TECHNICAL REPORT
ME-3

AIR-SUPPORTED TENTS FOR MILITARY USE

by

Constantin J. Monego
MECHANICAL ENGINEERING DIVISION

July 1965

U. S. Army Materiel Command
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

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FOREWORD

The studies in this report were conducted by the Tentage and Equipage Branch, Mechanical Engineering Division, under Project Number 1K643303D54623. Mr. C. J. Monego served as Project Engineer.

The studies summarized in this report represent the development of air-supported tents as one approach taken by the Army to provide mobile shelters of reduced weight, cost and cubage. The report includes the factors which are considered in the development of these tents. In addition, study areas for future research in both tent design and tentage materials are indicated.

The report was prepared for the conference on Aerospace Expandable Structures, held 23, 24, 25 October 1963 in Dayton, Ohio, sponsored by the Air Force Propulsion Laboratory, Dayton, Ohio. The paper was presented at the conference and subsequently published in the transactions of this conference(1).

Acknowledgement is made to Mr. W. C. Whittlesey and Mr. C. W. Weikert of the Mechanical Engineering Division, U. S. Army Natick Laboratories, for their encouragement and support of this work. Acknowledgement is also accorded the personnel of the Engineering Laboratory for their assistance in setting up tests and obtaining test data; to the Clothing and Organic Materials Division for information on fabrics and coatings; and to the Bell Telephone Laboratories of Whippany, New Jersey, for their cooperation in furnishing electrical test data on the fabrics.

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ABSTRACT

The use of air-supported tents represents one approach taken by the Army to provide shelters of reduced weight, cost and cubage, which can be easily transported, erected and struck for more mobile Army operations.

The Army has developed several single- and double-wall, air-supported tents, some of which possess unique operational features difficult to obtain by other means of construction. One feature is the quick-release device for missile tentage, which provides the means for instant striking of the tent; another is the radar transparency of the thin skin structure, especially important for shelters covering tracking radar.

The shelters developed vary in shape and size, from spherical radomes to cover radar antennas to cylindrical tents with rounded ends to cover missiles on launchers. Information on the design of spherical radomes is adequately covered in the literature. Wind tunnel studies were conducted on the elongated tent to obtain design data for this type. As expected, it was found that the wind loading on the tent varied with the angle of wind apprcach. The tent inflated to "q" and in a steady, broadside wind, vibrated in phase. To stop this vibration, it was necessary to inflate the tent to 2 "q".

Wind tunnel studies are now underway to obtain information on a theoretical basis for the design of flexible air-supported tents of different shapes.

The properties of the fabrics developed for Army air-supported tents are given with specific reference to low temperature characteristics, weight, and electrical properties.

In the development of the fabrics, correlations are shown between dielectric constant and bulk density of textiles for both coated and uncoated fabrics. The elastic modulus of fabric obtained in uniaxial and biaxial stress are compared and discussed with possible implication to the design of air-supported tents. These are two of the problem areas in which further fabric investigations will be made.

AIR-SUPPORTED TENTS FOR MILITARY USE

1. Introduction

Modern scientific and technological developments made in military equipment and in support of a mobile army have resulted in the need for a new type of tentage. The need for the new tentage varies from highly specialized items for the missile program to large maintenance tents for ground vehicles and aircraft. Operational requirements for tents that most effectively support mobility concepts can be found in references 18 and 19, and may be summarized as follows:

Maximum utility space - To provide necessary work areas, unhampered by internal supporting poles and frames.

Lightweight, low bulk and cube - To increase transportability.

Minor maintenance and site requirements - To minimize logistical support.

Expandability - To reduce number and types.

Versatility and adaptability - To meet unique military field tentage requirements.

Easy and quick erecting and striking capability - To conserve time and manpower.

Protection capabilities - To protect field combat troops against environmental stresses and CB agents.

The use of air-supported tents, which can be easily transported, erected, and struck for more mobile Army operations, represents one approach taken by the Army to provide mobile shelters of reduced weight, cost, and cubage.

With the development of air-supported tents, the technology of tent making is developing step by step from a traditional craft to a branch of scientific engineering. This is a parallel development: Production engineering and scientific design. These two are interdependent for progress and support; the tents cannot be fabricated without materials--materials cannot be developed without knowing the end use conditions of the tent.

