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ENGINEERING FACTORS TO BE CONSIDERED IN TENTAGE

by

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 83-19

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ABSTRACT

An analysis is presented of the relationship between engineering factors of importance in tentage. Because the scientific literature on tentage is so limited, the analysis is qualitative. The purpose is therefore to provide a guide, rather than a textbook, for use in the design of tents and for guiding the selection of future R/D projects related to tentage. Two appendices are included which are intended to be of direct use in tent design activities. Appendix A is a sample tent design checklist which includes the factors discussed in the text, and Appendix B presents a matrix which summarizes the degree to which the various factors are inter-related.

RÉSUMÉ

Ce document présente une analyse des relations entre différents facteurs d'ordre technique dont il est important de tenir compte lors de la conception de matériel de tente. Étant donné que la documentation scientifique sur le matériel de tente est très limitée, cette analyse est qualitative seulement. L'objectif est donc de fournir un guide, plutôt qu'un manuel complet, qui peut être utilisé lors de la conception de nouveaux modèles de tentes, et qui peut faciliter le choix des futurs projets de recherche et de développement dans le domaine du matériel de tente. Le document comporte deux appendices conçus pour servir directement à la conception de nouveaux modèles de tentes. L'appendice A est un exemple de liste de contrôle qui inclut les facteurs dont il est question dans le texte, et l'appendice B est une matrice qui résume les corrélations entre les différents facteurs.

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1. INTRODUCTION

The "how" and "why" of the engineering factors of tentage has not, to date, been researched extensively. No doubt there have been numerous preliminary investigations of tent performance [1,2], however, most of these investigations have not been published as the literature contains only a few specialized works. Much of what is written is knowledge obtained as a result of field experience and, while this experience is a very valuable guide, a theoretical and experimental assault on tentage mysteries is long overdue.

The purpose of this report is to define as many potential areas of concern as possible. This report is intended for use by the tent designer as a guide or checklist of parameters to consider when designing a tent and also to the researcher as a guide to areas requiring attention. This report is not intended to attribute a level of importance to specific factors.

Prior to the commencement of any investigation, it is often helpful to outline the areas where some knowledge is available and the areas where work must be done to obtain more information. For the investigation of tentage this step is both simple and difficult; "simple" because all areas require further investigation and "difficult" because the relative importance of each area is not completely known and some significant areas may not even be recognized at this time.

Research planners who use this report as a guide should determine the most pressing areas of investigation on the basis of their needs, their field experience and on the results of further investigations.

This report is divided into four areas of concern. First, there is a section on general considerations which are not related to materials. Second, there are membrane considerations which will "cover" the aspects related to fabrics which form the shell of the tent. Third, there are the support considerations encompassing the problems related to the frame which supports the fabric shell. The fourth area is that of anchoring, the means of securing the tent to the ground.

A concluding chapter will list some potential research projects which would address some of the more outstanding design problems associated with the development of tentage.

Appendix A provides the reader with a checklist which may be used to evaluate a tent design. It may also be used as a requirements list upon which a tent design can be based.

Appendix B provides the reader with a chart which illustrates how factors interact with one another. Much of the chart is speculative but it does show the complexity of the problem of tent research and design.

2. GENERAL FACTORS

2.1 TENT SIZE REQUIREMENT

The tent size is determined by specifying the number of men or the volume of equipment which must be sheltered. Floor areas and headroom are two primary variables. They should be specified by optimizing the tent dimensions to physical criteria as well as habitability criteria.

Physical criteria determine the optimum tent design from the required physical dimensions of the material or personnel to be sheltered. Habitability criteria are required to ensure the comfort of personnel who are to be sheltered in the tent.

Typically [3] a man requires a sleeping space 2 meters long by 0.6 meters wide. The physical criteria for the tent design would specify such dimensions and the number of men that are to be sheltered as a minimum requirement in determining the floor area of the shelter. Habitability criteria might allot additional floor space for the inclusion of equipment or additional sleeping space. While a shelter for ten men would require a minimum floor area of 12 sq.m, the actual style of the tent must be specified before a practical minimum floor area could be calculated.

The height of the tent may depend on several variables, both physical and habitability criteria. The minimum height of the tent may depend on the physical requirement on the slope of the exterior wall. For example, the wall may be required to shed snow and rain. The maximum height may be determined by the physical requirement of minimum tent weight or heat loss, both of which are dependent on surface area and hence dependent on the height of the tent.

Constraints on the height optimization may be imposed by the operational needs of the user. The user may stipulate a habitability requirement on the minimum height to allow the sheltered personnel to sit, stand or move around inside the tent. This design aspect depends upon the operational needs of the user.

2.2 STYLE

The style of the tent will also depend upon the physical as well as the various habitability criteria.

Wind loading, requirements for heat and ventilation, and camouflage all depend on the shape of the tent. Comfort and convenience also depend a great deal upon style; for example, usable headroom and obstructions such as center-poles.

The style will also determine the complexity of the tent. Designs preferred for comfort and convenience often require some intricate frame designs and construction techniques.

2.3 THEATER OF OPERATION

The intended theater of operation is an important consideration in choosing the proper tent. A tent designed for use in a tropical rainforest may be of little use in the Arctic. If one tent design is to be used exclusively to fulfill the user requirements in all theaters of operation, then the requirements for operation in all of the climates must be investigated. If several tents are to be designed for use in specific theaters of operation, each design should be optimized to the needs of its particular theater of operation before other features are built in to extend their usefulness to other theaters of operation.

Environmental loads that the tent will experience will be determined to a large extent by the theater of operation. In general, wind, rain, ice, blowing sand and snow must be considered when designing a general purpose tent. Also, protection from insects could be a major health and comfort criterion.

