AD

TECHNICAL REPORT
NATICK/TR-78/009

COMPARATIVE EVALUATION OF CONCEPTS FOR MODULAR TENTAGE

JANUARY 1978

Approved for public release;
distribution unlimited.

UNITED STATES ARMY
NATICK RESEARCH and DEVELOPMENT COMMAND
NATICK, MASSACHUSETTS 01760

Aero-Mechanical Engineering Laboratory

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NATICK/TR–78/009
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE *(and Subtitle)*: COMPARATIVE EVALUATION OF CONCEPTS FOR TENTAGE
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER: NATICK/TR–78/009
7. AUTHOR(s): Arthur R. Johnson
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Engineering Sciences Division (DRXNM–UE), Aero-Mechanical Engineering Laboratory, US Army Natick Research & Development Command, Natick, MA 01760
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62723A, 1L762723AH98, AE028BG
11. CONTROLLING OFFICE NAME AND ADDRESS: Engineering Sciences Division (DRXNM–UE), Aero-Mechanical Engineering Laboratory, US Army Natick Research & Development Command, Natick, MA 01760
12. REPORT DATE: January 1978
13. NUMBER OF PAGES: 59
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*:
15. SECURITY CLASS. *(of this report)*: Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

FIELD OPERATIONS, FIELD TESTS, TENTS, AIR–SUPPORTED STRUCTURES, INFLATABLE STRUCTURES, SHELTERS, ARMY TENTAGE, FIELD ARMY, FIELD EQUIPMENT, MODULAR CONSTRUCTION, HABITABILITY

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

This report was prepared to provide a procedure for evlaluating the usefulness of various tentage concepts to the Army. Four concepts with different structural designs and components are studied. Important characteristics of tentage for Army use are identified and an evaluation scheme based on operational and logistical priorities is used to determine the best type of structure for the assumed priority list. Recommendations are made to develop prototypes, collect field data from use of prototypes, determine field priorities through use of a

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. Abstract (cont'd)

questionnaire, and to use the evaluation scheme presented in this report to determine a new family of modular tentage for the Army.

PREFACE

New tentage concepts have recently entered the state-of-the-art stage in development. Also, other countries and industry have developed various types of modular tentage (common components and extendable in length). As a result, it was necessary to determine the usefulness of the new concepts to the Army. As a result, the following study was made by the US Army Natick Research and Development Command.

Appreciation is expressed to Dr. Leslie A. McClaine, Dr. Earl C. Steeves, and Mr. Donald B. Shaw of the Aero-Mechanical Engineering Laboratory at NARADCOM for their valuable comments throughout this study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

COMPARATIVE EVALUATION OF CONCEPTS FOR MODULAR TENTAGE

1. INTRODUCTION

Past studies by Bass, Green, and Pohlman[1] and by Eggemeier, McGinnis, and Bensel[2] have stressed the need for field shelters with greater mobility, a modular construction concept and improved habitability as compared to the present pole-supported general purpose tentage. In an effort to provide Army tentage which more effectively meets the operational needs of the field Army today within the limits of current technology, the possible use of new concepts, fabrication techniques, materials, and tent systems must be considered and investigated.

This study evaluates several alternative structural options by comparing their engineering properities and cost data, and the degree with which they might meet selected needs and requirements. The evaluation is carried out quantitatively by assigning priority values to the requirements and comparative numerical scores for each concept's fulfillment of the requirement. These priorities and scores are combined to give an overall rating of the concept. The need for futher exploratory developments is pinpointed, and a development program is recommended.

Thus, the overall study will attempt to assess the impact and feasibility of using new technology and modular concepts and to define the improvements which might be achieved over current Army tentage by a development program. The purpose of the study is to guide the development program based on our present knowledge, it is not intended to provide the final decisions on answers to the need.

2. ALTERNATIVE CONSTRUCTIONS TO BE CONSIDERED

a. Discussion of Modular Tentage

In this report modular tentage means a tent system which has as many common components as possible and is designed so that it has common length units or a basic structural module which can attach end to end for extending the length of a tent; if possible, expansion in width would be a desirable feature. The development of a modular

---

1. Bass, W. W., Green, R. G., and Pohlman, R. L., "Shelters Requirements for the Army in the Field, 1966–1980," Logistic Studies Office Memorandum CORG–M–209, US Army Combat Developments Command, Combat Service Support Group, Fort Lee, Virginia, June 1966.

2. Eggemeier, F. T., McGinnis, J. M., and Bensel, C. K., "A Human Factors Survey of Army Tentage," Technical Report TR–75–32–FSL, US Army Natick Laboratories, Natick, MA, April 1974.

tent system will certainly result in a family of tents with standardization of parts and will provide a greater opportunity to match field shelter requirements against available tentage. The degree to which modularity is incorporated will depend on the number of sizes required, the use of each of the sizes, and whether expansion can be accomplished in width as well as length.

It is felt that any structural concept (frame, pole, etc.) can be made to extend in length and that no extensive development work is required in this area. However, the ability of a tent to expand in width is not clearly understood. Some thought was given to this problem and the ideas summarized in Appendix A were used to conclude that, currently, there is no feasible method of expanding in width which will not cause one or more of the various widths to be under-designed, over-designed, or contain too many parts for efficient assembly.

To indicate how a modular tent system can reduce the complexity or diversity of the current tent system's inventory, Table 1 was constructed. Three basic tent sizes are suggested and some of the current standard tents have replacements indicated. In addition to having fewer types of tents, the possibility of changing the size of a tent to better meet special field mission requirements will be provided by a modular system.

b. Frame-supported Tent

Frame-supported tents for this discussion are considered to consist of a variety of metal beams, fittings, and truss members which are fastened together in the field to form a support structure. The fabric environmental barrier is then pulled over the framework, and anchors and guy lines are attached. Figure 1 shows the important characteristics of a metal frame-supported tent. The essential components are the frame members, the fabric, and the guy lines and anchors.

There have been some recent developments in modifying existing frame-supported tents into modular tent systems. These tents feature an aluminum frame and an outer skin of cotton sateen. Flies with metal eave and ridge extenders are included with these tents, while large screened windows and vents in the roof increase their habitability in tropical or desert operations.

In terms of mobility, frame-supported tents are generally considered least attractive. However, some of the newly developed frame-supported tents are easy to erect and require no special equipment. There is, however, a larger manpower requirement for erection of frame tents than for any other type of tent.

c. Pole-supported Tents

Pole-supported tents, as shown in Figure 2, consist of a number of side poles and center poles, a fabric cover, and the required guy lines and anchors. These tents are

TABLE 1. SUGGESTED SIZES FOR MODULAR TENTS AND SUGGESTED SUBSTITUTIONS FOR CURRENT STANDARD TENTS

Suggested Sizes

Designation	Length (m)	Width (m)	Peak Height (m)	Expansion Increment (m)
Tent a	3.0	3.0	2.5	1.5
Tent b	9.75	4.88	3.0	3.25
Tent c	5.0	8.0	7.0	3.25

Suggested Replacements

	Current Tent	New Tent
1.	General Purpose Small	Tent a
2.	Command Post M-1945	Tent a
3.	Flyproof Kitchen M-1948	Tent b
4.	General Purpose Medium	Tent b
5.	General Purpose Large	Tent b
6.	Tent-Assembly M-1942	Tent c
7.	Expandable Frame Tent	Tent a
8.	Tent-Maintenance Shelter	Tent b
9.	Tent-light Metal Maintenance Medium	Tent b

FIGURE 1. FRAME SUPPORTED

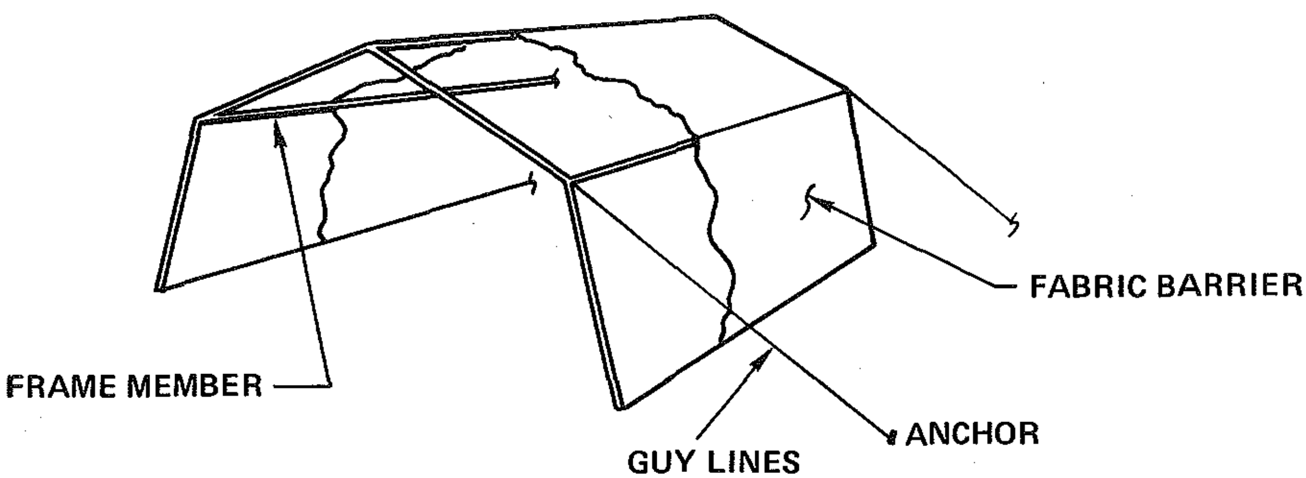
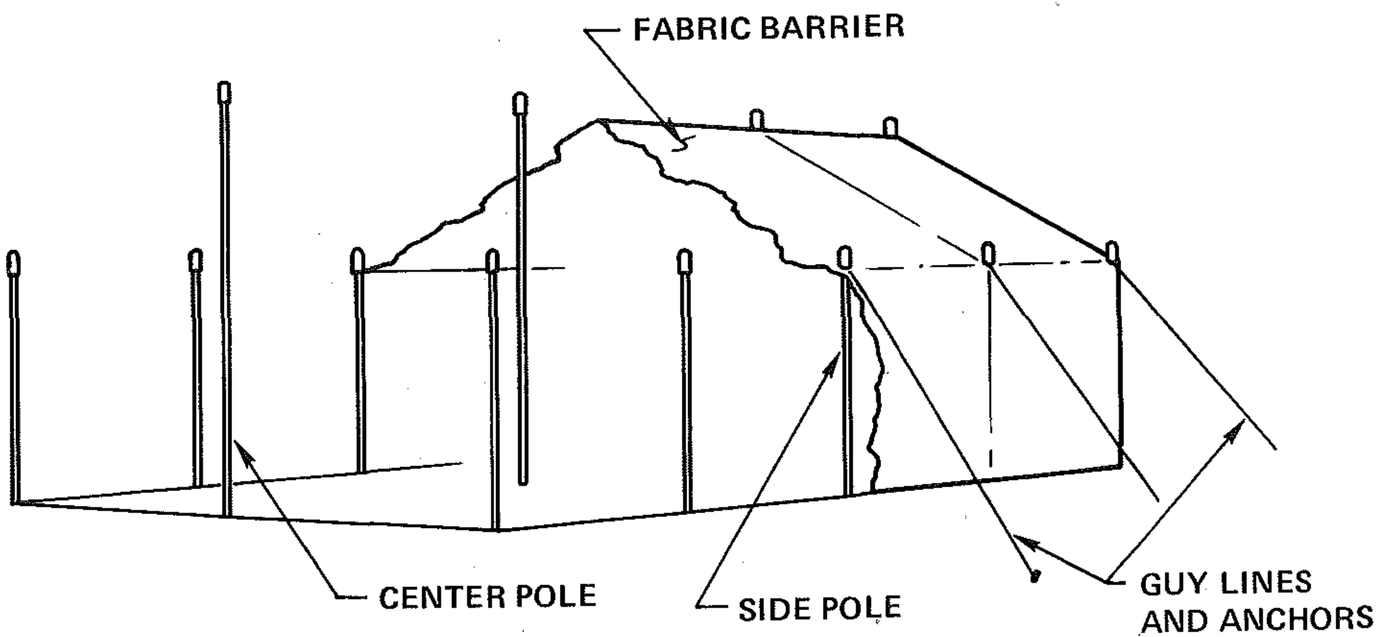


