications to F33615-67-C-1259: P002-1 Dec 67, P003-6 Dec 67, P008-16 Jan 68, and P016-24 Feb 69 with the following exceptions:

Work on the 24' x 40' shelter performed after a basic design change was initiated at a meeting at Hq. TAC, Langley AFB, Va. on 8 Aug 67 will be reported as part of the final report of Air Force Contract AF 33(615)3242. This design change made the 24' x 40' shelter, in effect, a part of a family of shelters with the hangar developed under contract AF33(615)3242 with many of the components interchangeable with those in the hangar. Due to this interchangeability the reporting of this "utility" shelter, as developed after this date, logically should be included with the report of the hangar as will so be reported in the AF33(615)3242 final report.

In addition this final report will include the portion of the work authorized under S/A #11, AF33(615)3242 dealing with foamboard research and development. Though authorized under the referenced contract, the effort was intended solely toward improving the material used in the folding portion of the personnel shelter designed and procured under contract F33615-67-C-1259 and it is therefore appropriate to include it in the final report for F33615-67-C-1259.

Work covered between 15 December 1966 and 1 November 1969 is covered by this report.

This report was prepared by Professor James M. Alexander of the department of Industrial Design (principal investigator), W. Randall Wakefield, research assistant (project leader), Professor Karl H. Merkel of the Department of Architecture and Professor Bahram Bahramian of the University of Dayton who had chief responsibility for structural analysis. The work was performed at the College of Design, Architecture and Art at the University of Cincinnati with that portion occurring after October 1 1968 being performed at the quarters of the Shelter Design Group of the College of Design, Architecture and Art at 3333 Vine Street, Cincinnati, Ohio.

In addition to the authors, the following contributed significantly to the work under the contract: Professor Joseph M. Ballay of the Department of Industrial Design, Lawrence L. Fabbro, Research Assistant and several upper class co-op students of the college.

The authors wish to thank the Air Force project engineers, Mr. Robert P. Huie, Captain Anthony Zappanti, and Mr. Fred W.

Forbes and his staff for their assistance in scheduling Air Force facilities for testing, for providing necessary supporting equipment and man power, and lending their knowledge to the investigations and designs herein.

This report was submitted by the authors: Professor James M. Alexander, Professor Karl H. Merkel and Mr. W. Randall Wakefield, and Professor Bahram Bahramian, February 1970.

This technical report has been reviewed and is approved.

FRED W. FORBES
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ABSTRACT

Lightweight, 100% recoverable expandable shelters for high mobility applications are described. Concepts developed include small size shelters (13' to 16' span) and medium size shelters (24' to 30' span).

The small shelter concepts described utilize light weight thin sandwich construction "foamboard" in unique folding applications. Geometry details, manufacturing difficulties, erection procedures, and testing are discussed for the concept selected for development.

Ultimate practical span for foamboard constructions are discussed (a 50' span hangar).

Also included is a section devoted to basic research on development of more durable and stronger foamboard composites to be utilized on the designs generated.

Early foamboard concepts for medium size general purpose shelters are also discussed.

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ABBREVIATIONS USED

al	Aluminum
AFTM	Air Force Technical Monitor
BBPS	Bare Base Personnel Shelter
E	Modulus of Elasticity
I	Moment of Inertia
MD	Machine Direction of roll process skin materials
mil	.001 inch
MSF	1000 square feet
MVTR	Moisture Vapor Transmission Rate
O.D.	Olive Drab (color)
PE	Polyethylene
RTV	Room temperature vulcanizing
U Factor	Rate of thermal transmission for a composite
UV	Ultraviolet energy
XD	Cross machine direction of roll process skin materials
LES	Lightweight expandable shelter
ES/C	Expandable Shelter/Container

I

INTRODUCTION

A. LIMITED WAR, HIGH MOBILITY SHELTER CONCEPTS

Lightweight, highly mobile shelters have moved to the foreground as a vital recognized need of the military in the past two years. When existing practices of providing shelter are examined, many gross inefficiencies can be found that point to the need for a research and development effort such as this.

Because the duration of occupation in a specific situation is usually unknown "going in", the common practice for providing various types of shelter was to build structures employing traditional methods and materials that were of a permanent nature (even if not in name). The largest portion of military activity has been characterized by limited warfare situations and counter-insurgency actions which dictate rapid changes and develop needs for relocation and mobility.

Further, the required level of sophistication for these structures is becoming greater. Whereas the Army's principal function is achieved by the occupation of land, the Air Force's function only begins here. In order to support multi-million dollar fire control systems, the entire base must be highly efficient. These requirements dictate a need for advanced sophisticated shelters that would be economically impractical to abandon when geographic changes become necessary. One can readily see the practicality of 100% recoverable, lightweight, high mobility shelters.

A desirable derivative of such an "R and D" effort would be a significant reduction in the man hours required for the daily living tasks. Experience has proven that troops living in an "austere" situation will continue to elevate their standard of living utilizing any free time available. If designs generated could avoid this environmental deficiency, considerably more manhours could be devoted to fulfilling the assigned tasks.

Much of the essential background work was performed under a previous Air Force contract, AF33(615)1285, where concepts utilizing paper-plastic combinations were investigated. As part of the effort, prototype structures were built and tested under a broad spectrum of climatic conditions and the resulting data generated became an important basis for the follow on work under this contract.

The primary intent was to prove that foamboard could be used in an effective manner to provide a durable, lightweight, 100% recoverable, highly mobile design that would make possible easy operation by combat troops under severe use conditions. Small shelters were intended to be used for billeting of personnel and contract 1285 demonstrated the suitability of foamboard for buildings in this 16' x 32' size range. The second major goal was to investigate the suitability of foamboard for larger size shelters (approximately 24' x 40' in plan). Prototypes were to be the means of development demonstration for this phase of the work.

The last portion of work included in this contract was an investigation of ultimate practical span capabilities in foamboard. The specific intent here was toward a 50' span hangar.

The work was planned to include the conception of unique designs for the small and medium shelter applications. The designs would then be detailed to a level sufficient for structural analysis and critical sections would be "mocked up" and tested where necessary to determine their workability. After final detailing, subcontracts would be let for production of prototypes. Finally, testing of these prototypes would provide input to alter the designs where weaknesses were discovered. It was the intent of this effort to provide shelters for the first major test of high mobility equipment on a large scale deployment basis - operation "Coronet Bare" at Northfield, South Carolina in the Autumn of 1969.

Although the contract work involved concurrent studies of small and medium size shelters, it was felt for reasons of clarity and continuity that the work done after the very early concepts be divided into two major sections. Therefore Section III deals with Bare Base Personnel Shelters, and Section IV is involved with early development on Bare Base General Purpose Shelters.

As noted in the "foreword" of this report, work subsequent to August of 1967 on the General Purpose shelter will be included in final reporting on contract AF33(615)3242 because of its relevance to the hangar developed under that contract.

Similarly, foamboard research work performed under contract AF33(615)3242 will be reported in this contract because of its relevance to the BBPS being developed herein.

This report covers all work performed under the basic contract (with the above deviations) and all amendments thereafter.

II

OBJECTIVES AND DEFINITION OF THE PROBLEM

A. OBJECTIVES

The objectives of this effort were to 1) deliver three refined prototypes of the "folded beam" modular 16' x 32' shelter developed under contract AF33(615)1285, 2) investigate and further develop shelters of the small size (16' x 32' and 13' x 35') utilizing foamboard materials similar to those used in contract 1285, 3) investigate and develop an "intermediate" size shelter (24' x 50'), and 4) investigate maximum span capabilities of the generic foamboard materials to test the concept of a 50' span hangar.

Materials utilization and expertise learned under contract 1285 were to be the foundation for this work. These shelters would provide support for the "Bare Base Mission" concept of limited warfare. Development techniques employed involved design conception, shelter models (where applicable), prototype fabrication, and testing and evaluation. The effort provided for a "second generation" prototype and evaluation program for items (2) and (3) above.

Restraints and considerations that would influence the design effort can be listed as follows:

1) Investigation of one-piece folded and multi-piece construction techniques.

2) Primary materials considerations were in the area of economical composite sandwiches such as foamboard.

3) Materials used should possess these characteristics: low cost, lightness of weight, and resistance to fire, moisture, rot, fungus, punch and penetration.

4) High expansion ratios (10:1 and better) are desireable from packaged to use modes.

5) "Universal" adaptability of the shelter to various climatic conditions.

6) Use life of 5 years with 5 disassembly/erection cycles per year (25 total). Shelf life: 10 years.

7) Snow loadings at 10 pounds/square foot for roofs with 10% or greater slopes and 20 pounds/square foot for flat roofs.

8) Wind loading capabilities at 60 knot continuous and 90 knot gusts.

9) Compatability with 463L pallet system and consideration of the C-130 as the prime mover.

Specifically, 16' x 32' shelters were to be built for further testing in SEA. The four small (16' x 32' and 13' x 35') shelters were to be used primarily for billeting, and the two utility (intermediate) shelters were to become general purpose shelters for various uses.

B. DEFINITION OF THE PROBLEM

1. Personnel Shelters

The research and development efforts toward modular buildings of the small personnel shelter size demonstrated principal problem areas that future development work should try to reconcile. It is understood that this effort is concerned with structures that are very nearly 100% recoverable for future re-deployment. Structures that satisfy the above criteria and provide a significantly higher standard of living "going-in" to an FOB, provide the commander with many more usable man hours to support fire-control systems. If costly technicians could move into well-lighted, ventilated, sophisticated structures with hard floors, they should be free to devote more time to the stated business at hand. Concepts developed must provide for rapid, simple erection by the ultimate users without special hoists, cranes or other specialized equipment and tools. Repair should also be accomodated in an easy manner by the users.

Previous designs for small shelters fell short of expectations in many areas. Packaging materials must be extremely durable and should become an integral part of the completed structure. A durable, easily cleaned, and stable floor is essential to upgrading the living conditions of the men. If this isn't provided initially, time will be found to procure and install one.

Perhaps the most critical comments in reference to shelters developed by work such as this have been in the area of general durability. Materials such as foamboard are inherently fragile even though they are easily patched. The structural requirements that were imposed on this contract generate even more concern over the support of the foamboard infill. The 60 and 90 knot winds require additional bracing of the material.

2. General Purpose Shelter

It was the initial intention of this effort to develop a general purpose shelter of foamboard materials using techniques learned on the personnel shelter. Folded beam modules explored under the previous contract showed promise of working well. There appeared to be some question as to whether an aircraft would "cube-out" with only a few general purpose shelters aboard. Further, structural considerations listed above become substantially more critical in reference to a building of 24' span. Supplemental bracing could become so complex and extensive as to make the concept impractical.

All of the same environmental constraints as listed in II.B.1. above were applicable to this shelter also.

3. Ultimate Foamboard Span Analysis

As part of the total effort, the ultimate spanning capability of relatively thin foamboard composites was to be tested. By relatively thin, it was understood to be composites less than 1/2" thick because of the difficulty in scoring and folding thicker sections. If a 50' span could be achieved, then an extremely light weight inexpensive hangar could be a reality. The statement of work directed this contractor to conceive designs for beam sections and then test their structural integrity. No fabrication of a test arch was provided under this contract.

4. Special Note On Nomenclature

The intermediate span building in this effort has been referred to by several different names. As the structure became more of a reality, it was called the "Utility" shelter, and as it went into limited production, the name "General Purpose" shelter seemed to be the most descriptive to the Air Force users. Our concern is that the reader will understand that the names "intermediate", "Utility", and "General Purpose" shelter all refer to the same 24' x 50' concept area.

Similarly, the personnel shelter started out nominally at 13' x 35' in plan and was finally referred to as the "Bare Base Personnel Shelter" or BBPS, and had plan dimensions of 13' x 33'.

III

TECHNICAL DISCUSSION - BARE BASE PERSONNEL SHELTERS

A. PROPOSAL AND EARLY CONCEPTS

The original proposal on this contract outlines, under small and medium size shelter concepts, three primary areas of investigation.

1) One piece folded plate structures - whereas concepts using this principle can be successful in terms of lightness, structural integrity, and weather sealing, they can present problems in manufacturing complexity and package bulk. The erection procedure can also be difficult if special equipment is not provided.

2) Modular structural units - these designs tend to be very convenient in terms of standardization, simplicity of manufacturing, and ease of assembly. Difficulties arise in the area of weather seals along the many joint lines, and misalignment of modules over rough terrain.

3) Demountable structures with non-structural infill - These concepts have the advantage of being most easily interpreted in standard materials thereby simplifying the design process. However, this must be balanced against the possibility of paying a drastic weight and erection time penalty. Also, there appeared to be little likelihood of significantly improved shelters being developed.

Designs initiated during the initial phase of investigation were of the general types depicted in (1) and (2) above. During this early period, it was assumed that the small and intermediate span structures would be closely aligned and use similar techniques and materials, viz. scoring and folding of foamboard. Each individual design was appraised for its packageability, load/span capabilities, and manufacturability which became the basis for the probable plan dimensions (small versus intermediate). These designs are treated separately below.

1. Boxed Accordion Concept (13' x 35')

This concept involved use of the shipping package as part of the shelter. The box size of 3'w x 13'l x 8'h was derived from the interior configuration of the C-130 aircraft. Using bi-folding floors of about 8' length, the total shelter would expand to 35' (see figure 1). Some apprehension was expressed over the small 13' width because of 463L pallet restrictions of 108" x 88" and the less desirable usable interior width.

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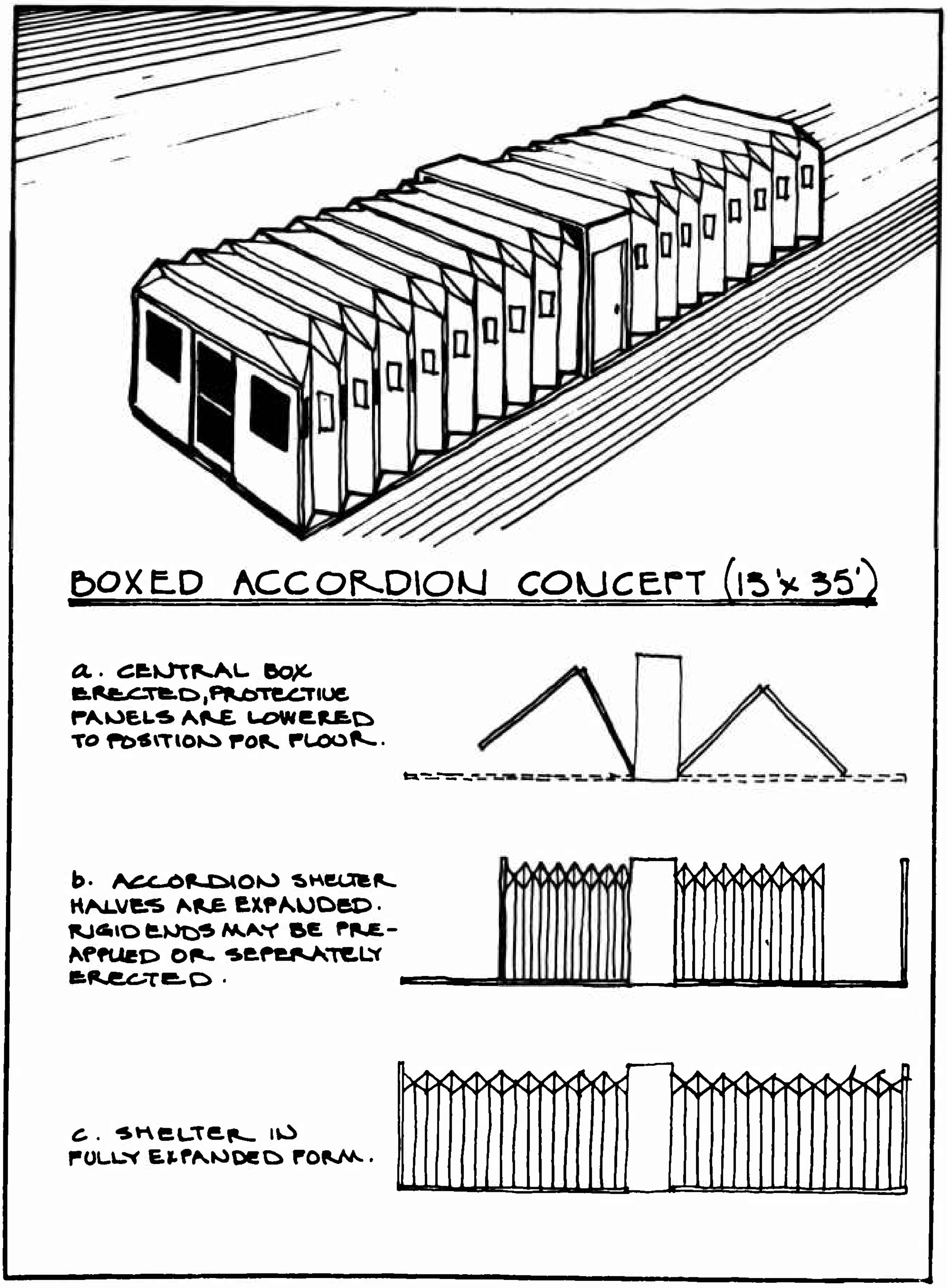


Figure 1. Boxed Accordion Concept (13' x 35')

The folding principle was of the one-piece folded plate variety. Two possible folding patterns were explored. The first configuration allowed the sidewall legs of the foamboard shell to fold in and under 180° (see figure 2). The alternate configuration allows the sidewall legs to fold in only 100° from the horizontal (see figure 3).

In the 100° configuration, the folding pattern becomes simple and easier to manufacture, but the sidewall legs project into the usable storage cube within the box where they are vulnerable to shifting contents.

The 180° configuration allowed a 160 cubic foot usable cubage in the interior for storage of cots, footlockers, pillows, and other personnel gear for 11 men. The primary drawback to this design was the complexity of manufacturing the two-plane diamond knee connection at the sidewall-roof joint. Because of the unique nature of this folding pattern, the sidewall legs drop down 90° to vertical as the shell is expanded to the use mode. The attractiveness of this concept warranted further study to overcome the aforementioned obstacles.

2. Boxed Accordion Concept (16' x 32')

This concept attempts to combine the advantages of a rigid box as the center-core portion of the shelter and the more attractive 16' width that Headquarters TAC felt was essential.

Here again, the one-piece folded plate principle was employed but with a variation. The 8' x 8' x 4' box holds four 90° folded sections - each of which expands to a 100° wall and roof panel 16 feet in length. Field connections are made at the center-core box, the ridge, and the two piece endwalls. See figure 4.

Disadvantages became apparent in the erection procedure as difficulties could be expected in making the field joint at the roof. The two piece endwall would have posed a difficult structural problem. The narrow restricted area of the center made arrangement of the interior difficult. Erection time appeared to be somewhat excessive because of the great number of field-joints in the shell, endwalls, and floors. Lastly, the available storage cubage was only 90 cubic feet.

This concept further pointed out that any sectional field connections are better made along vertical lines rather than horizontal lines.

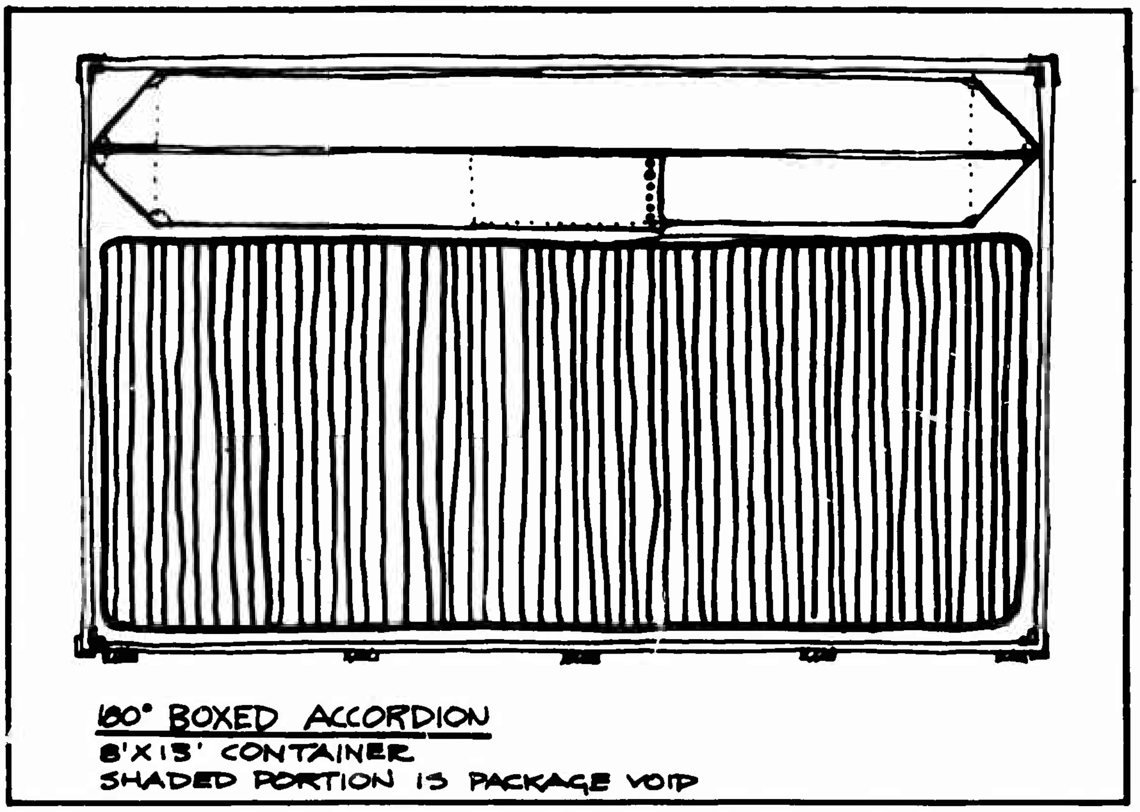


Figure 2. Shelter Folding Configuration (180°)

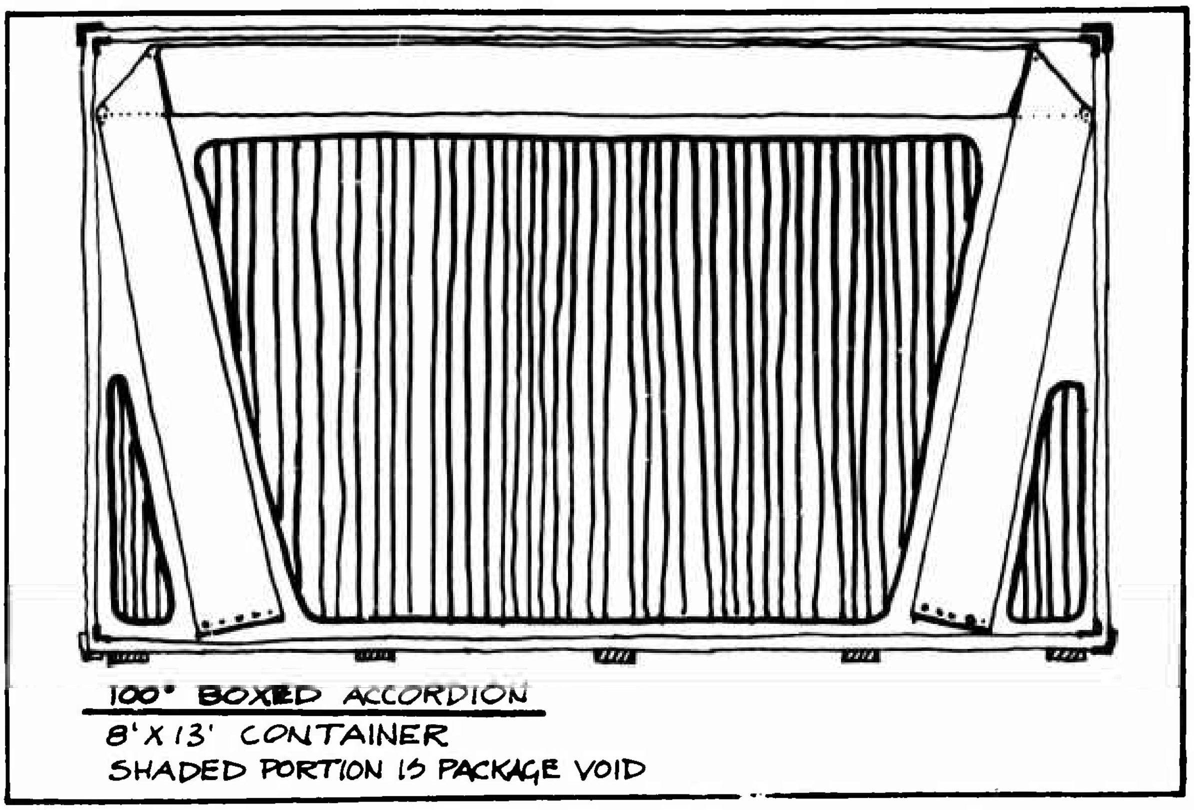


Figure 3. Shelter Folding Configuration (100°)

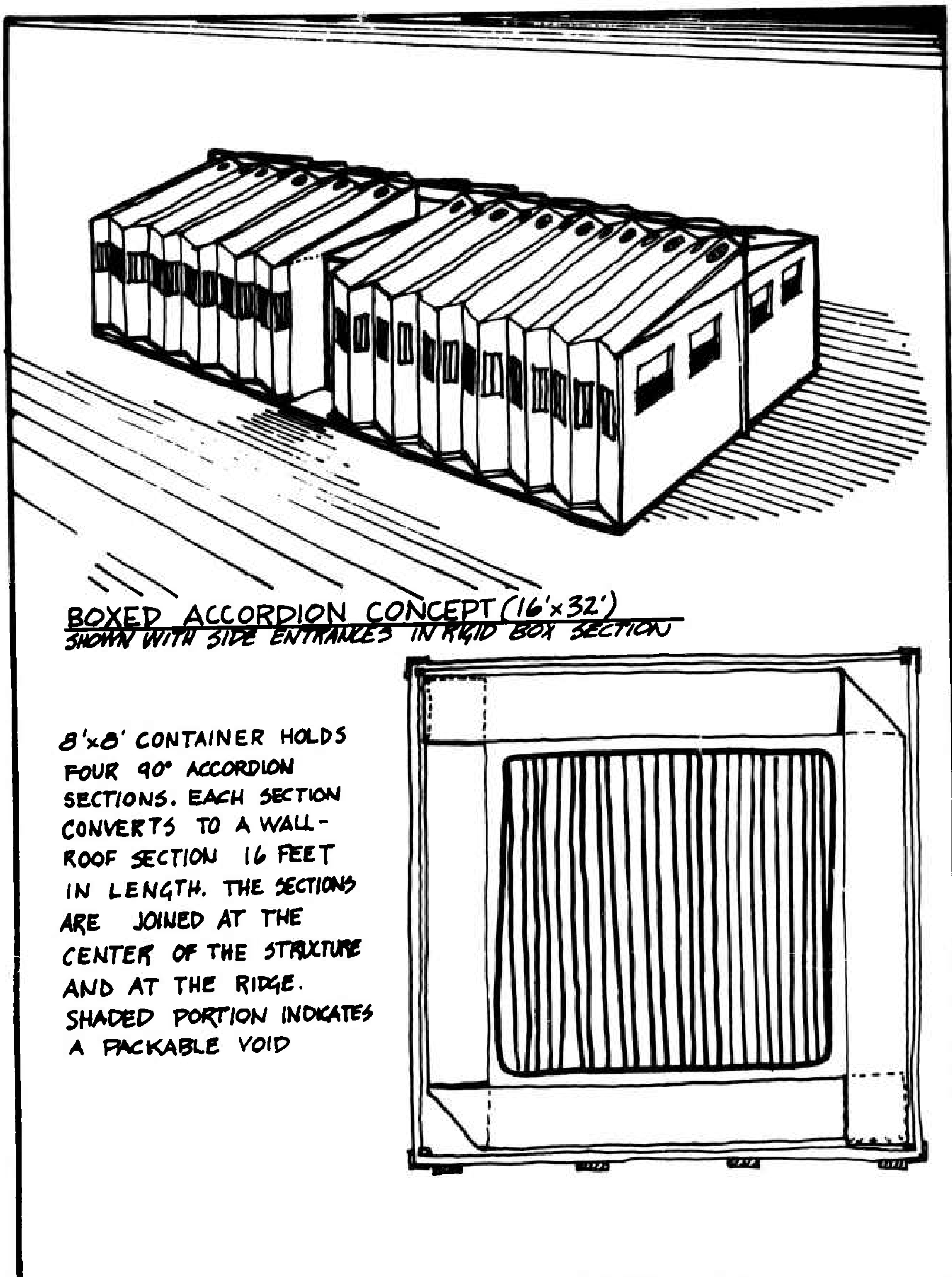


Figure 4. Boxed Accordion Concept (16' x 32')

3. <u>One-Piece Square Fold Accordion Concept (13' x 32')</u>

This concept also uses the one-piece folded plate principle in an attempt to alleviate much of the field joinery. A one-piece, 90° accordion fold capable of being expanded to a 13' x 32' shelter could pack in a box comprised of the modular floor and endwall panels (see figure 5).

Figure 6 shows the erection procedure. The only field joints involving the shell were at the endwalls and floors. These would, however, be additional components to the shipping box which could be misplaced. Other disadvantages were in the multiple-piece floor (stability and complexity), difficulty in erection of such a large shell without damaging itself, stability of the two piece endwalls, and the need for extensive internal "skeletal" beams to support the shell. Internal cubage again was about 90 cubic feet.

4. <u>Flat Fold Accordion Concept (16' x 32' or 24' x 40')</u>

This concept is based upon a simple fold development. It encompasses a system of structural possibilities rather than a specific solution. The fold develops the knee joint between vertical sidewall and 10° - 15° roof slope. The shapes develop good versatility in terms of division of structure (one-cycle modules versus multi-cycle modules), folding for packaging, and size of module and structure. See figures 7, 8, and 9.

Figure 8 shows some of the possible advantages of the concept. Strengths developed seemed significantly better than any other concept and, in fact, might be capable of attaining the 24' span. The long shell-to-shell joints create definite weather sealing problems when the concept employs several separate modules. In the one-piece configuration, folding and shipping becomes a problem, and the folding procedure might be impossible to accomplish with such large boards. This is explained by the unnatural configuration during expansion of the joint.

5. <u>Diamond Section Module Concept (24' x 40')</u>

The difficult 24' span could be achieved with a double wall, two-cycle module as shown in figure 10. This concept would allow a thinner board because of the effective depth gained, and integral two part spline. This space within the walls could be used for post erection utility distribution. Further, such a structure would be excellent for thermal insulation in Arctic uses.

Here again, the joints between modules present weather seal problems. Previous experience in this area has led this contractor to believe that these joints are very difficult to seal and transmit forces poorly from one module to another. Figure 11 shows other utilization details.

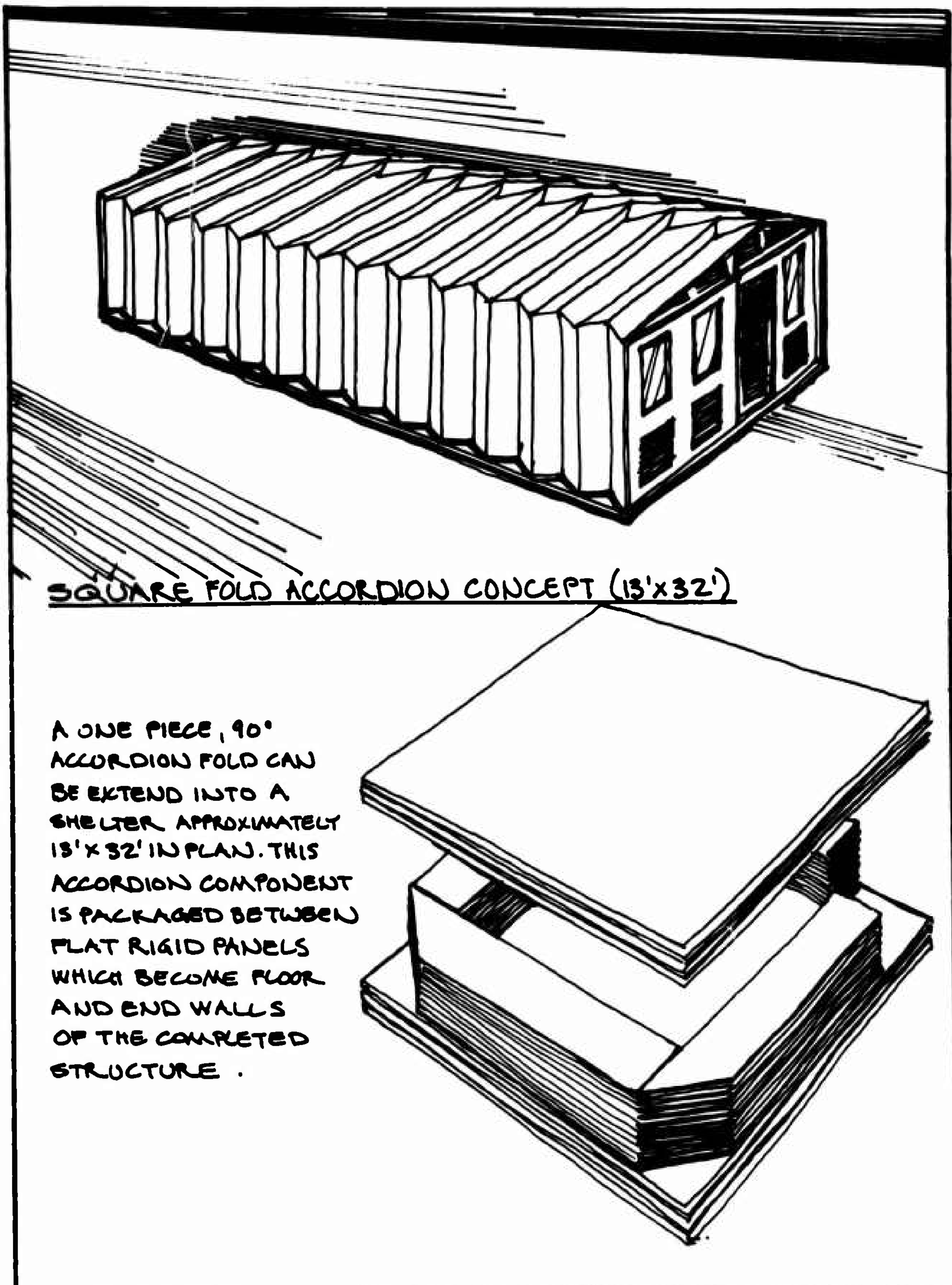


Figure 5. Square Fold Accordion Concept (13' x 32')

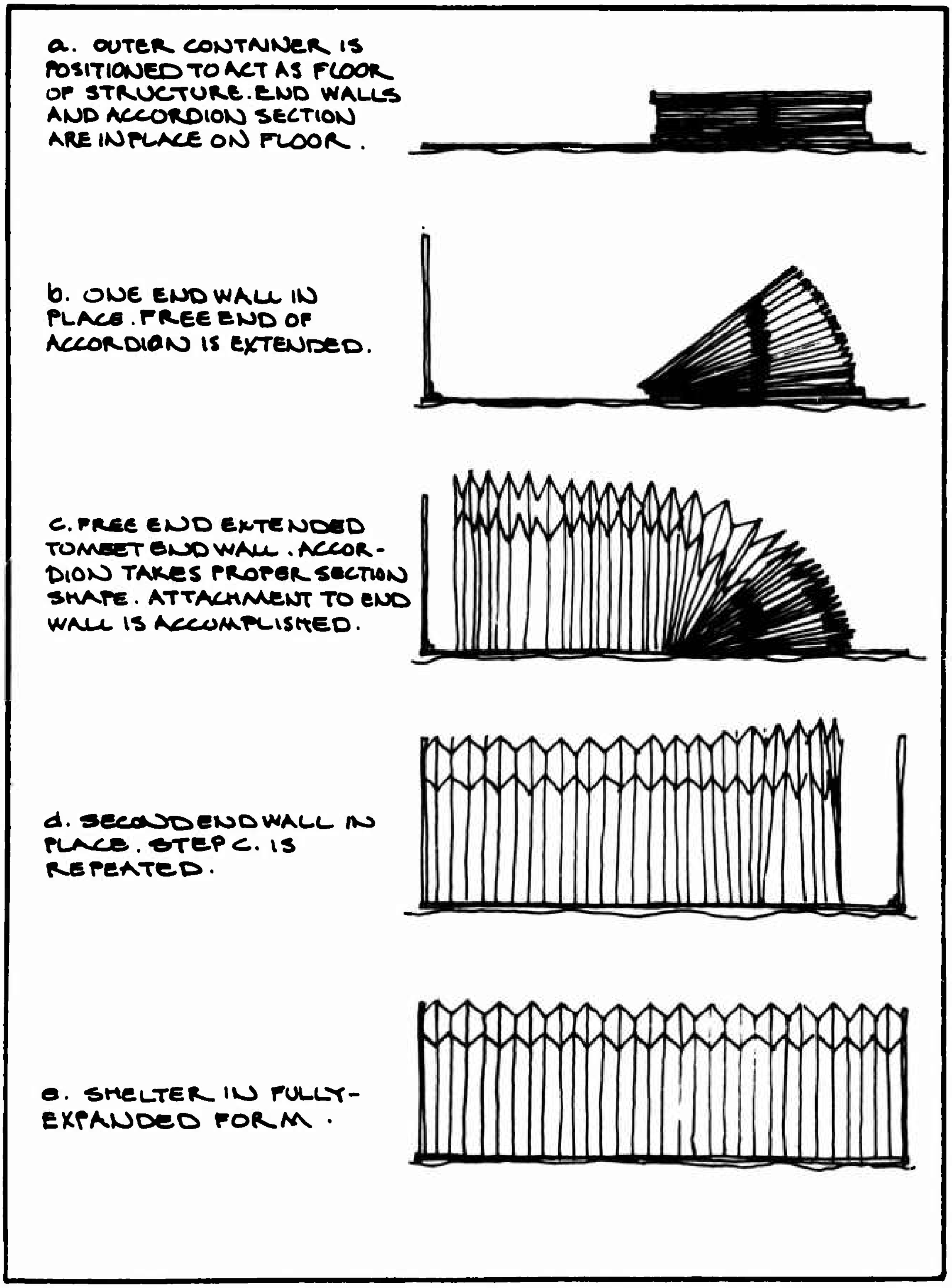


Figure 6. Square Fold Erection Procedure

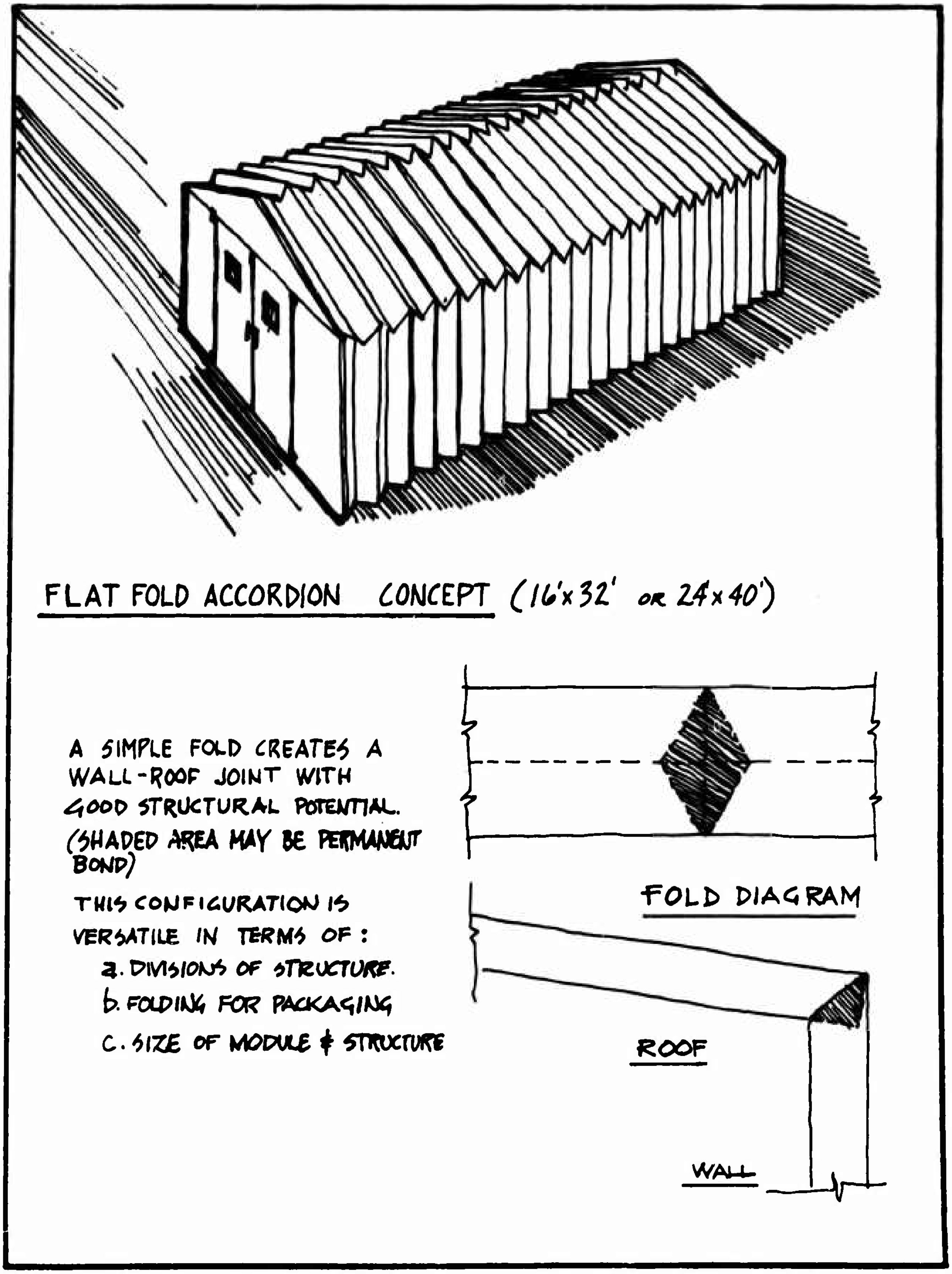


Figure 7. Flat-Fold Accordion Concept (16' x 32' or 24' x 40')

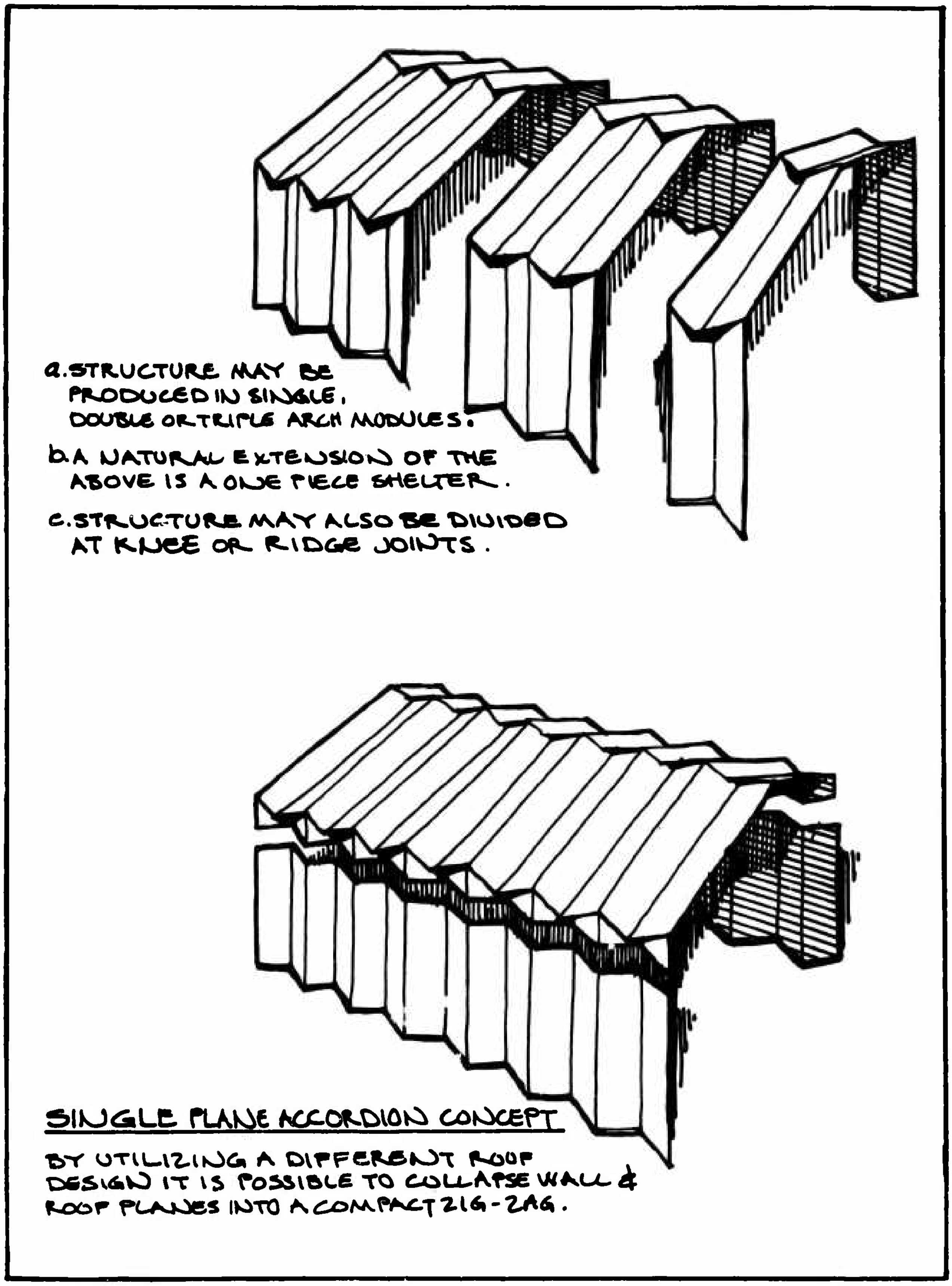


Figure 8. Flat-Fold Accordion Concept - Details

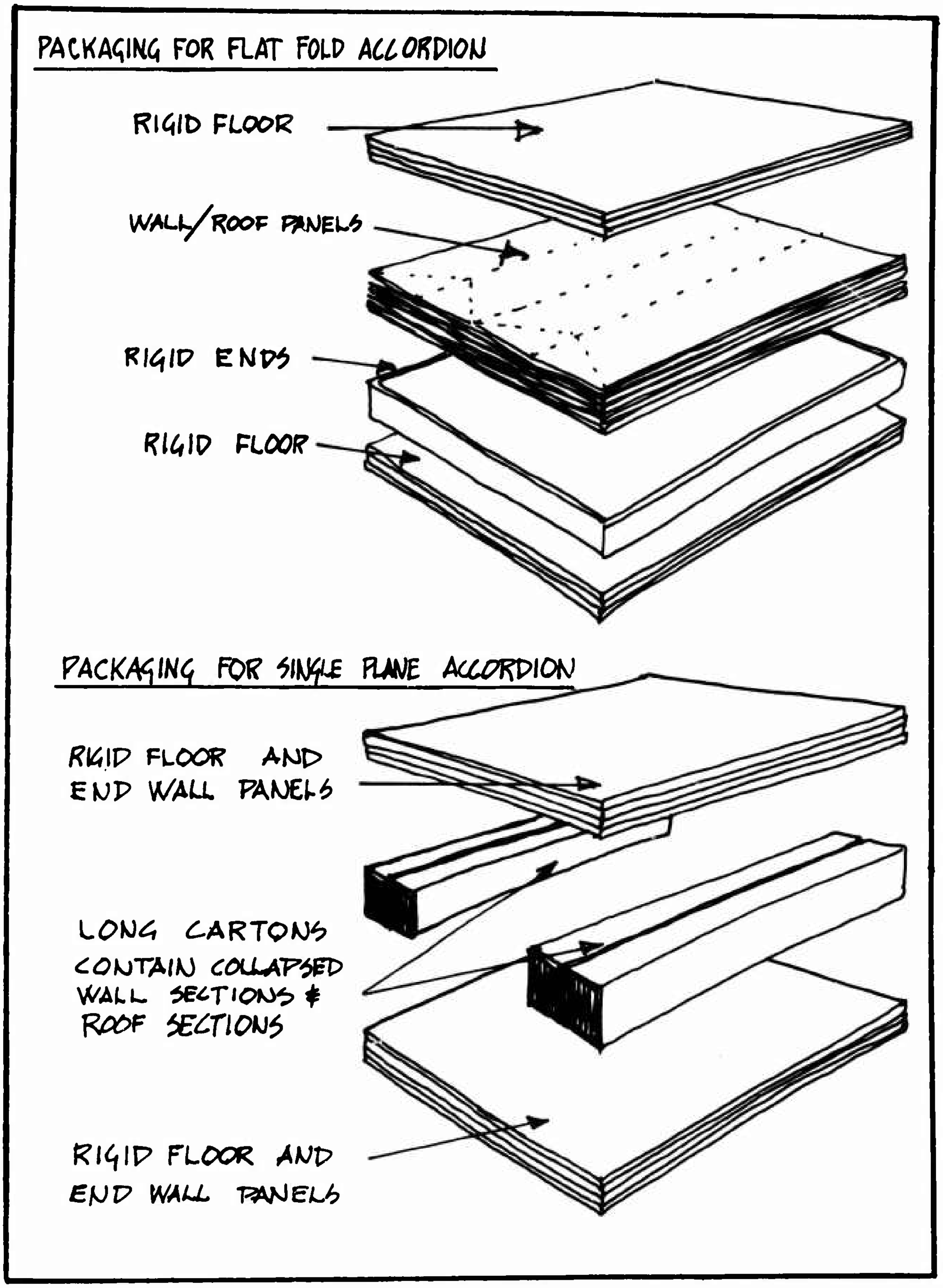


Figure 9. Flat-Fold Accordion Concept - Packing

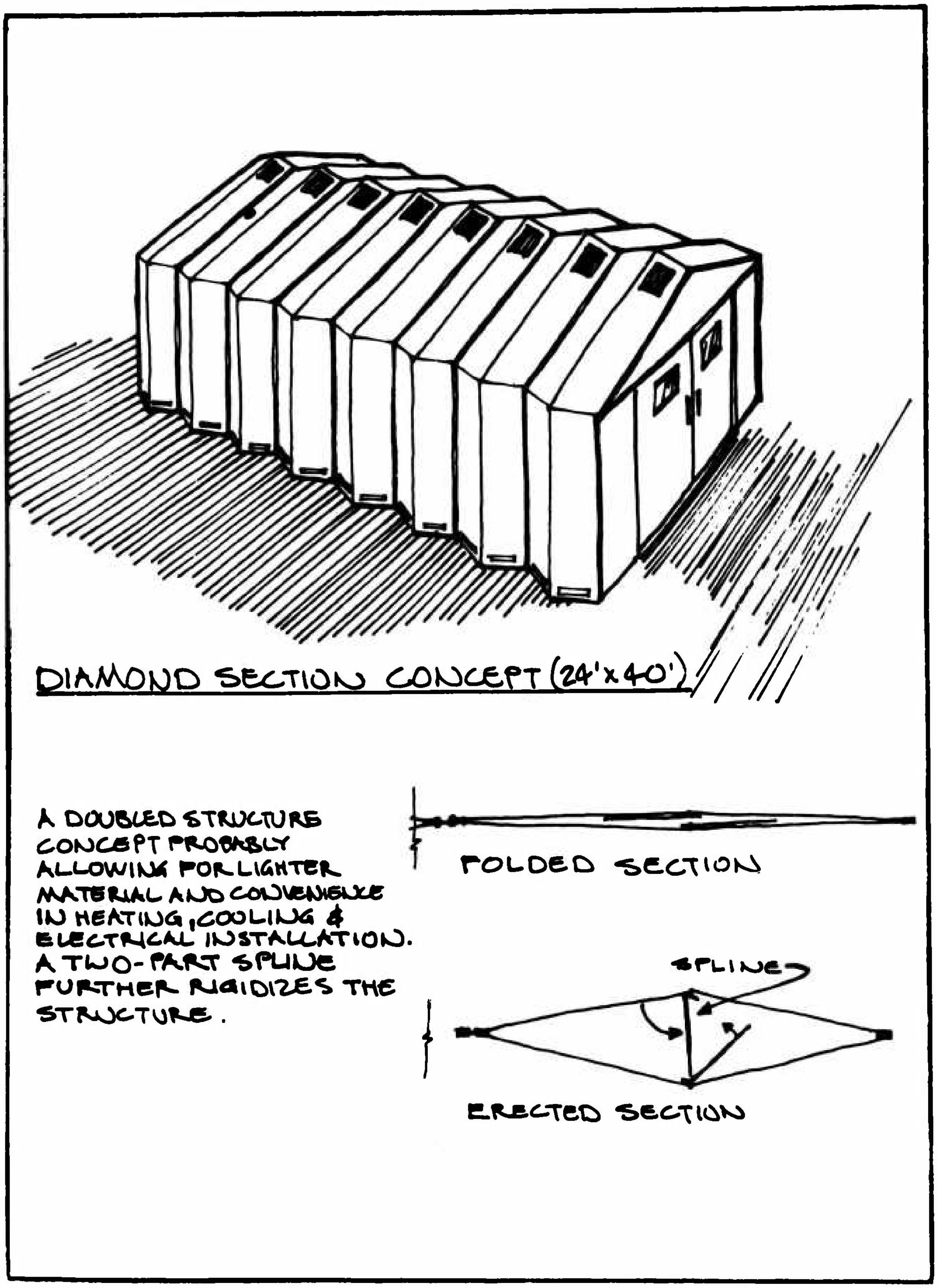


Figure 10. Diamond Section Concept (24' x 40')

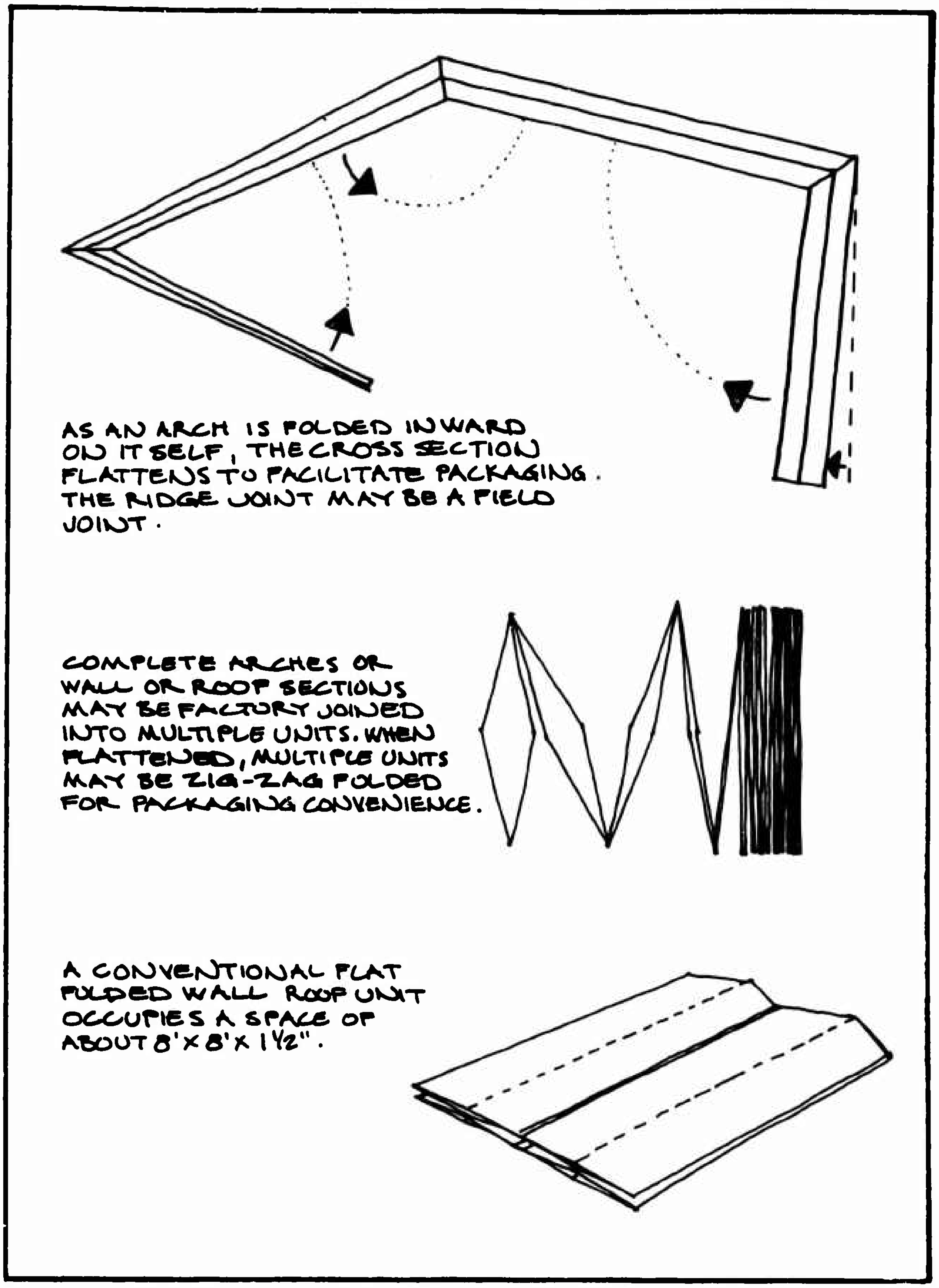


Figure 11. Diamond Section Concept - Details

6. Space Utilization Study and Comparison of Shelters

Studies were undertaken to determine the possible usable equipment arrangements within the various size structures (16' x 32', 16' x 35', and 13' x 35') in personnel billeting applications. The plans depicted in figure 12 represent generous proportions of space per man. For example, a somewhat tighter arrangement of the 13' x 35' shelter with bunk beds would provide quarters for 22 men.

In order to evaluate the physical characteristics of the seven concepts, table 1 has been prepared. The weight, cost and erection time comparison is on a relative basis only, that is, the "square fold accordion" concept weighs the least, is the cheapest and could probably be erected in a very short time. This, of course, was not the only basis for study. Actual achievement of the "square fold accordion" would probably have been very difficult in terms of manufacture and packaging.

TABLE 1. COMPARISON OF SHELTER CONCEPTS

CONCEPT	PLAN SIZE	PACKAGED SIZE	(1) PACKAGED CUBE	PACKAGED WEIGHT	ERECTION TIME	COST
BOXED ACCORDION (SMALL)	13'x35'	3'x13'x8'	(2) 310 cu.ft.	2	1	3
BOXED ACCORDION (MEDIUM)	16'x35'	3'x8'x8'	(3) 200 cu.ft.	4	2	4
SQUARE FOLD ACCORDION	13'x32'	3'x8'x8'	(3) 200 cu.ft.	1	1	1
FLAT FOLD ACCORDION (MEDIUM)	16'x32'	2'x8'x8'	(4) 130 cu.ft.	3	2	2
ACCORDION PLANE	16'x32'	3'x8'x8'	(5) 200 cu.ft.	3	2	2
FLAT FOLD ACCORDION (LARGE)	24'x40'	4'x4'x8'	130 cu.ft.	5	3	5
DIAMOND SECTION	24'x40'	4'x5'x8'	160 cu.ft.	6	3	6

(1) Includes re-usable packaging but not pallet
(2) Includes 160 cu.ft. packable void and rigid floor
(3) Includes 70 cu. ft. packable void and rigid floor
(4) Includes rigid floor but no packable void
(5) Includes 30 cu. ft. packable void and rigid floor
(6) Does not include rigid floor or packable void

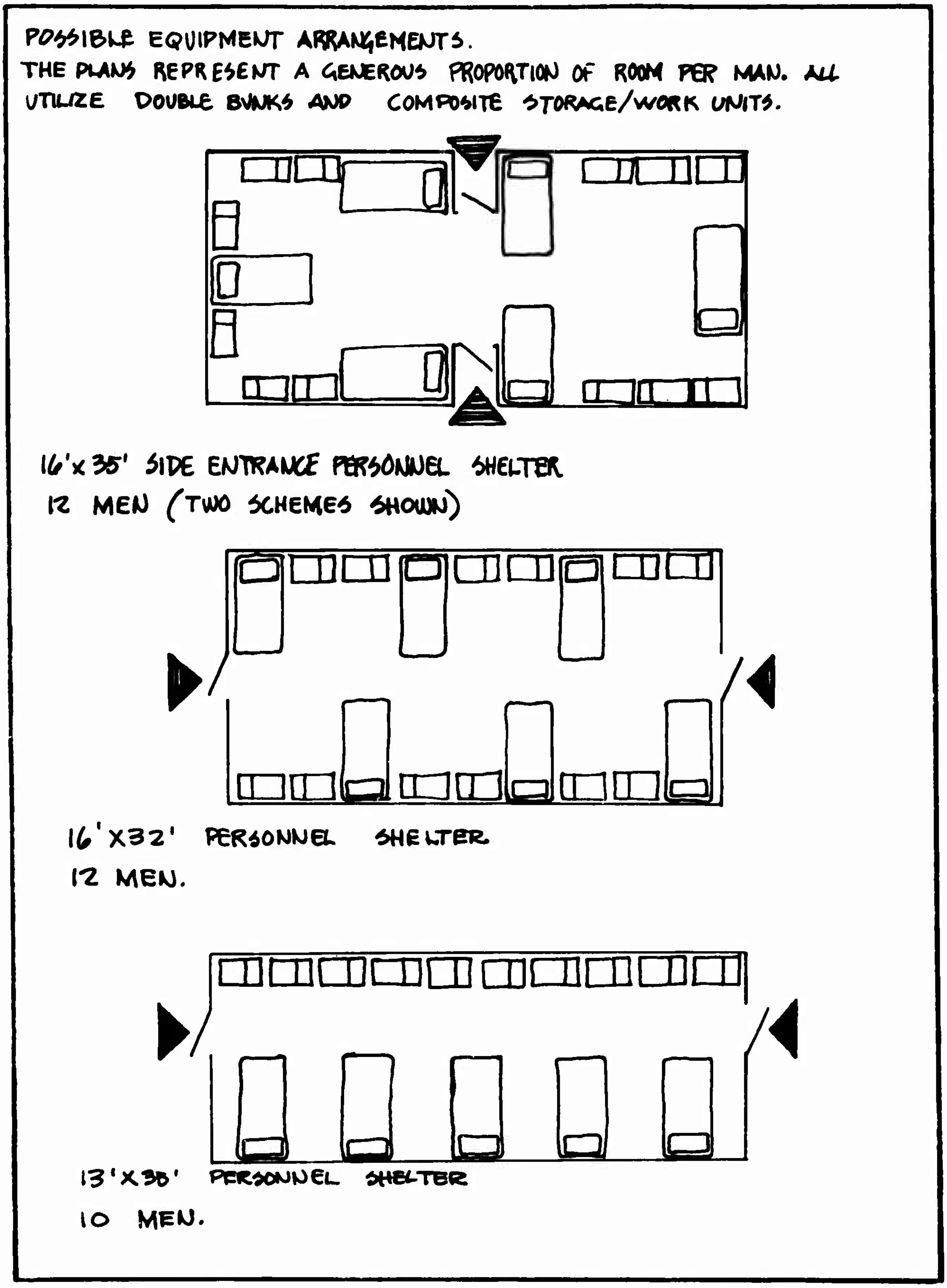


Figure 12. Space Utilization Plans

7. Long Span Foamboard Study

As mentioned previously, a study was undertaken to determine the maximum practical span capacity of foamboard material of the type used in the smaller shelter concepts. If this became a reality, then a hangar capable of enclosing an F-4 aircraft could conceivably weigh only a fraction of what a hangar of the more conventional metal beam and panel concept could weigh. This could have allowed for erection of a hangar with no special hoisting equipment.

An optimum material and beam section was sought in an attempt to span 50 feet. It is known that the structure is feasible with treated paper faced foamboard. However, the bulk imparted by enough foamboard for a 50' span - 80' long structure appeared to greatly exceed the cubage goals of the proposed structure. The possibility exists, however, that high-strength skins with high density foam formulation may render one of the concepts usable. This would have to be accomplished with a sophisticated materials research effort.

Results of the loading tests are enclosed in Appendix "B". Figures 13 and 14 show the most promising possible section and an overall concept sketch for a 50' span hangar. Figure 15 shows two completed box modules assembled as the first two links of a 50' arch span, where figure 16 shows the unfolded module pattern for another possible box section.