Development engineering is defined as the building of prototypes meeting user requirements. Scientific design is defined as the design of the tent--the starting point of development engineering--including research and development on structures and materials which will produce an end item suitable to meet the operating characteristics required for Army operations.

It is the intent of this paper to present both development engineering and the scientific design of air-supported Army tents. The development engineering phase will be covered by a brief discussion of some of the air-supported tents developed for the military. The scientific design phase will be covered by discussing some of the interesting aspects of the work leading to the development of air-supported tents, and pointing out areas which require additional research and development.

2. Production Design for Air-Supported Tents

In this portion of the report, some of the air-supported tents developed for the military will be described along with information relative to background, unique features, and pertinent test data. The development and testing of the air-supported tents can logically be divided in three phases:

a. An exploratory study of the development and testing of air-inflatable structures.

b. Development of special-purpose tents in support of the missile program--single-wall, air-supported tents.

c. Development of maintenance tents--double-wall, air-supported tents for Army vehicles and missiles.

(1) Exploratory Study

Under the exploratory study, two tents will be discussed: A one-man mountain tent developed for the Army and a 20 x 40 inflatable air-matt maintenance tent developed for the Air Force.

(a) One-Man Mountain Tent (Inflatable)

This tent was developed to meet the need for a self-contained unit which could be easily and quickly erected under extreme cold and high winds. The tent (Fig. 1) developed for the Army(21) measures 2 feet 11 inches wide, 7 feet 7 inches long, 3 feet 2 inches