FIGURE 2. POLE SUPPORTED



assembled by laying out the site, staking, and positioning the poles, laying out the fabric roof, lifting it into position and attaching the sidewalls.

There are several areas in which pole-supported tents can be improved. First, the habitability of pole-supported tents would be improved if provisions were made for ventilation. Second, these tents could be made more mobile by reducing the effort required to drive the large number of anchors used by pole-supported tents. However, it is felt that very little mass or bulk reduction is possible on these tents.

The center pole restricts the usefulness of the cover area in such functions as maintenance which require large unobstructed spaces. This disadvantage must be considered in evaluating the concepts.

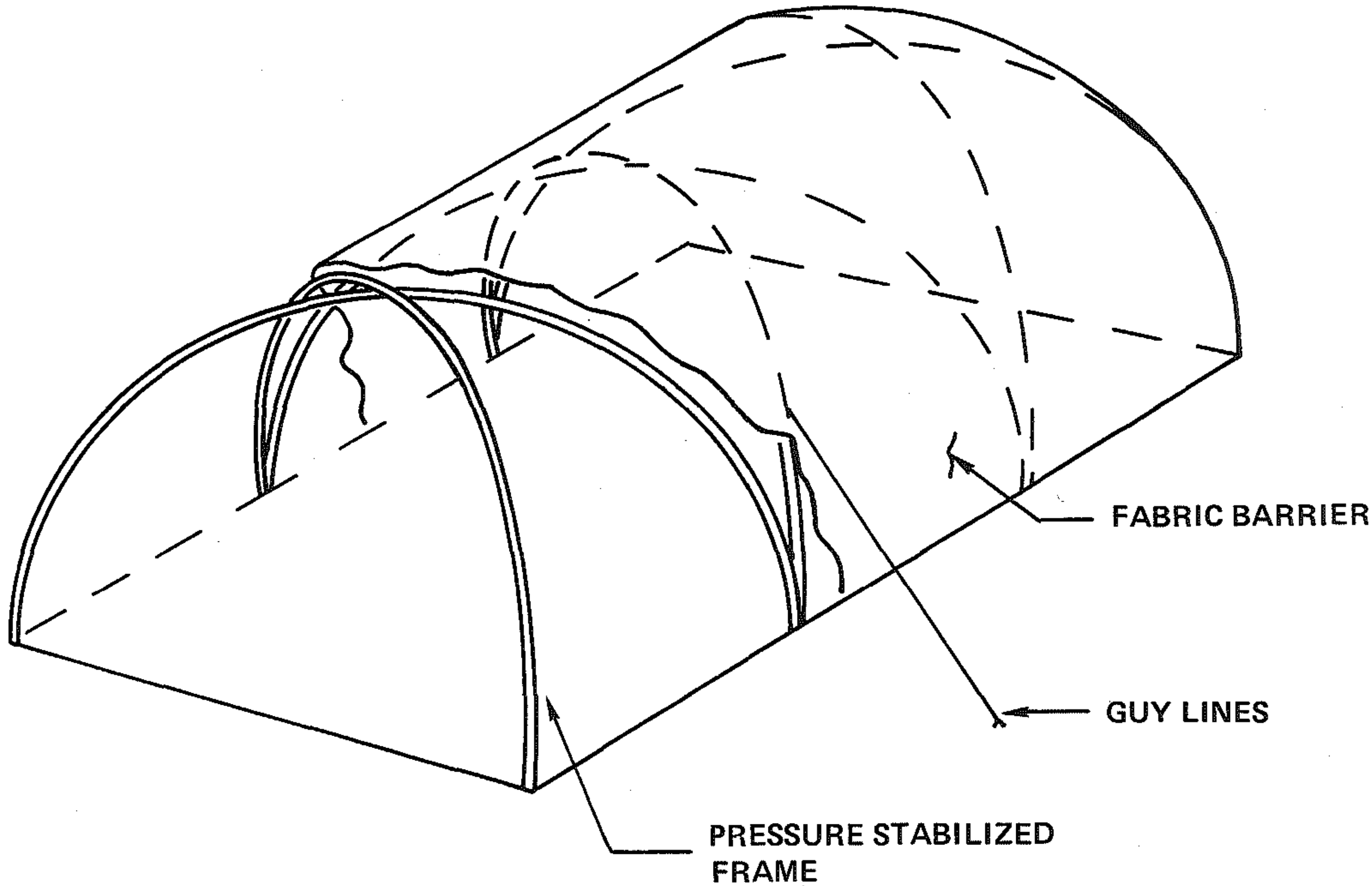
Pole-supported tents of rectangular configuration can be made to extend in length. The components of the extendable tents would be: (1) an end section consisting of a longitudinally sloping roof section and, (2) central sections which can connect either to each other or to an end section.

d. Pressurized-rib tent

The pressurized-rib tent consists of a frame of highly pressurized (compared with present air-supported tents) structural elements supporting a lightweight fabric barrier, as illustrated in Figure 3. Since the structural elements are pressure-stabilized, they can be fabricated from lightweight, flexible materials such as cloth, thus reducing the mass and the bulk of the frame in the transport configuration. It is felt that small and medium size tents could be constructed as an integral unit, that is, with the fabric barrier attached to the support structure, so that when deployed there would be no assembly in the field other than attaching units lengthwise. Thus, a modular unit would be self-contained and erected as a unit upon inflation. Large size tents could be assembled on the ground and then inflated. Pressurized-rib tents require air-inflation equipment but such equipment need not be dedicated to a single tent. This inflation equipment might place a large mass penalty on the concept which will have to be considered in a trade-off with the ease and speed of erection possible with this concept.

The pressurized-rib tent can be made modular by fabricating two types of units (which are able to attach to each other): (1) an end unit having doors, and (2) an extendable section made to attach to either another extendable section or an end section. This concept has the highest potential for modularity in that sections of the tent can come as an integral unit so that they need only be positioned, attached, and inflated; that is, nearly no assembly would be required in the field. Note, low-pressure tents are not being considered because they require a constant supply of air, and are not considered to be mobile enough for general purpose tentage.

FIGURE 3. PRESSURIZED RIB (AIR SUPPORTED)



e. Geodesic Tent

Geodesic tents, illustrated in Figure 4, are not a developed concept. However, recently the concept of quick-erect geodesic-type tents has become of interest to the Army. The acclaimed advantage of this concept was that large structural frameworks can be supplied in low volume packages which expand into the support structure with no assembly required. Thus frameworks "pop" up, fabric is pulled over the framework, and guy lines attached. However, this study indicates that, contrary to early claims, when designed to take the required snow loads, the framework can be expected to be similar in mass and bulk to a frame-supported tent, and because of the high number of frame joints, fabric costs are expected to the high and fabric mass increased by the large number of reinforcements required. However, they are included in this study because of the recent interest in their potential pop-up or rapid-erection feature. An outline of the calculations used to estimate the loads in a geodesic tent due to an applied snow load is given in Appendix B.

There are other shortcomings of the rapidly erectable geodesic-type structures. First, the members must be joined with ball-type joints capable of allowing the structure to open and close. This adds mass and cost to the structure. Also, if a few mechanical joints become damaged, then the ability to open and close the structure may be lost. Thus, high-quality, rugged joints would be required to assure that the support structure remains useful. It should be noted that the models have demonstrated ability to open and close after receiving extensive damage to the members, but that soundly designed, lightweight joints have not yet been developed. It should also be noted that there is no cost data in this report on geodesic tents since there is not enough information on the hardware designs, etc., to make meaningful estimates.