2.4 HEATING

Heating a tent in the field is usually accomplished by burning naphtha or propane in small stoves. The hot combustion products rise due to a density difference with the surrounding air as well as to the initial velocity of the expanding gas as it leaves the stove. Thus a mixture of natural and forced convection accompanies the heating of the tent.

After the initial push as the combustion products expand into the atmosphere, natural convection carries the warm air to the top of the tent.

As this air cools, it begins to sink down to the floor, loosing heat out the walls of the tent as it goes. Thus, the temperature in the living space of the tent is often the lowest [4,5].

The effectiveness of using additional insulation on the tent walls, such as with tent liners, should be considered. A comparison of fuel savings with the cost and weight of the liners is required to determine if the additional insulation is cost effective [6]. A measurement of the change of the temperatures in the tent is required to determine the effectiveness of the liner as a thermal insulator.

The use of forced convection as a means of improving the temperature distribution within the tent and possibly a saving of fuel, should also be considered. Small fans could potentially be used to force the warm air at the peak of the tent down to the inhabited level of the tent where the heat is required.

When the sheltered personnel are in contact with the floor, body heat is lost to the floor by conduction. Similarly, heat is lost to the floor from the air above it. Thus, in some instances, insulation of the floor may be desirable. The penalties of insulating the floor will include increased tent weight and cost. The floor of the tent would also be subject to greater wear than would other parts of the tent, which would necessitate replacement of the floor more often than say a wall section.

2.5 VENTILATION

Proper ventilation of an inhabited tent is essential for the well-being of the sheltered personnel. Fresh air must be supplied to replace air consumed either by people or by stoves and lanterns. Fresh air is also required to flush out the exhaust gases from the stoves. The air in the tent should be replaced at a rate which maintains acceptable levels of oxygen, carbon monoxide, carbon dioxide, water vapour and any other gaseous combustion products [7,8,9,10].

In climates which are hot and humid, ventilation may be required to maintain the interior of the tent at tolerable ambient conditions. In weather which is hot with a considerable amount of sunlight, ventilation will be required to minimize the effect of solar heating.

Vents in the upper regions of a tent are required to move exhaust gases. The air and gases which are expelled from the discharge vents must be replaced by incoming fresh air which may be brought in through vents in the lower regions of the tent.

Forced convection, by means of fans, which might produce a more uniform tent temperature may also bring higher concentration levels of noxious gases than would normally occur down to the living level of the tent. Thus, investigations of for. convection should include monitoring the gas concentration levels throughout the tent.

While it is necessary to provide proper ventilation, it must be recognized that the shelter may be used in an atmosphere which would pose a health problem for the sheltered personnel. Examples of this would be an emergency shelter in an area where a chemical accident or fire has occurred or a shelter which must be used in an area subjected to chemical warfare. Precautions must be taken which will prevent any contaminating compounds from entering the living space of the shelter. Suitable filters may be required in the air vents both for inlet and discharge air.

2.6 ACCESS

Entry and exit from the tent should be easily accomplished without the use of intricate closure systems. The effectiveness of fasteners in cold or wet weather must be considered. Also, blackout requirements for tactical operation will require special considerations for the tent door.

Zippers often freeze in cold weather conditions, making them ineffective as a fastener for doors. Button-like fasteners leave gaps open in the door through which wind, sand or snow may enter the shelter.

Tunnel entrances, which are tubes of material equipped with a drawstring to close them, have been used on several of the newer commercial tents. These entrances may be closed effectively with no fear of freezing or allowing wind blown particles to enter the tent. They do, however, restrict the user's movements while passing through the tunnel.

Tunnel entrances seem to be a promising solution to the tent door problem with few undesirable qualities. An alternate solution may be possible by using continuous fasteners, such as "Velcro-fasteners", which perform similarly to zippers. The usefulness of a system such as this will depend on the lifetime of the fastener under adverse conditions as well as the susceptibility of the fastener to fouling, and preventing closure.

3. MEMBRANE FACTORS

3.1 TENSILE STRENGTH

The tent membrane will be required to handle both static and dynamic loads. Static loads may result from ice, snow, rain or sand accumulation, depending on the location, climate and the style of the tent.

Dynamic loads will most likely occur due to the wind. The magnitudes of the loads depend upon the wind velocity, the exposed membrane area and the orientation of the exposed membrane surface.

If a fabric is stronger in one direction than in the other, then it may be oriented in the membrane so that most of the stress is carried in this direction. This requires that the stress field in the membrane be known. Alternately, if the stress field is known, the fabric may be "tailor made" to provide adequate strength in the directions required without over-designing in other directions. This would result in reductions in weight and cost.

The strength of the material, both in tension and shear, may be adversely affected should the material become wet, frozen or subjected to other adverse operating conditions. In these cases, the designer must be aware of the existing operating conditions and the potential hazards which could adversely affect the performance of the membrane material.

3.2 TEARING PROPERTIES

The tearing properties of the fabric must be well understood. When a tear or hole occurs in the membrane, propagation must be arrested, either by repair or by some built-in failsafe feature, such as that found in ripstop nylon, so that the tent does not become useless as a shelter.

Tearing strength and tensile strength are integrally related, tearing often being the end result of exerting a stress on the material which is greater than the breaking tensile strength of the material. Once a tear has started, it may propagate at what appears to be a lower stress than the ultimate tensile stress. This may be due to stress concentration at the tips of the tear. Here, only a few fibres are carrying the load which was normally carried by the fibres broken by the tear. In a attempt to arrest the tear, regularly placed, stronger threads may be used in the material, as in the case of ripstop nylon.