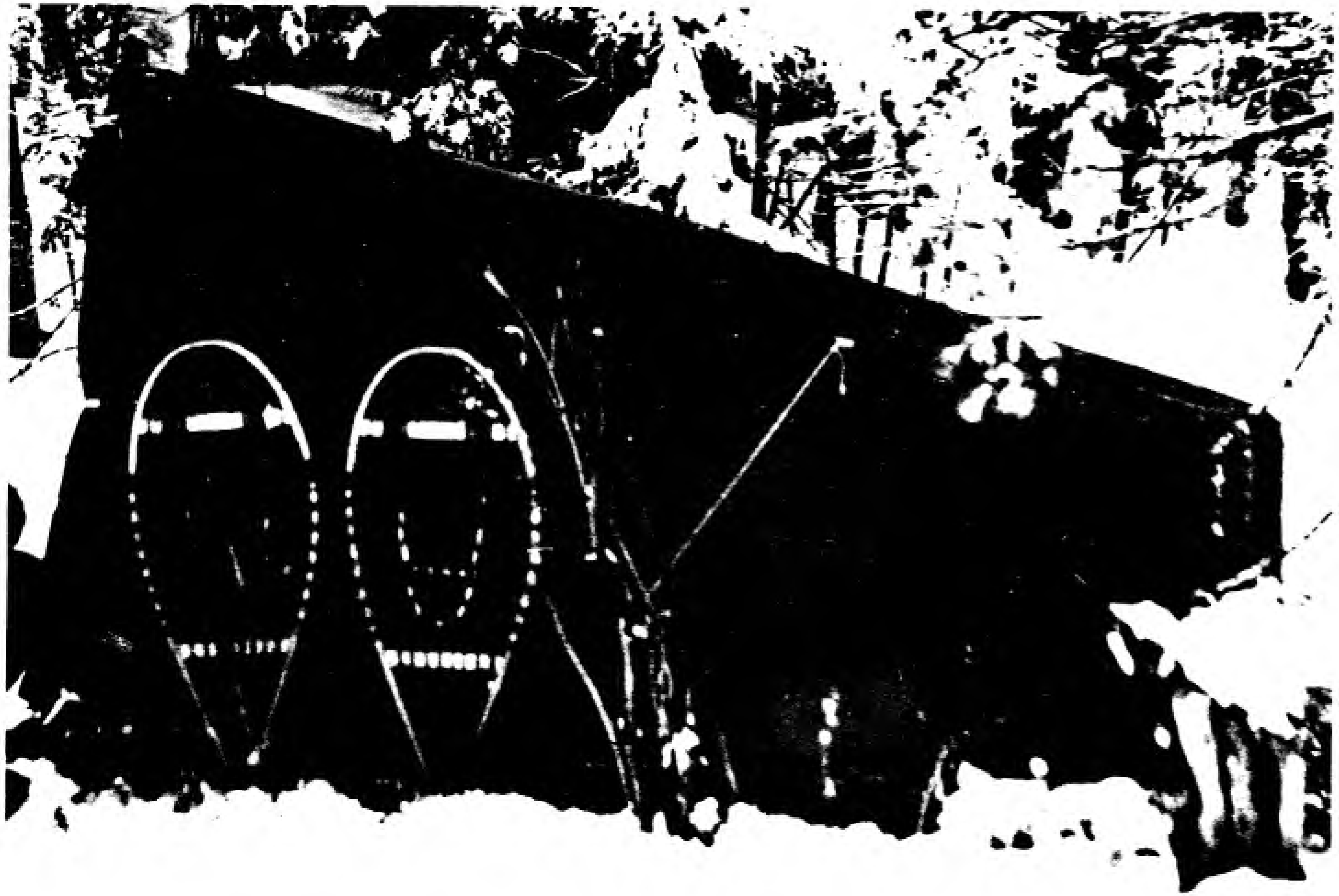

Figure 1. One-Man Mountain Tent (Inflatable)

high in front decreasing to a width of 1 foot 9 inches, and a height of 1 foot 4 inches in the rear. It weighs 14 pounds. The tent consists of an A-shaped frame made from three inflatable tubes running down the front and across the ridge. The tent was tested at Mount Washington, New Hampshire, during the winter of 1949-50. As a result of tests, the tent was found to be too heavy and bulky for its intended use. In addition, after two weeks of use in cold weather, the inflated beams developed minute air leaks at almost every seam and corner, requiring frequent reinflation to keep the tent erect.

(b) Shelter, Inflatable, 20 x 40

This tent was developed by the Air Force as a maintenance shelter(15). The tent (Fig. 2) was constructed of air-matt material 3 inches thick when inflated. It covered an area 20 feet wide by 40 feet long. The tent was tested at Fort Churchill, Manitoba, Canada, during the winter of 1953-54 and Mount Washington, New Hampshire, during the winter of 1954-55. This tent, when compared to the same size standard frame-type tent, was lighter in weight, more compact, and easier to transport and erect. However, the tent required more fuel to heat than an insulated frame-type tent and was not considered sufficiently durable for field operations in cold weather. The air-matt material from which the tent was made became too stiff and developed minute air leaks which were difficult and in some instances impossible to locate and repair.

The two field trials on air-inflatable tents provided the following information:

(a) The full benefit of air-supported structures cannot be realized in small personnel tentage--one- and two-man tents; it can only be realized in larger maintenance and special-purpose tentage needed to meet specific operational requirements.

(b) The tents tested lacked the durability required for Army field operations. Nevertheless, it was considered that the principle inherent with air-supported tents; i.e., low weight, bulk and ease of erection, possessed sufficient merit to warrant further development. Accordingly, the Army entered into the second phase of its development of air-supported structures.

(2) Development of Special-Purpose Tents

The second phase consisted of the development of single-wall tents to meet specific Army requirements in support of the missile