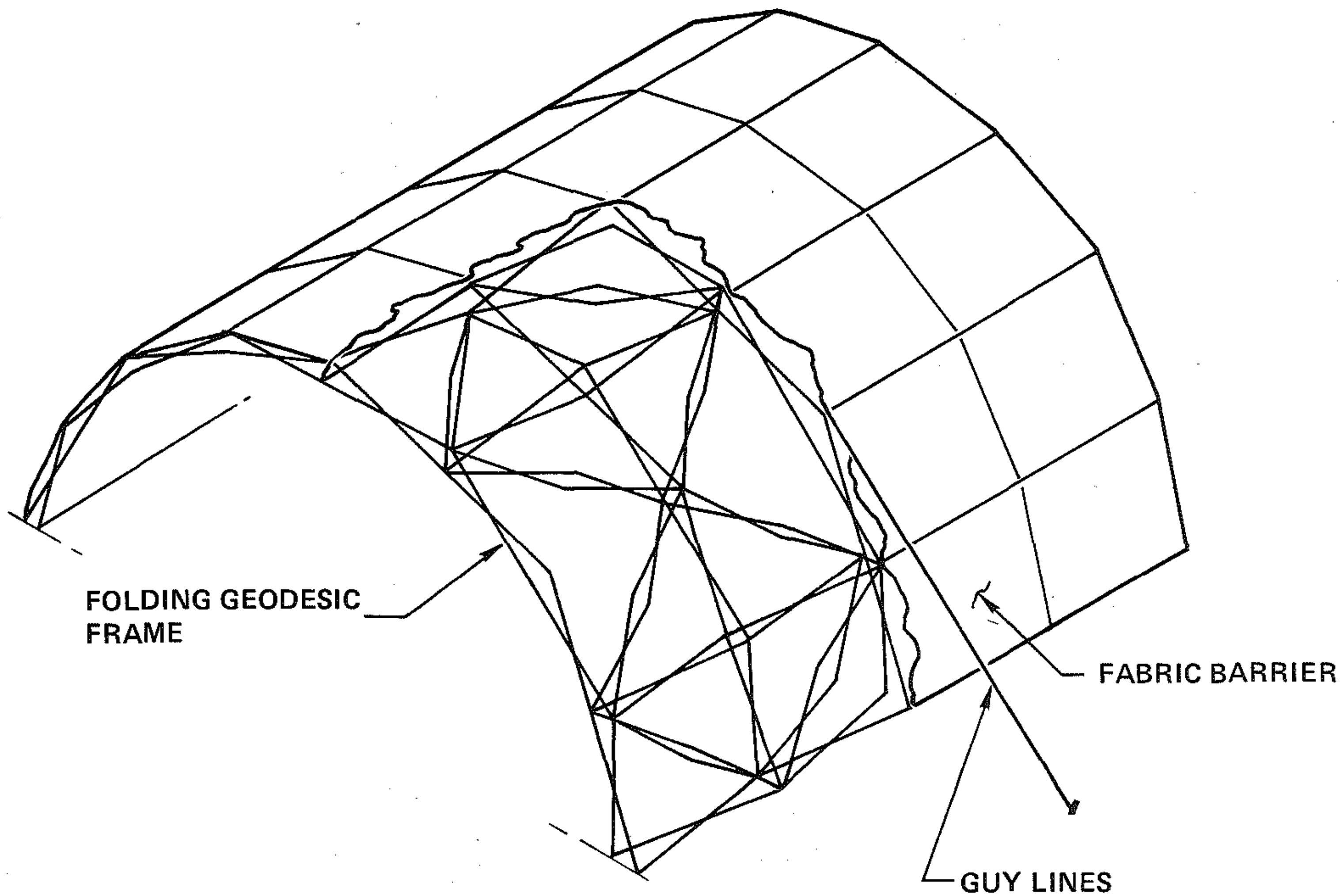
The geodesic structure could be made modular by using a semicylindrical construction (arch) for the support frame. Longer structures are made simply by adding arches in tandem. Fabric covers would be made to fit the modular arch sections and join to each other. End walls and arch ground anchors would then complete the structure. As in the frame-supported and pressurized-rib concepts, there would be few guy lines required.

Designing of the geodesic tents to provide improved habitability would be similar in most respects to that of other concepts. However, windows and vents may be difficult to provide in practice. The large number of components of the frame which are in contact with the fabric will restrict the size and locations of the windows and vents. These contact points will also require reinforcement areas on the weather cover. This will increase the mass and cost of the cover, indicating that the resulting cover may be comparatively heavier and more costly for this concept than for others.

3. CHARACTERISTIC DATA ON ALTERNATIVE TENTAGE CONCEPTS

In order to provide some information for a rational comparison of tent concepts, available data on mass, cost, time to erect, etc., for a group of standard and prototype

FIGURE 4. GEODESIC



Army tents was used to arrive at the figures listed in Table 2. These data represent the range of values existing or calculated for the various tents or tent concepts examined, as shown in Tables 3 and 4 for frame and pole-supported structures, respectively. The data presented in Tables 3 and 4 were extracted from office literature in the Aero-Mechanical Engineering Laboratory at NARADCOM. No correlation of tentage properties vs span was found in the data. Available cost data were adjusted to a common FY76 base. The data presented for the pressurized-rib tent were estimated from office literature related to on-going contracts to develop pressure-stabilized arches. The estimates for the geodesic tentage data were the results of an analysis to determine the mechanical properties of the tubing required in a typical geodesic structure under snow load. The geodesic analysis is summarized in Appendix B. Also, Tables 2, 3 and 4 have been left incomplete in some areas due to a lack of available data in the associated areas.

The data for frame-supported tentage in Table 2 split into two categories. The first category was for maintenance shelters which are generally heavier and more costly than similar tents for general use. The second category was general frame-supported tents, and the data in Table 2 for these tents was obtained from the data in Table 3 associated with (1) the XM75 tent, and (2) the Aerofab tent.

It should be noted that Army general-purpose tentage is now restricted primarily to the pole-supported classification,[3] and thus if any other structure is adopted there could be some major logistical property changes in the Army's tent supply since packaged cube, erection time, total tentage mass and cost vary markedly for different structures, as is evident in Table 2.

Table 2 provides some interesting insight into variations among these alternative tent constructions. Specific notice should be taken of the variations in mass and bulk, ease of erection, and cost. These are:

1 From the standpoint of minimizing weight and bulk, the pole-supported tentage is much better than the frame. The geodesic requirements were calculated to provide the minimum structure to support the dead loads; its mass falls at the low end of the frame weight spread, as might have been expected. The mass and bulk values for the pressurized rib structure are comparable to those of pole-supported and much less than those for metal frame structures.

2 From the standpoint of ease of erection, the frame-supported range below pole-supported structures in manhours required to erect. The manhour requirement for pressurized-rib ranges is still lower.

---

3. "Reference Manual on Shelters," US Army Natick Laboratories, Natick, MA, January 1972.

TABLE 2. APPROXIMATE PROPERTIES OF ARMY TENTS PER SQUARE METER FLOOR AREA

TENT / PROPERTY	FRAME SUPPORTED MAINTENANCE	FRAME SUPPORTED GENERAL	POLE SUPPORTED	PRESSURIZED RIB	GEODESIC
Support Structure Mass Kg/m^2	5.2 – 11.9	3.8	0.19 – 1.64	1.85 – 2.54	2.85
Fabric Mass Kg/m^2	1.9 – 5.2	2.2 – 2.8	1.7 – 2.8	1.71	1.71
Tent Mass Kg/m^2	7.7 – 16.9	5.7 – 6.6	1.9 – 6.3	3.56 – 4.25	4.56
Packaged Cube m^3/m^2	0.39 – 1.77	0.025	0.010 – 0.022	0.011 – 0.014	0.036
Man Hours To Erect mh/m^2	0.124 – 0.539	0.027 – 0.056	0.056 – 0.146	0.021	—
Cost of Support Structure \$/m^2	—	37.3 – 40.3	1.4 – 7.8	47.1 – 83.0	—
Cost of Fabric \$/m^2	—	26.4 – 36.5	11.0 – 25.5	—	—
Complete Tent Cost \$/m^2	—	63.7 – 76.8	17.1 – 31.4	—	—

TABLE 3. APPROXIMATE PROPERTIES OF STANDARD AND PROTOTYPE FRAME-SUPPORTED TENTS

FRAME TENT \ PROPERTY	FLOOR AREA m^2	SUPPORT STRUCTURE MASS Kg	FABRIC MASS Kg	TENT MASS Kg	PACKAGED CUBE m^3	MAN HOURS TO ERECT	COST OF SUPPORT STRUCTURE $	COST OF FABRIC $	COMPLETE TENT COST $
FRITSCHE	29.7	172.	56.	228.	33.2	16.	3785.	1802.	5587.
XM75	47.6	181.	132.	313.	1.2	1.3	1775.	1256.	3031.
AEROFAB	23.8	91.	53.	144.	—	1.33	959.	869.	1828.
MEDIUM PORTABLE SHELTER	55.7	—	—	227.	43.0	8.	—	—	—
SMALL PORTABLE SHELTER	26.8	—	—	163.	26.8	3.33	—	—	—
MAINTENANCE SHELTER	43.5	343.	227.	570.	25.7	9.	—	—	—
AVIATION SMALL ADJUSTABLE	11.1	99.	23.	122.	6.1	2.	—	—	—
ARMY AIRCRAFT MAINTENANCE	516.	—	—	8722.	914.	240.	—	—	—
FRAME TYPE MATING	44.6	402.	150.	552.	49.7	24.	—	—	—
FRAME TYPE CHECKOUT	50.2	596.	135.	731.	19.7	8.	—	—	—

TABLE 4. PROPERTIES OF STANDARD POLE-SUPPORTED TENTS

POLE TENTS \ PROPERTY	FLOOR AREA m^2	SUPPORT STRUCTURE MASS Kg	FABRIC MASS Kg	TENT MASS Kg	PACKAGED CUBE m^3	MAN HOURS TO ERECT MN-HRS	COST OF SUPPORT STRUCTURE $	COST OF FABRIC $	COMPLETE TENT COST $
ARCTIC – 10 MAN	18.5	3.6	30.8	34.4	0.207	2.70	25.	471.	496.
COMMAND POST M1945	18.6	—	—	116.6	0.280	1.67	63.	257.	320.
G. P. LARGE	87.0	111.1	190.5	301.6	1.954	7.50	356.	1279.	1635.
G. P. MEDIUM	47.6	78.	132.	210.	0.934	2.67	287.	525.	812.
G. P. SMALL	18.5	21.3	52.6	73.9	.227	2.00	145.	435.	580.
LIGHTWEIGHT	10.5	3.6	21.8	25.4	0.108	1.25	—	—	—

3 The cost data indicate that pole-supported structures are much less expensive than metal frame structures. The estimated cost of the support structure for pressurized-rib concept is higher than that for the metal frame. It should be recognized that these values in Table 2 were obtained from frame- and pole-supported tentage varying in size and function. In an effort to overcome this handicap, data were derived for a single size structure and are compared in Table 5.

In Table 5 the standard General Purpose Medium tent which is a pole-supported construction was taken as a base, and values for the other alternative constructions in the same size were calculated from comparison. The metal frame construction used represents a development in the prototype stage; it has a folding arch which minimizes the number of parts and simplifies assembly. Again, specific notice in Table 5 should be taken of the comparative mass and bulk, ease of erection, and cost. These are:

1 The mass and bulk are a minimum for the pole-supported and pressurized-rib alternatives. The metal frame-supported concept is markedly higher as is also the geodesic construction.

2 The ease of erection is; for this particular size, reasonably comparable for the three basic constructions; no value is given for the geodesic since no prototype has been built and questions with respect to erection still remain unanswered.

3 Again, the cost of a pole-supported tent is considerably less than that of a frame-supported tent. The pressurized-rib construction estimate is the highest; this cost is based on one construction technique used in initial prototype studies, other fabrication techniques are under study.

As mentioned earlier, if a construction other than the present pole-supported concept was to be used for general purpose tentage, there would be marked logistical impacts. Table 6 shows estimated cost, mass, and cube increases or decreases which the Army will be required to absorb, if the type of support structure alone is changed in current medium-size general-purpose tentage from pole-supported to any of the others being considered here. These figures are based on an estimated annual draw-down of 1162 general purpose medium-type tents and the data in Table 5. If the support structures are considered to last twice as long as the weather-protecting fabric, then Table 7 shows the estimated average cost increases over pole-supported for the total life of the structure assuming the annual draw-down figure being used. Table 7 was included in case future studies are biased toward cost; that is, the adjusted figures considering the total life of the support structure may be more meaningful.

