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# AN EVALUATION OF THE [illegible] INFLATABLE MEDICAL TENT

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE [illegible]

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# AN EVALUATION OF THE TRELLEBORG INFLATABLE MEDICAL TENT

by

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
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## ABSTRACT

The Trelleborg Medical Tent, an inflatable tent of interest to the Canadian Forces, has been investigated to assess its potential in providing both a medical shelter and a collective protection shelter. Pressurization measurements are reported and a general purging analysis is included. Thermal and structural properties are reviewed. Dynamic (wind) loads and static (snow) loads have also been analysed.

## RESUME

La tente médicale gonflable Trelleborg, qui présente un intérêt pour les Forces canadiennes, a été examinée afin de déterminer la possibilité de l'utiliser comme abri médical et comme abri de protection collective. Les mesures de la pression interne ainsi que les résultats d'une analyse de l'air évacué sont notés. Les propriétés thermiques et structurales de la tente sont examinées, et on analyse aussi des charges dynamiques (vent) et des charges statiques (neige).

# 1.0 INTRODUCTION

This report describes an evaluation of the Trelleborg Inflatable Medical Tent (1) which is being considered for use by the Canadian Forces (CF), both as a mobile medical shelter and as a collective protection shelter. The tent is a semi-cylindrical shelter, made of a polyvinyl chloride (PVC) coated fabric, supported by four inflatable ribs (Figure 1). The basic concept is that a section of this tent be equipped with an airlock and a liquid-chemical repelling fly so that it could be used as a chemically secure shelter. The tent may be erected in modular form, including as many sections or airlocks as required.

This study notes some of the physical properties of the tent, advances procedures for establishing the pressurization capabilities and the heating properties of tents, makes general comments on the tent and investigates some aspects of the tent's incurred loads. A discussion of purging of the tent is also presented.

# 2.0 GENERAL OBSERVATIONS

## 2.1 PHYSICAL PROPERTIES

Some of the important physical characteristics of the Trelleborg Medical Tent are listed in Table 1.

The PVC coated material provides a durable covering which is easily cleaned with soap and water, kerosene or acetone. The general construction of the tent appears sound, based on observations made at the DREO Tent Testing Facility, however, extensive field trials on the tent must be held before any definitive conclusion can be made in this area.