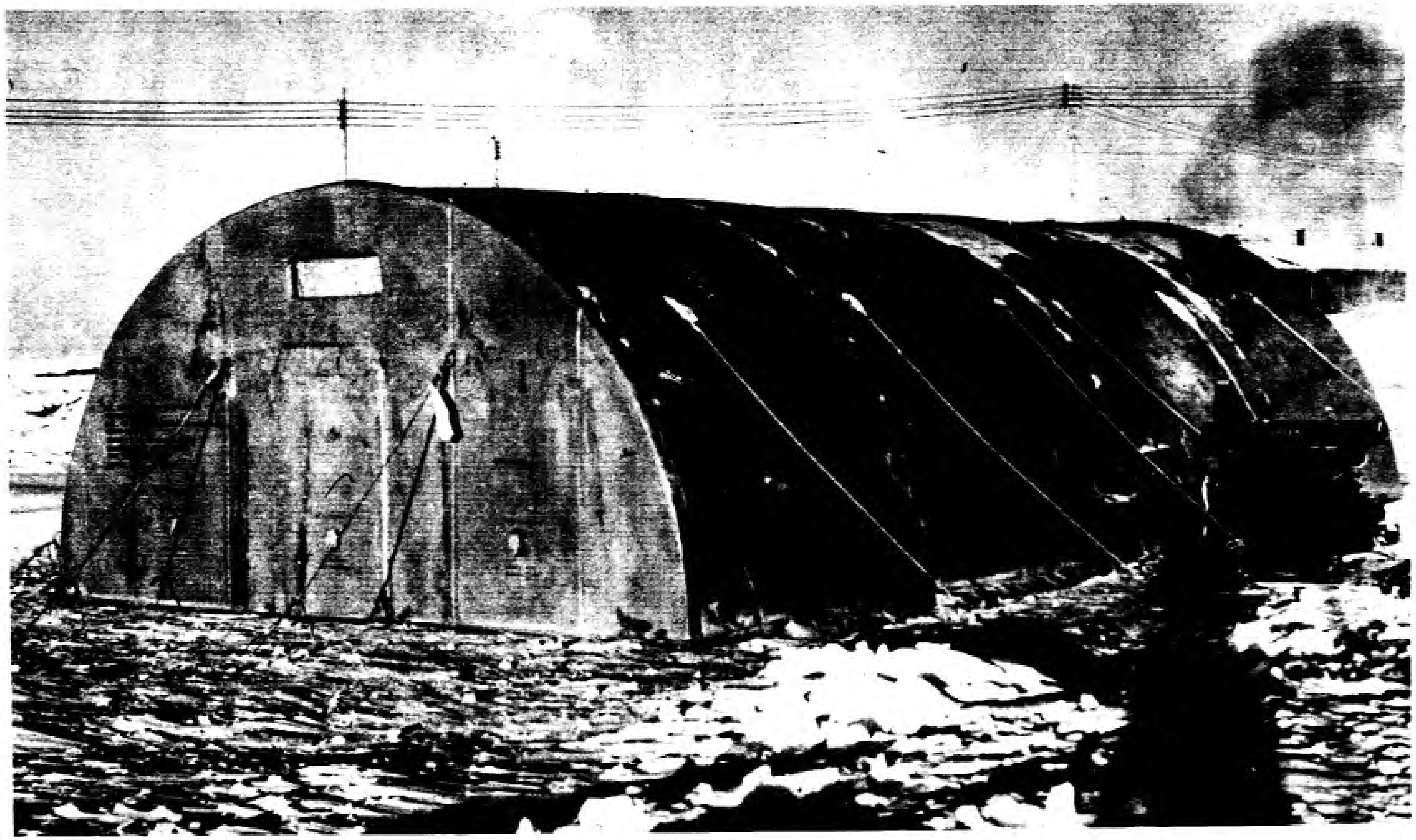

Figure 2. Shelter, Inflatable, 20' x 40'

program. These tents possessed unique operational features difficult to obtain by other means of construction and certainly could not be met with conventional tentage of the pin, pole or frame type. One feature is the quick-release mechanism, which provides the means for instant striking of the tent. The quick-release device (Fig. 3 and 4) utilizes a heavy-duty slide fastener and lanyard. A quick pull on the lanyard opens the tent in halves, taking advantage of the inflation pressure to throw the sides back and away from the equipment. A second feature is radar transparency of the thin skin structure, which is especially important for shelters covering tracking radar.

Missile shelters are required to protect the missiles and sensitive electronic radar equipment against the damaging effect of wind, rain, and snow; also, to shelter maintenance crews performing routine check-out services as well as maintenance operations.

Six tents, based on the single-wall, air-support principle, will be discussed. These are as follows: Shelter, Air-Supported, Vertical Check-Out (Redstone); Tent, Nike Hercules, Air-Supported; Tent, Air-Supported, Nike Hercules Launch Area for Field Army; Tent, Air-Supported Launcher, Hawk System; Tent, Radome for Track Antenna and Acquisition Radar Sets; Tent, Air-Supported, Storage Type.