3.3 FATIGUE

Fatigue of the membrane material will occur in the dynamic loading situations. Flapping and repeated bending of the material, notably in cold weather, may decrease its useful life. Stress concentration points are prime targets for failures due to fatigue.

3.4 WEAR PROPERTIES

The knowledge of the effects of abrasion of the membrane on its material performance is required to ensure that the fabric properties do not degrade significantly with normal use. Packing and day-to-day use of the tent will result in the fabric coming into contact with many kinds of rough surfaces, resulting in wear.

Wear reduces the breaking strength of the material, adversely affecting both the tearing and fatigue properties of the membrane. In places where the membrane comes into contact with the frame, wear will occur as a normal process of using the tent. Reinforcement or replaceable pads may be successfully used at these points to prevent excessive wear of the tent membrane proper.

3.5 REINFORCEMENT

A fabric which has sufficient tensile strength to withstand the uniform stress field may be insufficient in the areas around stress concentration points. In these cases, it may be cost-effective to reinforce the material if sufficient information is known about the stresses involved and the properties of the reinforcing material.

Stress concentrations will occur around the guy rope attachment points and at points of contact between the membrane and the frame. Also, stresses may be greater around the tent door when the door is being opened or closed. If the tent is poorly erected, or the terrain is not level, additional stress may be placed on the membrane at unexpected points which could lead to premature failure.

3.6 DEGRADATION OF PROPERTIES

Once the properties of interest of the membrane fabric have been determined, the degradation of each of these properties should be examined.

Degradation of the properties may occur simply with time, but usage and exposure will be responsible for much of the degradation of properties of a tent in active service.

Physical properties such as the tensile strength, water-repellency, chemical-repellency and fading may be affected with time and use.

Temporary degradation of material properties may occur as a result of transient conditions such as soaking from rain or freezing. Restoration of the material properties to their previous level may be possible with subsequent appropriate action by the user.

3.7 LIGHT TRANSMISSION

CF Specification LES 9/79 [11] states that the tent fabric: "be of such material and design that a 500 candle power light suspended in the centre of the shelter does not show through the material under conditions of darkness".

If light is transmitted out through the tent wall, the interior of the tent will be darker than if the light is reflected back into the interior of the tent. A similar problem will exist if light is absorbed by the tent fabric. This may make it difficult to work in the tent at night due to the low light intensity. It may also be depressing to the occupants, creating a morale problem. Thus, when the tent fabric is chosen, light transmission through the fabric should be investigated for all configurations in which the tent may be used.

3.8 CHEMICAL RESISTANCE

The effects of exposure to corrosive materials on the performance of the tent fabric should be known. This is required to ensure that the structural integrity of the tent will be maintained under extremely adverse conditions.

The fabric's permeability to harmful chemical compounds and hence its protection for the occupants is also a factor to be considered. If a chemically resistive coating is used, the coating must be capable of adsorbing to the fabric without compromising other desirable properties of the fabric. Once the coating has adsorbed to the fabric, it must remain intact under adverse conditions to provide reliable protection for sheltered personnel.

3.9 NATURAL BIOLOGICAL RESISTANCE

Many materials, notably natural fibres, are prone to rotting if certain precautions are neglected. Fungi may rot the tent membrane, creating weak areas which may result in eventual failure. Certain fungi may present a health problem to sheltered personnel.

The effects of natural biological attacks on the tent membrane can often be reduced to an acceptable state by proper maintenance of the tent membrane. It may be expected that the requirements of natural fibre membranes will be different from those of synthetic fibre membranes. First-hand experience and scientific knowledge in mycology will be instrumental in determining proper maintenance procedures.

3.10 FIRE RESISTANCE

Fabrics available for use in tentage have a wide variety of combustion properties, such as the ease with which it is ignited and its flame spreading characteristics [12]. Also, the products of combustion from a burning membrane should be known to determine if there is a toxicity threat.

Flammability guidelines have been established for the manufacturing of commercial tentage [13]. These guidelines may be used in conjunction with military requirements to provide a guide for the selection of a safe tent fabric.

3.11 WATER REPELLENCY

To ensure the comfort of the shelter's occupants or the serviceability of sheltered equipment in a rainy environment, the tent fabric should be water-repellent or water-proof.

Some materials are inherently water-repellent, while others require a water-repellent coating be applied. The ability of the fabric to shed water or to hold compounds which will shed water should be well understood.

Water-repellent materials which are porous to water-vapour, (so-called breathing fabrics), may be preferable to materials which are completely water-impermeable or water-proof. Water-repellent materials would permit the exchange of water vapour from the tent interior to the environment during normal use while keeping occupants sheltered during rainy periods.

The effectiveness of breathable fabrics at low temperatures should be investigated to ensure that the water vapour passes through and does not condense in the fabric where it would subsequently freeze and block the further passage of water vapour. This would negate any benefits of using the breathing fabrics in this type of climate.

3.12 CAMOUFLAGE REQUIREMENTS

The tent fabric must be capable of accepting and retaining camouflage patterns consistent with current military requirements. The ability of the fabric to accept dyes or other pigmentations should also be considered, especially for use in commercial tentage. Similarly, the colouring must not fade or wash away with time and exposure.

3.13 THERMAL RESISTANCE

The thermal resistance of single layers of existing tent fabrics is small. Increasing the thickness of these fabrics does not increase the thermal resistance significantly, however, it does increase the weight of the tent which is usually undesirable.

Most of the thermal resistance of a tent wall will result from the layers of relatively still air (so-called Boundary Layers) which lie immediately adjacent to the fabric. Increased thermal insulation may be obtained by introducing additional boundary layers of still air. This can be accomplished by using tent liners which provide additional surfaces on which the boundary layers can form. These liners can have the advantage of providing insulation while being light in weight. The durability of the liner may be the limiting factor in determining the liner weight.

