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RELOCATABLE MAINTENANCE HANGAR CONCEPT EVALUATIONS

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AIRCRAFT	AIR-SUPPORTED STRUCTURES	WEATHERPROOFING

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report was prepared to summarize the effort undertaken to evaluate concepts and determine a program for development of the Relocatable Maintenance Hangar. Five basic shelter concepts were considered, analyzed, and evaluated against desired characteristics. The information presented includes the basic structural characteristics and the associated technical barriers involved in the development of each concept.

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PREFACE

Draft requirements for the Relocatable Maintenance Hangar (RMH) indicated that a Double-Wall Tent was the original type of structure desired. However, later investigations indicated that a Double-Wall Tent was not a practical solution for the RMH. Subsequently, requests came in from AMC to evaluate the Tension Structure and the Frame and Panel Structure as possible RMH structures. As a result, the following study was made by the Natick Development Center.

The information presented on the Frame and Panel Structure was extracted from unsolicited information received from the Lockheed-Georgia Company in reference to their LocArch structure.

Appreciation is expressed to Dr. Leslie McClaine, Engineering Science Division, AMEL for his valuable comments throughout this study.

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A. INTRODUCTION

This study represents a systems analysis on the development of a Relocatable Maintenance Hangar. The hangar is intended to provide all weather protection for the maintenance of helicopters and fixed-wing aircraft. The size requirement is 18 m wide at 6.1 m high and about 30 m in length. In addition, the hangar is intended to be used repeatedly in tactical field operations and must be transportable by USAF Cargo Aircraft, Army Cargo Helicopters, and ground vehicles. The effort undertaken on the Double-Wall tent gave results which indicated this structure may not be practical and that other methods to satisfy the requirement should be investigated.

In this report, the alternative structural options are evaluated, conclusions are established with regard to the alternatives, and a program is outlined for advanced development to meet this requirement.

B. ALTERNATIVE STRUCTURAL CONCEPTS

Five concepts were considered in this study and a brief description of each follows.

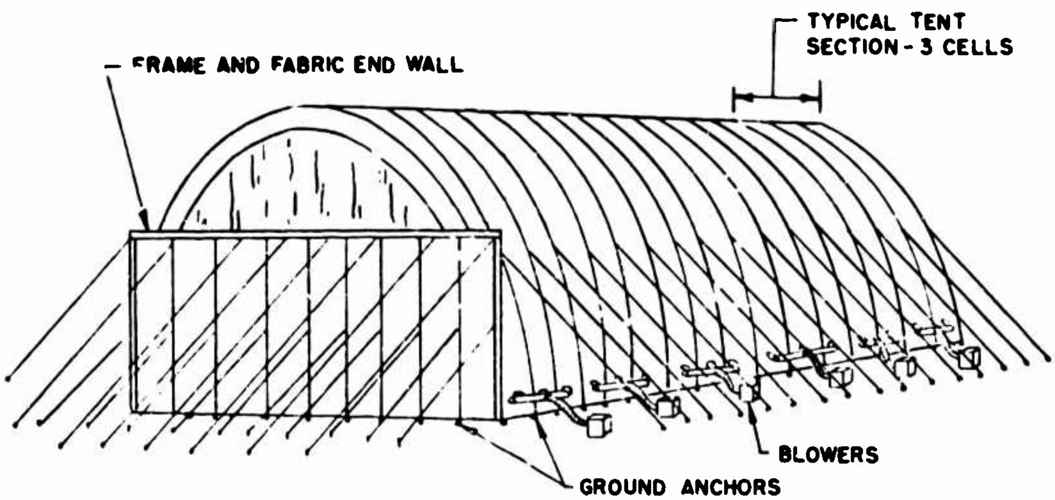
1. The Standard Double-Wall Air-Supported Tent (Fig. 1). This structure would be similar to the MUST inflatable units currently being used by the Army, but a much larger size will be required. The structure is made from a number of multiple cell units. That is, each unit has inner and outer skins connected with webs forming cells. The cells contain bladders which are inflated to moderate pressures (about 14 to 21 kPa). The units are then connected to form the shelter.

2. The Inflated Tube Tent (Fig. 2). The major characteristic of this concept is that it consists of individual inflated tubes connected in groups and covered with a weatherproof membrane. The inflation pressures are similar to those used in double-wall tents (14 to 34 kPa).

3. The Pressurized Rib Tent (Fig. 3). Of major importance in this structure are the pressure stabilized beams and arches used to support the weatherproof membrane. Various frame work alternatives in assembling the beams and arches to provide structural stability can be considered. For simplicity in analysis and estimating, the configuration shown in Fig. 3 was used. Inflation pressures can range up to 345 kPa.

4. The "Tension Structure" (Fig. 4). This type of structure consists of relatively few compression members arranged so that a large area is covered by a membrane in tension. The membrane is usually cable reinforced and guy lines or anchors are required to keep the structure properly shaped and secured.

5. The "Frame and Panel" Structure (Fig. 5). This consists of metal arches spaced 2.4 m apart with composite panels joining the arches. The panels form the weather boundary and add to the stability of the structure.