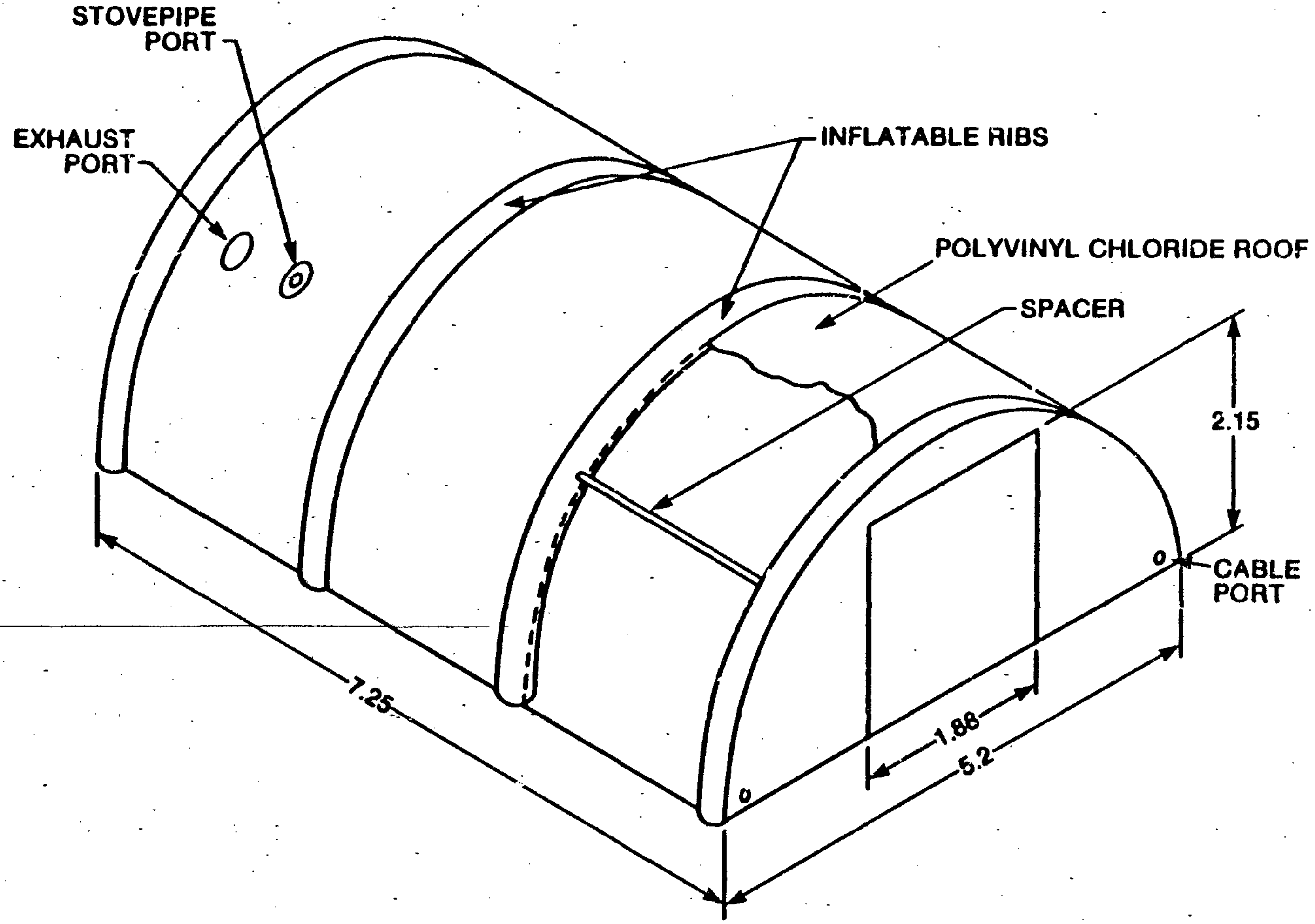


Figure 1: Schematic of Trelleborg Medical Tent.

## TABLE 1

## Physical Characteristics of the Trelleborg Medical Tent and Support Equipment (1)

### Medical Tent

| | |
|---|---|
| Length | 7.25 m |
| Width | 5.20 m |
| Height (Maximum) | 2.60 m |
| Floor Area | 37.7 sq.m |
| Number of Doors | 2 |
| Door Height | 2.15 m |
| Door Width | 1.88 m |
| Number of Rib Spacers | 6 |
| Packed Weight (With Spacers) | 227 kg |
| Packed Volume (Without Spacers) | 1 cu.m |
| Packed Spacer Volume | 0.024 cu.m |

### Support Equipment

### Air Pressure Fan

| | |
|---|---|
| Power | 700 W |
| Voltage | 230 Vac |
| Weight | 20 kg |
| Packed Volume | 0.055 cu.m |

### Equipment/Repair Kit

| | |
|---|---|
| Weight | 180 kg |
| Volume | 0.5 cu.m |

## 2.2 ERECTION AND STRIKING

The erection and striking of the tent is easily accomplished, even by novices. The instruction manual is short, to the point and clear in its instructions. With this manual or a small amount of instruction the tent may be quickly erected and put in use. Table 2 lists some typical erection and striking times as performed by personnel familiar with the tent.

It was found that three to five men were adequate for the efficient erection of the tent. As the tent weighs approximately 250 kg, it would be most convenient if the tent were to be unloaded from the transport vehicle as close to its final destination as possible. With some effort, four men can carry the tent several metres.