(a) Shelter, Air-Supported, Vertical Check-Out (Redstone)

This tent was developed to provide all-weather protection for the missile and personnel performing check-out operations(10, 18). The shelter (Fig. 5) measures 24 feet in diameter and stands 18 feet 6 inches high. This tent met all the requirements for attachment and rapid erection and removal, and provided full protection against weather including winds up to 40 mph. It is so designed that it can be attached while the missile is horizontal, raised to a vertical position, and inflated within 4 minutes. The shelter can be released from the missile by pulling a cord which disconnects the shelter and allows it to drop to the ground away from the launching pad in two to three seconds.

This development constituted an exploratory effort in an area never before attempted--the enclosure of a missile thrust unit within an air-supported structure. The scientific and technical gains have contributed to the successful development of the other air-supported tents which follow.

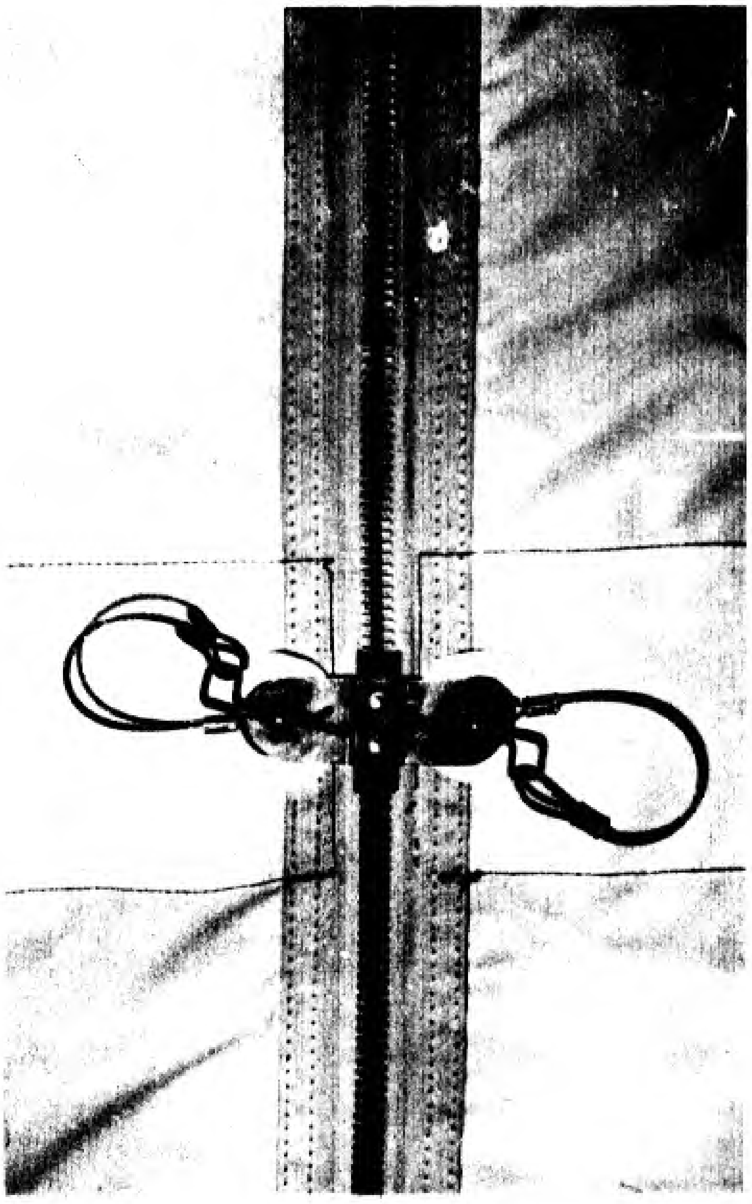

Figure 3. Quick-Release and Slide Fastener (Closed)