NOTE: GUY LINES ARE ONLY REQUIRED FOR HIGH WIND CONDITIONS

FIG. I DOUBLE-WALL AIR-SUPPORTED RMH CONCEPT

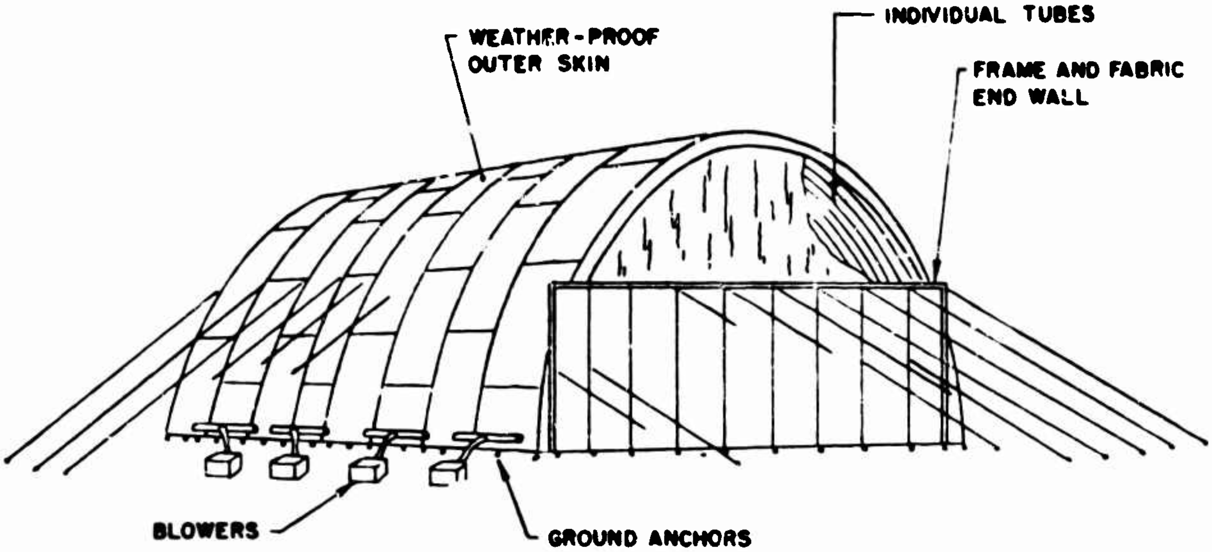


FIG. 2 INFLATED TUBE TENT CONCEPT FOR RMH

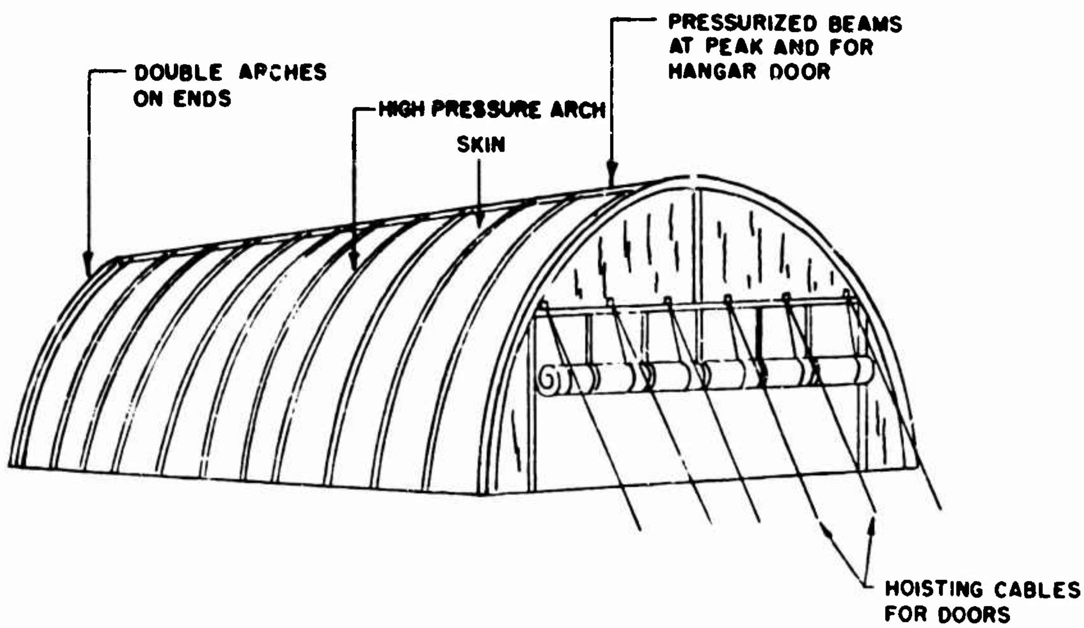


FIG. 3 PRESSURIZED RIB TENT CONCEPT FOR THE RMH

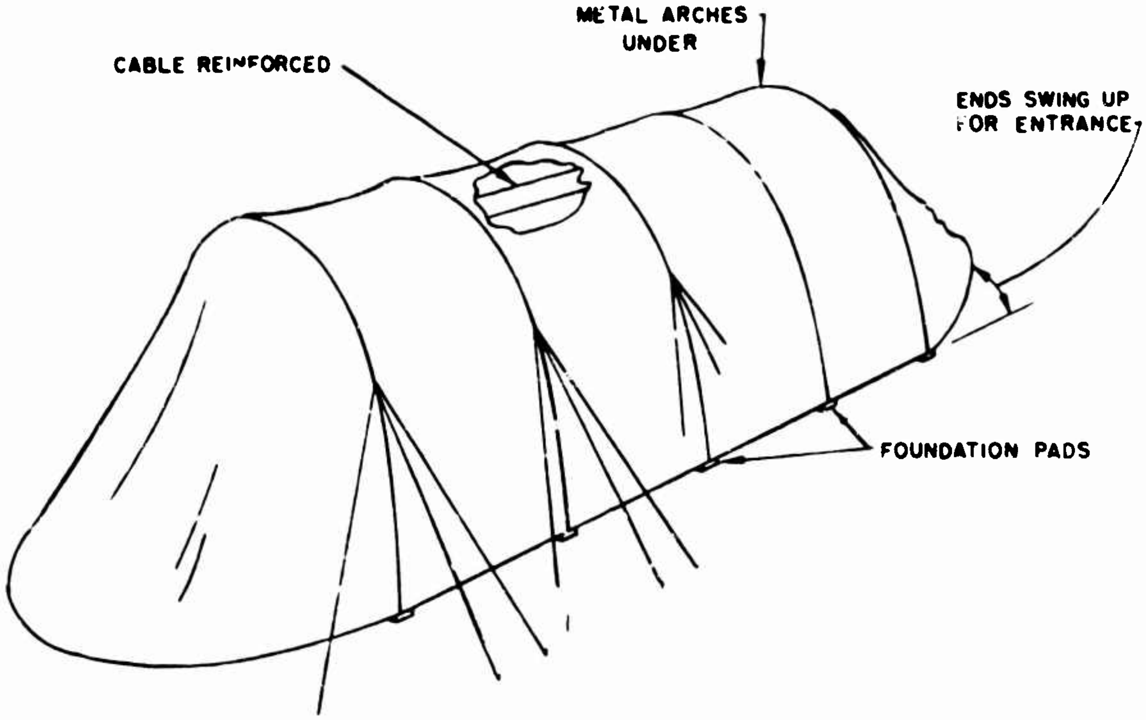


FIG. 4 TENSION STRUCTURE CONCEPT FOR RMH

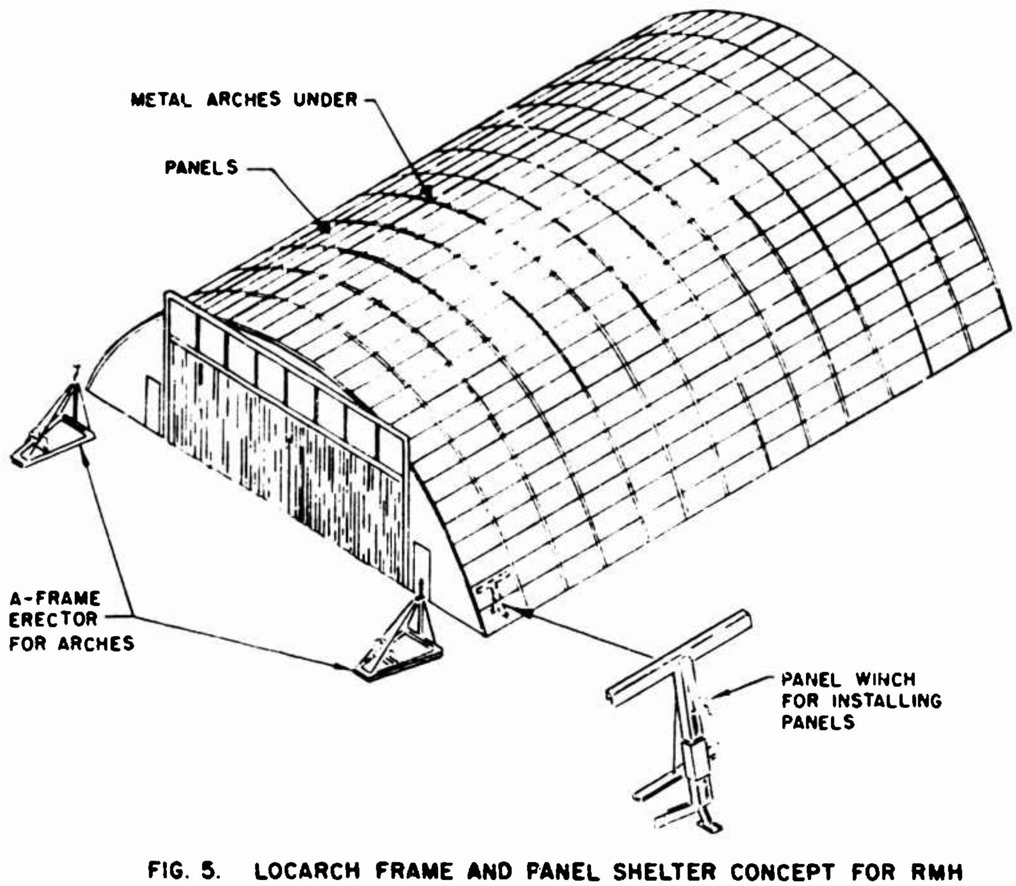


FIG. 5. LOCARCH FRAME AND PANEL SHELTER CONCEPT FOR RMH

C. EVALUATION SCHEME

The RMH requirements can be separated into two different sets of priority rankings which significantly alter the type of shelter to be developed. Under one set the need is for a highly mobile tactical field unit, and under the second the need is for a semi-permanent structure (see Table 1).

In this study, the alternative concepts will be evaluated against each of the two rankings of shelter requirements. In Section D, the climatic requirements are further defined and restricted.

An evaluation of each shelter concept and a comparison of the concepts will be made by first developing preliminary design information on each concept and then listing the shelter concepts in descending order as determined by their relative ability to satisfy each of the desired requirements. The general characteristics of each shelter concept are developed in Appendices A through C and the relative ability of each concept to meet the individual requirements is indicated and discussed in Section E. Conclusions and recommendations for future development are given in Sections F and G, respectively.

D. GENERAL CLIMATIC REQUIREMENTS AND THEIR RELATION TO THE RMH

1. Past proposed Required Operational Capabilities (ROC's) for the RMH indicate that the hangar is to be designed for climates 1-8. An abbreviated list of the most significant design factors from AR 70-38 "Research, Development, Test, and Evaluation of Material for Extreme Climatic Conditions" for climates 1-8 follows:

a.	Temperature	−54°C to 52°C
b.	Solar radiation	$(4.09)\ 10^6 \ \frac{J/m^2}{hr}$
c.	Humidity	100%

d. Wind velocity at 3 m above ground

28 m/s with gusts to 44 m/s;

and when exposed to coastal or mountain regions

36 m/s with gusts to 54 m/s

TABLE 1

RMH REQUIREMENTS BY PRIORITY

Case 1

HIGHLY MOBILE FIELD MAINTENANCE HANGAR

Highest Priority:

(1) Low shipping mass and bulk.

(2) Short time to erect and disassemble.

(3) Minimum ancillary equipment.

(4) Ability to erect on uneven ground.

(5) Readily maintainable in field.

Lower Priority:

(1) Resistance to deterioration from solar load, mildew, etc.

(2) Resistance to severe weather conditions.

(3) Resistance to hostile conditions.

(4) Minimize cost of item.

(5) Minimum need for further technical developments.

Case 2

SEMI-PERMANENT RELOCATABLE MAINTENANCE HANGAR

Highest Priority:

(1) Resistance to deterioration from solar load, mildew, etc.

(2) Readily maintainable in field.

(3) Resistance to high wind loads and snow loads.

(4) Minimize cost of item.

(5) Habitability comparable to permanent structure.

Lower Priority:

(1) Low shipping mass and bulk.

(2) Short time to erect and disassemble.

(3) Minimum ancillary equipment.

(4) Ability to erect on uneven gound.

(5) Resistance to hostile conditions.

Wind speed ratio to 3 m value

Height (m)	Ratio
3.0	1.00
4.6	1.07
7.6	1.13
15.2	1.24
22.9	1.29

e. Snow load (kPa)

Not cleared	1.90
Cleared after snow fall	0.96
Cleared during snow fall	0.49

2. Technical problems which occur for the double-wall tent in relation to the wind speed are illustrated in Fig. 6.

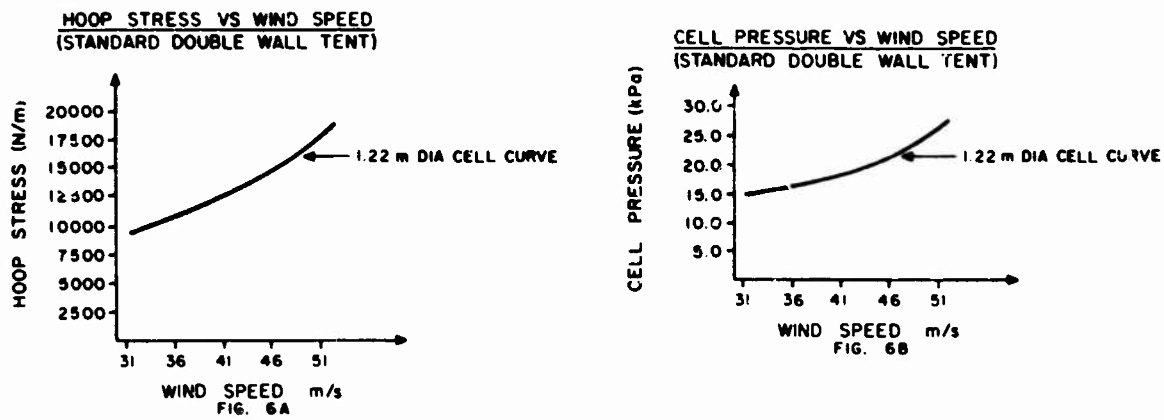


Fig. 6. Influence of Wind Speed on Standard Double-Wall Tent

Note that the required wind speed, 36 m/s, and the fact that the structure is about 15.2 m high, lead to a design wind speed of 44.6 m/s (steady) with gusts to 67.0 m/s.

It was decided that designing a highly mobile tactical shelter for these extreme wind speeds was not feasible. For example, reducing the steady state wind speed from 44.6 m/s to 36 m/s drops the cell hoop stress by 22%. Similar results are also obtained for ground anchors, guy lines, etc.

Preliminary calculations were also done for snow loads, and a relaxation of the 1.9-kPa requirement to the 0.96-kPa requirement was decided upon so that the cell pressures and base fabric weights would not be unreasonable for a highly mobile tactical shelter.

Thus, all of the fabric shelters discussed are best estimate designs for 36-m/s winds and 0.96-kPa snow load.

E. COMPARISON OF ALTERNATIVE STRUCTURAL CONCEPTS

1. Mass and Bulk Concept Comparisons (Appendix B)

a. List of estimations:

(1)	Tension Structure	6850 kg	2 containers
(2)	Pressurized Rib	7670 kg	2 containers
(3)	Inflated Tube	9[illegible]0 kg	4 containers
(4)	Double-Wall Tent	11000 kg	4 containers
(5)	Frame and Panel	31800 kg	5 containers

Note: The container size was chosen as 2.4 m x 2.4 m x 3 m so that each unit's mass would be less than 6800 kg.

b. Concepts (1) to (4) are reasonably close in mass and all are much less than (5). Also, (3) and (4) are higher in both mass and bulk than (1) and (2) for two reasons. First, the bulky and heavy frame and fabric endwalls were used in concepts (3) and (4) while lighter methods were used in (1) and (2). Second, there is about twice as much fabric in concepts (3) and (4) than in the single-skin concepts, (1) and (2).