Wind penetration of the membrane, movement of the walls or rapidly moving air over the walls all tend to disrupt the still air layers, significantly reducing the thermal resistance of the tent. Properties of the tent walls such as the air permeability, dynamic response and the ability to form thick boundary layers must be known to determine the thermal resistance of the tent. Air permeability is dependent upon the tent fabric only, whereas the dynamic response and boundary layer formation will depend on the tent shape as well as on the membrane fabric.

3.14 FABRIC WEIGHT

Military requirements for basic personnel shelters [11] require that the tent should be designed to be broken down into loads which can be carried by a soldier on his load carrying equipment in conjunction with his basic personal load. ("...All Components forming a shelter must be capable of being distributed for carriage by no other soldiers than those who will occupy the shelter..."). Thus in the interests of mobility, the tent fabric should be as light as possible without compromising other requirements or affecting the tent's structural integrity.

3.15 COST

Trade-offs between cost and performance must be made. A priority list for performance characteristics should be established for the tent fabric listing essential requirements, desirable features and undesirable attributes. Then, after considering the items in the preceding sections, a choice of the tent fabric may be made with respect to cost. Note, however, that even unlimited funds may not be sufficient to procure a tent fabric which meets all of the requirements if the requirements are too stringent for the existing state-of-the-art. Appendix B may be of use in determining the effects of performance trade-off on cost as well as on other factors.

4. SUPPORT FACTORS

4.1 FRAME SIZE AND SHAPE

The size of the frame will, in most cases, be established by specifying the shelter size requirement. The frame must be of a size and shape such that the interior of the shelter satisfies all of the habitability and physical requirements imposed on the tent design. It must be remembered, however, that in general the larger the frame, the more it weighs. Thus, a trade-off between convenience and size may be required to allow the shelter to be easily transportable.

The shape of the frame will be determined by the style of the shelter. Optimum arrangement of the frame members will produce the shape of the shelter desired while providing the proper amount of load carrying capability for the frame.

Easy erection of the shelter is equally important. This will be appreciated most when the tent must be erected or struck under adverse conditions. Thus, smaller tents with a simple frame may be preferred to a large or complex frame.

4.2 MECHANICAL PROPERTIES

The mechanical properties of the frame materials must be such that the frame performs in an acceptable manner under the specified operating conditions for a specified lifetime.

When the operating conditions have been specified, then the load carrying requirements must be determined so that a quantitative evaluation of the frame members may be made. The loading characteristics will be determined mainly by the size and shape of the shelter. The load carrying capabilities of the frame will be determined by the strength of each member as well as the arrangement of each member in the frame.

4.3 FRAME STRENGTH

The frame strength must be determined by considering both static and dynamic loading. Static loading could result from an accumulation of snow or ice while dynamic loads could result from gusting winds.

Bending and buckling analyses will play important roles in determining the strength requirements for static loading. Fatigue analysis will similarly be important for dynamic loading assessment.

Static loading of the frame can be analysed, both theoretically and experimentally, with relative ease. By stipulating the maximum design load that the frame must support, the frame member size may be choosen such that the incurred stresses under these extreme conditions are less than the maximum allowable stress of the material. Once a maximum load has been specified, operational procedures may be required to ensure that the incurred loads stay below the maximum load level or the ultimate strength of the material.

Fatigue analysis is more difficult than the static loading analysis. Fatigue analysis will require extensive experimental tests to establish the incurred loads and the rate of application to each of the load bearing members. Following this, statistical analyses are required to determine the optimum member size which gives an acceptable mean time to failure.

4.4 STRESS CONCENTRATION

Stress concentration invariably arises when load bearing members are joined together, when a load bearing member has an abrupt change of shape, or when a crack or hole is present in the member. In tents which have multimember frames, stress concentrations will most likely occur around the frame joints although provision should be made to accommodate stress concentrations due to cracks in the frame members. Points of stress concentration may readily attain stress levels which are several times larger than the nominal stress level in that member.

Experimental analyses are required to determine the magnitude of the increased stress as well as their distribution. Once the stresses are established, steps may be taken to provide adequate strength in the regions of known stress concentration.

4.5 MEMBER SHAPE

The frame members should be easily handled, especially under adverse conditions, should have a high ratio of load carrying capacity to weight and should be made of material which is easily obtained from existing industrial standards to minimize cost. The frame members should be easily connected with a minimum of incurred stress concentration at the joint.

Frame members used in current tentage (commercial and military) are almost exclusively circular in cross-section. Circular frame members have the property of allowing assembly without regard to the axial orientation of the member. Circular members are relatively easy to handle and they may be designed to be packed inside one another.

The intensity of the stresses in a loaded member may depend to a large extent on the member shape and its orientation to the load. This is especially true of bending or torsional stresses where most of the incurred stress is carried in the outermost regions of the member. Therefore, judicious selection of the member shape could result in a superior ratio of load carrying capability to weight.

Undoubtedly the cost of members with a circular cross-section would be less than other, non-standard cross-sections. Also, the availability of replacement members may be severely limited if non-standard members are used. There is not, however, an intrinsic structural requirement that the frame members be circular in cross-section.

The cost-effectiveness of choosing a member with a non-standard cross-section would have to be established by accounting for any additional productions costs due to the non-standard design as well as any savings on lesser amounts of material used. Simultaneously, the influence of the frame member on improving the overall system, from a military point of view, must be considered. This is a factor which may be difficult to assess monetarily.