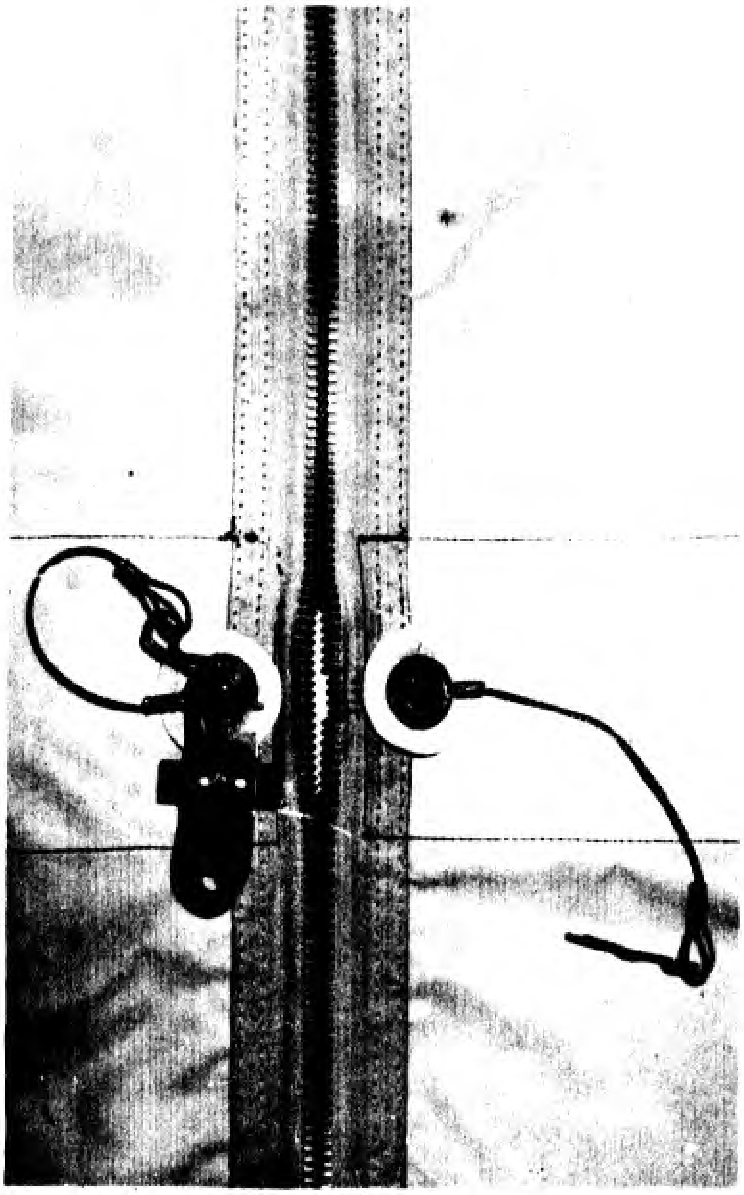

Figure 4. Quick-Release and Slide Fastener (Opened)