4. COMPARATIVE EVALUATION

a. Introduction

The purpose of the comparative evaluation is twofold. First, it should suggest a procedure for comparing the concepts available for Army modular tentage, and second,

TABLE 5. ESTIMATED PROPERTIES OF 4.88m WIDE BY 9.75m LONG TENTS. (TAKEN FROM BEST DATA AVAILABLE ON XM75 FRAME TENT, ALUMINUM POLE G.P. MEDIUM TENT, PRESSURIZED RIB TENT, AND GEODESIC TENTS, ALSO, IT WAS FELT FINAL FABRIC COST AND MASS WOULD BE ABOUT THE SAME FOR EACH CONCEPT AND AND IS SO REFLECTED BELOW.)

PROPERTY \ TENT	FRAME SUPPORTED	POLE SUPPORTED	PRESSURIZED RIB	GEODESIC
SUPPORT STRUCTURE MASS Kg	181.	78.	72.	135.
FABRIC MASS Kg	132.	132.	132.	132.
TENT MASS Kg	313.	210.	204.	267.
PACKAGED CUBE m^3	1.19	0.57	0.50	1.71
MAN HOURS TO ERECT MH	1.3	2.7	1.0	———
COST OF SUPPORT STRUCTURE $	1775.	327.	4480.	———
COST OF FABRIC $	1256.	1256.	1256.	———
COMPLETE TENT COST $	3031.	1583.	5736.	———

TABLE 6. LOGISTICAL CHANGES EXPECTED BY CHANGING SUPPORT STRUCTURE, TOTAL PER YEAR FOR MEDIUM SIZE TENTS WITH A PEACETIME DRAW DOWN ESTIMATE OF 1162 TENTS PER YEAR

ITEM \ TENT	POLE SUPPORTED	FRAME SUPPORTED	PRESSURIZED RIB	GEODESIC
COST TOTAL COST INCREASE	\$1.84 million ———	\$3.52 +1.68	\$6.67 +4.83	———
MASS TOTAL MASS INCREASE	244.0 Mg ———	364.0 +120.0	237.0 –7.0	310.0 +65.0
BULK TOTAL BULK INCREASE	662.0m^3 ———	1383.0 +721.0	581.0 –81.0	1987.0 +1325.0

TABLE 7. AVERAGE COST DATA IF SUPPORT STRUCTURE HAS LIFESPAN EQUAL TO TWICE THAT OF THE FABRIC PARTS. BASED ON PEACETIME DRAW DOWN ESTIMATE OF 1162 TENTS PER YEAR

ITEM \ TENT	POLE SUPPORTED	FRAME SUPPORTED	PRESSURIZED RIB
COST TOTAL	$1.65 million	$2.49	$4.06
COST INCREASE	---	+0.84	+2.41

it should provide the developers and users with recommendations which can be either accepted for development or modified through independent priority changes to determine an alternative development program.

In this section of the study a brief outline of past tentage studies relating to modular tentage will be presented. Then the characteristics of tentage which have been determined most important to the users will be abstracted from this outline for use as the basis of the trade-off study. Recommendations will be made with regard to the conflicting characteristics of tentage so that clearly defined priorities for the modular tent system will be available for the comparative evaluation. A scheme for rating the concepts will be presented and evaluations of the concepts will be made for small, medium, and large tents (sizes suggested in Table 1). The evaluations will be done under two different priority ratings so that the effect of changing priorities can be observed.

b. Basis for Evaluation

(1) Summary of Previous Tentage Studies:

(a) Summary of the Study Done by the Combat Service Support Group, Fort Lee, Virginia (see reference 1):

This study used a questionnaire about shelters in which the user was asked to answer in detail questions relating to dimensions, mobility requirements, climatic design criteria, auxiliary equipment requirements, etc. It was found that tents are the most used type of shelter (more than 50% of the force structure shelter requirements), and that they are also universally unacceptable. Some general reasons why tents were not considered acceptable are:

1 To heavy and bulky.

2 Too difficult to erect and strike.

3 Arctic-sod cloths freeze to the ground, resulting in torn fabric.

4 Arctic-present liners, including door flaps, do not provide adequate protection.

In view of the facts that:

1 There was no effort underway to improve general purpose tents.

2 Current Army doctrine stressed the need for high mobility.

3 Over 77% of responses stipulated a requirement for rapid emplacement and displacement.

4 The predominant frequency of movement for tents is weekly.

The Combat Service Support Group suggested that "development effort be concentrated in the area of tentage to fill the void of acceptable items of this type."

In the area of climatic design they found that wind and rain were the most important environmental elements from which the tent should provide protection. Next in importance were snow, cold and heat. Other design areas evaluated included the importance of proximity of enemy forces, fire, blackout, etc. They found "only 24–26% of the users considered proximity of enemy action and remoteness of friendly support forces as important factors." Fire was also considered of minor importance by the users, but the authors felt that this hazard should be reduced in future tents. Finally, over 92% of the users suggested tents be designed for blackout, camouflage, air circulation, heating, and lighting.

Recommendations for improvement of tentage as a result of this study included the development of a modular-type tent system, as can be seen by the following suggestions for improvement of tentage:

1 Tents should be of rectangular configuration with expandable elements.

2 They should be able to join end to end.

3 Center poles, if used, should be lightweight and extendable.

4 Material should be lighter, fire resistant, and mildew resistant.

5 There should be ease of setup, erection, and striking.

6 Tent interiors should reflect light (maximum).

7 Liners and floors for tents should be made optional.

8 Ventilation should be more adequate.

9 External noise should be suppressed.

10 Large tents should allow for nose-in Army aircraft maintenance.

11 The small tent system should be able to be man-transported.

(b) Summary of Information Extracted from Report by Eggemeier, McGinnis, and Bensel (see reference 2):

This study sent a specially designed questionnaire to both military and civilian designers and users to help evaluate the performance of tantage in the field. The three major areas of concern were: (1) adequacy of environmental protection, (2) adequacy of space, and (3) ease of erection, striking, and packing. The following quotations from reference 2 are a few of the many observations made in the report cited above:

Things disliked most: ". . . . . the specific complaints noted with respect to the 4- to 6-man, 10-man, and larger sizes of tents. Concerning problems in erecting, striking, and packaging of tents, all were considered too difficult or too complex to erect, and too heavy and bulky for ease of these functions."

". . . . . namely that this particular panel, even when asked to name areas not noted previously, identified three major areas of concern regarding tentage: (1) environmental protection, (2) ease of erecting, striking, and packing, and (3) adequacy of space . . . . ."

Environmental Protection: ". . . . . failure to provide adequate protection from heat and dust were cited as the principal failings of the 4- to 6-man, 10-man, and larger tents."

In relation to erecting, striking, and packing the tent: "Problems with the tent itself were followed, in order of magnitude, by cold weather difficulties, difficulty at night, and problems associated with wet weather."

In relation to habitability: ". . . . . makes it clear that a majority of respondents favor inclusion of a floor in all sizes of tents." ". . . . . the primary reasons for preferring a floor in tents of all sizes included an increase protection from ground water or dampness, warmth, and protection from insects or rodents. Increased weight and bulk was the principal reason offered for a preference to not have a floor in the tent."

Design of materials and repairs: ". . . . . the inside and outside frame supports are preferred to the pole type of support in all these sizes of tents . . . . and an inside frame the preferred support among 10-man tents. The inside and outside frame supports are approximately equal in preference among the 4- to 6-man tents."

In relation to maintenance and repair: "The majority of recommendations centered upon the need for new adhesive for inclusion in the repair kits. The current cement was rated unserviceable, missing, or of inadequate quantity . . . . while others expressed a desire for a patch that could be used with cold-wet materials or for self-adhesive repair tape."

(c) Summary of Foreign Tentage Reports Received under this Study at NARADCOM:

Many foreign governments have recognized the need for modular tentage systems. The following material represents the highlights of both what these other governments have done and what they have recommended for new modular tent systems. This material has been abstracted from various unclassified Defense Intelligence Information Reports (cited in bibliography) and from office literature at NARADCOM. The details of all the sources are numerous, and to avoid confusion they will not be cited in the following summary.

1 Australia: The Australian army has developed a standard family of tents which uses common design of components and limits the variety of sizes and shapes to about five different combinations.

In summary: "Cotton/polyester, corespun fiber fabric, tubular aluminum frame-supported, interchangeable components that are easily assembled with slip joints. No centerpost. Minimum guy lines. Nylon inner roof coated one side with aluminum; double ceiling reduces internal temperature, prevents condensation, increases illumination, and acts as a light barrier. Extends in length with 3.0 m sections. The tent doors can be opened to three positions to allow large vehicles or aircraft maintenance (engines only)."

All five of the tents are modular in the sense that they are made from common components and are extendable in length. The habitability of these tents was also improved over older tents by the aluminum-coated inner roof, as mentioned above, and the inclusion of provisions for ventilation.

2 Canada: Information was obtained from two sources in private industry and one source in the Canadian government. One manufacturer has developed a frame-supported modular tent which uses aluminum poles and special snaphooks to make the frame easy to erect. The tent can be ordered in any length desired. Longer tents are made by adding additional standard frame components and extending the fabric; it is in this sense that these tents are of modular construction.

Another manufacturer has concentrated on developing tension-type structures for large tentage needs. These tension-type structures consist of aluminum ribs supporting a plastic fabric membrane. The tents can be obtained in any length by simply adding arches, and membrane sections attach between the arches. Thus, the idea of modularity is again present in these tents in that they have a standard construction from common components which can be modified in the field for any length. This manufacturer has also made an important observation about the lack of a sound basis for design of tentage structures.

The Canadian government has developed a prototype modular tent system. The tents developed have aluminum frames as a support structure. The modular system contains a basic arch-type frame-supported tent section which is capable of attaching either to another tent section or to a large connector. The connector allows the modular system to extend on both sides in a perpendicular direction.

3 Italy: The Italian Army has studied and tested a modular tent system. The tent system had modules with lateral openings so that groups of tents could be made "in various combinations to satisfy the most diverse military requirements." In all, there were three types of modules. First, there was "a simple tent extension module with light-admitting windows; this produces modular tents of 9 m, 12 m, etc." Second, "an extension module provided on one side with a 2-meter-wide opening equipped with an accordion joint which permits the module to be connected with another tent of the same type, which can be placed either parallel or perpendicular to the first tent." The third module was "an extension module provided with two opposing doors generally similar to those under part b), thus permitting a double connection with unified tents set on both sides of the first tent."

In general, the tents were frame-supported and of "light alloy." The tents also have windows and vents. However, the erection of the support structure appears to be complex. There are too many components and joints to be assembled in the field.