Member failure and replacement must also be considered in choosing the member shape. These points are discussed under the next heading, "Member Failure".

4.6 MEMBER FAILURE

In the event of a premature failure or a loss of frame members, repair, replacement or an improvised substitution may be required to render the shelter serviceable. The frame design should therefore be simple enough to allow field repairs without excess labour. Thus, oddly shaped connections and irregularly shaped beams may be a poor choice.

Tree limbs or saplings may be substituted temporarily for the frame members if they are available. These may replace circular members quite readily, however, connections for other member shapes may be more difficult. Conversely, reinforcement of damaged members with available materials may be accomplished with greater ease if certain non-circular members are used.

4.7 FRAME MATERIAL

The frame material should be selected to ensure that the resulting frame members satisfy the above considerations as well as being light in weight and readily available. The weight of the members will depend upon the size and design of the members, the strength of the chosen material and the density of the chosen material. Manufacturing costs of the frame members will vary with the material used adding another consideration to the choice of the frame material.

4.8 TEMPERATURE CHARACTERISTICS

The temperature characteristics of the frame material is an important consideration if the shelter is intended for use in many theaters of operation. In cold weather, reduced flexibility could create problems when impact loading or repetitive loading occurs. In warm, moist climates, oxidation of the frame members may be important.

The coefficient of thermal expansion must be considered when designing the member joints. Sufficiently large tolerances must be allowed to permit assemble of the frame over the entire temperature range for which the shelter is intended to be used. This problem will be minimized if materials of similar thermal expansion coefficients are used.

4.9 FRAME-MEMBRANE INTERFACE

The attachment of the membrane to the frame should be easily accomplished and provide a durable connection. Likewise, during disassembly of the shelter, the membrane should be easily removed from the frame. These points are particularly important when cold weather or tactical situations require that the handlers wear hand protection which reduces the dexterity of the user.

The loads experienced by the membrane should be transferred as uniformly and as continuously as possible to the frame. In doing so, the even distribution of the load should produce fewer stress concentration points within the frame.

4.10 FRAME FOOTING

The footing of the frame should have a sufficiently large surface area that the pressure distribution over the footing is small compared to the load carrying capabilities of the terrain.

4.11 TOOLS FOR ASSEMBLY

Ideally, no special tool should be required for the erection of a shelter. It must be remembered that if a special tool is required, there exists the possibility that it may be broken or lost. Such a tool would also add weight to the kit. Thus, it is important to design any frame connections in such a way as to facilitate assembly and disassembly with a minimum of additional equipment.

5. ANCHORAGE FACTORS

5.1 GUY ROPES

When the loads on the tent have been established, it is possible to determine the load which must be carried by the guy ropes. The static tensile strength of the rope is usually a known parameter, thus, the choice of a guy rope from static load criteria is straightforward. This is tempered, however, by other considerations such as those discussed below.

The physical properties of the guy ropes should be established for operational conditions as well. This may include the tensile strength of the rope when it is wet, frozen or subjected to high temperatures. The flexibility and creep of the rope at various temperatures should be known also.

Dynamic loading of the tent, due to gusting wind for example, also produces a dynamic load in the guy ropes. Again, dynamic or impact loading can significantly reduce the ultimate strength or ultimate stress which the rope can carry. Fatigue analysis of the guy rope may also be necessary in this instance.

The guy ropes come into contact with other surfaces at several points: the tent anchors, the attachment tabs at the tent and the tension adjustment device. If the ropes slide over these surfaces while under load, abrasion of the ropes may occur. This could significantly reduce the ultimate strength of the rope and lead to a premature failure. Thus, it may be necessary to select a rope which does not wear easily and to institute inspection procedures in order to avoid unexpected breakages of guy ropes due to abrasion.

Rotting of the guy rope would reduce the ultimate strength in much the same manner as abrasion. Rotting may occur anywhere on the rope, not just at points of contact. Rotting may be prevented with the use of synthetic ropes or reduced by providing proper maintenance for natural fibre ropes.

Stress concentrations in the rope may occur in knots, at points of attachment to the tent membrane, the tent anchors and the guy rope tension adjustment device. The magnitude of the increased stress at these points should be established and steps taken to reduce the stress concentration as much as is feasible.

Since guy ropes must be carried along with the tent, their weight should be as low as possible. Minimizing the weight of the rope requires choosing the smallest diameter of rope which has a sufficiently large load carrying capability. Ropes of different materials will have different breaking strengths, weights, abrasion properties and so on. Again, an optimization procedure should be followed in choosing the guy rope.

5.2 TENT CONNECTION

Most connections between the guy ropes and the tent proper are made directly to the tent membrane although, in some designs, the guy ropes connect to the frame.

The tent connections on the membrane should distribute the load over a large area, as stress concentrations will occur in the membrane around these points. Distribution or reduction of the concentrated load may be facilitated by reinforcing the membrane in these areas.

Different means of attaching the connecting tabs to the tent membrane are available. Sewing is the traditional means of attaching the tabs. Glueing and ultra-sonic welding of the tabs to the tent have recently become feasible alternatives to sewing. The designer must know the types of loads as well as the magnitude of the loads which the joints will experience and understand the ramifications of applying these loads to the joint.

Similarly, the interface between the connecting tabs and the guy rope should provide a large area of contact to minimize stress concentration in the guy rope. This may also help in reducing wear due to abrasion at the interface.

The material of the tent connections should have physical properties similar to the tent membrane as it must perform in much the same manner.

5.3 ANCHORS

Improvised tent anchors may often be obtained quite readily from the surrounding landscape. In cases where this is not feasible, man-made tent anchors are required.

The loads of the anchors of a tent are directly related to those encountered in the guy ropes.