In summary, until prototype end wall concepts have been fabricated and evaluated, concepts (1) to (4) should all be considered similar in mass and bulk, but concept (5) must be considered as heavier and more bulky than concepts (1) to (4).

2. Structure Erection and Striking Concept Comparisons

a. List of estimations:

Note: In expressing the time to erect in terms of days, a 6-man crew was assumed and a best estimate was made based on the erection procedure outlined in Appendix C.

(1) Pressurized Rib	1 day
(2) Inflated Tube	1½ days
(3) Double Wall Tent	1½ days
(4) Tension Structure	2 days
(5) Frame and Panel	3½ days

b. In comparing these concepts, it should be noted that erection time of the Frame and Panel structure could possibly be reduced by 1/2 day with a larger crew (about 9 men).

The short erection time of concept (1) would increase if a reasonable "quick high-pressure" inflation system could not be developed.

Concepts (2) and (3) are expected to take more time than (1) to erect for two reasons. First, there are more components involved in (2) and (3) which require positioning, fastening, etc. Second, a more complex end wall is involved in concepts (2) and (3). The end wall in concept (1) is inflatable.

Concept (4) is expected to be difficult to erect; that is, it is expected to have a high safety risk. The erection difficulties involve properly securing the arch foundations, connecting inter-arch cables (arches are widely spaced and must be erected individually), and positioning and connecting the fabric skin sections over the erected arch cable network.

In summary, concepts (1), (2), (3), and (5) all have erection schemes which appear feasible. The time and effort to erect the shelters separates the concepts into two groups: (1), (2), and (3) are relatively quickly erectable; (5) is more time consuming to erect. The erecting of concept (4) does not appear to be feasible (because of the relatively difficult and possibly dangerous tasks which would be required of untrained personnel).

3. Ancillary Equipment

It appears that only two concepts may require special equipment if developed. First, the Double-Wall Tent may require forklift trucks (or a similar capability) to maneuver heavy tent sections. Second, the Tension Structure may require a crane and staging to assemble without imposing safety hazards on untrained personnel.

4. Ability to Erect on Uneven Ground

All pneumatic concepts and the Tension Structure could be adapted to uneven ground sacrificing only weather tightness and aesthetic appearance. Erecting a Frame and Panel Structure on uneven ground would be difficult. Lockheed-Georgia Company claims the LocArch (Frame and Panel) can be erected "over terrain which varies a maximum of 0.61 m over the projected floor area".

5. Maintainability in Field

This generally minor design characteristic singled out the development of fabric coatings to replace bladders as an important area for technical development work on the pneumatic structures.

a. Maintenance of pneumatic shelters mainly involves monitoring the inflation system and repairing leaks when necessary. Due to the size of the cells, tubes, and pressurized ribs in the pneumatic concepts, it is recognized that bladders would be difficult to remove, repair, and replace in the field. Thus, a coating process should be developed which will retain the air and be repairable in the field.

b. The Tension Structure would require periodic checking of the guy lines. This would lead to maintenance which involves tightening the longitudinal cables and driving new anchors when necessary. A failure of this cable network would cause a collapse of the structure.

c. Field maintenance on the Frame and Panel structure would involve replacing or patching damaged panels. It is expected that this type of failure would be of low frequency. Patching panels in place should not prove difficult; however, if the maintenance requires the removal of panels, it is expected that the removal operation could be extremely difficult unless the site was perfectly level.

6. Resistance to deterioration from solar load, mildew, etc. The fabric structures are not expected to resist the elements as well as the Frame and Panel structures. However, if fabrication failures do not occur, the fabric material can be expected to have a five-year

field life. Experience has shown that fabric structures which are erected and struck many times experience damage to the coating and seams which reduces their ability to resist deterioration.

7. Resistance to Severe Weather Conditions

The fabric structures can be designed for high winds and large snow loads. But, as explained in the section on General Climatic Requirements, these structures are not intended to be permanent and are thus designed for lower, more common load conditions. The pneumatic structures have the ability to recover from an overload and still be usable.

In summary, the pneumatic structures and the Tension Structure as estimated here are intended to withstand 36 m/s winds or 0.96 kPa of snow. The Frame and Panel Structure is intended to withstand 31 m/s winds (gusts to 46 m/s) or 1.9 kPa snow (1.9 kPa until 20° roof slant with a reduction of 0.024 kPa for each degree of arch slope over 20°).

8. Resistance to Hostile Conditions

The Frame and Panel and Pressurized Rib structures would rate highest in this area. However, the Double-Wall, Inflated Tube, and Tension Structure rate low since

a. Small weapons fire could quickly destroy the Double-Wall or Inflated Tube Tent.

b. The loss of a small number of guy lines could cause the collapse of the Tension Structure.

It should be noted that the effects on these shelters of shock waves for artillery, mortar, etc. are not known.

9. Minimize Cost of Item

The estimated cost of the first shelter for each concept is given including the associated development costs. The cost of each additional shelter will be approximately equal to the manufacturing cost listed below in thousands of dollars.

a. Tension Structure

Manufacturing cost	122
Development work	130
Drawing package	72
Total cost	324

b. **Pressurized Rib**

Manufacturing cost	167
Development work	130
Drawing package	72
Total cost	369

c. **Inflated Tube**

Manufacturing cost	201
Development work	160
Drawing package	72
Total cost	433

d. **Double-Wall Tent**

Manufacturing cost	232
Development work	130
Drawing package	72
Total cost	434

e. **Frame and Panel Shelter**

Manufacturing cost and Drawing package	680
Development work (prototype section, etc.)	260
Total cost	940

10. Minimum Need for Further Technical Development

Against this requirement, the Frame and Panel Structure ranks highest; except for the need to demonstrate the feasibility of scaling up existing structures, the only problem we foresee is the need for an adequate end-wall design to provide for the hangar entry by large helicopters.

The Double-Wall and Inflated-Tube, air-supported tents should be capable of design within the present state-of-the-art based on past field experience with Double-Wall air-supported structures. However, the RMH is a much larger structure than assembled heretofore and numerous alternatives must be examined in the development of the final design. It is believed that bladders could be used in this structure as in past designs, but field maintenance operations would be simplified if coating procedures could be developed to eliminate the need for bladders.

The design of a Pressurized Rib tent is not yet fully within the state-of-the-art. This concept is currently under exploratory development. We have developed the data and relationships necessary to design the structure and have proven out the feasibility of manufacturing the straight beams and arches required for the structure by a weaving technique. Currently under development is the technique for coating these elements so that they will retain air under high pressure without bladders. For this structure, we believe that the use of bladders will not prove a feasible alternative. Therefore, in this case, the development of a suitable coating technique must be considered a technical barrier which must be satisfactorily overcome to achieve success.

The Tension Structure should be capable of design within the current state-of-the-art. However, a considerable design effort will be required to provide suitable erection techniques and an adequate end wall entry.

The studies required for each concept together with cost estimates for the effort are summarized below.

a. Frame and Panel Structure

Development Area	Estimated Cost (thousands)	
(1) Scale up existing design to dimensions required by the RMH. Fabricate a full-scale prototype consisting of three sections.	Contract for (1)	$200
(2) Develop an end wall design compatible with Frame and Panel concept. Model test at least two concepts and fabricate one full-scale	Contract for (2)	40
	In house monitoring	20
	Total	$260

b. Inflated Tube Tent

Development Area	Estimated Cost (thousands)	
(1) Examine alternative methods for tube fabrication including coating procedures to eliminate bladders. Make model tubes and lab test. Choose best method and fabricate four prototype cells. Determine best method for grouping cells, fastening skin fabric panels together, and attaching the skin to the cells. Fabricate a prototype hangar section from the four tubes.	Contract for (1)	$100

b. Inflated Tube Tents (cont'd)

Development	Estimated Cost (thousands)	
(2) Develop an end wall design compatible with the Low Pressure Tube concept. This includes model testing at least two concepts and fabricating one full-scale end wall.	Contract for (2)	40
	In house monitoring	20
	Total	$160

c. Pressured Rib Tent

Development Area	Estimated Cost (thousands)	
(1) Investigate new concepts for rib fabrication including new coating procedures to eliminate bladders. Fabricate model ribs and lab test. Determine best method of fabricating ribs and make three full-scale prototype ribs. Develop the necessary skin-to-rib and skin-to-skin fabric fastening methods and include them in a full-scale prototype hangar section consisting of two arches with skin. Develop an inflation system which can quickly erect the structure and maintain the required 275 to 345 kPa.	Contract for (1)	$ 60
(2) Model test various geometrical arrangements of ribs to determine the most stable configuration. Use the results to finalize design of Pressurized Rib Tent for RMH. Test the fabric end caps to determine their ability to transfer external loads on the rib to the ground without causing failure (developing leaks, etc.).	In house testing for (2)	50
	In house monitoring	20
	Total	$130

d. Double Wall Tent

Development Area	Estimated Cost (thousands)	
(1) Examine alternative fabrication procedures with the objective of reducing fabric handling and sewing to a minimum during production. Design a weather tight fastening scheme for joining the large tent sections. Develop coating procedures to eliminate bladders. Select the best design and fabricate one 3-cell full scale tent section for testing.	Contract for (1)	$ 50

d. Double Wall Tent (cont'd)

Development Area	Estimated Cost (thousands)	
(2) Devise several methods for handling large and massive tent sections in the field with portable lightweight equipment. Choose best method based on field testing and deliver one item/system.	Contract for (2)	$ 20
(3) Design an end wall compatible with the Double Wall Tent Concept. Work will include model testing at least two concepts and fabricating one full-scale end wall.	Contract for (3)	40
	In house monitoring	20
	Total	$130

e. Tension Structure

Development Area	Estimated Cost (thousands)	
(1) Determine the detail design of the metal arches including the connecting mechanism for joining beam sections and a method of transferring the load to the ground (foundation design and arch attachment). Develop a complete erection sequence which is safe for unskilled crews. Develop a method for connecting large skin fabric panels together consistent with the erection schem. Determine the detail design of the end of the hangar such that guy lines required for structural stability do not interfere with aircraft entering and leaving the hangar. Fabricate a full-scale partial prototype for testing.	Contract for (1)	$110
	In house monitoring for (1)	20
	Total	$130

F. EVALUATIONS AND CONCLUSIONS

1. Concept selection for the "Highly Mobile Field Maintenance Hangar" option.

Under this option, the highest priority requirements from section C are: (1) low mass and bulk, (2) quick erection and striking, (3) minimum ancillary equipment, (4) ability to erect on uneven ground, and (5) readily maintainable in the field.