4 Japan: The Japanese have done a study which identifies some of the merits and demerits of various characteristics of general purpose tents. The study was done as a first step in developing a new family of tents. Major faults in current tent system cited are: "Various types of tents are used; the structures, parts, etc., of each tent are wanting in interchangeability; the weight of the tent is too heavy; the tent is inferior in habitability, and the tent is inferior in camouflaging property." In their "valuation study" they considered different areas of usage of the tent system and recommended a system for each. Their recommendations were based on the following five "valuation items," or characteristics:

a Adaptability: To select the desirable system from the viewpoint of use.

b Multi-usability: To evaluate whether or not the tent system can cope with the change in the scale of unit or in quantity of duties.

c Simplification: To evaluate whether or not the tent system is simple in structure and high in utility.

d Handling property: To evaluate whether or not the tent system is easy in handling for setting up, removal, maintenance, storage, etc.

e Economical property: To evaluate whether or not there is any difficulty or wastefulness on the function of the tent system from the viewpoint of supply and use.

Although they did an analysis of the supporting system, they did not recommend one. The recommendations were restricted to tent shape and size for specific duties. The system recommended was extendable in length, usable in both cold and warm climates, and had a basic floor area of about one-half that of the GP Medium tent used by the US Army. Another system was recommended (similar to GP Small in US Army) with a floor area of 12 m^2, able to extend in length, and able to be used in cold and warm areas. Detailed tent designs were not presented.

5 United Kingdom: Private industry in the UK has developed a frame-supported tent which is assembled by inserting poles into slipjoints (similar to the US Army experimental GP Small tent). The tent frame is extendable in length, and the fabric cover has windows. "The general purpose unit tent does not require poles and guylines. It is equipped with overlapping doors at both ends. The tent is currently in commercial production in the United Kingdom. It is suitable as sleeping or mess tent, office tent, first aid post, stores, and general shelters."

6 West Germany: Private industry in West Germany has developed a lightweight frame tent "with heavy waterproof cotton canvas draped loosely over the tubular steel frame and fastened with straps and buckles. The canvas is also strapped to anchor plates and staked to the ground; a polyvinylchloride sod strip protects the bottom against rot." . . . . . "Among the many advantages of these pole-free tents are: elimination of the need for excess erection space for guy lines and pegs which also result in a neater appearance, completely unobstructed working space, and the provision of higher walls and entranceways to accommodate mess hall and hospital furnishings and to permit entry of ambulances and other vehicles." These tents were primarily designed for emergency medical use and are of a heavy-duty construction similar to military tents.

The West German military has developed a modular-type tent which is used for a field bakery. The tent is extendable in length and has ceiling vents. The supporting structure is of frame type but details of the design were not provided. They have also developed a modular-type maintenance tent which is frame-supported, extendable in length, and has windows for lighting and ventilation. The frame is identical to their bakery tent, thus showing a benefit of modular systems.

In summary, the data presented in this section on previous tentage studies clearly indicate that there is a need to improve the US Army tent system, and that modular tentage has been recognized by the Army, foreign governments, and private industry as having both financial and logistical advantages over a system of tentage in which each need is met by a specific design.

(2) Selection of Important Tentage Characteristics

The background information presented above can be used to determine the most important characteristics of Army tentage, identified by the users, for a new modular tentage system. The following characteristics were extracted from the references cited above and are considered, in this report, as the most important characteristics in tentage design.

1 Basic protection from the elements; that is, protection from rain, wind, snow, etc. Although this area is mentioned in more detail under some of the other characteristics, it is important to recognize (when making any changes to tentage) that protection from the elements is the purpose for tentage existing, and changes should not be made that decrease a tent's abilities in this area. Inclusion of a tentage repair kit which is attached to each tent section will help insure that the tent will protect from the elements throughout its lifespan.

2 Adequacy of space for functional need. The requirements which justified the development of the current variety of tent sizes indicates that adequacy of space is important. The development of modular tents, as suggested in the background information above, will increase the Army's ability to meet a variety of space requirements with a minimum number of common components. Design of the support structure should be done with provisions for unencumbered floor space as an objective.

3 A highly mobile tent system. There is a desire for a highly mobile Army. Tentage is used in more than 50% of the force shelter requirements, and therefore a mobile tent system will help increase the mobility of the forces. There are two main areas in which tentage mobility can be measured. First, the total mass and bulk of the tent should be kept to a minimum. Second, tents should have the ability to be erected and struck easily and rapidly in all types of weather and at night.

4 The tents should have blackout, camouflage, and flame and mildew resistant capabilities. These characteristics are related to the fabrics used and are needed to assure that the tents are usable in combat situations where enemy detection of the tent or high flammability could be hazardous to the personnel. Also, tents should have the ability to be stored for long periods of time. Inclusion of an optional vestibule or improved door design will improve blackout characteristics for tents which are in proximity to enemy forces and also improve the heat retention properties of the tents.

5 Improved habitability: Designs which improve a tent's habitability characteristics should be considered if they do not decrease the tent's ability to protect military personnel from the elements or to prevent detection of the tent by the enemy. Improvements can be made by including attachable floors, liners, and flies as optional equipment. Floors will help keep out insects, animals, and dust, etc. Liners will help retain heat in tents which are properly sealed from drafts. Flies can protect closed tents from excessive solar heating in deserts or tropical areas, but are not very helpful for tents that have cross ventilation. Past evidence on this subject is sparse, and further studies are required. Modular tentage with standardization of parts will allow all of these items to be optional and not represent a large increase in the inventory. Provisions could be made for improved ventilation of the tents and for increased interior reflectance to provide better interior lighting.

There is another characteristic of tentage which may be important to the Army but which is not usually identified by the users in the field. The following item is a continuation of the list given above but is not extracted from the background data cited above.

6 Cost of the tent system: It is possible that one tent construction may satisfy tentage requirements better than other constructions but that the best construction has a much higher cost than the other constructions. If this is the case, then the Army must decide if the additional capabilities are justified by the cost difference. Recognize that in weapon systems the improved operational capability is usually desirable and justifies the cost difference. It should be noted that costs which may be necessary to provide a more effective tent system will be minimized by standardization of components and making the structure modular; this is further justification for making any new tent system modular.

(3) Establishment of Priorities among Characteristics

There are six important tentage characteristics mentioned above. It is not possible to design a tent which can meet all of these without facing conflicts between the characteristics. The purpose of this section is to suggest how priorities may be associated with the six characteristics.

(a) General Arrangement of Priorities:

Some of the characteristics are much more important than others and may be considered as essential, while the remaining ones may be considered as desirable. Here design decisions will be simpler so long as design conflicts do not occur among essential characteristics. In short, the ability of a tent to meet an essential characteristic should not be sacrificed to improve a desirable characteristic. An outline of essential and desirable characteristics follows:

1 Essential Characteristics:

a Tents should offer basic protection from the elements.

b Tents should have blackout, camouflage, flame-resistant, and mildew-resistant capabilities.

2 Desirable Characteristics:

a Adequacy of space for functional need.

b A highly mobile tent system.

c Improved habitability.

d Low cost of the tent system.

(b) Breakdown Related to Choosing a Support Structure:

It will be necessary to determine a support structure for the tent. If one considers the six important characteristics for tents, Table 2 and Figures 1–4, then the following important characteristics can be identified as those best classifying the tentage constructions with respect to support structure:

1 Adequacy of space for functional need.

2 A highly mobile tent system.

3 Low cost of the tent system.

These can be further broken down and named as shown in the following list of detailed characteristics which will have priorities associated with them and be used in the evaluation of the concepts presented in section (c), below.

4 Characteristics related to support structure:

a Unencumbered floor space.

b Ability to erect and strike rapidly and easily.

c Minimum mass and bulk.

d Low cost of the tent system.

Here "a highly mobile tent system" has been broken down into **b** and **c**.

(c) Detailed Design Conflicts:

Some of the detailed conflicts which occur when designing a new tent system are presented below. Actual input from the field by personnel using prototype tents of each construction will be required before the full list of conflicts is known and before priorities and choices on these conflicts can be fully recommended. An "X" is placed next to the items which have been given priority in our considerations of the list.

1	Low mass and bulk	X		Unencumbered floor space
2	Low mass and bulk		X	Blackout capability
3	Low mass and bulk		X	Improved habitability (optional fly, floor, liner, vestibule, etc.)
4	Erect and strike quickly	X		Improved habitability (optional fly, floor, liner, vestibule, etc.)

5 Blackout capability	X '	Improved habitability (optional fly, floor, liner, vestibule, etc.)

The following conflict occurs within a desirable characteristic ("a highly mobile tent system") and is worth a short discussion.

6 Low mass and bulk	' X	Ease and rapidity of erection and striking

Here mobility can be broken down into ease of erection and transportability. Erecting efforts intensify with tent size, and thus in large tents the importance of erecting easily may become more important than transportability (measured by mass and bulk). However, for the smaller tents this conflict becomes less meaningful since both the total erection effort and the total mass and bulk are relatively small. Perhaps for small tents the priority could be assigned to "low mass and bulk" to increase the ability of small tents to be transported by man.

(4) Scheme for Rating Concepts

The tentage constructions considered in this report can be compared using characteristics related to the support structure. That is, characteristics which do not relate directly to the support structure, such as basic protection from the elements, blackout, camouflage, etc., can all be provided in each tentage construction with about equal logistical cost and are not important when comparing alternative structural concepts. The evaluation can be carried out by assigning numbers to each concept according to its ability to satisfy a required characteristic relative to the other concepts. First, the characteristics are rated according to their priority. Scores of 10, 7, 4, and 1 are given, respectively, for the first, second, third, and fourth priority areas among those characteristics related to support structures. Then each of the concepts is scored with regard to its ability to meet each of the characteristics when compared to each other. Place scores of 5, 3, and 1 are given. The score of 5 signifies the structural concept which best provides the given characteristic, the score of 3 signifies the concept which next best provides the given characteristics, and the score of 1 signifies the concept which most poorly provides the characteristic. The data of Table 2 will be used to determine these place scores with the data for frame tents being taken from the column on general frame-supported tents. The characteristic of "unencumbered floor space" which is not presented in Table 2 will have the following ratings associated with each concept. A score of 5 will be given to the frame-supported (all sizes) and large pressurized-rib concepts since they do not have any obstructions in the central floor area and have nearly vertical sidewalls allowing maximum use of the floor area. A score of 3 will be given to both the pressurized-rib concept (small and medium size) and the geodesic structure since they have no obstructions in the central floor area but have curved sidewalls making efficient use of the floor area near the sidewall difficult. Finally, a score of 1 will be given to the pole-supported tent since the obstruction of central floor space by the center poles is considered the least desirable form of obstruction.