It was found that most of the air trapped in the ribs during the striking procedure could be expelled by rolling the tent along its length towards the open air-valves. When the tent was then unrolled, it folded much more easily and more compact than when this step was omitted. Walking on the deflated ribs was not found to be particularly effective for expelling the trapped air, and this practice runs the risk of puncturing the rib. Zippering the doors shut prior to striking the tent also made packing of the tent somewhat easier.

## 2.3 INFLATABLE RIBS

The electric inflation fan used to inflate the supporting ribs of the tent operates on 220 Vac at 700 W. It delivers 15 l/s maximum and attains a maximum pressure of 18 kPa. At this rate, a single rib requires approximately one and one-half minutes to inflate fully. It may be convenient to supply an inflation fan which can operate with other electrical power sources such as 48 Vdc (vehicle battery) or 110 Vac. A pressure regulator could be used which, when used with air compressors currently available on some CF vehicles, would supply air at a maximum pressure of 18 kPa.

There was air loss from the ribs, but it was found to be relatively slow. When the tent was left unattended for several days, the pressure in the ribs did drop, but, it remained sufficiently high to

## TABLE 2

Typical Erection and Striking Times of the Trelleborg Medical Tent Under Ideal (Summer) Conditions
(Terms in brackets refer to manual inflation)

| Action | Time (min) |
|---|---|
| **Erection - Four Man Crew** | |
| Unpacking | 4 |
| Inflation: Electric fan | 6 (20) |
| Inserting Floor | 1 |
| Stake and Guy | 2 |
| Subtotal | 13 (27) |
| Connection/Erection of the Black-out Section | 5 |
| Total Time Required | 18 (32) |
| **Erection - One Man Crew** | |
| (Steps as above) | |
| Total Time Required | 45 |
| **Foot-pump Inflation/Tube** | 5 |
| **Striking - Four Man Crew** | |
| Removal of Floor | 1 |
| Deflation Time/Tube | 3 |
| Removal of Trapped Air | 3 |
| Folding - Tent and Floor | 5 |
| Packing - Tent and Floor | 3 |
| Packing - Poles | 1 |
| Packing - Accessories | 1 |
| Total Time Required | 17 |

support the weight of the tent. Under adverse weather conditions, such as heavy winds or snow-fall, it is recommended that the rib pressure be maintained at the nominal operating pressure of 18 kPa to ensure optimum performance of the tent. To maintain this condition, the ribs may require topping-up to operating pressure perhaps as often as every three days. This time will depend upon the condition of the valve seal and the integrity of the inflatable rib inner-tube. Changing ambient temperatures may cause some fluctuation in the rib pressure, although it is not expected to be an important factor. A faulty valve or a puncture in a rib inner-tube could cause the rib to deflate more rapidly than was observed while the tent was under test at DREO.

As depicted in Figure 1, the inflated ribs are held apart by aluminum spacer bars. It was found that, when a rib was deflated, the adjacent spacer bars fell out of place. This is potentially hazardous to personnel or equipment located beneath the spacer bars. It is recommended that a safety strap arrangement be used to keep the spacer bars from falling should a rib deflate.

Guy-ropes, although not essential for the erection or use of the tent, may be important in some situations. It was found that if one of the center ribs deflated, the end-guys would hold the tent erect and functional. In heavy winds, especially for an empty tent, the guys may be necessary to secure the tent to the ground. During pressurization tests, the tent inflated and the ribs were lifted off of the ground entirely. In this situation, lateral guys may be necessary to keep the edges of the tent on the ground. A securely guyed fly-sheet may also be of use in keeping the tent on the ground.

It was found that, even after limited use, the plastic fasteners used to connect tent sections together had worn significantly. This was primarily due to friction caused when the rope used to secure the fastener was pulled through the connector. If the rope fastener is to be used, it may be necessary to use metal components. Alternatively, each fastener could be supplied with its own key which would replace the rope. This type of fastener may even facilitate assembly. Fasteners of this type are currently under study within the Directorate of Clothing General Engineering and Maintenance (DCGEM).