On the basis of comparisons in the previous section, the Inflated Tube Concept and the Pressurized Rib Concept are best suited for the "Highly Mobile" case.

The Tension Structure is a less desirable concept because (1) the erection is expected to be complicated and possibly dangerous, and (2) there is danger of structure collapse if not properly anchored and guyed.

The Double-Wall Tent is not considered practical because (1) the tent sections are relatively massive (360 to 455 kg ea.) and (2) experience with similar but smaller units indicates that typical maintenance requirements (fixing bladders, repairing web to skin seam failure, etc.) would be difficult.

The Frame and Panel Structure cannot meet the low shipping mass and bulk requirements for a highly mobile structure and is, therefore not considered. As discussed in the previous section, the Inflated Tube Tent is within the state-of-the-art. The development work required is necessary to define the best fabrication techniques since the required structure is much larger than any previous design. Also, as shown in the previous section, the Pressurized Rib concept should meet the requirements even better than the Inflated Tube concept. However, we do recognize a technical barrier (coatings to replace bladders) in this concept which must be overcome for successful design. Work to date on this barrier appears promising.

The best approach to the development of a "Highly Mobile" hangar in the first year would involve pursuing both the Pressurized Rib concept and the Inflated Tube concept. The progress of each could then be studied in the early development stage to determine which would be fully developed.

2. Concept selection for the "Semi-Permanent Relocatable Maintenance Hangar" option.

Under this option, the highest priority requirements from section C are: (1) resistance to deterioration from solar load, etc., (2) readily maintainable in the field, (3) resistance to high wind loads and snow loads, (4) minimize cost of item, and (5) habitability comparable to a permanent structure. The structure best meeting the above requirements (except for cost) is the "Frame and Panel" hangar. However, in this case it appears the higher cost of the item is justified since it is essentially designed for climates 1 to 8, while the other concepts are not so designed. In addition, it is anticipated that the habitability of a Frame and Panel Structure would be significantly higher than the other concepts.

3. Option trade-offs and program considerations.

The "Highly Mobile" and "Semi-Permanent" options differ markedly in estimated values for the RMH requirements. This can be clearly seen below where the values are listed side by side. Values are given only for the concepts recommended in parts 1 and 2 above. If the technical barriers required for development of the Pressured Rib concept are overcome, then the differences between the two options listed on Table 2 will be a maximum.

Only the Highly Mobile Option, with the Pressurized Rib Concept, comes close to meeting the gross mass and bulk guidance for the RMH of one 2.4 m x 2.4 m x 3 m container of less than 6800 kg. Also, to remain within the lift capability of a CH-47 helicopter, a container size of 2.4 m x 2.4 m x 3 m was chosen so that each container would not exceed 6800 kg.

The Inflated Tube and the Frame and Panel concepts are both within the state-of-the-art; thus the risks associated with either option are about equal. A technical barrier does exist with the Pressurized Rib option but the dual development approach on the "Highly Mobile" option will offer the opportunity for marked advances in the product with a minimum development cost, and no risk with regard to meeting the option choice.

The costs are markedly greater for the Frame and Panel structure. However, the higher cost buys more comfort and ease of maintenance with a corresponding decrease in mobility and increased reaction time. Other much heavier structures which are not as convenient to erect and dissassemble as the Frame and Panel are less costly. Consideration should be given carefully to the Army's needs. If high mobility is not essential, other semi-permanent options with somewhat greater reaction times can be obtained at lower costs.

G. PROGRAM RECOMMENDATIONS

Two different approaches are outlined below allowing the development of both a "Highly Mobile" and a "Semi-Permanent" hangar. The time period covers FY76 through FY78. In FY78, a decision will be made to continue either the "Highly Mobile" or the "Semi-Permanent" hangar.

1. Highly Mobile (Table 2)

   a. In FY76, the Pressurized Rib and Inflated Tube concepts would be considered. The contract work would be directed as previously suggested. In summary, new and existing fabrication procedures for each concept would be tested, and partial prototypes would be delivered to NDC for testing.

   b. FY77 work will depend on the results of the FY76 effort. If one or both of the pneumatic concepts prove feasible for development, than one full-size prototype will be made of the best concept in FY77. In addition, it will be necessary

TABLE 2

CONCEPT TRADE–OFF DATA

Requirement	Highly Mobile Option		Semi-Permanent Option
(See Evaluation Scheme)	(Pressurized Rib)	(Inflated Tube)	(Frame and Panel)
1. Shipping mass and bulk 2.4 m x 2.4 m x 3.0 m containers	7666 kg 2 containers	9934 kg 4 containers	31752 kg 5 containers
2. Time to erect	1 day	1½ days	3½ days
3. Ancillary equipment	none	none	none
4. Erect on uneven ground	good	good	poor
5. Maintainable in field	development required	development required	good
6. Resistance to deterioration	5 years maximum	5 years maximum	5 years minimum
7. Severe weather resistance	fair but can recover after failure	fair but can recover after failure	good if properly anchored
8. Resistance to hostile conditions	good	poor	good
9. Minimize cost (1st item plus development)	$369,000	$433,000	$940,000
10. Minimum need for technical development	tech. barrier – coatings to replace bladders	state-of-the-art but a new concept	modify an existing design – little required

to develop an end wall compatible with the concept chosen. If, however, it is determined that the pneumatic concepts require too much development work for the fabrication of a full-scale prototype by the end of FY77, then it will be necessary to abandon the "Highly Mobile" concept and develop only a "Semi-Permanent" Hangar as described below.

c. The FY78 effort should be a breakaway from the development effort to allow the MDC to evaluate the prototypes obtained and to start a contract for the final complete prototype for TECOM testing.

2. Semi-Permanent

The semi-permanent concept does not appear to require any difficult developments. However, the cost of the item is expected to be high (first prototype 600 to 700 thousand; cost reduction on actual production not known). Under the funding proposed, the development of this item would involve a contract including the engineering work required for scaling up a similar existing design and the development of an end-wall compatible with the hangar design.

FY77 funds would involve a contract to develop a full-scale prototype. FY78 funds could then be directed as mentioned above.

APPENDICIES

Appendix A Development of Cost Factors and Requirements Common to Several Alternative Structures

Appendix B Cost Estimations and Packaging Requirements for Each Shelter Concept

Appendix C Field Erection Concepts for Each Shelter

Appendix D Summary of Design Calculations for RMH Concept Evaluations

APPENDIX A

DEVELOPMENT OF COST FACTORS AND REQUIREMENTS COMMON TO SEVERAL ALTERNATIVE STRUCTURES

A. Raw Material Costs

1. Fabric

The material used in the MUST double-wall air-supported tentage is sufficient to withstand the stresses imposed by low pressure inflation (13 to 35 kPa).

(a) Current material cost for Type 1, Class 1, MIL-C-43285 O.D. is $6.56/m in 1.32-m widths, or $4.97/m². This represents the cost of essentially all the fabric material except the bladders.

(b) Current material cost for the MUST bladders is $3.01/m in 1.52-m widths or $1.97/m².

2. Aluminum extrusions for all uses.

Aluminum extrusions can usually be purchased for less than $4.41/kg.

B. Labor and Overhead Factor

The MUST double-wall air-supported tent was again used as a basis. Each unit is priced at $30,000 and consists of a corridor connector, four sections, two ends, and one air lock. The cost of the two ends and the air lock is about the same as one tent section, and the cost of a corridor connector is about $7000. This leads to a cost of $4600 per section. The amount of material per section was then estimated after reference to the drawings for the MUST unit. The current material prices were as listed in Section A above, and the ratio of the total tent section cost (fabricated) to the material cost was then calculated to be 3.64.

C. Density Factor for Packaging Inflatable Tents

One section of a MUST double-wall tent was weighed, its mass determined, and the cube measured. The results yielded a density of 148 kg/m³.

D. Anchoring Kit for Air-Supported MMH Tents

Note: The following kit does not include optional power tools for driving anchors. However, when figuring erection time, it was assumed power tools were being used.

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General items:

2 tape measures, 3.05 m long
1 tape measure, 30.5 m long
2 sledge hammers, 3.63 kg each
250 .10 m arrowhead tent anchors (5 boxes of 50 each)
1524 m .48-cm-diameter aircraft cable (or rope of similar strength) for guy lines.

Volume:

(1) 6 boxes, .91 m x .30 m x .10 m for tape measures, sledge hammers, and anchors (extra anchors included).

(2) 5 boxes, .91 m x .456 m x .30 m for guy lines (extras included) Mass: (includes mass of pine wood boxes)

(1)	6 boxes @ 35 kg ea	=	210 kg
(2)	5 boxes @ 87 kg ea	=	435 kg
	Total	=	645 kg

APPENDIX B

COST ESTIMATIONS AND PACKAGING REQUIREMENTS FOR EACH SHELTER CONCEPT

A. Standard Double-Wall Air-Supported RMH Concept (Fig. B1a)

1. Requirements for cell skins, bladders, mass, and bulk.

Design calculations indicate the double-wall tent will require an internal radius of about 11 m with 1.22-m diameter cells pressurized to about 17.2 kPa. The proposed tent would have about 13 sections with a cell construction as shown in Fig. B1b.

The amount of material required for each tent section was calculated. An extra 10% of material was included for fabrication losses when determining the cost, and an extra 20% of material mass was included when determining the total mass to account for adhesives, stitching, and fasteners. The total cost, package volume, and mass for the 13 tent sections was then calculated.

Assuming 2.4 m x 2.4 m x 3.0 m shelter-containers are to be used for shipping the RMH, then four sections were found to fit into one container. A total of 2¼ containers were then required for the 13 sections.

2. Frame and fabric end wall (Fig. B1c)

The simplest concept for an end wall is a hanging fabric reinforced with vertical metal poles. The top of the vertical poles have rollers which ride in a horizontal track allowing the door to open. Other methods of fabricating the end wall are being considered (from pressure stabilized beams, and from detachable fabric sections) but weight and bulk estimates made based on the frame and fabric end wall should be conservative when compared to the other concepts.

The following assumptions were made so that estimations of the cost, volume, and mass of an end wall could be made.

a. The vertical members are simply supported at the top (by a horizontal beam), at the center (by a guy line), and at the bottom (by a ground anchor).

b. Guy lines are out about 10.7 m to obtain longitudinal support of beam BC (Fig. B1c).

c. A one-dimensional non-extensional deflection of the fabric between the beams can be used to estimate loads on the beams.

d. Beam BC will be estimated so that it can contain rollers, etc. for the sliding door.