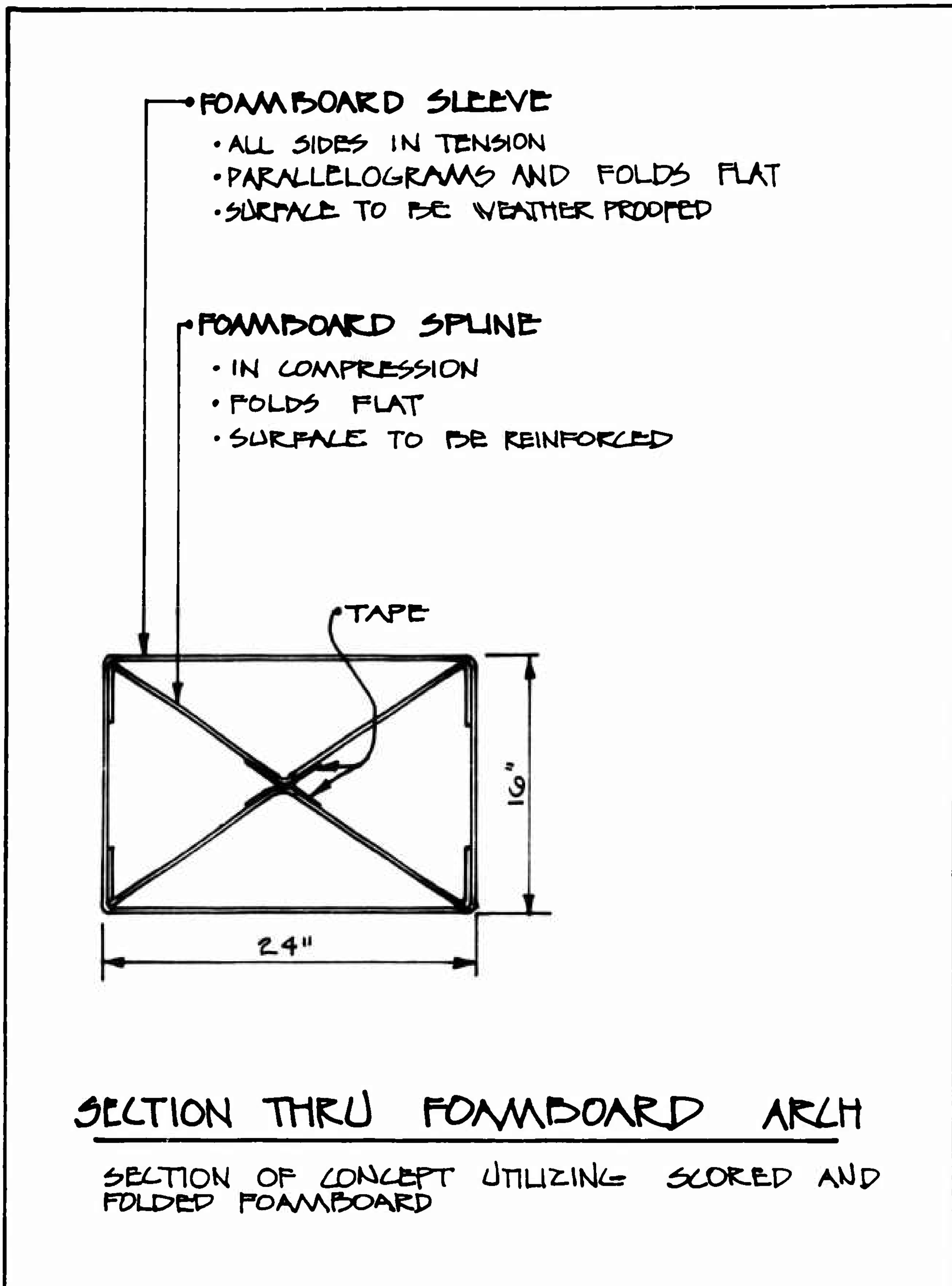


Figure 13. Section through Foamboard Arch

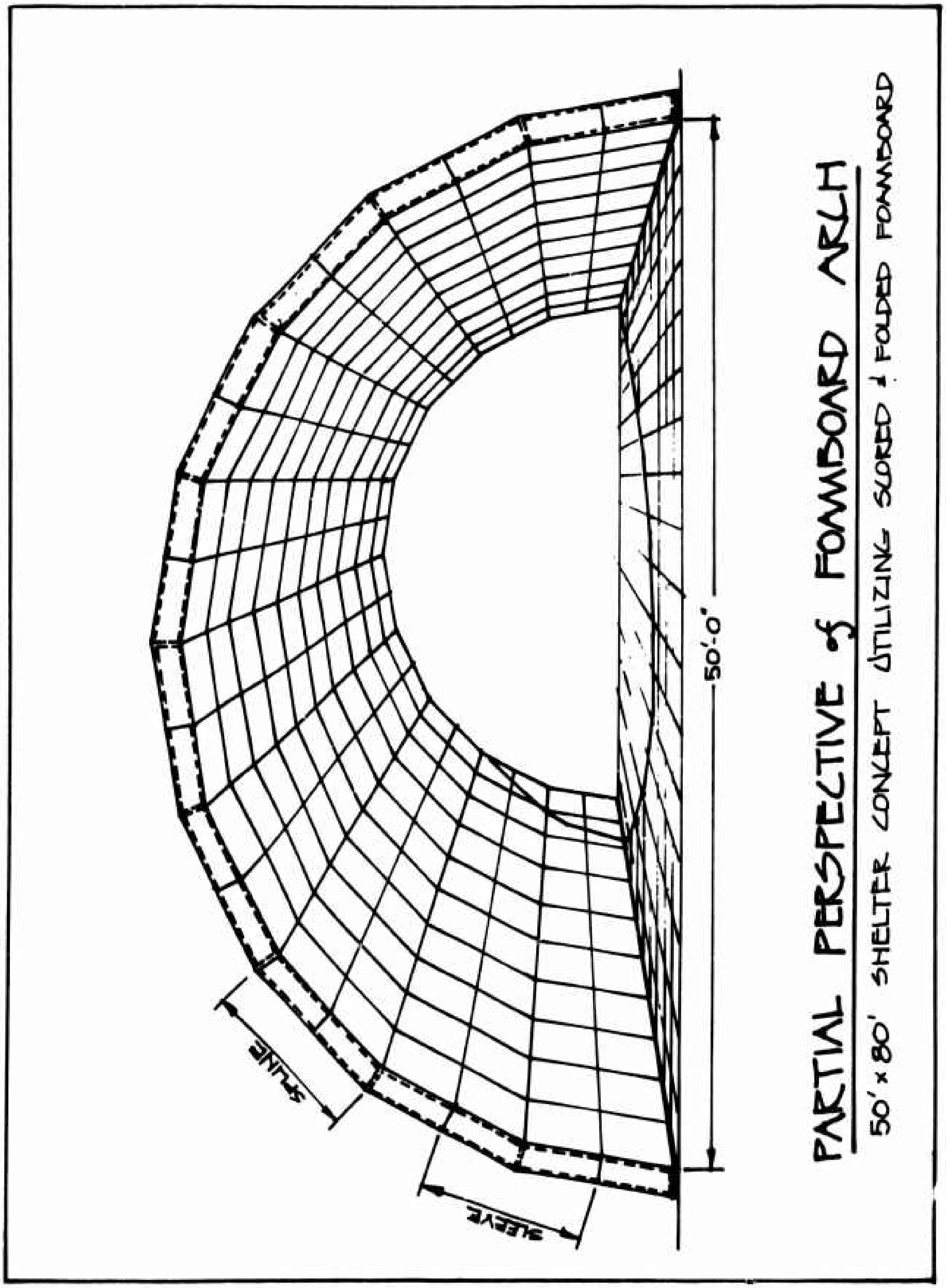


Figure 14. Partial Perspective of Foamboard Arch (50' span)

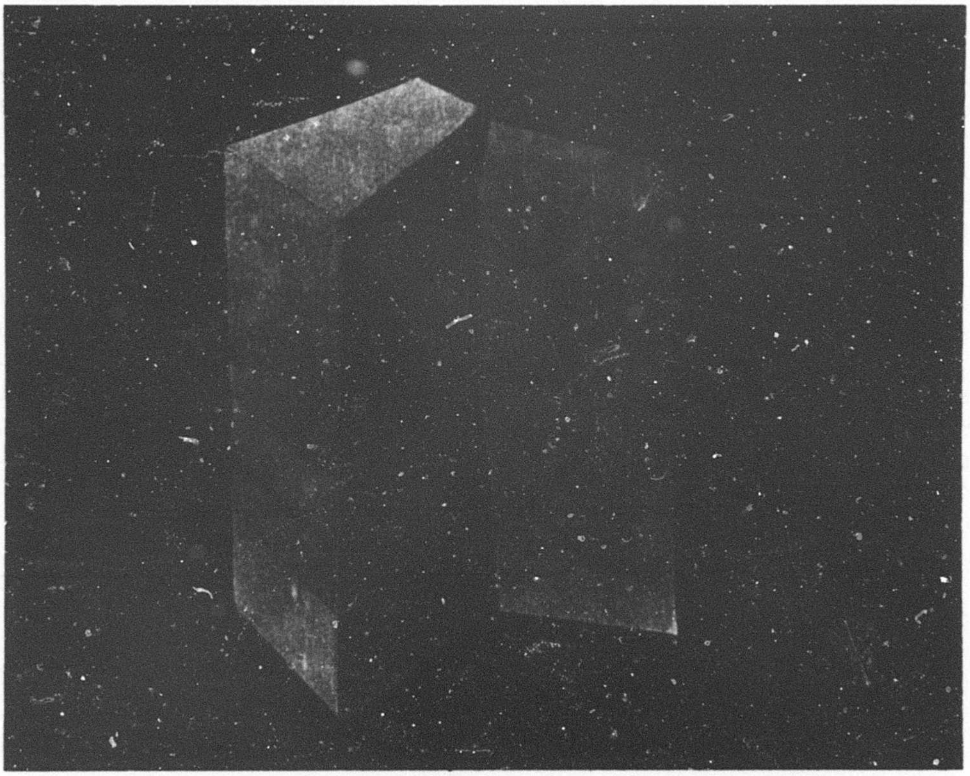


Figure 15. Foamboard Arch Modules - Joined

Figure 16. Foamboard Arch Module - Unfolded

B. 16' x 32' "L.E.S." CONCEPT

1. After preliminary concepts were developed and presented at Langley Air Force Base, two promising concepts were selected for further development of joining and feasibility. These were the 16' x 32' "L.E.S." concept and the 13' x 35' "E.S/C." or "Boxed Accordion" concept. This section deals with the 16' x 32' longitudinally expanding type shelter.

Even though the 13' x 35' design concept was generally preferred because of its overall clarity, simplicity, and ease of erection, the 16' x 32' design was attractive enough for further development because of its more usable plan dimension and lighter weight. Both concepts were built in model form to check out assembly sequence and for presentation to the AFTM. Figures 17 and 18 show the model of the L.E.S. and figure 19 and 20 show the E.S/C. Boxed Accordion concept model.

The following problems developed relative to the two candidate concepts:

13' x 35': Design could be inefficient in that only eleven men could be housed per shelter. Storage space within box may not be adequate.

16' x 32': Erection sequence seemed complex. Apparent lack of structural rigidity despite sufficient strength by preliminary stress analysis. Integral floors difficult to achieve.

2. Preliminary Design Solutions

Since the only enclosing material for this concept is foamboard, the structure weighs very little, but several problems develop. There is no rigid, hard element (such as a center-core box) to which supplementary bracing can connect. Therefore, the joints are primary structural connections and deserve special consideration.

The erection procedure is complex for a building of this size. Figure 21 shows the basic procedure for the enclosing shell. The grade beams that are shown in place at (1) are in lieu of a rigid floor, and provide the module anchorage. The restraining straps are released and the module is partially expanded, tipped into place on the grade beams and anchored. The center-ridge section is then lifted to final position, locked, and the vertical seams are flashed.

The basic endwall framing and details are shown in figure 22. Stability is obtained by folding square box columns, tying them to the door jam, and bracing the primary enclosing shell. An alternate method of providing the endwall enclosure was developed as a folded plate wall (figure 23). This alternate method would have yielded a more rigid endwall but its utilization would have

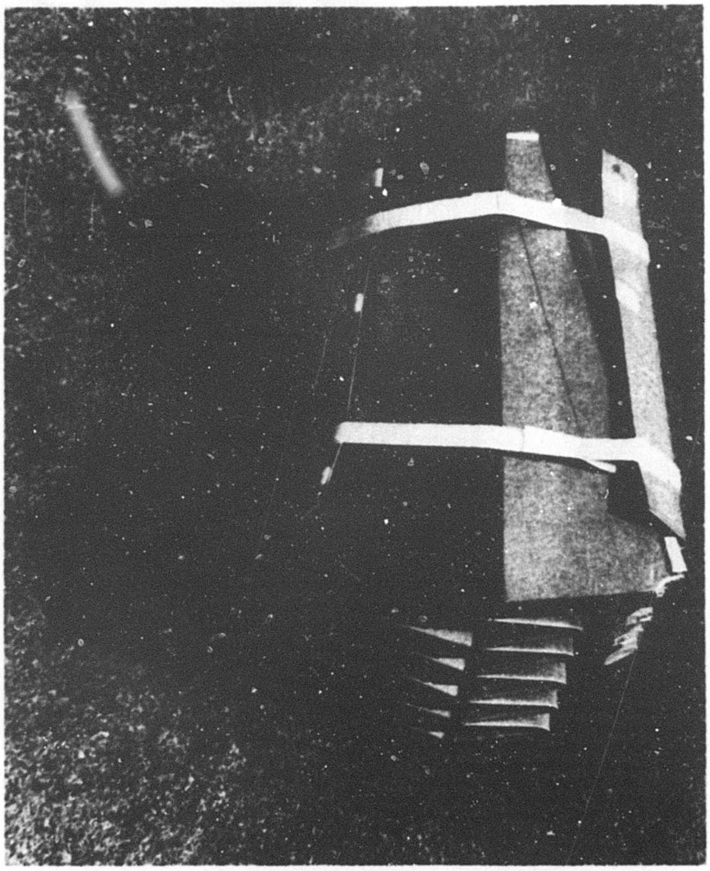


Figure 17. Folded LES Concept

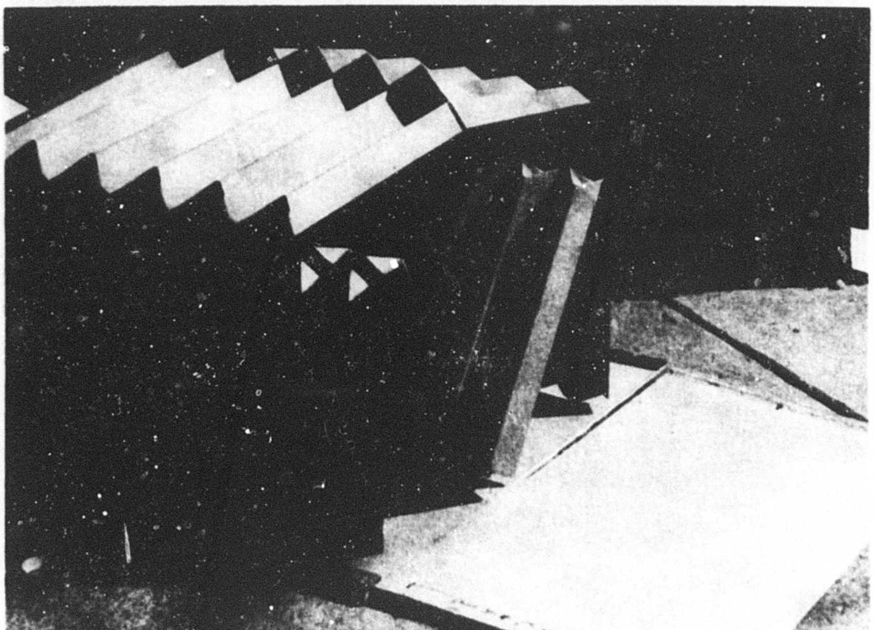


Figure 18. Partially Erected LES Concept

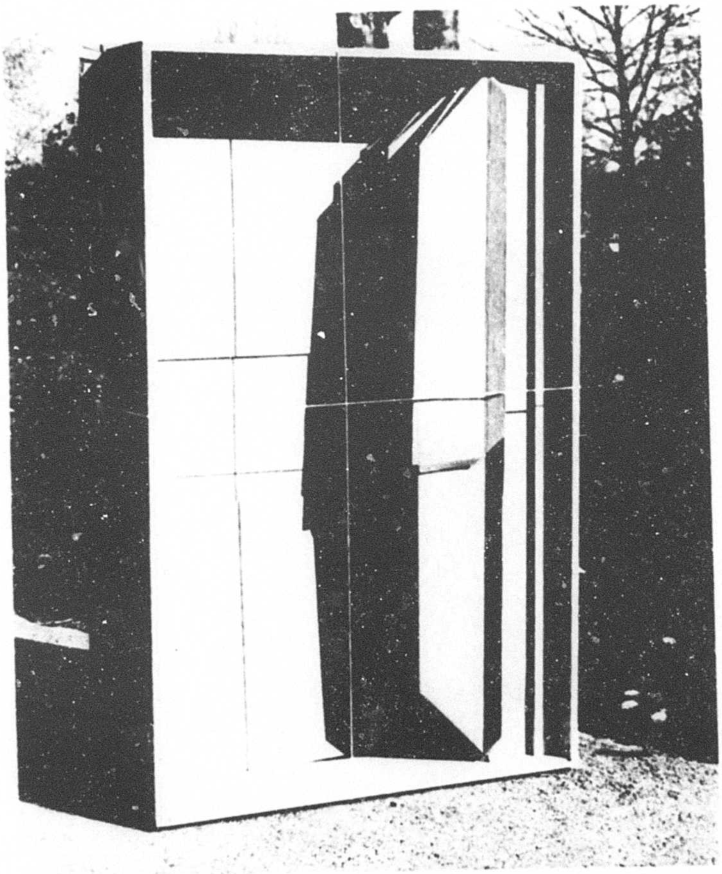


Figure 19. Folded ES/C Boxed Accordion Concept

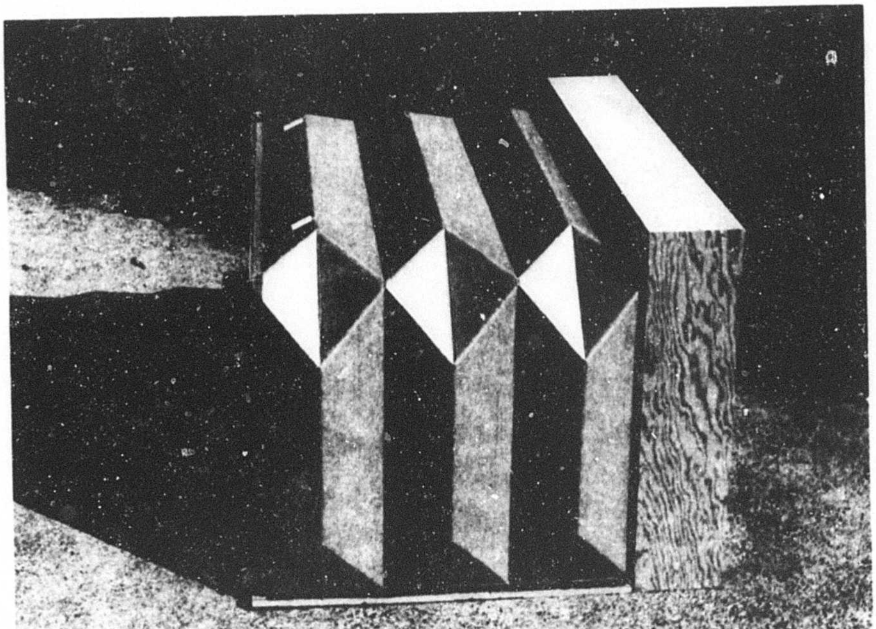


Figure 20. Erected ES/C Concept

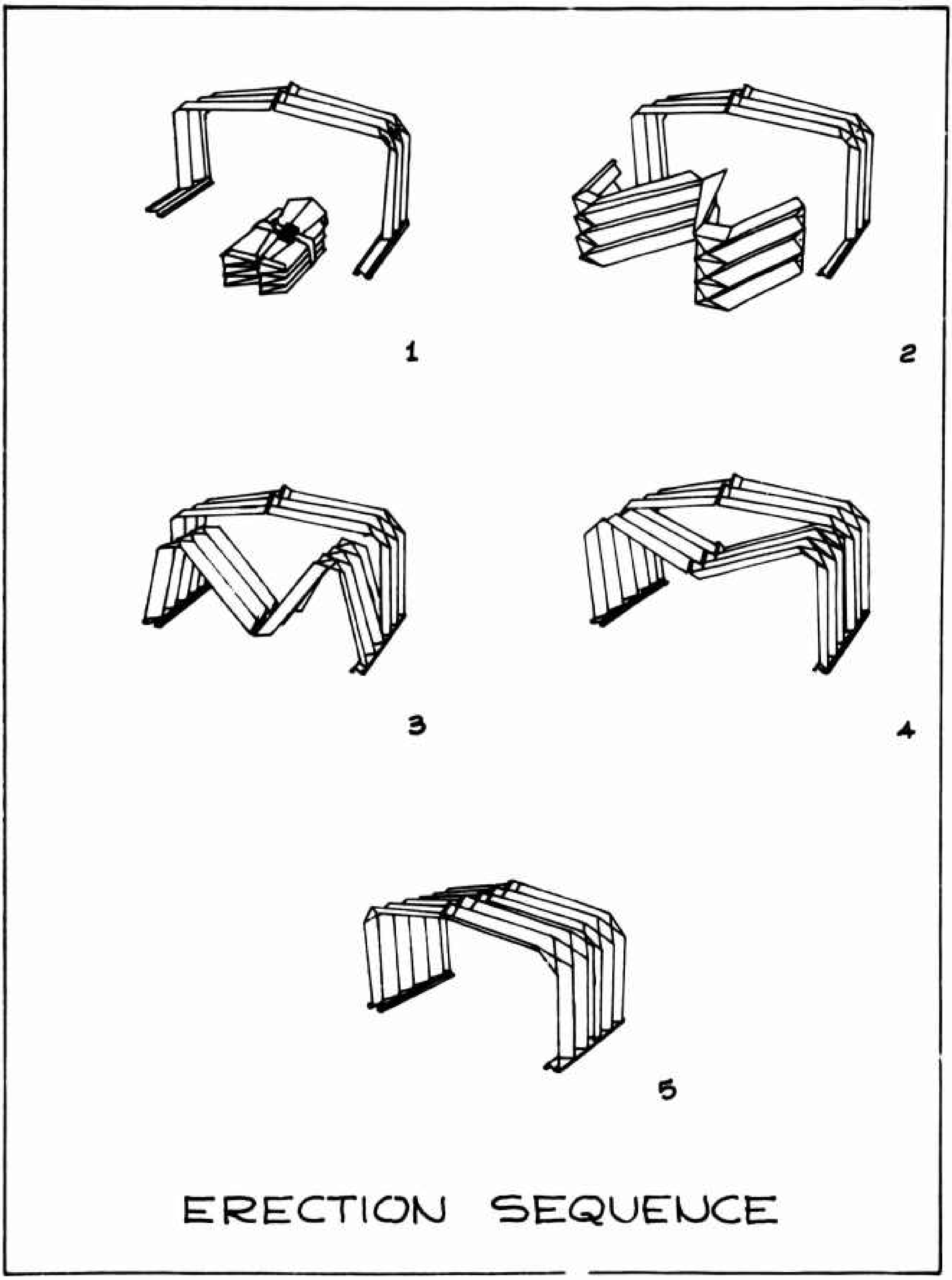


Figure 21. LES Erection Sequence

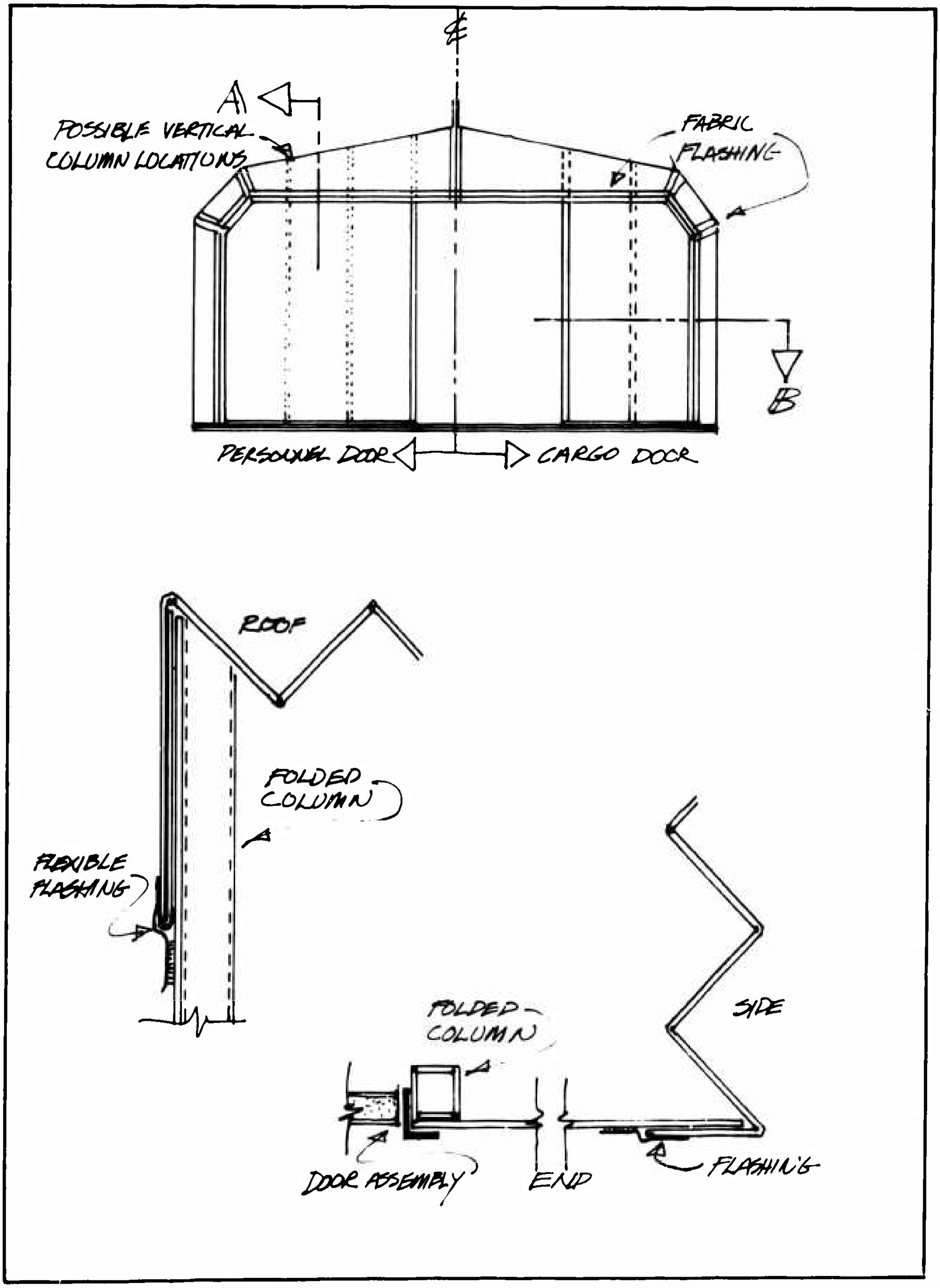


Figure 22. LES Endwall Framing Details

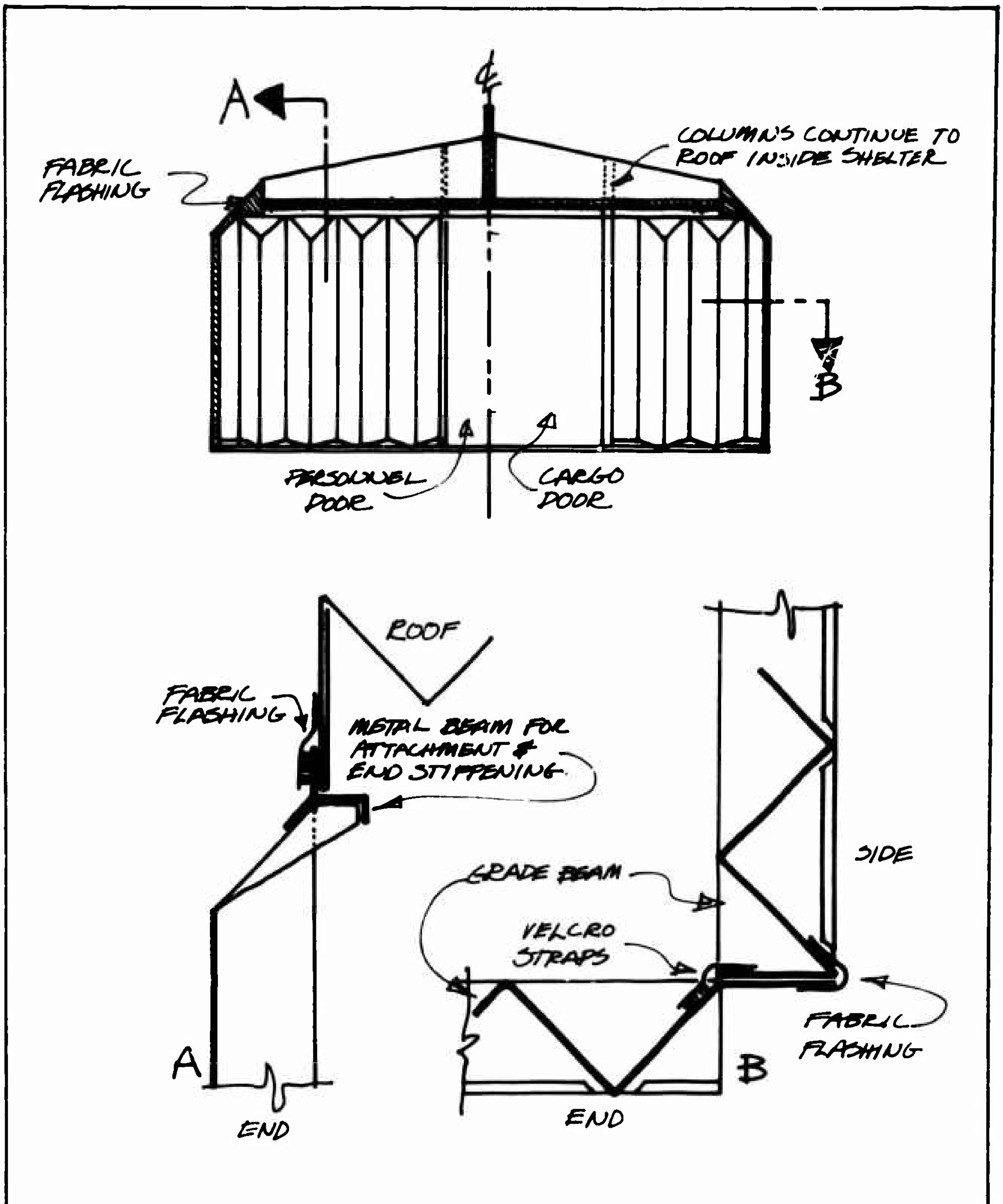


Figure 23. LES Alternate Endwall Details

been quite complex. Figures 24, 25 and 26 show reinforcement details and the sealing techniques between modules, along with several proposed ridge and floor sidewall joint possibilities. Ventilation could have been achieved with vacuum-formed plastic ports as shown in figure 27.

3. When the two concepts had been developed far enough to allow evaluation, full scale mock-up sections were produced. This provided an efficient means of mocking up the joining details developed, as well as demonstrate the structural soundness of each concept. Static loading tests were conducted of various sections for both L.E.S. and ES/C designs. Figure 28 shows the erected partial section of the ES/C concept and figure 29 shows the 16' x 32' L.E.S. concept ready for test loading. Unfortunately, original artwork of these tests and mockups is not available due to the later bankruptcy of the sub-contractor that performed them - International Structures Corporation.

4. As the mock-up sections of the L.E.S. and E.S/C. concepts were evaluated, it became apparent that certain problems were evident in each structure. Relative to the E.S/C. structure, these can be listed as:

a. Greater level of close tolerance production required.

b. Smaller shelter size - accommodates only 11 men.

c. Large size of the box may be detrimental to logistics.

d. Shelter weight would be greater for a smaller available area.

Relative to the L.E.S. concept, problems were listed as:

a. Lack of overall rigidity for the 16' span.

b. No integral floor system provided.

c. Packaging not as clear and foolproof.

d. Complexity of erection.

The data generated in this section became the basis for selection of one small size concept to be fully developed.

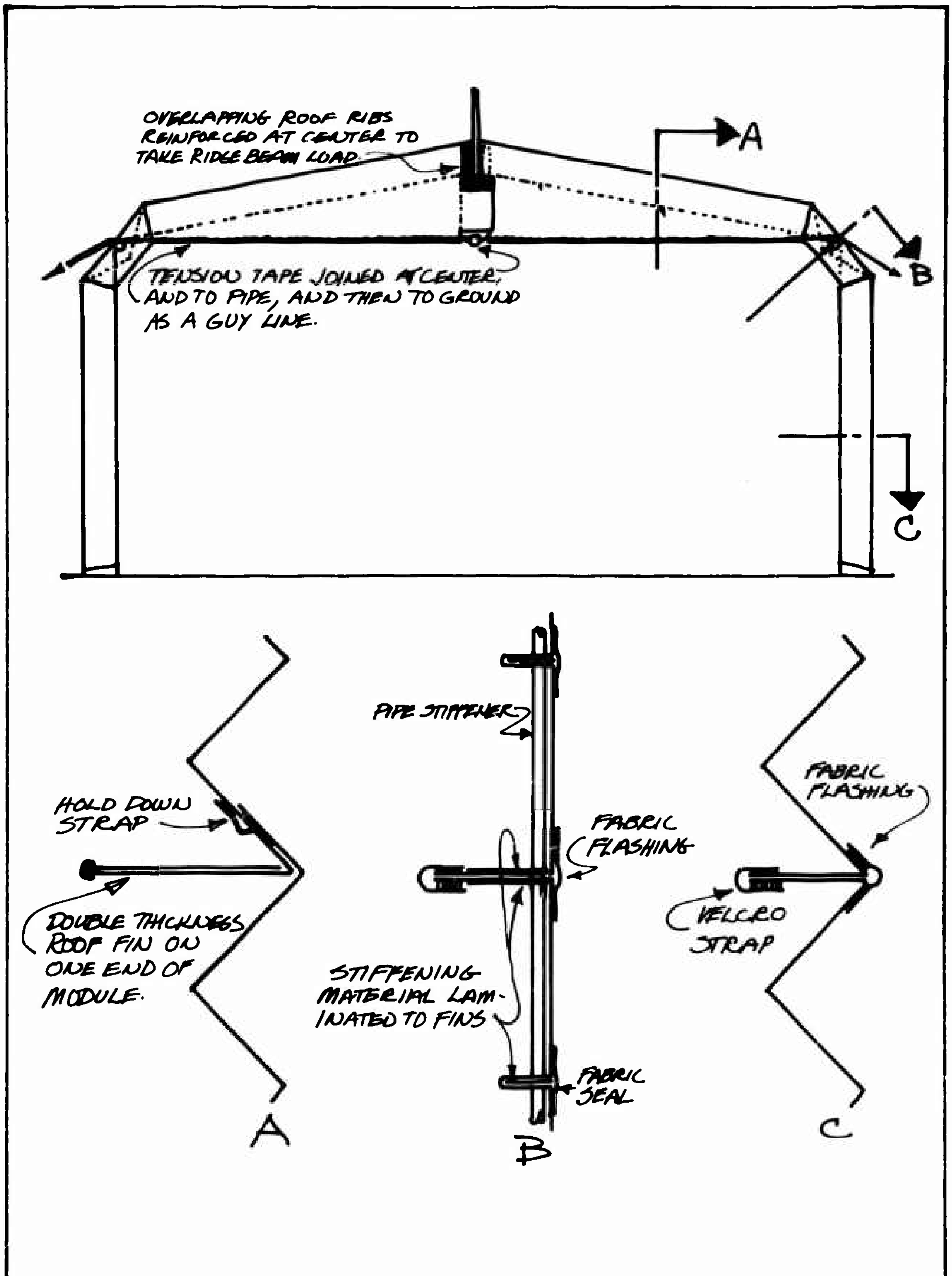


Figure 24. LES Joints and Reinforcement

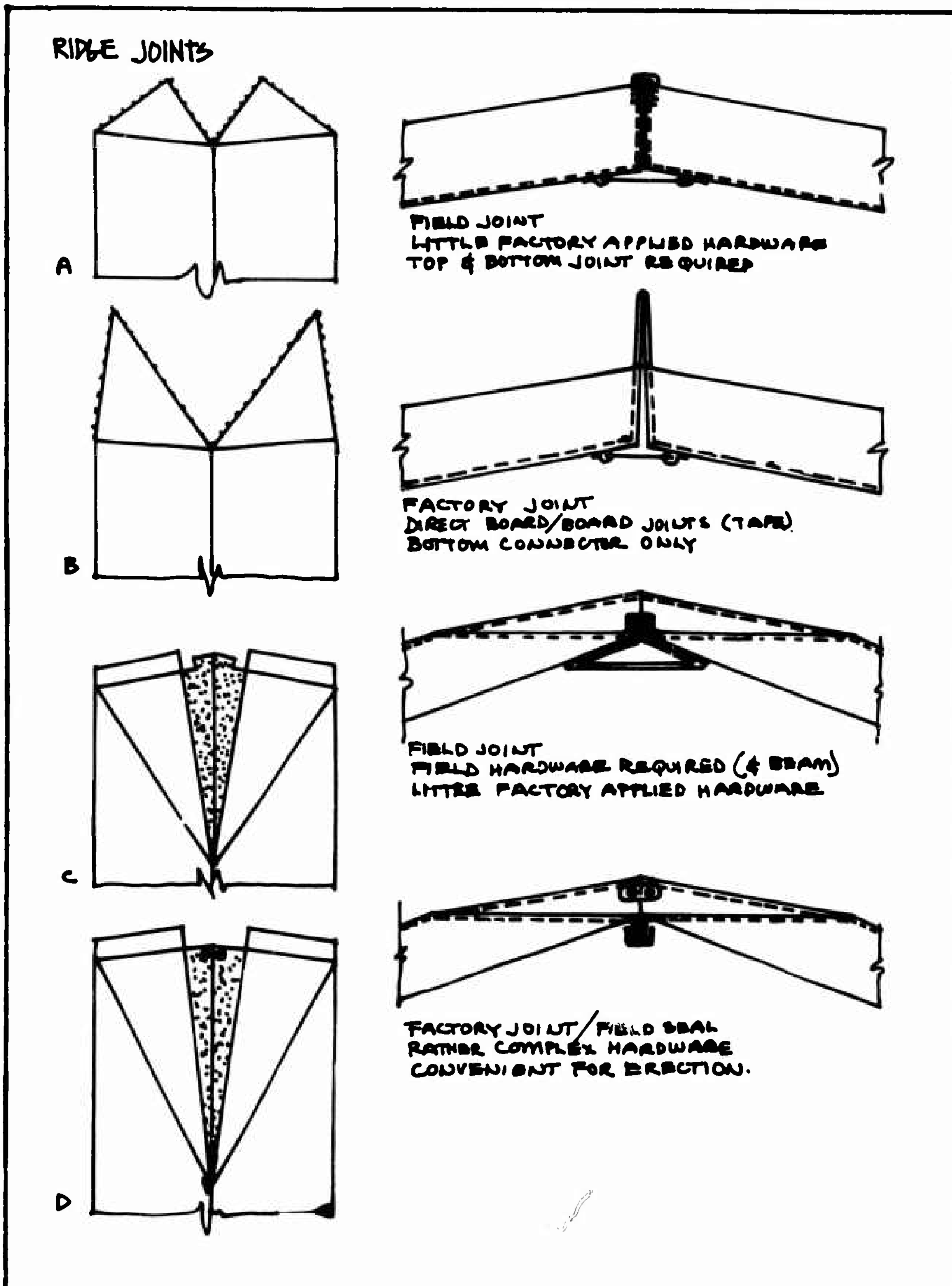


Figure 25. LES Joint Details

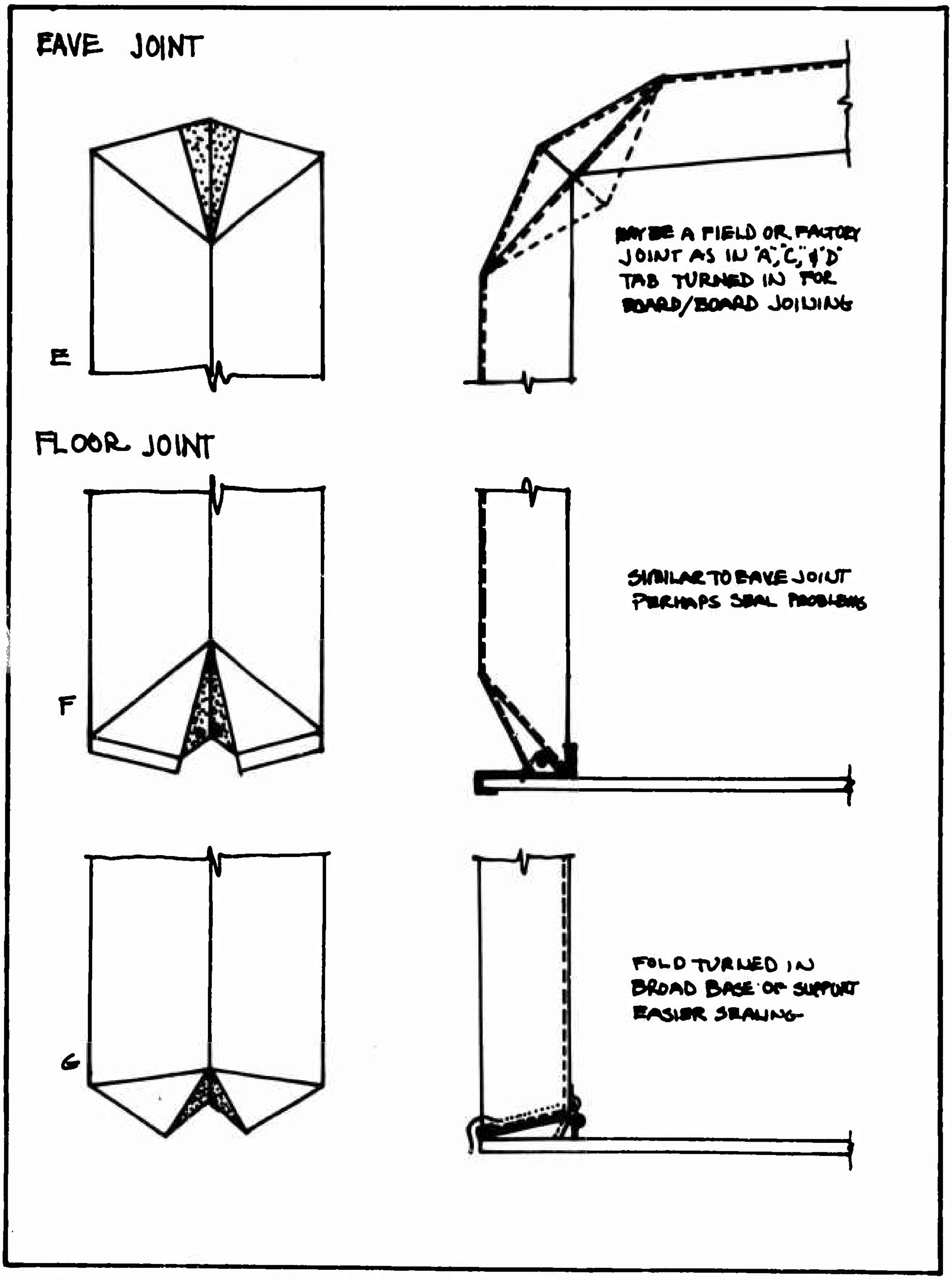


Figure 26. LES Joint Details

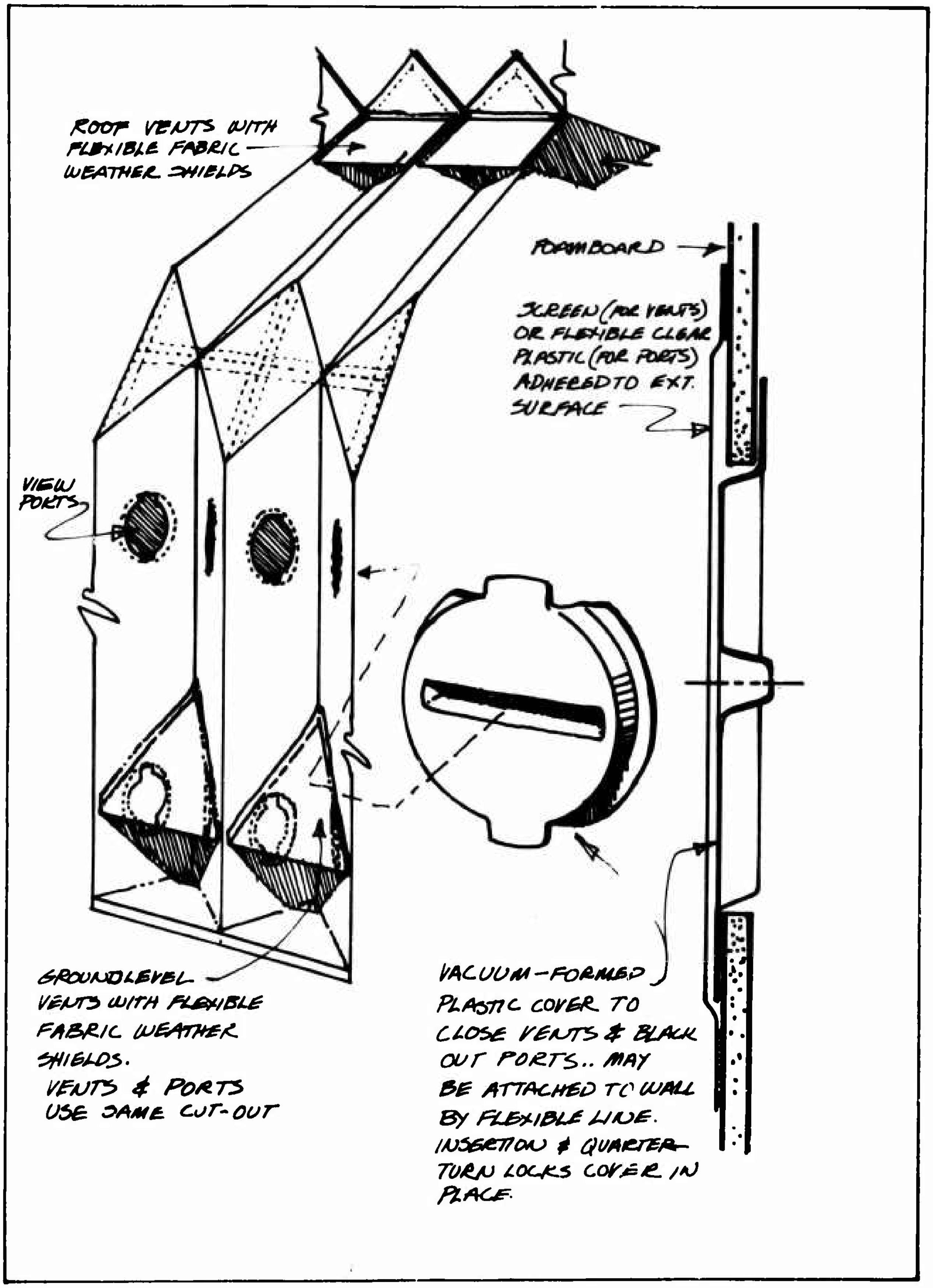


Figure 27. Vent and Window Concepts - LES and ES/C

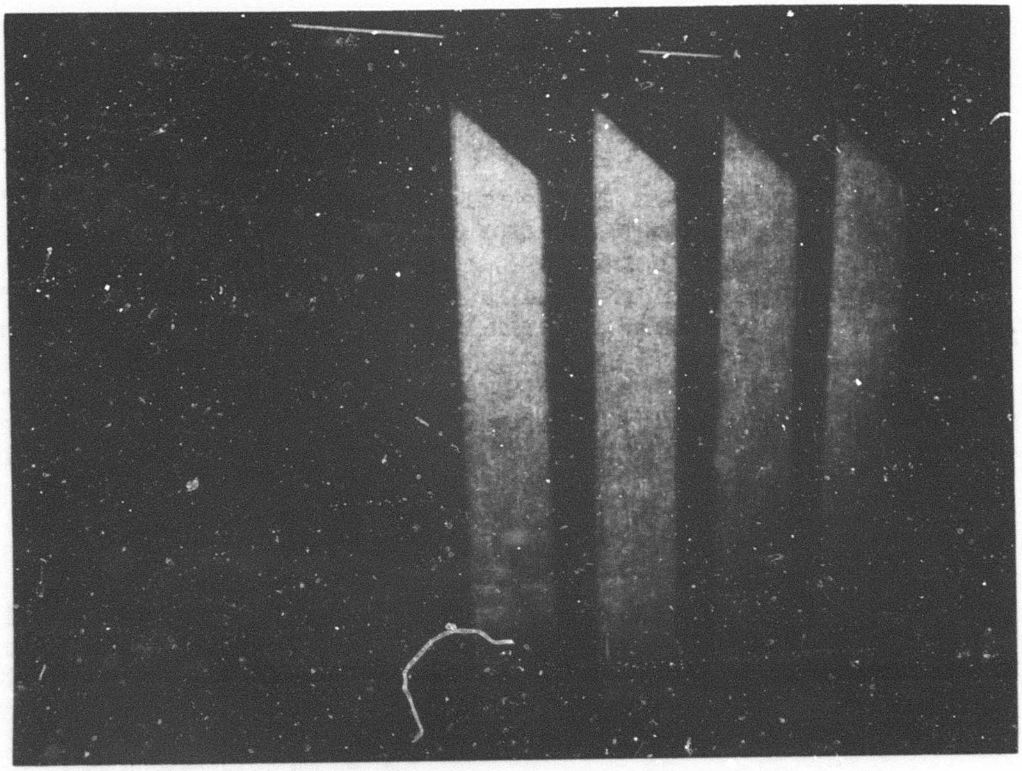


Figure 28. ES/C Full Scale Shell Mock-Up

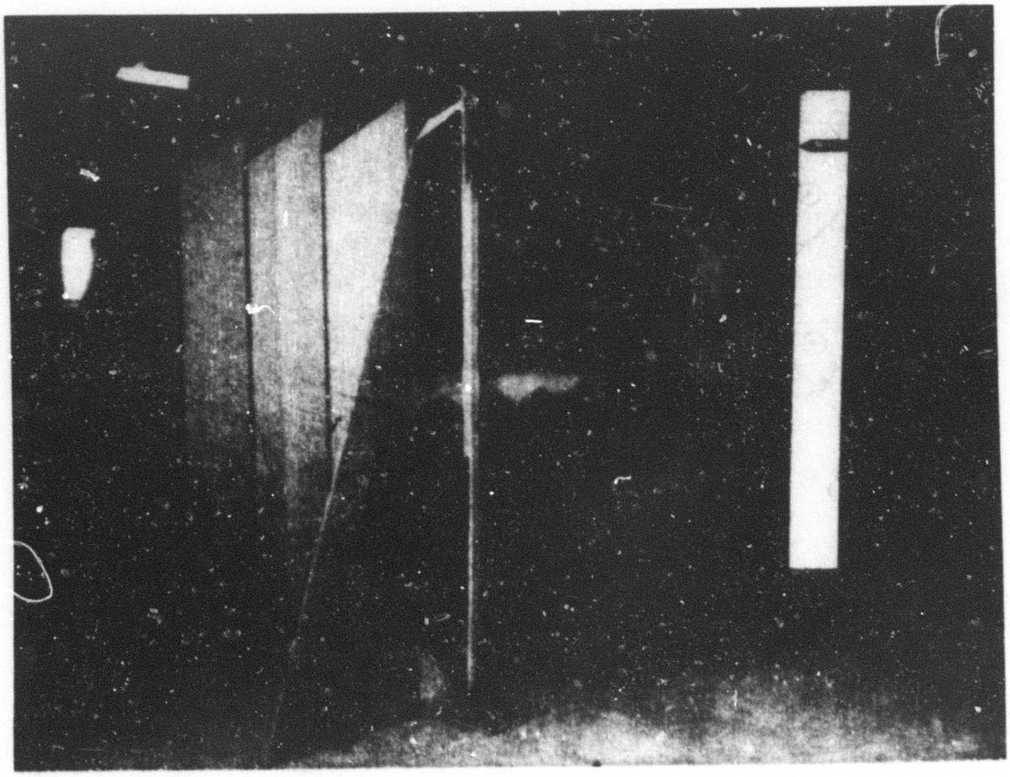


Figure 29. LES Full Scale Mock-Up

C. 13' x 35' BOXED ACCORDION CONCEPT

1. Early Development

The concepts discussed in section "A.1." through "A.5." above were jointly developed by the University of Cincinnati and a subcontractor, International Structures Corporation - a company with experience in manufacturing methods involving foamboard as a prime structural material. The selection of a concept for further development and prototyping was made at conferences at Langley Air Force Base in April of 1967 and other conferences involving AFAPL, ASD, Headquarters TAC, and the University of Cincinnati. Providing that the resultant shelter was approximately 35' long, the 13' x 35' concept was to be the design selected for full prototype development.

a. The 13' x 35' accordion fold center-core box design gains 80% of its enclosure surface from foamboard. The remaining 20% is made up of endwalls and the center core box. Floors are rigid and leveled providing maximum comfort for occupants. The principal development that allows the success of the concept is the diamond-shaped knee joint fold depicted in figure 30. Later developments also allowed a unique fold at the base of the sidewall that converts the zig-zag corrugations to a straight line. This allowed a substantially simpler sidewall-to-floor joint. (See figure 31.)

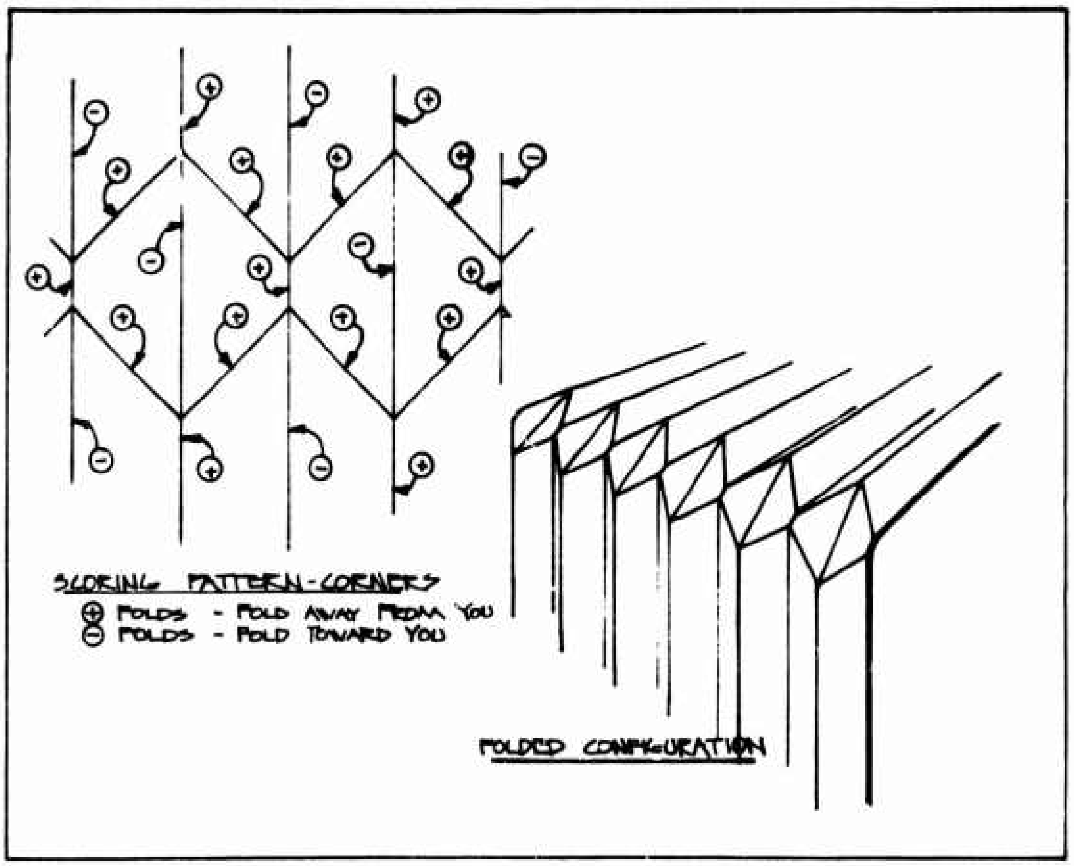


Figure 30. Foamboard Shell Knee Joint - Scoring and Folding

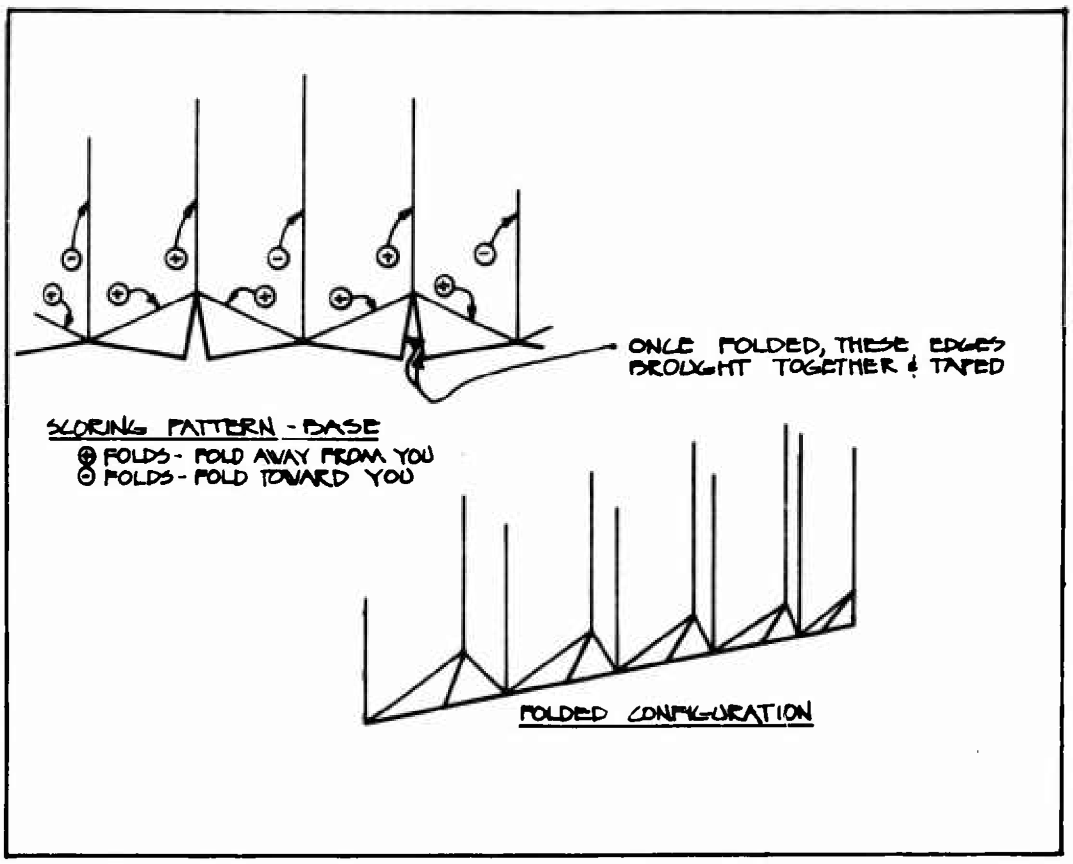


Figure 31. Foamboard Shell Base - Scoring and Folding

Utilizing the above described geometry, the shelter size becomes a function of the principal transporting aircraft's interior configuration and the 463L size restrictions. With a C-130, the practical cargo compartment length is 40'. Therefore, the maximum length of a shelter box, with clearance between boxes, would be 13'. The width of the boxes is controlled by the allowable width of the standard 463L pallet - or 9'. If we assume 6 shelters per aircraft, the box could be 4 1/2' wide, and nine shelters would require a 3' wide box. This width, in conjunction with the box height, determines the erected shelter length. The box height, again, is restricted to about 8'5" by the clearance required in the aircraft. The nominal dimensions of the box (after an optimization study was conducted) became 13'L x 3'W x 8'H.

The erection sequence for this shelter is extremely simple. Figure 32 shows the package positioned for erection. The floors fold down after unlatching them from the box as shown in figure 33. The endwalls, stored in the box, are then moved out-board, positioned, and fastened to the floor. Two rigid shell-support beams are unfolded and positioned from the center-core box to the tops of the endwall. The folded foamboard shell is then expanded by pulling the board out over the supporting beams (see figures 34 and 35). Final connections of the shell to the endwall, floors, and center core box complete the basic erection procedure (figure 36).

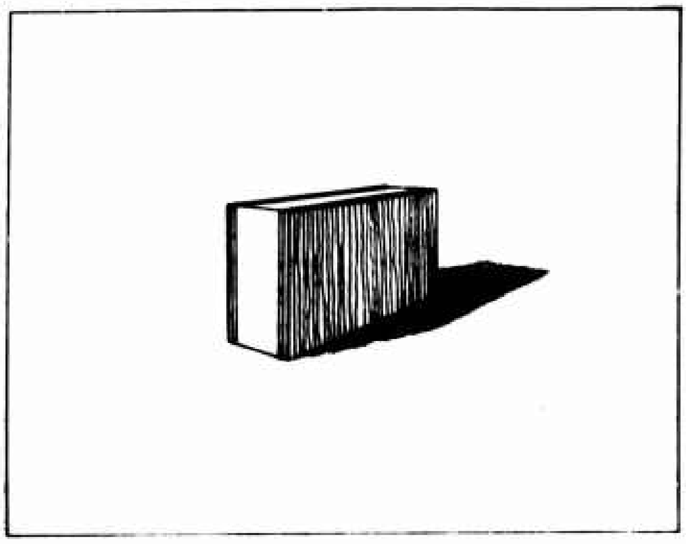


Figure 32. Shelter in Packaged Mode

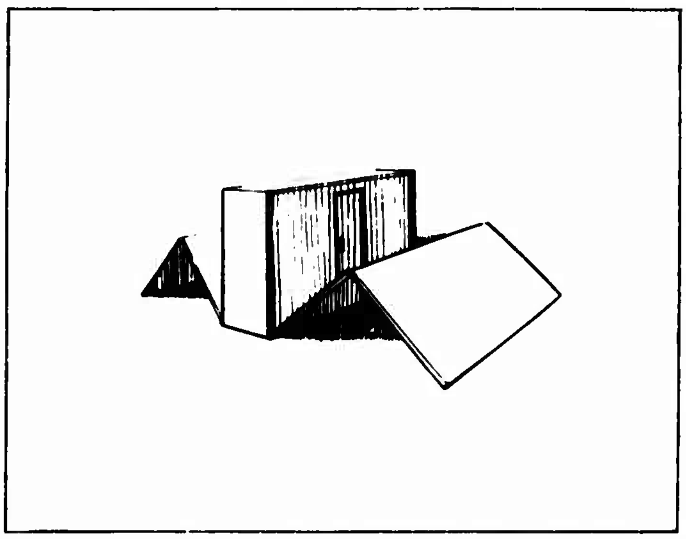


Figure 33. Unfolding Floor Panels

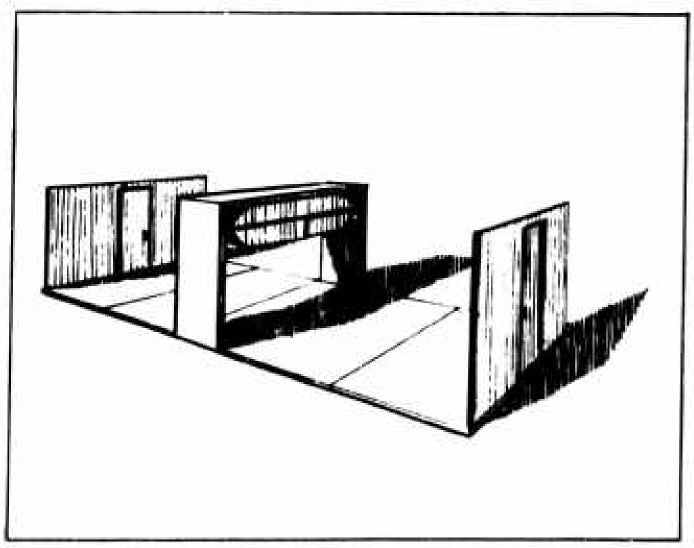


Figure 34. Positioning the Endwalls

Figure 35. Expanding the Foamboard Shell

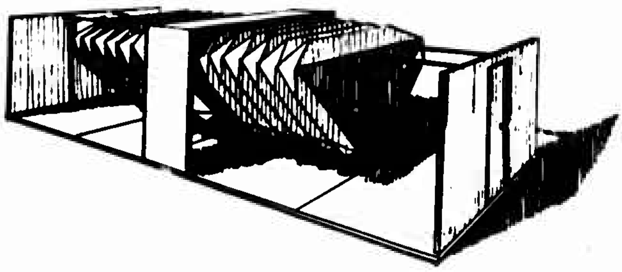
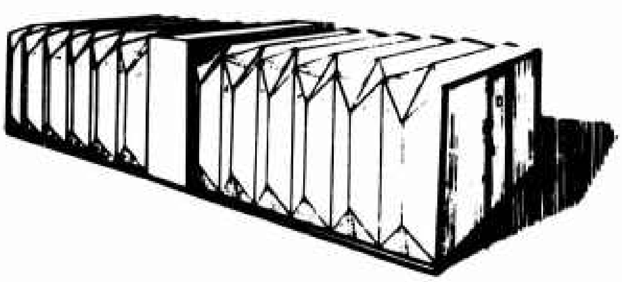


Figure 36. Completely Erected 13' x 35' Shelter



The first responsibility was to test the feasibility of the overall concept. Analysis and testing was conducted to determine whether the necessary components would package in the 36" width.

Utilizing a preliminary structural analysis of the foamboard shell by Structural Mechanics Associates (see below - III B.1.b.), it was determined that a nominal thickness of 0.30" would be required for the loading imposed. Then it was determined that this thickness required 40% more space to fold at moderate pressure than the theoretical stacking thickness calculated for this design.

Therefore:

No. of Panels/Side	Theoretical	Actual
22	26.4"	37.0"
20	24.0"	33.6"
19	22.8"	32.0"
18	21.6"	30.3"
17	20.4"	29.4"
16	19.2"	28.56"

The angle between panels when the structure is extended until the wall and roof are at right angles is pre-determined to be 130°. It is not possible to vary this angle or expand a side of the structure to any desired length. Consequently, the length of the structure is determined by the width of each panel. Figure 37 shows the expanded geometry. The length of each panel can be analyzed by:

$$l = w \cos 25^\circ$$
$$\cos 25^\circ = 0.906$$
$$l = 0.906\, w$$

Overall length of unit = 35' - 3' (box) = 32' x 12" = 384"

One end of the shelter = $\frac{384}{2}$ = 192"

Number of panels needed per side = $\frac{192}{l}$ and:

If w = 12.0", l = 10.88" and 17.66 panels are needed.
If w = 12.5", l = 11.33" and 16.94 panels are needed.
If w = 13.0", l = 11.78" and 16.30 panels are needed.
If w = 13.5", l = 12.23" and 15.70 panels are needed.