## 3.0 PRESSURIZATION TESTS

A simple procedure was used for establishing the pressurization capabilities of tents designated for use while subjected to an internal over-pressure. Pressurization tests were performed on the Trelleborg tent using an electrically powered Herman-Nelson Heater/Blower to supply the air. The air flow-rate was measured using an orifice plate flowmeter with D-1/2D pressure taps and an inclined manometer. Flow coefficients for the orifice plate flowmeter were calculated according to standard practices (2). A "flow resistance" was calculated for the tent based on the following relationship:

$$R = P_m/Q \qquad [1]$$

where, R is the flow resistance (Pa.s/m$^3$)
$P_m$ is the mean tent pressure (gauge) (Pa)
Q is the volume flowrate into the tent (m$^3$/s)

The results of the tests are summarized in Table 3. In Section A of Table 3, the tent was not modified in any way. Vents were closed by pulling the drawstrings only. Chimney hole covers were closed, as were the door zippers.

In Section B of Table 3, the tent was modified slightly. For these tests, all vents were tied off and sealed using tape. Chimney holes were taped shut and covered with plastic. One of the doors into the tent was sealed as well as could be achieved by taping over the zipper and weighting the bottom flap. The other door was weighted at the bottom only. Attempts to seal the tent completely were only partially successful as it is difficult to find an adhesive which will stick to PVC temporarily and yet form a good seal.

Included in Table 3 is the time required for the tent to reach the steady-state mean gauge pressure from the initial, ambient pressure. This quantity is denoted by the symbol $T_{ss}$.

The variations in the data of Section B in Table 3 are due in part to the difficulty in maintaining a good seal around entrances to the tent.. However, it can be seen that even though the seal in the tent was incomplete, there was a substantial gain in the flow resistance of the tent when the modification for Section B were made. The mean flow resistance of the "sealed" tent was approximately 369 (Pa.s/m$^3$) compared with 126 (Pa.s/m$^3$) of the standard tent. It is expected that when the tent is more effectively sealed, the flow resistance will reach a value of approximately 416 (Pa.s/m$^3$). This is the estimated flow resistance for the tent with two doors, closed by zippers around the entire door periphery, and only one vent through which air is supplied to the tent.

When the tent experienced the larger overpressures of Section B, the tent inflated, lifting off the ground near the wall by as much as thirty centimeters. At that point, the tent was held erect by the overpressure alone. This action may cause problems which may possibly be remedied by using guy-ropes as noted in the previous section.

## TABLE 3

### Results of Pressurization Tests on the Trelleborg Medical Tent

| Air Flow-rate ($m^3/s$) | Mean Pressure (Pa) | Flow Resistance ($Pa.s/m^3$) | $T_{ss}$ (min) |
|---|---|---|---|
| SECTION A | | | |
| 0.2208 | 28.61 | 129.51 | 12 |
| 0.2680 | 33.59 | 125.33 | 3.5 |
| 0.2905 | 36.08 | 124.20 | 3.5 |
| SECTION B | | | |
| 0.2167 | 69.66 | 321.46 | 4 |
| 0.2729 | 118.18 | 433.05 | 2.5 |
| 0.2868 | 100.75 | 351.33 | 2 |

It was found that the Black-Out Section, an additional section of tentage which can be added to the medical tent, would not hold a significant overpressure in its current form. This is primarily due to the closure system of the door. A more effective "air-lock" could be made from the Black-Out Section if a more secure closure system were to be used.

If two main sections of tentage are to be used in modular form, several recommendations are in order:

1) To maintain sufficient overpressure and to minimize purge time, each section of tentage may require its own source of filtered air.

2) To minimize the intrusion of external air into the tent at their juncture, the tents should be joined at the connection flap around the door rather than at the flap around the end wall. This would produce a connection with the smallest seam area through which outside air may enter.

3) The region around the junction of the two tents must be pressurized to prevent intrusion of chemicals into the tent. This may be accomplished by ensuring that one of the two doors at the junction of the tents is open.