To obtain a combined rating reflecting both the characteristics priority and the concept ranking, a product score will be used. The product score is computed by multiplying the priority score by the place score for each characteristic and concept. The final rating for a given tent construction is obtained by summing the product scores, and it will be this score that will be used in the final evaluation.

c. **Evaluation of the Concepts**

A comparative analysis of three of the four tent constructions presented in this report will be made in this section. The geodesic tent will not be considered because there is not enough known about the cost of fabricating this concept for general tentage use, and there is also not enough known about the ability of this concept to be erected and struck when designed for general tentage use. The rating scheme outlined above will be used, and a separate rating will be made for each of the tent sizes suggested in Table 1. It is important to note that the results of the comparative analysis will change when a different priority ranking is assigned to the tentage characteristics. To demonstrate this there will be two priority orderings considered for each tent size.

The ratings given each of the tent constructions for its ability to satisfy the characteristics are given below:

1 Unencumbered floor space: The justification for these scores is given in (4), above.

a 5 points: frame-supported (and large pressurized-rib)

b 3 points: pressurized-rib (medium and small sizes)

c 1 point: pole-supported

2 Ability to erect and strike: These scores were obtained by comparing the total man-hours per square meter floor area required to erect these tents, as given in Table 2.

a 5 points: pressurized-rib

b 3 points: frame-supported (medium and small sizes)

c 1 point: pole-supported (and large frame-supported)

3 Minimum mass and bulk: These scores were obtained by comparing the total mass and total bulk figures in Table 2. The pole-supported and pressurized-rib constructions were numerically close in their ability to satisfy this characteristic and were considered equal for this evaluation.

a 5 points: pressurized-rib

b 5 points: pole-supported

c 3 points: frame-supported

4 Low cost of the tent system: The scores given below were obtained by comparing the cost of the support structures in Table 2. It is felt that the fabric envelope of the tents and the associated anchoring hardware will be close enough in cost so as to justify not including them.

a 5 points: pole-supported

b 3 points: frame-supported

c 1 point: pressurized-rib

The two priority orderings used in the evaluations given below are designed to show the effects of changing the priority of "low cost of the tent system." Cost will be considered first as the highest priority and second as the lowest priority in each of the three tent sizes suggested in Table 1.

(1) Small Tent

The small tent is the most widely used tent. It is used as a command post, fire direction center, battalion aid station, housing, or any other similar general-purpose use. It is felt that the erection effor has a relatively small impact on the mobility of small tents, and thus the ability to erect and strike easily was given low priority in relation to minimum mass and bulk and unencumbered floor space. Minimum mass and bulk was ranked ahead of unencumbered floor space since, if mass and bulk can be made low enough, the small tents would become man-transportable, which is a capability they currently do not have. The priority orderings are as follows:

(a) With Low Cost as High Priority:

1 Low cost of the tent system

2 Minimum mass and bulk

3 Unencumbered floor space

4 Ability to erect and strike easily

(b) With Low Cost as Low Priority:

1 Minimum mass and bulk

2 Unencumbered floor space

3 Ability to erect and strike easily

4 Low cost of the tent system

The results of the evaluation with "low cost of the tent system" as the highest priority is shown in Table 8. It is seen that the pole-supported tent is clearly indicated as the best concept under this set of priority orderings. Results with "cost" as the lowest priority, shown in Table 9, indicate that the pressurized-rib concept best meets this second set of priority orderings.

(2) Medium Tent

The medium tents are used mainly for personnel housing, mess tents, storage, or for any other general purpose. This tent size is used almost as widely as the smaller size tents and thus represents a larger impact on the Army when considering the cost of the tent system. Also, this tent must be highly mobile since it is moved as frequently as the smaller tents. These tents can become difficult to erect, due to their size, and since mobility is an important factor for these tents, then the ability to erect and strike easily was given a priority rating above unencumbered floor space and minimum mass and bulk. Furthermore, since these tents are too large to transport by man, unencumbered floor space was given a higher priority rating than mass and bulk. Thus, the priority orderings used are as follows:

(a) With Low Cost as High Priority:

1 Low Cost of the tent system

2 Ability to erect and strike easily

3 Unencumbered floor space

4 Minimum mass and bulk

(b) With Low Cost as Low Priority:

1 Ability to erect and strike easily

2 Unencumbered floor space

3 Minimum mass and bulk

4 Low cost of the tent system

TABLE 8. SCORES FOR CONCEPT EVALUATION OF SMALL TENTS WITH LOW COST AS HIGHEST PRIORITY

CHARACTERISTIC	PRIORITY SCORE	PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
		PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	4	3	12	1	4	5	20
ABILITY TO ERECT & STRIKE	1	5	5	1	1	3	3
MINIMUM MASS AND BULK	7	5	35	5	35	3	21
LOW COST OF TENT	10	1	10	5	50	3	30
TOTAL PRODUCT SCORE			62		90		74

TABLE 9. SCORES FOR CONCEPT EVALUATION OF SMALL TENTS WITH LOW COST AS LOWEST PRIORITY

		PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
CHARACTERISTIC	PRIORITY SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	7	3	21	1	7	5	35
ABILITY TO ERECT & STRIKE	4	5	20	1	4	3	12
MINIMUM MASS AND BULK	10	5	50	5	50	3	30
LOW COST OF TENT	1	1	1	5	5	3	3
TOTAL PRODUCT SCORE			92		66		80

The results of the numerical evaluation with "low cost" as the high priority is given in Table 10. The frame-supported tent, under these priority orderings, appears to be the best candidate. However, there is not a large spread in the ratings which indicates, in a quantitative way, that the frame-supported tent is not highly recommended over these others for this priority ordering. Table 11 indicates the numerical evaluation when "low cost" is given a low priority. The pressurized-rib tent is indicated as the best concept under this ordering of priorities.

(3) Large Tent

Large tents are used for hospital wards, storage, quartering of troops, and maintenance of vehicles and small aircraft. Maintenance of vehicles and aircraft requires unencumbered floor space and for this reason "unencumbered floor space" was given a high priority than both the "ability to erect and strike easily" and "minimum mass and bulk." Also, since these large tents must be erected by unskilled personnel, and since difficult procedures for erection could prove to be unnecessarily hazardous to personnel, the "ability to erect and strike easily" was given a priority above "minimum mass and bulk." Thus, the priority orderings used are as follows:

(a) With Low Cost as High Priority:

1 Low cost of the tent system

2 Unencumbered floor space

3 Ability to erect and strike easily

4 Minimum mass and bulk

(b) With Low Cost as Low Priority:

1 Unencumbered floor space

2 Ability to erect and strike easily

3 Minimum mass and bulk

4 Low cost of the tent system

The numerical evaluation with "low cost as the high priority is given in Table 12. Although the pole-supported tent was included in the table, it is not considered an acceptable concept due to the obstruction of floor space presented by the center poles. It appears that with "low cost" as the high priority, the frame-supported tent and the pressurized-rib tent are equally recommended structures. When "low cost" is given a low priority, then the numerical evaluation, in Table 13, indicates preference for the pressurized-rib concept.

TABLE 10. SCORES FOR CONCEPT EVALUATION OF MEDIUM TENTS WITH LOW COST AS HIGHEST PRIORITY

		PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
CHARACTERISTIC	PRIORITY SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	4	3	12	1	4	5	20
ABILITY TO ERECT & STRIKE	7	5	35	1	7	3	21
MINIMUM MASS AND BULK	1	5	5	5	5	3	3
LOW COST OF TENT	10	1	10	5	50	3	30
TOTAL PRODUCT SCORE			62		66		74

TABLE 11. SCORES FOR CONCEPT EVALUATION OF MEDIUM TENTS WITH LOW COST AS LOWEST PRIORITY

		PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
CHARACTERISTIC	PRIORITY SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	7	3	21	1	7	5	35
ABILITY TO ERECT & STRIKE	10	5	50	1	10	3	30
MINIMUM MASS AND BULK	4	5	20	5	20	3	12
LOW COST OF TENT	1	1	1	5	5	3	3
TOTAL PRODUCT SCORE			92		42		80

TABLE 12. SCORES FOR CONCEPT EVALUATION OF LARGE TENTS WITH LOW COST AS HIGHEST PRIORITY

		PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
CHARACTERISTIC	PRIORITY SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	7	5	35	1	7	5	35
ABILITY TO ERECT & STRIKE	4	5	20	1	4	1	4
MINIMUM MASS AND BULK	1	5	5	5	5	3	3
LOW COST OF TENT	10	1	10	5	50	3	30
TOTAL PRODUCT SCORE			70		66		72

TABLE 13. SCORES FOR CONCEPT EVALUATION OF LARGE TENTS WITH LOW COST AS LOWEST PRIORITY

		PRESSURIZED RIB		POLE SUPPORTED		FRAME SUPPORTED	
CHARACTERISTIC	PRIORITY SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE	PLACE SCORE	PRODUCT SCORE
UNENCUMBERED FLOOR SPACE	10	5	50	1	10	5	50
ABILITY TO ERECT & STRIKE	7	5	35	1	7	1	7
MINIMUM MASS AND BULK	4	5	20	5	20	3	12
LOW COST OF TENT	1	1	1	5	5	3	3
TOTAL PRODUCT SCORE			106		42		72

d. **Discussion**

Ultimately the decisions on the relative priority ranking of characteristics and on the choice of alternatives must be those of the user. However, this study, which varied the ranking of the cost in an extreme manner, can provide insight and guidance to our development program.

When cost was taken as the lowest priority, the air-stabilized frame structure was the choice of structure for the small, medium, and large tentage; this is a reflection of the fact that it appears to be capable of providing lowest weight and bulk as well as greatest ease and speed of erecting and striking. When cost was taken as the highest priority characteristic, the results were quite different; for this set of priorities no one structure was the choice, but instead the choice was pole-supported, metal frame, and metal- or air-stabilized frame structures for, respectively, the small, medium, and large tents.

These results certainly emphasize the need for further development efforts on reducing fabrication costs for air-stabilized beam structures, if this construction which appears to offer so much in improved operational capabilities is to be fully competitive. The results also suggest that the ideal family of general-purpose tentage might effectively use different structures for different size tentage. This latter point deserves further discussion.

It is not surprising that improvements in operational capability may come at additional cost. But the additional cost may only be justifiable if it has real significance in terms of operational capability. In terms of real time savings the maximum saving in erection and striking time may be on the order of hours for a large tent and only minutes for the small. A further consideration is that large quantities of small and medium tents are procured and used, whereas only a few large tents are required. With these thoughts in mind, the choice of retaining pole-supported structures for the small general-purpose tent appears to be a reasonable decision. Again, for the medium tent the choice of a metal frame support appears to be good decision. Marked improvements in operational capability will be achieved for the smallest increased cost. The larger weight and bulk of this structure compared to the air-stabilized frame is not a significant drawback in this size tentage. As we progress to the large tent, the folding metal frame structure will become more difficult to erect and the greater weight and bulk becomes more of a hindrance to erection and striking; thus, for the largest tent, the air-stabilized frame structure becomes the best choice because it can provide the most significant improvement in unit mobility for the additional cost.