Calculations were made using approximate methods to transfer the wind load (814 N/m^2) to the hanging beams. The results yailded a 9.53 cm x 0.476 cm x 3.68 kg/m aluminum tube for tha vertical members and a 15.2 cm x 5.16 cm x 5.4 kg/m aluminum channel for the horizontal top member. The cost, mass, and bulk of the end wall were then calculated.

3. Packaging requirements using 2.4 m x 2.4 m x 3 m shelter containers:

a.	13 tent sections	2¼ containers
b.	End walls	½ container
c.	Guy lines and anchors	¼ container
d.	Blowers and erection tools	1 container
	Total	4 containers

4. Summary of data estimations for Double-Wall Air-Supported RMH concept:

			Cost (thousands)	Mass (kg)
a. Fabric for cell skins				
5348 m^2 @ \$4.97/m^2	=		\$26.6	
Labor @ overhead factor	=	x	3.64	
Total cost/mass	=		\$96.8	3266
b. Fabric for bladders				
6188 m^2 @ \$1.97/m^2	=		\$12.2	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		\$44.4	1339

c.	End walls			
	Fabric and aluminum	=	\$ 3.5	
	Hardware (estimate)	=	0.5	
	Subtotal	=	4.0	
	Labor and overhead factor	=	x 3.64	
	Total cost/mass	=	\$14.6	602
d.	Material for joining tent sections			
	402 m^2 @ \$4.97/m^2	=	x \$ 1.9	
	Hardware (estimate)	=	2.4	
	Labor and overhead factor	=	3.64	
	Total cost/mass	=	\$15.6	408
e.	Anchors and guy lines (Appendix A)			
	Estimated cost/mass	=	\$ 4.5	635
f.	Blowers and manifolds			
	13 blowers, estimated cost/mass		\$ 4.0	454
g.	Shelter-containers for shipping 4 – 2.4 m x 2.4 m x 3 m shelter-container units Estimated cost/mass	=	\$40.	3629
h.	Erection tools			
	Winches, cables, anchor driving equipment, and possibly a wagon type unit for positioning tent section in field Estimated cost/mass		\$10.0	454

i. Tent skirts for weather-proofing ground boundary

100 m^2 @ \$4.97/m^2	=	\$ 0.49	
Fasteners (estimate)	=	0.10	
Labor and overhead factor	=	3.64	
Total cost/mass	=	\$ 2.1	272

j. Total of all items

Cost	=	\$232,000
Mass	=	11060 kg

B. Pressurized Rib Tent Concept for RMH (Fig. B2)

1. Concept design requirements

Preliminary analyses indicate that an internal arch radius of 11 m and tube diameters of 0.3 m to 0.46 m will be required to make a suitable structure for the RMH. The arches would be separated by 2.44 m and would have a material modulus of 3.3 x 10^6 N/m. Calculations for a 0.46-m diameter arch indicates that a cell pressure of 276 kPa would be sufficient for a pressurized rib tent which must withstand about 0.96 kP snow load or a 36 m/s wind.

The material mass density required and the cost per square meter has been linearly scaled from contract information described below for the above design. It is expected that the cost of weaving the material would be drastically lower than experienced in the study cited, since the contract pricing is based on the cost of experimental material.

2. Cost, volume, and mass of the pressurized tubes

An estimate of the total length of the pressurized beams and arches was made. A raw material cost of \$4.41/kg, similar to the cost of commonly used synthetics, was used to determine the total raw material cost. Data was taken from a NDC contract for fabrication of pressure stabilized structural elements. Since the stresses are approximately three times higher in the RMH than in the referenced contract, a factor of 3 was used to determine the material mass per square meter. The cost of weaving was assumed proportional to length. Tooling rentals, loom programming, and initial setup time were taken to be the same as those in the reference contract. The coating changes were scaled proportional to the area for the tube skins, and bladders were included for this estimate (bladders are not recommended in the end item).

3. Cost, volume, and mass of skin material and pressurization equipment.

The skin material area consisted of the two semi-circular end wall areas and the semi-cylindrical tentage area. A material cost of $\$4.97/m^2$ and a density of $0.509\ kg/m^2$ were used with the packaging density of $148\ kg/m^3$ to determine the data for the skin material. The cost of pressurization equipment was taken as 1.5K along with a mass of 363 kg.

4. Packaging requirements using 2.4 m x 2.4 m x 3 m shelter containers

a.	Pressurized ribs	1-¼ containers
b.	Skin material and end wall fabric	¼ container
c.	Guy lines and anchors	¼ container
d.	Pressurization equipment and tent ground skirt	¼ container
	Total =	2 containers

5. Summary of data estimations for Pressurized Rib RMH concept. Items which are the same as those in the Double-Wall tent are repeated here for completeness.

			Cost (thousands)	Mass (kg)
a.	Fabric for tent skin			
	1180 m @ \$4.97/m	=	\$ 5.9	
	Labor and overhead factor	=	x 3.64	
	Total cost/mass	=	\$21.5	600
b.	Pressurized ribs and beams for end walls			
	Total cost/mass	=	\$95.9	3382
c.	End wall fabric			
	$422\ m^2$ @ $\$4.97/m^2$	=	\$ 2.0	
	Labor and overhead factor	=	x 3.64	
	Total cost/mass	=	\$ 7.3	227

d. Hardware and fabric for joining tent sections

Estimate, similar to double-wall:

401 m^2 @ \$4.97/m^2	=	\$ 2.0	
Hardware	=	2.4	
Subtotal	=	4.4	
Labor and overhead factor	=	x 3.64	
Total cost/mass	=	\$16.0	408

e. Anchors and guy lines (Appendix A)

Estimated cost/mass	=	\$ 4.5	635

f. Pressurization equipment

Total cost/mass	=	\$ 1.5	363

g. Tent skirts for weatherproofing ground boundary

100 m^2 @ \$4.97/m^2	=	\$ .50	
Fasteners	=	.10	
Subtotal	=	.60	
Labor and overhead factor	=	x 3.64	
Total cost/mass	=	\$ 2.2	272

h. Shelter-containers for shipping

2 – 2.4 m x 2.4 m x 3 m shelter-container units

Total cost/mass	=	\$20	1814

i. Total of all items

Cost	=	\$168,900
Mass	=	7701 kg

C. **Inflated Tube Tent Concept for RMH (Fig. B3)**

1. The Inflated Tube Tent will be similar to the standard double-wall in appearance. However, the cell construction will be different in that the cells will be individual and have a circular cross section. The cells will be joined with straps and the entire tent covered with a weather-proof outer skin.

2. The cost, mass, and bulk of the end walls, joining hardware, anchors, guy lines, blowers, and ground skirts are the same as estimated for the double-wall tent. The tubes, bladders, and outside weather skin were estimated as follows. The tubes were taken as 1 m in diameter pressurized to 18 kPa, and fabricated from 0.169 kg/m^2 nylon. An extra 10% was added to the raw material requirements for fabrication, and an extra 20% was added to the mass to estimate the effect of adhesives, stitching, etc. A packaging density of 148 kg/m^3 was used to determine the packaging bulk.

3. Packaging requirements using 2.4 m x 2.4 m x 3 m shelter-containers:

a.	Tent cells and weather skin		1-¾ containers
b.	End walls		½ container
c.	Guy lines and anchors		¼ container
d.	Pressurization equipment and tent ground skirt		1 container
	Total	=	3-½ containers

Entire shelter will be packaged in 4 containers. Any extra p··kaging space in the containers could be used by deploying agency to ship special an··lary equipment required by the mission.

4. Summary of data estimations for Inflated Tube Tent RMH concept. Items which are the same as those in the double-wall tent are repeated here for completeness.

			Cost (thousands)	Mass (kg)
a. Fabric for cells and bladders				
Material cost	=		$ 27.5	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$100	3221

b. Fabric for tent skin				
Material cost	=		$ 6.5	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$ 23.7	724
c. End walls:				
Fabric and aluminum	=		$ 3.5	
Hardware (estimate)	=		.5	
Subtotal	=		4.0	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$ 14.6	602
d. Anchors and guy lines (Appendix A)				
Estimated cost/mass	=		$ 4.5	635
e. Blowers and manifolds				
13 blowers, estimated cost/mass	=		$ 4.0	454
f. Shelter-containers for shipping 4 – 2.4 m x 2.4 m x 3 m shelter container units				
Estimated cost/mass	=		$ 40	3620
g. Tent skirts for weatherproofing ground boundary				
100 m^2 @ $4.97/$m^2$	=		$ .49	
Fasteners (estimate)	=		.10	
Subtotal	=		.59	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$ 2.1	272

h. Material for joining tent sections; joining fabric sections, joining cells in groups, etc.

401 m^2 @ $4.97/$m^2$	=		$ 1.9	
Hardware (estimate)	=		2.4	
Subtotal	=		4.3	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$ 15.6	408

i. Total of all items

Cost	=	$204,500
Mass	=	9945 kg

D. **Tension Structure Concept for the RMH** (Fig. B4)

1. Design comments

Tension structures are designed so that there is a small number of compression members and one fabric envelope. A 0.96-kPa snow load requirement was used to estimate the member size. Some of the items are the same as those required for the double-wall tent.

2. Arch requirements

Calculations indicate that if the span between the arches is 6.4 m, then a bending moment of about 67.8 kN·m will be developed in the arches. If 6061-T6 aluminum is used to fabricate the beams, then the required section-modulus is about $2.79 \cdot 10^{-4}$ m^3. A 25.4-cm-deep box type beam having a mass density of about 9.67 kg/m can satisfy this requirement.

Note: The assembled design will provide the arches with out-of-plane support.

Each arch will be sectioned in about 14 units, the joining hardware should have a mass of about 2.72 kg per junction. It also will be necessary to shape the beams to a 6.76-cm camber in the 2.44-m lengths.

Note: The arch proposed here is similar in mass, etc. to that proposed for the Frame-and-Panel (FP) concept, but the span between arches in this case is more than twice the span between arches used on the FP concept. This is because the FP concept was designed to withstand loads imposed on permanent structures, while the Tension Structure is being designed for a reduced load. (The extreme loads have a low probability of occurrence and the reduced load allows emphasis on the portable concepts.)

3. Cost, mass, and bulk of arches and associated components.

The total length of arch beams required was calculated and density figures given above were used to determine the total mass and bulk. A cost factor of $4.41/kg was used to estimate the raw material cost, and the total fabricated cost was determined by multiplying the raw material cost by the ratio of 3.64 (fabrication cost to material cost), as determined in Appendix A.