The following modifications would improve the pressurization performance of a single tent section:

1) All but one or two air vents and all chimney holes should be eliminated.

2) Power cable tunnel vents should be replaced with sealed electrical junction boxes mounted in the tent wall.

3) If the rear door on the secure section of the tent is not required, it should be eliminated or at least be provided with improved means for further sealing against air-leakage.

4) All doors should include a fastener across the bottom which would seal the doors at the floor.

If a tent is modified as noted above, it is expected that it will have a flow resistance of approximately 416 (Pa.s/m$^3$) as previously calculated. Thus, a Herman-Nelson, which is capable of delivering air at flow rates between 0.229 and 0.458 (m$^3$/s) would provide an overpressure of between 95 and 190 Pa respectively. The Trelleborg blower, which delivers 0.611 (m$^3$/s) would provide an overpressure of 254 Pa. These estimates assume that the resulting overpressures are within the delivered head capabilities of the fan.

## 4.0 PURGING

Purging of the interior of airlocks and tents may be required to remove hazardous chemicals which have contaminated the interior. Purge time for air-locks and entire tents depends upon several parameters. A brief and simplified mathematical analysis of the purging processing is included here.

Initially it is assumed that any contaminant which enters the air-lock is uniformly distributed throughout the entire volume. The governing differential equation for this problem is:

$$\frac{dC}{dt} \times V = -C \times Q \qquad [2]$$

where, C is the concentration of the contaminant in the air-lock as a function of time,
t is the time from the start of purging,
V is the volume of the air-lock,
Q is the rate at which filtered air is being supplied to the air-lock.

The solution for purging time from this differential equation is:

$$t = (V/Q) \times \ln(C_i/C) \qquad [3]$$

where, $C_i$ is the initial concentration of the contaminant in the air-lock.

Experimental investigation indicates that equation 3 should be amended to:

$$t = (V/(Q \times k)) \times \ln(C_i/C) \qquad [4]$$

where k is an empirically determined constant which compensates for unequal mixing of the fresh, incoming air and the contaminated, internal air. The value of k has been reported to be within the range 0.35 to 0.39, but this value may be dependent upon the shelter size and shape (3).

By specifying a safe concentration level "C", and knowing the air flow-rate into the tent and the tent volume, the required purge time can be calculated for the tent for any initial concentration using equation 4.

## 5.0 HEATING

One section of the Trelleborg Tent was instrumented with thermistors and heated with forced air electric heaters to determine its heating properties. Analysis of the data (4) indicates that the tent has a temperature rise per Watt of heat input of 0.0074 ± 0.001 C/W over the wind speed interval 0.5 to 4.0 m/s. The value of the temperature rise per Watt was found to decrease approximately linearly with increasing wind speed from 0.0086 C/W at 0.5 m/s to 0.0057 C/W at 4.0 m/s. Heat loss through the floor varied from 2 to 7% of the total heat loss from the tent. This heat loss will be a function of several parameters including ground temperature, air temperature and wind speed. It is expected, based on experiments with other tents (4), that a single layer, fabric liner would approximately double the relative temperature rise per Watt of heat input to the tent.

## 6.0 STRUCTURAL

As the Tent Research Facility at DREO is not currently equipped to investigate the structural capabilities of tents, no direct measurements of loading carrying capacities were made. Estimates of the incurred wind loads are presented which are based upon work performed for the Natick Laboratories (5,6). Estimates of the load carrying capabilities of the arches may be obtained following the procedures of Steeves (7). Some general observations of the structural capabilities of the tent are made and calculations pertaining to the enhanced load carrying capacity of a pressurized tent are presented.

## 6.1 WIND LOADS

During one particularly violent wind storm (gusts of 90 km/hr were experienced), the leading edge of one of the tents lifted, pulling the pegs from the ground. The tent then commenced to roll away, driven by the wind. The tent sustained only minor damage to the outer shell before it came to rest. It may therefore be necessary to increase the size of the skirt around the edge of the tent and to weight the skirt with soil or snow to prevent lifting of the tent during heavy winds. It is expected that the tent will be stable in winds up to approximately 100 km/hr if this procedure is followed. It is recommended that the tent be put to trial in an area which regularly experiences heavy winds to confirm the tent's capabilities.