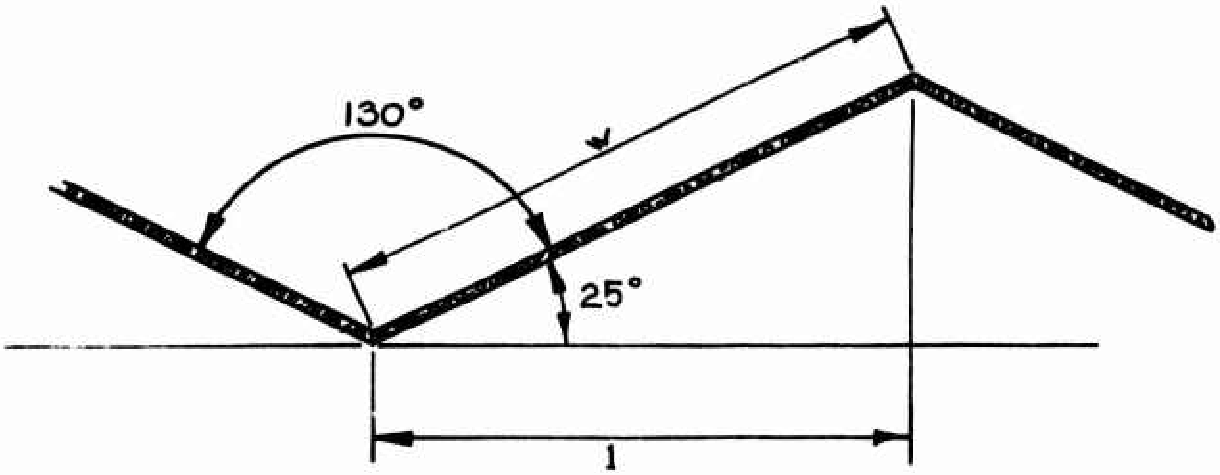


Figure 37. Basic Foamboard Geometry

Therefore, the approximate length of each pleat or panel becomes 12.5" to 13.0" long to end up with 8 cycles with one long leg at the shelter box.

The unique nature of the foamboard fold allows the sidewall legs to draw up for storage and result in a 160 cu.ft. storage void. Conferences with Natick Laboratories were held to obtain data on the proposed contents of this void, i.e. the proposed furniture and equipment. The following tentative list was established.

TABLE 2. BARE BASE FURNITURE; EST. CUBE, SIZE AND WEIGHT

ITEM	DIMENSIONS (INCHES)	CUBE	WEIGHT
Modular Desk (1)			
Folded	29 x 16 3/8 x 21 3/4	6.0 $ft.^3$	65 lbs.
Set-up	29 x 45 3/8 x 20	15.2 $ft.^3$	
Tables (1)			
Folded	30 x 48 x 2 1/2	2.1 $ft.^3$	44 lbs.
Set up	30 x 48 x 30	25.0 $ft.^3$	
Folded	30 x 72 x 2 1/2	3.1 $ft.^3$	55 lbs.
Set up	30 x 72 x 30	37.5 $ft.^3$	
Cot (2)			
Folded	38 x 4 3/4 x 7 7/8	.83 $ft.^3$	17 lbs.
Set up	77 1/2 x 27 x 17	21.0 $ft.^3$	
Chair (1 and 2)			
Folded	18 x 16 x 3	0.5 $ft.^3$	3 lbs.
Set up	16 x 13 x 26	3.1 $ft.^3$	

NOTES: (1) For office use
(2) For billeting use

No information was provided on mattresses, blankets, pillows, foot lockers, or other equipment for the interior.

b. Structural Studies

1.) Structural Mechanics Associates was employed to make a structural analysis of foamboard geometry on the L.E.S. and E.S/C. concepts to determine optimum configurations. Early studies on these concepts assumed an angle between pleats of 89° with the pleat length around 12". This study proved that the optimum included angle was around 125° and this became the basis for the analysis in the previous section.

2.) As mentioned before, part of the potential success of this shelter development program lies in material selection and/or development. The foamboard material used previously as prime structure for shelters (by the University of Cincinnati, International Structures Corporation, and the G. T. Schjeldahl Company) all suffered from serious drawbacks such as poor flammability characteristics, moisture-vapor absorption, and poor structural toughness. The polyethylene faced boards were seriously damaged by prolonged weather exposure. This UV degradation leaves the kraft paper exposed and free to absorb moisture. The, wet-dry cycling causes gross failure within 18 months.

In an effort to alleviate this, an experimental skin material utilizing aluminum foil and a strong vinyl-film face was developed. ISC fabricated a model of their commercial shelter with this material to evaluate its handling properties. Largely on the strength of this test, the board was tentatively selected for the prototype work done on this contract.

3.) In order to gain confidence in the structural engineering design involving the folded plate shell, it became necessary to conduct a series of tests to determine the exact physical characteristics of various foamboard types under consideration. Tensile, sheer, compression and flexual characteristics are evaluated. The skin composite mentioned in (2) above proved to be the strongest board due to the aluminum reinforcement layer, and further influenced the selection of this board for prototypes. A summary of the complete test results are included in Appendix "B".

c. At this point in the work, contractual difficulties arose from the financial position of our sub-contractor, International Structures Corporation. ISC filed for voluntary bankruptcy and our sub-contract with ISC was terminated (July 1967).

2. <u>Prototype #1 Development and Construction</u>

a. To facilitate the design finalization and construction of prototypes, a new sub-contractor was sought. The G. T. Schjeldahl Company of Northfield, Minnesota was selected because of its experience with foamboard shelters. GTS was also able to employ several key personnel of the now defunct ISC to maintain continuity on the program.

b. Mock-Up Development

1.) On 8 August 1967, a status review conference was held at Langley Air Force Base. As a result, the following additional design parameters became apparent:

- Shelters shall have exhaust fans in each unit.
- A personnel door in the container was removed as a requirement because of structural problems imposed.
- Leveling should be designed to accommodate a maximum variance of 1" in 10'.
- Palletizing the shelter will present a problem.

Also presented was the requirement for a 100% full-size operational mock-up of the shelter to test the erection system and other components. This required a change in the scope of the contract.

Design variations were developed for critical joints throughout the shelter. Figure 38 shows variations considered for the foamboard-shell-roof to container bulkhead connection. The last concept showed merit as the fabric flashing kept debris from being blown back above the shell near the box. Figure 39 shows four

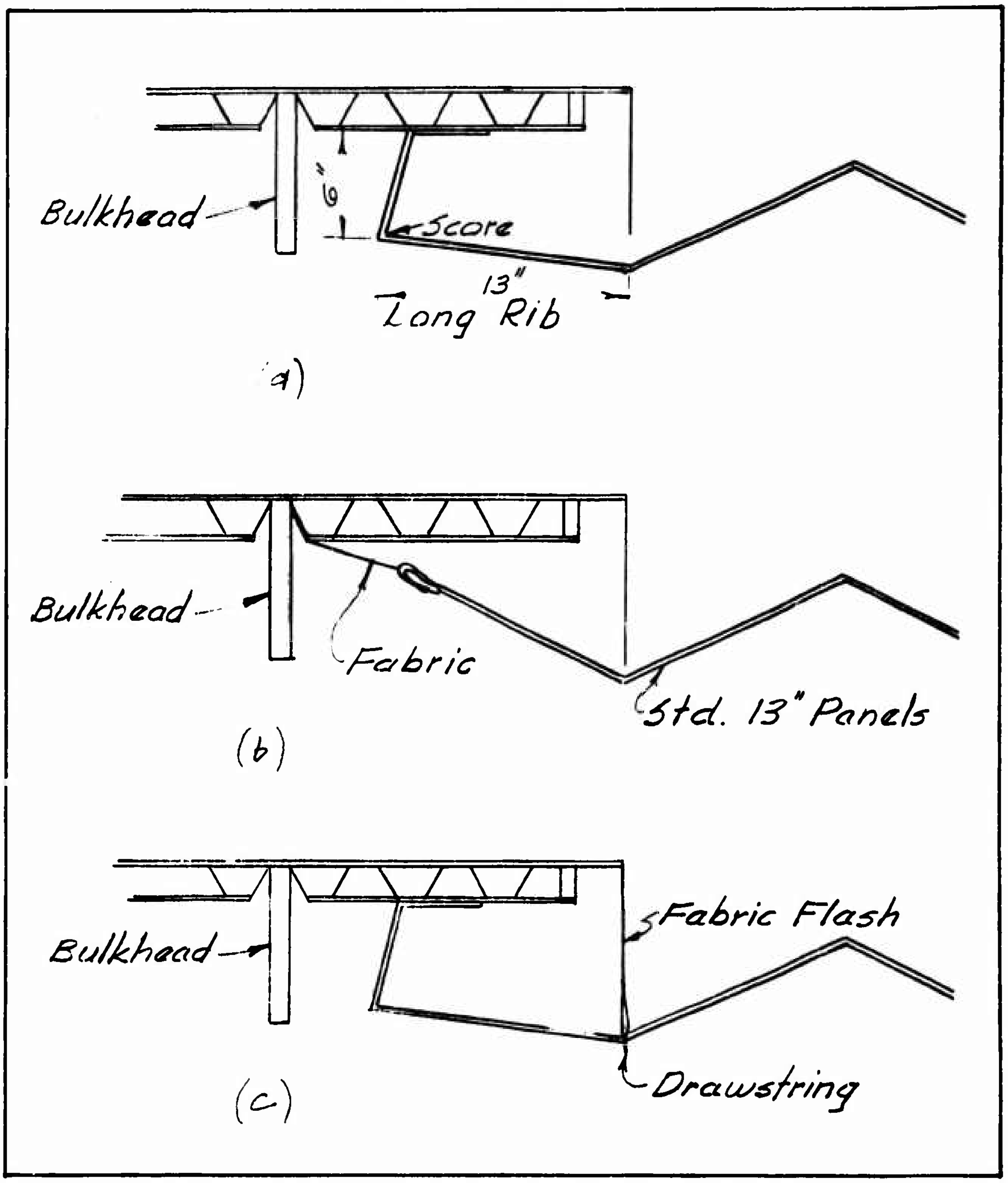


Figure 38. Foamboard Shell-to-Container Bulkhead; Attachment Variations

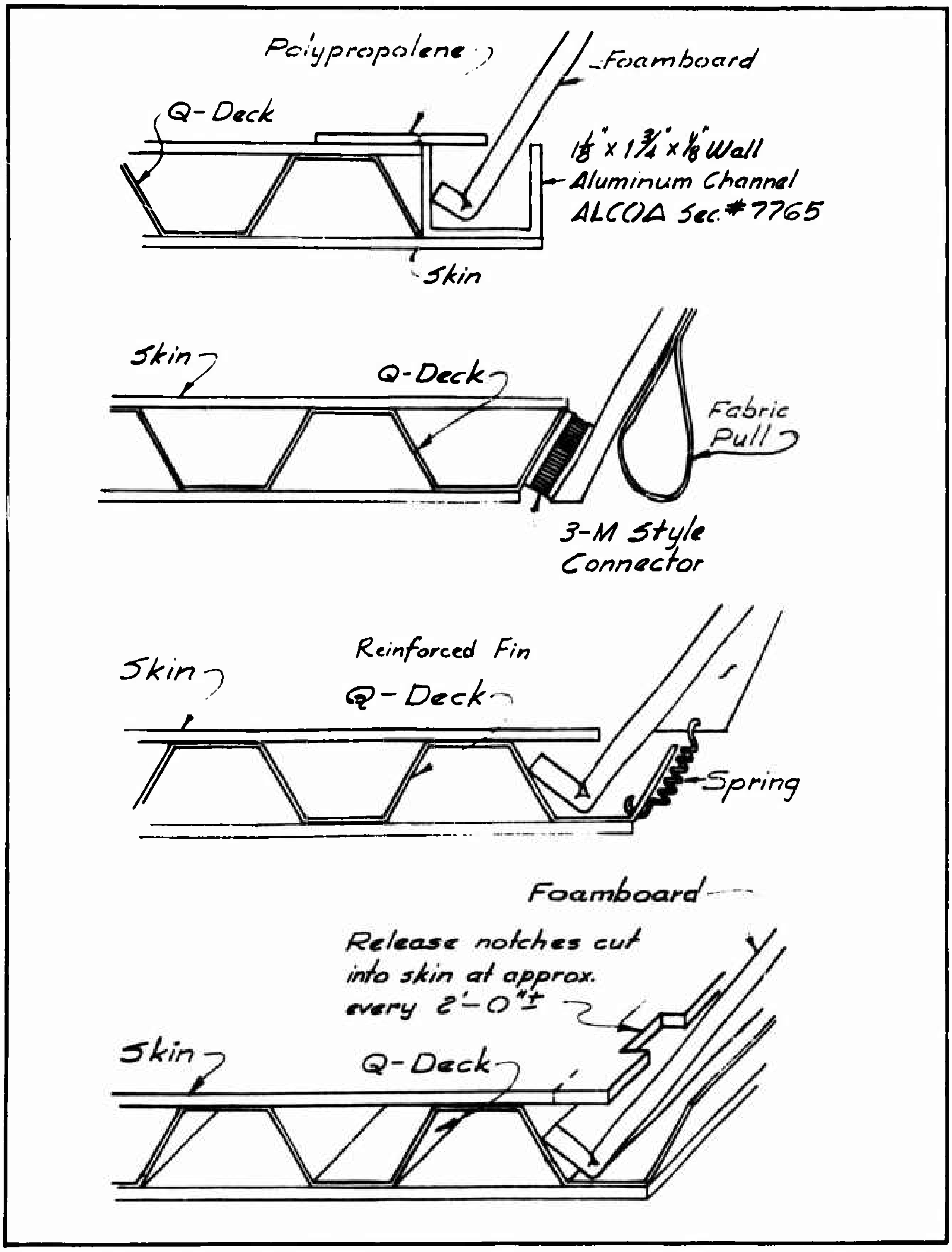


Figure 39. Foamboard Shell-to-Floor Edge; Attachment Variations

variations considered for the foamboard shell sidewall-to-floor connection.

Tentative design of section thicknesses was made to allow work to proceed on the mock-up structure and can be listed as follows:

<u>CENTER-CORE/BOX</u>	
<u>Roof and walls:</u>	2 1/4 in.
Longitudinal Roof Rib:	1 in. wide x 9 3/4 in. deep
Floor:	2 in.
<u>SHELTER</u>	
<u>Shell:</u>	0.30 in.
Endwall:	1 in.
Floor:	1 1/4 in.

2.) In order to fabricate a mock-up of the foamboard shell part, it became necessary to design and fabricate the tooling required to score and heat-seal/join the nominal 4' wide sections. It was decided, for reasons of economy, to combine the scoring dies and heat sealer equipment capabilities on one structural frame. Manufacturing would be accomplished by installing the heat-sealing heads, then joining enough board to make one shell (1/2 shelter). Then, these sealing heads would be removed, and the scoring dies installed. Since score lines are required on both sides of the board, both top and bottom dies have positive elements, and a pair of (+) and (-) lines are made at each press closing. Board would be indexed through the machine one score-line at a time using the previously made line as an index for the next line. The basic frame as shown in figure 40 is composed of two 14" deep wide-flange beams at top and bottom. Web stiffeners are used intermittently along the entire length of all four beams. A 10" space is created between the upper and lower elements. It became necessary, at a later date, to add a truss-like assembly at top and bottom to reduce deflection when the press was under closing pressure.

Figure 41 shows the frame set up as a scoring press. The upper dies are bolted rigidly to the upper beams, while the lower die platen rests on 6" diameter flexible fire hoses. When an electronically operated valve is opened, air inflates the hoses causing the dies to close on the foamboard. Figure 42 shows the heat-sealer arrangement. Since the area under pressure is relatively small, there is one hose under the bottom bar and the other hose above the upper heating bar. This insures good element contact along the entire 18' long area. A small air cylinder operates a heat-sealing tape tensioning device.

It should be noted that this press design was unsuitable for high production. Again because of economics, the press length was limited to 18 feet which was just long enough to seal the horizontal joint across the diamond - thereby joining the entire roof and sidewalls. Figure 43 shows three major steps in the shell production, The bottom view shows the press used to make the longest sealing joint - 18'. If the press span could be increased

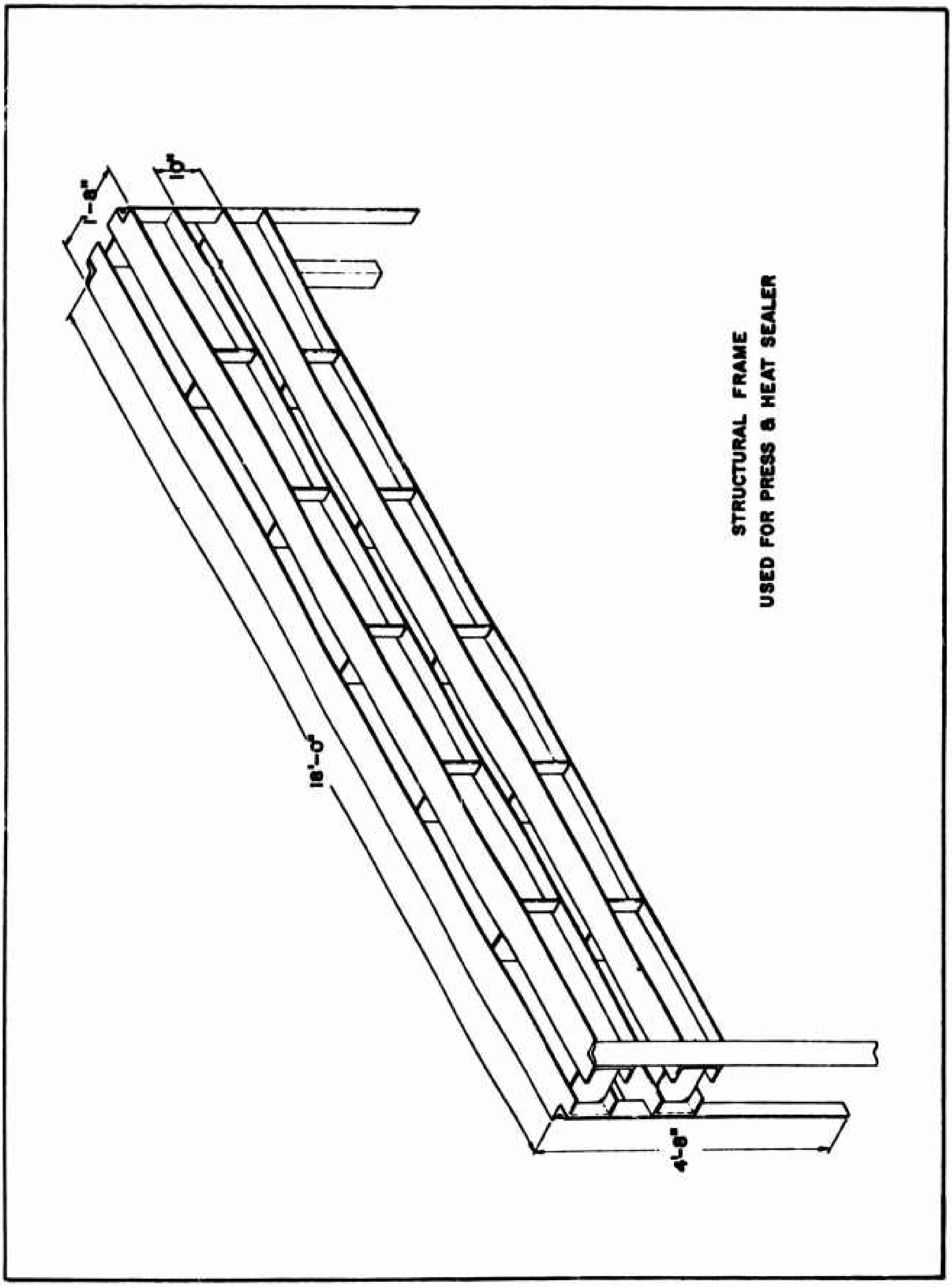


Figure 40. Views of Structural Frame used for Press and Heat Sealer

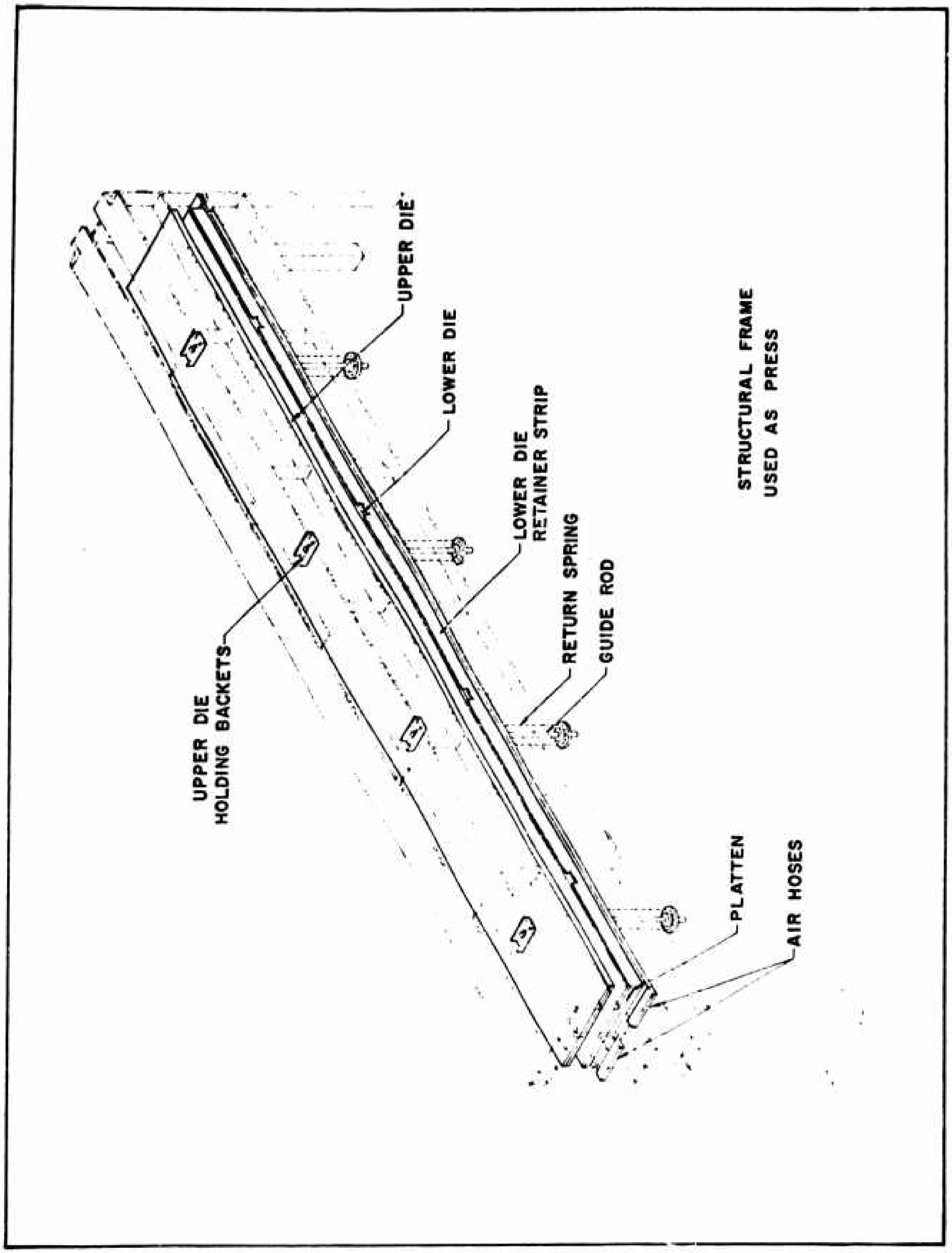


Figure 41. Structural Frame Used as Press

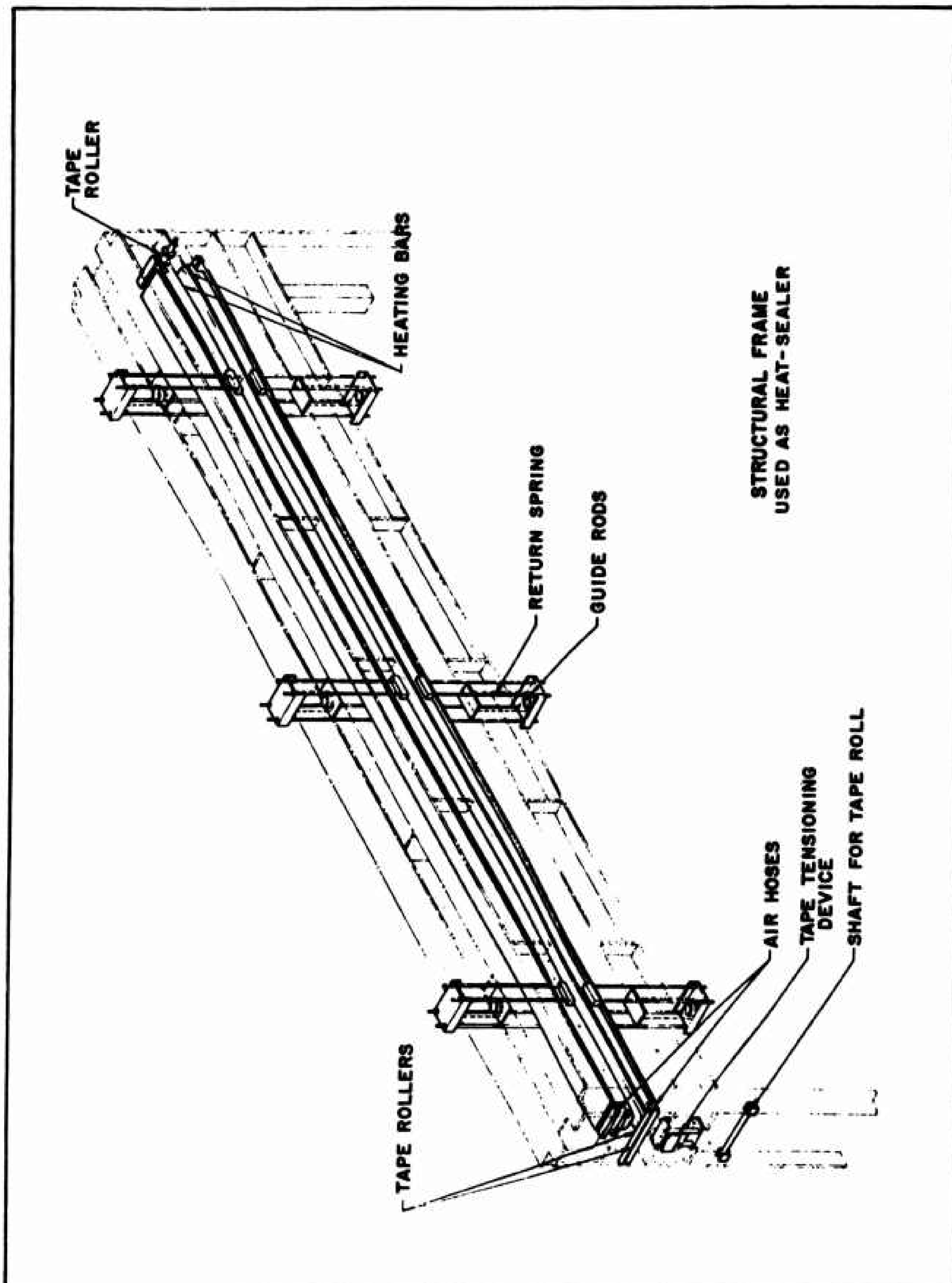


Figure 42. Structural Frame Used as Heat Sealer

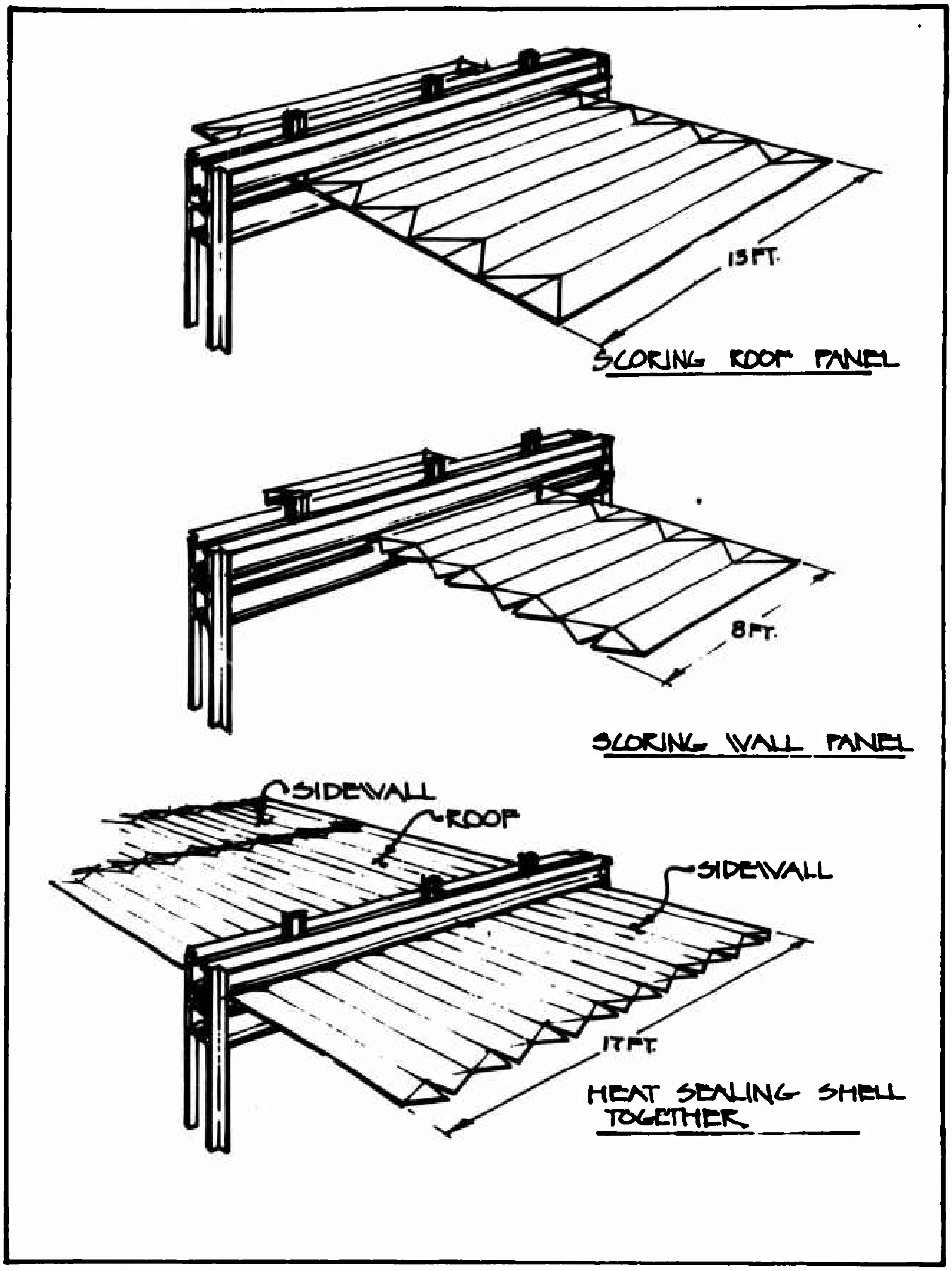


Figure 43. Manufacturing Stages in Foamboard Shell Production

to about 28', the roof and both sidewalls could be joined and make one large (27' x 18') foamboard sheet that would allow a single die impression of the entire 28' length. This would also do away with the troublesome horizontal joint across the diamond fold.

3.) On 20 October 1967, a conference was held at the Northfield, Minnesota plant of G.T.S. to review the completed mock-up structure. Representatives from AFAPL, ASUC, Hq TAC, AFOCE, CECOG, ASJT, and this contractor were present. The following criticisms were noted relative to the design:

- Plywood for flooring and container should be considered.
- Paper in the skin laminate of the foamboard must be re-evaluated to determine if it could be eliminated.
- An integral pallet is the desired approach on the concept and therefore a study on such a design was authorized.
- If possible, the floor should be raised several inches above the ground for drainage.
- The concern of emergency egress for the flight crew under a nine-shelter loading was brought up again.
- A more secure locking device for closing the container was required.
- A cheaper, simpler integral window for the endwall should be considered.
- Structural analysis of the endwall should be re-examined to resolve obvious weaknesses.
- The foamboard shell should have some abrasion resistant material applied at contact points with the roof beam.

Figure 44 shows the foamboard shell being folded for mock-up disassembly.

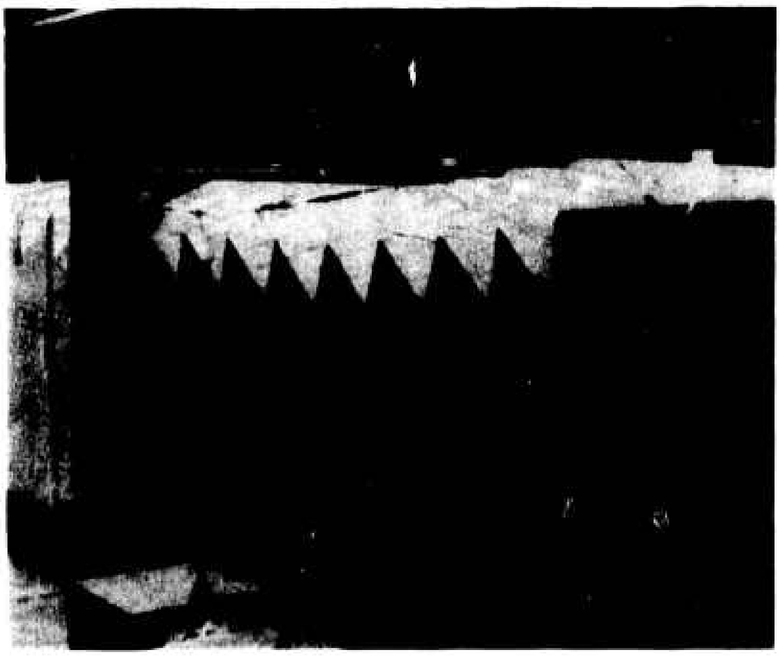


Figure 44. 13' x 33' BBPS Mock-Up Structure

c. Integral Pallet Study

A study was undertaken to determine the implications of combining 463L pallet features into the bottom of the center-core box to enable the shelters (in groups of 3) to be loaded directly into the aircraft. A primary requirement was to provide lifting capability by forklift through fork holes in the shelter bottom. This caused the container floor/pallet to be at least 4 1/2" thick and raised the overall shelter height to nearly 8'2". Weight was also gained due to the heavy pallet, extrusions, floor support jacks, and floor panel structural members to allow the greater span. The anticipated increase was around 280 lbs., but it was hoped most of this would be offset due to the elimination of a need for a separate pallet.

Brooks-Perkins Company was contracted to build the shelter bottom elements. Since they had considerable experience in the pallet area, they became a logical choice for this work. Figure 45 shows the pallet construction details proposed, and figure 46 shows various designs for tie-down joints to resist uplift under high wind conditions. The pallet was constructed of end-grain balsa core with .070" aluminum bottom skins and .030" top skins. After joining the upper assembly to the pallet, 1/4" plywood was bonded to the top skin as a walking surface.

d. Prototype #1 Construction

In designing the structural panels for the hard components areas (floor panels, endwalls, center-core box walls and floors), certain economies in the area of cost and weight could be realized by the use of a corrugated aluminum material known as "Q-Deck". When used in conjunction with plywood top skins (treated to prevent deterioration from termites), the composite had desirable characteristics for floors. Because of the elaborate framing problems, however, a foam-core sandwich became the selection for the endwalls. Skins were custom laid-up fiberglass-reinforced polyester resin.

An investigation of possible tapes to be used to hold and seal the PVC-coated five ply foamboard joints was conducted with the following results:

A two-inch wide five-ply skin with polyethylene barrier film (same as skins) was heat sealed to the existing PVC skin with success; however, the problem of the kraft paper edge exposure still was present. This condition was undesirable since water could "wick-in" and cause delaminations. In an attempt to resolve this, the polyethylene barrier film was peeled off and the paper was saturated with a thermosetting adhesive. This sealed the paper, but still allowed the aluminum fractures that weakened the tape.

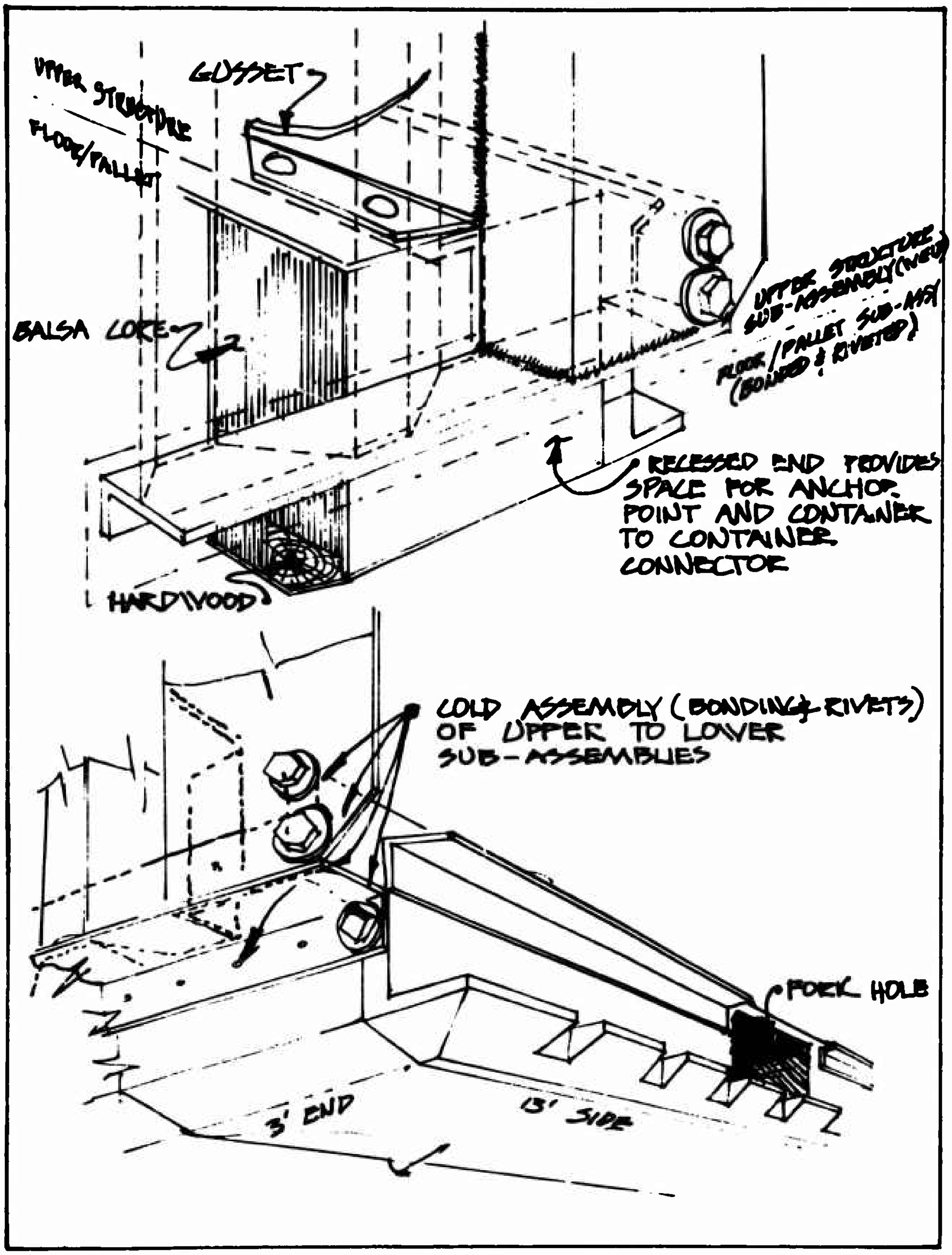


Figure 45. Center-Section Corner Assembly Details

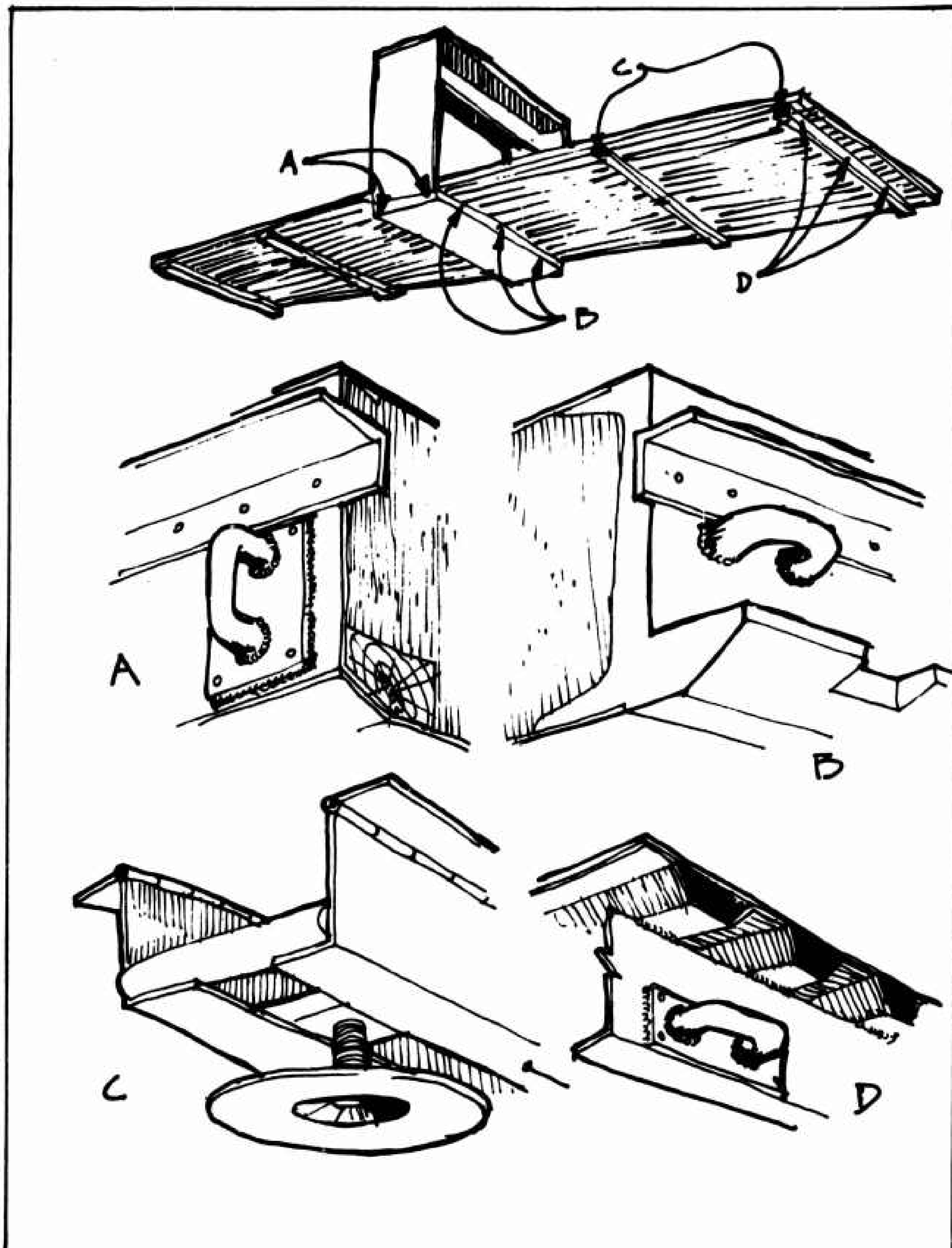


Figure 46. Shelter Anchoring Locations and Ties

After extensive testing, it was determined that a combination of 1.0 mil polyvinyl floride film laminated to a 2.2oz polyester fabric (heat sealable) would be the best for bonding to the PVC coating. Bonding capabilities, while a major criterion for the selection of tape, are not the only reason for the selection. Because of the apparent fracture of the aluminum foil at the fold lines, it was decided to predetermine the position of all score lines and apply this same tape material to these areas. Scoring would be accomplished over the tape. If a fracture occurs in the aluminum, this procedure would prevent moisture absorption. The polyester fabric is a 2.2 oz. rip-stop material with a 122-6 point count.

Figure 47 shows the prototype #1 design for attachment of the shell to the endwall. The detail is essentially the same at the side at the endwall (continuous). Velcro, while open to criticism because of cost, is still extremely attractive because of the mechanics of its operation.

Figure 48 shows the shell sidewall joint to the floor edge. Mounted in the floor is a small, inexpensive die-cast aluminum cam. Attached to the shell are discontinuous aluminum channels with a projecting tab. The foamboard (with channel) is dropped into the "trough" at the floor edge, the cam is turned and rides over the tab on the channel locking the sidewall securely. The cam is self-adjusting because of its inclined plane mating surface.

Figures 49 and 50 show sections through the floor leveling jacks. Figure 49 also shows the pre-hinged endwall in the erected position. Figure 50 shows the center floor hinge and jack in the erected position. It should be noted that this hinge is offset to allow the endwall to fold between the two floor beams thereby giving it protection. When the shelter is folded up, the jack bearing pads provide the means of securing the entire floor-endwall assembly closed in the box (see figure 51).

Roof beams were built up of wood rather than metal due to high development costs. The original design called for telescoping beams (to allow packaging since they were 17' long), but the wood "T" section was selected so pretensioning adjustments could be built in.

Figure 52 shows the electrical distribution system installed in prototype #1. Convenience outlets were mounted on a loose all-weather wire and plugged in after erection. A breaker-box/ service entry plug was mounted back to back in the center-core box sidewall. For this prototype, lighting was accomplished with all-weather cord strung along the roof beams.

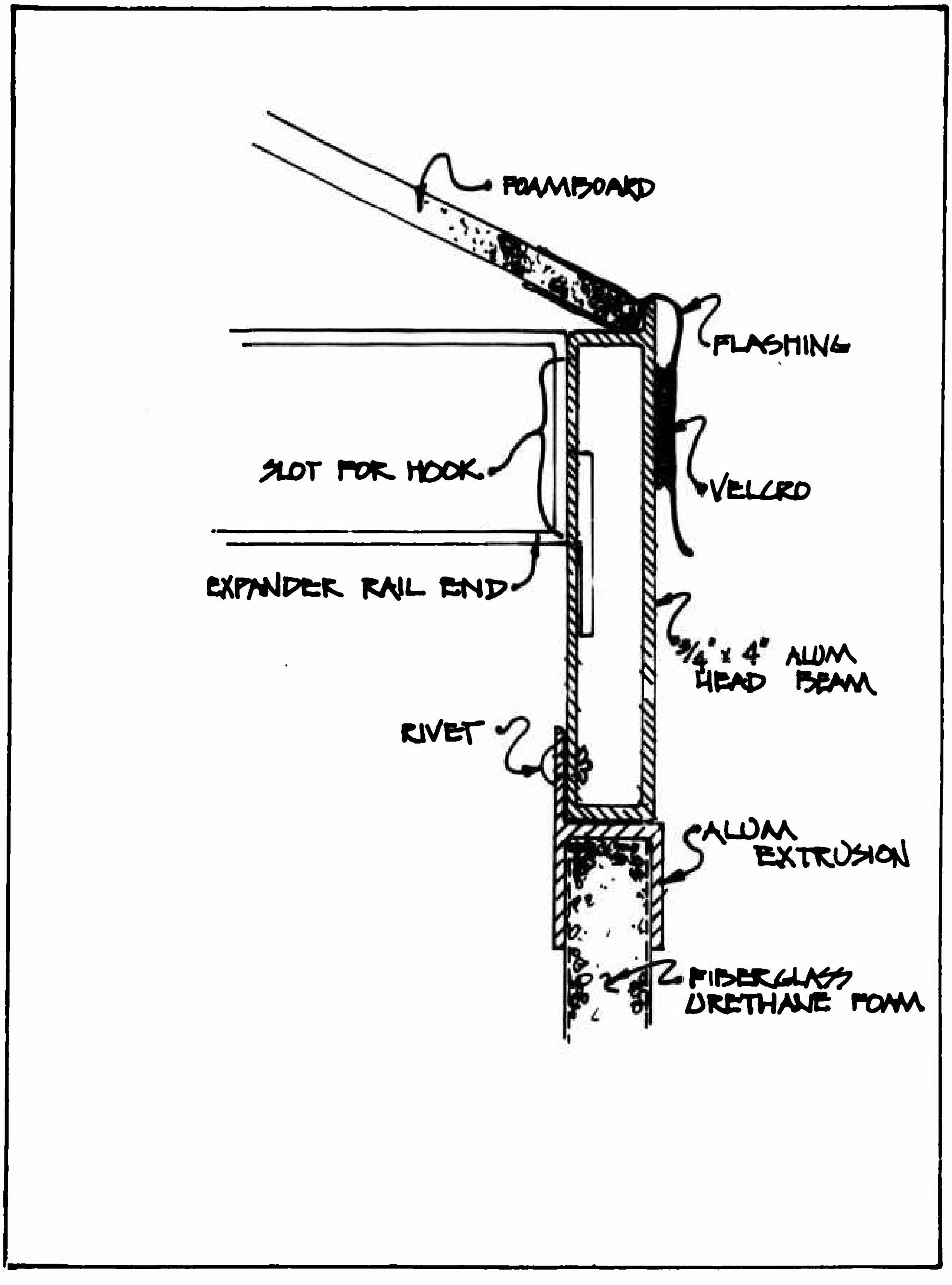


Figure 47. Foamboard Shell to Endwall Connection

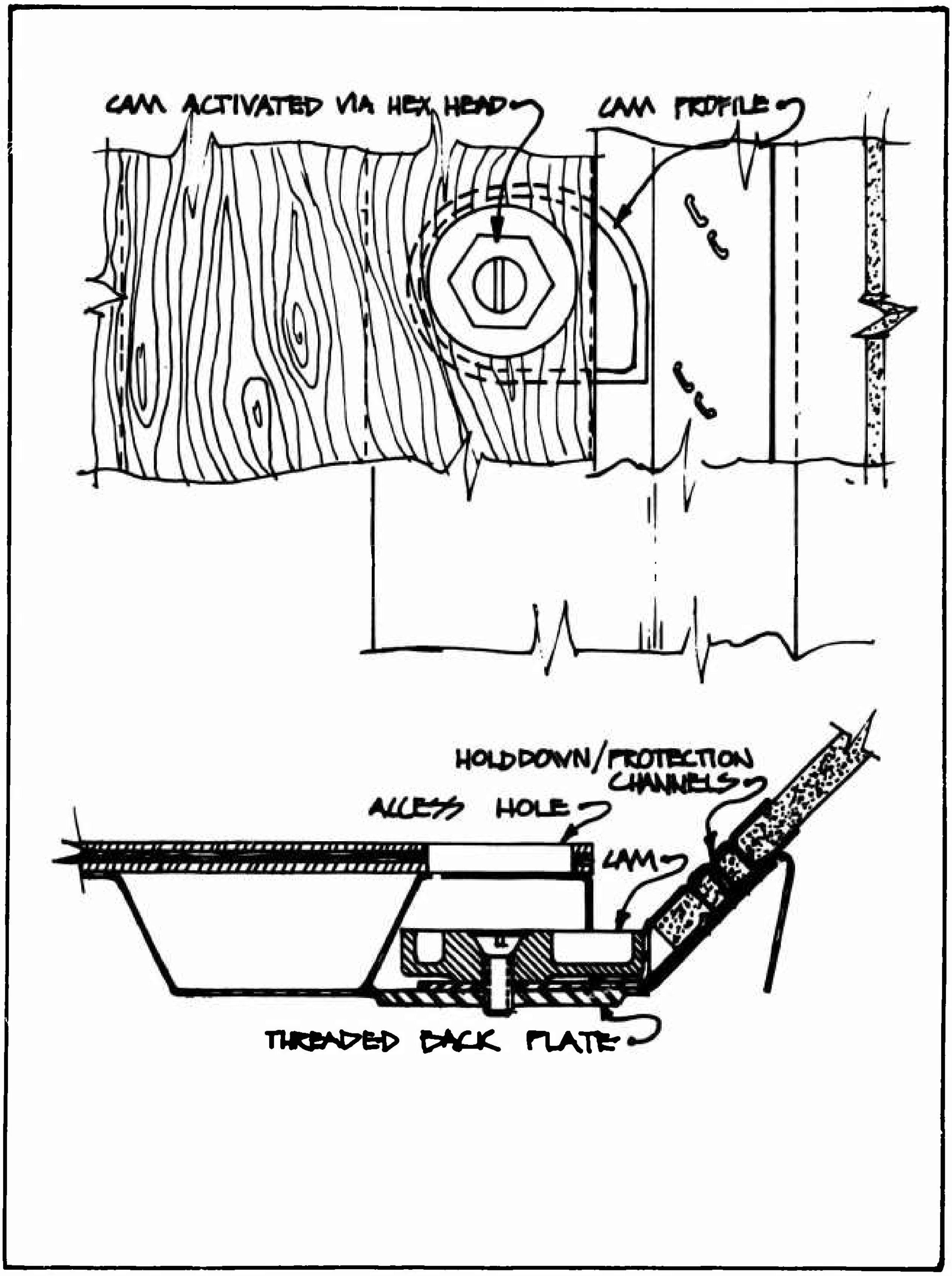


Figure 48. Foamboard Shell to Floor Connection

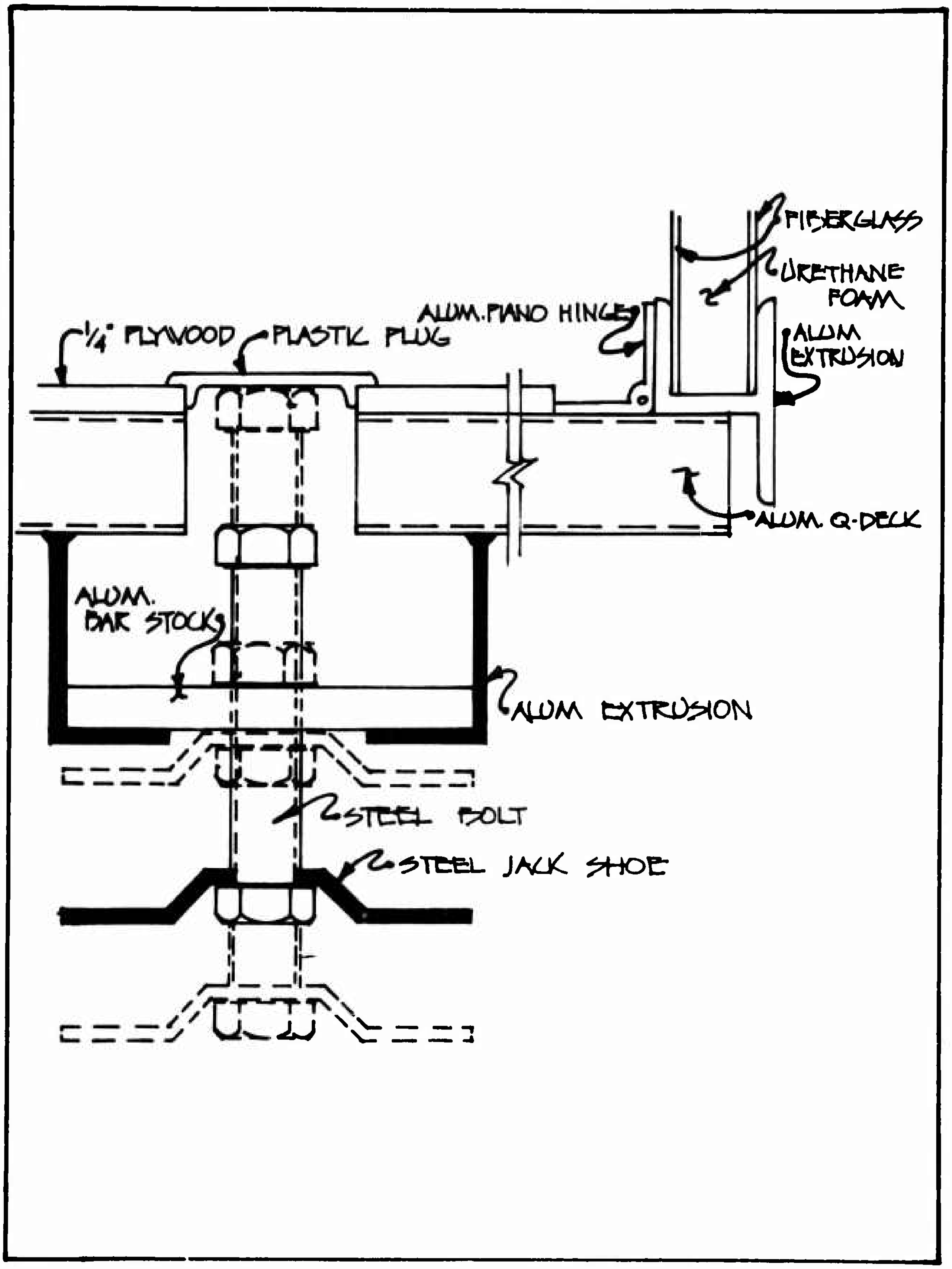


Figure 49. Floor Leveling Jack at Endwall

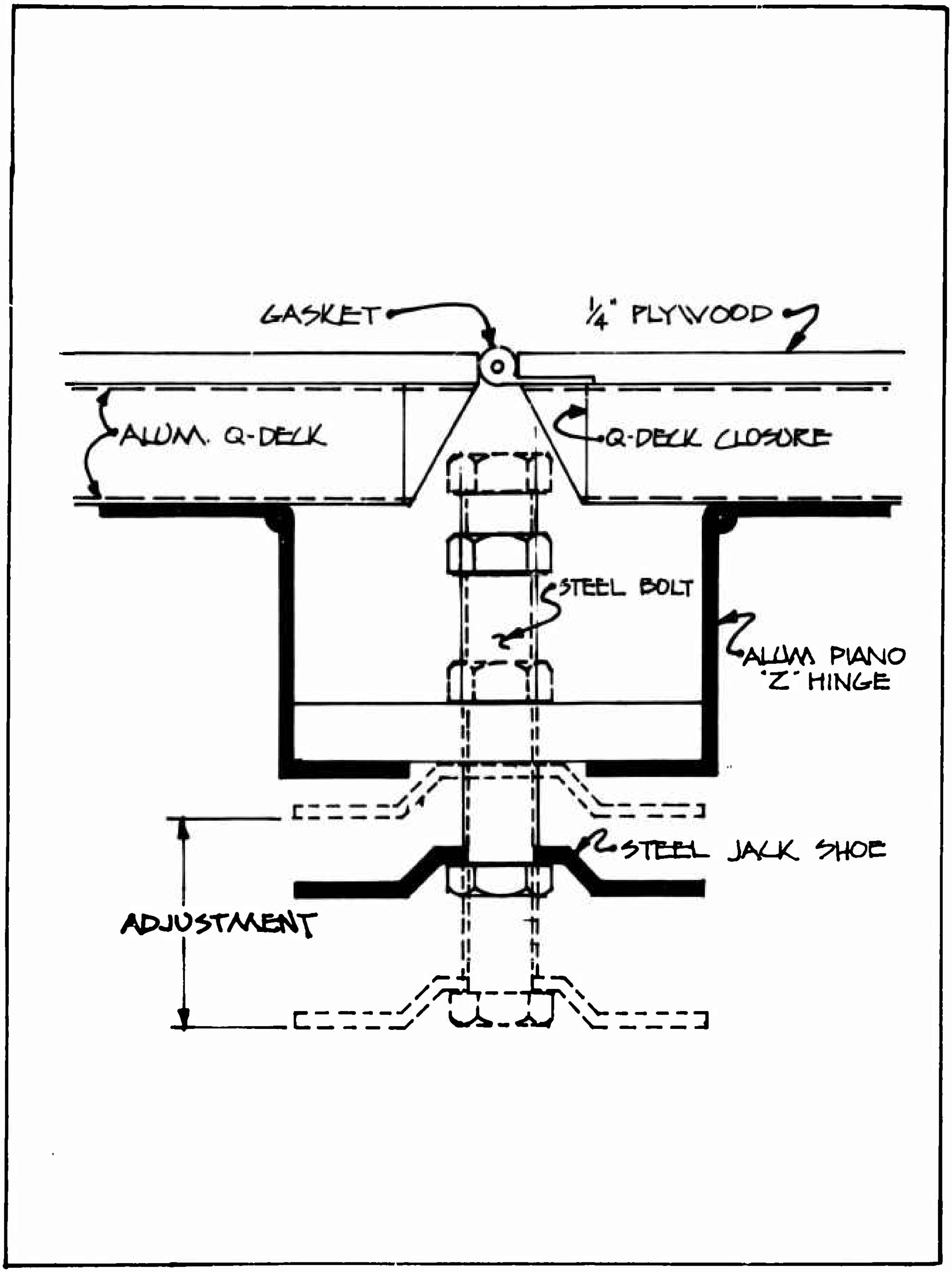


Figure 50. Floor Leveling Jack Between Floor Segments

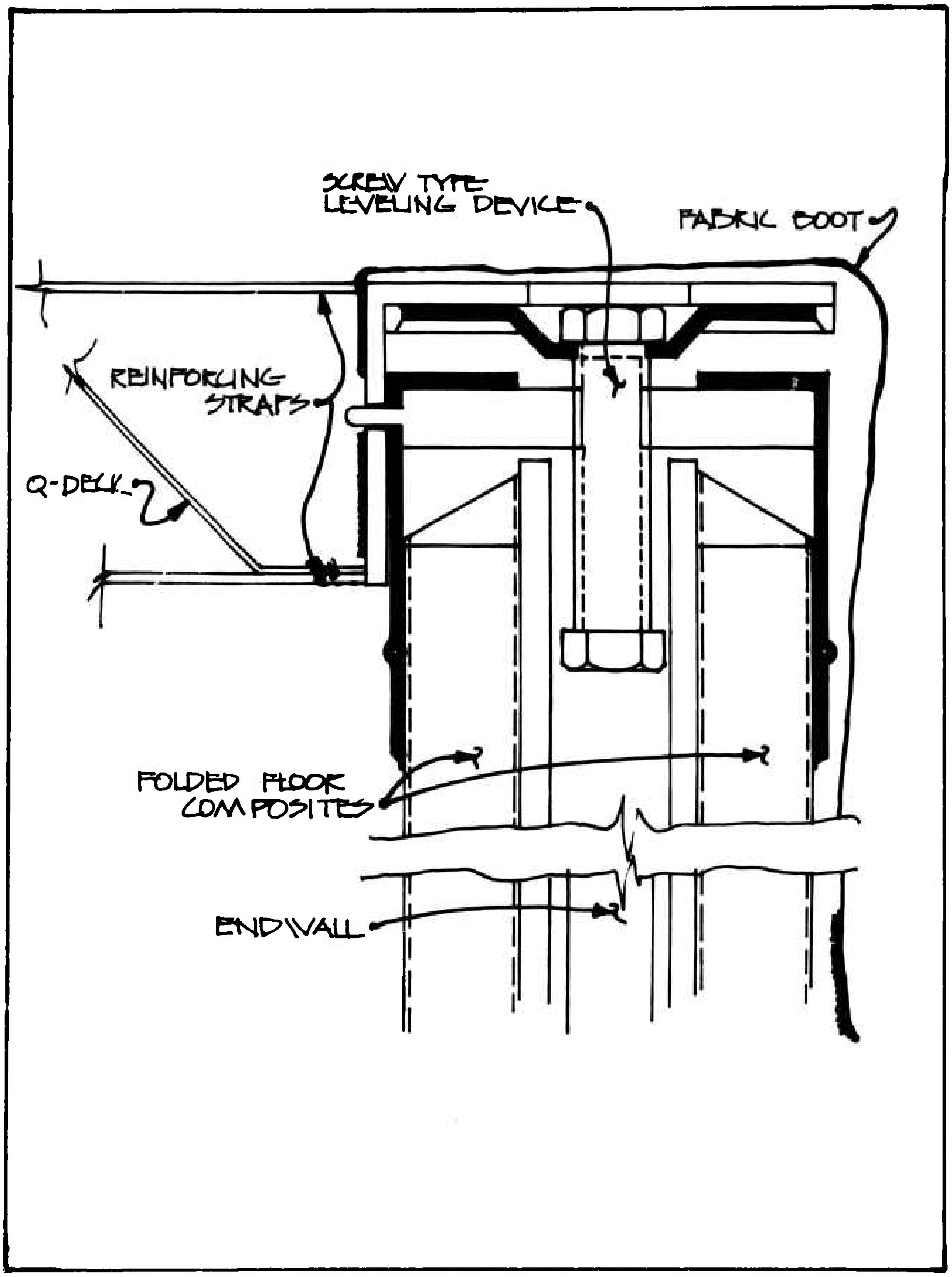


Figure 51. Folded Floors in Container Mode

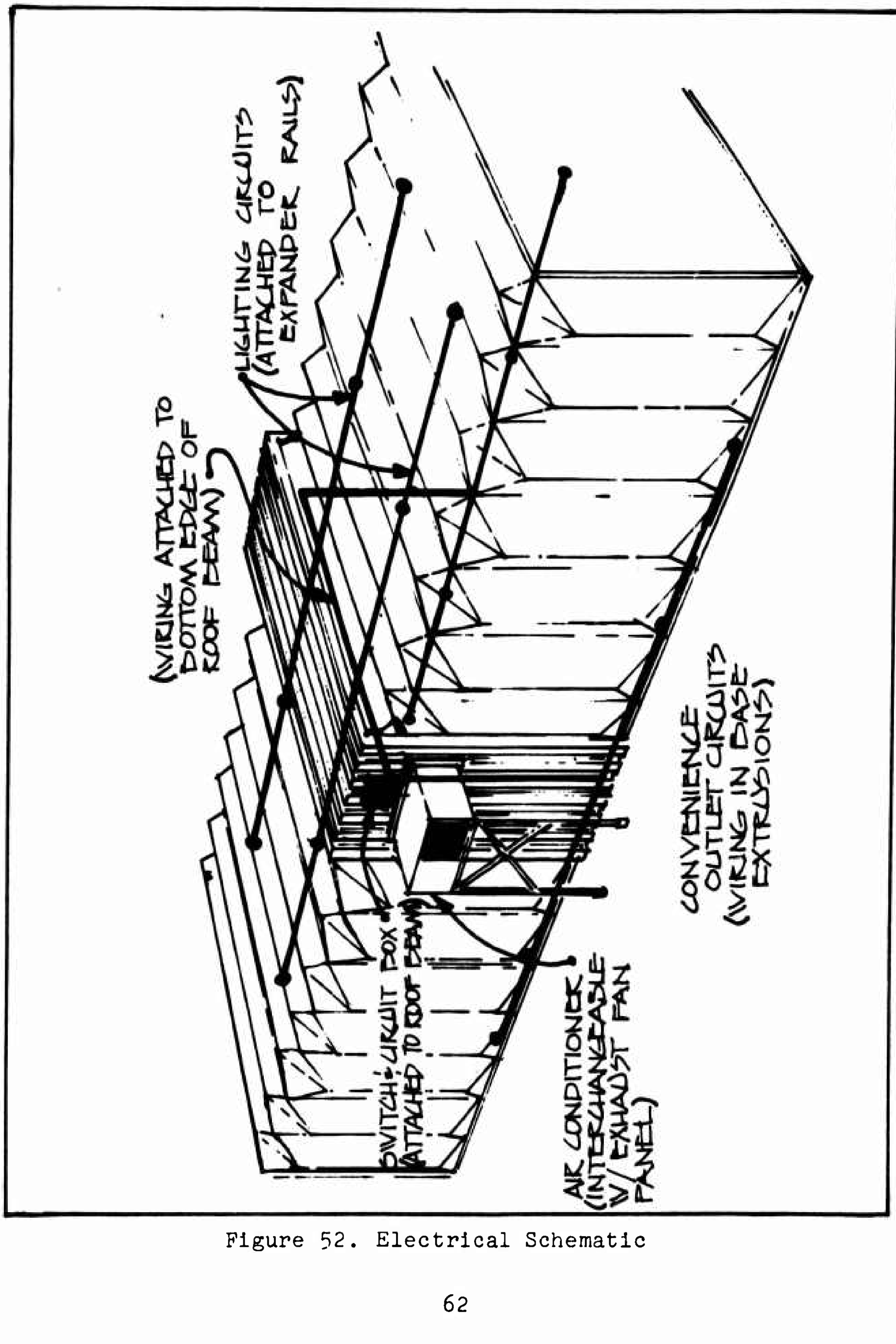


Figure 52. Electrical Schematic

Untimely material deliveries slowed the construction of prototype #1. Since the PVC coated skin for foamboard was a first-trial for that particular system, yield was very poor. Shearing, squaring and splicing became necessary before the scoring could be accomplished. In building up the box, the welding operations were slow due to difficulties with the thin "Q-Deck" material. Quality of the Brooks-Perkins supplied pallet was poor but this can be attributed to the "first article" nature of the design.