Foundations for the arches were sized assuming a base of medium clay able to support 192 kPa. The skin fabric figures were based on a raw material cost of $\$4.97/m^2$, a material density of 0.509 kg/m^2, and a packaging density of 148 kg/m^3. The arch connecting cables were assumed to be 0.635-cm-diameter 7 x 19 aircraft cable (610 m total). Two metal tripods, about 3.7 m high, and two winches rated to 22.2 kN were used as the erection kit. Ladders, staging, etc. were not included but would be required to install arch connecting cables and weather skin. The total package requirements based on the above were (a) metal arches 3/4 container, (b) skin fabric, cables, foundations 3/4 container, (c) guy lines and anchors 1/4 container, and (d) ground skirts and material for fabric junctions 1/4 container. Container size was 2.4 m x 2.4 m x 3.0 m.

4. Summary of data estimations for Tension Structure RMH concept. Items which are the same as those in the double-wall tent are repeated here for completeness.

			Cost (thousands)	Mass (kg)
a. Fabric for tent skin				
Material cost	=		$ 8.6	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$31.3	816
b. Arches				
Material cost	=		$ 8.0	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$29.2	1814

c. Hardware and extra fabric for joining skin sections

Similar to other tent requirements

Total cost/mass	=		$15.6	408

d. Anchors and guy lines (Appendix A)

A more complex guy line system is required for the Tension Structure to insure stability.
Estimated cost/mass (twice double-wall)

Estimated cost/mass (twice double-wall)	=		$ 9.0	1270

e. Tent skirts for weatherproofing ground boundary

120 yd² @ $4.00/yd²	=		$ .48	
Fasteners	=		.10	
Subtotal	=	x	.58	
Labor and overhead	=	x	3.64	
Total cost/mass	=		$ 2.1	272

f. Shelter-containers for shipping

2 – 8 x 8 x 10 ISO shelter-container units

Total cost/mass			$20	1814

g. Erection tools

Material cost	=		$ 2.0	
Labor and overhead factor	=	x	3.64	
Total cost/mass	=		$ 7.3	227

h. Arch connecting cables and hardware

Material cost	=	$ 2.0	
Labor and overhead factor	=	x 3.64	
Total cost/mass	=	$ 7.3	227

i. Total of all items

Cost	=	$121,800
Mass	=	6848 kg

E. Frame and Panel Structural Concept for RMH (Fig. B5)

The following information is presented as extracted from a submission by Lockheed-Georgia Company, the developers of this shelter structure:

Lockheed-Georgia Company proposes to supply one prototype LocArch hangar, 30 m span by 32 m long, and 10 m high. The shelter will be a lightweight, air transportable structure, comprised of easily erectable components. These components will be capable of being shipped and stored on re-useable shipping pallets or containers. The components will be capable being assembled into an erected shelter at a deployable site, using untrained personnel without the use of power.

1. Shipping Pallets/Containers

The contractor proposes that the pallets or containers used for shipping and storage be government furnished equipment. The components of the shelter will be designed to fit inside and be transported in the standard 3 m military container or pallet.

2. The Shelter Structure

The shelter will include the following components:

a. Fourteen basic beam assemblies, each consisting of fifteen beam segments.

b. Thirteen arch sections, each consisting of 31 arch panels.

c. Two endwalls with large airplane doors and smaller personnel entry/egress doors.

d. Twenty-eight base rail sections that tie together to provide the foundation for the building.

e. Two A-frame type arch erection winches.

f. One panel erection winch.

g. All base pads, guy lines, etc., necessary to anchor the building to the base system. The anchoring of base system into the ground will not be included as part of the shelter.

h. All flashing, weather stripping, etc., required to seal the shelter from the design weather extremes.

i. All erection tools and equipment necessary to erect the shelter and strike it.

3. Characteristics

The performance characteristics of the shelters are defined as follows:

a. Shipping and Storage – The shelter and erection aids will break down into components for shipping on pallets or inside container. The loaded pallets or containers could be air-transportable in a C-130 aircraft.

b. Erection and Striking – The palletized shelter components shall be capable of being systematically removed from the pallet and erected into a shelter using untrained manpower. The shelter shall be erectable by six men in 30 hours or less. The maximum striking effort shall be 180 manhours. An Operating and Maintenance Manual will be provided that will provide the erection sequence in an illustrated step-by-step approach. All components will be identified and coded for ease of assembly.

c. Terrain Capability – The shelter will be capable of being erected over terrain which varies a maximum of 61 cm over the projected floor area.

d. Watertightness – The shelter in the erected mode will be watertight when subjected to the rainfall and wind conditions which can be expected at deployment sites. For leak test purposes, a rainfall of 7.6 cm per hour with 18 m/s winds shall demonstrate site conditions.

e. Operability – The shelter will be capable of a minimum of 10 erection and strike cycles. Normal wear and tear and repairable damage can be expected. The building will be designed for a five-year minimum operational life, or ten-year storage life, or a pro-rate combination of each.

f. Environmental Conditions – The shelter will be designed and constructed to withstand the environmental conditions specified with no effective degradation of materials or performance.

(1) Wind – The shelter will withstand winds of 31 m/s with gusts to 46 m/s, when properly anchored at the base. The endwalls will withstand these loads in both the open and closed modes.

(2) Temperature – The shelter in the erected or shipping mode will be capable of withstanding temperatures of -54° C to +52° C.

(3) Solar Ultraviolet Radiation – All exposed material in the shelter and pallet will be capable of withstanding exposure to normal solar ultraviolet radiation for the temperature environment specified for the useful life of the shelter and pallet without degradation of performance.

(4) Snow – The erected building will withstand snow loads of 1.92 kPa over the horizontal projected area with a decrease of .02 kPa for each degree of arch slope over 20°.

g. Safety – The design of the building will contain features which will reduce or eliminate hazards to personnel without impairing the erectability of the assemblies.

h. Major Assemblies –

(1) Beam Assembly – The basic beam assembly shall function as the major load carrying member of the arched structure. The beam assembly will be made from extruded aluminum. It incorporates twin track rails into which the panels will slide.

(2) Panel Assembly – The panel assemblies provide a rigid cover for the shelter. The panel assembly comprises injection-molded foam polycarbonate. All panel assemblies are identical. The panel assemblies interlock with each other and tie into the tracks of the beam.

(3) Endwalls – The endwall assemblies will be assembled and erected with the end arches. The endwall assemblies will comprise aluminum extrusion posts that support a heavy duty fabric wall. The fabric will be "Herculon-80" or equivalent, a commercially available PVC-based material with loose-weave nylon mat reinforcement. Each endwall assembly will have a large airplane door that swings open like a curtain and two smaller fabric personnel entry doors at the corners. A minimum opening of 20 m wide by 6 m high shall be provided for airplane movement into the hangar.

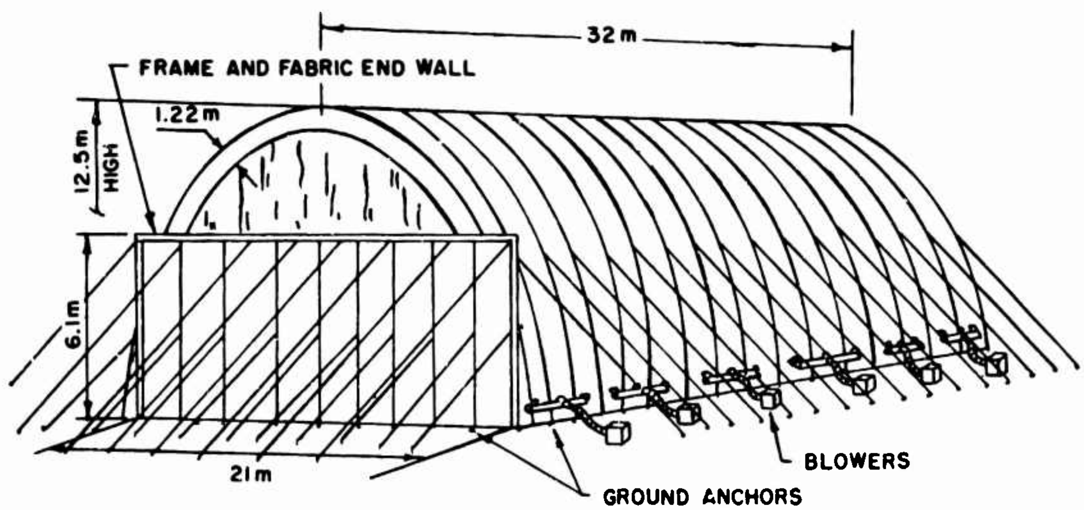
(4) Erection Equipment – All erection equipment is manually operated. The shelter can be erected without the use of any power. Power erection equipment can be supplied as an option.

(a) A-Frame Arch Erector – Two A-frame erectors will be provided. The arch erector components will be designed and constructed to assemble with captive hardware to form an assembly capable of picking up the design load.

Ground plates will be sized to support the load on soil with an allowable bearing pressure of 72 kPa.

(b) Panel Winch Assembly – This assembly will be mounted between two arches at the joint of the first and second beam segments. A heavy duty panel winch will be used. The panel winch is used to pull up or pull down the panels on the arch tracks. All hardware will be captive.

(5) Base System – The base system will comprise 6061-T6 aluminum channel extrusions to which clevises are welded. The arch beam assemblies will be pinned to the clevis sections. The base segments pin together and will be designed to support the shelter loads on soil with an allowable bearing pressure of 72 kPa. There will be tensioning devices for each base section. The tensioners tie down the panel rows to the base rails. Anchoring systems for tying down the base rails into the soil are not included.