Estimates of the wind loads on the tent may be made by knowing the wind speed and several other physical parameters. The general mathematical relationship is:

$$F = C\rho AV^2/2 \qquad [5]$$

where, F is the load or force on the tent,
C is the load coefficient (drag or lift),
$\rho$ is the air density,
V is the air velocity,
A is the tent floor area.

Studies conducted at U.S. Natick Labs (5,6) indicate that the maximum drag coefficient for structures similar to the Trelleborg tent is between 0.2 and 0.33. Maximum lift coefficients were found to be 0.43 (5) and 0.55 (6).

Anchor and guy-line load coefficients may be used with equation [5] to determine the aerodynamic load placed on the anchor or guy-line. Note that if the tent is subjected to an overpressure, the load placed on the anchors and guy-lines must be calculated from the vector sum of the aerodynamic loads and the internal pressure loads.

If the tent is to be used without guy-lines, Dietz (6) recommends using a maximum anchor load coefficient $C_{a1}$ of 2.05. This means that the maximum load carried by each anchor will be:

$$F_m = C_{a1}\rho AV^2/2N \qquad [6]$$

where N is the number of anchors used around the periphery of the tent.

If guy-lines are attached along the side of the tent, midway up the height of the tent and making a 45 degree angle with the ground, the load coefficient for the mean anchor load is $C_{b1} = 0.75$ and the mean guy-line load coefficient is $C_{g1} = 0.425$ (6). Measurements on wind tunnel models indicate that maximum loads experienced by anchors and guy-lines were twice and four times as large as the respective mean loads.

The mean vertical loads, $F_{mv}$, carried by the guy anchors may be calculated by:

$$F_{mv} = C_{g1}\rho AV^2\sin(\theta)/2M \qquad [7]$$

where M is the number of guy-lines and θ is the angle between the ground and the guy-line. By specifying a "design-maximum" wind speed, V, the size and number of guy anchors can be determined from Equation 7 and the holding characteristics of the anchor design. For example, the current design has four guy-lines, M=4, and for a wind speed of 20 m/s, each anchor would experience a load of approximately 7.36 N.

## 6.2 STATIC LOADS

During tests at the DREO Tent Research Facility, a build-up of approximately ten centimeters of wet snow on the roof of the Trelleborg tent caused the tent to collapse. The tent was unattended and unheated which, under normal operations, would likely not be the case. Some measure of preventive maintenance is required under adverse conditions to ensure that the tent does not become over-burdened. When the snow was removed from the collapsed tent, the tent immediately rose back to its normal shape with no apparent damage. Heating of the tent and periodic removal of snow from the tent roof should be sufficient to ensure that the tent will not collapse under similar weather conditions.

If the tent is pressurized, its static load carrying capabilities will be increased. However, if the tent is pressurized and not constrained verticaly, the tent will experience a larger lateral wind load. The increase in the static load carrying capabilities of a pressurized tent can be considerable. As an example, Figure 2 shows a hypothetical build-up of snow on the roof of a pressurized tent. The calculations indicate that for every ten Pascals of overpressure in the tent, one additional centimeter of "standard snow" may accumulate on the tent without adding an additional load to the ribs.