The size and shape of the tent anchor is important to the load carrying capability as these factors will determine how the load is transferred to the surrounding ground. As various landscapes may have different load carrying capabilities, the tent anchors must either be designed for the worst case or several specific designs must exist for different applications.

The size and shape of the tent anchors will also determine the ease in which the anchors may be driven into and extracted from the various types of terrain. The anchor material is important as some materials do not have a sufficiently high ultimate stress to be driven into some particularly hard terrains such as frozen or rocky ground. Also, the surface properties of some materials may reduce friction with the ground when the anchor is being driven in or extracted from the ground.

Stress concentrations may occur while the anchors are in use as well as while they are being driven in or extracted from the ground. Stress concentration will occur in the area surrounding the attachment point to the guy rope. The magnitude of the stress concentration in the anchor, however, may be of lesser significance than the accompanying stress concentration in the guy rope itself. The high stresses involved in driving or extracting the anchor from the terrain may require a stronger anchor than that which would be necessary to simply support the tent. This may not be true of all terrain, however, it is probably true of most terrain.

The weight of the anchors must be kept at a minimum as with all of the other components of the shelter. Similarly, any tool that is required for installing the anchor should be light but durable.

The anchor cost should also be low as these components of the tent may be more prone to loss and breakage due to the inherently rough handling they receive.

5.4 TENSION ADJUSTMENT

Tension adjustment in the guy ropes is necessary to expand the tent to its proper shape, provide sufficient support for the frame and to prevent over tightening of the guy ropes. Under changing climatic conditions, the tension in the guy ropes may change. For example, if the guy ropes are properly tensioned while wet, subsequent drying may produce excessively large stresses if the guy rope should shrink while it dries.

The tension adjustment device should be secure in various climatic conditions as well as being easily manipulated under these conditions. Slippage of the device could also cause wear in the guy ropes, leading to premature failure of the guy rope.

Rubber shock cords may be of use in some cases as a tension regulator, however, the adjustment capability of these devices may not be sufficient for general useage.

Again, weight and cost of the device must be minimized. This is not a particularly stringent requirement in this case as several devices currently exist on the market which perform well while being light in weight and inexpensive.

6. COMMENTS ON EXPERIMENTAL INVESTIGATIONS OF TENTAGE

The following list of research projects presents a guide for investigation of tentage design factors. The projects listed cover areas which appear to be of current major concern to tent designers. The description of each project is kept general as each researcher will undoubtably have a preferred method of approaching the problem subject to requests from the designers.

6.1 HEATING

Heating a tent may be either desirable, as in winter months, or undesirable, as during the summer. To minimize the amount of fuel required to heat a tent or to maximize the amount of heat lost from a tent, a detailed knowledge of temperature distribution in the tent is required. Also, knowledge of how the heat is transferred within the tent and to the surroundings is required. Auxiliary heating and solar heating will also affect the ventilation of the tent, which relates this project to the next project listed.

6.2 VENTILATION

Knowledge of airflow patterns in the tent and the way in which air is exchanged with the surroundings is required to determine how the tent is heated or cooled, whether or not there is sufficient ventilation to provide a healthy atmosphere and proper operation of the gas burning stoves.

6.3 FABRIC STRESS ANALYSIS

When the applied loads on the tent have been established, the loads and stresses carried by the tent membrane may be estimated to determine the strength requirement of the membrane material. In addition to this, stress concentration points must be investigated to determine the increased strength requirements in these areas.

Fatigue studies, or the rate and frequency of loading, should also be investigated to determine if fatigue is a problem and if it is, what can be done to reduce the probability of failure due to fatigue.

6.4 FRAME STRESS ANALYSIS

The requirements for this project will be similar to those outlined in the previous project.

6.5 INCURRED LOADS

The loads that the tent experiences may be due to externally applied forces, both static and dynamic, or internally applied forces created during the erection of the tent. The externally applied forces will be functions of size, shape, wind speed or static load magnitude, guy tension and tent orientation to list the most obvious factors.

Scale model wind tunnel tests will be important in this project as will static loading of full size tents.

6.6 ANCHOR DESIGN

Loading carrying capability, driving and extraction forces and durability of an anchor should be investigated to determine an anchors usefulness. The medium into which the anchor will be placed will also play an important role, and the anchor shape which performs best in a given terrain will have to be determined.

7. ACKNOWLEDGEMENT

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APPENDIX A

TENT DESIGN CHECKLIST
(Sited numbers indicate relevant sections of text)

General

Size ____________________
Style ____________________
Environment ____________________
Heating Requirements ____________________
Adequate Ventilation ____________________
Maximum Wind Speed ____________________
Maximum Static Load ____________________
Useful Temperature Range ____________________
Lifetime ____________________
Access ____________________
Total Cost ____________________

	OVERDESIGN	ADEQUATE	UNDERDESIGN
MEMBRANE FABRIC			
Tensile Strength (3.1)	____	____	____
Shear Strength (3.2)	____	____	____
Fatigue Resistance (3.3)	____	____	____
Reinforcement (3.5)	____	____	____
Degradation Resistance (3.4,3.6)	____	____	____
Light Transmission (3.7)	____	____	____
Chemical Resistance (3.8)	____	____	____
Biological Resistance (3.9)	____	____	____
Water Repellency (3.11)	____	____	____
Porosity (3.7,3.8,3.11,3.13)	____	____	____
Weight (3.14)	____	____	____
Colour Retention (3.12)	____	____	____