Thus a tentative conclusion can be reached that a new generation of General Purpose Tentage might include pole-supported, metal frame, and air-stabilized frame structures for, respectively, the small, medium, and large tents, but this conclusion is reached based on limited or no field experience for the newer concepts. To provide the experience and firm data which the user will require to justify specific priority ranking of characteristics and final decisions with respect to alternative structures, it is necessary to develop prototype structures for evaluation in field environments under field operational conditions.

It should be recognized that this evaluation is based entirely on structural alternative. It has been assumed that the design improvements relating to the use of lighter weight fabrics and the achievement of greater habitability would be applied to all structures.

5. CONCLUSIONS AND RECOMMENDATIONS

a. Conclusions

The following points brought out in this study warrant emphasis and consideration in the on-going development programs.

(1) There is a long history of user dissatisfaction with the standard field tentage available today. The tentage currently being used by the Army does not reflect the capabilities for habitability, ease of erection and striking, low mass and bulk, and the ability to expand as desired by the users.

(2) Alternative constructions and modular designs are available today which could provide improvement operational performance in the field and should overcome many objections to present tentage.

(3) A procedure for rating alternative options is developed in this study which is dependent on a priority ranking of essential and desirable characteristics and a relative ranking of the alternatives with respect to their ability to meet each required characteristic. The use of this procedure is demonstrated for two situations in which low cost is the most important and least important required characteristic.

(4) This study, which varied the ranking of the cost in an extreme manner, suggests to us that the ideal family of General Purpose Tentage might effectively use different structures for different sized tentage. A tentative conclusion is reached that the pole-supported structure should be retained for the small tent, that the metal frame structure with special rapid erection features should be developed for the medium tent, and that an air-stabilized beam structure is the best choice for the large tent.

(5) The study indicates that an additional financial investment may be required to field metal or air-stabilized beam structures. However, it should be noted that the investment will buy tentage with greater mobility and habitability, thus improving the living and working conditions for the soldier in the field and the operational effectiveness of the Army field units; furthermore, the investment should be partially offset by long-term savings resulting from development of modular structures which can permit a reduction in the number of different tents fielded and the logistical support requirements for field tentage.

b. Recommendations

Since this report has served to identify the need for a new Army modular tentage system and has shown that different tentage constructions can be rationally compared to one another, the recommendations given below are related to defining how the new modular tentage system should be developed.

NARADCOM should develop prototypes of pole, frame, and pressurized-rib construction which include improvements in design suggested in this study. The prototypes should be tested by the Army in simulated war operations so that the users can provide data on the ability of the prototypes to function in the field. A study should then be undertaken to evaluate the tents by a method similar to the one given in this report. That is, (1) the most important characteristics of tentage in the field should be determined from user inputs based on actual testing of different types of tents, (2) the priorities among the important characteristics should be determined by personnel in charge of the field logistics, and (3) the tents should be evaluated as was done in this report to determine the system which actually functions best in the field for the Army.

BIBLIOGRAPHY

Barnes, W. R., Williams, G. W., Harvin, R. L., and Finch, R. B., "Tent Design and Construction." IIR University of Louisville through NRC/NAS, QMCR&D Textile Series Report No. 15, Tent Research Report No. 1, May 1946.

Intelligence Information Report 2–252–0135–76 of 22 March 1976, subject, "General Purpose Tent by Edington," United Kingdom.

Intelligence Information Report 2–252–0316–76 of 30 June 1976, subject, "Tents by LANCO," West Germany.

Intelligence Information Report 2–252–0475–75 of 2 December 1975, subject, "Tents and Tarpaulins by Gottschalk," West Germany.

Intelligence Information Report 2–253–0889–75 of 16 December 1975, subject, "Concept Requirements for New Family of Tents," Japan.

Intelligence Information Report 6–850–0347–75 of 16 September 1975, subject, "Tents and Shelters," Italy.

O'Callahan, John C., "NONFESA – Nonlinear Finite Element Structural Analysis Code for the Analysis of Stresses and Deflections in Frame-supported Tents," Bolt, Beranek & Newman, Inc., Report No. 2803, Contract No. DAAG17–73–C–0107, March 1975.

"Reference Manual on Shelters," US Army Natick Laboratories, Natick, MA, January 1972.

Remington, Paul J., O'Callahan, John C., and Madden, Richard, "Analysis of Stresses and Deflections in Frame-supported Tents," Technical Report TR–75–31–AMEL, US Army Natick Laboratories, Natick, MA, April 1974.

Remington, Paul J., O'Callahan, John C., and Madden, Richard, "Finite Element Analysis of Scale-Model Frame-supported Tents," Technical Report TR–76–21–AMEL, US Army Natick Research and Development Command, Natick, MA, March 1975.

TB 381–5–17, Technical Bulletin, "Foreign Material Catalog, FOMCAT Vol 17," 11 November 1975, Headquarters, Department of the Army.

APPENDICES

APPENDIX A

EXPANDING TENTS IN WIDTH

The following table presents a summary of the ideas considered for designing a modular tent system in which small tentage structures can be expanded with common components into tentage structures with a larger span. It is important to recognize the conflicting design problems which arise in this effort. The structural loading, regardless of tentage construction, increases as the span of the structure is increased. Thus, a member's load-carrying ability must be increased as the span is increased if the basic design of the tent is to remain the same. Increasing a structural member's load-carrying capability means changing its physical properties so it is no longer identical (standard) to the member used for the smaller span. Thus, it appears that increasing widths with similar constructions is impossible without over- or under-designing one of the structures.

Another possibility is to change the method of assembly of the common components so that an efficient structure is assembled at each width. The ideas presented in Table A1 were developed to investigate the possibility of changing the method of assembly of standard parts to gain the ability to construct various width structures in the field from common components and are presented for future reference. Unfortunately, it is felt that the drawbacks outweigh the benefits.

TABLE A1 - IDEAS FOR EXPANDING TENTS IN WIDTH

TENT CONSTRUCTION	IDEA	BENEFIT	DRAWBACK
Pole Tents	1. Have two size poles. Size #1 used for all parts in smaller tent while size #2 is required only for center pole of larger tent. Longitudinal span is same in small tent and large tent.	More common parts than in current General Purpose tent system.	Ridge heights must be a specified value on the small tents (twice the side wall height) which may not be desirable.
	2. Reduce longitudinal spacing of center poles on larger tents so that center poles (longer in assembled form) can be made from the same poles used in the small tents.	All poles are identical	More fabric work is needed and it may increase the total weight of the tent since more poles will be required. Also, there will be more center poles to interfere with the use of the interior space.
Frame Tents	1. Use one design for purlins and arch members and increase width of tent by doubling the length of the roof arch members; then the perimeter of the envelope has constant length changes when going from the smaller to the larger tents. Make standard rectangular pieces of fabric which can be joined together to make the necessary weather envelope. Note,	Damaged fabric can be replaced by just replacing a standard section.	Extra reinforcement areas may be required in all the fabric panels so that they are all interchangeable. This will add weight to the fabric. Also, weather junction will add weight to the basic tent for any given size.

TABLE A1 - CONTINUED (PAGE 2 OF 2 PAGES)

TENT CONSTRUCTION	IDEA	BENEFIT	DRAWBACK
Frame Tents (continued)	the weather seam is undone only when the tent is having its size changed.		
	2. Use identical purlins and double up on the larger tent to make "beams."	Simple to assemble, only a small number of parts are different in each given tent size. Larger tents could be designed with a good factor of safety while still keeping the corresponding smaller tents lightweight.	Each size tent requires a different set of fittings to assemble the tent. The built-up arch will be inherently unstable out of its plane and may require additional hardware to support snow loads.
	3. Use two size purlins and extend the purlins to change width and peak height. In addition, vary longitudinal support frame spacing as width is increased.	Simple to assemble the frame. All fittings are the same for each size tent.	This odd frame spacing may require too much fabric work. That is, too many accessories on fabric to make fabric usable on different width tents.

APPENDIX B

ESTIMATION OF TENTAGE PROPERTIES FOR AN EXPANDABLE GEODESIC MAINTENANCE SHELTER

The quick-erect geodesic structure has become of interest to the Army for possible use in the areas of shelters or camouflage. Since there was no technical information available on these structures when they were introduced to the Army in model form, the following stress analysis was undertaken. This stress analysis is only a first cut at understanding the structural behavior of the geodesic concept. If the concept is shown not feasible for tentage, then the more extensive and sophisticated calculations need not be done.

In order to simplify the analysis, a semi-cylindrical shelter was considered. The model chosen for examination with the finite element program NONFESA[1,2,3] consisted of one-half of one geodesic arch from a semi-cylindrical shelter. A symmetrical snow load having a magnitude of 479 Pa was applied, and the boundary conditions on the model were varied to represent two extreme conditions of arch behavior. First, the arch was assumed to be part of a along semi-cylindrical structure. This required that the model be constrained (by symmetry, etc.) from longitudinal deformations. Second, the arch was considered to be free longitudinally to determine the bahavior of the arch when neighboring arches move freely in the longitudinal direction. Both cases were considered for design.

The model used in the computer program is shown for two different configurations in Figures B1 and B2. It should be noted that the diagonal members, labeled in Figure B1, are made of continuous members in the real structure and are pinned together at the

---

1. O'Callahan, John C., "NONFESA – Nonlinear Finite Element Structural Analysis Code for the Analysis of Stresses and Deflections in Frame-supported Tents," Bolt, Beranek & Newman, Inc. Report No. 2803, Contract No. DAAG17–73–C–0107, March 1975.

2. Remington, Paul J., O'Callahan, John C., and Madden, Richard, "Finite Element Analysis of Scale-Model Frame-supported Tents," Technical Report TR–76–21–AMEL, US Army Natick Research and Development Command, Natick, MA, March 1975.

3. Remington, Paul J., O'Callahan, John C., and Madden, Richard, "Analysis of Stresses and Deflections in Frame-supported Tents," Technical Report TR–75–31–AMEL, US Army Natick Laboratories, Natick, MA, April 1974.