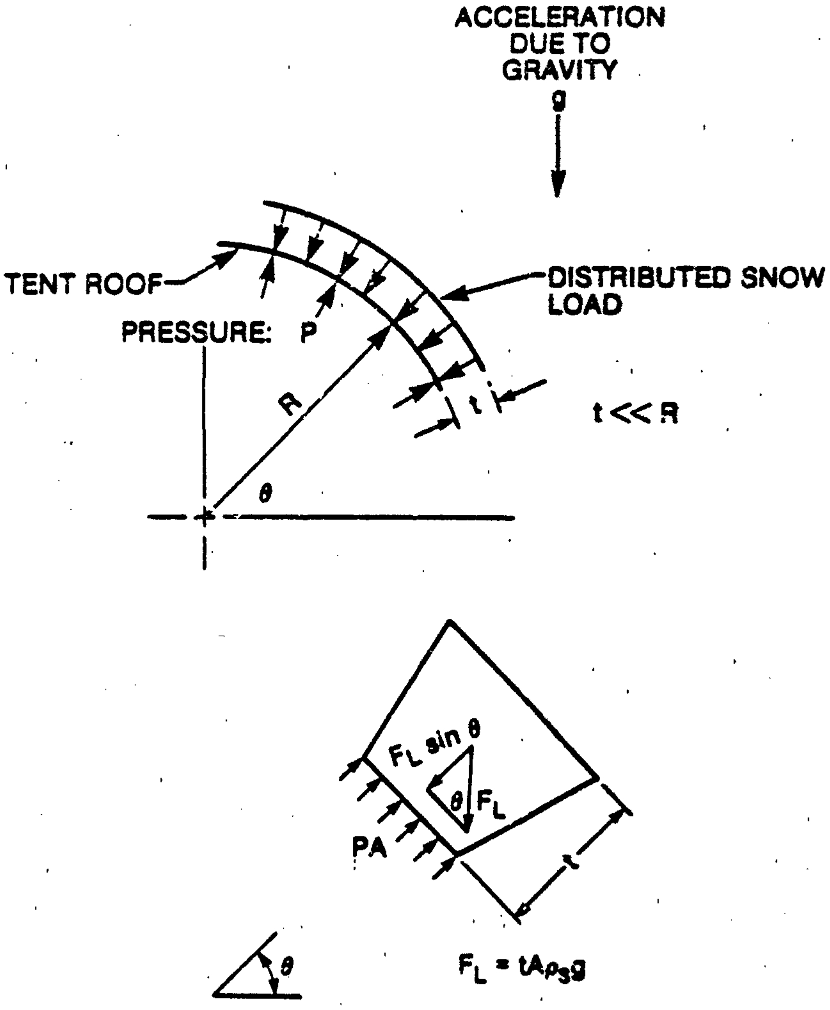
## 7.0 SUMMARY AND CONCLUSIONS

The Trelleborg tent, although not without some problems, appears to be a very good shelter. The tent is easily and quickly erected, even by novice users; it is easily cleaned; it is durable; if suitably anchored, it is tolerant of moderately high winds. The tent has a flow resistance of 128 $Pa.s/m^3$ when an overpressure is applied and it is predicted that a modified version of the tent which eliminates many of the unnecessary vents will have a flow resistance of 416 $Pa.s/m^3$.

Because of its weight and size, the tent should be transported by vehicle. It is possible but awkward, for the tent to be moved by four men in its packed state for several meters. The tent may be readily moved when erected to facilitate modular expansion.

The mean internal temperature rise above ambient per Watt of heat input for the tent is approximately 0.0074 C/W. This value was observed to vary linearly from 0.0086 C/W at a wind speed of 0.5 m/s to 0.0057 C/W at 4.0 m/s. Heat loss to the floor was found to represent only 2 to 7% of the total heat loss of the tent. It is expected that a liner consisting of a single layer of cloth would approximately double the mean internal temperature rise per Watt of heat input from the tent.

The tent requires minimal maintenance under adverse weather conditions to ensure that snow accumulation or wind loads do not become excessive. It is expected that superior static load carrying capabilities would be achieved by using additional guying and by applying overpressures to the tent.



A: ROOF SURFACE AREA

$\rho_s$: SNOW DENSITY

**FORCE BALANCE**

$$PA = tA\rho_s g \sin \theta$$

$$P = t\rho_s g \sin \partial$$

*Figure 2: Analysis of the Increased Load-Carrying Capacity Due to Pressurization of the Trelleborg Medical Tent.*

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