All aluminum assemblies underwent extensive preparation for final painting. It became necessary to fabricate a reclamation tank for the deoxidizer and coating operation of the large center section. The cleaning was accomplished using "Oakite 34" deoxidizer mixed with water and sulfuric acid. After the cleaning and a rinse, the "Alodine 1200S" and water solution was used as a conversion coating.

Figure 53 shows the corner of the pallet with the tie-down rings installed. Figure 54 shows a view of the box upper assembly with the 24" x 24" utility panel opening, where figure 55 shows the lower assembly with attached gussets ready for mounting to the pallet.

Figure 53. Corner of Pallet with Tie-Down Rings

Figure 54. Container Upper Assembly

Figure 55. Container Lower Assembly

e. Prototype #1 Testing and Evaluation

On 9 February 1968, the first prototype of the personnel shelter was delivered and erected at the Northfield, Minnesota plant of the subcontractor. The erection was carried out in -10° F weather, and required eight manhours with a four man crew. Some problems became evident as the erection procedure was carried out. Accordingly, the shelter was brought back to the shop to rework major difficulties.

The chief concern was in the area of delamination of the foamboard skin near score lines. Thermal cycling was suspected as a cause, but was disproved by later testing. Corrections made on the unit included:

1.) Addition of aluminum skins to bottom of floor panels to decrease deflection.

2.) Endwall was cut down to provide better fit to the foamboard shell.

3.) Neoprene strips were fabricated to seal the floor-to-sidewall and floor-to-endwall joints.

4.) Blackout curtains were attached to endwalls to cover window and door glazing.

5.) Tie down rings were installed in center section so all loose items could be secured during shipment.

6.) Aluminum angles were attached across one end of center section to facilitate access to top of shelter.

7.) Long "oval" bearing pads were installed on floor jacks along center hinge line to reduce stability problems encountered with the round design.

8.) Worn flashings were replaced and sharp edges filed to prevent recurrence of the problem.

9.) Operating cautions and instructions were stenciled on the structure at key points.

Figure 56 shows the shelter before erection after a cold soak and figure 57 shows the shelter being erected. Figure 58 shows flexible plastic heating duct in place inside the erected shelter.

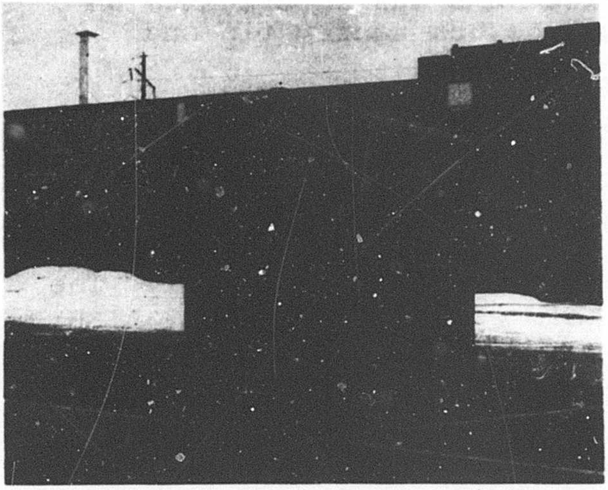


Figure 56. Prototype #1 Prior to Testing

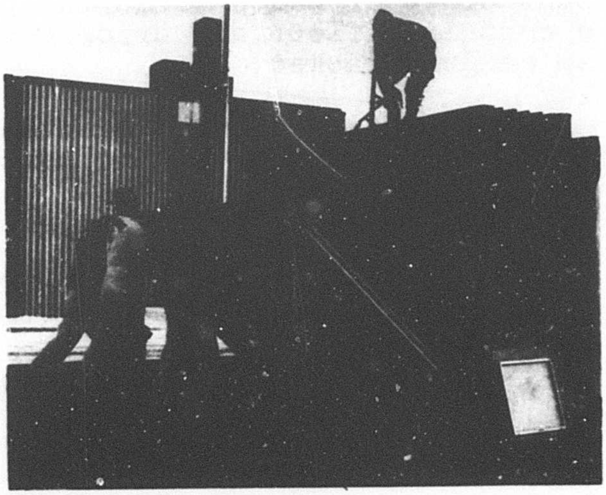


Figure 57. Erecting Prototype #1

Figure 58. Heating Duct in Place

On 26 March 1968, the shelter arrived at Eglin Air Force Base for testing by the Red Horse Squadrom at the climatic hangar. Initial observations were as follows:

- A deep, damaged area of the box edge angle was inflicted during shipment. Probable cause was a cable abrading this area.
- Several deep dents in the bottom floor skins were inflicted.
- Paint on the shelter exterior was abraded. Investigation of anodic finishes or analyn conversion coatings should be made.
- "Pop" rivets were used incorrectly in many locations on the shelter. A "D" ring was pulled off in transit.

The shelter was transported one mile by forklift to the climatic hangar test site. Since the temperature in the hangar was ambient with the exterior, the test was commenced immediately with a rain soak in the packaged mode for 1/2 hour. The rain cycle was stopped and the erection was started immediately. A small amount of water had entered the package and was in evidence on the container floor and dripped from the box center rib and beam hangar bracket.

The shelter was then erected by a four man novice crew. Time for erection was two hours or eight man-hours. Critical observations are listed below:

- The straps restraining the shell are too complex and numerous.
- The sidewall to floor fastener still works poorly. The elimination of tools for this skill would be advantageous.
- Shell handstraps work well but four on each quarter shell should be used.
- Design of tools provided is poor. Stock tools would be better but elimination of tools is optimum.
- Latching system for doors is poor. Honeycomb-core doors would also be desirable.
- Container-to-shell flashing boot should be longer and have continuous Velcro.
- The top of the roof beams should be covered with Teflon or Tedlar tape to prevent abrasions to the shell. Center joint of beam must be free of sharp edges that could snag foamboard.
- As endwall is folded, it should have a means of anchoring it to prevent flopping. This caused a loosening of the floor hinges.
- Angle at edge of box needs reinforcing to prevent deformation.
- Use of pop rivets should be very selective. Types used around endwalls caused leaks. Generally, the expanded portion is too small and pulls through the material being fastened. Frequently, the mandrel falls out and allows the connection to leak.
- Horizontal shell joint between roof section and sidewall leaks. Adhesive on tape may be the problem.
- "D" rings on box are inadequate - use two at each end.
- Construction of box (attachment of angle to Q-deck) should utilize fully welded (or epoxy potted) seams. Caulking used proved to be only cosmetic and didn't stop leaks.

Generally, it was felt that the design was simple and the erection procedure was easily accomplished by untrained personnel. Figures 59 through 65 show the shelter being erected at Eglin, and figure 66 shows delamination blisters on the foamboard shell.

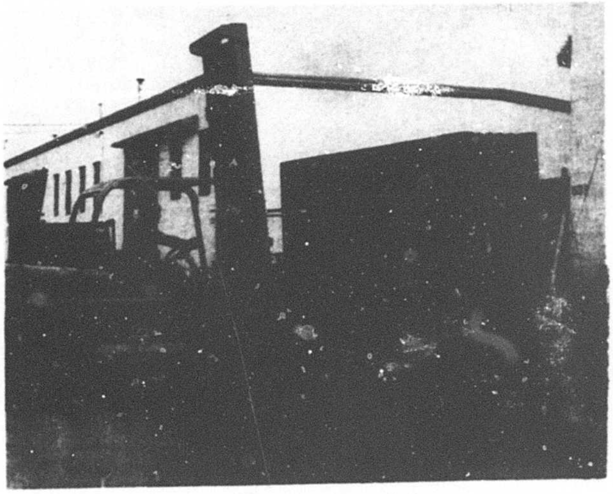


Figure 59. Transporting Prototype #1

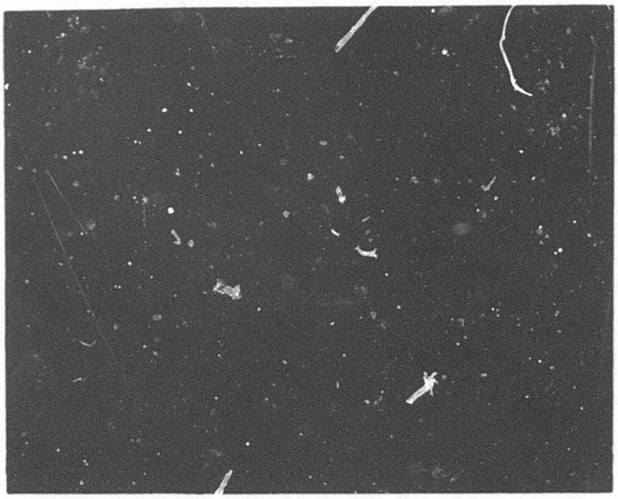


Figure 60. Rain Testing: Climatic Hangar

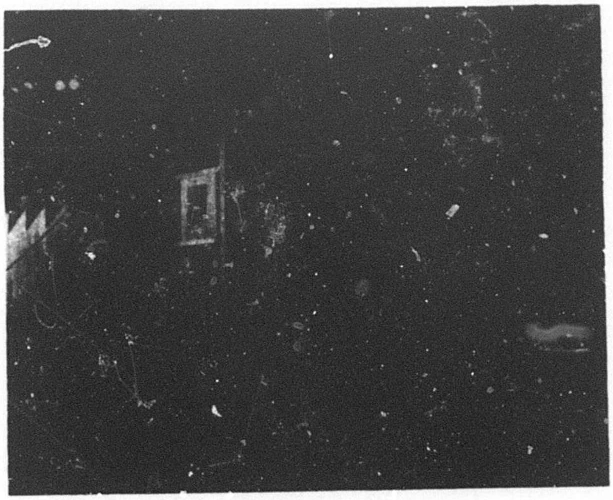


Figure 61. Lowering Floor Segments

Figure 62. Leveling Floor at Endwall

13'x 35' PERSONNEL SHELTER
TESTING AT CLIMATIC HANGAR - EGLIN AFB

Figure 63. Assembling Roof Beams

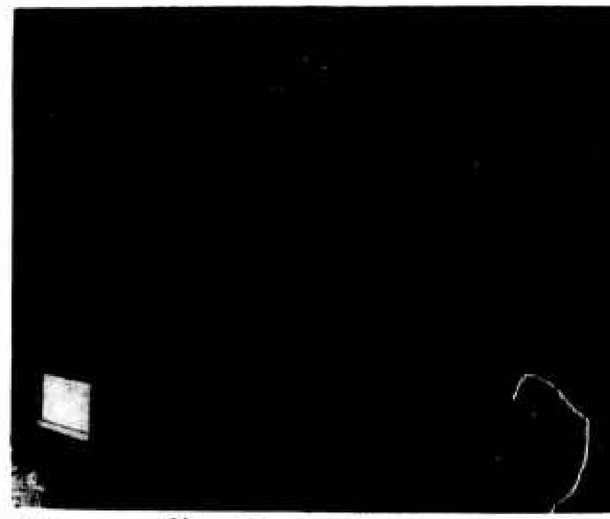


Figure 64. Expanding Foamboard Shell

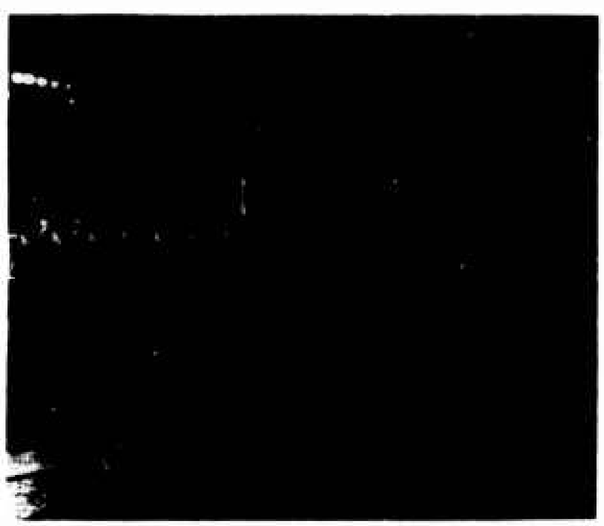


Figure 65. Completely Erected Shelter

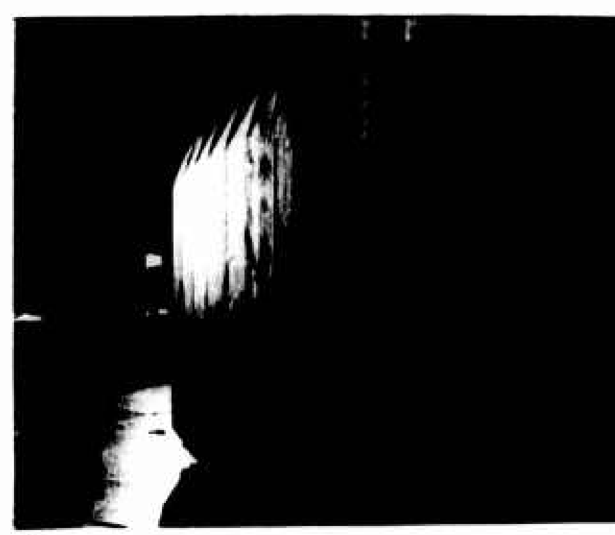


Figure 66. Delamination Blisters on Foamboard Sidewalls

13'x 35' PERSONNEL SHELTER
TESTING AT CLIMATIC HANGAR - EGLIN AFB

3. Improved Prototypes Development

a. Experience realized from the first prototype was applied to the design drawings for the succeding three prototypes. The most crucial area of concern was still in regard to foamboard. Consequently, U.C. and G.T.S. representatives made investigations of foamboard alternatives and possibilities with the Celotex Corporations' home office in Tampa in an attempt to eliminate delamination.

One possible solution was in the area of water-blown foams. This would eliminate the freon gas within the board but would result in a less desirable "U" factor. Reservations were also expressed at the possibility of water vapor within the finished product that could also cause paper weakening.

Board run for prototypes II, III, and IV would have a higher degree of foam cure. This would be accomplished by slower feed speed and higher oven temperatures. The skin material was essentially similar to prototype I, the basic difference being that the exposed face was a PVC film laminated to the foil rather than a thin PVC coating. This vinyl formulation was high-impact resistant to avoid the cracking previously experienced.

As part of the redesign effort toward new prototypes, extensive re-analysis of the entire structure has been made to insure its integrity in the packaged mode, that is, it must withstand the "8G" critical aircraft crash loading. The analysis showed that the prototype I design was inadequate in the area of the box, rib, and roof beams. This changed the nature of the design for these components considerably.

The box became an integral bonded assembly of aluminum skin sandwich panels, the rib required extensive reinforcement, and the beams became built-up box structures from aluminum sheet. As learned from the previous prototype, the floors required an aluminum skin-sandwich panel with paper-honeycomb cores.

The re-design became most apparent at the center-core box. Starting at the pallet, the fork-lift holes were increased in depth to allow safe entry. All corners of the bonded assembly were sealed by potting with epoxy. Folding step-units were designed into end panels and the roof (as hand holds) see figure 67. Large tie-down rings were also provided on the exterior and on the pallet/floor for tiedown of contents. The structural redesign also necessitated two welded gussets at the top of the box (each end), and six gussets at the bottom corner of the box (each end). See figure 68. The center-rib in the box continued to utilize plywood, but an aluminum channel was added to the bottom as a tension member. The electrical system in the box was also revamped with exposed conduit on the interior panel face.

Floor operation was improved by the use of a single piano-hinge rather than the less reliable offset hinge used in prototype I. This was allowed by the changing of the end wall hinging

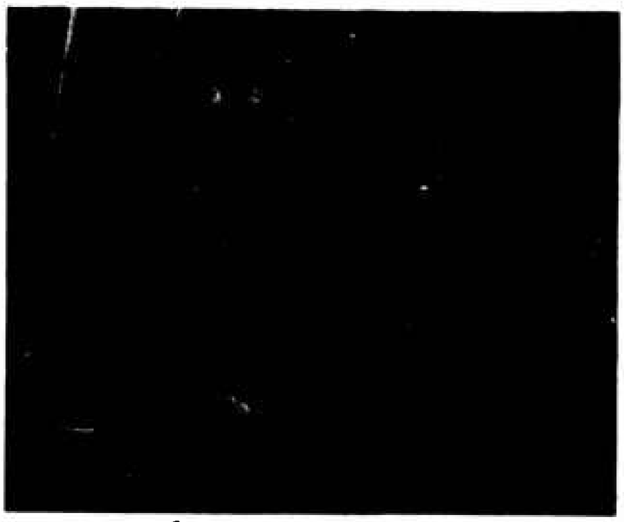


Figure 67. Folding Step Unit on Box Exterior

Figure 68. Gussets on Container Interior

from the prototype I design. The edges of floor panels were closed out with an equal leg angle set at 45° to meet the sidewall. Captive quarter-turn fasteners were attached to the angle and engaged oblong gromets in the close-out channels on the foamboard (see figure 69). Floor panels were supported by 16 cast-aluminum jack supports placed at the center hinge line and along the end wall (figure 70).

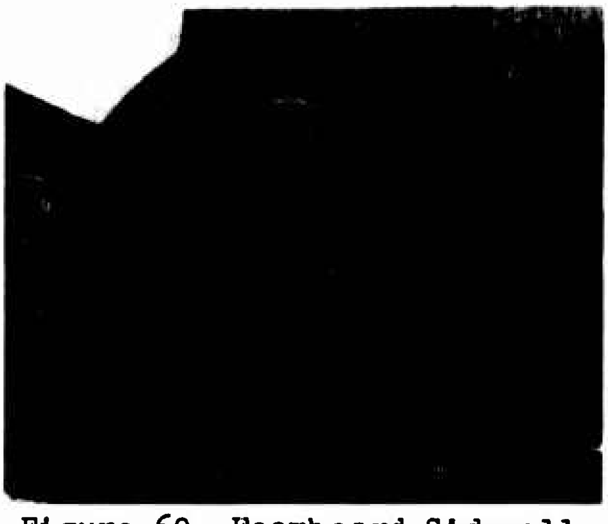


Figure 69. Foamboard Sidewall to Floor Connector

Figure 70. Aluminum Supporting Jack

The roof-support beams were wired to allow integral lighting rather than a separate loose system as in prototype I. Again the beams were adjustable in length to allow for irregularities. Each beam plugged into the center-core box rib by a single plug (figure 71).

Figure 71. Beam Connections at Center Rib

The foamboard-shell-sidewall to center core box connection was made with a vinyl-channel material that has shown great promise. The material is extruded around continuous perforated flat steel strips, then rolled into the channel configuration. When attached to fabric flashing, the closure can be snapped over continuous projecting edges with strengths around 30 pounds per inch width at 90° angle-of-pull.

End walls were redesigned to use windows with self-storing glazing and screens. Becuase of cost limitations, it was felt that a stock aluminum door was still in order even though it was less desirable than a "special item" because of heat loss. Structural extrusions were bonded into the end wall and a fiberglass skin sealed the panel. The end walls are loose rather than factory hinged.

b. Construction of prototypes II, III, and IV proceeded with no serious problems. The center core box sections required re-work after the structural re-analysis. Aluminum skins were bonded to the panels after inserts were placed for attachment areas.

The roof beam design proved to be too expensive for mass production. The beam was very light in weight and extremely efficient but did suffer from durability problems. Sheer plates had to be added at the hinge joints.

Because of the above-mentioned problems and related developments in manufacture of the foamboard shell, the delivery of the last three prototypes was delayed and greater expense was incurred than had been anticipated. The completion of all prototypes was, therefore, terminated at the convenience of the government. Delivery of these prototypes was accepted with prototype II 95% complete and prototypes III and IV 50% complete.

After substantial deliberation, it was decided that prototype II was sufficiently complete to allow modified testing of overall concept and detailing. Prototype III would be completed by AF technicians utilizing experience gained by the evaluation of prototype II, and design fixes developed by this office for the planned quantity procurement. This latter shelter would undergo the tropic jungle test program in the Canal Zone, Panama.

c. Prototype Testing and Evaluation.

Prototype II was erected and repackaged six times at WPAFB over a three month period after delivery. The first observation is in regard to the box construction. As mentioned previously, the critical nature of the box's structural design was brought to light. The temporary solution was to utilize the "Q-deck" material in sandwich panel construction by the addition of aluminum skins. There was, of course, and increase in the total shelter weight to 2600 pounds. If the maximum pay load for the Bare Base mission is 28,500 pounds, this allows 3166 pounds for each loaded shelter and the allowable weight for contents is only 566 pounds.

The following observations were also noted:

- Jacks should be built into the box for leveling.
- Internal components should be re-organized.
- The floor leveling jacks should allow for greater variation.
- Sidewall to folding-floor joint needed restudy.
- Floor outlets should be examined to study seals.
- Velcro at endwall should be restudied.
- The positioning of the endwall in the slot at the outboard floor is difficult. Consideration should be given to hinging the endwall permanently in lieu of a loose end wall.
- The end wall fit with the shell is poor. More clearance is required.
- The hand holds bonded to the foamboard shell work well but additional ones would facilitate erection in high wind.
- A better door design is still required. The flush latch hardware was inadequate in regard to durability and ease of operation.

In September of 1968, the tropic test of the personnel shelter prototype III and the utility shelter prototype I was conducted in the Canal Zone, Panama. This prototype (III) was completed and modified with the intent of evaluating three critical areas.

Since there were some problems encountered with the foamboard shell material, it was felt that a durable coated-fabric fly over the shell would present an effective temporary solution. On one end of the shelter, the standard fabric boot flashing was installed, while the other end was covered with a MIL SPEC neoprene-coated nylon facric, type I, class III. This fly covered the entire shell from box to endwall.

The shelter was also fitted with 16 two-ton Heine-Warner scissors jacks. It was felt that an extremely desirable leveling range could be obtained by utilization of such a design. Figures 72, 73, and 74 show a mock-up of the design developed. The maximum and minimum extensions provided all the capability that would be needed. The jacks used in the test did not have the larger base plates that were required.

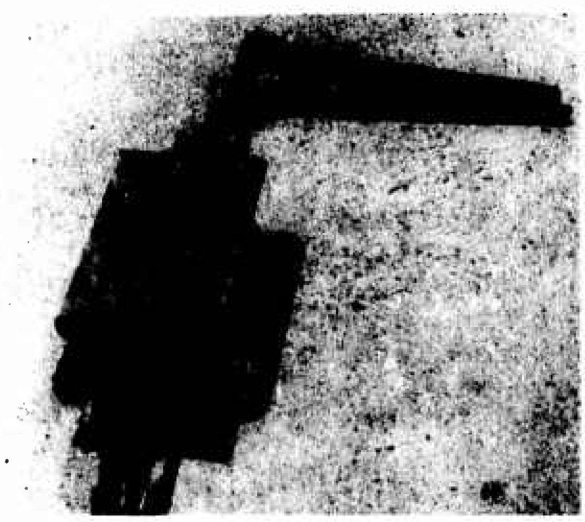


Figure 72. Support Jack with Operating Tool

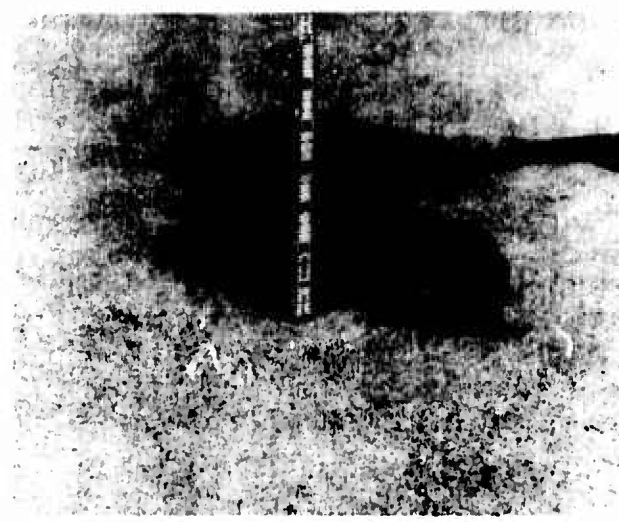


Figure 73. Minimum Jack Extension

Figure 74. Maximum Jack Extension

Lastly, the vinyl edge extrusion proposed to hold the shell in place around the box, floors, and around the end wall was evaluated. The material could be best utilized if a nylon-supported vinyl flap were heat sealed to the channel to facilitate attachment of flashing.

The test was carried out during the rainy seasons and the earth was poor in bearing for this test. Nevertheless, the jacks satisfied the leveling requirements with only minimal difficulty. The vinyl-edge extrusion closure worked well and was specified later for procurement, The fabric fly was also utilized with little or no difficulty.

The complete Panama Test Report is included as Appendix "C". Weather data is enclosed also which show temperature differentials between ends of the shelter (fly covered versus uncovered).

This completed the active phase of environmental testing of the BBPS but the shelter prototypes II and III remained at WPAFB for indefinite testing under the ensuing winter conditions. Both BBPS prototypes and prototype I of the General Purpose Shelter were erected at the top of the accelerator runway. This has proven to be an area of severe wind conditions and the constant wind vibration might induce fatigue.

Prototype II was set on the low aluminum jacks originally provided. The center-core box was anchored to the earth at four points. Prototype III was set on the modified scissors jacks and the box was set on wood skids to raise it to an optimum position for jack operation. This shelter was not anchored to the ground.

On December 31, 1968, the shelter prototype III was destroyed when 38 knot winds were experienced. This was attributed to the failure to tie the shelter down securely. As the wind loading increased, the shelter moved or twisted on the extended jacks and then the latter tipped over dropping the floor sections and breaking the segmented vinyl-edge extrusion joint. This released the foamboard shell which, acting like a sail, ripped the shelter apart. End walls were then lifted from the floor edge channel and, as the bottom kicked out, the roof beams were distorted and failed.

The important lesson learned from the incident was that a shelter such as this must be securely anchored to the ground at specified points to prevent up lift. The need for this is further emphasized because of the airspace created beneath the floor segments. Figure 75 shows the destroyed shelter at WPAFB.

Figure 75. Destroyed Prototype III at WPAFB

4. Production of Procurement Drawings

Testing of prototypes II and III demonstrated clearly the value of the BBPS concept. The development was judged to be sophisticated enough to allow procurement of a significant number of demonstration production models. It was felt that the most useful procurement drawing package would utilize a set of drawings that described prototype III with some further modification to reflect true mass production design solutions.

Significant redesign was carried out in the area of center section construction, pallet elimination, roof beam design, floor-endwall folding procedure and flashing-fly cover design. After re-analysis, the estimated weight was 2550 pounds.

The actual procurement package drawings were, by necessity, detailed conceptual drawings with complete suggested details. It was anticipated that with this procedure, the various bidders for the procurement contract will adapt, if necessary, the suggested techniques of joints and construction methods to their own techniques. This, coupled to a performance type specification, should produce the best, cheapest and lightest shelter.

Specific solutions finally developed and recommended are shown in figures 76 through 89. The center section box was designed to utilize panels of constant thickness (2") for roof, sidewalls, and the floor. The differing loads are handled by increasing the skin thicknesses. In general, most attachments to the box are surface mounted.

Floor panels are 1.25" thick, similar to prototype II but without plywood top surfaces. Close-out members on three sides of the panel are a common 1 1/4" x 1 1/4" aluminum channel while the fourth side is closed out with the continuous hinge member - thereby eliminating the hinge mounting operation. The same technique of hinge mounting is used at the endwall thus allowing the four floor segments to be identical.

Endwalls were redesigned to allow the use of a honeycomb core in lieu of Urethane foam. Integral 1" x 1" square aluminum tubing became the load carrying members in the wall. It was recommended that the convenience outlets be surface mounted conduit on the endwalls rather than loose "all weather cord" type provisions along the floor. The perimeter of the endwall would be closed out with a special aluminum extrusion that accepted the vinyl closure trim.

In consideration of the foamboard shell, it was noted in all testing phases that the material would have difficulty in satisfying the five year use life required (see section V-Foamboard Research and Development). Therefore, a fabric weatherproofing fly has been designed to cover the foamboard shell. It is intended that as the board becomes more sophisticated, this fly can be eliminated.

The final design for the roof beams allows a simple rectangular box section. The design allows the shell to expand across the side of the beam. In final load-bearing position, the beam is rotated 90°. This allows a deeper structural section yet also allows the beam to be inserted between the shell roof and sidewalls in the closed mode. Actual beam construction is from a common interlocking extrusion that can be assembled either by dip-brazing or mechanical fasteners. A one-piece extrusion could be used if a slightly heavier beam were acceptable.

The suggested design for the leveling/tie down system utilizes the scissors jack with modified top and bottom plates. When these jacks are extended 12 to 14 inches, they become unstable under high winds. This problem was alleviated by a stake-down system employed at the four outermost corners of the erected shelter. Although the system depicted is complex, it accomplishes its designated functions without extending outside of the shelter periphery. Leveling of the center section prior to erection is simply accomplished using the four jacks built into the box. The constant thickness panels for walls, ceiling, and floor of the box have allowed this as a permanent installation.

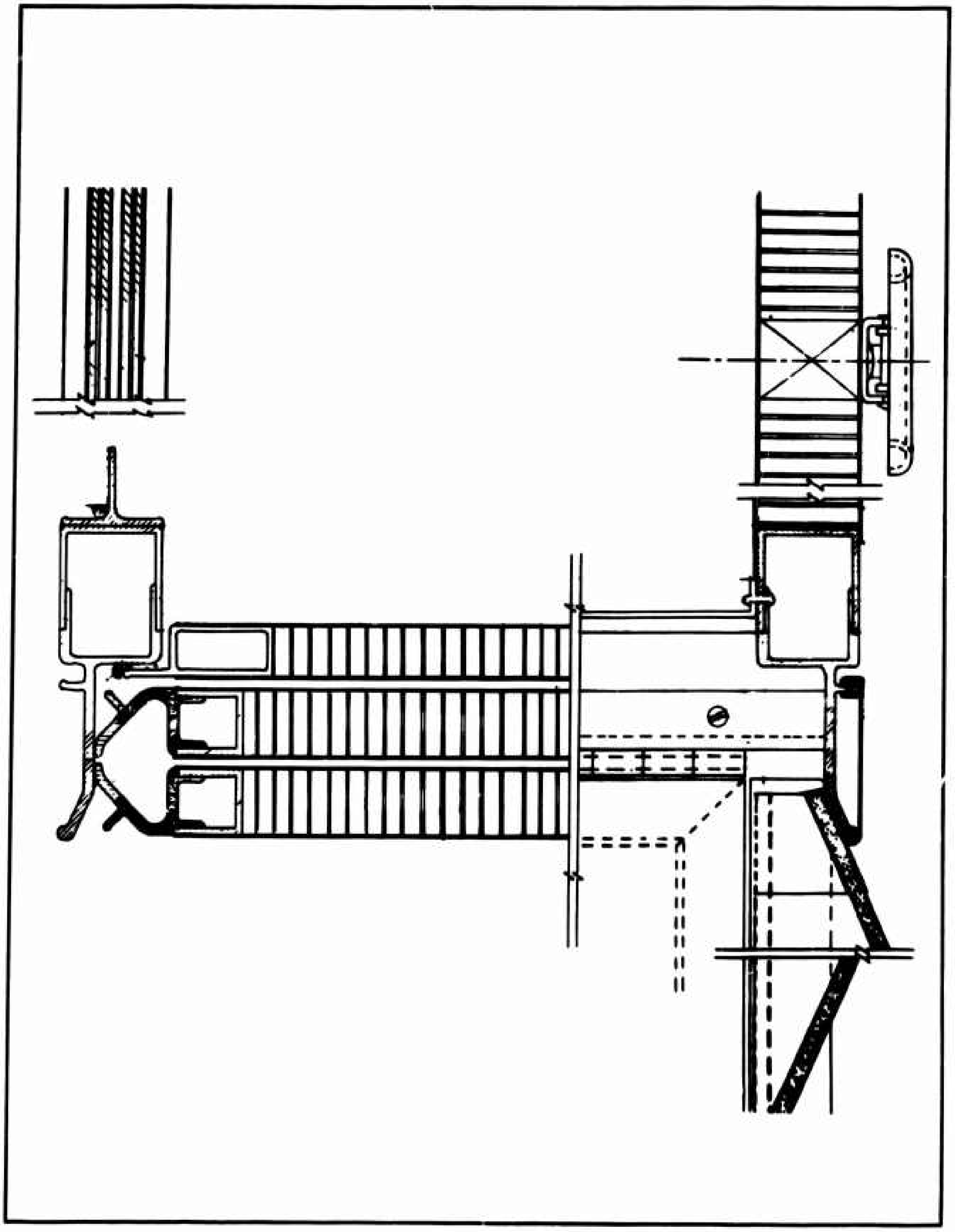


Figure 76. Horizontal Section Through Container

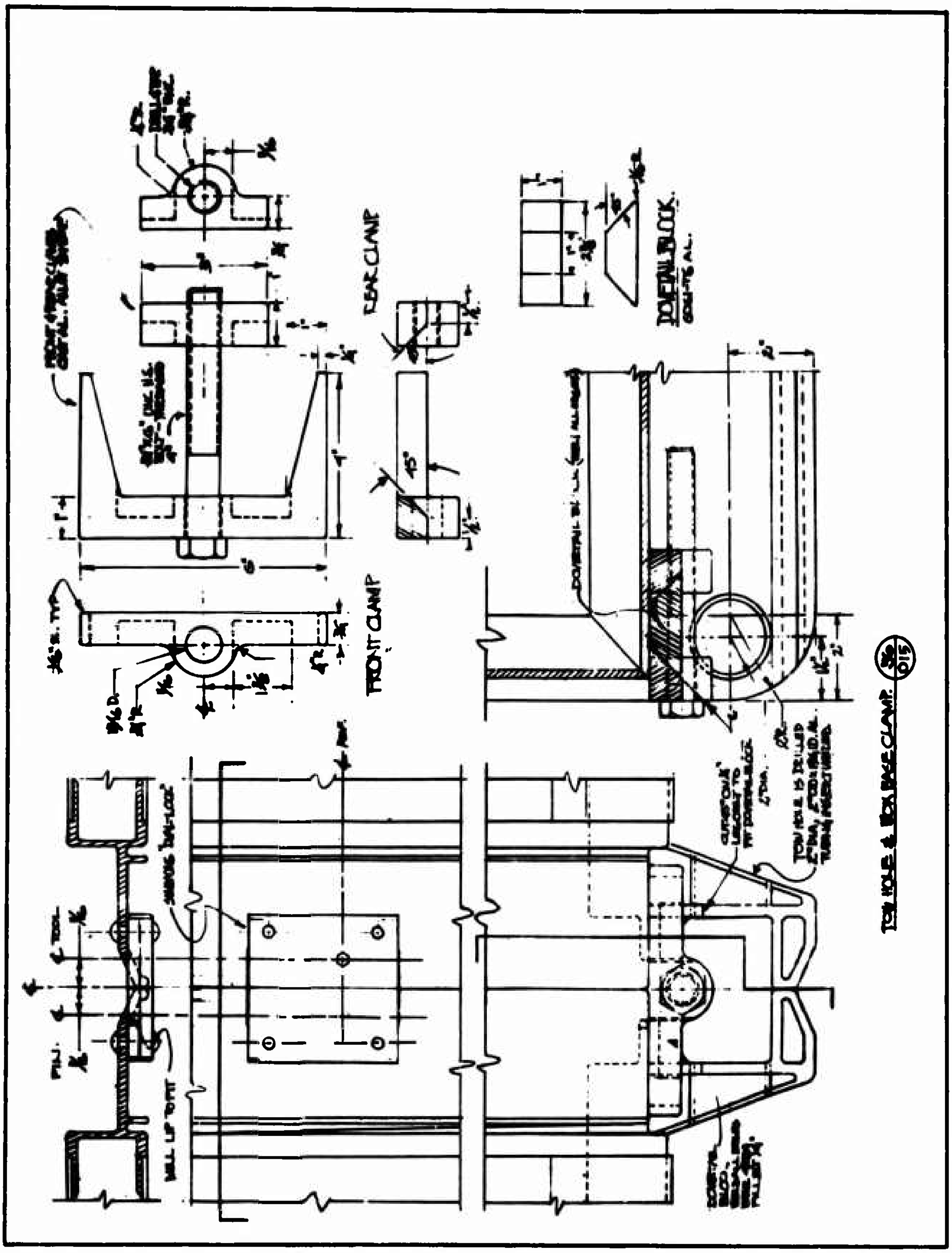


Figure 77. Box-to-Box Clamping Devices

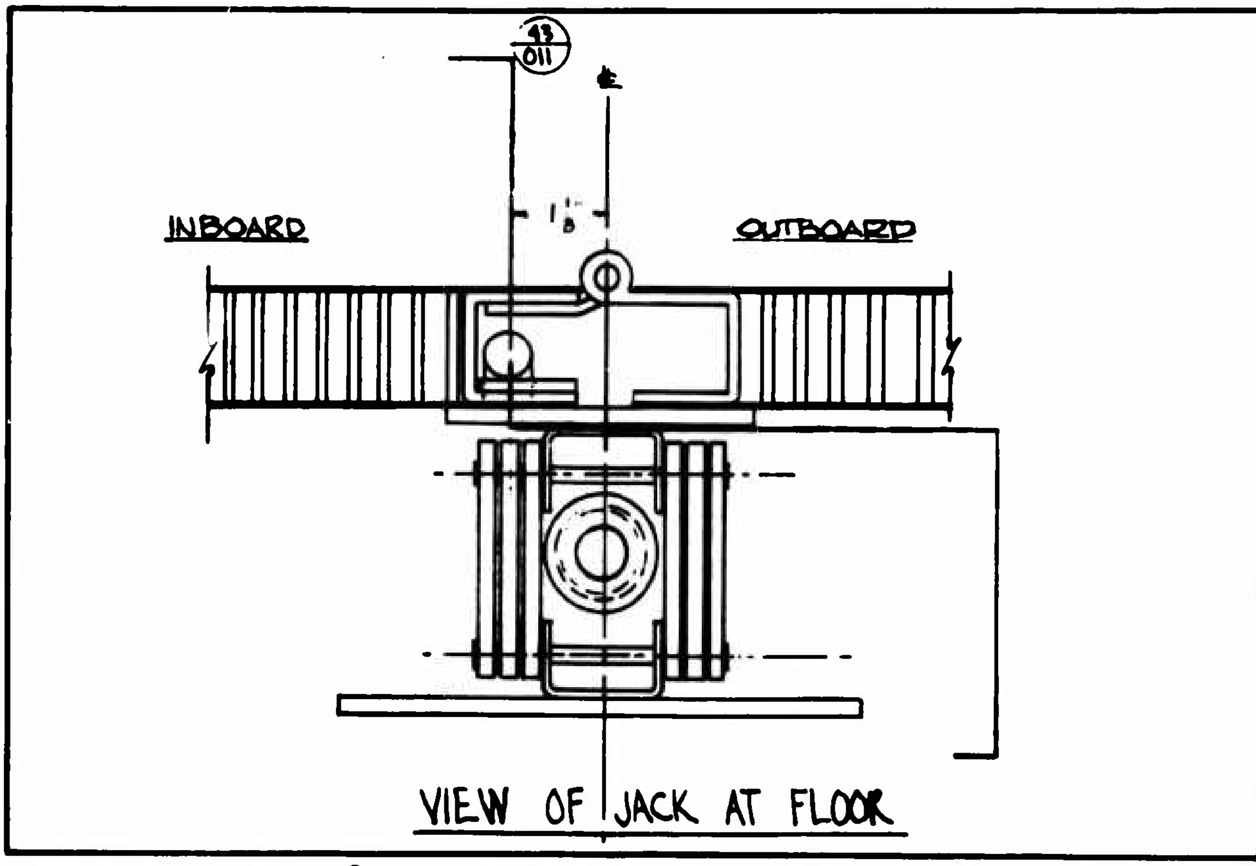


Figure 78. Support Jacks between Floor Segments

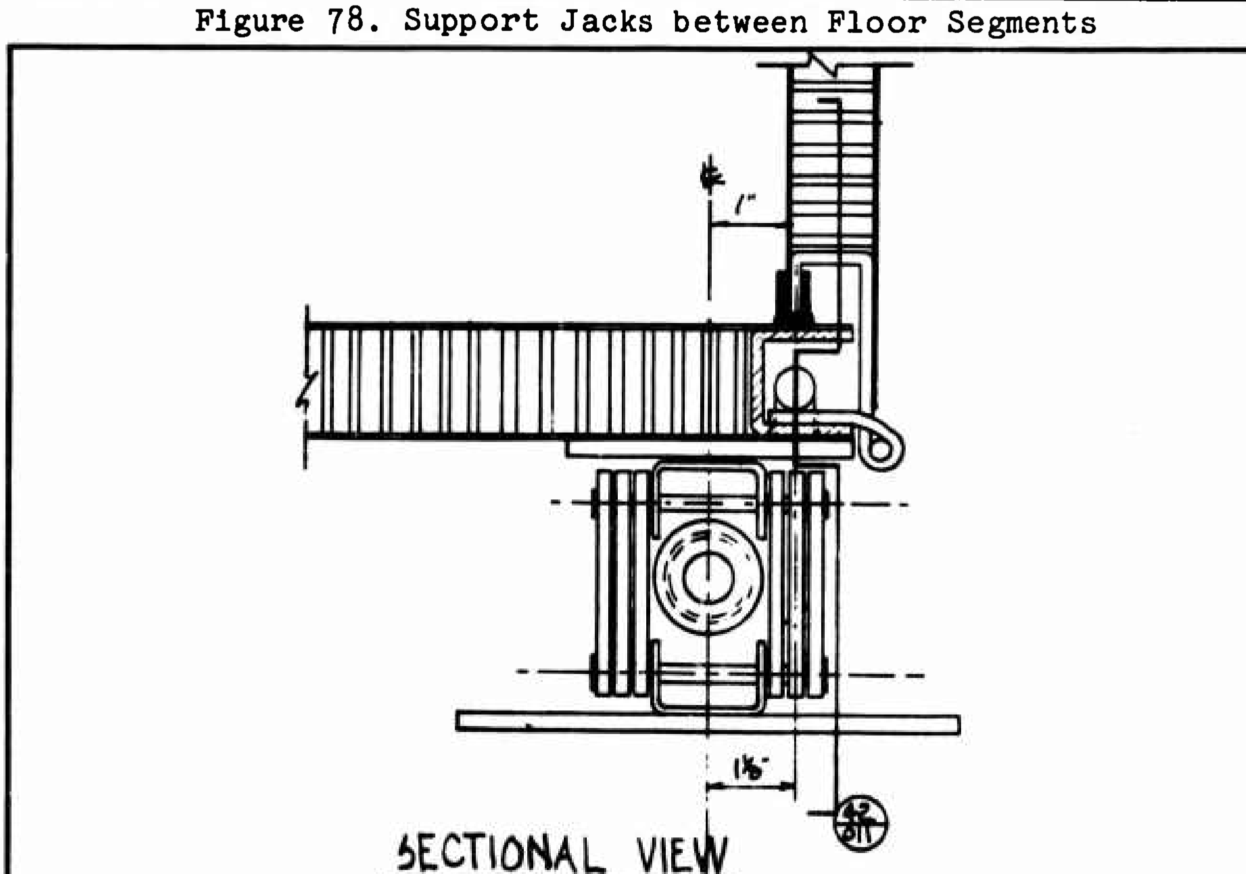


Figure 79. Support Jacks at Endwalls

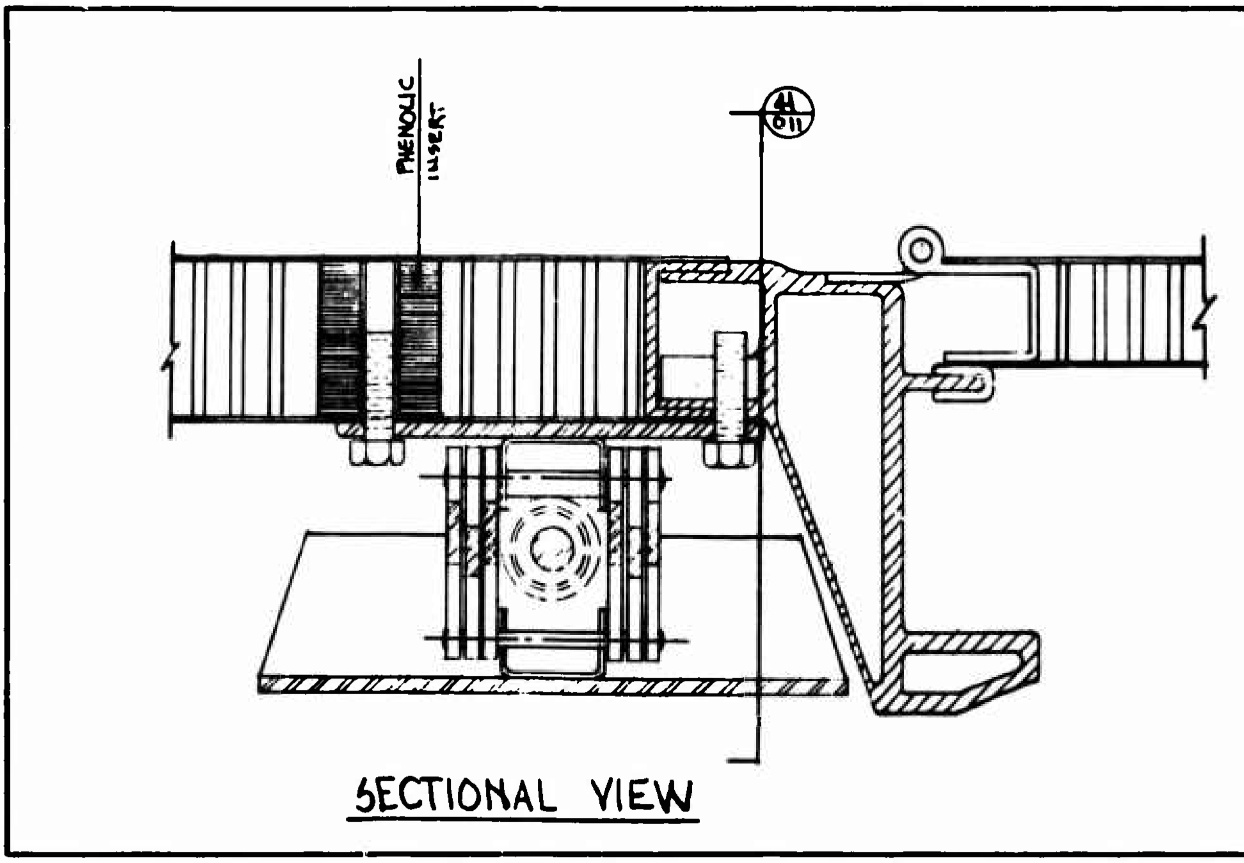


Figure 80. Support Jack at Center Section

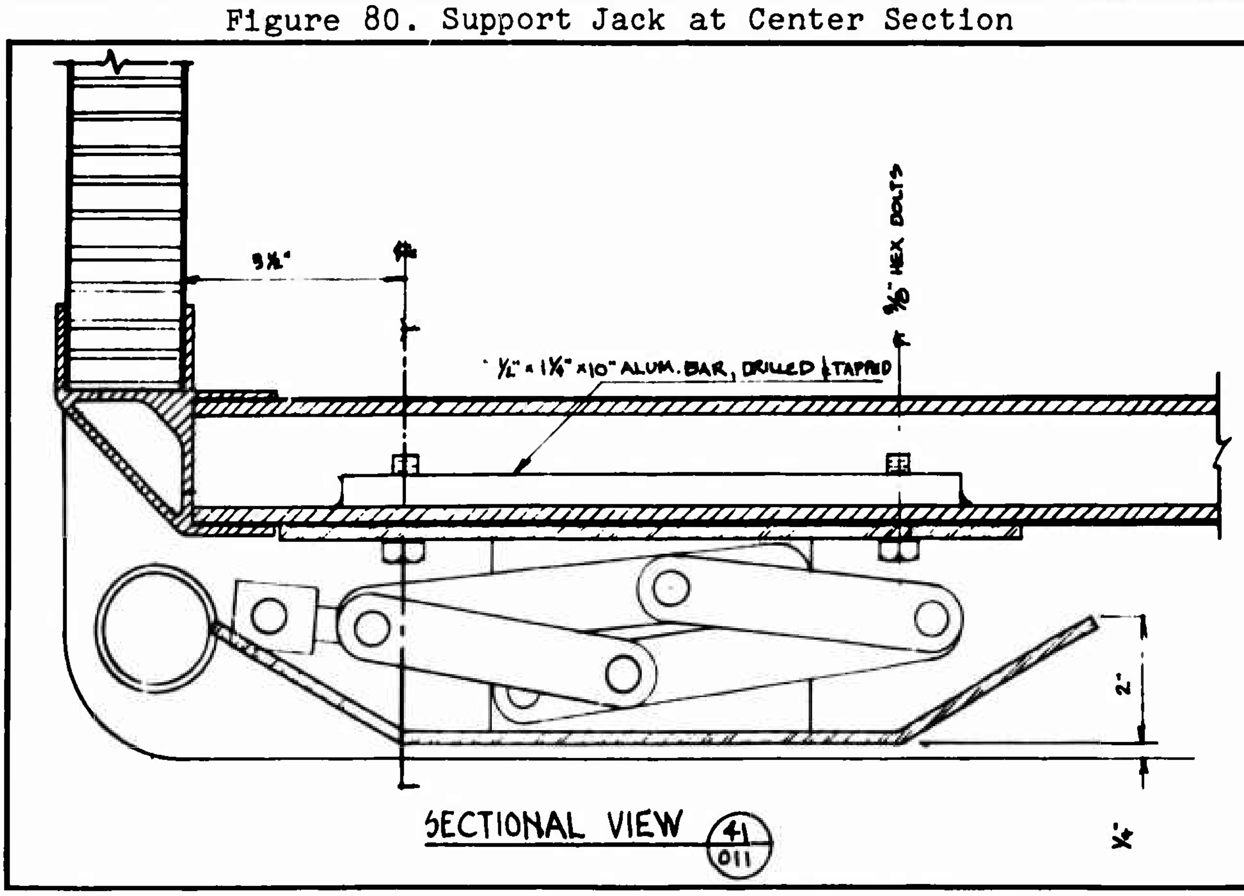


Figure 81. Support Jack at Center Section

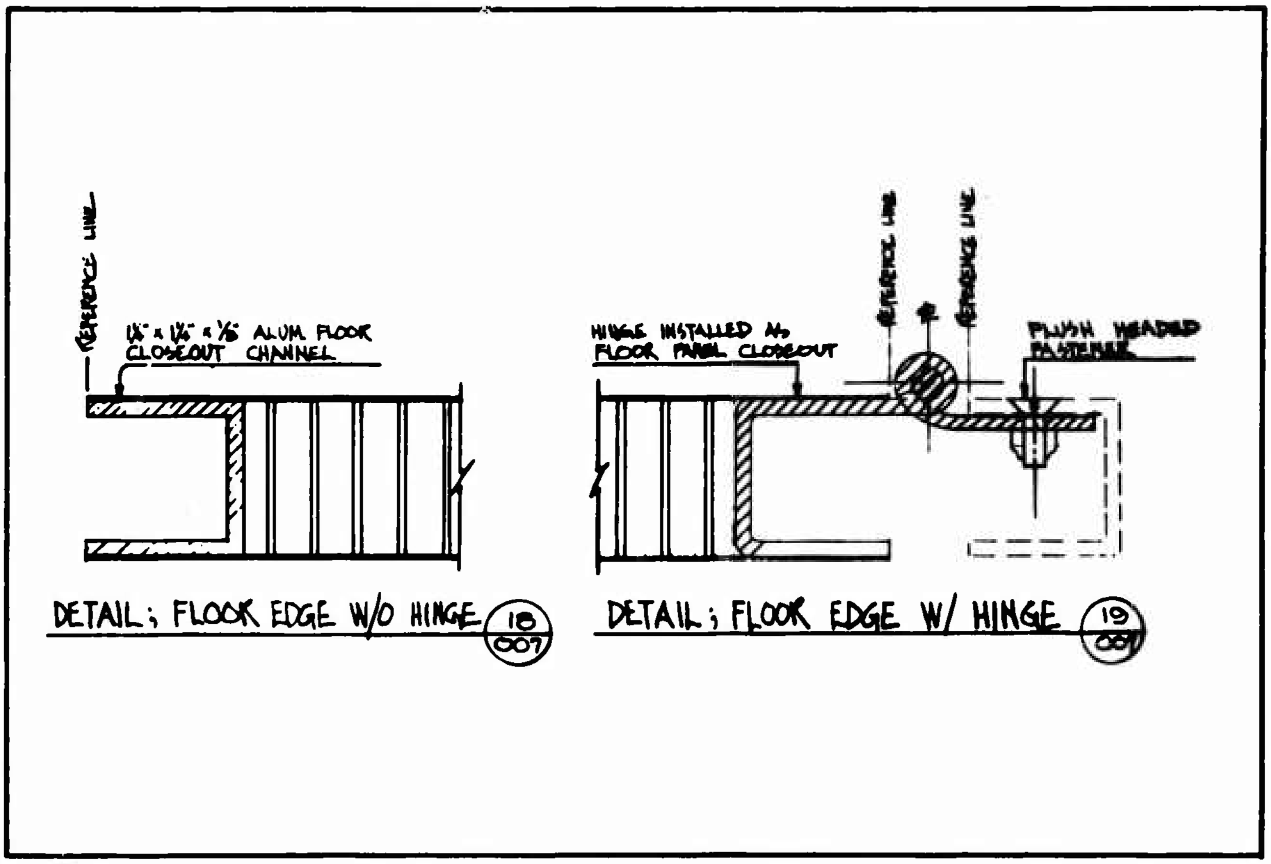


Figure 82. Floor Edge at Hinge Lines

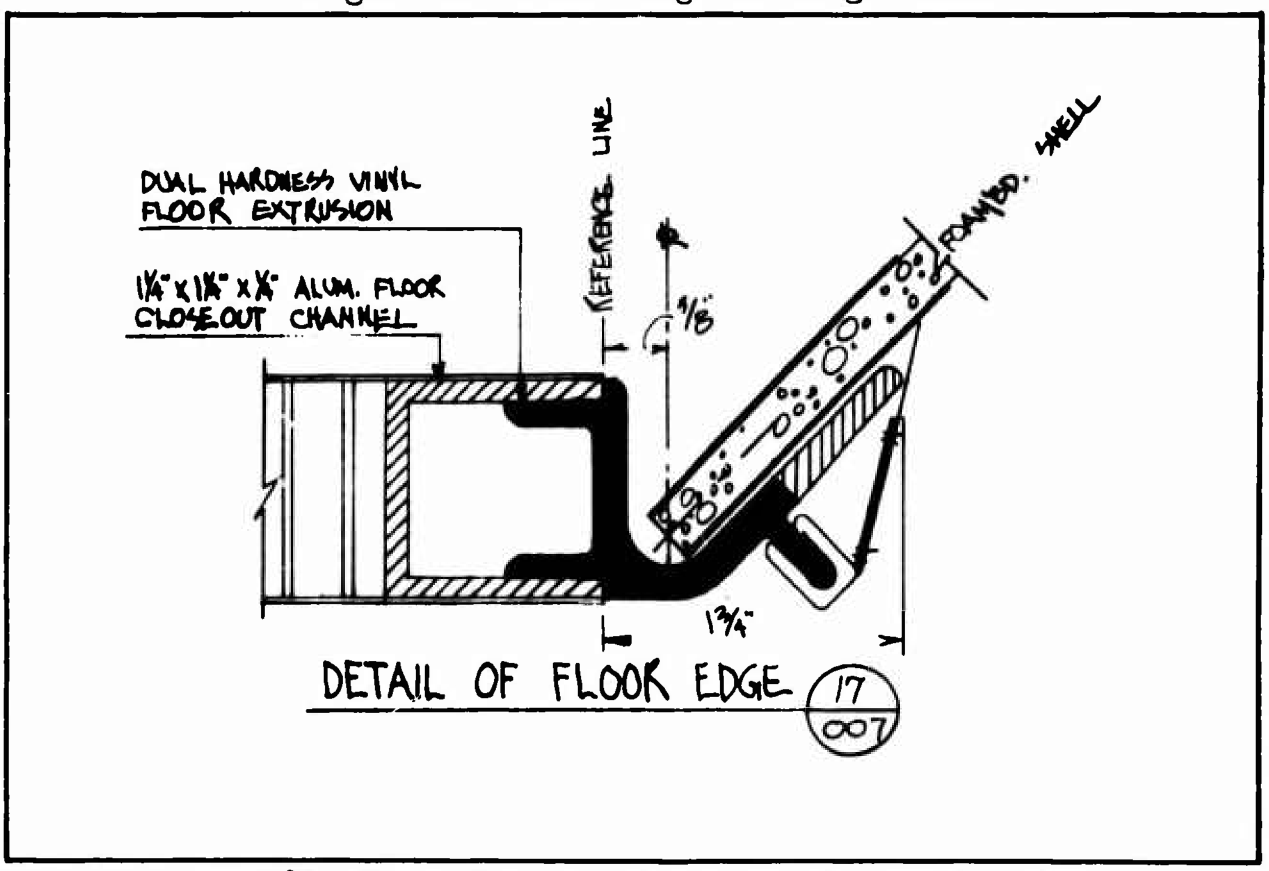


Figure 83. Floor Edge to Foamboard Sidewall Joint

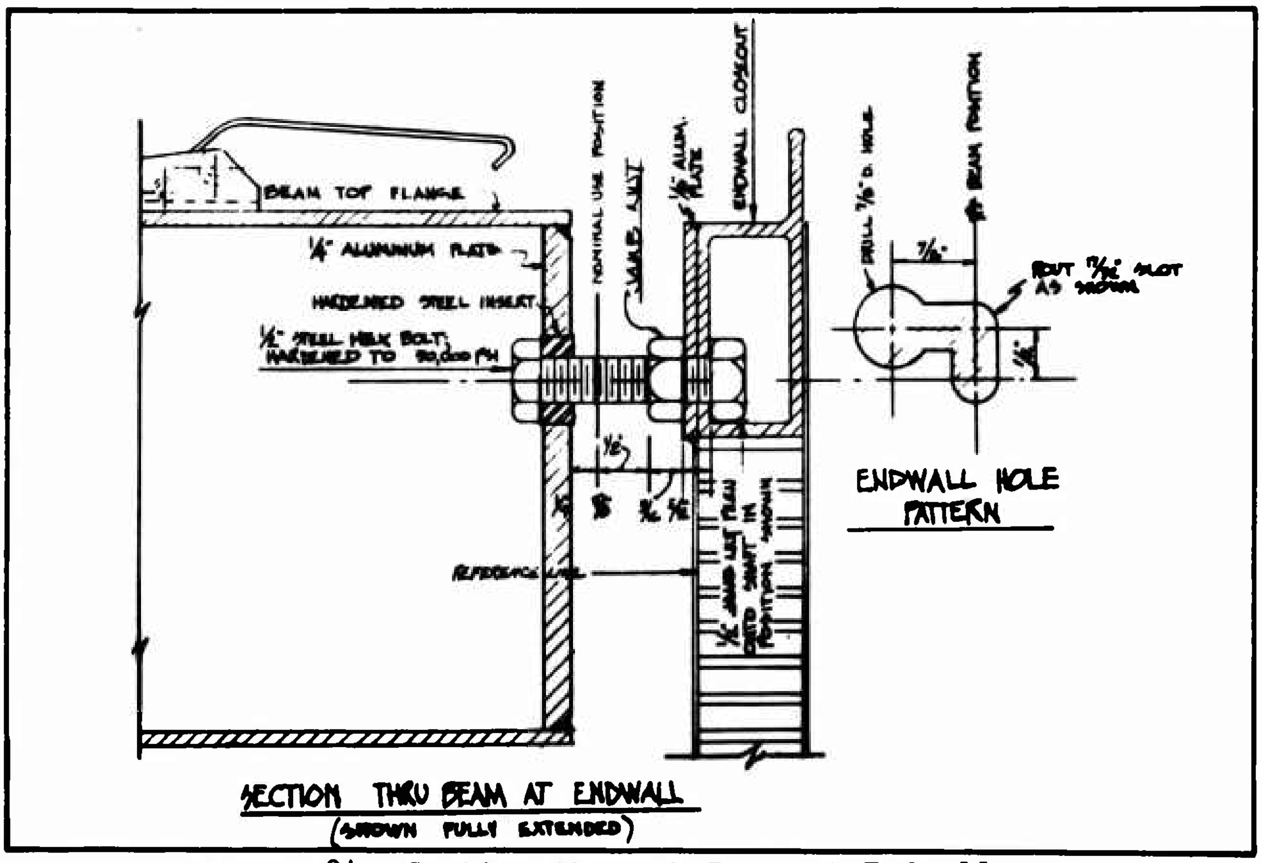


Figure 84. Section through Beam at Endwall

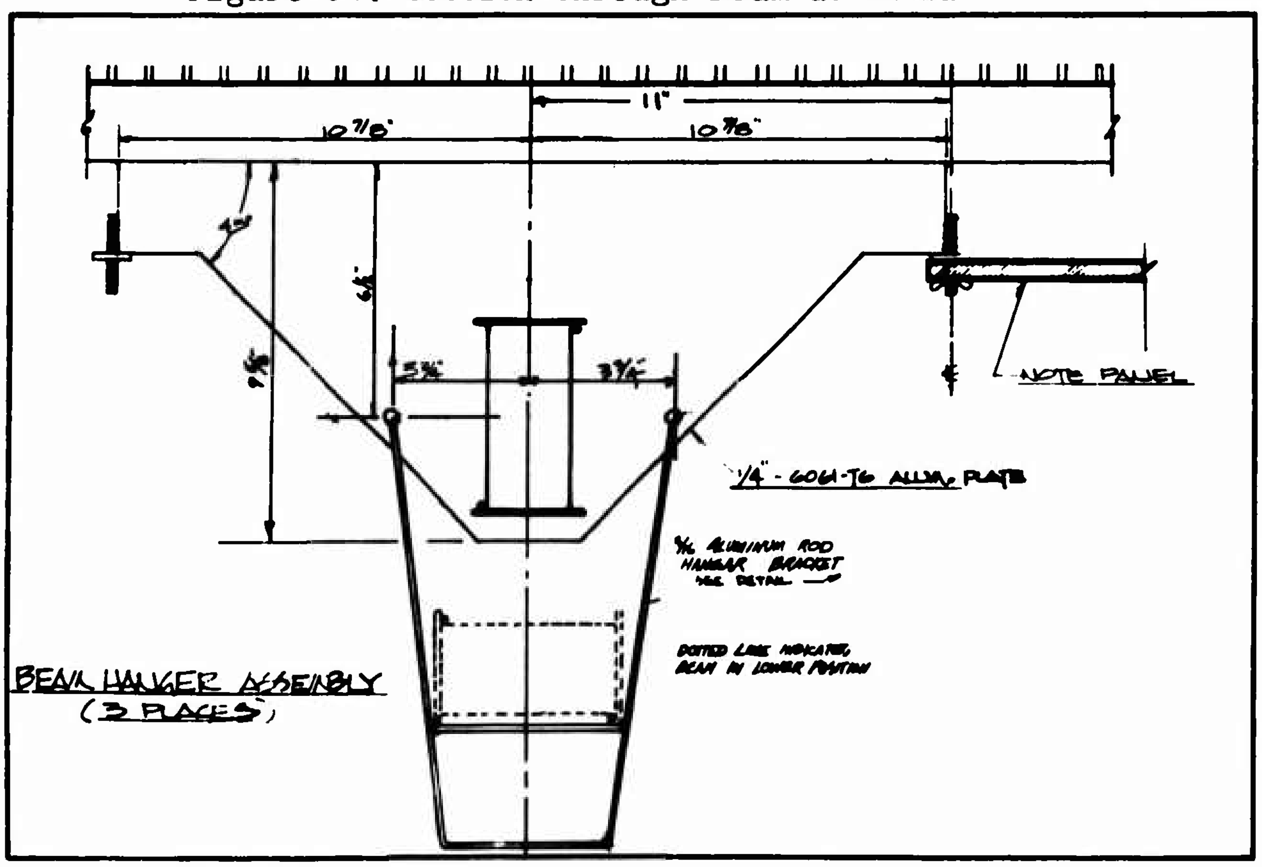


Figure 85. Beam Hangar Assembly

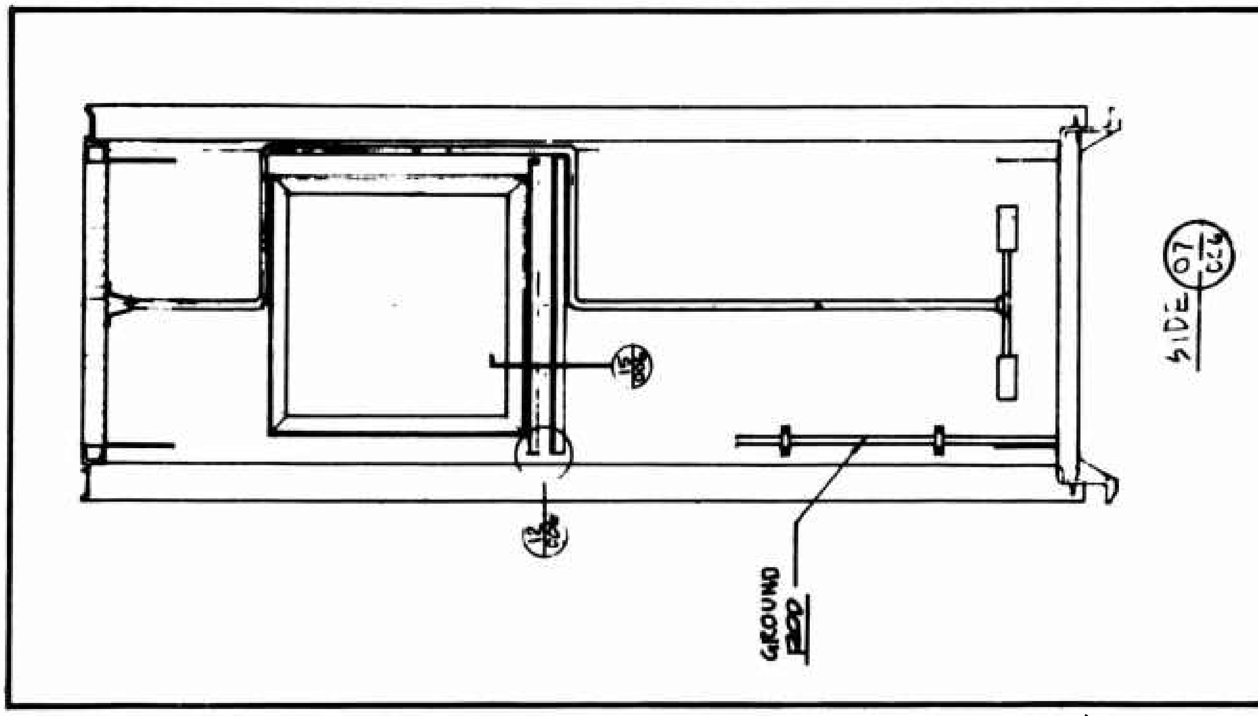


Figure 86. Container Interior (Utility Opening End)