	OVERDESIGN	ADEQUATE	UNDERDESIGN
FRAME MEMBER			
Shape			
Strength (4.3,4.7)			
Fatigue Resistance (4.6)			
Stress Concentration (4.4,4.5)			
Joints (4.4,4.8)			
Fabric Interface (4.9)			
Weight (4.7)			
Corrosion Resistance (4.7)			
Joint Stress Concentration			
GUY MATERIAL			
Tensile Strength (5.1)			
Fatigue Resistance (5.1)			
Wear Resistance			
Stress Concentration (5.1)			
Rot Resistance (5.1)			
Weight (5.1)			
Tent Connection (5.2)			
Anchor Connection (5.3)			
ANCHOR			
Size (5.3)			
Shape (5.3)			
Strength (5.3)			
Stress Concentration (5.3)			
Weight (5.3)			
Guy Connection (5.2)			

COST

		Acceptable	Unacceptable
Fabric	$ ______	______	______
Frame Member	$ ______	______	______
Guy	$ ______	______	______
Anchor	$ ______	______	______
______________		______	______
TOTAL	$ ______		

APPENDIX B

FACTOR INTERACTION

Successful analysis of many problems, indeed even a qualitative understanding of the problem, depends upon the success of isolating the contributing factors and analysing each one independently if possible.

Figure 1 gives a partial list of factors which affect the performance of tentage. The figure shows which factors if changed (independent variable) will affect the factor which is under consideration (dependent variable). The figure attempts to differentiate between "significant" interactions and "insignificant" interactions. The lack of scientific data in the field necessitates that most of the assigned interaction ratings are speculative and reflect the opinion of the author.

A description of each of the factor identifiers is given below. Each factor description reflects information contained in the main text, and thus will not be detailed. As noted each factor is viewed separately as an independent and as a dependent variable which gives rise to the non-symmetrical table.

Glossary to Figure 1

General	- refers to parameters which are common to many factors.
Size	- refers to the size of individual components of the tent or the size of the complete tent.
Style	- refers to the shape and construction of the tent in general.
Weight	- refers to both the weight of the entire tent and its individual components.
Environment	- refers to the ambient climatic conditions in which the tent will be used or stored.
Heating	- can be by stove, solar or electricity, and includes heat losses by convection, conduction and radiation.

Ventilation	- is the displacement of air in the tent, intentional or otherwise, by ambient air through vents, penetration of the membrane, the door, or under the tent wall.
Loading	- can be static or dynamic, for example snow or wind, placed on the tent by any means.
Fatigue	- is the wear of any component of the tent by repetitious loading cycles.
Stress Concentration	- is the increased level of stress in a component of the tent which may be caused by a fault in a component or an irregularly shaped load-bearing member.
Degradation	- is applied generally to represent any reduction of a component's performance from the "new" design performance.
Access	- is the entrance to the tent, be it merely a flap or an elaborate doorway, the closure system included.
Cost	- refers to either the cost of the entire tent or of a single component.
Membrane	- refers to factors of the tent fabric.
Tensile Strength	- is the maximum static load that the membrane can carry.
Tear Strength	- is the maximum static load that the membrane can carry without causing a tear to propagate through the fabric.
Abrasion	- is the wear of the tent fabric due to friction between the tent fabric and other objects such as the frame, the ground, etc.
Reinforcement	- is the strengthening of selected portions of the membrane or the frame by the addition of extra material.
Rotting	- refers to the reduction of performance of the membrane due to the action of naturally occuring chemicals or fungi.
Porosity	- the amount of space between the fibres of the membrane.

Chemical Resistance - is the ability of the membrane to withstand direct contact with chemicals which may be highly toxic or corrosive, and which are not generally found in nature.

Flammability - refers to the ease in which the membrane can be ignited, or the ability of the membrane to sustain combustion after the source of ignition is removed.

Water Repellency - is the ability of the membrane to shed water and prevent water from penetrating through the membrane.

Colour - refers to the ability of the membrane to accept and retain dyes as well as its ability to resist discolouration.

Light Transmission - the ability of the membrane to prevent direct loss of light or to reduce the brightness of the emitted light to tolerable levels.

Support - refers to the frame or pneumatic structure which gives the tent its characteristic shape.

Tensile Strength - refers to the maximum load that an individual member can carry in tension or compression.

Shear Strength - refers to the maximum load that an individual member can carry in shear.

Member Shape - is the shape of the components of the frame or of the components of the pneumatic structure.

Frame Strength - is the maximum load that the frame can carry when it has been assembled and the tent is erected.

Footing - refers to the member of the frame which distributes the load of the tent over the ground.

Tools - refer to any tool which is required to erect or repair the tent and may include tools which have other functions in the tent group.

F/M Interface	- is short for the Frame/Membrane Interface, or the areas of the tent where the frame and the membrane come into contact.
Anchorage	- refers to the components of the tent which hold the tent to the ground.
Guy Tensile Strength	- is the maximum load that the guy line can carry.
G/M Interface	- is short for the Guy Line/Membrane Interface where (or if) the guy line is attached to the membrane.
G/F Interface	- is short for the Guy Line/Frame Interface where (or if) the guy line is attached to the tent frame.
G/A Interface	- is short for the Guy Line/Anchor Interface where the guy line is attached to the anchor.
Anchor Tensile Strength	- is the maximum normal stress which the material of the anchor can withstand.
Anchor Shear Strength	- is the maximum shear stress which the material of the anchor can withstand.
Anchor Shape	- is the shape of the anchor as designed or after use.
Anchor Size	- is the size of the anchor.
Anchor Load Cap	- is the load carrying capacity of the anchor.
Tension Adjustment	- refers to any problems associated with the guy line tension adjustment device.