NOTE: GUY LINES ARE ONLY REQUIRED FOR HIGH WIND CONDITIONS

FIG. B1a DOUBLE-WALL AIR-SUPPORTED RMH CONCEPT

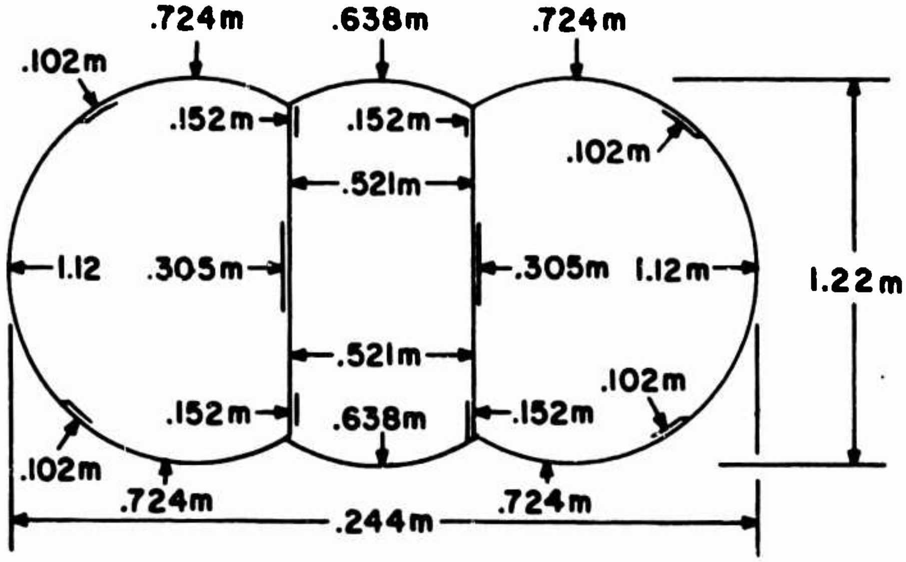


FIG. B1b CROSS SECTION OF THREE-CELL UNIT

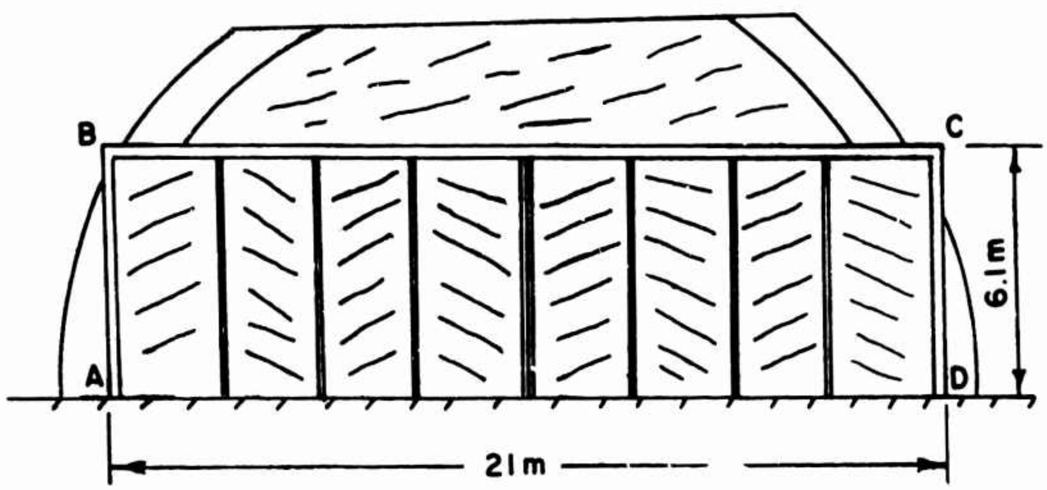


FIG. B1c VIEW OF END WALL

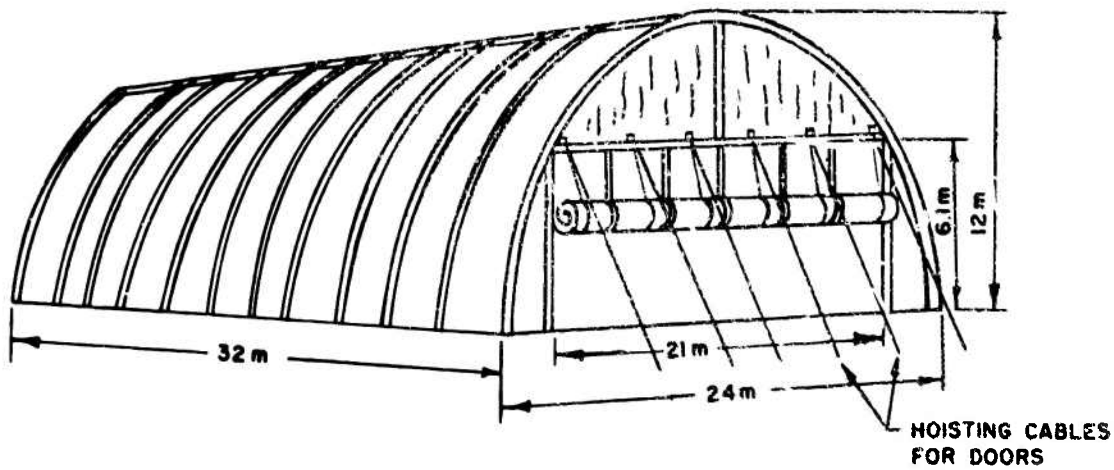


FIG. B2 PRESSURIZED RIB TENT CONCEPT FOR THE RMH

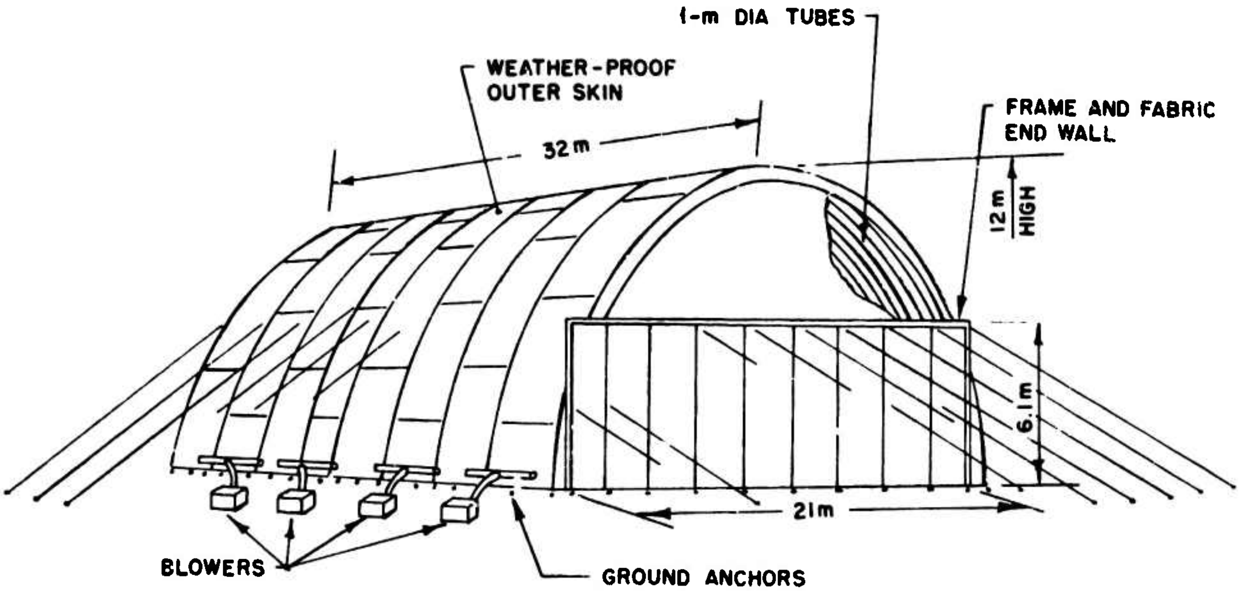


FIG. B3 INFLATED TUBE TENT CONCEPT FOR RMH

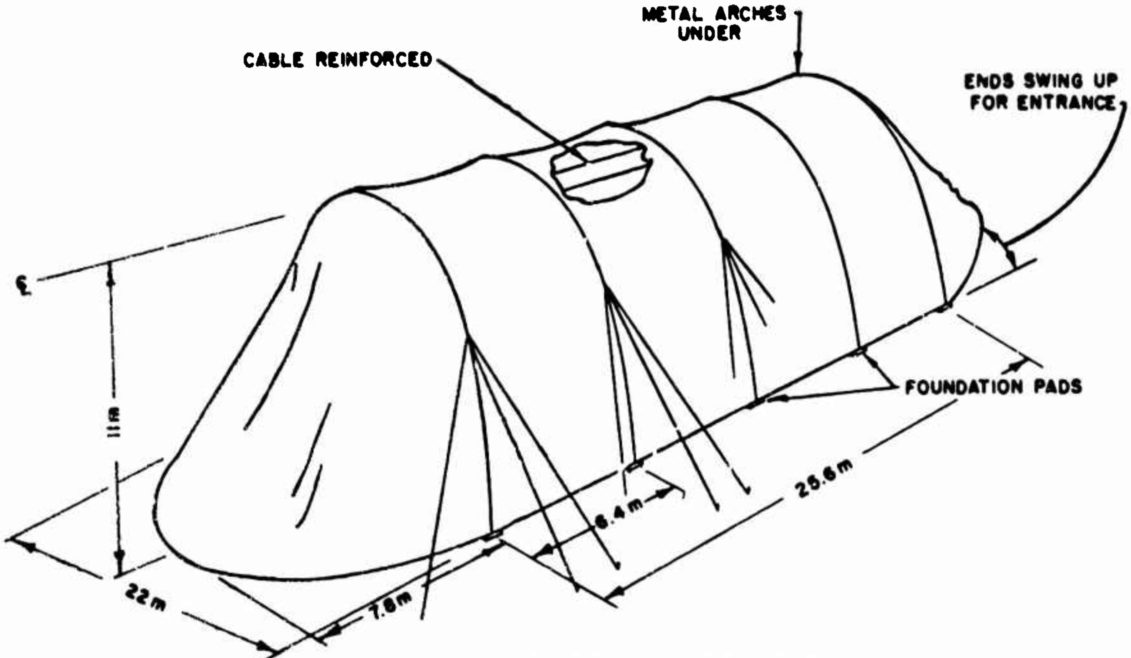


FIG. B4 TENSION STRUCTURE CONCEPT FOR RMH

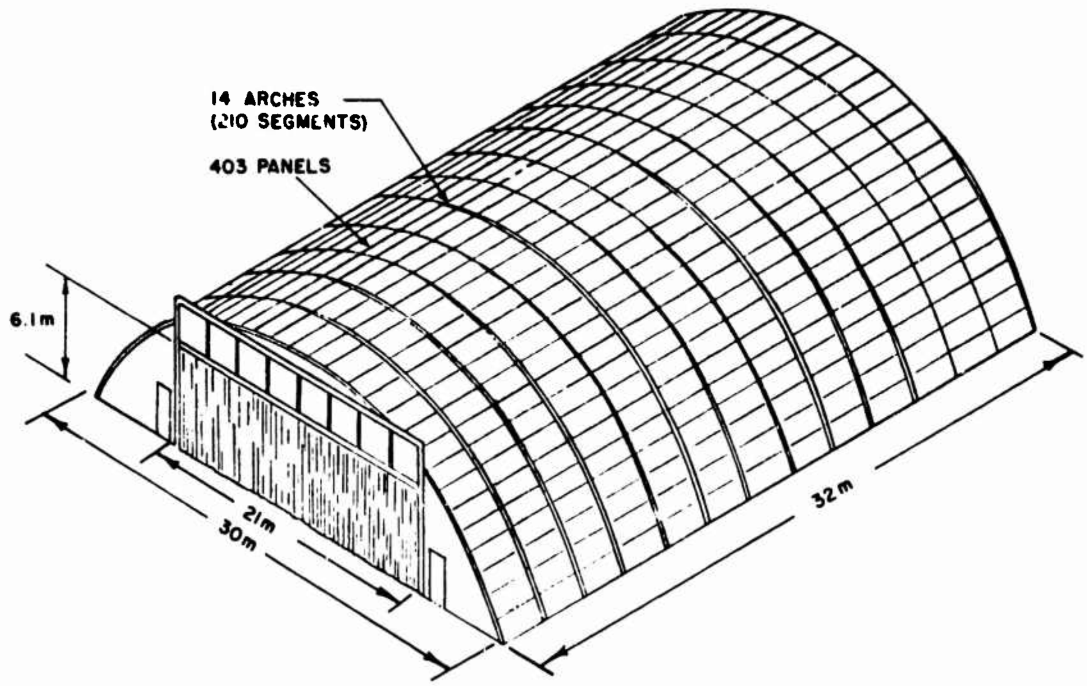


FIG. B5 LOCARCH FRAME AND PANEL SHELTER CONCEPT FOR RMH

APPENDIX C

FIELD ERECTION CONCEPTS FOR EACH SHELTER

	Estimated manhours required
A. Double-Wall Tent	
1. Layout site	2
2. Drive anchors	16
3. Unpack containers, position sections, position blowers, etc.	8
4. Unroll cells, make section connections inflate, etc.	16
5. Erect end walls	24
Total of 66 manhours or 6 men/1½ days.	
B. Pressurized Rib Tent	
1. Layout site	2
2. Drive anchors	16
3. Unpack containers, position tent components, compressors, etc.	4
4. Unroll fabric cells, connect fabric to anchors/guy lines.	8
5. Connect skin to ribs, inflate, and secure.	8
Total of 38 manhours or 6 men/1 day.	