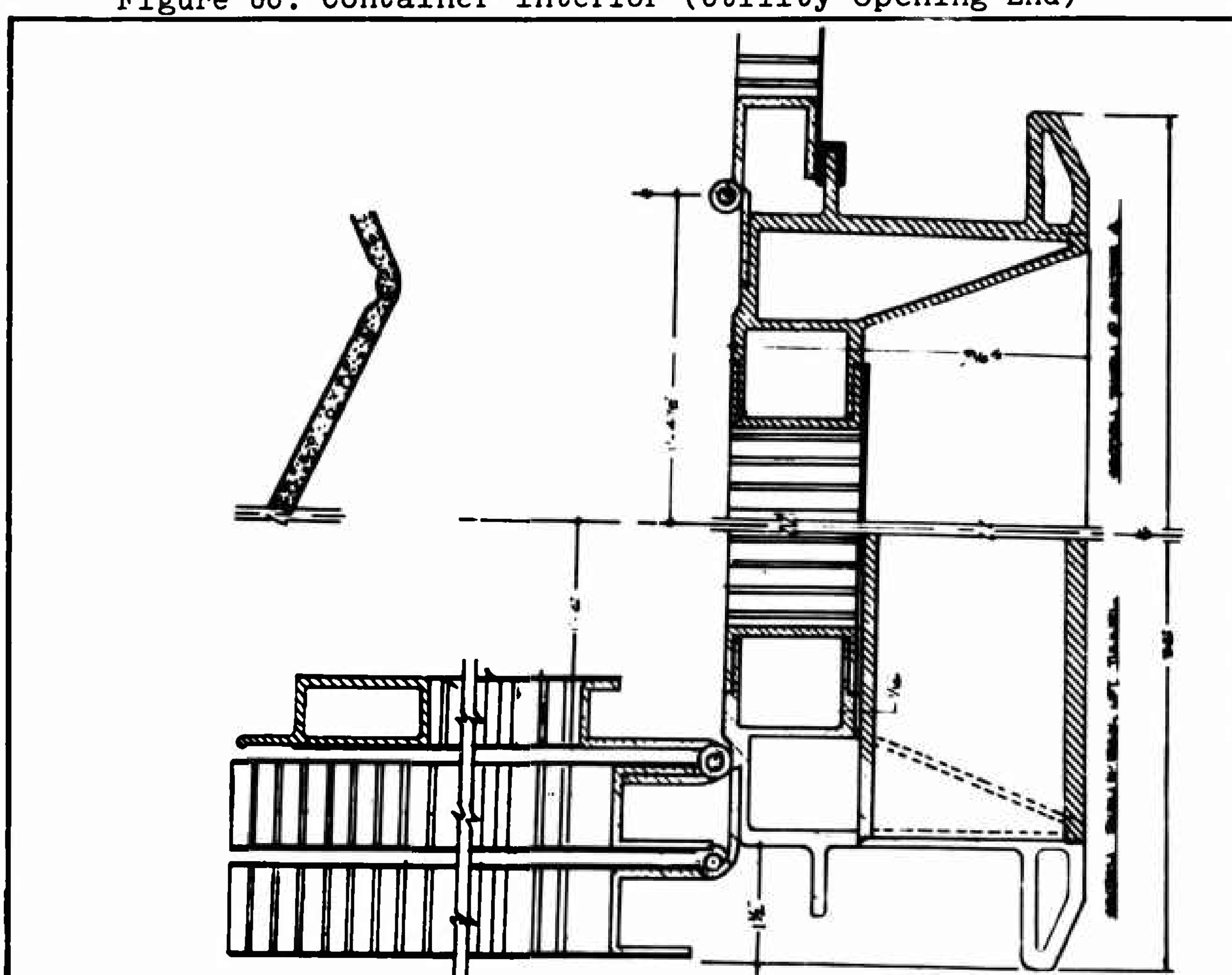


Figure 87. Vertical Section through Container

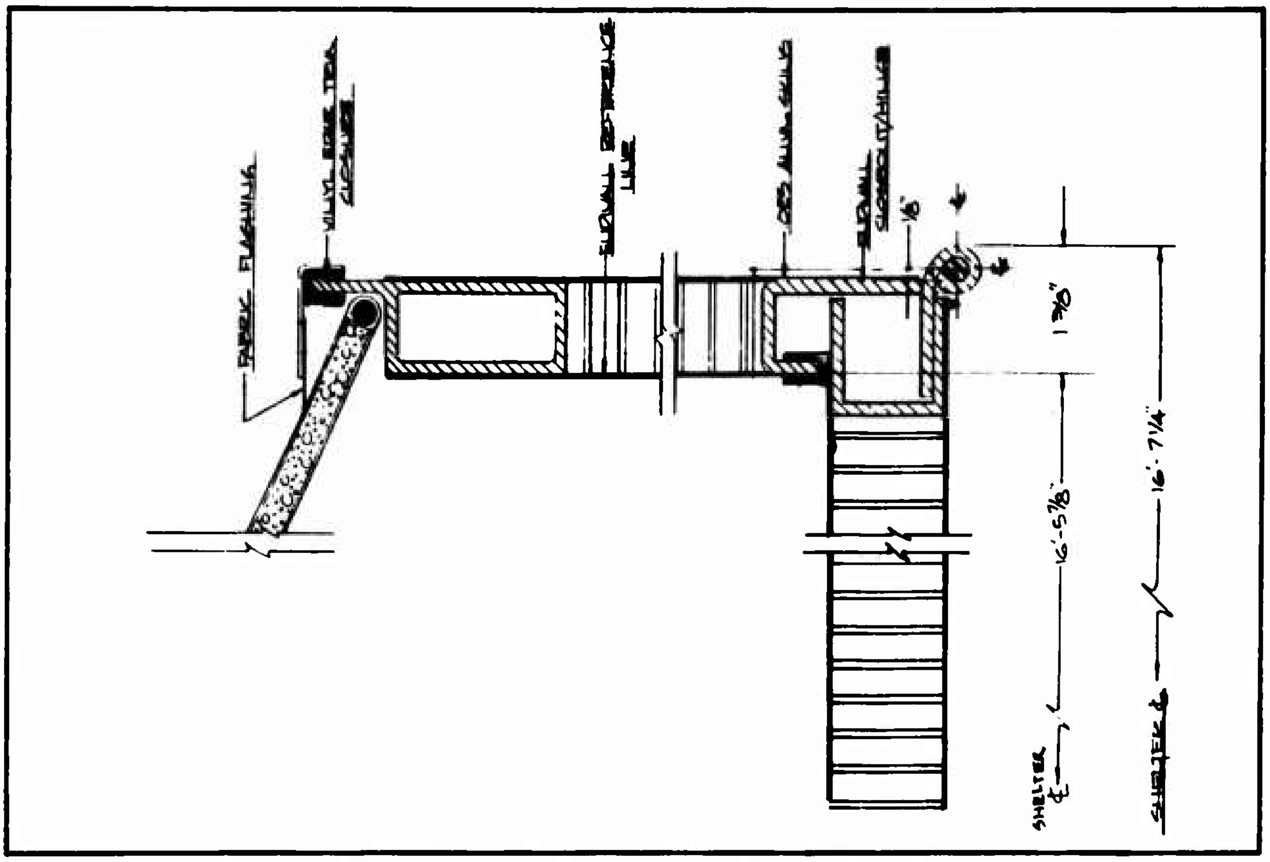


Figure 88. Vertical Section through Endwall

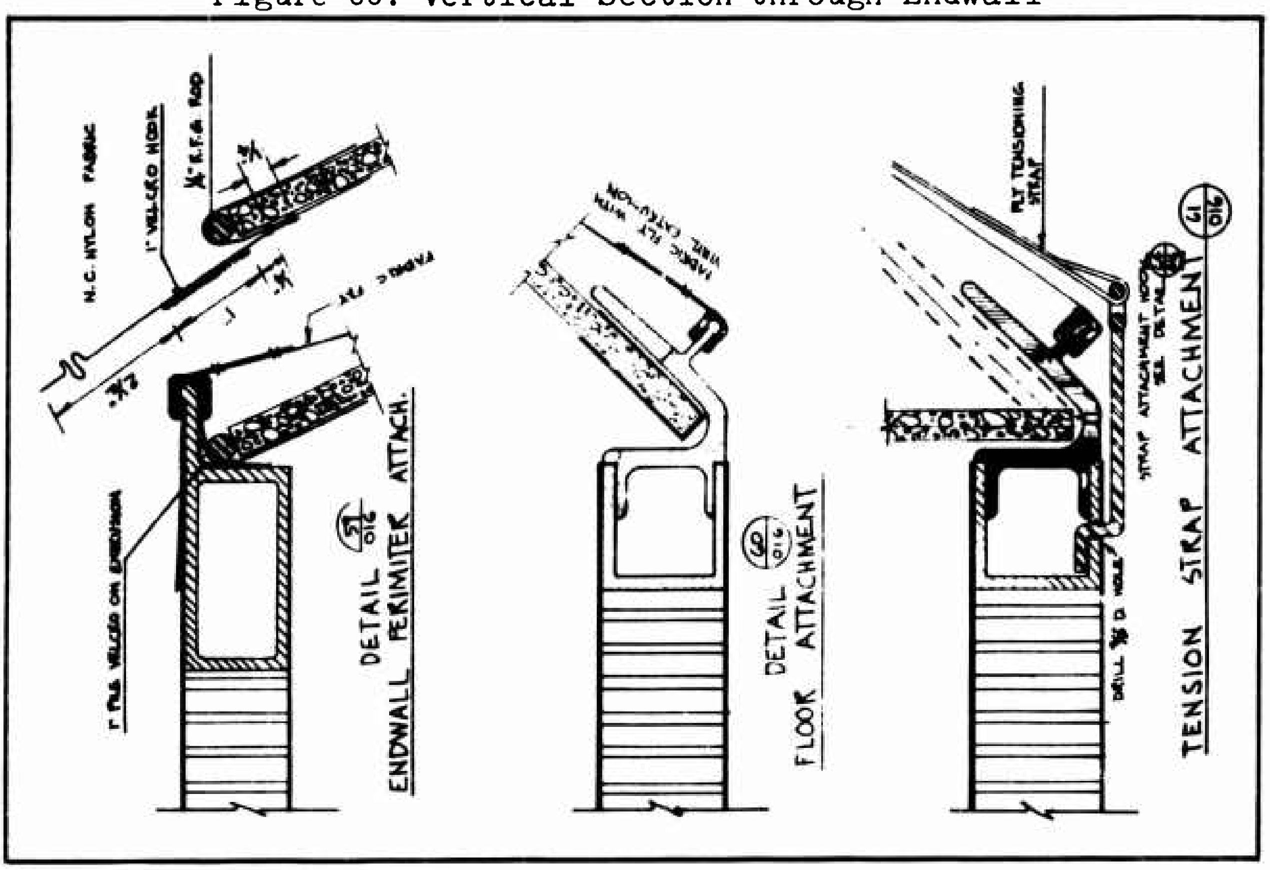


Figure 89. Attachment Details for Auxiliary Fly Cover

IV

TECHNICAL DISCUSSION-BARE BASE GENERAL PURPOSE SHELTER

A. PROPOSAL AND EARLY CONCEPTS

Section III A of this report outlines the general concepts discussed in the proposal as they might apply to both small and medium size buildings. Also discussed are five early concepts presented at TAC Headquarters.

The basic use intended for the building was multi-purpose and there was no requirement for hard, integral, re-usable flooring. The approximate size requirements were listed at 24' x 40' in plan with an 8' high sidewall. The concepts discussed above all had deficiencies in the area of complexity and lack of reliable sealing of some joints. Again, it should be mentioned that these concepts under development utilized foamboard as the prime structural and enclosing material. In a sense then, this became a basic test to determine if a building of this span could practically be developed and be consistent with good design and safety practices. The design requirements established dictate a rather difficult strength problem at the knee joint of the structure vertical sidewall-to-roof joint) regardless of whether the roof becomes a partial arch or a simple center-line pitched roof. For this reason, it became apparent that a folded beam must be developed to handle the primary structural role.

1. Modified Diamond Folded Plate Concept

In an effort to gain great depth of section at the knee joint, this folded plate concept was developed. Three foot wide sheets of 1/2" or 3/4" foamboard would be scored and folded (as shown in figures 90 and 91) in a triangular configuration. Each 3' wide module would have sidewalls and roof panels factory joined. Module-to-module joints would be accomplished by turning the edges up and clipping an aluminum channel over them. The structure would be erected by tipping up the rigid modules one at a time making weather seals. No end walls were developed for this concept.

This system was not developed further in favor of the frame and structural panel system because of manufacturing problems and poor erection procedure with unskilled labor.

2. Frame and Structural Panel System

Structural materials to be used include 1/4" thick foamboard beams and columns. The columns would require additional wrapping with fiberglass filaments at the knee joint. In erection, this joint must be pinned to make it more rigid. The infilling panels would be foamboard also (aluminum reinforced skins). The panels would be attached with webbing straps. See figures 92 and 93.

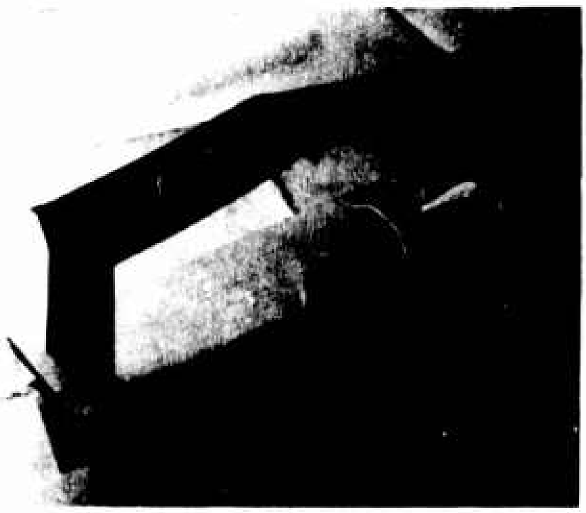


Figure 90. Modified Diamond Concept

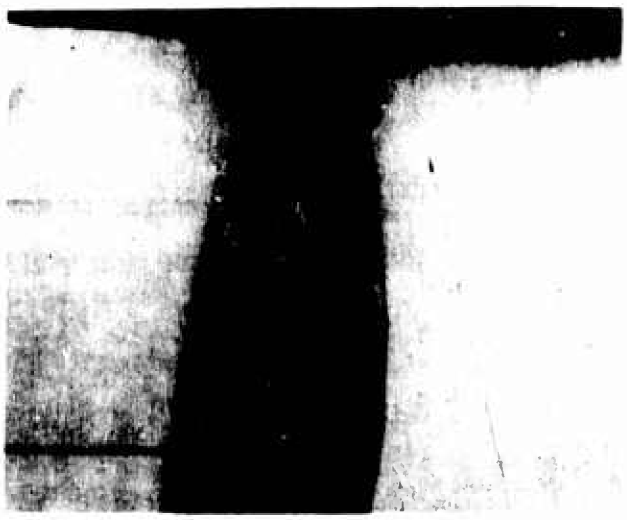


Figure 91 Modified Diamond Concept

The shelter would be erected by securing the rigid arch frames, erecting them and holding them secure by placing the side wall panels. Roof panels would then be placed on the rigidized frame. Figures 93 through 97 show the proposed shelter erection procedure.

A weight analysis of the concept was developed. The packaged shelter (less endwalls) would weigh 1700 pounds and would cube out at 564 cubic feet. These figures cover 19 bays plus one additional frame section and would yield a building 24' wide by 50.7' long, 8' high at knee and 11' high at the ridge.

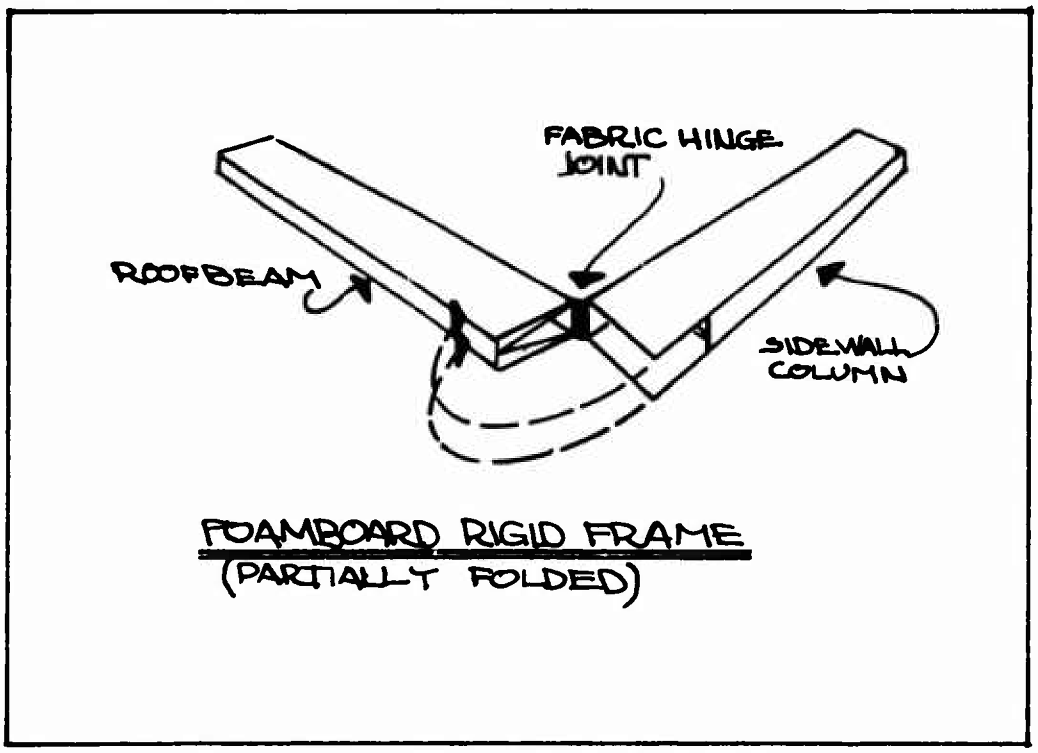


Figure 92. Rigid Frame Elements

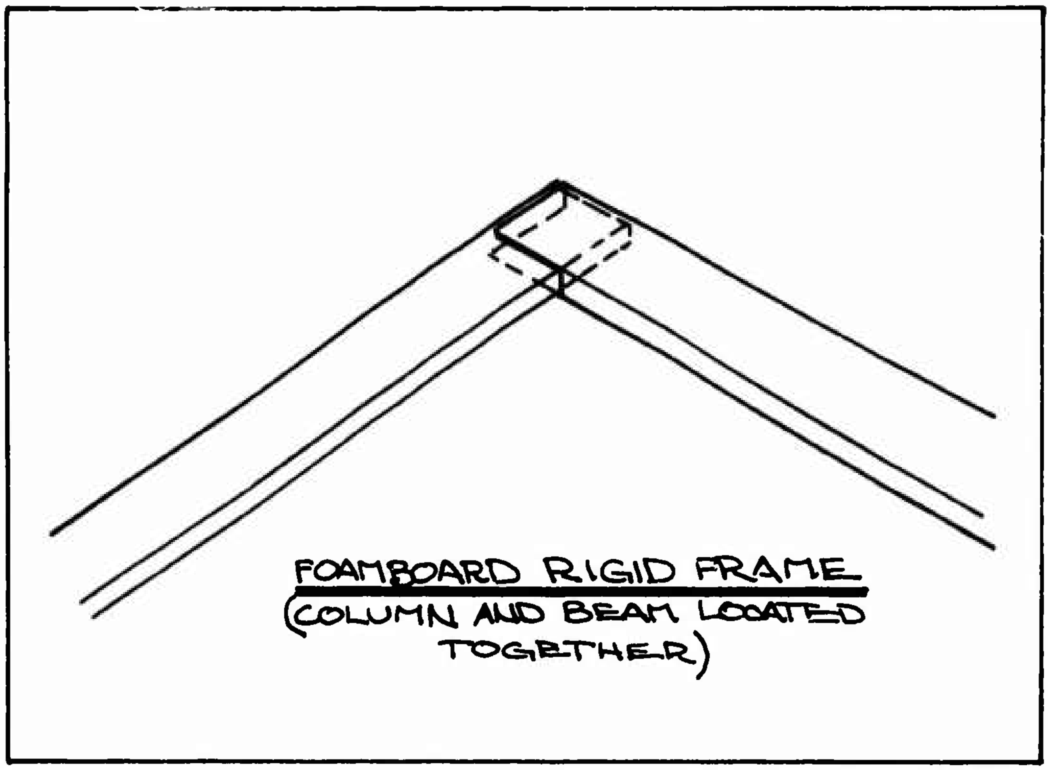


Figure 93. Rigid Frame Folded Together

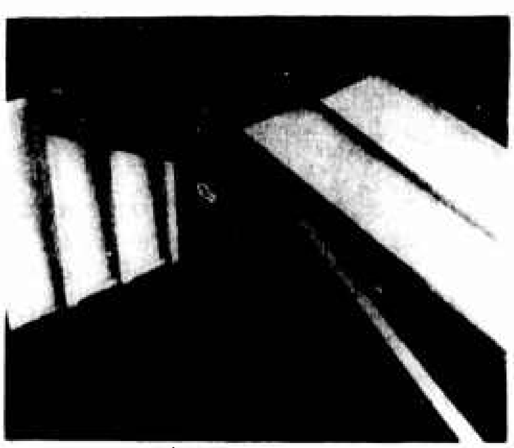


Figure 94. Exterior View

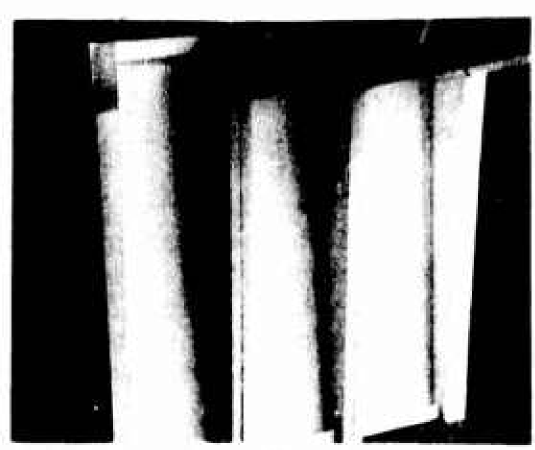


Figure 95. Interior View

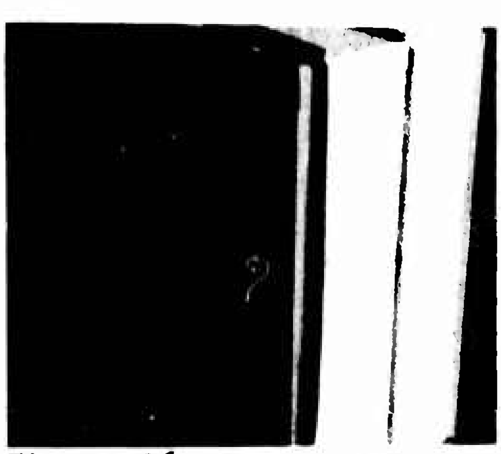


Figure 96 Knee Joint

Figure 97. Overall View

B. ADVANCED GENERAL PURPOSE SHELTER CONCEPTS

The design emphasis for this structure type was drastically altered by a TAC directive dated 16 June 1967. A summary of the design requirements and goals is extracted below:

DIMENSIONS: Minimum 24' x 48', maximum 25' x 50' plan with 12' high vertical sidewalls.

PACKAGING: Re-usable, rigid type.

DOOR CONFIGURATION: Shall incorporate 12 - 11' x 11' wall units completely interchangeable with:
4 double door units (vehicular access)
2 pedestrian door units
6 window units (light and ventilation)

FLEXIBILITY: Total interchangeability. All door units could be positioned along one wall.

The remaining requirements remain essentially the same except for the goals which are listed as:

COST: $2,000.00
ERECTION TIME: Eight (8) man-hours.
PACKAGED VOLUME: 600 cubic feet
WEIGHT: 3600 pounds

The above requirement for the openable 11' x 11' doors dictated the major change in emphasis. Previous investigations and concepts were directed toward providing shelter with only endwall openings of a large size thus allowing a floor-sidewall structure with equal stress and uniform loading points. This condition would allow the use of light weight beams and panels in unitized construction that would eliminate the need for purlins.

The new opening requirements dictated a post and beam system. A rigid condition was required to accomodate the extreme load concentrations at the joint of beam and column. Further, the beam and column must be capable of spanning 12' unsupported. The infilling panel could not be expected to be part of the structural system since the panel could be opened or removed.

Materials for the beam/column system had to be capable of resisting the higher stress and provide a fixed joint at the knee. This eliminated previously considered light weight materials such as foamboard.

1. Rolled Steel Section Concept

This concept is based upon an identical cross-shaped beam and column of 16 gauge steel. The possibility exists that this could be accomplished with aluminum extrusions. The joint between beam and column would be accomplished by an angled spline, as shown, whether the connection is straight or a corner (components illustrated in figure 98). The cross shape is required to accomodate the panel connection and seal. The roof panels are supported by arched beams spanning 24' between columns and supported by legs inserted into column tops. Rigidity in the roof plane is assisted by fixed length cables attached to a leg on the roof arch beam and crossing the bays diagonally. The roof panels span 12' between arches and are secured to arch channels by a clamping device. Thus with the rigid roof panel connection and the diagonal cables, the roof plane becomes quite stable. Figure 99 shows the assembled components.

The rigid spline, although developed to provide the rigid knee joint, did create assembly and disassembly problems with the great surface contact area that the components slide across. Burrs, dirt, corrosion, and slight deformations could cause damage or prevent erection. The possibility of all sidewall panels being used for vehicle access precludes the possible use of a grade beam to resist racking.

Component weight and manufacturing tooling costs also presented some potential problems. Extensive further development was deemed necessary for this concept.

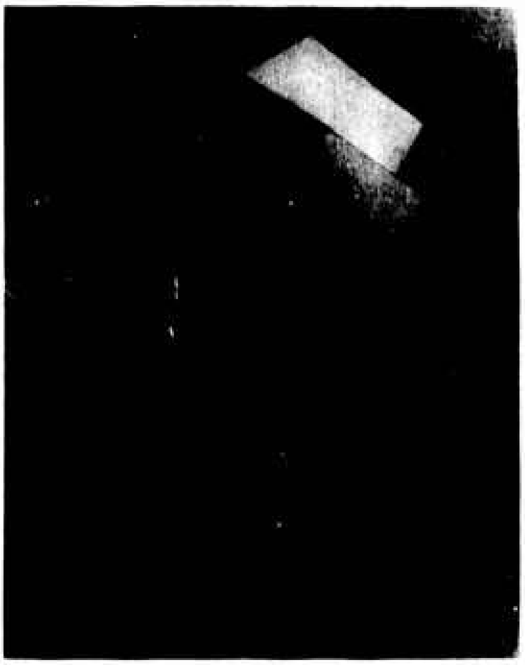


Figure 98. Rolled Steel Components

Figure 99. Typical Joint

2. Steel Bar Joist System

This concept makes use of essentially the same infilling panel system for roof and side wall. In order to resolve the horizontal loading forces acting at the beam/column joint, a deeper section beam is required to effect a fixed end condition eliminating rotation about this joint. An open web (bar joist) was anticipated for the roof beam because of great strength and low weight. The roof is still a rigid foam sandwich panel inserted into the top chord channel of the 24' span. The column is a built-up gauge metal configuration which allows beam and panel connections in any direction and creates the weather seal. The erected structure is shown in figure 100.

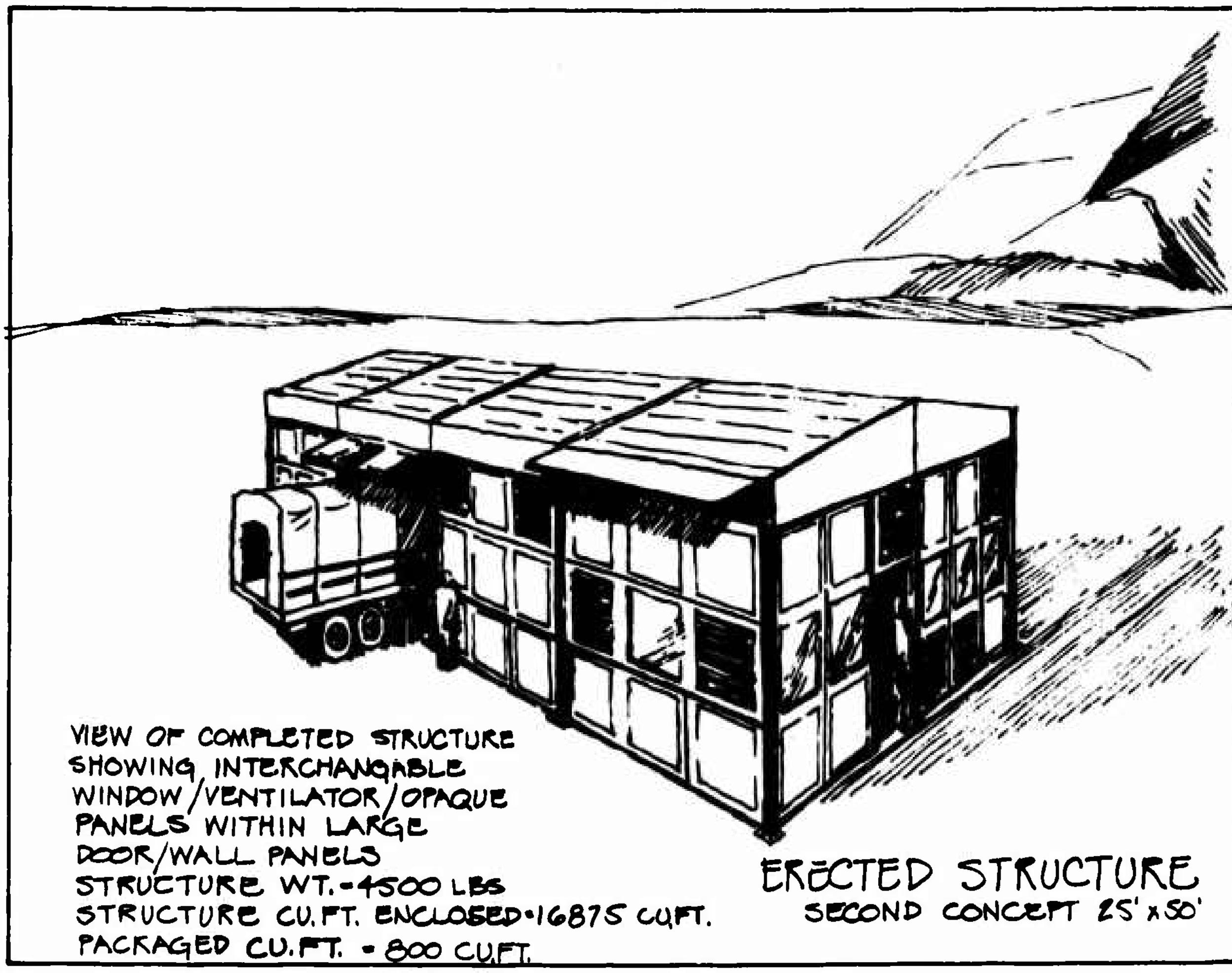


Figure 100. Erected Steel Bar Joist System

The erection procedure is as follows:

(1) Location of column base plates and anchorage to the ground.
(2) Place column shafts and plumb after leveling.
(3) Place and secure bar joists.
(4) Place and secure roof panels.
(5) Place and secure interchangeable wall panels.

It should be noted that the concept has flexibility in both plan dimensions. The module size becomes 24' x 12', and the columns could also serve to support interior partitions of the same exterior panel system. This flexibility does not increase cost or weight of the 25' x 50' structure but only requires careful attention to details with this expandability in mind. Figure 101 shows the erection procedure, while figures 102 and 103 show details of construction and utilization.

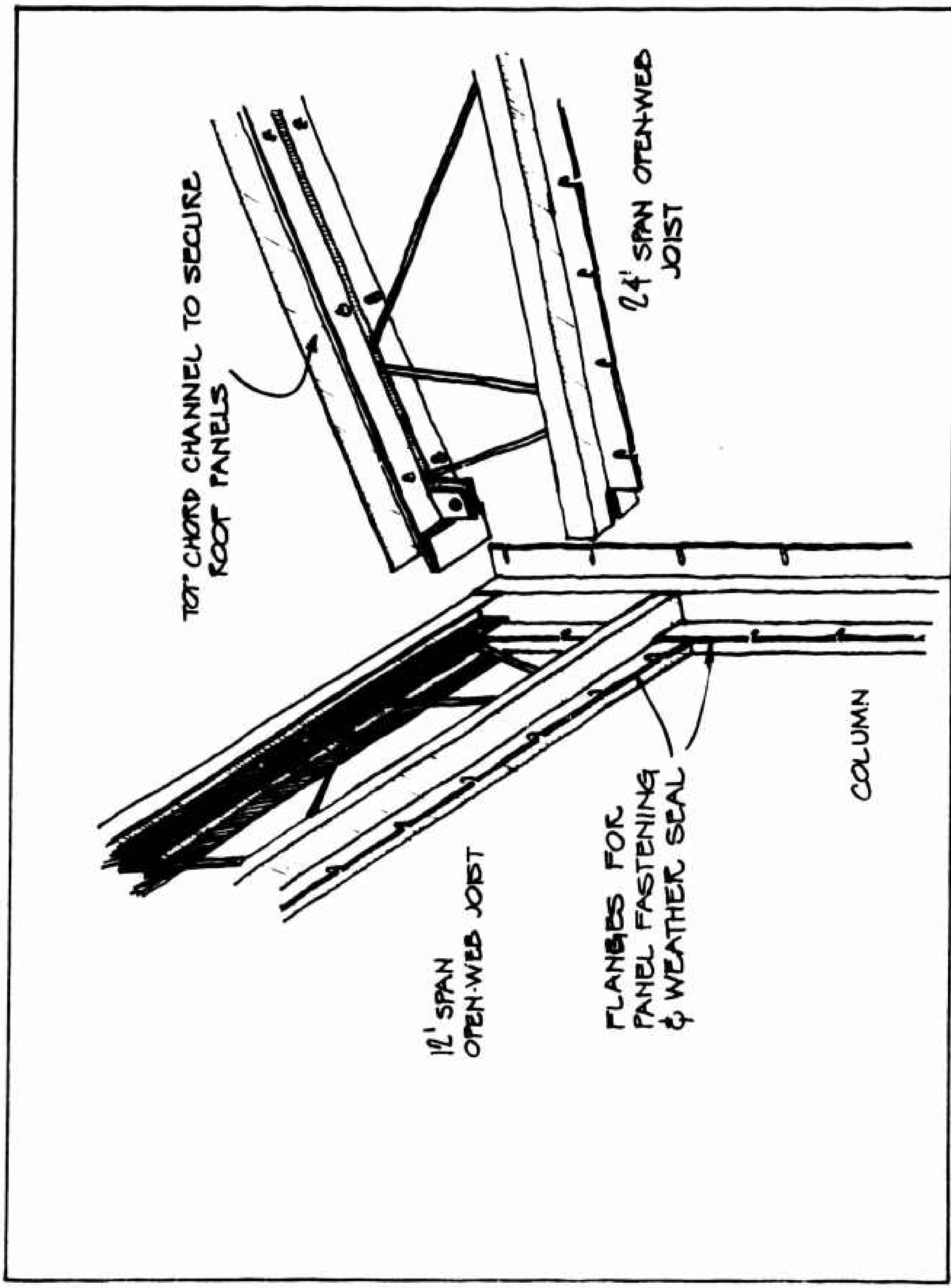


Figure 101. Erection Details - Steel Bar Joist System

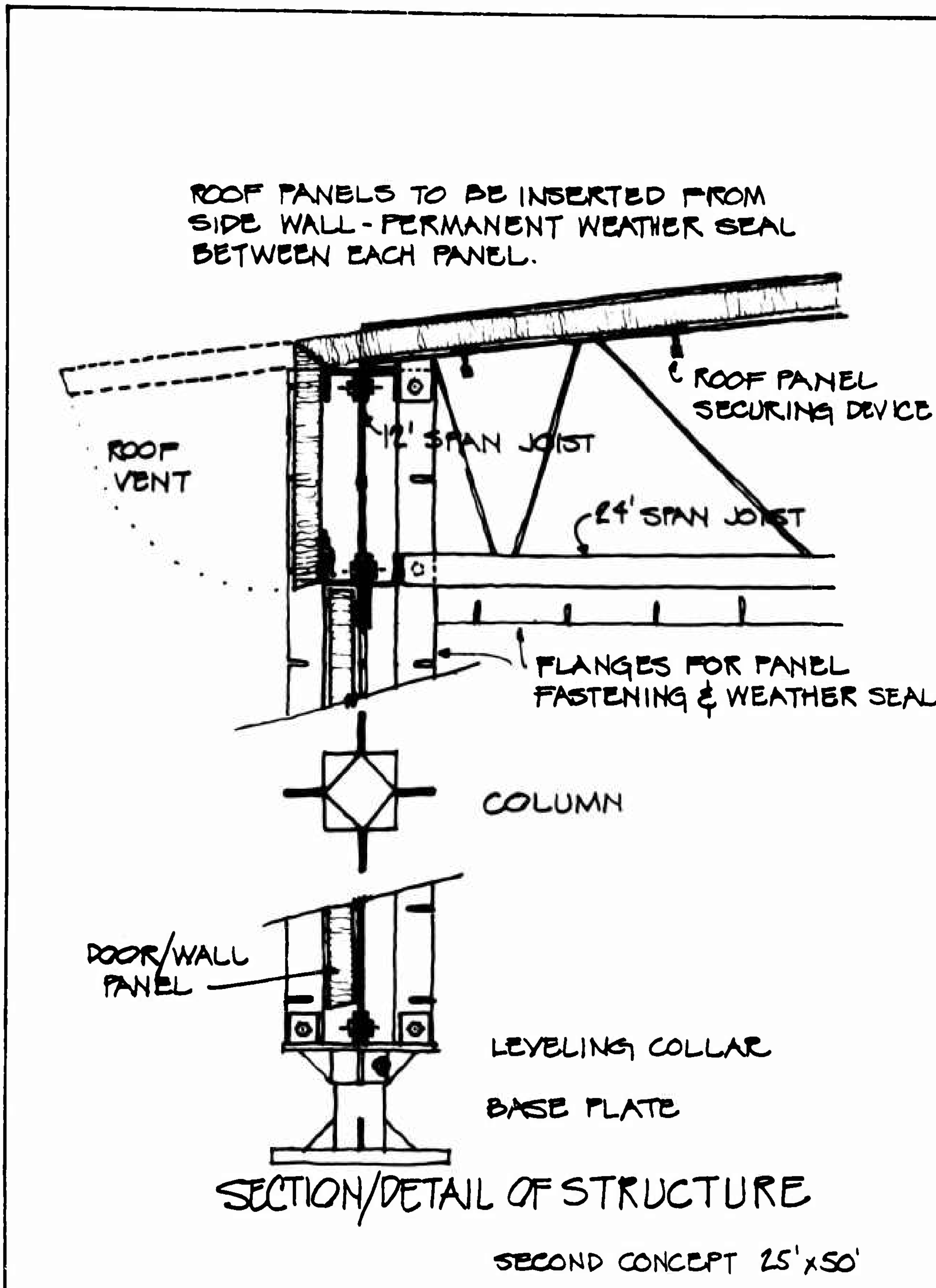


Figure 102. Sectional Details - Steel Bar Joist System

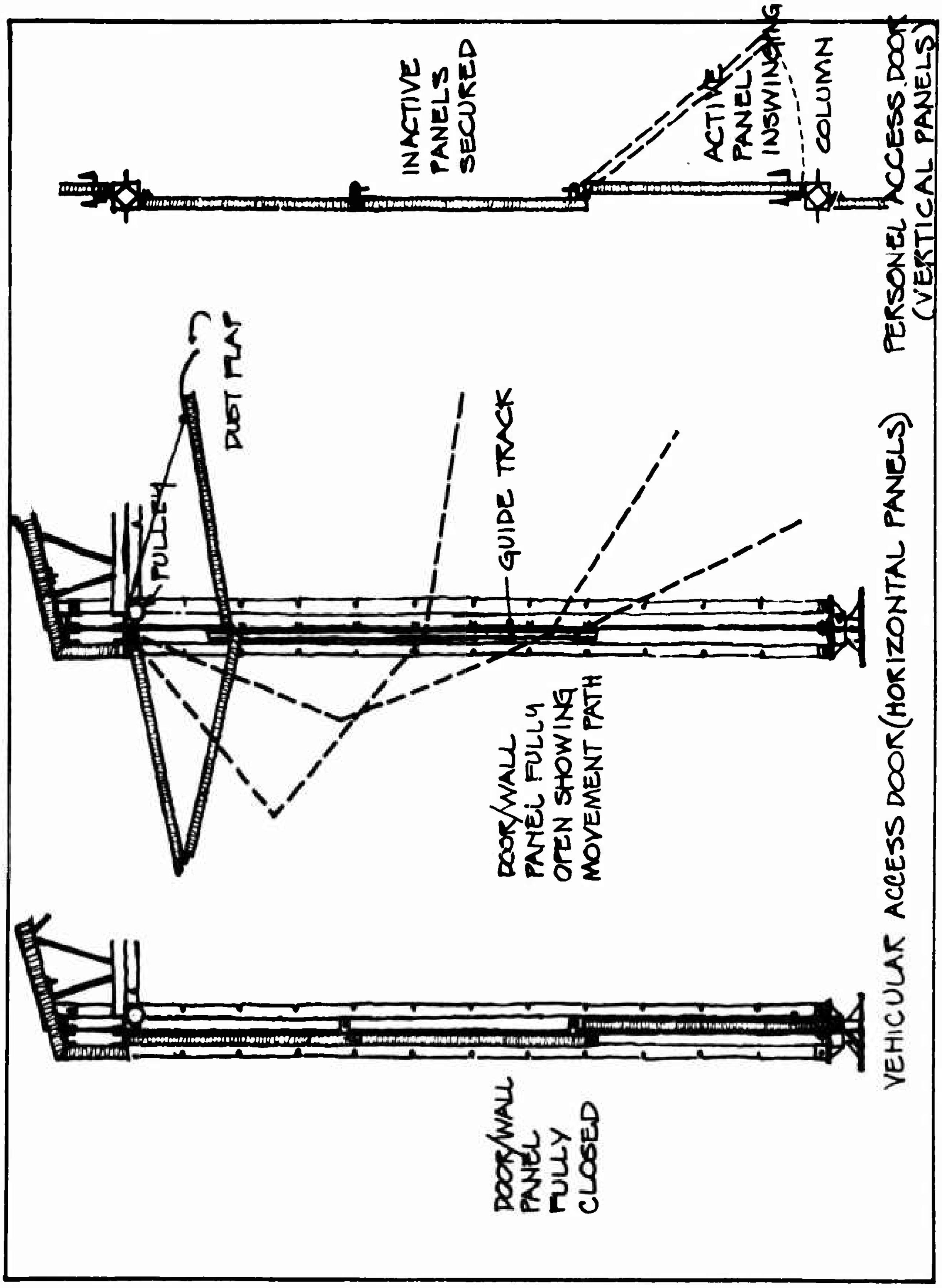


Figure 103. Panel Utilization Details

C. STANDARD HANGAR COMPONENT CONCEPT (CURRENT)

A major status report was held at Langley Air Force Base on 8 August 1967. At this meeting, several of the previously mentioned concepts were presented for consideration. However, the most appealing concept for this intermediate size structure utilized standard components of the portable aircraft hangar being developed under contract AF33(615)3242. The advantages of such a structure become obvious immediately. Great economies could be realized by identical components. Tools could be amortized faster, smaller inventories of spare parts are necessary, overall development and testing becomes cheaper, and similarities of erection procedure should save considerable time in deployment.

Six possible configurations were presented utilizing standard components exclusively and with special adaptor parts. Figure 104 shows the concepts with standard components only where figure 105 shows the more efficient and interesting possibilities that could be obtained with additional special components. In figure 105, the second concept seems to be optimum in that it provides more than the minimum profile required and has a roof configuration that provides excellent roof drainage and easy flashing. Figure 106 shows the various components required to build the basic enclosing shell without endwalls, and figure 107 shows a simple profile comparison of the standard hangar versus the proposed intermediate size general purpose shelter. Figure 108 shows a rendering of the completed proposed shelter with a possible endwall design.

1. Cube/Weight Analysis

When the building length goal is assumed to be around 50', the following analysis would yield a 50'3" long structure:

- Six (6) panel spaces and five (5) spacer segments yields building plan = 29'-6 x 54'-3 Area = 1610 sq.ft.
- Cubic enclosure = 300 sq. ft. x 54'-3" = 16,300 cubic ft.
- No. of arch beams = 12 x 6 = 72 x 40# = 2880 pounds
- No. of panels = 6 x 6 = 36 x 45# = 1620 pounds
- Base Pads = 14 x 40 = 560 pounds

For one endwall:

- Panel = 300 sq. ft. x 1.3 lb./sq.ft. = 390 pounds
- Columns at 3.5#/ft. 2 x 35 = 70
- Beam at 2.0#/ft. 2 x 16 = 32
- Door hardware (est.) = 100

592 pounds
x2
1184

therefore, TOTAL = 6244 pounds

by weight, 4.4 shelter per C-130 deployment.

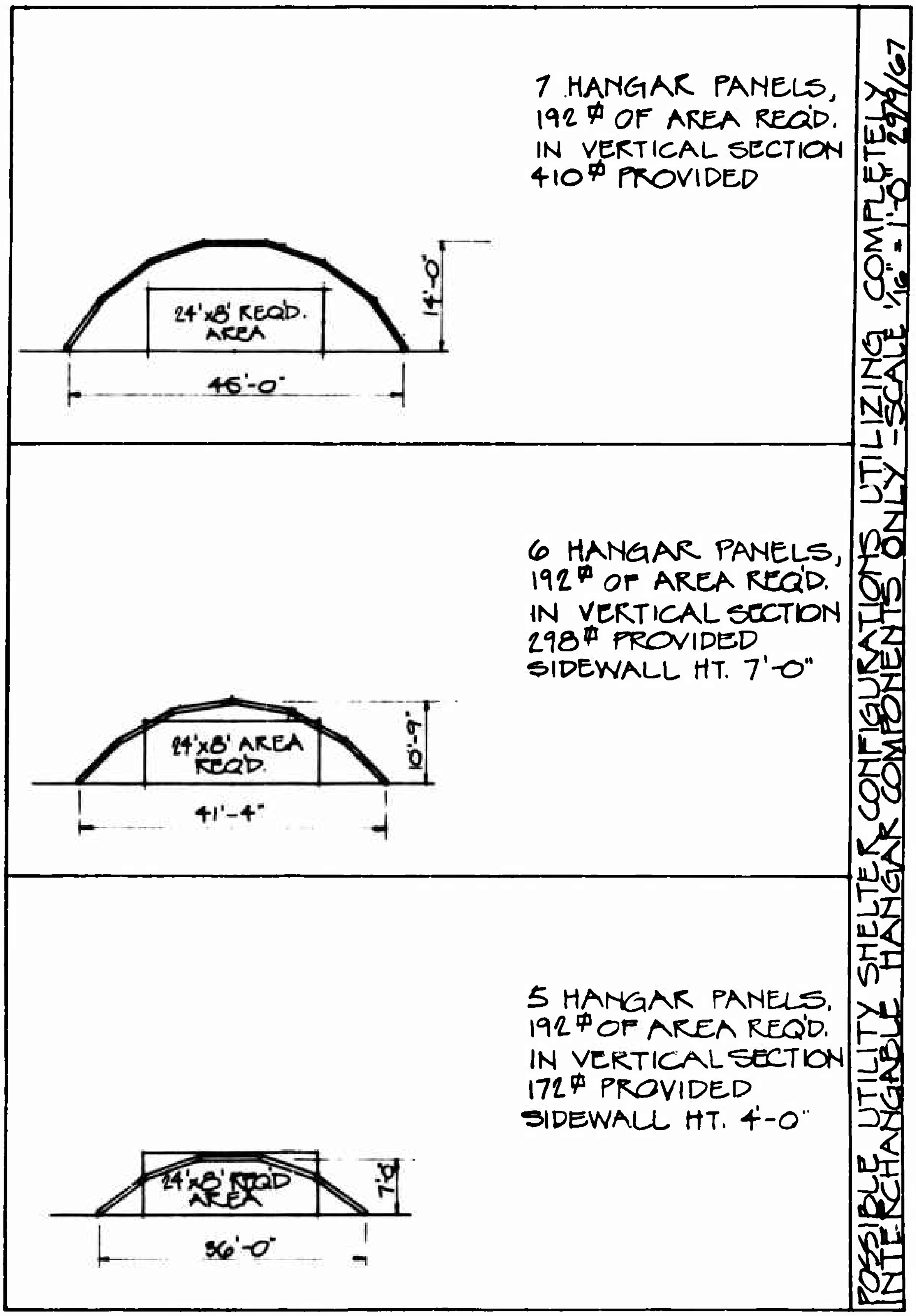


Figure 104. Possible Shelter Configurations - Standard Components

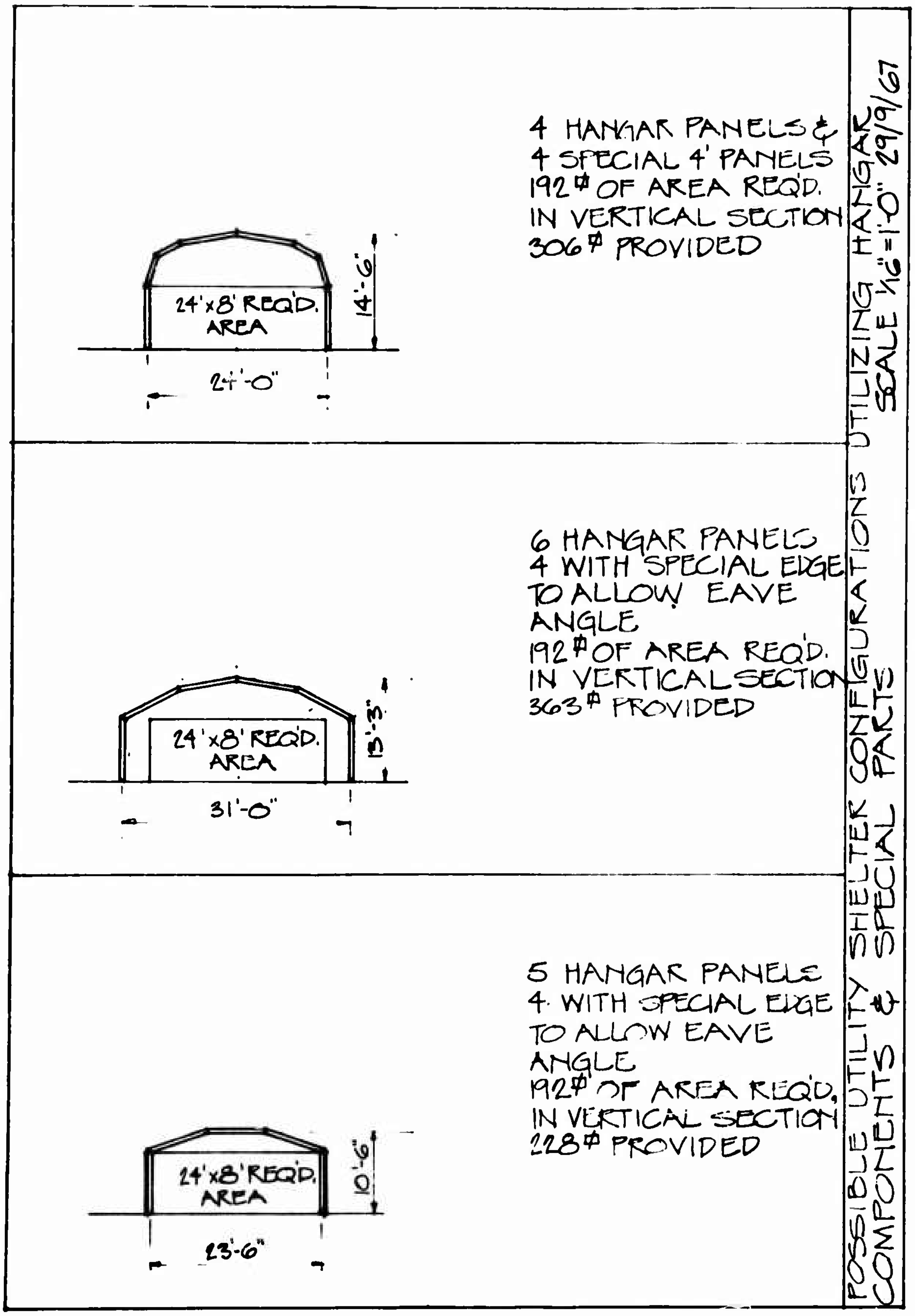
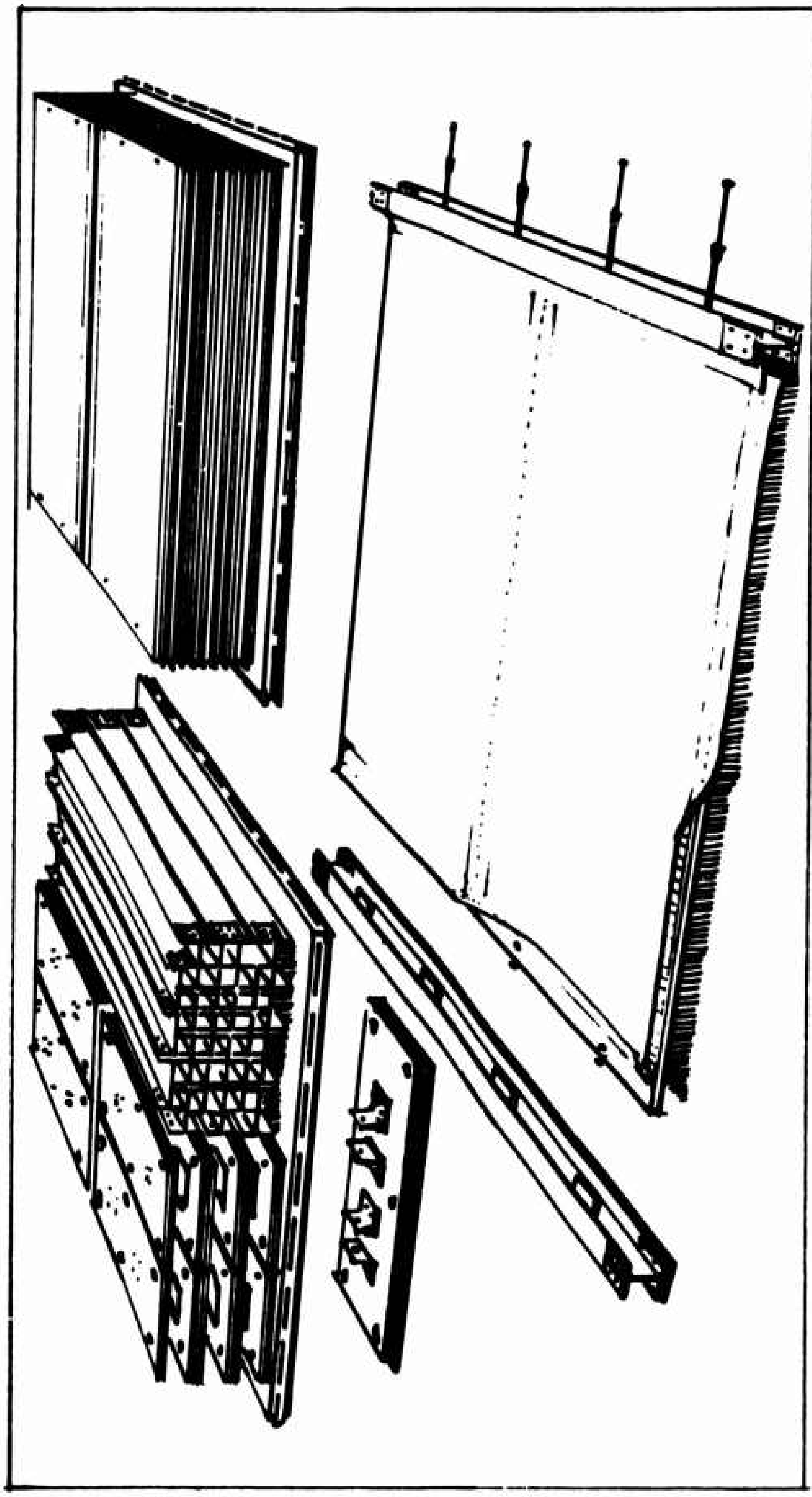


Figure 105. Possible Shelter Configurations - Special Components



STRUCTURAL SYSTEM FOR HANGARS AND INTERMEDIATE SIZE BUILDINGS

A. Laminated composite panels; when joined between two beams, form structural module.

B. Aluminum beam sections with high strength hinge and pin end joints. Assembling modules at hinge and pin joints produces one arch.

C. Base module or arch is anchored to bearing pads.

D. Successive arches are joined by short, adjustable purlins which may be used as a ladder.

Figure 106. General Purpose Shelter - Structural Components

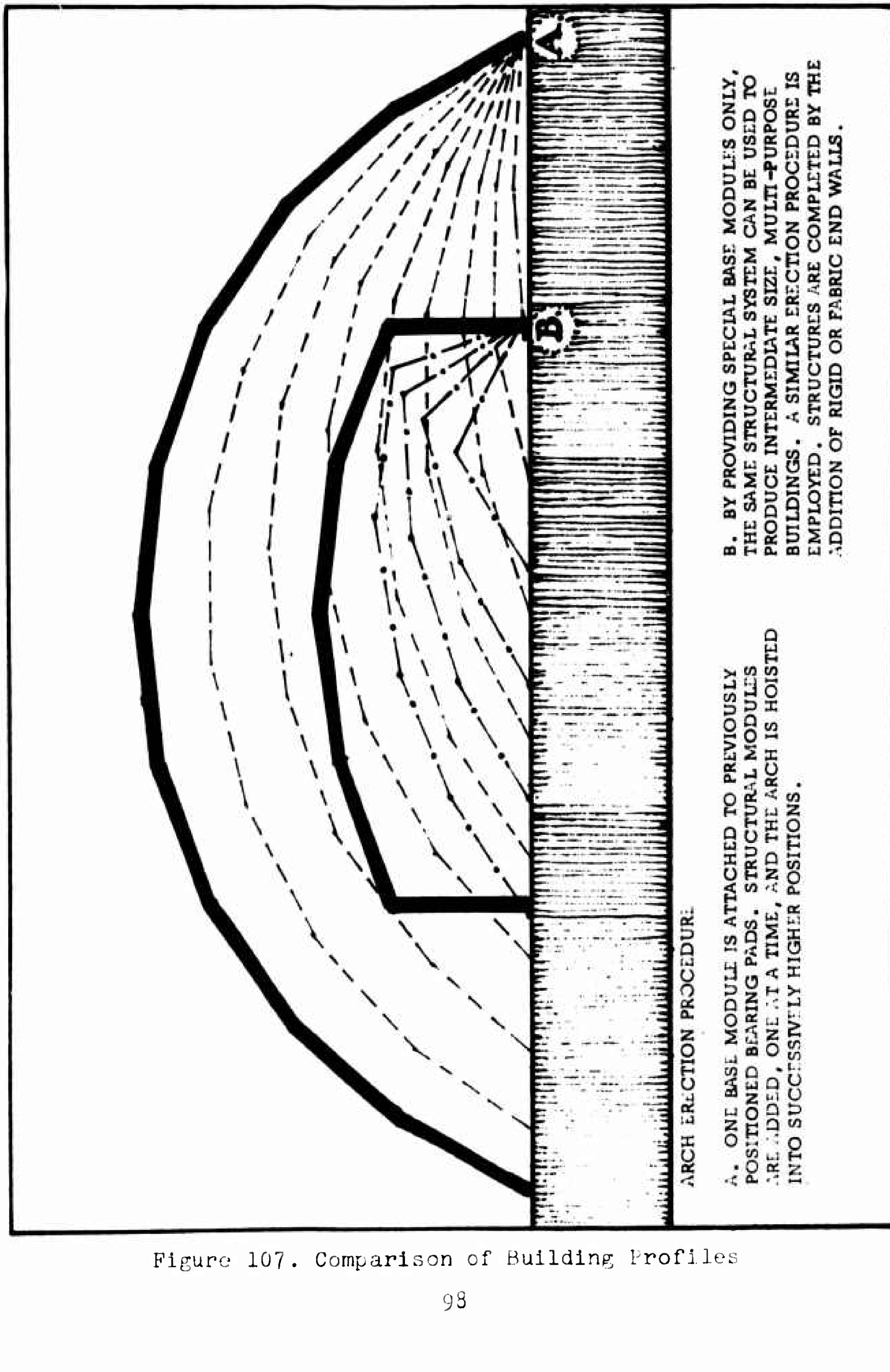


Figure 107. Comparison of Building Profiles

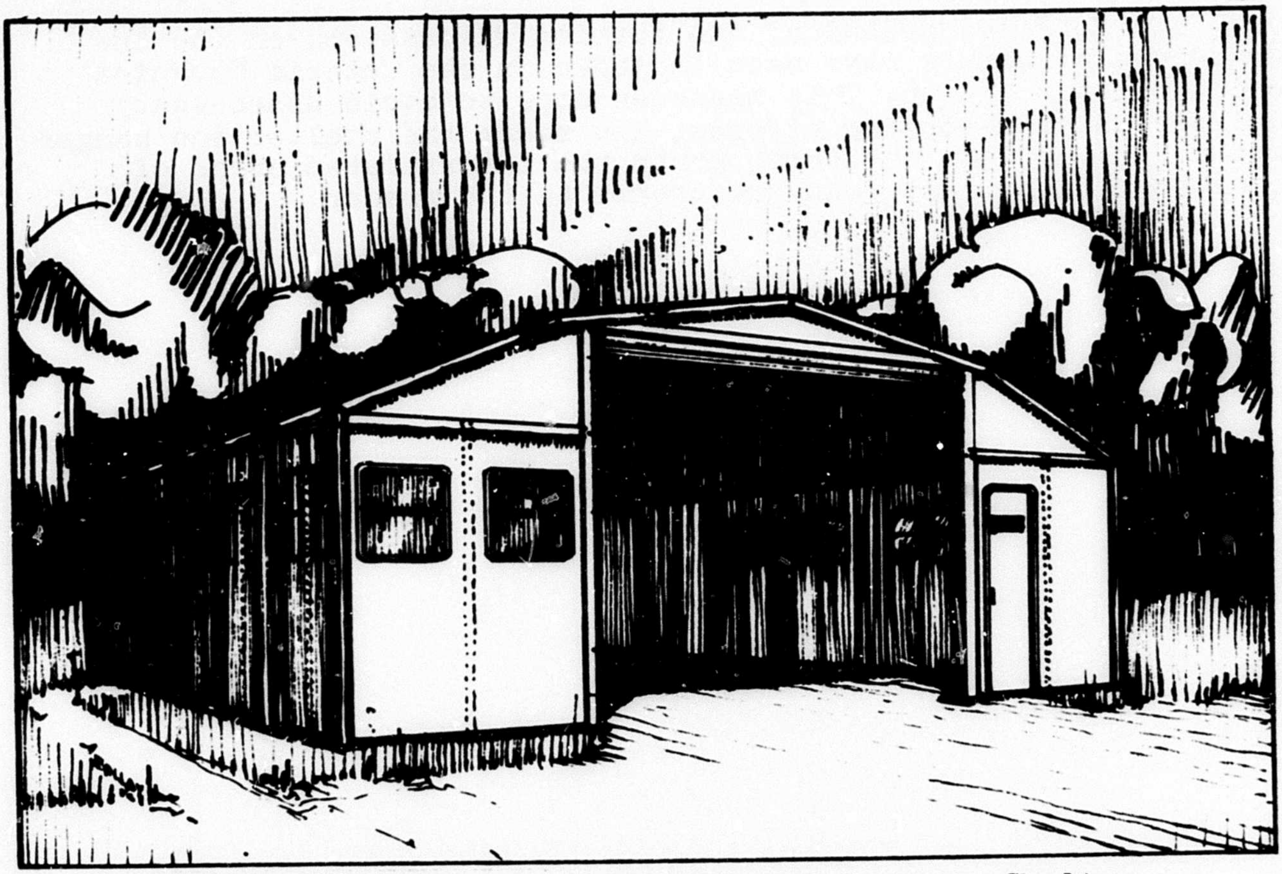


Figure 108. View of Erected General Purpose Shelter

If the building length is reduced to five panel spaces and four spacer elements, the building plan becomes:

- 29'6" x 45'	Area = 1327.5 sq. ft.	
- Cubic enclosure = 300 sq. ft. x 45'	= 13,500 cubic ft.	
- No. arch beams =	12 x 5 = 60 x 40#	= 2400 pounds
- No. panels	6 x 5 = 30 x 45#	= 1350 pounds
- Base pads	12 x 40	= 480 pounds
Endwalls remain at 592# each		= 1184 pounds
TOTAL		= 5414 pounds

and 5.07 shelters per C-130 deployment.