INDEPENDENT VARIABLE / DEPENDENT VARIABLE	GENERAL													MEMBRANE											SUPPORT							ANCHORAGE									
	SIZE	STYLE	WEIGHT	ENVIRONMENT	HEATING	VENTILATION	LOADING	FATIGUE	IMPACT LOADS	STRESS CONCENTRATION	DEGRADATION	ACCESS	COST	TENSILE STRENGTH	TEAR STRENGTH	ABRASION	REINFORCEMENT	ROTTING	POROSITY	CHEMICAL RESISTANCE	FLAMMABILITY	WATER REPELLENCY	COLOUR	LIGHT TRANSMISSION	TENSILE STRENGTH	SHEAR STRENGTH	MEMBER SHAPE	FRAME STRENGTH	FOOTING	TOOLS	F/M INTERFACE	GUY TENSILE STRENGTH	G/F INTERFACE	G/M INTERFACE	G/A INTERFACE	ANCHOR TENSILE STRENGTH	ANCHOR SHEAR STRENGTH	ANCHOR SHAPE	ANCHOR SIZE	ANCHOR LOAD CAPACITY	TENSION ADJUSTMENT
SIZE		1		1									1																												
STYLE	1			1									1																												
WEIGHT	1	1		1					1				1	1	1		1		1	1	2	1			1	1	1	1		1		1				1	1	1	1		2
ENVIRONMENT																																									
HEATING	1	1	2	1		1	1						1					2	1																						
VENTILATION	2	1		1	1		1						1					1	1																						
LOADING	1	1	1	1		1						1																	1				1	1	1					1	1
FATIGUE	2	1	1	1			1		1	1	1	1		1	1	1	1	1	2	2		2	2		1	1	1	1	2			1	2	2	2	1	1	1			
IMPACT LOADS	1	1		1			1	1		1	1								1									1				1	1	1	1						1
STRESS CONCENTRATION							1	1	2		1	1					2										1		1									1			1
DEGRADATION	2	1		1			1	1	1	1		2		1	1	1	1	1		1	1	1	2		1	1					1	1	1	1	1	1	1				
ACCESS	1	1		1	1	1							2	1	1	1	1			1		1		1																	
COST	1	1	1		1	2					1	1		1	1		1	1		1	1	1	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1		2
TENSILE STRENGTH	1	1	1	1			1	1	1	1	1		1		1	1	1	1	1	1	1	1	1								1			1							
TEAR STRENGTH	1	1	1	1			1	1	1	1	1		1	1		1	1	1	1	1	1	1	1								1			1							
ABRASION				1			1					1					1														1			1							
REINFORCEMENT	1	1	1	1			1	1	1	1	1	1	1	1	1	1									1	1	1	1	1		1			1		1	1	1	1	1	
ROTTING				1		1					1		1						1	1		1	1								1			1							
POROSITY				1	1	1						1	2			1	1	1		1	1	1		1							1			1							
CHEMICAL RESISTANCE				1		1						1	1			1	1	1	1		1	1									1			1							
FLAMMABILITY				1	1								1					2		1		1	1																		
WATER REPELLENCY		1		1		1						1	1			1	1	1	1	1	1										1			1							
COLOUR				1	1						1		1					1		1	1	1		1							1			1							
LIGHT TRANSMISSION		1	1								1	1	1			1	1	1	1	2	2	2	1								1			1							
TENSILE STRENGTH	1	1	1	1			1	1	1	1	1		1													1	1	1	1		1		1								
SHEAR STRENGTH	1	1	1	1			1	1	1	1	1		1												1		1	1	1		1		1								
MEMBER SHAPE	1	1	1	1			1	1	2	1	1		1												1	1		1	1		1		1								
FRAME STRENGTH	1	1	1	1			1	1	1	1	1		1												1	1	1		1		1		1								
FOOTING	1	1	1	1			1	2		1			1														1	1													
TOOLS		1	1	1									1																												
F/M INTERFACE	1	1	2				1	1		1	1		1	1	1	1	1	1							2	2	1	1					2								
GUY TENSILE STRENGTH	1	1	2	1			1	1	1	1	1		2																				1	1	1					1	1
G/F INTERFACE	2	1		2			1	1	1	1	1		1												1	1	1	1				1									1
G/M INTERFACE	1	1		2			1	1	1	1	1		1	1	1	1	1	1														1									1
G/A INTERFACE	1	1		2			1	1	1	1	1		1																			1				1	1	1			1
ANCHOR TENSILE STRENGTH	1	1		1			1	1	1	1	1		1																								1	1	1	1	1
ANCHOR SHEAR STRENGTH	1	1		1			1	1	1	1	1		1																							1		1	1	1	1
ANCHOR SHAPE	1	1		1			1	1	1	1	1		1																							1	1		1	1	1
ANCHOR SIZE	1	1		1			1	1	1	1	1		1																							1	1	1		1	1
ANCHOR LOAD CAPACITY	1	1		1			1	1	1	1	1		2																							1	1	1	1		1
TENSION ADJUSTMENT	1	1		1			1	1	1	1	1		1	1	1										1	1		1				2		2						1	

1 = Significant Interaction
2 = Small Interaction

Figure 1

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An analysis is presented of the relationship between engineering factors of importance in tentage. Because the scientific literature on tentage is so limited, the analysis is qualitative. The purpose is therefore to provide a guide, rather than a textbook, for use in the design of tents and for guiding the selection of future R/D projects related to tentage. Two appendices are included which are intended to be of direct use in tent design activities. Appendix A is a sample tent design checklist which includes the factors discussed in the text, and Appendix B presents a matrix which summarizes the degree to which the various factors are inter-related.

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ENGINEERING FACTORS

DESIGN CRITERIA

RESEARCH GAPS

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