FIGURE B1. SIX SECTION ARCH (3 SHOWN)

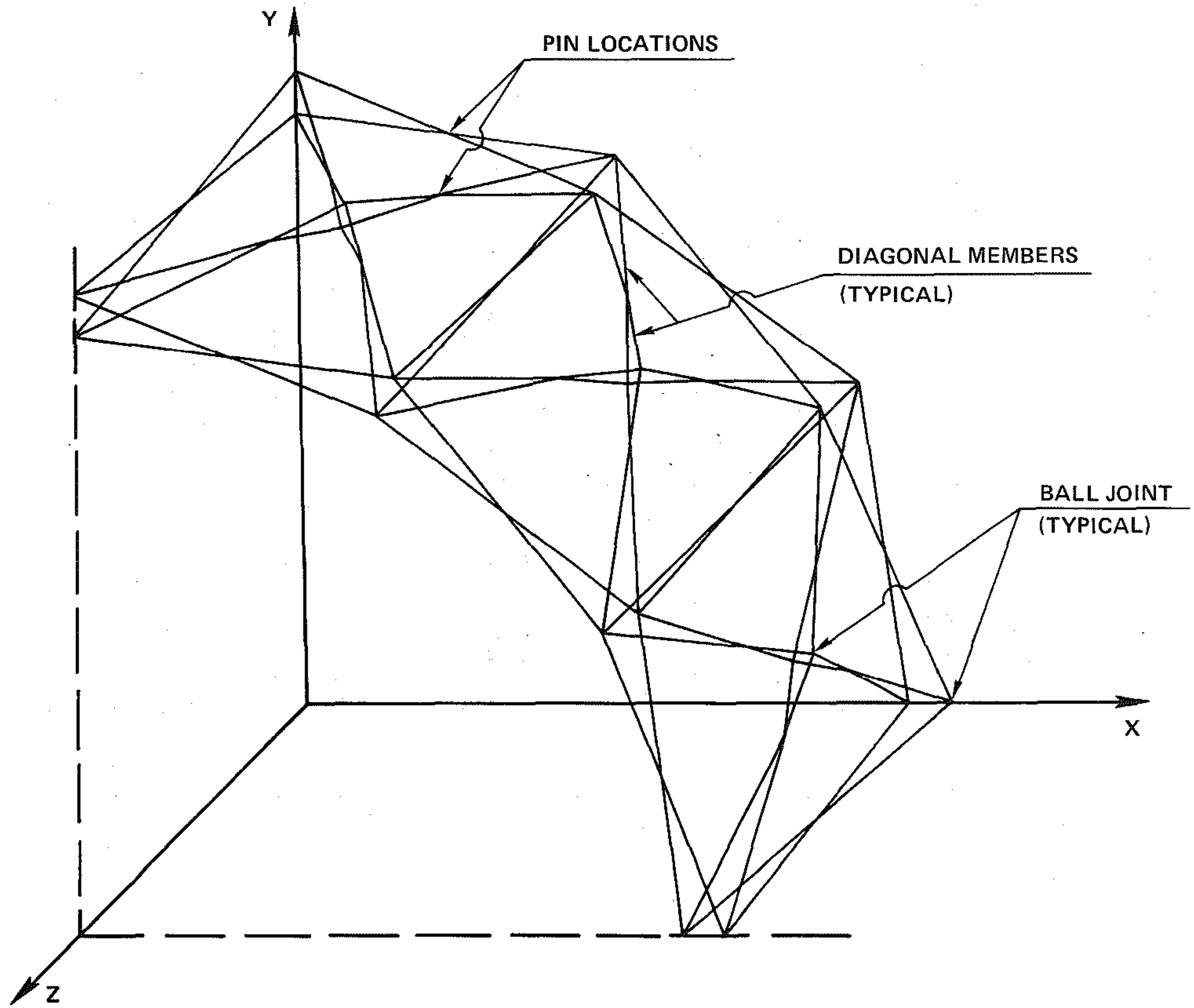
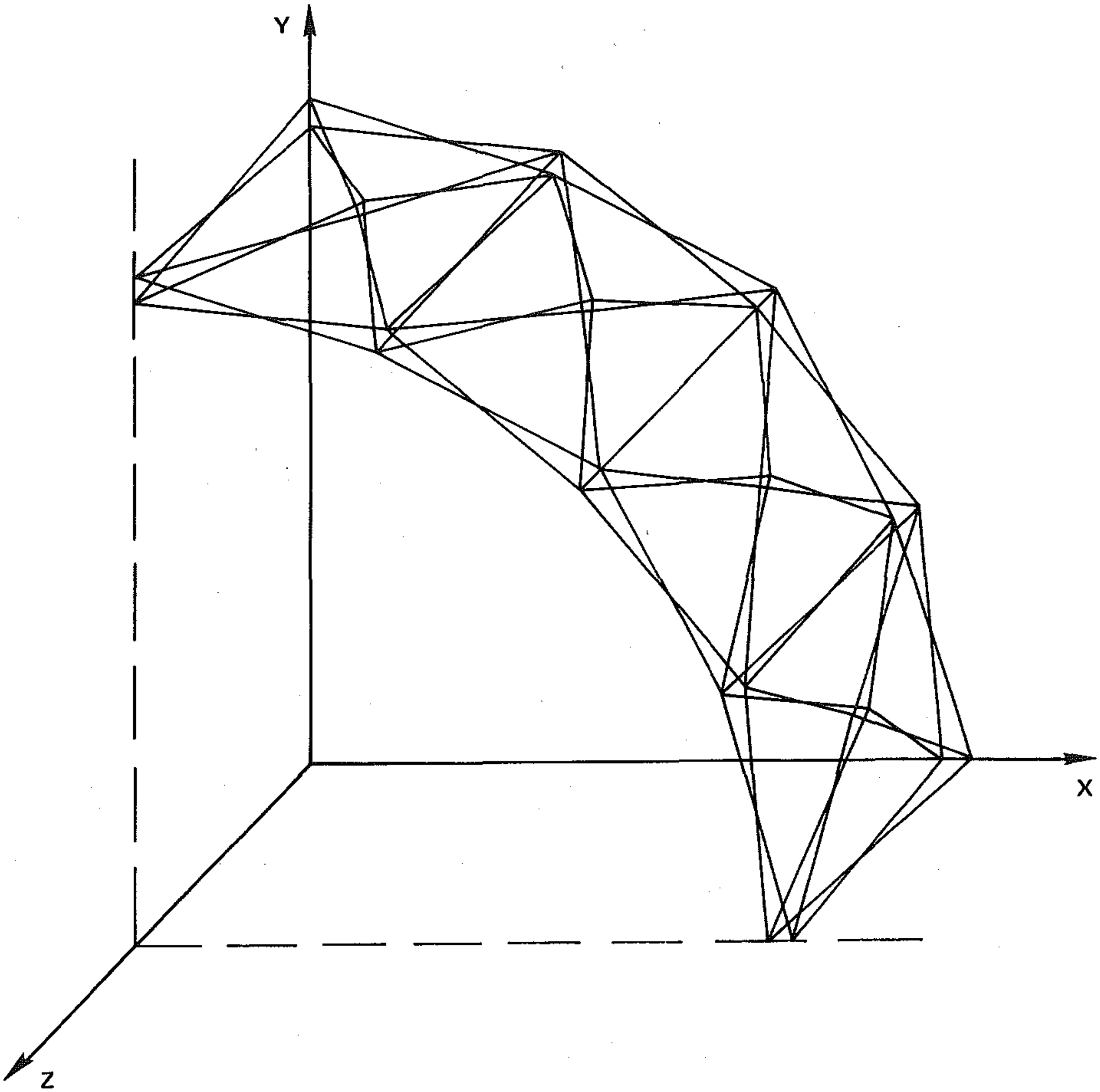


FIGURE B2. EIGHT-SECTION ARCH(4 SHOWN)



location shown in Figure B1. When the structure is being erected all members are attached with either ball joints or pinned connections. These diagonal members do not theoretically intersect at all stages of the opening, and they consequently bend during the erection. The actual process of the structure reaching a condition such that it will not collapse when the external opening forces are withdrawn was not studied here. The model used properly modeled ball joints with respect to the load transfer mechanism through the ball joint. However, the pinned joints were considered welded, thus reducing the flexibility of the structure and modifying the type of internal load distribution to be calculated from that of the actual structure. It was not determined if considering the pinned joints welded was the reason for the structure demonstrating the ability to carry external snow loading without collapsing, or if the structure demonstrated the ability to carry the snow load because the final position chosen for the diagonal members is representative of a geometrical construction which is stable even with the pinned connections. In either case, this analysis assumed that the loads in the structural members from the erection process are small when compared with the loads in the structural members due to the application of an external snow load. It was further assumed that this structure gains its load-carrying abilities with the members acting as truss members (load-carrying ability through compression and tension of the members). Thus, slender beam members (low capability in bending) were used in the program which allowed the structure to be modeled in three dimensions, as shown in Figure B1, and allowed the external loads to be easily applied (use of truss members would not allow proper application of the snow load to the pinned truss members).

The finite element program chosen for the analysis was NONFESA. This program was specially developed for analysis of tentage structures and contains many capabilities beyond those used for this analysis. Only a static linear analysis was considered here. It was necessary to write a FORTRAN program to generate the data decks required by the finite element program so that various spans, materials, and number of sections could be modeled with ease.

Data were obtained for an arch with 6.1 m span and both 6 and 8 sections on the arch circumference. The tubing used in the calculations was 3.175 cm X 0.159 cm X 0.408 kg/m aluminum tube. The element forces were obtained for the 479 Pa snow load using this structural tubing. These element forces were then used to update the design of the tubing, but new element forces were not computed. That is, the design tubing was not used in another analysis to update the element forces and obtain a refined design. This was justified by the fact that the new design tubing was very close in physical properties to the tubing used in the analysis.

To determine the design tubing a survey of the output data was made and the most severe element loading conditions were considered. Attention was paid to the longer elements, and the design sizes chosen were based on combined stresses and Euler buckling theory. For ease of data processing, the failure was considered to occur when sum of the maximum bending stress and the axial stress in the element exceeded the Euler buckling stress, which in all cases was less than the yeild stress.

The structural mass per square meter was estimated by considering both a 6-section and an 8-section arch configuration which was two bays long, see Figure B3. The total tubing mass was determined for each of the following cases:

1) 6-section arch, longitudinal deformations constrained,

2) 6-section arch, longitudinal deformation free,

3) 8-section arch, longitudinal deformations constrained, and

4) 8-section arch, longitudinal deformations fixed.

All nodes with four or more members entering were estimated to have a mass of 0.340 kg each, and all others were considered pinned and assigned the mass of a 0.635-diameter X 5.08-cm long bolt with a hex head nut. The average of all the total masses per square meter for an entire two-bay structure was then used.

The structure cube was determined by calculating the average number of tubes per bay in an eight-section, two-bay-long tent, as shown in Figure B3. There were 13.1 members per bay. Then each bay of 13.1 members were assumed to be capable of being packaged in a box whose length was the length of the longest tubing member and whose end dimensions were 6.40 d X 3.20 d, where d = the diameter of the tubing being packaged. All packaged cube per square meter flow area values were then averaged as was done above for the total mass per square meter.

The cubic mass per square meter for the fabric, anchoring equipment, and other items was taken to be the same as that used for pressurized-rib concept. The results of the analysis are:

Support structure mass	= 2.85 kg/m^2
Fabric mass	= 1.71 kg/m^2
Total structure mass	= 4.56 kg/m^2
Package cube	= 0.036 m^3/m^2

FIGURE B3. TWO-BAY GEODESIC STRUCTURE