Clearly, it seems then that a goal of 5 general purpose buildings of the latter plan dimensions seems a realistically attainable goal. The expansion ratio for such a building as the latter becomes very attractive -- approximately 28:1.

2. Annotation to Complete Reporting on Intermediate Size Structure

From the discussion in this section, it can be seen that the nature of the development for this structure closely paralleled the development activities of the hangar structure on contract AF33(615)3242. Further, as mentioned in the "Foreword" to this report, the detailed technical and testing discussions on the intermediate structure have been included in the Interim Technical Report on this hangar. This has been done to avoid unnecessary duplication of reporting efforts, and since the shelter and hangar form a "family" of shelters, group the interrelated areas of development for easy ready reference to the reader.

V

FOAMBOARD RESEARCH AND DEVELOPMENT

A. INTRODUCTION

The notion of a thin, sandwich construction paper/plastic enclosing material with scoring and folding capabilities dates back to early 1964 when this office was engaged in shelter development under AF33(615)1285. The unique properties of foamboard to be scorable and foldable allowed significant strengths to be developed from an inherently fragile material. The reader is referred to the report "Research and Experimentation on Unique Expandable Shelter Concepts for Limited War Applications" report number AFAPL -TR-65-116, Volumes I and II for discussions on this early work. The possibilities revealed from this investigation proved the area dynamic and full of promise. This also demonstrated the need for further investigation (F33615-67-C-1259) which is the basis for this section.

As the development work under 1259 proceeded, it became obvious that some problems in the foamboard material still hindered the effort. Inconsistency of quality and poor skin durability were the liabilities of the Bare Base Personnel Shelter prototypes.

This part of the report covers the work performed under amendment number S/A #11 to contract AF33(615)3242. As an expedient to accommodate this necessary work, contract 3242 was used to fund the effort; however, the material under development was to be utilized on the BBPS under contract F33615-67-C-1259. Therefore, it was felt that the reporting on this work should be included herein because of the obvious reference to these shelters.

B. OBJECTIVES AND DEFINITION OF THE PROBLEM

1. Objectives

The objectives of this effort were to survey available thin film materials as possible foamboard substrates, select and run promising combinations, evaluate physical properties and suitability as a material for the Bare Base Personnel Shelters, and make appropriate recommendations to the Air Force.

Because of the limited budget available for this work, and because of the immediate need for useful data (to aid in the procurement of personnel shelters) certain restraints and considerations were present during the effort. The restraints include:

a. Restriction to the use of Celotex Corporation's continuous foam-in-place facility. Because of the limited budget, no process changes involving capital expenditures were considered.

b. Use of a urethane foam core.

c. Three-tenths inch (.3") nominal board thickness. This was a function of geometry and stacking thickness.

Other goals can be listed as:

d. A fire-retardant composite was desirable.

e. Elimination of foam to skin delamination problems.

f. Elimination of skin fractures due to folding.

g. Board must withstand 60 mph continuous and 90 mph gusts in design configuration.

h. Maintain structural integrity after long exposure to water.

i. Resistance to U.V., vermin, mold, fungus, mildew and rot.

j. Cost must be limited to 6¢ to 10¢/square foot in large quantity production.

Trial runs of promising combinations were to be made as necessary, followed by a series of tests to determine their physical properties. If these physical characteristics showed significant improvements over existing materials, then full-scale folded configurations were to be evaluated for wind load capabilities and durability.

2. Definition of the Problem

To provide a clear understanding of the problem, a short history of foamboard structural usage in the past five years is in order. The initial Air Force experience with the material was obtained through two prototype structures. One of these was designed in 1964 by the University of Cincinnati; the other was designed in 1965 by the G. T. Schjeldahl Co. These structures utilized a 1/4" thick product of the Monsanto Corporation called "Fome-Cor", made of polystyrene foam and 69# natural kraft paper. When the board was scored and folded, it yielded easily and the score lines were retained when stored flat for a long period. The basic problem with this material was in the vulnerability of the skin, that is, it became necessary to protect the paper with a two-part epoxy paint after cutting and scoring was completed. In later considerations on manufacturability, it was believed that this post application of the finish would be too slow and costly.

Near the conclusion of the University of Cincinnati contract AF33(615)1285, a prototype structure was made of Celotex Corporation's "Technifoam" board. This material, though similar to

"Fome-Cor" utilized a polyurethane core. The prime attractions of the Celotex product were:

a. The urethane core provided the best "U" factor of any possible core material.

b. The urethane allowed elevated temperature heat sealing for attachments, a technique not compatible with polystyrene. This permitted greater production speed than RTV adhesives.

c. The Celotex board was available with a polyethylene finish which would lead us to the belief that it could be produced with any number of different thin-film finish materials.

d. The urethane provided a stronger sandwich than the polystyrene-foam core.

It was discovered, however, that the urethane foam had a very strong recovery memory. Therefore, with the folded beam design (see figure 109), the score lines disappeared after a six-month shell life. Any future designs using the Celotex board

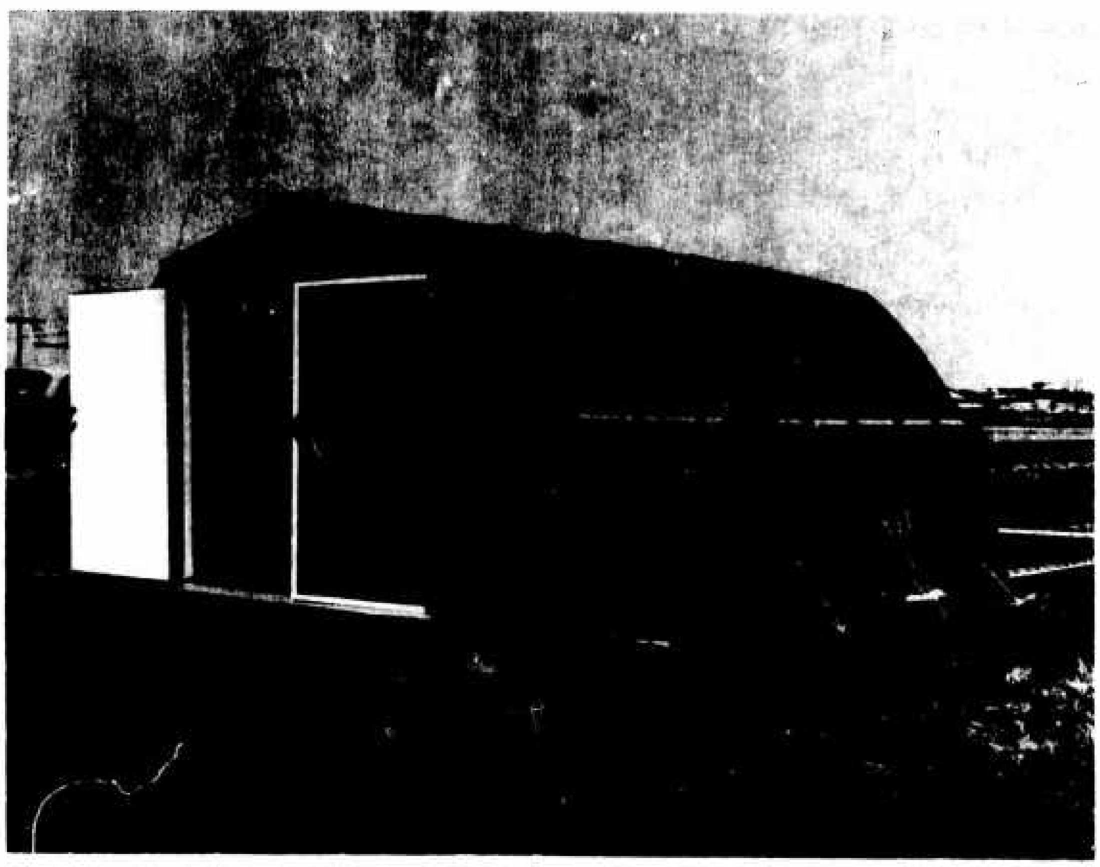


Figure 109. 16' x 32' Folded Beam Shelter

would have to allow the material to remain folded if the board was intended to retain its scored mode for several months at a time.

When contract F33615-67-C-1259 was started, it was felt that with the BBPS designs available, a urethane core foamboard shell could be considered again. This was principally due to the folded storage positions of the board and the partially folded deployment position.

Concurrently, the major sub-contractor, International Structure Corporation, was doing research to develop a vinyl-faced foamboard suitable for manufacture on the Celotex processing line and had, in fact, produced some for experimental use. The material seemed to alleviate most problems that had been experienced in previous foamboard constructions, and therefore, the initial prototypes of the BBPS utilized this substrate/foam combination. (See figure 110.)

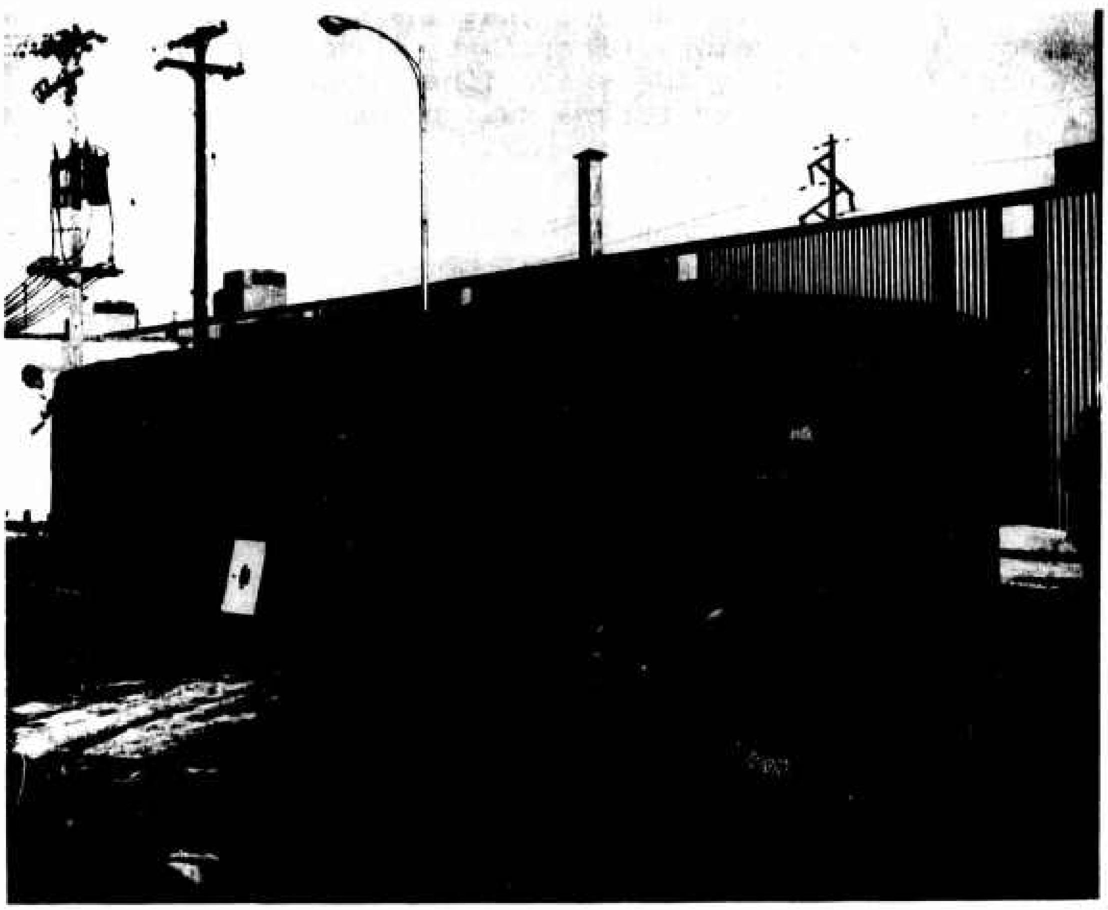


Figure 110. 13' x 35' Bare Base Personnel Shelter

In reviewing BBPS prototypes constructed under this contract, many deficiencies became apparent in the foamboard shell, all primarily dealing with the material and fabrication techniques. These can be summarized as follows:

a. Appearance of blisters near the folding lines (apparent delamination)

b. Fractures (cracks) in the skin at the fold lines due to high stress concentration and/or fatigue.

c. Water absorption through cracks mentioned in (b.) above.

d. Urethane foam aging resulting in brittleness. This made the folding after scoring difficult.

e. Poor adhesion of heat seal tapes.

f. Difficulty in bonding attachments to the shell skin. Most techniques were too slow.

g. Inconsistent board thickness. This also caused a high board rejection rate.

h. General lack of durability of the board at all stages of manufacturing and use.

It was the specific intent of this effort, therefore, to alleviate these problems by development of a better raw material and associated manufacturing techniques. Further, developments were to be proved by testing and, if warranted, full-scale mock ups.

C. SAMPLE PRODUCTION AND EVALUATION

1. Material Selection and Subcontractors

The effort to solve the aforementioned problems was started in late October, 1968. It was felt that the paper was the single biggest limitation in producing durable foamboard. Therefore, the initial approach was in the area of non-paper structural bases for skin material. The field of plastics seemed to present obvious advantages in that most are not water absorbers and many formulations possess the capacity for repeated flexure without fracture. Further, it was known that many plastic materials were in use in the packaging industry and tools and techniques were available, thus eliminating the need for costly capital equipment development.

As early as June of 1968, attention was drawn to a recent development of E. I. DuPont Co.: TYVEK spunbonded olefin. TYVEK is a registered trademark for a family of tough, durable sheet products made from 100% high density polyethylene fibers by an integrated spinning and bonding process. The sheet web is formed by the random distribution of very fine continuous fibers which are bonded to one another by heat and pressure. The tensile properties and resistance to tear seemed extremely good. Also, because of the porous nature of the surface it was felt that TYVEK could be the foam-skin interface with a resultant extremely strong bond. This would provide us with a probable solution to the delamination problem.

A trade off study between TYVEK and other sheet plastics commonly available and economically feasible showed that because of the TYVEK toughness (puncture resistance, tear resistance, tensile strength) and its wet-strength properties, it was a logical next step to run urethane foam bonding tests.

The Chase Bag Company of St. Louis, Missouri, provided the University of Cincinnati with handling properties data and TYVEK sheet samples which produced confidence that a prototype production run was in order. Although these hand samples, fabricated by Celotex, were of generally poor quality, it was believed that the foam-TYVEK bond was adequate.

At this point, studies were undertaken with Celotex to determine what restraints their processing would place upon trial runs. It was learned that the Celotex production line is the only "free-blown" urethane foam-in-place facility in the country capable of producing high quality boards as thin as 1/4". Other machines exist, but they are primarily designed to produce 3/4" and thicker board as insulation only. Board appearance and consistency is not of prime concern in such a use.

2. Trial Run #1 (5-Ply TYVEK) Discussion

When discussing skin constructions of foamboard, the two faces (interior and exterior-weathering) frequently have slight differences (such as color or a different exterior weathering face) that can lead to confusion. To clarify this, the skin constituents will be called out in a conventional manner (see figure 111). The exposed exterior face (a) is mentioned first followed by other films (b) and finally the foam interface film (c). When the opposite skin differs from (a) through (c), it will be listed (e) through (g) in that order.

a. In discussions with sub-contractors, it became apparent that any skin material must possess the following general constituents:

1.) A vapor barrier

2.) Structural Base

3.) A weathering surface

4.) A foam interface with suitable physical configuration

5.) A fire-retardant or self-extinguishing property

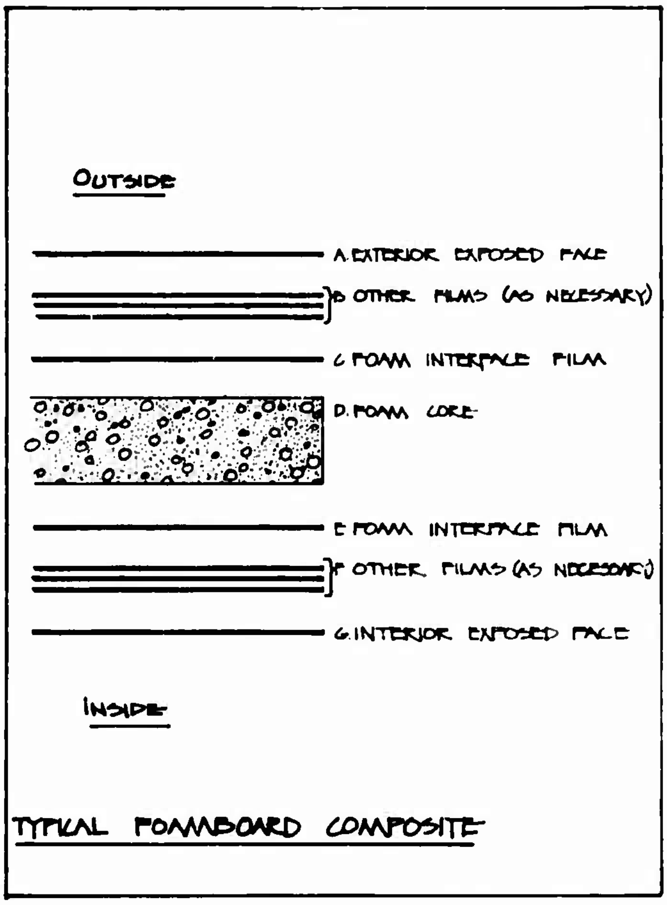


Figure 111. Foamboard Notations

These are discussed individually below:

VAPOR BARRIER: When polyurethane is foamed in place between two skins, a vapor barrier is necessary to prevent moisture from getting to the hot, expanding reaction. When moisture is present, CO_2 gas is liberated and creates voids in the foam. An MVTR similar to polyethylene or aluminum foil is necessary in the construction.

STRUCTURAL BASE: This is the backbone of any construction and absorbs the high web tension of the manufacturing process. Further, it must develop strength to give the board adequate stiffness and resistance to flexural, compressive and torsional loadings in use.

WEATHERING SURFACE (ENVIRONMENTAL SEAL): Perhaps the most stringent requirements are placed on this surface. For purposes of this investigation, we have been concerned with a five-year use life. UV exposure becomes a prime consideration over this period, and "chalking" is undesirable. The surfaces should be impervious to water and should not soil easily. The previously mentioned concerns of mold, mildew, rot and vermin are also factors.

FOAM INTERFACE PORTION: Whatever the interface material is, concern should be given to foam bonding. If the bond is poor, delaminations near fold lines can be expected. It was anticipated that a surface that was porous, or, in effect, possessed an increased surface area would provide a better bond.

FIRE BARRIER: Since the primary use of the proposed material is for living quarters, fire resistance is of prime concern. Metallic foils have delayed heat build-up in previous composites giving vital protection to the urethane core material.

The most common and economical adhesive for laminating the various constituents is polyethylene used with heat and pressure.

The decision on the selection of the "5-ply TYVEK" laminate was made after a series of conferences with sub-contractors. It was felt that the aforementioned requirements would be satisfied by a composite of five separate substrates.

Because of the inherent strength of TYVEK, it was felt that the bulk of the strength requirements could be satisfied by its use. Further, because of its porous nature, it became the foam interface surface. This was intended to help the foam bond and eliminate any delaminations. Data has also been produced on the weathering qualities of TYVEK. Polyethylene is not generally thought of as having a good weathering surface, however, when TYVEK is printed with a dark colored ink (desirable and necessary for our purposes) with a U.V. absorber added, it holds up remarkable well. Salt spray exposure tests for over two years have shown that the material maintains 90% of its physical strength when treated as mentioned above.

As a fire barrier, the addition of a thin sheet of aluminum foil was still felt necessary. Even very thin sheets would draw heat away and retard fire spread. An 1145 aluminum alloy sheet .00035" thick was selected. Further, to prevent any uneven temperature expansions, a balanced construction (symmetrical) was felt to be necessary. In order to assemble the composite, polyethylene was used as an adhesive.

Specification: The following specification was used in the trial run production:

- Style 1058 TYVEK (1.6 oz.), 6 mils, printed with o.d. ink with U.V. absorbers added
- Polyethylene film (10#), 2/3 mils, as adhesive
- Alloy 1145 aluminum foil, .00035"
- Polyethylene film (10#), 2/3 mils, as adhesive
- Style 1058 TYVEK (1.6 oz.), 6 mils, natural white
- Polyurethane foam, rigid, closed-cell, 2.4-2.7# density, non-burning, .3" thick
- Reverse of above skin construction.

b. Production and Related Problem Discussion

No problems developed as a result of the skin lamination. Procedures used were common in the packaging industry and no deviations were necessary.

The first trial run of the skin into board stock was on 7 February 1969. Representatives from the University of Cincinnati were present to observe the run. Since this equipment is of a proprietary nature, speculation is necessary as to the details of construction and operation at the starting end of the machine. (Figure 112 shows a side view of the machine as observed and represented by Celotex.) Once the run is started, speed is adjusted quickly to prevent the dispensed resins from running off the edge of the sheet as they are squeezed between rollers "A" and "B". This control is then apparently balanced against rate of flow and degree of cure of the foam. These settings then hold throughout the run. Generally speaking, the oven temperature, foam formulation, and dwell-in-the-oven time (running speed) are pre-determined by the desired density of foam and desired degree of friability (brittleness).

Upon inspection, the freshly run material evidenced a severe problem. The board had a very wavy appearance and had great variations in thickness. Upon pulling the facings away from the core, it was observed that there was a profusion of 1/8" to 3/16" bubbles or circular voids in the foam (see figures 113 and 114). This phenomenon is known to occur when there is water vapor present during the resin reaction, yielding CO_2 gas. Since the TYVEK printing inks used were alcohol based, it is believed that the moisture could not have been introduced through them. This problem is discussed later in detail.

The inconsistent board profile is believed caused by small variations (± 10%) in the overall skin thickness. This was later determined to be within the normal DuPont manufacturing tolerences.

Another problem was at the edge of the board produced, in that it possessed a bell-like configuration. This was later attributed to the plastic quality of the TYVEK material (see discussion in Section D.2.)

The most serious problem was felt to be the bubble-voids and the poor foam-skin bond. Any subsequent run should try to alleviate these problems as a primary step. Investigations with sub-contractors have lead to a theory of air-entrapment at the TYVEK/foam interface. Because of the porous, fiberlike quality of the TYVEK, air is present throughout the surface plys. As the production commences, rollers "A" and "B" (figure 112) squeeze the liquid resins into intimate contact with the skins and remove all ambient air. When the skins are smooth and non-porous, this is achieved with no difficulty, but the TYVEK apparently retains air deep in its bulk. This air, laden with small quantities

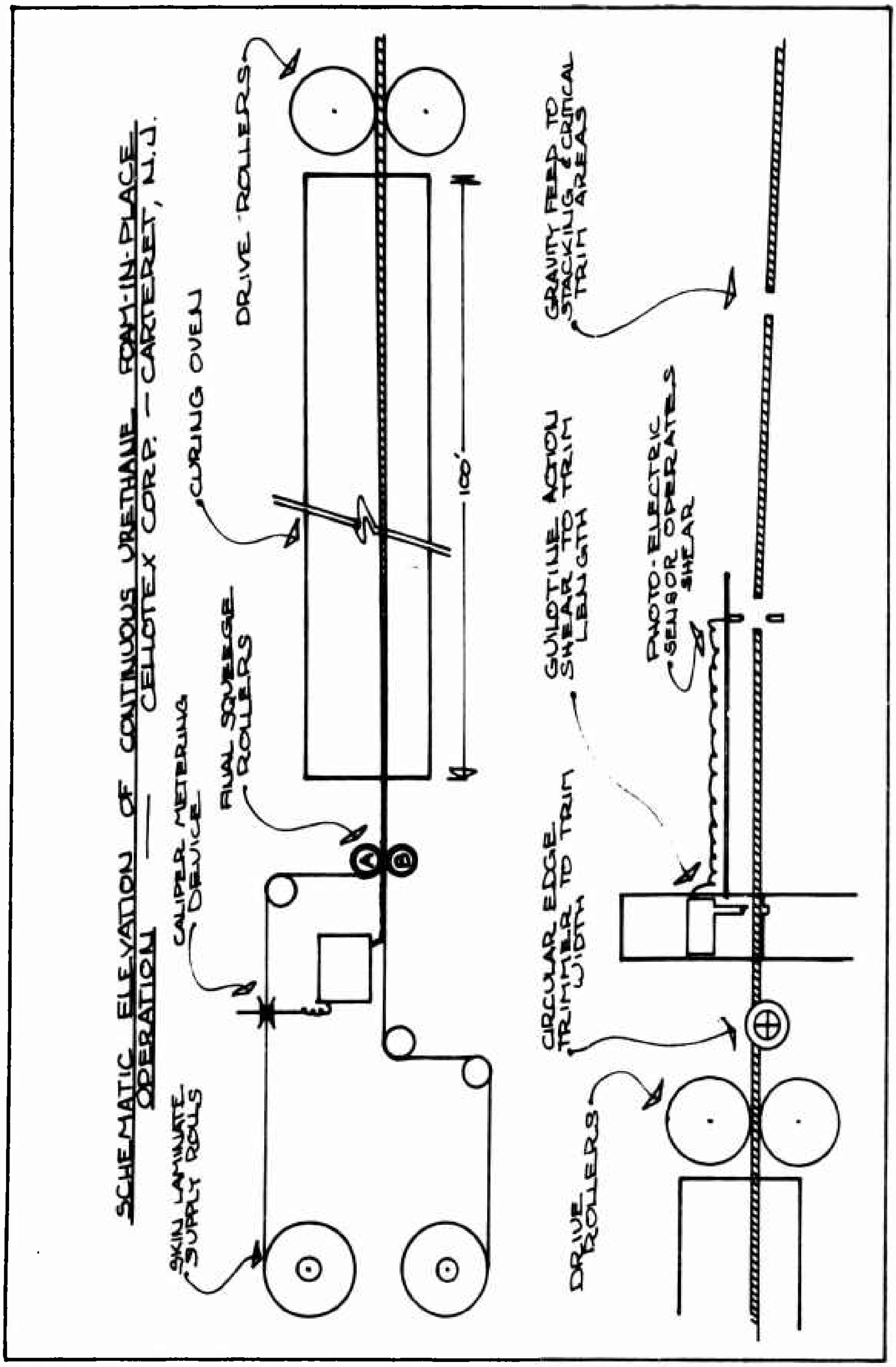


Figure 112. Schematic Diagram of Celotex Foamboard Facility

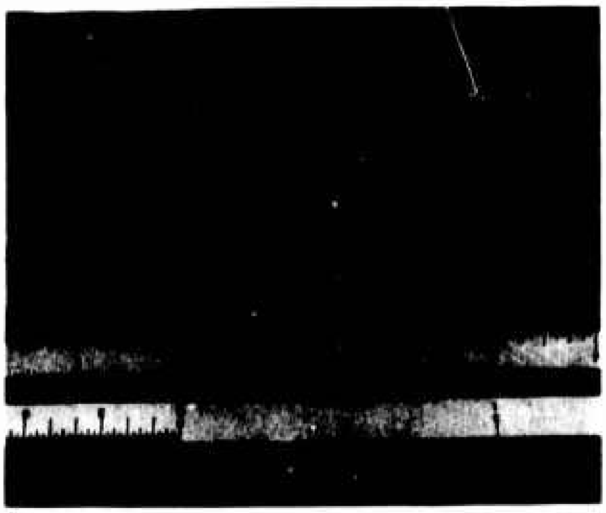


Figure 113. Trial #1
Edge Condition

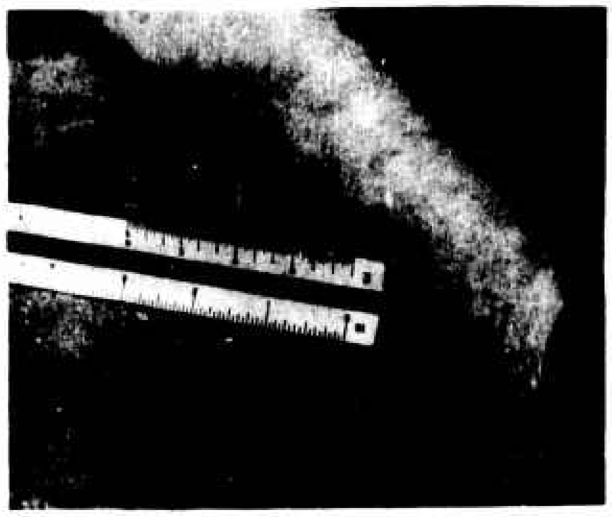


Figure 114. Trial #1
Bubble Voids in Foam

of moisture, is then present during the foam reaction, expands in the hot oven, and yields CO_2 gas. The result is as described above.

Physical Evaluation: As a matter of record, some physical properties were taken. It was felt that tensile properties and flexural properties should be evaluated in brief form. By way of comparison, three other types of foamboard were tested. Specimen "A" was the G. T. Schjeldahl Company's "plydome" material (opaque white polyethylene; 69# natural kraft liner board; clear polyethylene; urethane foam.) Specimen "B" was the 5-ply vinyl film board used by the University of Cincinnati on the second, third and fourth prototype structures of the BBPS. Construction was white vinyl film, aluminum foil, clear polyethylene, 49# kraft liner board, and clear polyethylene. Specimen "C" was Celotex' standard "Techni-foam" (TF-530) with a kraft paper and polyethylene skin. Specimen "D" was the TYVEK construction mentioned above. The results are tabulated in tables 3 and 4 below.

From the first table, we can see that the TYVEK has comparable ultimate strength to the 5-ply vinyl board but the resultant strain (elongation) is eight times as great. This brings up serious questions as to whether the TYVEK should be the prime structural constituent in the structure. Further, a quick, crude test of the ultimate flexural properties showed the TYVEK board a poor performer.

There are two conflicting opinions on the role of the aluminum in the foamboard skins when scored and folded. Each is concerned with two problem areas: the area at the score line and the flat areas at the folded plate which carry the brunt of the load.

A fracture of the aluminum in the vicinity of the score line creates no structural problems but would transfer the load (stress) onto the environmental sealing film which will yield freely,

TABLE 3. INSTRON TENSILE TEST ON FOAMBOARD SKINS

Performed at room temperature;
2 in./minute; 4" long specimens, x 1" wide.
"MD" = mach. direction; "XD" = cross direction

SPECIMEN NUMBER	TYPE AND THICKNESS	DIMENSIONS	ULTIMATE LOAD (LBS)	ELONGATION %
A-XD-2	"plydome"- .016"	1.0" wide	49.	3.5
A-XD-3	" "	" "	49.2	4.0
A-MD-2	" "	" "	123.	1.9
A-MD-3	" "	" "	110.	1.7
B-XD-1	"5-ply USAF" .020"	1.0" wide	68	4.8
B-XD-2	" "	" "	68	4.7
B-XD-3	" "	" "	69	5.4
B-MD-1	" "	" "	144.8	---
B-MD-2	" "	" "	136.5	2.5
B-MD-3	" "	" "	140.	2.3
C-MD-2	"Technifoam" (TF-530) .012"	1.0" wide	64	1.7
C-MD-3	" "	" "	62	1.7
C-XD-2	" "	" "	59	1.7
C-XD-3	" "	" "	62	1.6
D-MD-2	TYVEK .0125"	1.0" wide	113	31.0
D-MD-3	" "	" "	107	31.0
D-XD-1	" "	" "	96	31.0
D-XD-2	" "	" "	104	33.5

TABLE 4. FLEXURE TESTS ON FOAMBOARD SPECIMENS

Performed at room temperature, 10" span
simply supported, 2 point loading at center
3" apart, 1/8" radii load and supports, load
rate at 50 lbs./minute.

SPECIMEN TYPE	PHYSICAL DIMENSIONS (ins)	LOAD (lbs.)
5-ply USAF-MD	2.05 W x .300 T	18
" " -XD	2.05 W x .328 T	17
TYVEK	2.02 W x .30 T	6
Plydome -XD	2.0 W x .32 T	11
" -MD	2.0 W x .33 T	16

fracture and expose the core. In previous laminates this created a serious problem, but the TYVEK board would not suffer from such a failure since it behaves in such a "plastic" manner. The elongations should, however, be kept to below 5% to have a value as a beam structure. It was thought that the low elongations could best be accomplished by inclusion of relatively heavy (1.5 mils) aluminum foils. An alternate method would be to build up the bulk structural member (paper or TYVEK), but when one considers the "E" values of the TYVEK and foil, (since EI is a measure of stiffness) one can see that aluminum with $E=10 \times 10^6$ is more efficient structurally than TYVEK with $E=25{,}000$. Opponents to the heavy foil concept say that once the foil fractures, the structural integrity is gone. They feel the foil should be replaced (structurally) by high tensile strength skrims such as fiberglass. Proponents of the foil argue that foil cracks won't be propogated in high stress areas, or, more correctly, there is no great stress concentration along the score lines. After lengthy consideration, the latter philosophy was adopted.

As background to this section and to the test conclusions discussed later, Appendix B shows test set-ups and summaries of physicals for four different foamboards previously considered.

c. Conclusions

A "balanced" construction with TYVEK weather sealing exterior face is not practical for a "free blown" (free rising) urethane foam process such as the Celotex process. An "un-balanced" sheet still may be possible and in fact seems desirable as a flexible weather seal that remains intact even after repeated flexure and rupture of other components. Later in this report it will be demonstrated that this logic is sound and physical tests will substantiate it (see section D.2., model flexural tests).

3. Trial Run #2 (4-Ply TYVEK) Discussion

a. Theory and Specification

The principal intent of the second trial run was to prove that TYVEK could be a successful constituent in foamboard skin material and to reduce the resulting elongation of the overall skin. The latter goal, if achieved, would make the material suitable for structural applications such as the BBPS.

The primary role of the TYVEK was to be one of the exterior weathering face and also to contribute significant strength and provide working body (bulk). To achieve this, the weight of the TYVEK was increased to 9 mils, and a single sheet was used in lieu of two pieces of 6 mil material. This was done in an attempt to maintain a high level of tensile strengths.

To reduce the resultant elongation, a 1 1/2 mil aluminum foil was selected. This represented an increase of nearly 4 1/2 times the thickness used in the previous run. The intent was that the aluminum would share the load equally with the TYVEK and keep elongation down to around 4%, or at least stretch the straight line portion of the stress-strain curve into a usable range.

Specification: The following specification was used in trial production run #2:

- Style 1085 TYVEK (2.7 oz.), 9 mils, printed with o.d. ink with U.V. absorbers added
- Polyethylene film (30#), 2 mils, as adhesive
- Alloy 1145 Aluminum foil, 1 1/2 mils
- Polyethylene film (30#), 2 mils, as foam interface with heavy "corona" treatment.

Foam formulation was the same as the previous run: skin repeats on other face. The heavy "corona" (electrostatic) treatment was to be evaluated in anticipation that the foam/skin bond could be improved.

b. Production and Related Problem Discussion

The skin lamination was achieved with no problems, however in printing the o.d. ink, a wrinkle occurred over one area two inches wide and six inches from the edge. This was reported to have been caused by unfamiliarity with the relatively heavy aluminum foils, and the high web tension of the printing process.

Upon receipt of samples of this skin material, it was subjected to full tensile tests. Results from previous testing of laminates (see Table 3) were compared to this new data. This test indicated that the first laminate was good for an average of 110 lb./in. in the "MD" and 105 lb./in. in the "XD". Results from the second trial run specimens indicate tensile pulls in the range of 70-73 lbs./in. This was considerably below the expectation for this "improved" material. Also of concern was the high elongation of the second specimen - around 14%. This provided little improvement to the 31% of the first specimen.

For the purposes of this discussion, we will assume that there is no multiplication of tensile strengths beyond the sum of the individual constituents which go to make up the laminate - in each case, the TYVEK and the aluminum. The following properties are given by DuPont:

- Style 1058 - 6 mils; 45/37 strip tensile/in.; 32/33% elongation
- Style 1085 - 9 mils; 67/55 strip tensile/in.; 37/39% elongation.

With this, we can examine each lamination. In the first run, the composite was 1058 TYVEK, (6 mils) 10# P.E., .00035" aluminum foil, 10# P.E., and 1058 TYVEK (6 mils), or a total of 13.68 mils.

From previous data, we see that if the total laminate is tested to 113 p/i we can assume that the 1058 TYVEK could account for only 90 p/i (45 x 2). Therefore, since the soft polyethylene contributes negligibly, then the aluminum foil, or some multiplicity effect, must account for the other 23 p/i.

It was reasoned that since the "E" value of aluminum is 10×10^6 and the "E" value of TYVEK is around 26,000, a mil of aluminum contributes infinitely greater to the composite strength than does a mil of TYVEK. It was this reasoning that governed the material selection for trial run #2. Total thickness was 13.5 mils.

This total laminate tested, however to only 73 lbs./in. in tension. Since the TYVEK is good for 67 lbs./in., this indicates that only 6 lbs./in. were yielded from aluminum foil or some multiplicity effect. This phenomenon seems strange since the aluminum thickness was increased four and one-half times.

Inconsistencies in aluminum strengths were suspected and investigations were conducted. The possibility of a weaker alloy was suspected, but it was determined that in the 1145 series alloy used, .00035" foil has an ultimate tensile of 7000 psi. With the .0015", the ultimate tensile rises to 9000 psi. This would indicate a 28% increase in the tensile strength per unit area. These are, however, still extremely small portions of the total samples strength (around 2 to 4 lbs./in.)

The possibility of gaining significantly greater strengths could be obtained by going to harder tempers. This can be shown by the following physical data supplied by Anaconda Metals:

1145 annealed: .00025" to .00045", ultimate - 7000 psi
1145 annealed: .001" to .002", ultimate - 9000 psi
1145 full-hard: .00025" to .00045", ultimate - 20,000 psi
1145 full-hard: .001" to .002", ultimate - 22,000 psi
3003 full-hard: .001" to .002", ultimate - 31,000 psi

Although these would represent immense strength improvements, it should be noted that they are impractical to use. First, in order to roll hard tempers, copious amounts of oil are required. To laminate aluminum to the materials we are using, it must be clean and dry. Annealing drives off any rolling oils and is therefore a cheap way of preparing the material. To clean hard aluminum without annealing, expensive degreasing operations are required.

Another processing problem to consider is the tension of the web. This is a difficult (if not impossible) problem with hard tempers because of the high tension required; a bagging of the edge or center may result from stretching, and could even cause fractures. A tight, smooth web is essential to quality production.

The question of inconsistency between these two skin materials' physicals has not been adequately resolved. The only conceivable explanation must lie in some phenomenon of multiplicity of the assembled elements or a significant gain made through a "balanced" construction.

c. Foamboard Production

The completed substrate was processed into board with no difficulty. Foaming to the "corona" treatment polyethylene film inner face alleviates the problem of poor foam bond and air entrapment. Foam was uniform, but a more friable formulation would be desired. Friability would increase in time as the board cured more completely.

Although the foam-to-skin bond was good, the board was noted to have a peculiar "lead-like" quality. This can best be described as resembling lead in that it retains its configuration when flexed - that is, it is unstable. This property seems to be due to the soft, "punky" quality of the foam, and the high elongation of the skins. The skin stretches, yields permanently, then retains its flexed configuration. In this form, the board appeared to be unusable.

d. Conclusions

In general, spunbonded olefins have many attractive features, but their consideration as primary structural constituents is not warranted. The notion of a flexible sealing member that will not fracture under high stresses still seems valid, but strengths may have to be derived from foils. Recent possibilities are the steel foils which possess great strengths for very thin (.001") thicknesses. Attention must be given, however, to protection of the foil from rust and corrosion, and safety from the extremely sharp edges. There also is concern over any fractures cutting the skin and allowing moisture free access to the structural steel core.

D. <u>TEST RESULTS DISCUSSION</u>

1. <u>Full Scale Accordion Pleat Foamboard Shell Tests</u>

To provide a basis for structural evaluation of any small samples of candidate material, it was necessary to test a specimen of material with known physical properties. If tested in a situation that closely resembles the actual usage on the BBPS, then definitive data on wind load and snow loads can be calculated. The tests also demonstrated the mode of failure for the folded plate configuration.

The basic test was performed in two physical configurations. The first, with the folded plate elements not rigidly restrained in their normal geometry, and the second test with each cycle's geometry restrained by nylon webbing straps. This will be discussed in detail later in this section.

The general test set up is shown in figure 115. Test specimens were made up of four complete cycles of roof shell. To best simulate actual use conditions, all four cycles were loaded.

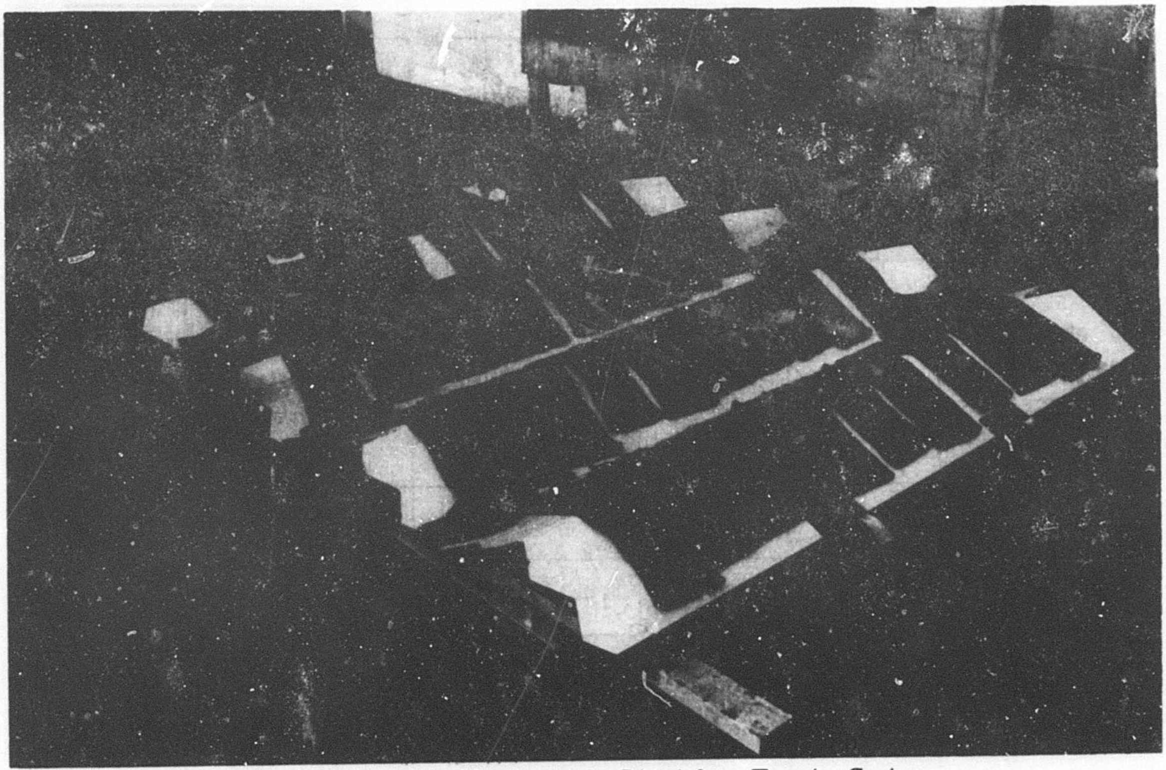


Figure 115. View of Static Test Setup

Initial loading observations, however, showed that the first and last cycles deflected unrealistically (see figure 116). It was felt that this was caused by the lack of support of adjacent cycles of foamboard (a 5th and 6th unloaded cycle). Bearing plates were attached to the supporting beams where the shell rested to prevent foamboard shear failures. (See figure 117).

Figure 116. Initial Deflection

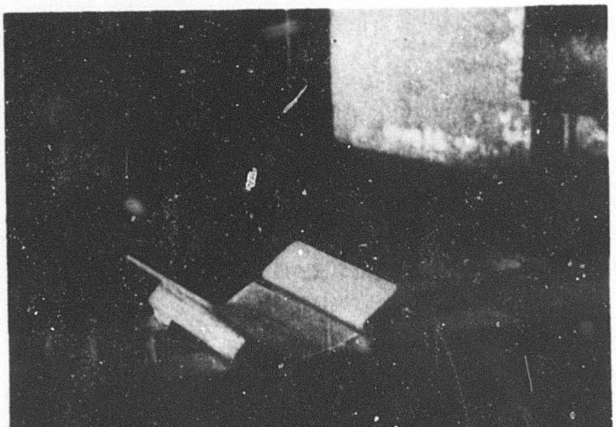


Figure 117. Bearing Plates

The first test was conducted at 40", 44", and 48" spans. Figure 118 shows the load-deflection curve for the 48" span.

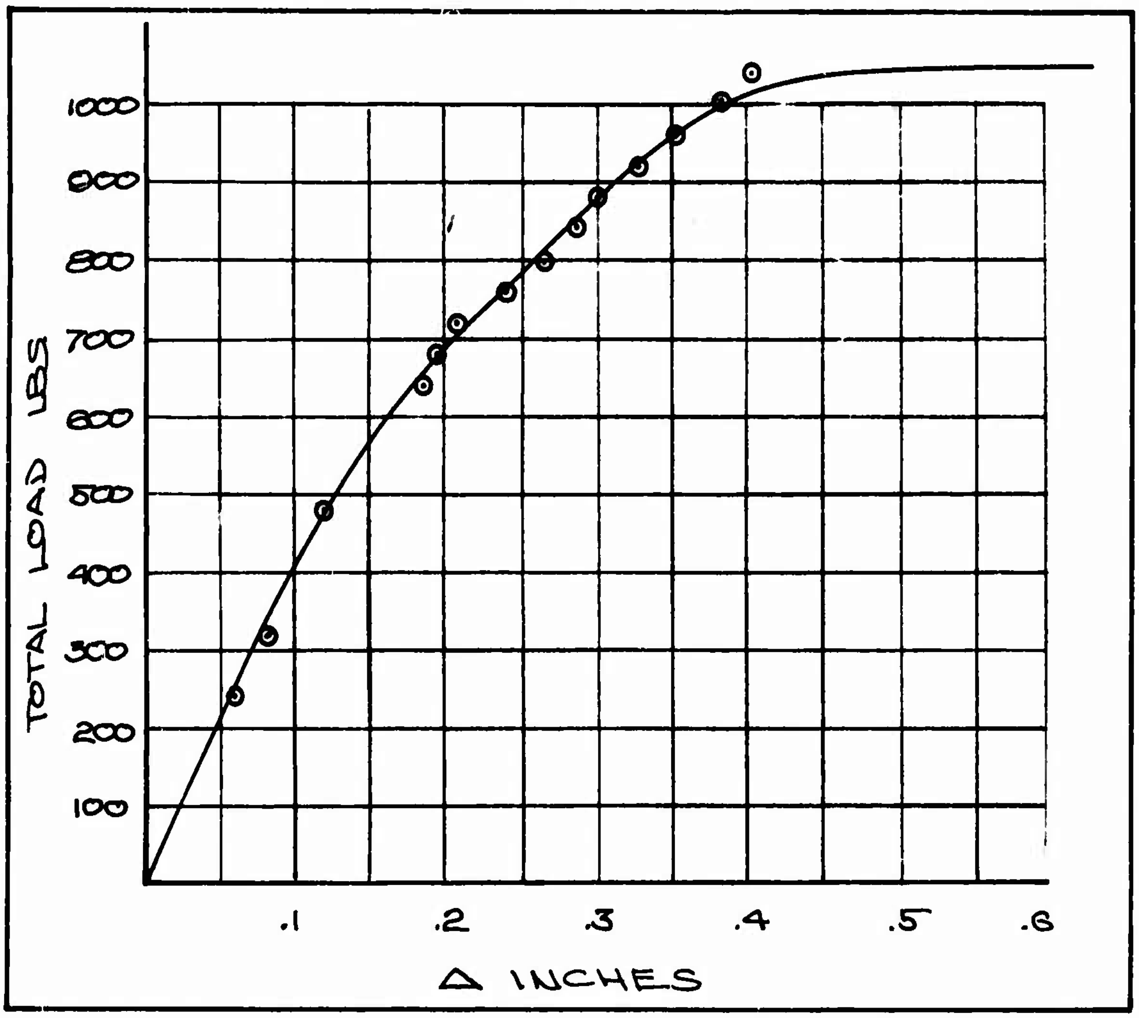


Figure 118. Load-Deflection Curve for 48" Span (Unstrapped)

$$\text{If } W/D = \frac{590}{.15} = 3933$$

$$= \frac{384\ EI}{5 \times 48^3}$$

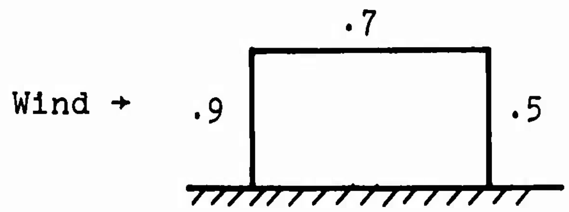
$$\text{Then } EI = \frac{5 \times 48^3}{384} \times 3933 = 5{,}663{,}991$$

EI per cycle = 1,415,997 or 1,400,000 approximately. From the foamboard tests in Appendix "B" we know that the maximum allowable working stress = 545 psi (factor safety 2.8) for any span:

$$F_b = \text{Allow. stress} = \frac{M \cdot Y}{I} \text{ or } M_{max} = \frac{FB \cdot I}{Y} \quad \text{and } 2Y = 5.31"$$

$$M_{max} = \frac{545 \times 4.1923}{5.31/2} = 860.56 \text{ lb./in. or } M = \frac{Wl}{8} = 860.56 \text{ lb/in}$$

These figures allow us to develop the necessary allowable load per square foot for any span. In considering wind, the coefficients have been determined as follows:



$$q = 0.00256\ V^2 \quad \text{where } V = \text{wind velocity in MPH}$$

$$q = \frac{\text{allowable load (lbs./s.f.)}}{\text{coefficient (from above)}}$$

The allowable wind load becomes: $V^2 = \dfrac{q}{0.00256}$

From this data, it was determined that the unstrapped shell would withstand 58 MPH continuous and 78 MPH gusts. This is not adequate by the contract commitment and therefore, the concept of the nylon webbing straps was investigated. This was introduced primarily because of observations of mode of failure in the first test. The peaks flattened out as the load was applied, thereby reducing the effective depth.

All other factors in the test remain unaltered, but the span was 74". Straps were placed at quarter-points and bonded to the shell with neoprene/nylon patches. Figure 119 shows the load-deflection curve, and figure 120 shows the straps in place on the test specimen. The resultant increase in allowable load is significant as shown in table 5.

TABLE 5. SUMMARY OF 5-PLY FOAMBOARD CAPABILITIES

LOAD CONDITION		UNITS	UNSTRAPPED	STRAPPED
Total Load/Ridge	Yield(working)	lbs.	93	150
	Ultimate	lbs.	167.5	220
Load	Yield	lbs/sq.ft.	7.88	12.71
	Ultimate	lbs/sq.ft.	14.19	18.64
Equivalent Wind Velocity on Sidewalls	Yield	mph	58.7	74.5
	Ultimate	mph	78.4	90.0

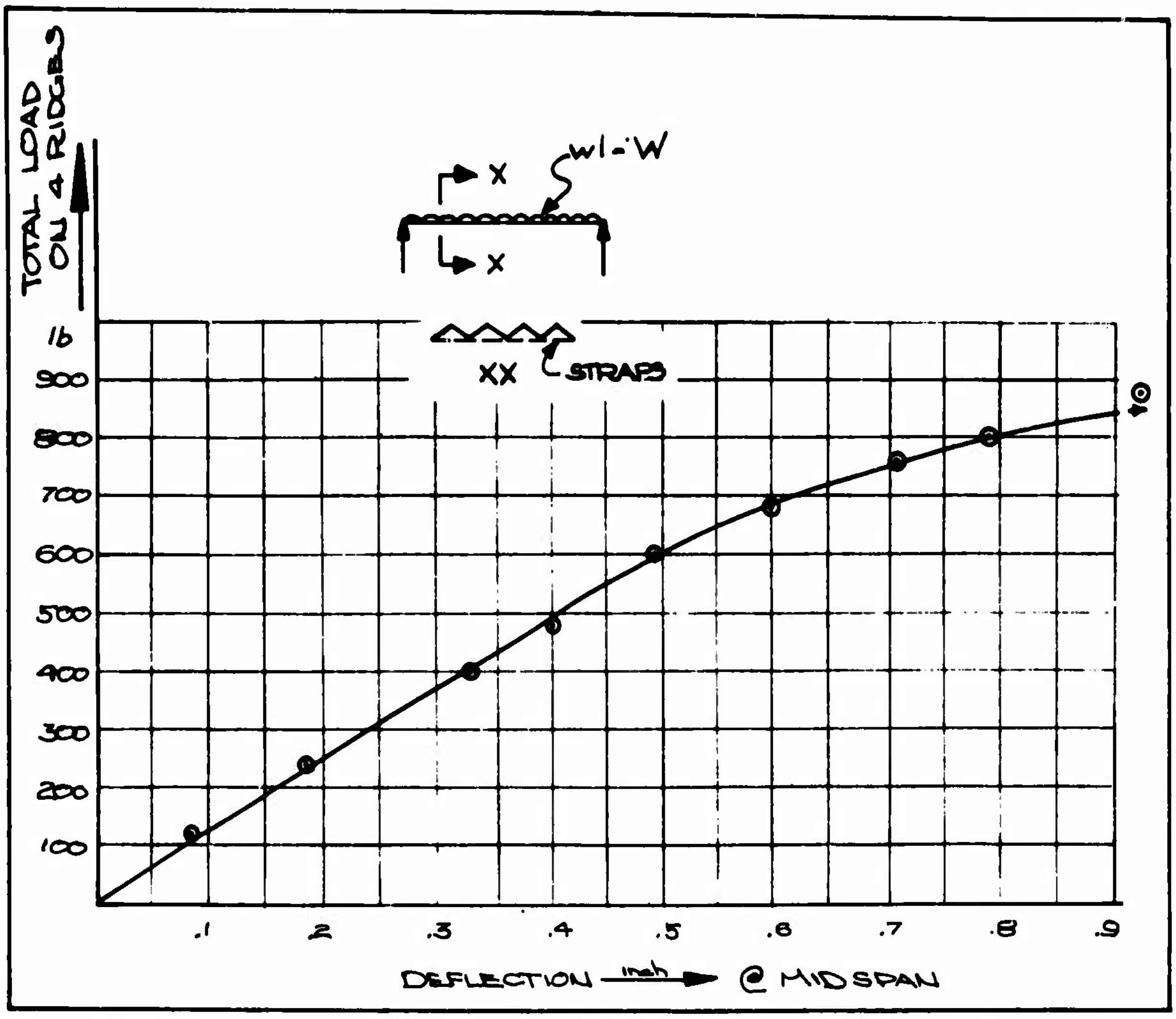


Figure 119. Load-Deflection Curve for 74' Span (Strapped)

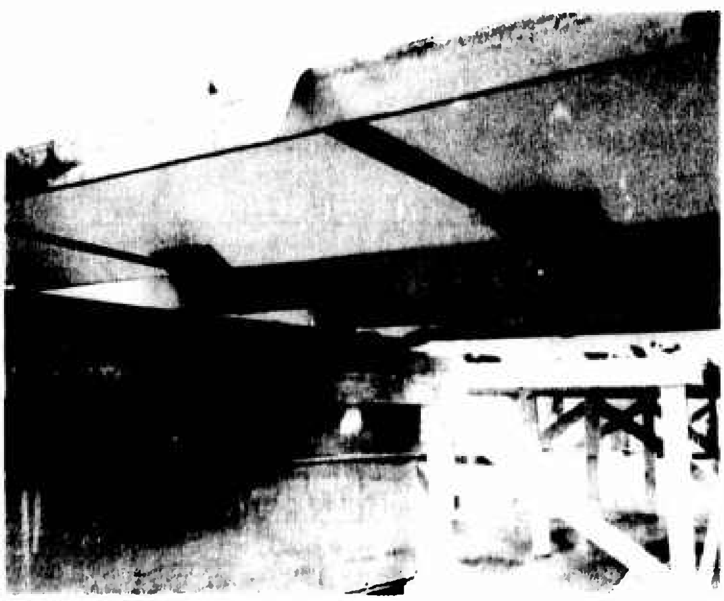


Figure 120. Foamboard Specimen with Straps

2. Laboratory Flexure Tests of Selected Foamboard

In order to provide a basis for comparison of existing, new and future foamboard composites, a small laboratory model flexural test was conducted. With the results of the previous section in hand, composite data generated from this test can be used to determine wind and snow load capabilities for any lab tested specimen used in the BBPS design.

Figure 121 shows the general test setup for the laboratory test. Specimens were simply supported on 1/8" radii, 17" span, loadings were uniformly distributed and applied at one pound per minute. Samples were 2 1/2" wide.

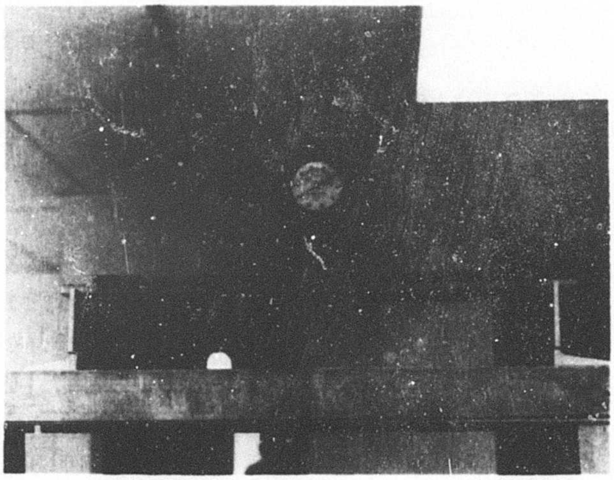


Figure 121. Laboratory Test Set-Up

The following materials were tested: all foam was polyurethane, 2.4 to 2.7# density, closed cell non-burning and board thickness was nominally .3". Actual thickness is recorded on each load-deflection curve (see figures 122 through 126).

TYPE "A" SAMPLES:	1/2 mil PVC coating (o.d. or white) 1 mil full-annealed aluminum foil 1 mil clear polyethylene as adhesive 49# natural kraft liner board 1 mil clear polyethylene as barrier interface
TYPE "B" SAMPLES:	1 mil PVC film (white) 1 mil full-annealed aluminum foil 1 mil clear polyethylene as adhesive 49# natural kraft liner board 1 mil clear polyethylene as barrier interface
TYPE "C" SAMPLES:	2 mil polyethylene film (o.d. or opaque white) 69# natural kraft liner board 2 mil clear polyethylene as barrier interface

Tests on Type "D" and "E" samples are similar to the previously outlined tests with the following exceptions:

1) Test span = 10"
2) Load increments = 1/2 pound
3) Samples not necessarily tested to destruction

TYPE "D" SAMPLES:
6 mil style 1058 TYVEK (o.d. ink with inhibitors)
1 mil clear polyethylene as adhesive
.00035" full-annealed aluminum foil
1 mil clear polyethylene as adhesive
6 mil style 1058 TYVEK (white, natural)

TYPE "E" SAMPLES:
9 mil style 1085 TYVEK (o.d. with inhibitors)
2 mil clear polyethylene as adhesive
1 1/2 mil full-annealed aluminum foil
2 mil clear polyethylene as barrier interface

The Type "D" samples were the only ones tested in which the barrier interface portion received no special treatment to allow better foam bond. On all other samples there was either a "corona" treatment or the poly was high-temperature extruded, producing the necessary oxide for adhesion.

Figures 122, 123, 124 indicate a straightforward stress-strain relationship for the materials presented. In general, the straight line sector at the beginning of the curve indicates that both the paper and aluminum are acting together within the plastic limit until the aluminum fractures. Then the paper absorbs the load at a slightly flatter slope until the ultimate stress is reached. Figure 124 shows only one slope before the yield which can be explained by the lack of aluminum in the composite. Figures 125 and 126 account for the unacceptability of the TYVEK materials for prime structural uses. Figure 125 has virtually no straight line sector, which demonstrates that as the material is stressed, it yields permanently. The aluminum (only .00035" thick) fractured below 2.0 pounds. Figure 126 shows the benefit of the much heavier aluminum sheet in the composite. The straight line segment of the curve is much longer and projects nearer the useful range (4 to 5 lbs.) before the aluminum fractures and the TYVEK absorbs the stress.
This "second" portion of the curve is very similar to the one in figure 125, which demonstrates that the TYVEK alone is working.

3. Heat Sealing Evaluation

Joining methods for assembling sheets of TYVEK finished board were also evaluated. The usual techrique involves 2" wide tapes that are coated with polyethylene or thermoset adhesives. The thermosets seemed attractive from an assemble standpoint since some such coatings are pressure-sensitive until cured under heat and pressure. Tests have shown poly to TYVEK to be relatively poor, but the thermosets showed promise from ultimate dependability and assembly ease. These tests were not expanded due to the problems encountered with the skin composite.

E. CONCLUSIONS

In summary, the following general conclusions have been drawn:

1. It is the consensus that the concept of foamboard or a cheap, thin-sandwich composite is an excellent possibility for several reasons:
   - Fewer on-site connections and joints
   - Lightweight components
   - Greater structural integrity
   - Economy
   - Excellent insulative qualities
   - Rapid mass-produced fabrication techniques
   - Great possibilities for environmental resistance

2. Plastic sheets (and, in fact, thin metal sheets less than .005") don't behave in predictable patterns. When utilizing these materials, a thorough verification of engineering data should proceed any trial production run.

3. A thorough understanding of polyurethane foam properties and processes should be undertaken by qualified consultants to project predictable behavior patterns of the material for this application.

4. The Celotex manufacturing process is an undue restraint upon the development of substantially improved materials. This sole source of foam-in-place board material seems to be the single biggest barrier to development.

5. There appears to be an exponential increase in tensile strengths as thin film composites are added rather than a single sum of the individual strengths of the constituents. This appears to happen in unpredictable patterns.