	Estimated manhours required
C. Inflated Tube Tent	
1. Layout site	2
2. Drive anchors	16
3. Unpack containers; position cells; connect blowers	8
4. Unroll cells, connect them in groups.	4
5. Overlay weathersealing skin and make connections	8
6. Inflate; layout end walls; hoist end walls into position; perform final securing	24
Total of 62 manhours or 6 men/1½ days.	
D. Tension Structure	
1. Layout site	2
2. Drive anchors	16
3. Unpack containers, position equipment.	8
4. Assemble arches; secure in vertical position	16
5. Connect tension cables; tighten cables to make frame rigid	4
6. Pull over fabric; make final connections	16
7. Assemble and erect end walls	24
Total of 86 manhours or 6 men/2 days	

E. Frame and Panel Structure

The following information is present as extracted from a submission by Lockheed-Georgia Company, the developers of the LocArch structure.

1. The two containers are positioned and the base rail laid out on the ground.

2. Arch beam sections for the first arch are socketed together, pinned to the first base rail and the door attached.

3. Using winches attached to the containers the first arch is raised into place.

4. The second arch is laid out and raised into position.

5. One 1.2 m x 2.4 m honeycombed panel is fitted between the first two arches and pushed up. The balance of the panels follow one at a time sliding up and over to complete the first arch. The sequence is repeated until the last arch.

6. The last arch is raised with the end door members attached.

Total of 180 manhours or 6 men/3½ days.

APPENDIX D

SUMMARY OF DESIGN CALCULATIONS FOR RMH CONCEPT EVALUATIONS

A. Double-Wall Tent

1. General

The design calculations which follow were done in accordance with "The Design Manual for Ground-Mounted Air-Supported Strutctures", NLABS Technical Report #69-59-GP. The material chosen for the design was nylon. A factor of safety of 3.0 was used on the uniaxial strength of the material. To facilitate comparing the characteristics of tents with different cell radii, a FORTRAN computer program was written to do the calculations.

2. Basic design decisions and assumptions

The following basic design decisions and assumptions were made after studying the requirements of AR 70-38, the R.O.C., the Design Manual, and other references included below:

a. The shelter must withstand a maximum wind speed of 36 m/s and the lowest temperature at which this wind is anticipated to occur is -31.7° C.

b. The shelter will operate at approximately sea level pressures and, when erected, will withstand temperatures to -54° C.

c. Cylindrical type construction will be used with a height-to-diameter ratio of 1/2. The inside radius will be 13.26 m and its length will be about 30.5 m.

d. The shelter will be designed to have flat ends and a width-to-length ratio of about 1/1.

e. Factor of safety determination.

This design is based on plain weave nylon fabrics, so to determine an appropriate factor of safety, reference was made to two technical reports by these laboratories: "The Biaxial Stress-Strain Behavior of Fabrics", Technical Report ME-4, November 1965; and "Biaxial Tensile Tester for Fabrics", Technical Report #67-71-GP, May 1967. In these reports, light nylon fabrics of similar construction to those used in air-supported tents were tested to rupture under uniaxial and biaxial load conditions.

Investigating the data and noting the comments given in the reports lead to the following general conclusion. When plain weave nylon fabrics are biaxially loaded, the strength in either direction (warp or fill) can drop to 50% of its uniaxial strength. Thus, if a factor of safety of 1.5 is desired, then the 1.5 should be applied to 50% of the uniaxial ultimate strength which results in a total factor of safety of 3.0.

f. The fabric coatings were chosen to be the same as the coatings used on the MUST inflatable shelters. These coatings are specified in MIL-C-43285B, Cloth, Coated (Chloroprene Base Coated, Chlorosulphonated Polyethylene Top Coated) and MIL-C-43808 Cloth, Coated, Nylon.

3. Results of calculations

Cells sizes from 0.61 m to 3.35 m in 0.3-m increments were considered. A wind range of 30 m/s to 51 m/s with 2.57 m/s increments was used at a temperature of -32° C for each of the cell sizes. A short section of the data calculated is given below.

Wind	=	36 m/s
Temp	=	-32° C
Inside Radius	=	11.0 m

Cell Dia. (m)	Cell Press. (kPa)	Hoop Stress (kN/m)	Cell Dia/Tent Dia.
.61	34.6	10.9	.025
.91	24.3	11.6	.036
1.22	17.0	11.0	.045
1.52	12.9	10.7	.054
1.83	11.0	11.1	.063
2.13	10.1	12.1	.070
2.44	9.2	12.7	.077

When the total tent mass was considered, the cell diameter of 1.22 m appeared as one of the better possibilities and was used for the concept evaluation.

4. Comments on calculations

a. The allowable range of two nondimensional parameters, w/d and w/l, were exceeded in the calculations. Thus, the predicted cell pressures are extrapolated values.

b. There is a large difference in the cell pressures required for a given tent when comparing results from wind tunnel tests on models to the calculated values predicted by the design manual. To try and determine better cell pressures, a comparison of calculated values versus actual values was made for a full-size tent which was tested in a wind tunnel. The wind tunnel test data is presented in "Data Book for Air-Supported Shelter Tests Conducted at NASA Ames 12 m x 24 m Wind Tunnel". (Received under contract No. DAAG17-73-C-0264.) The results are shown in Table 2. Wind Tunnel Test Nos. 11, 21, and 30 indicate that a cell pressure of 2.49 kPa was sufficient for stability at all angles of wind attack. The design manual indicates a cell pressure of 8.52 kPa should have been used. Thus, in this case, cell pressures of 1/3 the calculated value were sufficient for stability to the wind.

B. **Pressurized Rib Tent**

1. The theoretical basis used to analyze this structure was developed at the Natick Development Center; references (1), "A Linear Analysis of the Deformation of Pressure Stabilized Beams", TR 75-47-AMEL, and (2), "Behavior of Pressure Stabilized Beams Under Load," TR 75-82-AMEL. An a-priori knowledge of the material properties is required. Since there was not enough time to do extensive testing of materials, a prediction of the properties of Kevlar 29 (the material being used in a current "pressurized arch" contract) was made.

2. Two types of load conditions were considered. First a wind speed of 36 m/s with a profile as defined in "Wind Tunnel Tests and Analyses for Ground-Mounted, Air-Supported Structures", TR 70-7-GP, and second, a vertical uniform snow load of 0.957 kPa. In both load cases, the skin fabric between the pressurized arches was assumed to carry the load equally to each arch with no load components out of the plane of the arch.

3. Initial calculations indicated the snow load was more severe than the wind load. The snow load was then used for the design calculations. Investigations of the predicted strains indicated that constraining the arches from rotation at the ends (fixing the supports) gave higher strains than letting them rotate freely. This result is contradictory to what would be expected from using intuition and knowledge of strength of materials.

4. Using the information above and a computer program developed for the "Pressurized Beam Theory" a range of pressurized rib diameters and material properties were considered. The negative strains from the load were surveyed. When the negative

strain from the load was equal to the positive strain from pressurization, than a "wrinkling" failure was said to have occurred. The properties chosen for the design study were those felt most practical in pressure and material requirements which satisfied the no-wrinkle condition. The use of a predicted material modulus of $3.3 \cdot 10^6$ N/m, an internal tent radius of 11 m, the snow load of 0.957 kPa, and a rib diameter of 0.46 m lead to a required pressure of about 275 kPa. The "hoop" and "longitudinal" stresses from pressurization were about 60.4 kN/m and 30.2 kN/m, respectively. The maximum positive longitudinal strain from pressurization and external load yield a stress of about 102 kN/m. Thus, neglecting shear, the biaxial stresses of 60.4 kN/m and 102 kN/M had to be considered when determining the material properties.

C. Inflated Tube Tent

1. The calculations done for this concept were fundamentally the same as those done for the Pressurized Rib Tent. A vinyl coated nylon fabric, used in testing the pressurized beam theory reference in B above, was used as the design material for the calculations. Since for this concept the tubes are side by side, the external snow load was scaled to the tube diameters.

2. An internal tent radius of 11 m, a material modulus of $2.05 \cdot 10^5$ N/m, a tube diameter of 0.91 m, and a snow load of 0.957 kPa were chosen as the best results for the concept evaluations. The pressure required to prevent wrinkling was 17.9 kPa. The maximum longitudinal stress was 12.0 kN/m and the hoop stress was 8.2 kN/m.

D. Tension Structure

1. A detailed analysis of a Tension Structure was felt to be beyond the scope of a concept evaluation study. To obtain reasonable answers for the required size of the arch beams, several assumptions were made. First, the arches would not be subjected to out-of-plane deformations. Second, the vertical snow load was used since this load causes high foundation loads. Third, the portion of the vertical snow load each arch receives is proportional to the span between the arches.

2. One arch with a radius of 11 m was then analyzed. Both ends of the arch were considered constrained from translation but not rotation. A uniform vertical load of 6.13 kN/m was applied and the principle of minimum potential energy was used to determine the reactions at the support. The maximum moment was then calculated and found to be 56.8 kN/m. Using aluminum with a yield strength of $2.41 \cdot 10^3$ Pa, a section modulus of $2.36 \cdot 10^{-3}$ m^3 was then required. A box beam with 2.54-cm x 20.3-cm flange plates and 0.318-cm x 40.6-cm web plates was then designed to satisfy the required section modulus. The beam density was 35 kg/m and, with estimates of the additional mass required for joining arch sections, the total arch mass was estimated as 1389 kg.