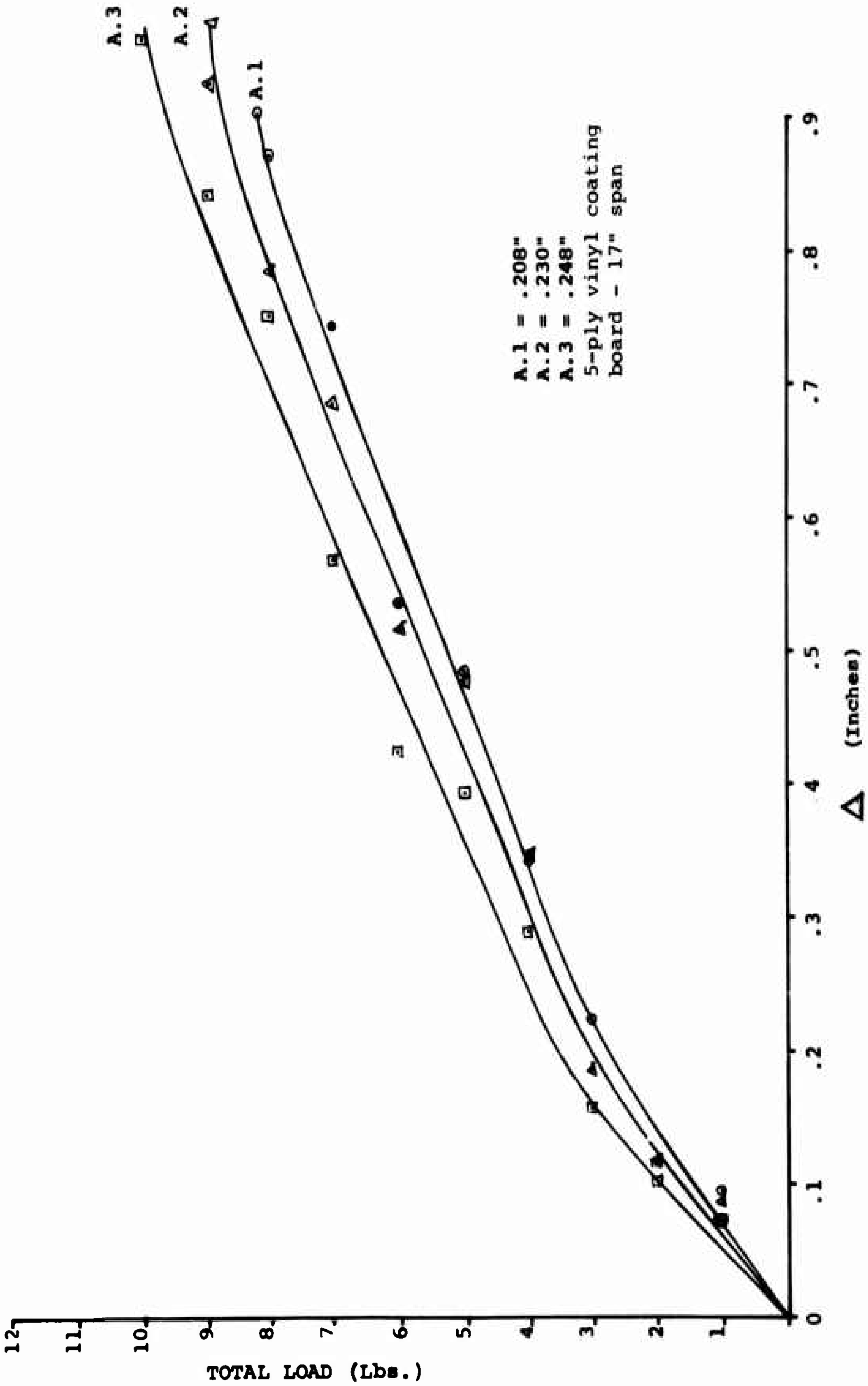


Figure 122. Load-Deflection Curve - Type "A"

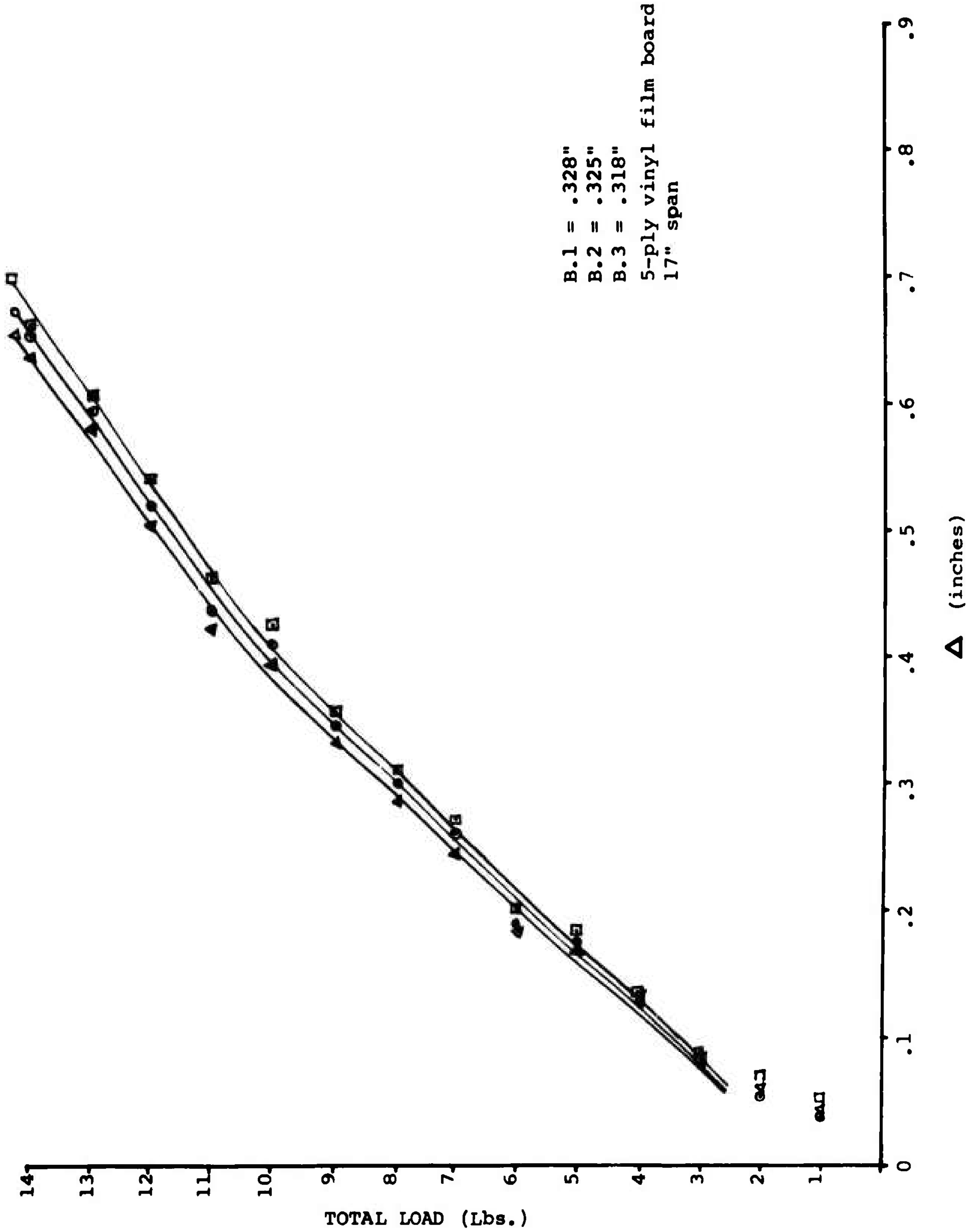


Figure 123. Load-Deflection Curve - Type "B"

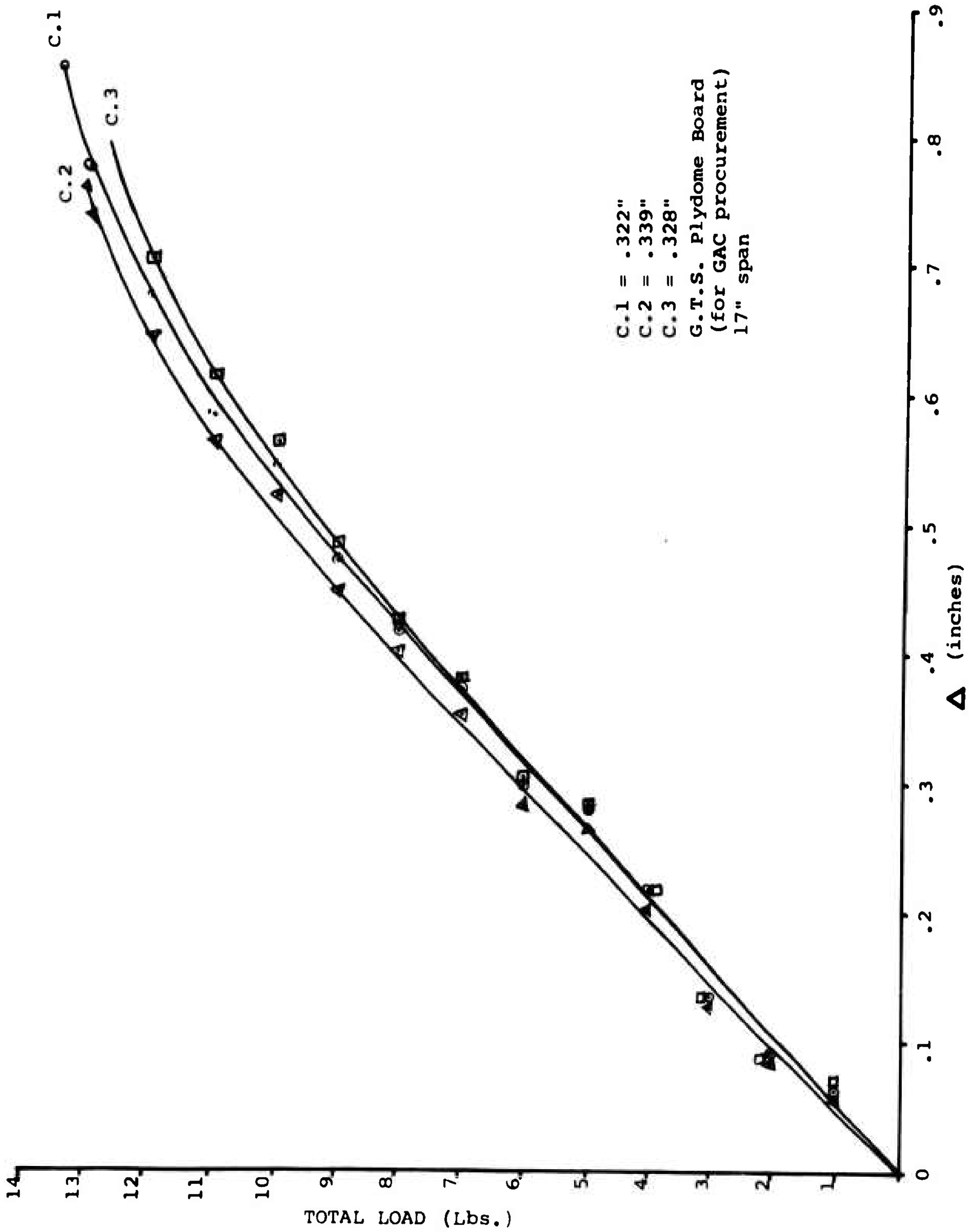


Figure 124. Load-Deflection Curve - Type "C"

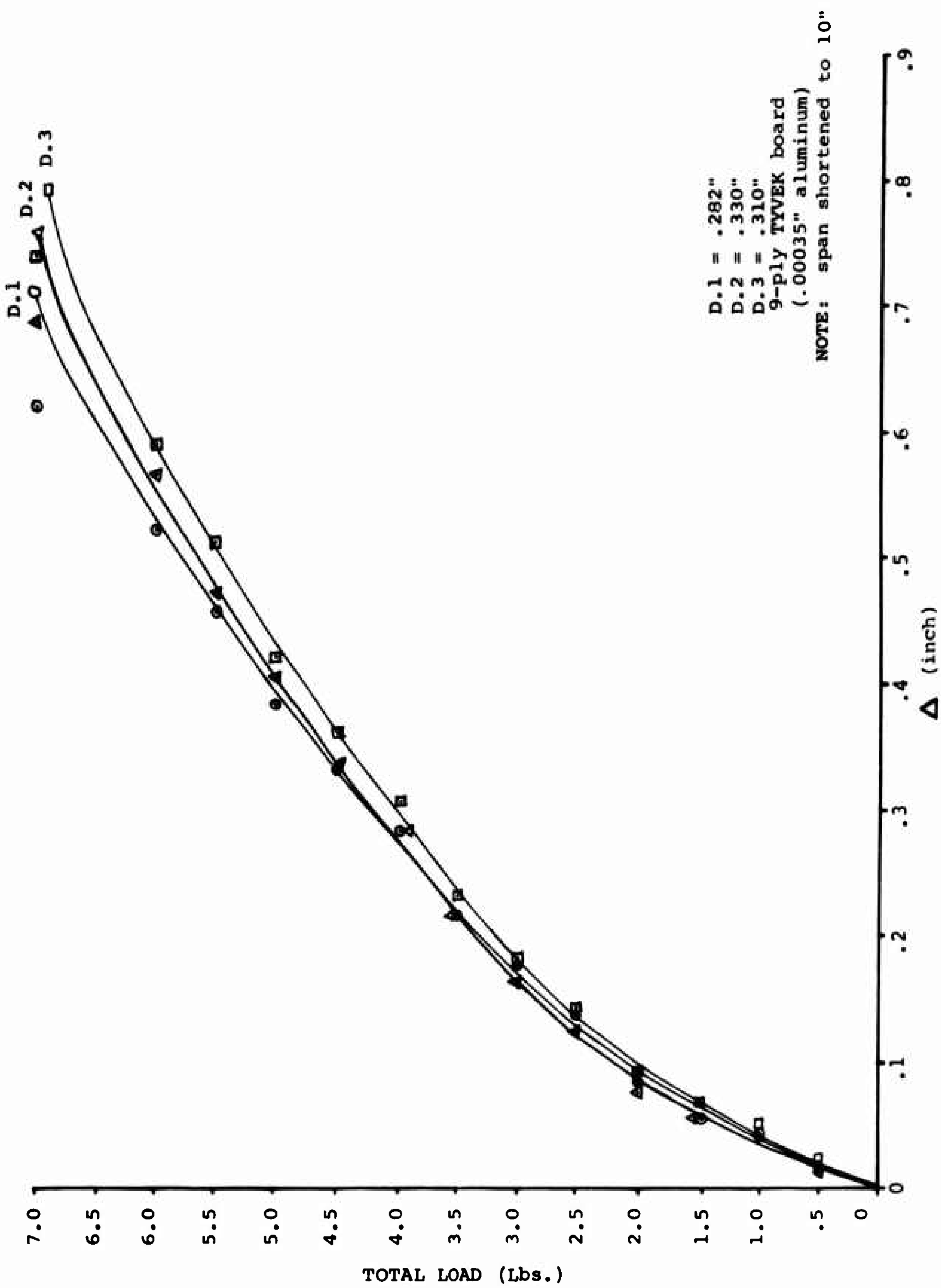


Figure 125. Load Deflection Curve - Type "D"

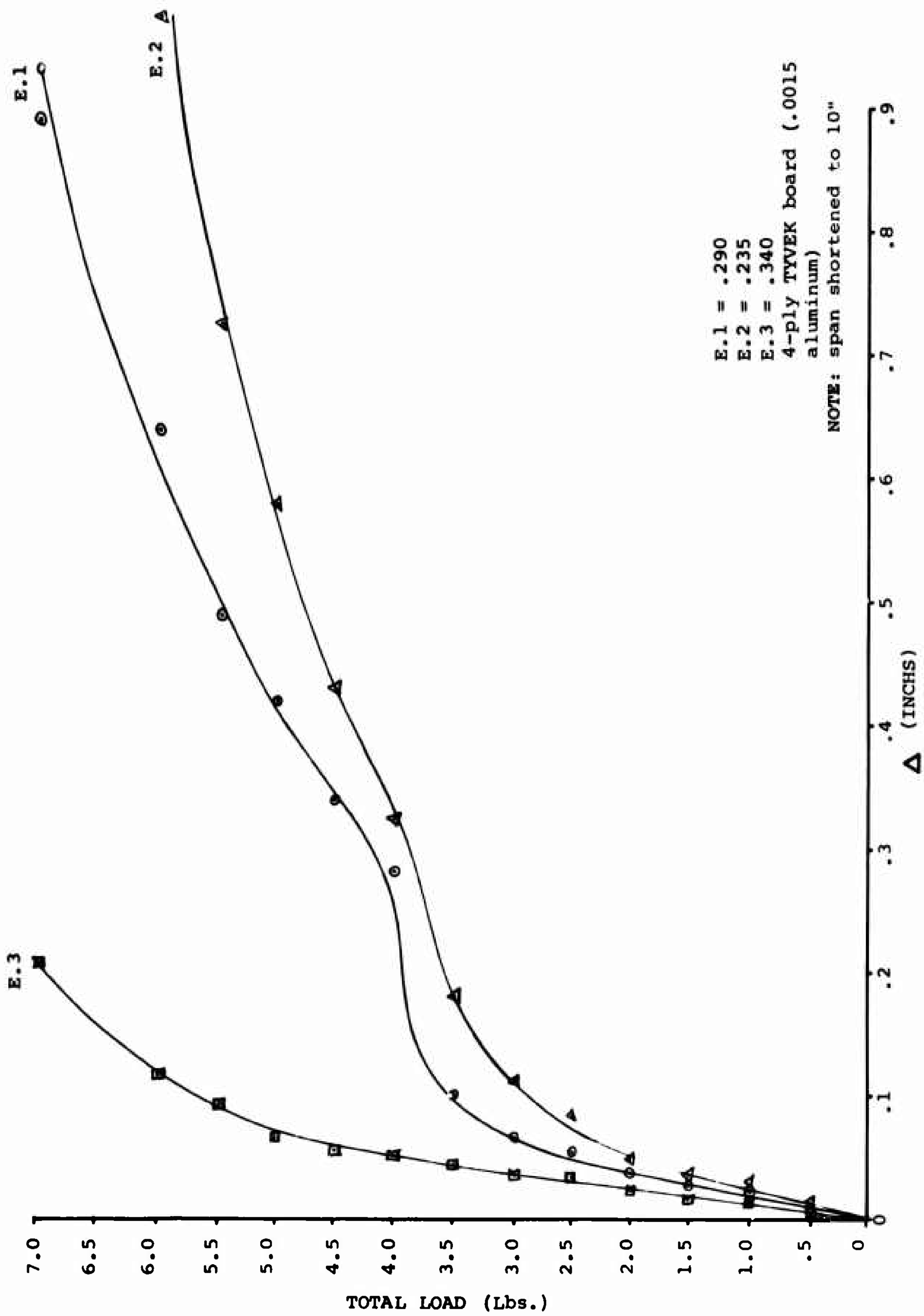


Figure 126. Load-Deflection Curve - Type "E"

VI

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Concurrence with Provisions of Contract

a. The concepts established for advanced modular shelters for small and medium size shelter applications followed the program outlined in the statement of work as amended at various points as the work progressed. Major amendments include the integral pallet feasability study, a size change for the personnel shelter to 13' x 33', a size change to 29' x 45' for the intermediate shelter, and a change in reporting procedure on the intermediate shelter.

The major deviation to the contract plan was, of course, the unanticipated partial termination of the contract that resulted in the delivery of uncompleted prototype III and IV of the personnel shelter. It is understood that this termination was for the convenience of the government, and it is felt that this action had a minimum impact on the successful development of production models of the personnel shelter.

b. The general program plan for investigation of new foamboard skin materials (as outlined in the proposal and work statement) was adhered to as this work was performed. Full-scale fabrication and testing of shells was accomplished at WPAFB, rather than in University facilities. This came about as a result of consultation with the AFTM, ACO and PCO and became an amendment to the contract.

Full scale test prototypes of the BBPS shells were not fabricated from the new TYVEK-faced board. As outlined in III B and C above, this further fabrication and testing would have served no purpose. Any data that could have been generated from such a test was reliably obtained from the small scale tests run on all materials.

2. General Conclusions on Shelter Concepts

a. The concept of rapidly deployable, 100% recoverable shelters that provide significant increases in user comfort and standard of living appears to be an easily attainable goal for the size buildings we are dealing with.

b. In order to attain expansion ratios greater than approximately 5:1 for small size shelters, unique methods of enclosure such as folded foamboard become necessary innovations.

c. In an effort to reduce dunnage, the current BBPS design is extremely effective. Rather than ship the personnel living gear separately (cots, footlockers, pillows, etc.), their inclusion in the shelter package could result in substantial savings. Reduction of pilferage is also significant.

d. Shelter leveling will always present problems. When a floor system is provided, it must be level -- not just planar. Attempts have been made to design a structure that could be erected on a planar surface only, but this has proven unsatisfactory. There is evidence to substantiate the theory that the more level the ground surface preparation is, the tighter the weatherseals can be.

e. For reasons of safety, the shelter must be anchored to the ground securely while the structure is being erected. With structures that utilize lightweight components, this becomes extremely important.

f. The cost goals imposed on the design are not attainable for the degree of sophistication desired. This is offset, however, by the dunnage costs eliminated.

g. A foamboard intermediate size structure (24' x 48') could be developed with current technology, but the expansion ratio would be so low as to be impractical.

h. Use of the hangar components developed to make an intermediate size shelter has proven to be an extremely efficient system with a high expansion ratio.

3. Specific Conclusions - Small Shelter Concepts

a. Concurrence with Provisions of Contract

Shelter prototypes were constructed according to the modified statement of work with exception mentioned in VI.A.1. above (partial temination). Because of the slight compression of schedule (in preparation of a procurement package for large scale acquisition), the planned testing program was modified.

Prototype I underwent cold-weather testing at the plant of the sub-contractor at Northfield, Minnesota. The tropic test program was planned to be conducted at the Climatic Hangar, Eglin AFB. This plan was followed; however, the full elevated temperature/humidity cycle was not imposed on the shelter because of previous scheduling commitments for the facility.

Prototypes II through IV were not tested according to the work statement plan because of the termination and additional compression of schedule. Prototype II was completed enough to allow modified testing at WPAFB (non-climatic) to evaluate operating characteristics and any inherent weaknesses.

As previously mentioned, Prototype III was completed by Air Force technicians and was tested for three weeks in the Canal Zone, Panama. No arctic operational testing was conducted on Prototypes II through IV.

b. The testing and evaluation phase disclosed data which allow the following conclusions:

1.) The foamboard shell material suffers from lack of durability. Weathering causes degradation when the substrate interior or unsealed edge is exposed.

2.) Although the foamboard shell is relatively thin (.3"), its thermal characteristics are very desirable in an arctic heating condition. Actual data was not developed on BTU output required to heat the unit.

3.) The longitudinal seams (heat seals) between foamboard walls and roofs should be eliminated if possible. This would require production of board in 28' lengths.

4.) It should be noted that the floor and leveling system is designed for billeting type uses. Office and shop type utilization (high concentrated loads) may severely damage the structure.

5.) In making the shell sidewall to floor joint, positive alignment longitudinally is required. Vertical alignment is somewhat more flexible when the roof beams are in their lower position. The last recommended design solution has effectively dealt with this problem.

6.) Wind velocities of the level required in the work statement were not experienced at any point in testing. It is known, however, that 40 knot winds can destroy the shelter, if not securely anchored.

7.) The overall erection sequence works extremely well. The factory hinged end wall is a great aid to this procedure.

8.) The floor support/leveling jacks may suffer from corrosion as they are made from painted steel. Dependable operation may be impeded by their use, but development costs for a corrosion-resistant version were not within the scope of this contract.

9.) The doors used in the end walls became thermal transmitters resulting in much heat loss. A custom built door would have many benefits but its cost versus operational benefits doesn't warrant its development at this time.

10.) It is anticipated that the shelters would be transported grouped three abreast and would lock into the 463L rail system. A C-130 full load would hold 9 such shelters - completely filling the available interior cubage of the aircraft. Air crew egress (through the back door) would be impaired at the wheel wells but this may be tolerated in a war time deployment. Since the wheel wells fall partially in row 2 and 3, three abreast could only be shipped in the first row.

4. General Conclusion on Foamboard Research Effort

The Type "B" foamboard (as delineated in the small scale foamboard test in section V.D.2.) is capable of withstanding wind loads of 74 MPH continuous and 90 MPH gusts in the strapped (maintained geometry) configuration. This was the only board tested that did meet the contract structural loading requirements. Note also this was in the strapped configuration.

Attachments to facings and joining of boards still can present problems. Generally, in consideration of rapid production, hot melt adhesives for attachments and heat sealing tapes (with thermosets or polyethylene backing) seem most desirable and, in fact, seem to be the only solutions for facings such as Polyethylene (TYVEK), Mylar, and Tedlar films. Vinyls, which present many problems in temperature expansion, contraction, and plasticizer migration, could be bonded with many common adhesives but this would be too slow to be practical.

In consideration of new skin materials, the foam interface is of primary consideration. Even though polyurethane will bond effectively to many surfaces, the surface must be smooth (rather than porous) to avoid air entrapment in the Celotex process. Olefin materials must have an oxide present to get a good bond. This can be produced by high-temperature extrusion coating or electrostatic treatment. Bonding to aluminum will require a shellac wash coat to allow adhesion. Materials must be free of moisture and must have a low MVTR to keep water vapor away from the reacting resins. TYVEK is therefore unacceptable for this interface.

An idealized foamboard specification has been formulated as shown below:

FOAMBOARD SPECIFICATIONS

PRODUCT DESCRIPTION: .3" thick polyurethane core foamboard sandwich panel, produced from free-blown foam-in-place operation.

FOAM: 100% closed cell polyurethane foam 2.35 to 2.75# density, non-burning.

SKIN MATERIALS: Various. Necessary properties listed below:

Perhaps the most critical attribute of any skin candidate is that of the smooth, non-porous foam interface surface. The Celotex process allows no air entrapment at this interface or a reaction will occur between the urethane resins and moisture in the ambient air, liberating CO_2 gas.

The skin must provide an MVTR comparable to polyethylene through the foam interface. Further, the skin must be either impervious to moisture or unaffected by it.

The goal for wet strength shall be 90% of original strengths (see below) and no appreciable degradation of strengths by wet/dry cycling.

Excellent U.V. exposure qualities. The use life of the material should approach 5 years.

Service environment of -40° F to +180° F with good low temperature foldability (without cracking) and with no chalking or plasticizer leeching from the skin at the indicated elevated temperatures. The material must be foldable without internal delamination of the plys or bulk of skin.

Ultimate tensile strengths of approximately 125# per inch width are necessary with maximum elongation of 4%. These figures indicate a relatively high modulus of elasticity in relation to plastic films. Unfortunately, when scoring and folding occurs, the stresses at score lines are comparatively great causing cracking. Ideally, the skin's exposed face should have a very elastic property that allows some resulting strain to occur without initiating a major structural crack.

It is desirable to have the "XD" strengths and elongation within 85% of the "MD" since the material is stressed extensively in both directions.

Capacity for easy color change of exposed surface.

Flame resistance required. Exact specifications not available, but when flame source is removed, the material should not sustain the flame longer than three seconds. "Self Extinguishing" would be an adequate goal.

Material must be resistant to mold, fungus, mildew and rot.

Surface finish must be bondable with inexpensive adhesives or must allow heat sealing without extensive preparation.

Some grease and oil resistance is necessary, i.e., no appreciable loss in strength when exposed to solvent vapors. A goal of 75% of original strength is desirable.

Material should be supplied in up to 56" widths, with rolls up to 50" diameter on 4" fiber cores without metal ends. Exposed face must be wound out on the rolls. Splices must be with high-temp tape.

B. RECOMMENDATIONS

1. Small Shelter Concepts

a. Investigate elimination of thru-metal on hardened panels such as floors, endwalls, and the center-core box. This would prevent frost formation and would reduce heat loss.

b. Foamboard shells should be viewed as field replaceable items with an approximate 2 year use life. Continued foamboard research is necessary and may eliminate the need for a fabric fly sheet over the shells.

c. It is recommended that an adjustable shipping adaptor rail be developed. This would allow shipment of shelters one or two abreast with full utilization of the 463L system.

2. Foamboard Research Work

To conclude research and development on this type of material at this point, with no further development follow-on, could not possibly be in the best interests of the Air Force. The benefits to be derived from expanded research in this area are immense in terms of weight-savings and, if good design practices are observed in utilization of such a material, man hours saved in use of such buildings and equipment.

It is recommended that a follow-on to this effort be initiated. This should be a broad, comprehensive investigation of presently available materials, new innovations in material, different core materials, high volume manufacturing processes for selected materials, and a study of fabrication techniques.

VII

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APPENDIX "A"

STRUCTURAL DESIGN OF BARE BASE PERSONNEL SHELTER

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APPENDIX "A"

STRUCTURAL DESIGN OF BARE BASE PERSONNEL SHELTER

General Nomenclature and Outline of Cases

The proposed personnel shelter must withstand several loading conditions. These have been grouped into two major categories for structural consideration.

In Part I snow loading is discussed. The contract calls for 20 lbs./sq.ft. on the roof. See figure 127, below, for the general dimensions.

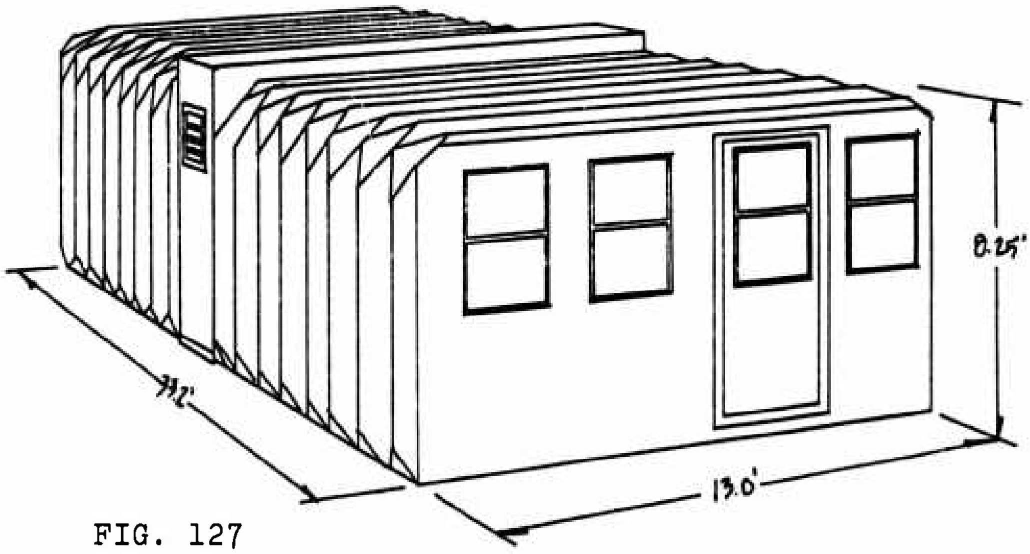

FIG. 127

Also included in Part I are floor loadings at 30 lbs/sq.ft.

Part II Investigates Wind Loadings.

As outlined, the requirement is for 69 m.p.h. continuous loadings or 90 m.p.h. gusts. The two cases for investigation are discussed below:

Case (1) When the wind blows from the side (into the 33' dimension):

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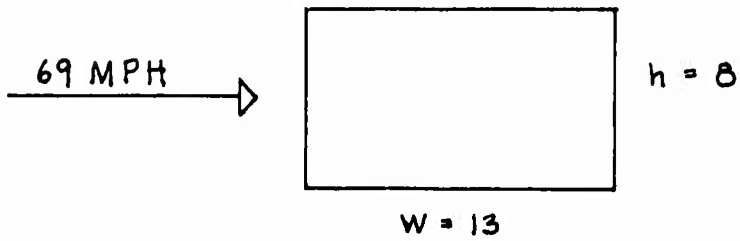

FIG. 128a

$q = 0.00256V^2 = 12.2$ lbs./sq.ft. (PSF)

$\frac{h}{\omega} = \frac{8}{13} = 0.615$

∴ The pressure coefficients[1] can be shown in figure 128b.

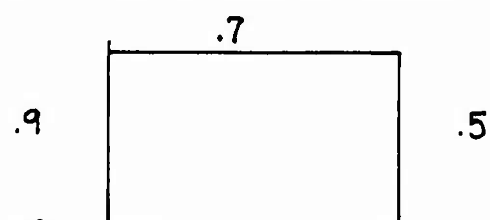

FIG. 128b

Since P=qc, then the loading on the specified structure will be as shown in figure 128c.

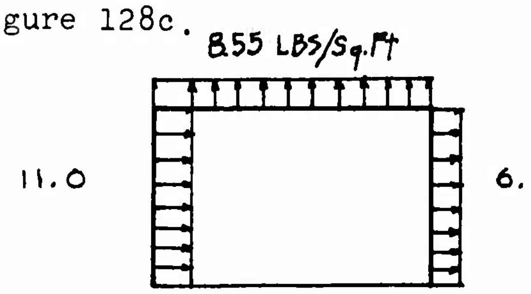

FIG. 128c

Case(II) When the wind blows in against the frontal face (into the 13' plan dimension), the pressure coefficients would be as shown in figure 129a,

Since $\frac{h=8}{\omega \ 33} = 0.242$

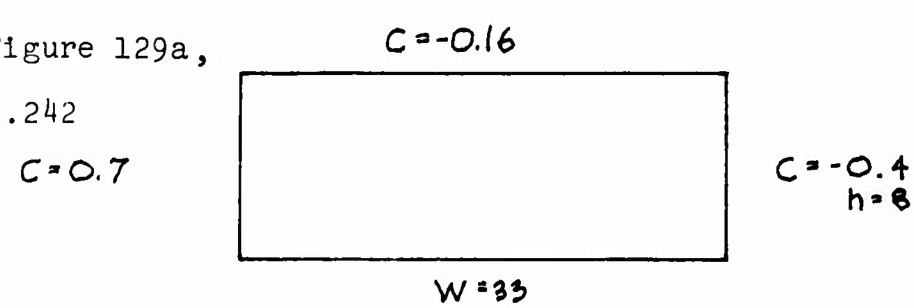

FIG. 129a

(1.) Reccommended Design Practices Manual, MBMA, 1967 Edition

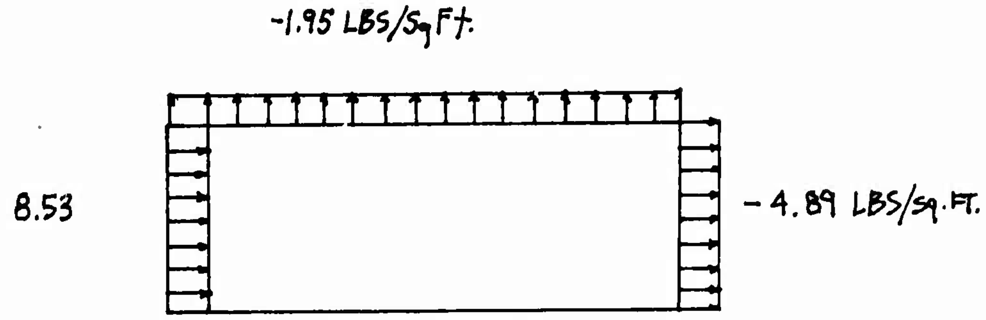

FIG. 129b

Since P = qc, the wind pressure loadings across the structure become as shown in figure 129b:

A general structural schematic of the personnel shelter is shown in figure 130. The basic notations used here are adopted throughout the analysis.

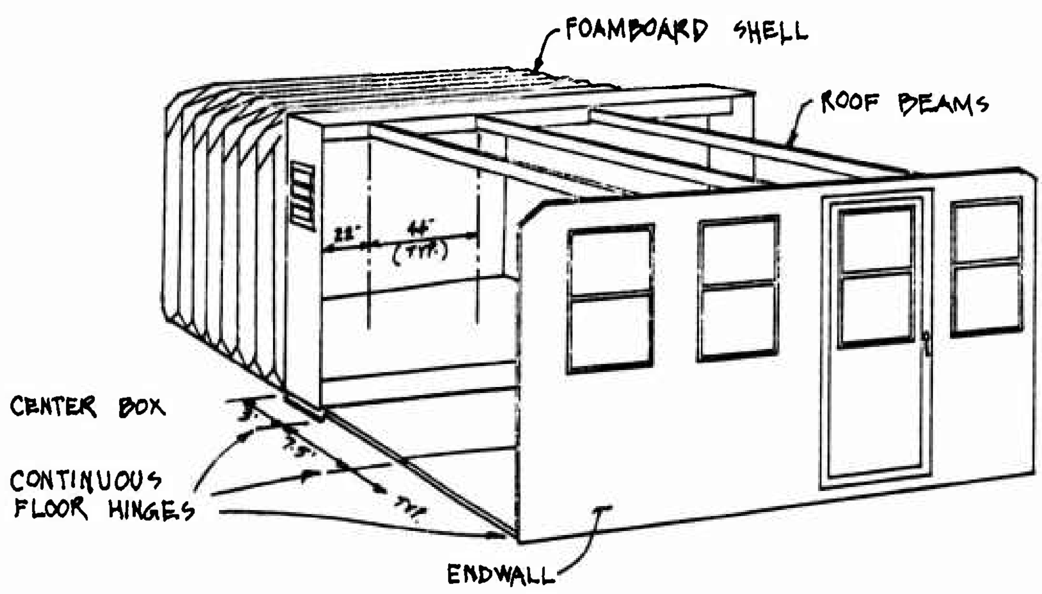

FIG. 130

Part II also concerns itself with loads imposed by logistics movements (dynamic loads).

Design of Roof Beams: Figure 131 shows over all dimensions of the roof beam in the use mode.

$$\omega = 20 \times \frac{44}{12} \times \frac{15}{16.5} = 66.7 \text{ lbs/ft.}$$

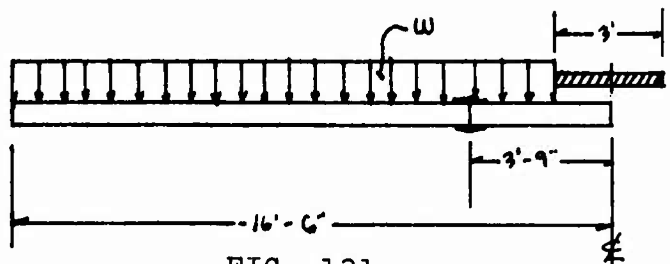

FIG. 131

Maximum moment in the center of the beam, $M = \dfrac{\omega \ell^2}{8}$

$$M = \frac{66.7 \times (16.5)^2}{8} = 2280 \text{ lbs. ft.}$$
$$= 2280 \times 12 = 27{,}400 \text{ lbs. in.}$$

Deflection of the beam at maximum loading condition (snow loading) is restricted to $\Delta = 2.0''$

$$\Delta = \frac{5\omega\ell^4}{384EI} = \frac{5 \times 66.7 \times (16.5 \times 12)^4}{12 \times 384 \times 10 \times 10^6 \times I}$$

$$\therefore \ I \text{ req'd.} = \frac{11}{2} = 5.5 \text{ in}^4$$

Figure 132 shows the proposed cross section for the roof beams.

$$I = \frac{3 \times 5^3}{12} = \frac{2.875\ (4.75)^3}{12}$$

$$= 31.2 - 25.6 = 5.6 \text{ in}^4$$

$$A = 5 \times 2 \times \frac{1}{16} = 4.75 \times 2 \times \frac{1}{8}$$

$$= 0.625 = 1.18 = 1.805 \text{ sq. in.}$$

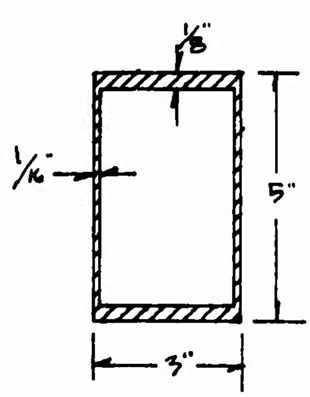

FIG. 132

Maximum stress in the beam becomes:

$$f = \frac{M.y}{I} = \frac{27400}{5.6} \times 2.5 = 12.220 \text{ p.s.i.}$$

Load across beam hinge:

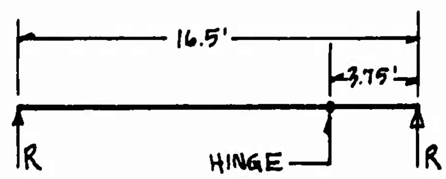

FIG. 133a

$$R = \frac{66.7 \times 16.5}{2} = 550 \text{ lbs}$$

$$M_{hinge} = R \times 3.75 - \frac{66.7\ (3.75)^2}{2}$$

$$= 2060 - 469 = 1591 \text{ lbs.ft.}$$

$$= 19{,}100 \text{ lbs. in.}$$

$$F_{on\ hinge} = \frac{19100}{5} = 3820 \text{ lbs.}$$

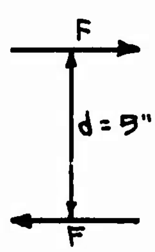

FIG. 133b

<u>Design of Center-section / Box:</u>

The total static loads on the box considering snow, dead weight of the shell, roof beams, etc.

= 4400 lbs.

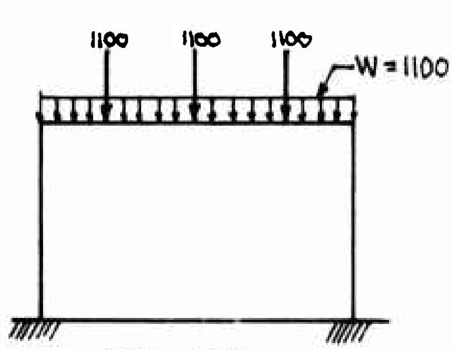

FIG. 134

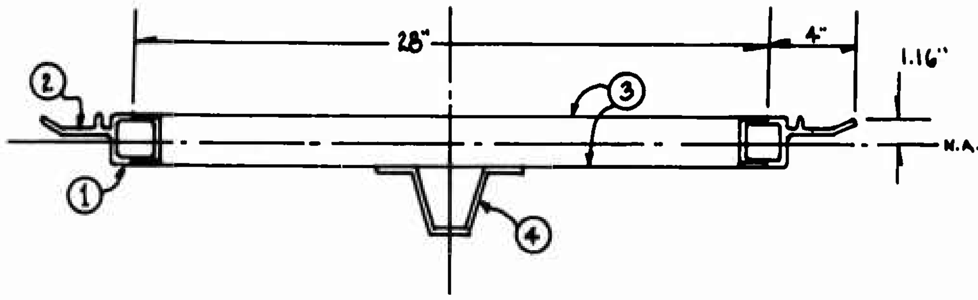

FIG. 135a

It is assumed that the roof and sides would be joined so as to act as a rigid frame.

Figure 135a shows the structural elements for the top of the box.

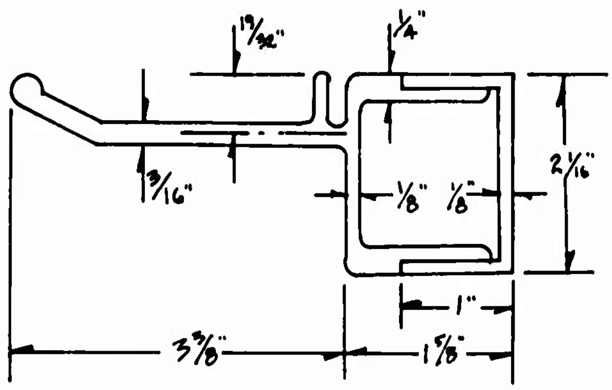

FIG. 135b

$A_1 = 2\,[2 \times 1.625 - 1.5 \times 1.375]$

$\quad = 2.38$ sq. ins.

$A_2 = 2[3.375 \times .1875]$

$\quad = 1.265$ sq. ins.

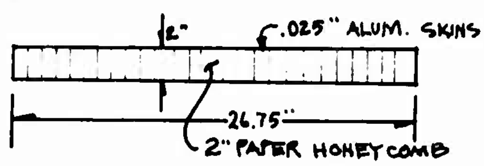

FIG. 135c

$A_3 = 26.75 \times 2 \times 1 \times 0.025 = 1.337$ sq. ins.

$A_4 = 0.759$ sq. ins. (Standard aluminum shape)

Total area for roof = 5.741 sq. in.

To determine the neutral axis position; taking moments about the top skin:

$$A_1 \times 1 = A_2 \times 0.594 = A_3 \times 1 = A_4 \times 2.9 = 5.741X$$

and $X = 1.16''$

To determine the moment of Inertia;

$$I_1 = 2\left[\frac{1.625 \times 2^3}{12} - \frac{1.375 \times 1.5^3}{12}\right] = [1.081 - 0.388]\ 2$$

$$= [0.693 \text{ in.}^4]\ 2$$

I_2 about its own axis is negligible

$I_3 = 26.75 \times 2\ [1 \times 0.025] \times 1^2 = 1.325 \text{ in.}^4$

$I_4 = 0.55 \text{ in.}^4$

$$I_{total} = 2 \times 0.693 + A_1 \times (0.16)^2 + A_2 \times (0.566)^2 + I_3 + A_3 \times (0.16)^2 + I_4 + A_4\ (1.74)^2$$

$$= 6.048 \text{ in.}^4$$

Figure 135d shows the structural elements for the box sidewalls;

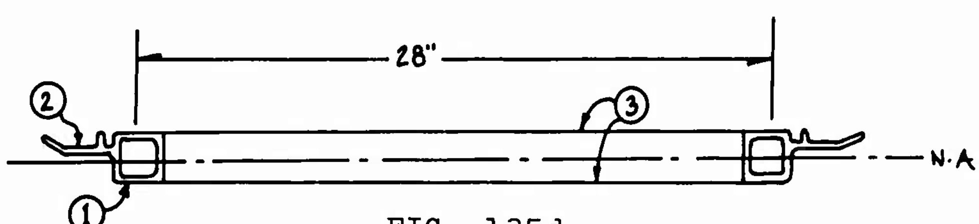

FIG. 135d

$A_1 = 2.38 + [2 \times 1 \times .125]\ 2$

$= 2.88$ sq. ins.

$A_2 = 1.265$ sq. ins.

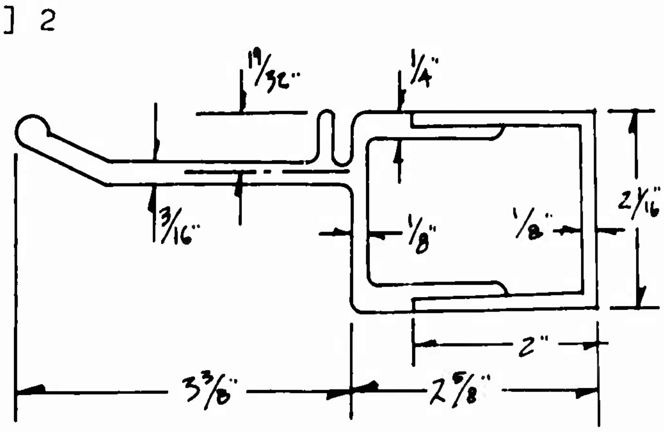

FIG. 135e

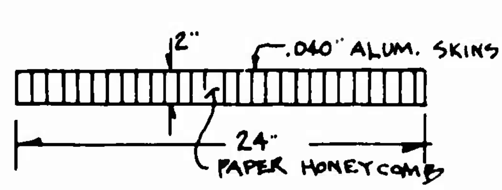

FIG. 135f

$A_3 = 24.0 \times 2 \times 1 \times 0.040$

$= 1.916$ sq. ins.

Total area $= 6.061$ sq. ins.

To determine the neutral axis position; taking moments about the top skin:

$$A_1 \times 1 + A_2 \times 0.594 + A_3 \times 1 = 6.061\ X$$

$$X = \frac{5.546}{6.061} = 0.915''$$

$\therefore$ eccentricity = 0.085"

To determine the Moment of Inertia;

$$I_1 = [.0693 + (\frac{1 \times 2^3}{12} - \frac{1\ (1.75)^3}{12})]\ 2$$

$$= (0.931)\ 2$$

I_2 about its own axis is negligible

$$I_3 = 24 \times 2(1 \times 0.040) \times 1^2 = 1{,}916$$

$$I_{total} = I_1 + A_1 x(0.085)^2 + A_2 x(0.321)^2 + I_3 + A_3\ x(.0.085)^2$$

$$= 1.826 + 0.0208 + 0.1301 + 1.916 + 0.01383$$

$$= 3.907\ in^4$$

Radius of gyration, $r = \sqrt{\frac{I}{A}} = \sqrt{\frac{3.907}{6.061}} = 0.803$ ins.

Moment Distribution across the Box:

$h = 8'$, $\ell = 13'$

$I_b = 6.048$, $I_c = 3.907$

M = Bending Moment

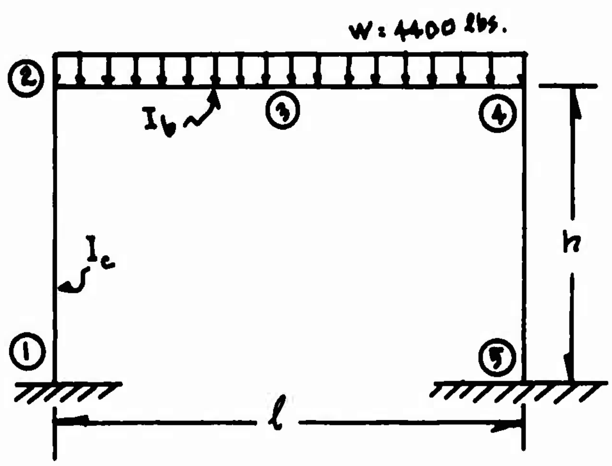

FIG. 136

$$M_2 = \frac{W\ell}{F}\text{(1)} \text{ where } F = 6\left(2 + \frac{1}{\phi}\right)$$

$$\text{and} \quad \phi = \frac{I_b}{I_c} \times \frac{\ell}{h}$$

$$\therefore \phi = \frac{6.048}{3.907} \times \frac{13}{8} = 2.49$$

$$F = 6\left(2 + \frac{1}{2.49}\right) = 14.40$$

therefore $M_2 = -\dfrac{4400 \times 13}{14.40} = -\ 3980$ lb.ft.

$$M_3 = \frac{W\ell}{8} + M_2 = 7150 - 3980$$

$$= +\ 3170 \text{ lb.ft.}$$

and $M_1 = -\dfrac{M_2}{2} = +\ 1990$ lb.ft.

The allowable stress in the sidewalls becomes: (2)

$$f_c = \frac{102000}{\left(\frac{K\ell}{r}\right)^2} \quad \text{and if } K = 0.7,\ \ell = 90''$$

$$= \frac{102000}{(78.5)^2} = 16.6 \text{ KSI}$$

And the actual stress in the sidewall is:

(1) Bending; $\sigma b = \dfrac{M.y}{I} = \dfrac{3980 \times 12}{3.907} \times 1 = 12230$ PSI

Figure 137 shows the bending moment diagram across the center box for snow loading.

(1) Frames and Archs; by Leontovich, P. 32

(2) Alcoa Structural Handbook, P. 110

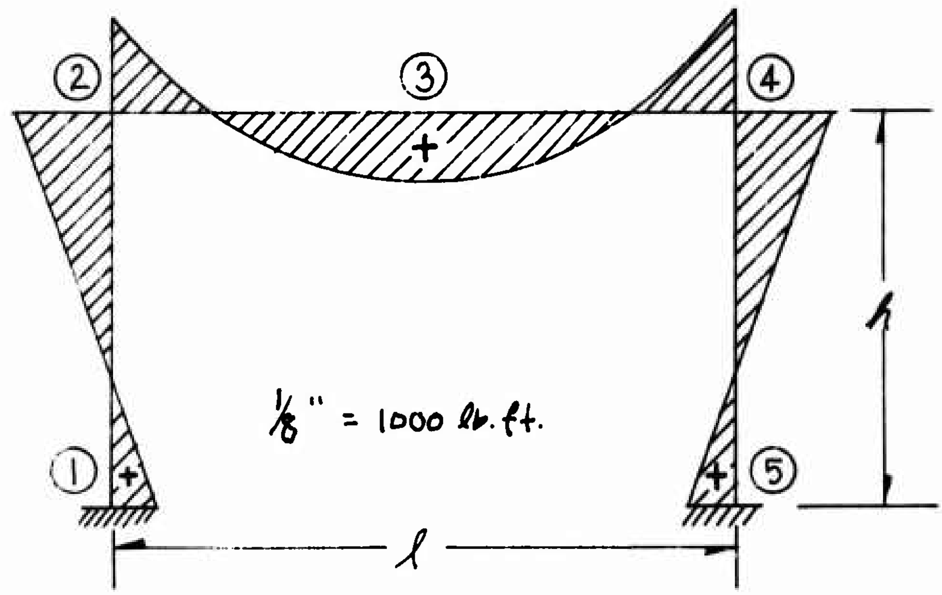

FIG. 137

(2) Direct Compression;

$$\sigma c = \frac{P}{A} = \frac{2200}{6.061} = 363 \text{ PSI}$$

Total stress = 12230 + 363 = 12593 PSI <16600 o.k.

Bending stress in the top of the Box is:

$$\sigma = \frac{M.y}{I} = \frac{3980 \times 12}{6.048} \times 1 = 7050 \text{ PSI} < 25000 \text{ o.k.}$$

Also, 1/4" thick aluminum gusset plates are required at all four corners of the box structure.

Design of Floor System

The flooring system must withstand 30 lbs./sq.ft. uniform loading.

$$W = \frac{30}{144} = 0.208 \text{ lbs/sq.in.}$$

Figure 138 shows the dimensions for a typical floor panel under consideration.

For the 1st degree of approximation, a unit width of the floor can be considered loaded uniformly and simply supported between hinges.

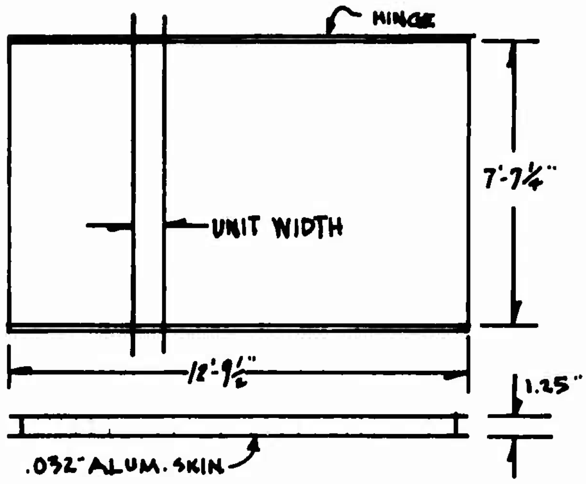

FIG. 138

Deflection of floor at mid-span:

$$\Delta = \frac{5\omega\ell^4}{384EI}$$

$$I = 2x1x\ 0.032"x\ (0.625)^2 = 0.025\ in^4/in.\ width$$

$$\therefore\ \Delta = \frac{5x0.208\ x\ (91.25)^4}{384\ x\ 10x10^6x0.025} = 0.75"$$

If allowable deflection $= \frac{1}{120}$ x span $= \frac{1}{120}$ x 91.25

$= 0.76" > 0.75"$ o.k.

Maximum stress developed in the floor $= \sigma b = \frac{M.y}{I}$

$$M = \frac{0.208\ x\ (91.25)^2}{8} = 216.5\ lbs.in.$$

$$\sigma_b = \frac{216.5}{0.025} \times 0.625 = 5420\ PSI < 25000\ o.k.$$

To determine the jack spacing under hinge lines between floors:

Loading, $\omega = 0.208 \times 45.5$

$= 9.45$ lbs./in.

$$I_{chan.} = \frac{1.25\ x\ (1.25)^3}{12} = \frac{1.125\ x\ (1.00)^3}{12}$$

$= 0.203 - 0.094 = 0\ .109\ in.^4$

$$I_{skin} = 2\ x\ 1\ x\ 0.032\ x\ (0.625)^2 = 0.025\ in\ ^4/in.$$

$= 0.0312\ in.^4/1.25\ in.$

Total I/floor edge $= 0.019 + 0.0312$

$= 0.1402$

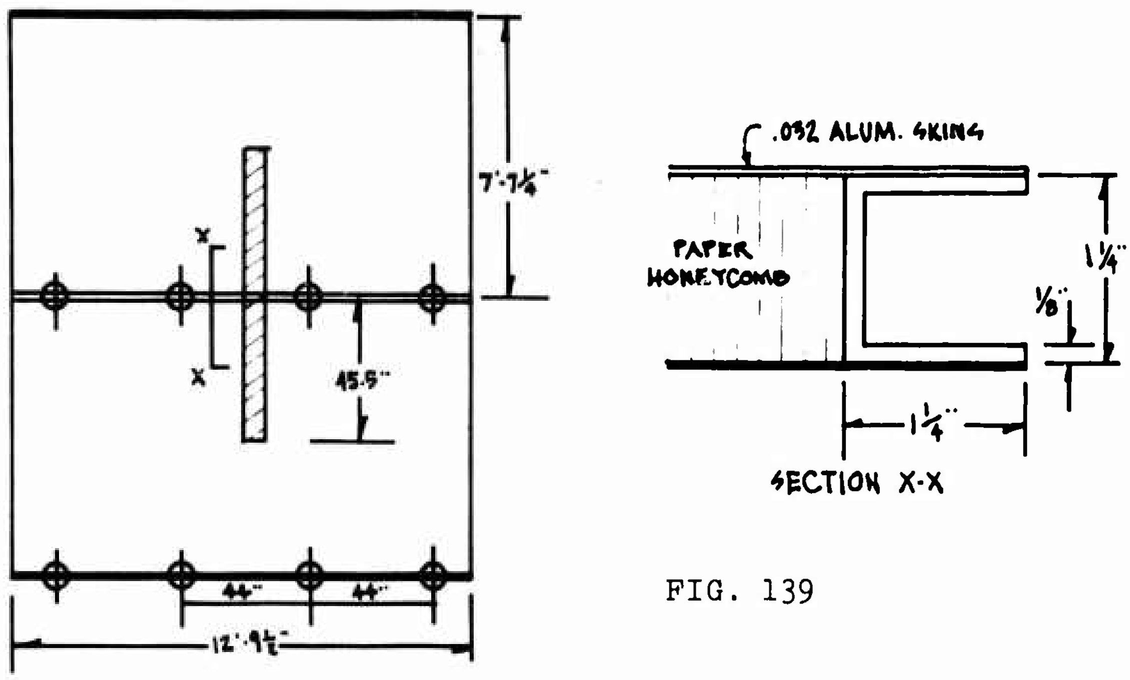

FIG. 139

If the distance between jack/supports is 44", the maximum deflection becomes:

$$\Delta = 0.0092 \frac{\omega \ell^4}{EI}$$

$$= \frac{0.0092 \times 9.45 \times (44)^4}{10 \times 10^6 \times 0.140} = 0.233"$$

If allowable deflection is limited to $\frac{1}{120}$ of the span

$$= \frac{1}{120} \times 44 = 0.367" > 0.233 \text{ o.k.}$$

Checking shear between Al skin and channel extrusion:

$$V = 9.45 \times \frac{44}{2} = 210 \text{ lbs.}$$

$$Q = 1.25 \times 0.032 \times 0.625 = 0.025$$

$$S = \frac{VQ}{Ib} = \frac{210 \times 0.025}{0.140 \times 1.25} = 30 \text{ lbs./sq. in. per inch}$$

Use 3/16" machine screws every 6" to fasten hinge to channel.

Endwall to Floor Connection (Hinge):

Determining loading,

Snow load = 3 x 550 = 1650

Endwall load = 160

$$\overline{1810} \text{ lbs.}$$

the load/unit length = $\frac{1810}{13}$ = 139 lbs/ft.

Assume 1.5" long curls on hinges. Therefore, 8 curls per foot.

load/curl = $\frac{139 \times 2}{8} \approx 35$ lbs.

Checking bending on the curls if they are not welded closed:

(1/4" ϕ pin, 1/8" thick curls)

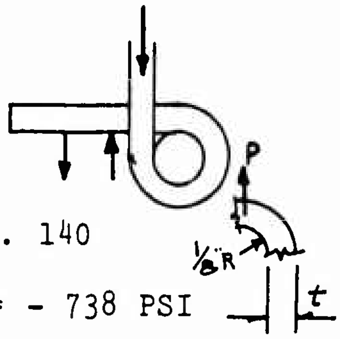

FIG. 140

$P.r = 35 \times \frac{3}{16} = 6.56$ lb. in.

$= \frac{6.56}{1.5} = 4.38$ lb.in/in length

$$\text{Max } \sigma_b = \frac{KM}{I} y \;^{(1)} = -0.81 \times \frac{4.38 \times 1/16}{0.0003} = -738 \text{ PSI}$$

$$= +1.30 \times \frac{4.38 \times 1/16}{0.0003} = +1180 \text{ PSI}$$

$$\sigma_t = \frac{P}{A} = \frac{35}{1.5 \times 1 \times \frac{1}{8}} = 187 \text{ PSI}$$

$\therefore$ Total σ = 1180 + 187 = 1367 PSI

(1) Strength of Materials, by Singer, P. 409

Design of Endwall:

The endwall is made of sandwich construction using aluminum skins. Edge extrusions close out the panel all around and other interior extrusions are provided for load bearing capability (see figure 141). Figure 142 shows the loading from the roof beams into the endwall.

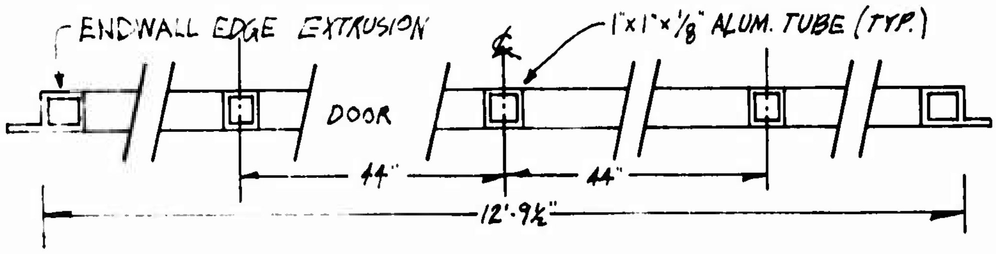

FIG. 141

The sectional properties of the endwall are as follows:

I = 0.412 (minimum)

A = 2.128 sq. in.

$\therefore r = \sqrt{\frac{I}{A}} = 0.44$

Allowable $f_c = \frac{102000}{\left(\frac{KL}{r}\right)^2} = \frac{102000}{(191)^2} = 2800$ PSI

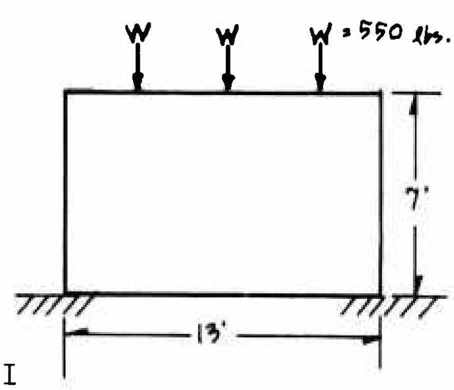

FIG. 142

The maximum stress created in the endwall

$= \frac{1810}{2.128} = 850$ PSI< 2800 o.k.

PART II WIND LOADING

As mentioned at the start of this analysis, case (I) and case (II) refer to the wind direction relative to the shelter.

Case (I):

Here the wind is blowing into the 33' dimension of the shelter (see fig. 15a)

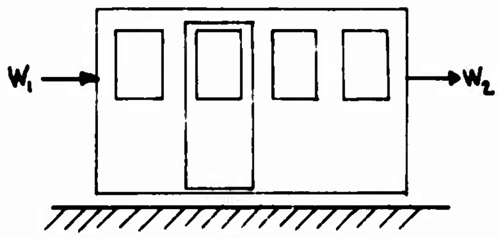

FIG. 143a

With the wind coefficients from the introduction we can determine the load intensity at a section through the foamboard shell as shown in figure 143b.

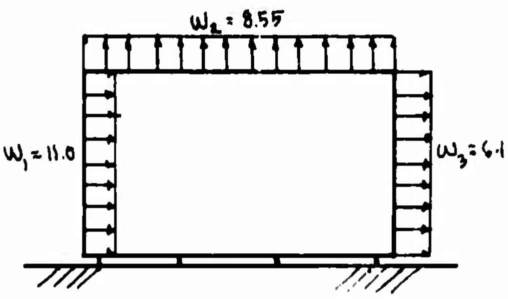

FIG. 143b

And from previous analysis, $W_1 = 726$ lbs. and $W_2 = 404$ lbs.

∴ the loading across the box can be shown in figure 144a :

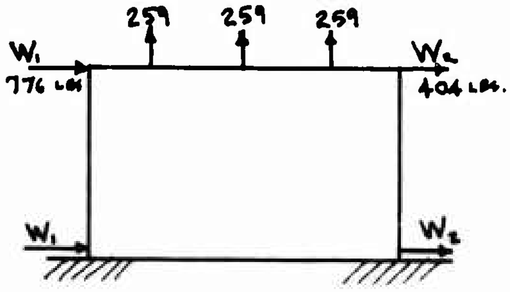

FIG. 144a

As shown in figure 144a, there would be uplift and side loading on the box.

(i) In consideration of uplift only (figure 144b)

$W = 3 \times 259 = 780$ lbs.

Since roof beams are continuous and the load is assumed to be spread evenly.

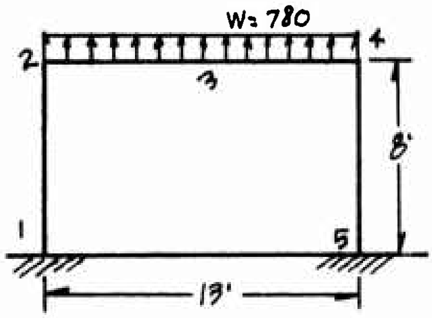

FIG. 144b

$M_1 = -\frac{WL}{2F} = -\frac{780L}{2x14.4} = -352$ lb.ft.

$M_2 = -\frac{WL}{F} =$ 704 lb. ft.

$\therefore M_3 = -\frac{WL}{8} + \frac{WL}{F} = -1265+704=-561$ lbsft.

(ii) In consideration of side load only (figure 144c).

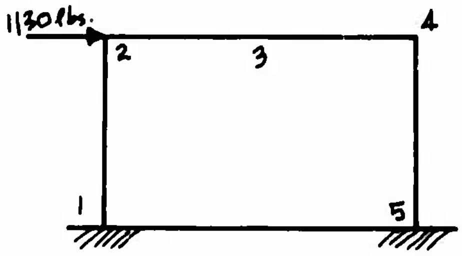

FIG. 144c

$M_1 = -Ph\ (\frac{1}{2}-K)$(1) ; $K = \frac{3}{D\phi}$

and $D= 2\ (1+\frac{6}{\phi})$

$K = \frac{3}{2(1+\frac{6}{2.49})\ x\ 2.49} = 0.485$

$\therefore M_1 = -1130 \times 8 \times (0.5-0.485) = -135$ lb.ft.

$M_2 = +PhK = 1130 \times 8 \times 0.485 = 4380$ lb.ft.

$M_4 = -PhK = -4380$ lb.ft.

The total of wind loading on the box can be shown in figure 145 and the moments are:

$M_1 = -487.5$

$M_2 = 5084$

$M_4 = -3676$

$M_5 = +135.5 - 352$

$= -216.5$

(1) Frames and Archs, by Leontovich, P. 31-41

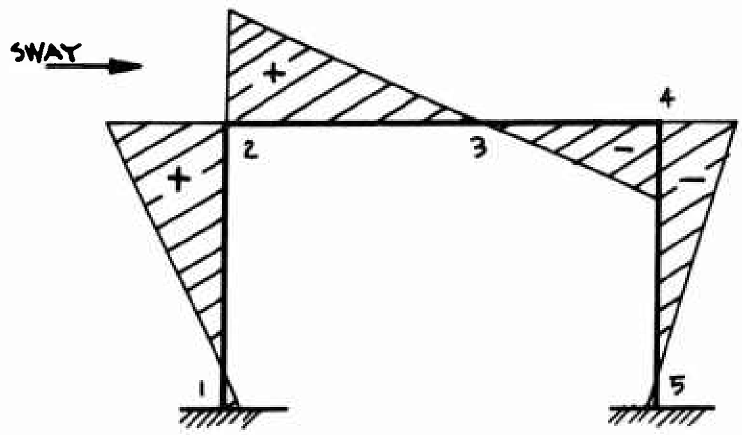

FIG. 145

Maximum stress created by wind in the box section.

$$\sigma_b = \frac{M}{I} y = \frac{5084 \times 12 \times 1}{3.907} = 15600 \text{ PSI} < 25000 \text{ o.k.}$$

Case (II)

Here, the effects of frontal wind on the structure are analyzed The loading coeffients and load intensity are shown in the introduction.

The load through the roof beams:

$F = 13x7\ (8.53 + 4.89)\ 1/2$

$= 610$ lbs.

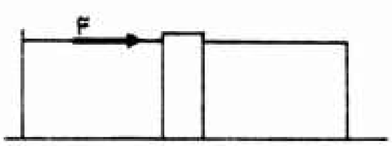

FIG. 146

It is assumed that this load is absorbed by the shell and the side walls of center box.

In considerations of uplift on the roof section, the critical case occurs in the foamboard shell (mid-span). Two cases are considered:

(i) If roof shell is not strapped down to the roof beams:

The reaction to the side walls of the shell

$= \frac{8.55x4}{2} = 47$ lbs. ft.

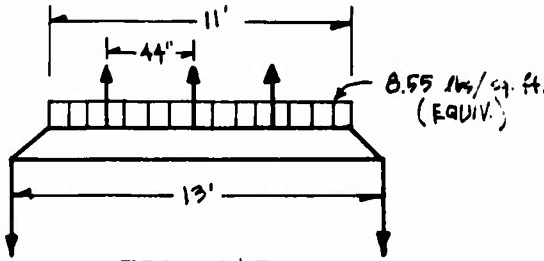

FIG. 147

From previous tests, it has been determined that the maximum capacity of the shell is 4.0 lb/sq.ft. at a span of 11': Therefore, the shell must be strapped down.

(ii) With the roof shell strapped to beams:

Load on each roof beam = $8.55 \times \frac{44}{12} = 31.4$ lb./ft.

load/ridge connection = $\frac{31.4 \times 22}{12} = 57.8$ lbs/ridge (fig. 148)

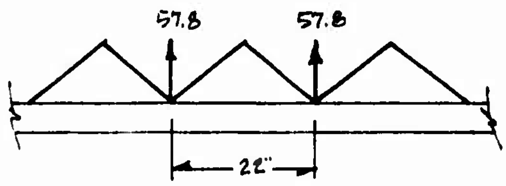

FIG. 148

In consideration of uplift load on the floor jacks, we again consider two cases:

(i) Due to side loading:

$610 \times 8 = 2F_2 \times 3$

$\therefore F_2 = \frac{1625}{2} = 812.5$ lbs/jack

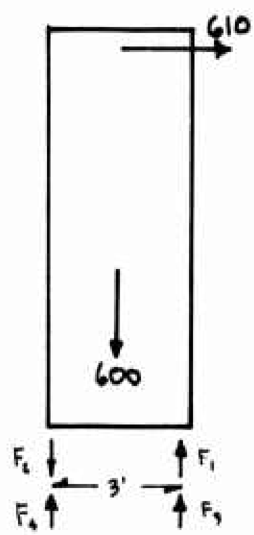

FIG. 149

$F_3 = F_4 = \frac{300}{2}$ lbs

$\therefore$ uplift/jack =667.5 lbs.

(ii) Due to uplift on the shell and roof:

16.5 x 11 x 12.2 x 0.5 = 1110 lbs. total uplift on half of roof.

Load/jack = 277 lbs.

Loads Imposed By Handling (Dynamic Loads)

Weight of each unit with accessories inside = 3000 lbs.

Dynamic factor of safety = 2.5

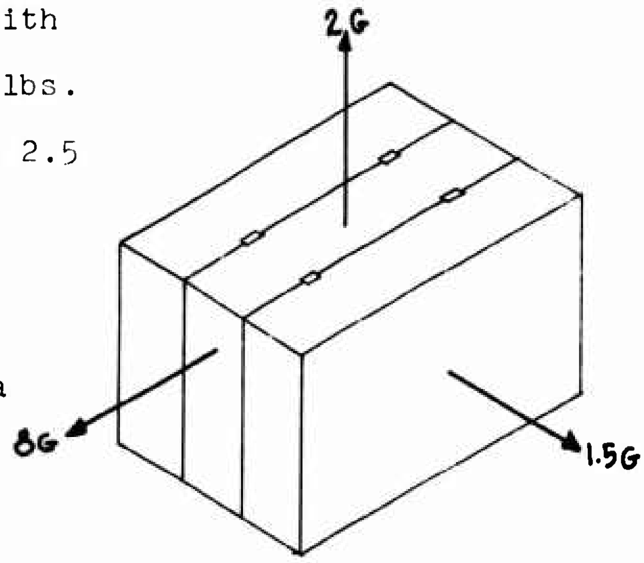

FIG. 150a

Therefore, the loads exerted at the connections between boxes are as indicated in fig. 150b.

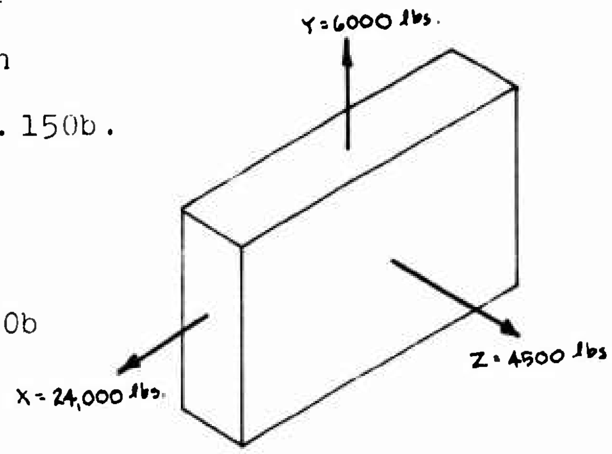

FIG. 150b

In the process of erection or lifting the shelters in 3's, the loads on box-to-box connectors will be as shown in Fig. 150c.

Taking moments about B,

$$\frac{22500}{2} \times 3 - 3000 \times 1.5 - T \times 8 = 0$$

$$T = \frac{31.5}{8} \times 1000 \simeq 4000 \text{ lb (tension)}$$

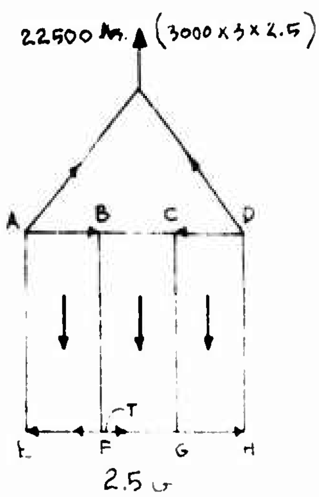

FIG. 150c

If one structure tilts, the load T on one cam lock is:

$3000 \times 2.5 \times 1.5 - T \times 6.5 = 0$

$T = 1710$ lbs. $\qquad F = 3000 \times 2.5$

$\therefore$ load/cam lock = 855 lbs. (tension)

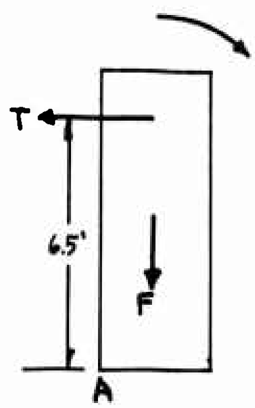

FIG. 150d

APPENDIX "B"

FOAMBOARD TESTING

APPENDIX "B"

FOAMBOARD TESTING

PROCEDURES AND SUMMARYS

Part I: Early Foamboard Material Evaluations

In order to assess the properties of several selected foamboard materials for the BBPS folding shells and other similar uses, it was necessary to perform a series of tests. All results were obtained through at least 3 samples of each material. The tests were:

1. Direct tension test
2. Direct compression test
3. Shear on composite
4. Shear test between skins and foam to measure bond of laminate
5. Normal flexural test.

The tests 1 through 4 consisted of testing specimens under the following conditions:

a. At normal room temperature and humidity
b. At +120°F temperature and normal humidity
c. At -40°F temperature
d. At normal temperature and elevated humidity (the critical part of the specimen was saturated with water for at least one hour prior to testing)

Other test specifics are listed below:

1. Tension tests were done on specimens prepared according to figure 151. Strains were measured across 1" long gauges at the location specified.
2. Normal compression testing was carried out on test specimens as shown in figure 152, using 1" gauge length.
3. Shear tests were carried out on samples as shown in figure 153 to measure shear strength of the total composite.
4. Skin-to-core shear bond tests were performed as shown in figure 154.
5. Flexural tests were carried out on specimens 15" long, 2" wide, with a concentrated point load applied at mid-span. Support was on fixed and pinned rollers. As load and deflection were recorded, "EI" was easily found by calculation. The general test setup is shown in figure 155.

The samples evaluated all had polyurethane foam cores of varying density (2.35 to 2.8#) and the skins were identical on both faces. Therefore, the basic skin construction will be identified with the overall board thickness.

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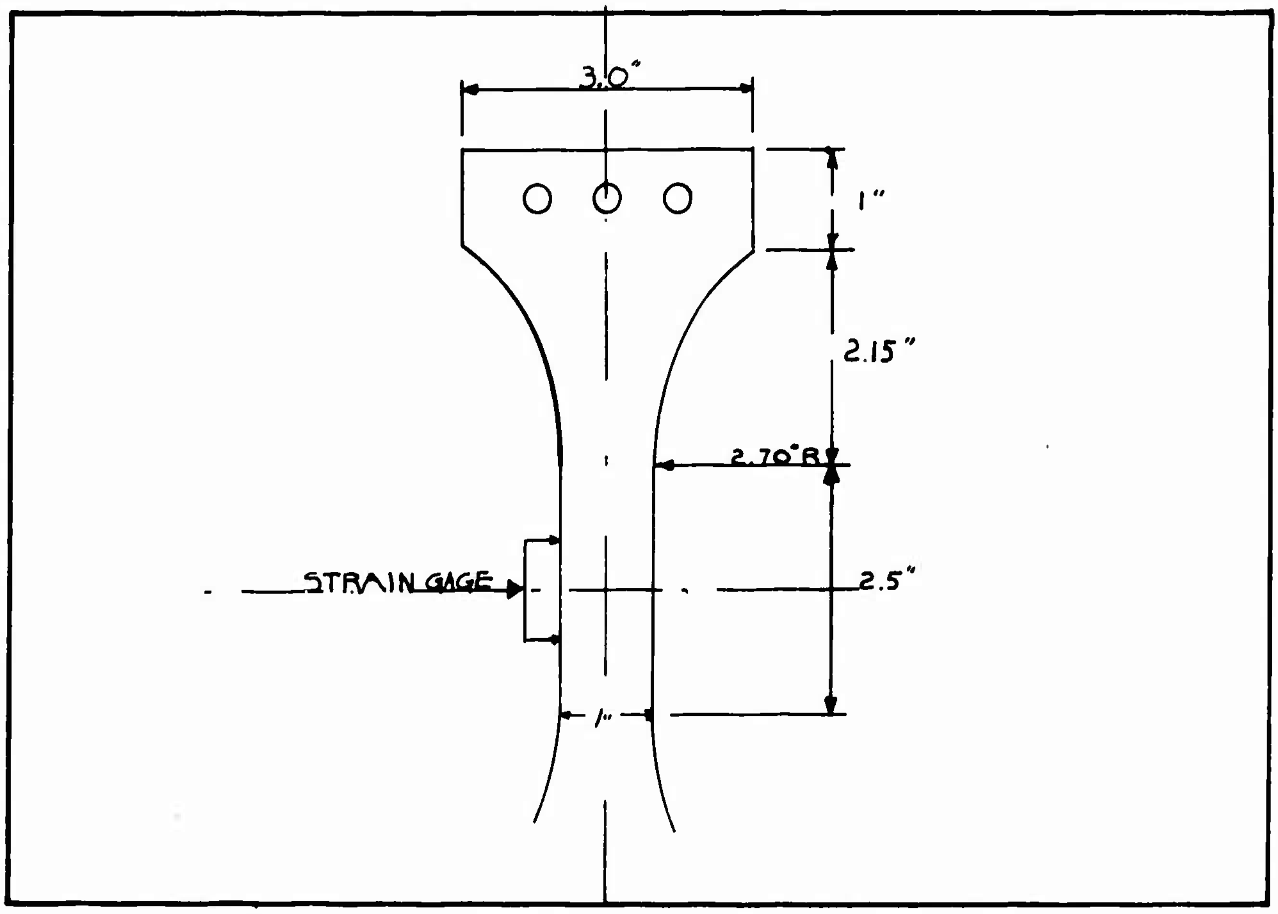

Figure 151. Typical Tension Test Specimen

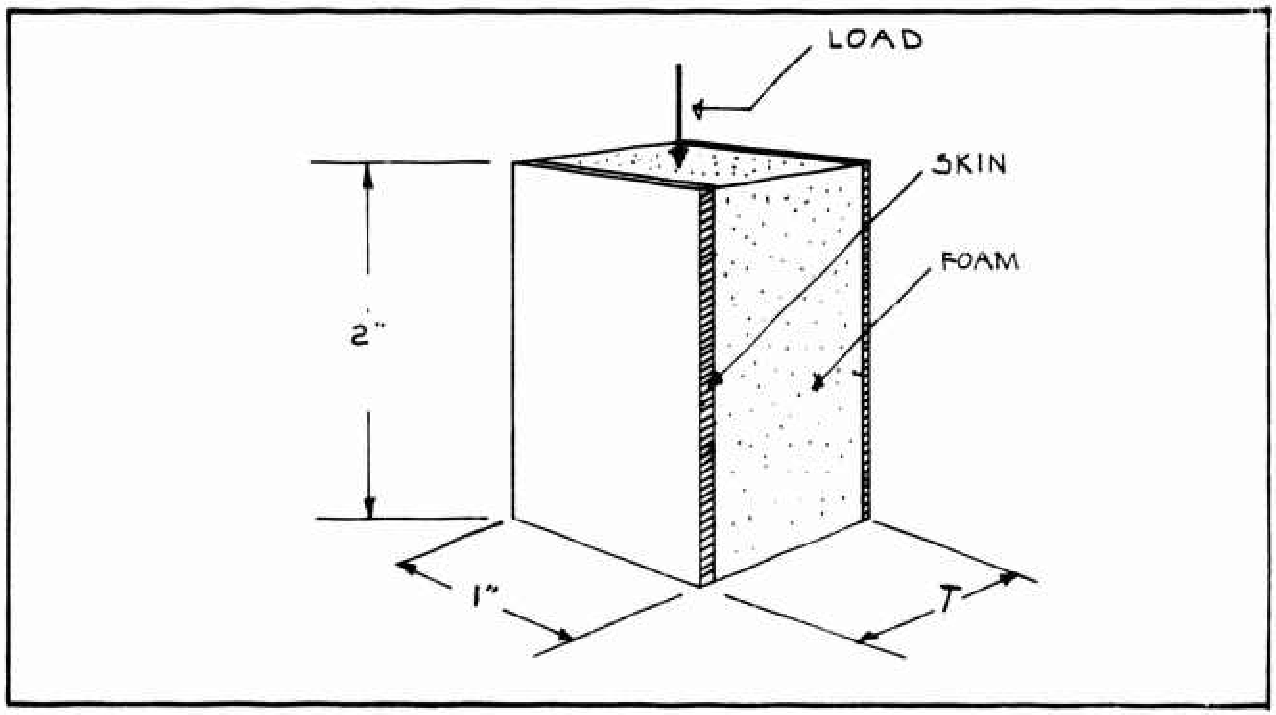

Figure 152. Typical Compression Test Specimen

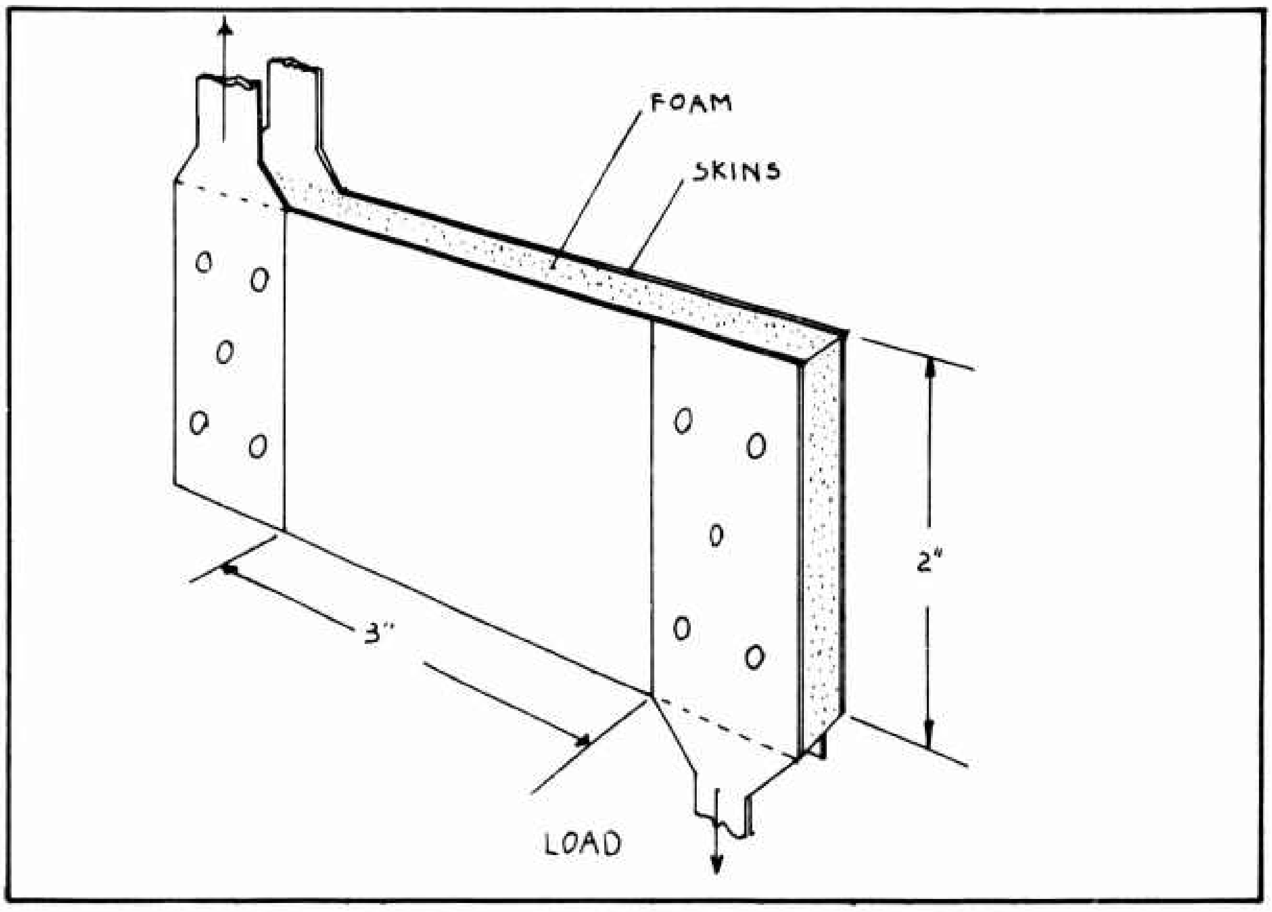

Figure 153. Typical Shear Test Specimen

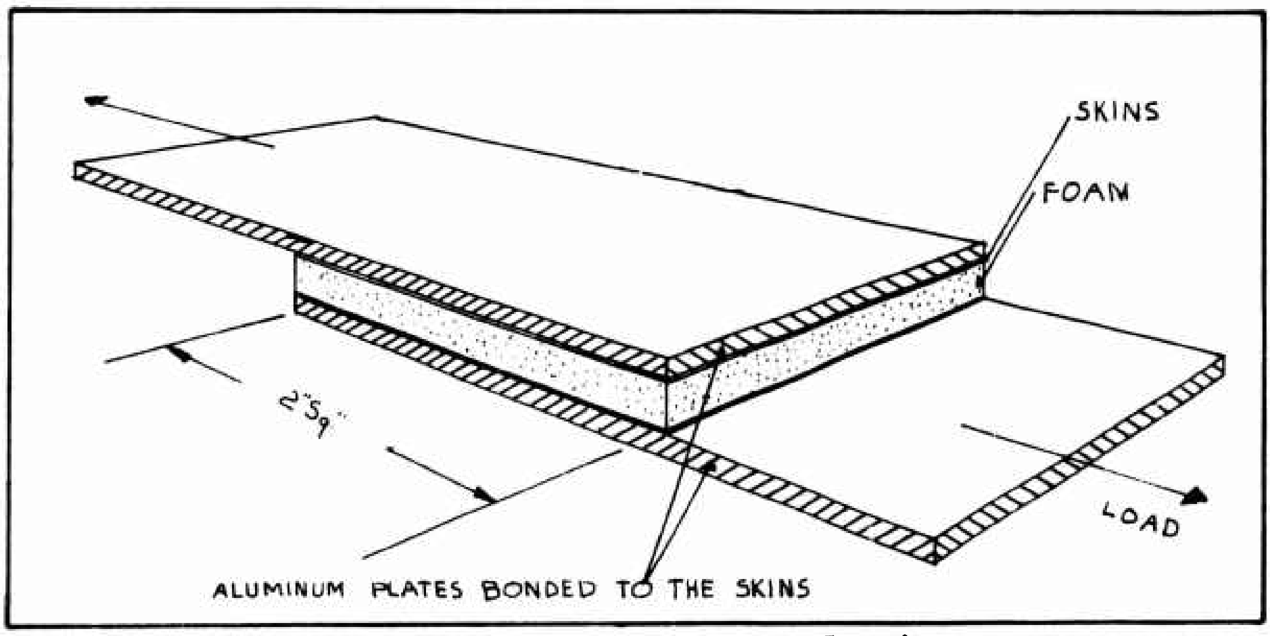

Figure 154. Typical Bond Test Specimen

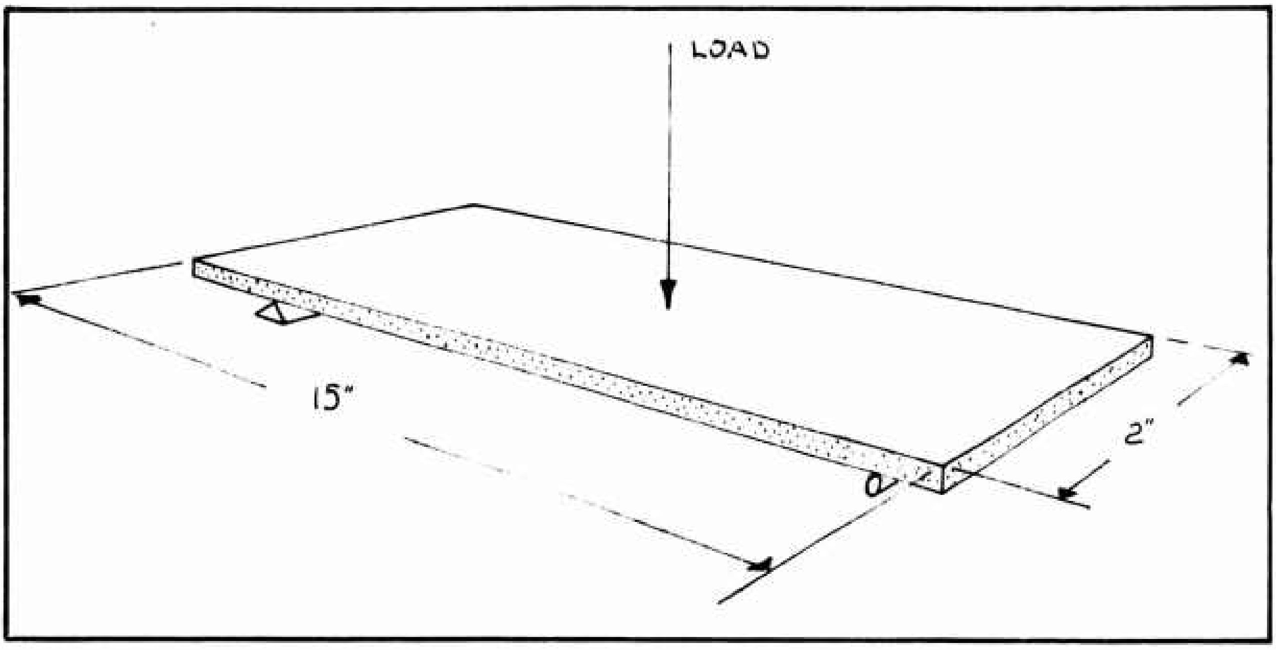

Figure 155. Typical Flexure Test Set-Up

Type "A" Samples (Allied Chemical Co.)
- 1/4" overall thickness
- 42# natural kraft paper
- 1.5 mil polyethylene film

Type "B" Samples (International Foam Corp.)
- 3/10" overall thickness
- 69# natural kraft paper
- 1.5 mil polyethylene film

Type "C" Samples (Allied Chemical Co.)
- 3/10" overall thickness
- 69# natural kraft paper
- 1.5 mil polyethylene one-face
- 5 mil polyethylene one face

Type "D" Samples (Allied Chemical Co.)
- 1/4" overall thickness
- 42# natural kraft paper
- 1 mil PVC film both sides
- 1 mil aluminum
- 1 mil polyethylene as adhesive

Table 6 shows a summary of these tests performed.

TABLE 6. SUMMARY OF TEST RESULTS ON FOAMBOARD
BASIC PROPERTIES

*: Values are based on properties of skins only, since foam was not found to have any practical strength.

PROPERTIES	UNITS	TYPE A	B	C	D
E* ($x10^{-3}$)	P.S.I.	160	438.0	392.0	338
T (Board)	IN	0.275	0.385	0.290	0.215
t (Skins)	IN	0.015	0.017	0.017	0.016
I* (1" width)	IN^4	0.00152	0.001475	0.00101	0.000726
σ_t (ult.)	P.S.I.	4000	6030	5830	6870
σ_c "	P.S.I.	1275	1190	1340	1520
σ_ω (F.S.=2.8)	P.S.I.	450	425	475	545
σ_s (in paper)	P.S.I.	27.5	27.5	27.5	27.5
EI		365	969	552	370

PART II: 50' Span Test Section Discussion

Sections are listed below by test number (1 through 8) with commentary on performance.

TEST #1

Cross Section	: 5 1/2" wide x 6" deep
Material	: 1/4" Technifoam untreated
Span	: 116" between supports
Purpose	: To determine how foamboard material will fail in a folded beam
Loading	: Distributed load applied in increments of four pounds per foot
Measurement	: Deflection was measured at each 4 pound increment at the quarter point
Maximum Deflection	: 1 23/32" at mid-span with 24 p/f
Comments	: The beam set for one hour with 24 p/f with negligible creep. The beam failed at 27 p/f in compression.

TEST #2

Cross Section	: 5 1/2" wide x 6" deep
Material	: 1/4" Technifoam untreated
Span	: 116"
Purpose	: To determine how foamboard material will fail in a folded beam
Loading	: Concentrated load at mid span applied in increments of 10 pounds
Measurement	: Deflection was measured at each 10 pound increments at quarter points
Maximum Deflection	: 1 3/32" at midspan with 100 pounds
Comments	: Failure at 104 lbs. Failure seemed imminent at 102 lbs. From beginning of evident failure at 104 lbs. to complete collapse took 10 to 15 seconds. Tests #1 and #2 confirmed expectations that foamboard materials would fail in compression by buckling at the point of maximum compression.

TEST #3

Cross Section	: Sleeve: 24" wide x 18" deep Spline: "X" shape inside sleeve
Material	: 1/4" technifoam untreated
Configuration	: Sleeve: 9'4" long with an 18° change of direction at center. Splines: two internal splines 4'8" (normal) long
Span	: 4'0" between supports
Purpose	: To investigate feasibility of the sleeve and spline concept. Test is of one full size sleeve and two half splines
Loading	: Distributed load applied in increments of 2 pounds per square foot.
Measurement	: Deflection measured at each 2 p/sf increment at quarter points

Maximum Deflection	: 25/32" at midspan with 22 p/sf
Comments	: At 24 p/sf the vertical wall collapsed at points of end support. This collapse was due to the high concentrated load at ends. There was no evident failure due to bending.

TEST #4

Cross Section	: Sleeve: 24" wide x 18" deep. Spline: "X" shape inside sleeve
Material	: 1/4" Technifoam untreated
Configuration	: Sleeves: Two sleeves 52" long. Spline: one continuous spline 104" long. The two discontinuous sleeves are taped together to prevent spreading apart.
Span	: 96" between supports
Purpose	: Test full size beam made up of two half sleeves and one full length spline. Also to investigate need for connecting discontinuous sleeves
Loading	: Distributed load applied in 2 pounds per square foot increments
Measurements	: Deflection measured at each 2 p/sf increments at quarter points
Maximum Deflection	: 5/8" deflection at midspan with 24 p/sf (384 lbs. total wt. on beam)
Comments	: This beam was not taken to failure. However, final failure would have been at the ends as in Test #3 due to discontinuity of sleeve-spline relationship. There was no evident failure due to bending.

TEST #5

This test was done with the same beam and conditions as Test #4 except that the two half-sleeves were not taped together.

Maximum Deflection	: 11/32" at midspan with 26 p/sf

Comments : After 3 hours with the 26 p/sf load no appreciable creep was evident. The center joint between sleeve ends had only spread about 1/8". The fact that the beam actually deflected less when not taped in the center is probably due to the fact that the beam was re-used and had taken a "set" from the previous loading. However, it is obvious that taping the sleeves together at their ends did not add to the strength of the beam. After setting for nine hours this beam failed and sagged to the floor at midspan. In this concept the spline, which is cross bracing within the sleeve, goes into compression and the sleeve goes into tension when loaded. From observation each diagonal of the spline starts bowing into compression. This was evidently the reason for failure of this beam. The paper facings have to be stiffened and the foam material thickened to achieve a better a/r ratio for the spline. The sleeve will only need to be weather proofed since it seems to be capable of resisting much greater tensile stresses. However, the sleeve will have to be reinforced at the line of compression where it makes the 18° bend at mid-point.

TEST #6

Cross Section : Three one foot beam sections were tested simultaneously made up of a sleeve and "X" spline.

1. 24" wide x 18" deep x 12" long
2. 24" wide x 16" deep x 12" long
3. 24" wide x 14" deep x 12" long

Material : 1/4" Technifoam untreated

Purpose : To study relative values of various beam depths

Loading : Distributed load applied in 4 pound per square foot increments

Measurements : Deflection of each diagonal bracing was measured @ 4p/sf increments

Maximum Deflection	:	1. 18" beam: 5/16" @ 24 p/sf - diagonal failed @ 28 p/sf 2. 16" beam: 9/32" @ 32 p/sf - 12/32" after 5 hours due to creep 3. 14" beam: 8/32" @ 32 p/sf - diagonal failed after 2 hours
Comments	:	Creep was evident in all three sections. The 16" deep beam not only seems to exhibit better strength but when folded is most compatible to the 463L pallet system.

TEST #7

Cross Section	:	One foot long beam section made up of a sleeve and an "X" spline. 14" deep section x 24" wide x 12" long.
Material	:	1/4" Technifoam untreated sleeve. 1/6" Technifoam epoxy resin impregnated spline
Purpose	:	To stiffen the spline
Loading	:	Distributed load applied in 2 pound per square foot increments
Measurement	:	Deflection of each diagonal bracing was measured @ 2 p/sf increments
Maximum Deflection	:	3/32" at 32 p/sf. 8/32" at 32 p/sf after 46 hours
Comments	:	Even though deflections and creep have been appreciable reduced, deflection due to creep is much too high.

TEST #8

Cross Section	:	An 18" deep beam section one foot long made up of a sleeve and an "X" spline.
Material	:	1/4" Technifoam untreated sleeve. 3/8" Technifoam epoxy resin impregnated spline
Purpose	:	To stiffen spline to point where creep does not occur under long-time loading

Loading	: Distributed load applied in 2 pound per square foot increments
Measurements	: Deflection of each diagonal bracing was measured at 2 p/sf increments
Maximum Deflection	: 1/32" at 32p/sf. 5/32" at 80 p/sf. 7/32" at 80 p/sf after 15 days
Comments	: The loaded beam section was subjected to sharp blows after 15 days before the 7.32" deflection was measured. The amount of creep is now negligible. The next step should be to test a full size beam and try to develop adequate strength to resist the 65 mph wind loading.

Here it should be noted that, even though this testing has given much valuable knowledge about the capabilities of foamboard materials, there are still many problems to be solved before a 50 foot span hangar is practical with this concept.

1. The beam must be strengthened to resist a maximum moment of 3200 ft. lbs. (a beam 18' long and 2' wide with 40 #/sq.ft. develops 3200 ft. lbs.)

2. Methods of connection must be found that would also provide weatherproofing.

3. Weight and cubage of this concept at this time is almost the same as the rigid fiberglass panel concept.

APPENDIX "C"

PANAMA TEST REPORT

APPENDIX "C"

PANAMA TEST REPORT

Part I - Objectives

This program was undertaken to test the utility shelter and the personnel shelters under tropical conditions. Representatives from the University of Cincinnati and the Aeronautical Systems Division (ASD) WPAFB were present for the 21 day test period (November 21, 1968 - December 13, 1968). The test was conducted at Howard AFB, Canal Zone, Panama. Howard AFB is located 5 miles east of the Panama Canal on the Pacific Coast.

The test had several general objectives:

1.) To evaluate the ease and efficiency of erection and disassembly for both shelters in a tropical environment with an inexperienced crew.
2.) To evaluate their livability in a tropical environment.
3.) To evaluate tropical weather effects on the shelters' materials and designs.

Specific points for evaluation on the personnel shelter can be listed as follows:

1.) Check for points of wear or damage from erection and use.
2.) Evaluate operation of scissors-type support jacks.
3.) Evaluate fabric-fly sheet over one-half the foamboard shell for exposure effects and its effect on interior temperature (comfort).
4.) Evaluate foamboard shell sidewall to floor-joint.
    Test results would be recorded by instrument, camera, and by observation.

It should be noted that complete coverage on the utility shelters' performance is included in the Interim Technical Report on contract AF33(615)3242 (see Foreword to this report).

Part II - Logistics

The shelters were transported out of WPAFB to Howard AFB by C-130 aircraft via Lockbourne AFB, Ohio. The personnel shelter was strapped to two standard 463L pallets. Since there was only one personnel shelter shipped, the integral 463L rail in the unit could not be utilized. No significant problems were encountered during on-loading, in-flight, or off-loading.

Assistance was provided by the Civil Engineering group 24th Special Operations Wing, Howard AFB. The selected erection site was a small, slightly rolling, open field next to a dense marsh (see figure 156). There was no undergrowth and the grass was cut weekly. Ground conditions were soft and moist from the daily rain. Actual soil bearing capabilities were not evaluated before erection.

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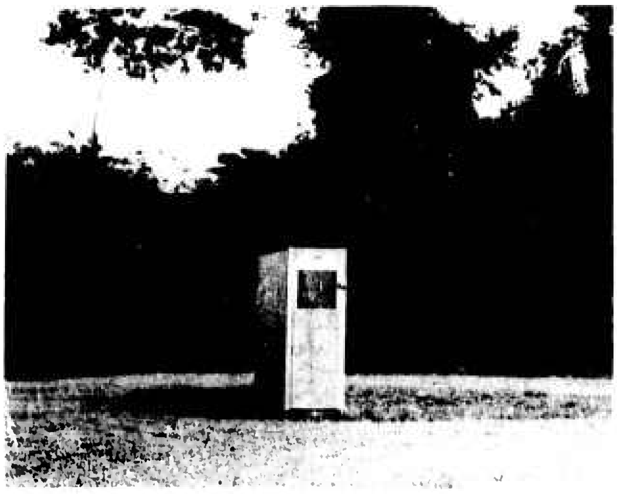


Figure 156. Prototype III at Test Site

Figure 157. Unfolding Floor Panels

A 10,000 pound capacity fork-lift transported the personnel shelter to the site and placed the center section on wood 4 x 4 timbers (in lieu of box jacks). Difficulty was experienced in fork lift entry to the holes provided in the shelter rails. The small vertical dimension of the hole has been corrected on later design data.

Part III - Personnel Shelter Erection

The BBPS Prototype III was erected on November 23, 1968 with an inexperienced crew of four in four hours. As mentioned previously, this prototype was fitted with scissors jacks for support and leveling, modified foamboard wall hold-downs and a fabric-fly over one half the folding shell.

Unfolding of the floor panels proved easy. (See figure 157.) The jacks were pushed into the mounting holes provided before the floors were lowered. Once all panels were lowered to position, the entire floor was leveled. Some difficulty was experienced with equalization of bearing on all jacks. This was due partially to the great number of jacks (4 per hinge line) and the rather soft condition of the soil. The handle attachment to the jack as provided was poor, a snap-on straight type connection would have allowed easier leveling adjustment at the two center jacks.

The method of retaining the jacks in the floor was rather unsatisfactory in this particular shelter. Several times while leveling the floors, the interior jacks came out of the mounting holes. Because of the retaining "O" rings and the cramped quarters, it was very difficult to push the units back into the sockets. A more positive connection to the floors would alleviate many of the problems.

Some difficulty was experienced in placing the loose endwall into the slot provided at the edge of the outboard floor segment (see figure 158). This floor section must be planar before the mating flange on the endwall will drop into place securely. Care in leveling will yield few difficulties in this area. Once leveled, the structure rested on a slight grade and had a slight twist but this did not adversely affect erection of the remaining components. The fabric-fly cover was attached to one end utilizing short pieces of the vinyl-"Quick-Edge" trim (see figures 159 and 160). This completed erection of the BBPS.

Figure 158. Erecting Endwall

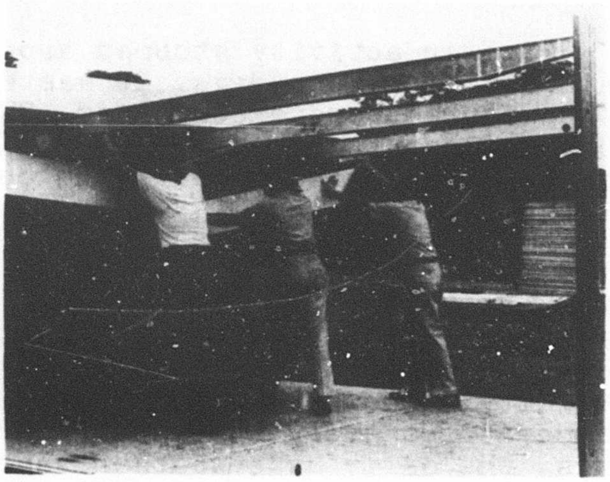


Figure 159. Unfolding Foamboard Shell

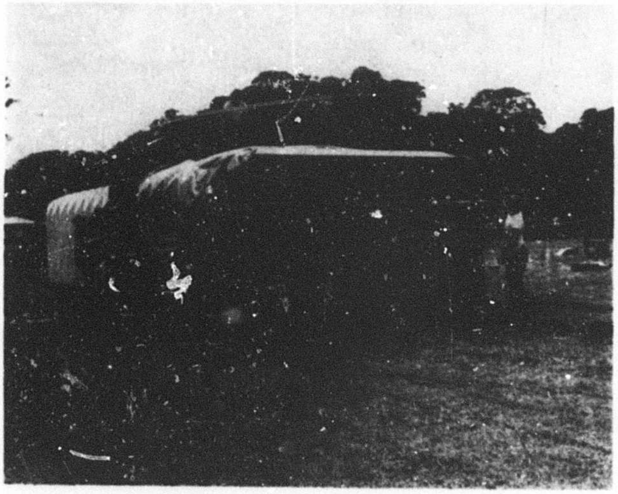


Figure 160. Fitting Fabric Fly

Part IV - General Weather Conditions

General conditions for the three week test period can be characterized as mild with occasional very heavy rain storms. Temperatures (dry-bulb, shade) ranged from the mid 70's at night to low 90's on several occasions. Rains would commence around 1200 in scattered bursts and would usually end by 1800. From 21 November to 25 November, the rain was generally very heavy reaching a peak once of 2 inches in one hour.

Shower activity stopped around 26 November and little or no rain fell for four days. It was during this period that the 90° temperatures were experienced. Shower activity increased again for the last two weeks. Humidity ranged from 70% upward for the entire test period. The ground conditions firmed up at the end of the test.

Temperature data around the shelters was taken by a Brown 12-track temperature recorder using thermister wire. Measurements were made at 6 points on and in the personnel shelter and one probe recorded ground temperatures. Barometric pressure, relative humidity, and weather observations were recorded along with the temperatures every half-hour from 0900 to 1700. To supplement this, the daily base weather reports (taken one mile away) were also transcribed and used. Tables 7 through 11 show performance curves for temperature and measuring points on the shelter.


Figure 161. Shelter Interior

The personnel shelter was tested with the doors at both ends open and the fan running (see figure 161). The structure did experience some heat build-up and the air-flow, even with fan running, was not adequate. No leaks appeared throughout the test. In heavy rains, the noise on the shelter became somewhat excessive.

Ultra-violet exposure was also evaluated on the neoprene-coated nylon fabric. A light white chalk started to appear after four days of exposure. This became heavier, of course, as the test progressed. It was not determined whether this was more pronounced because the neoprene-coated nylon was fire-retardant, but previous fabric did not experience this to as great a degree. Weathering of fire-retardant neoprene-coated nylon should, therefore, be evaluated.

Three thermister probes were attached to the outside of the structure; one on the foamboard shell, one on the top of the center-core/box, and one on the fabric fly. On the inside, two probes were place under the foamboard and fabric fly exterior points. The sixth probe was suspended near the center of the structure to measure inside air temperature.

Part V - BBPS Disassembly and Packaging

The BBPS was struck and packed in 10 man hours, with no great difficulties, on 10 and 11 December. The nylon webbing and buckles used to secure the folded foamboard shell during shipment were difficult to reconstruct. It is thought that they are overly complex for their function.

The shelter in its folded state provided shipping space for all test equipment, luggage, and spare parts for the utility shelter. Here the BBPS design proves extremely effective in overall concept.

Logistics movements for the return demonstrated no difficulties.

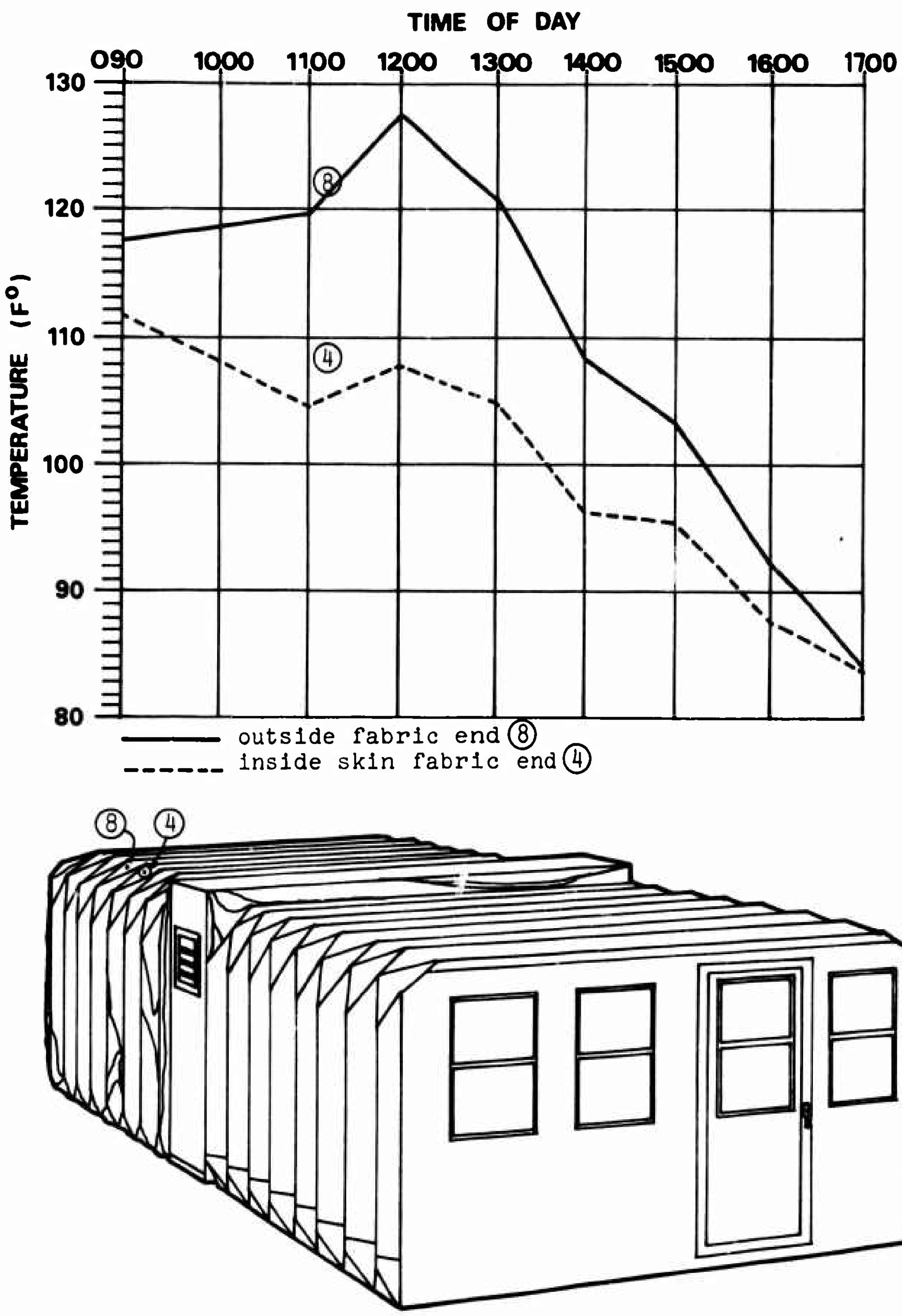
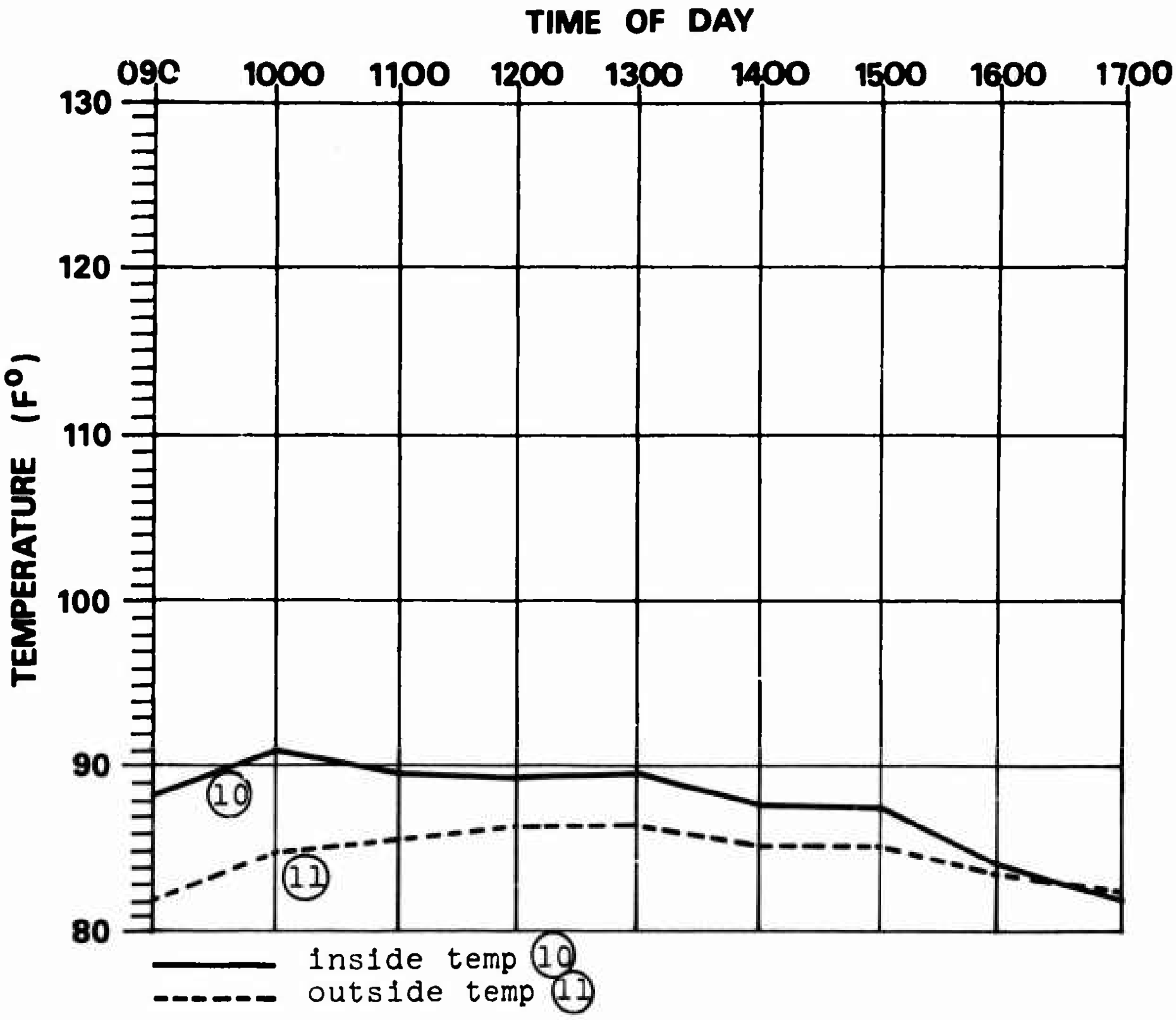

TIME OF DAY
090
1000
1100
1200
1300
1400
1500
1600
1700
130
120
110
100
90
80
TEMPERATURE (F°)
8
4
outside fabric end 8
inside skin fabric end 4
8
4

TABLE 7



TIME OF DAY
09C
1000
1100
1200
1300
1400
1500
1600
1700
130
120
110
100
90
80
TEMPERATURE (F°)
10
11
inside temp 10
outside temp 11

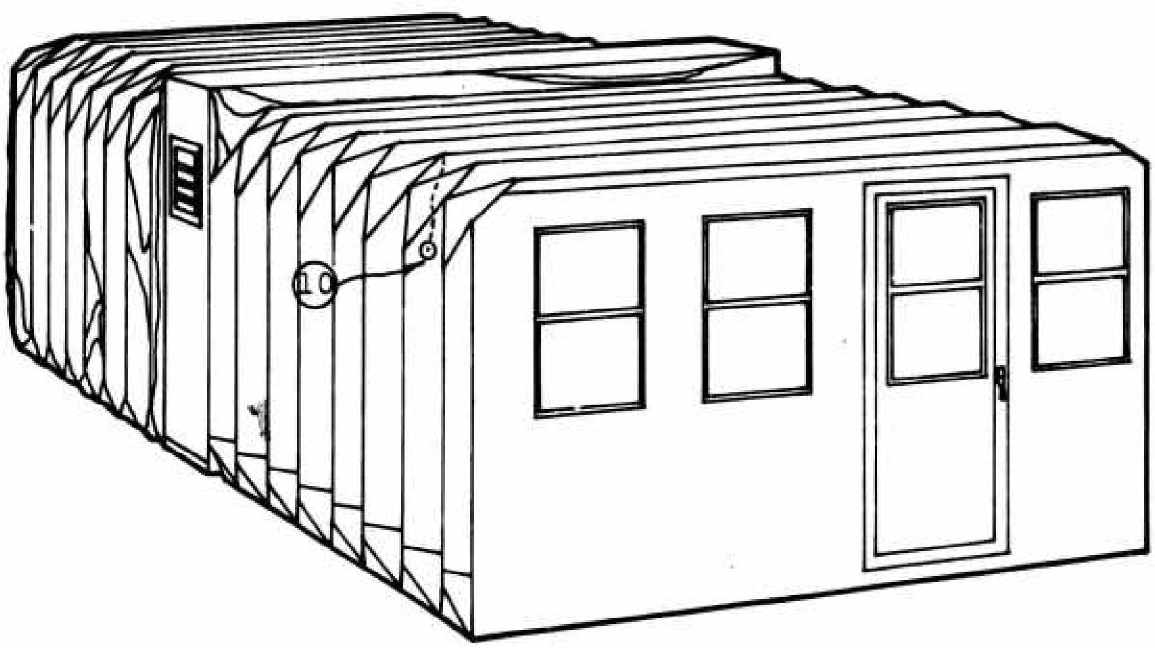


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TABLE 8

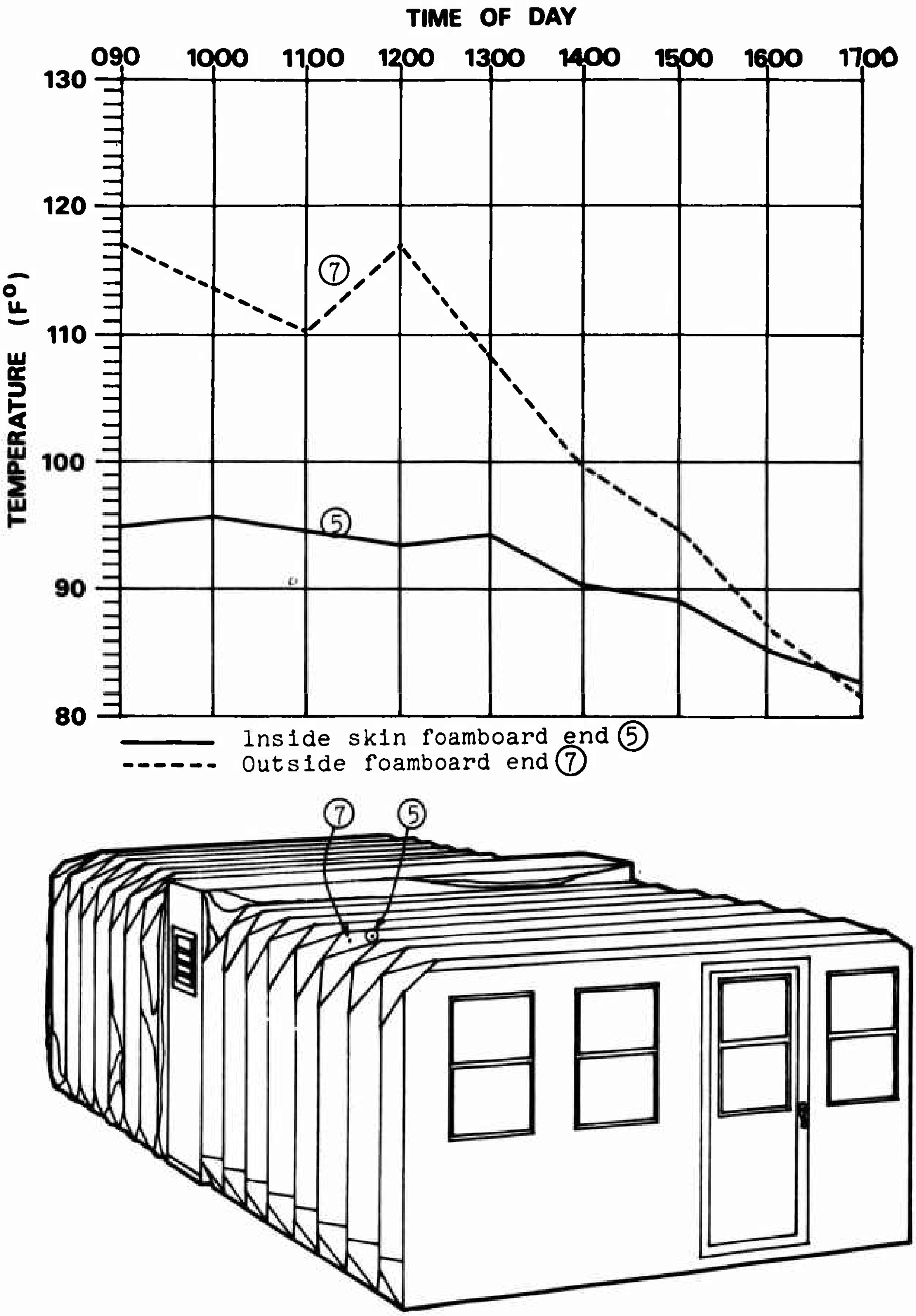
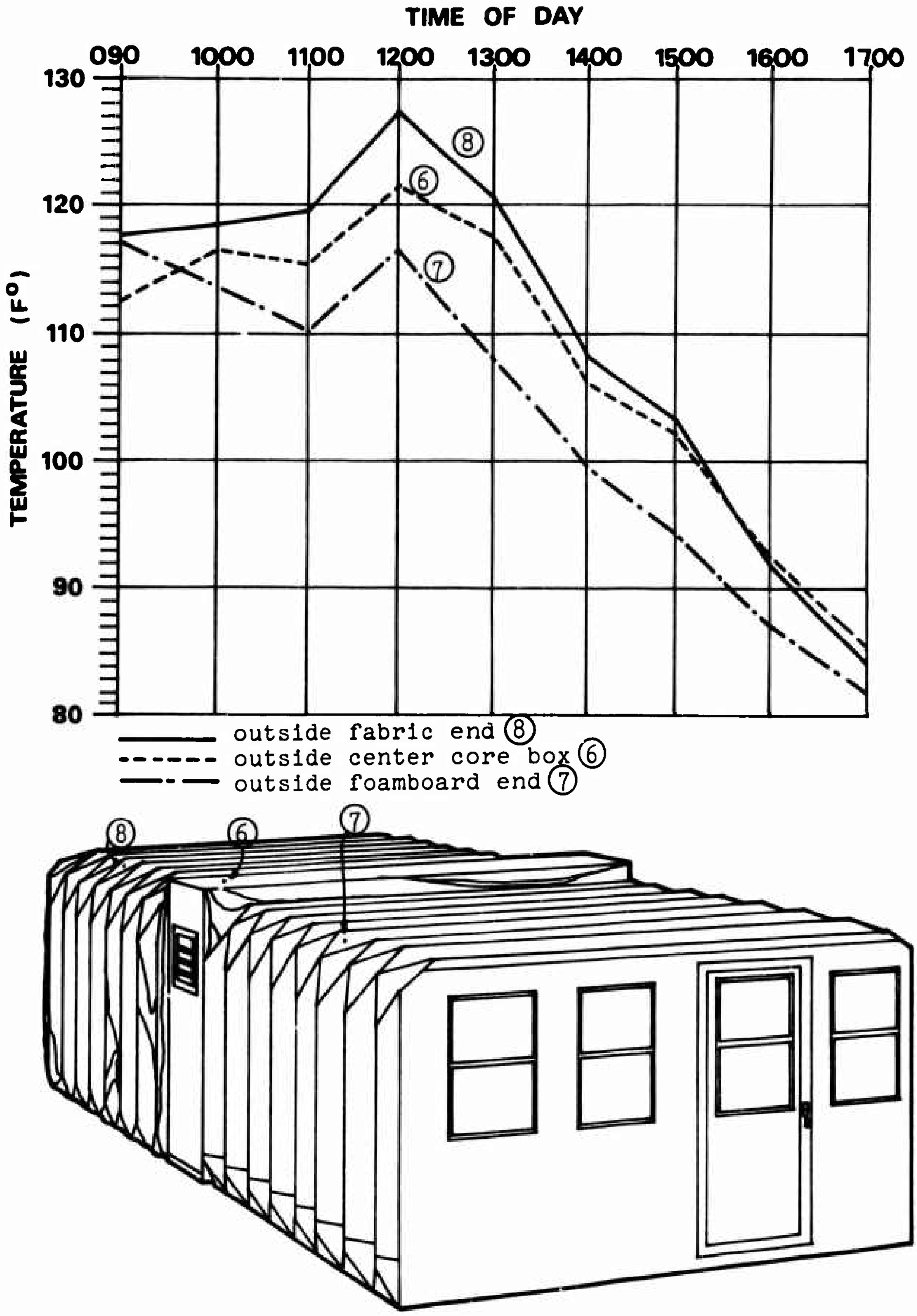

TIME OF DAY
090
1000
1100
1200
1300
1400
1500
1600
1700
130
120
110
100
90
80
TEMPERATURE (F°)
7
5
Inside skin foamboard end 5
Outside foamboard end 7
7
5

TABLE 9


TIME OF DAY
090
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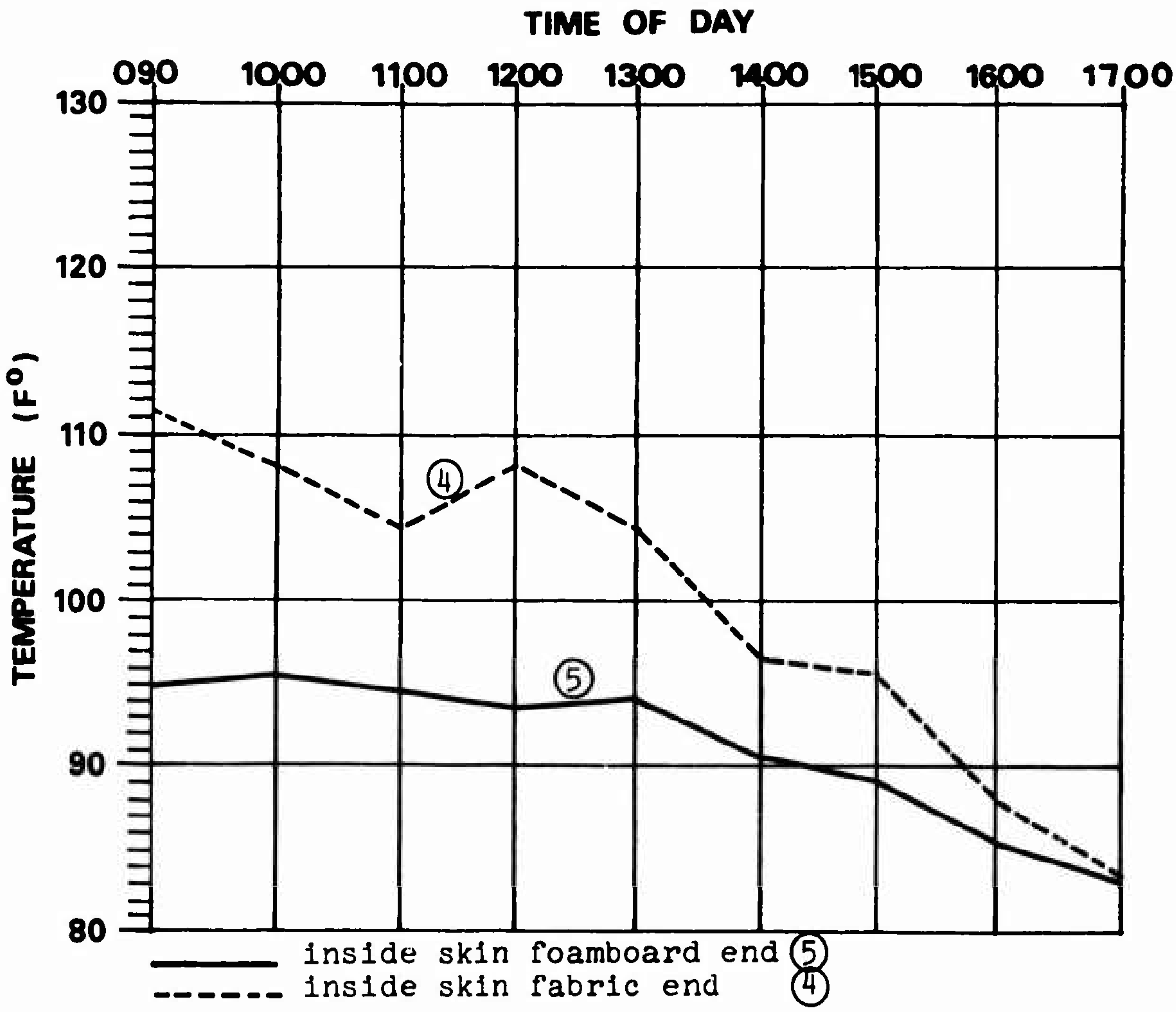
1100
1200
1300
1400
1500
1600
1700
130
120
110
100
90
80
TEMPERATURE (F°)
8
6
7
outside fabric end 8
outside center core box 6
outside foamboard end 7
8
6
7

TABLE 10


TIME OF DAY
090
1000
1100
1200
1300
1400
1500
1600
1700
TEMPERATURE (F°)
130
120
110
100
90
80
4
5
inside skin foamboard end 5
inside skin fabric end 4

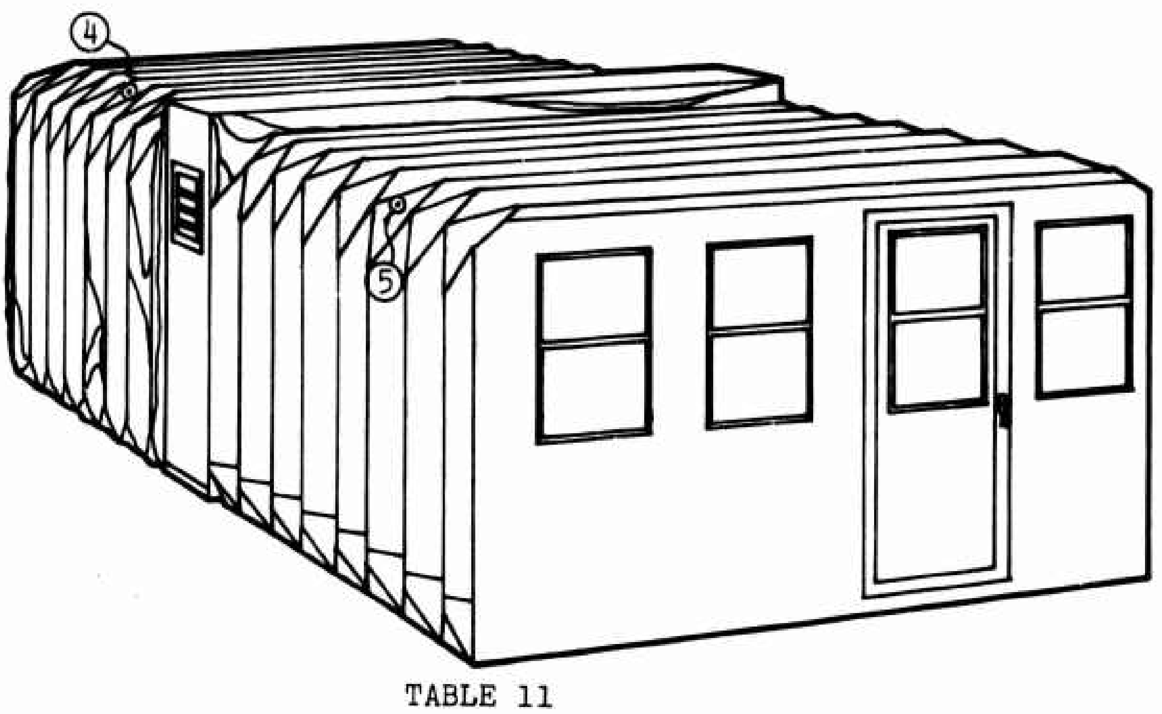

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TABLE 11

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Final Technical Report

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13. ABSTRACT

Lightweight, 100% recoverable expandable shelters for high mobility applications are described. Concepts developed include small size shelters (13' to 16' span) and medium size shelters (24' to 30' span).

The small shelter concepts described utilize lightweight thin sandwich construction "foamboard" in unique folding applications. Geometry details, manufacturing difficulties, erection procedures, and testing are discussed for the concept selected for development.

Ultimate practical span for foamboard constructions are discussed, (a 50' span hangar).

Also included is a section devoted to basic research on development or more durable and stronger foamboard composites to be utilized on the designs generated.

Early foamboard concepts for medium size general purpose shelters are also discussed.

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Lightweight high-mobility shelters for small and medium uses utilizing foamboard in scoring and folding applications. Modular buildings of larger span also discussed. Basic research on foamboard material.						

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Security Classification