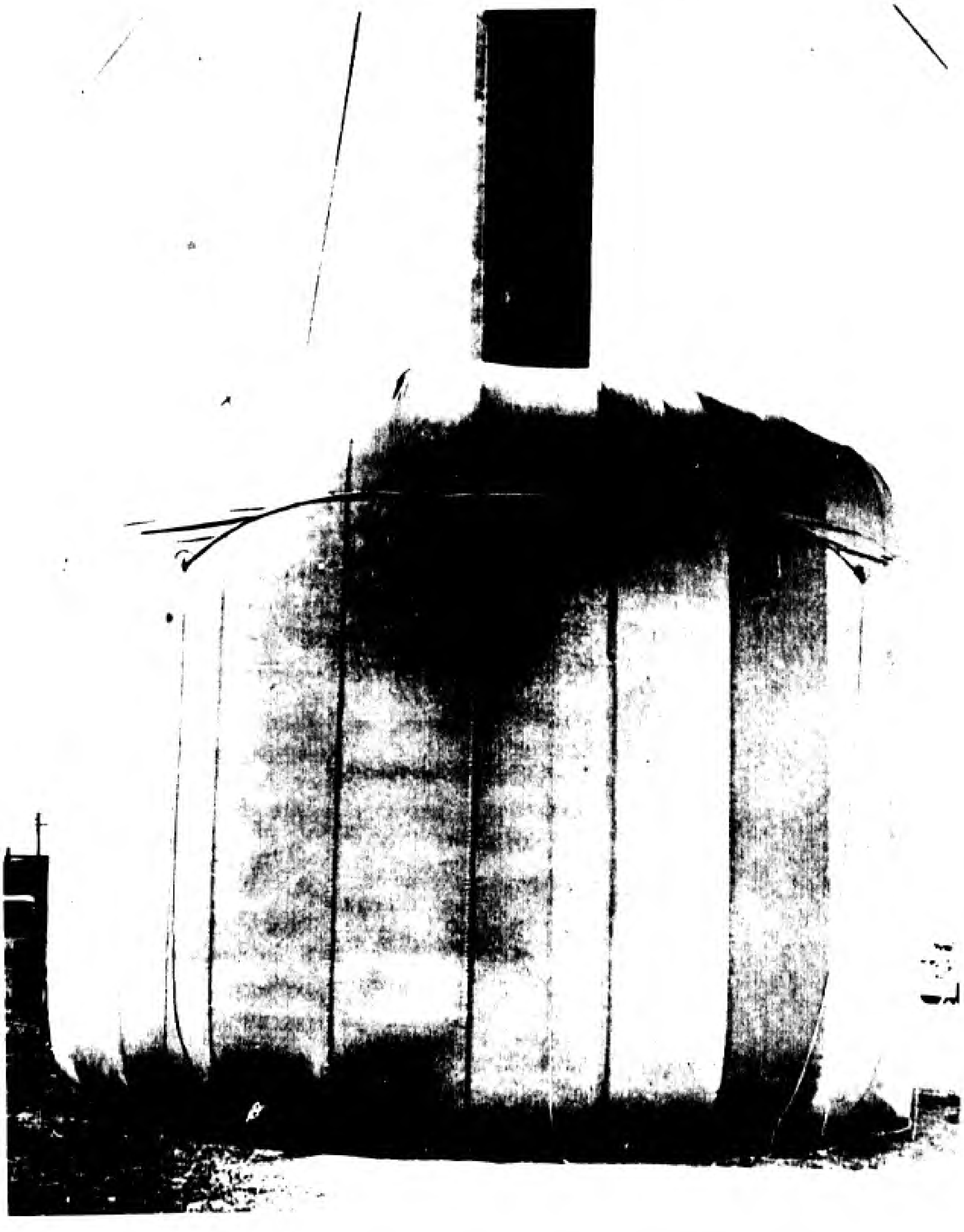

Figure 5. Shelter, Air-Supported, Vertical Checkout (Redstone)

(b) Tent, Nike Hercules, Air-Supported

This tent (Fig. 6) was developed to provide all-weather protection for the missile on the launcher and to shelter personnel performing check-out and maintenance services on the missile and launcher (18, 19). The tent measures 17 feet 6 inches in diameter and is 61 feet long and 13 feet high. The tent is designed to be installed on a recessed base, located between abutments, so that it will be partially protected from the full impact of the wind. This tent is equipped with a quick-release device which is manually activated by pulling a lanyard. A quick pull of the lanyard allows the shelter to split in two halves along its entire length, falling away from the missile in 1 to 2 seconds.

(c) Tent, Air-Supported, Nike Hercules Launch Area, for Field Army

This tent was developed to provide protection to personnel while performing maintenance and check-out services on the missiles on the launcher and to provide space for two additional missiles on the racks (19). This tent (Fig. 7) measures 40 feet wide, 70 feet long, and 20 feet high. The tent is equipped with a manually activated quick-release device which permits striking the tent in approximately 3 seconds. The development on this tent is completed and prototype tents are being fabricated.

(d) Tent, Air-Supported, Launcher, Hawk System

This tent (Fig. 8) was developed to provide cold climate protection to the Hawk Missile on the launcher and to operating personnel performing check-out and maintenance services (19). This tent is a 3/4 sphere, 28 feet in diameter and 21 feet 6 inches high. The tent consists of an outside envelope and an inside shell with an insulating air space between. The tent is erected over the Hawk launcher and the missile is fired directly through the tent.

(e) This tent (Fig.9) was developed to provide all-weather protection for both acquisition and tracking antenna. The tent is a 3/4 sphere, 27 feet in diameter and approximately 20 feet high (18). It is adaptable to both tower and ground mounts on a specially prepared base. The radome is equipped with a quick-release fastener which is manually activated by pulling a lanyard, which divides the tent in two halves completely uncovering the antenna.

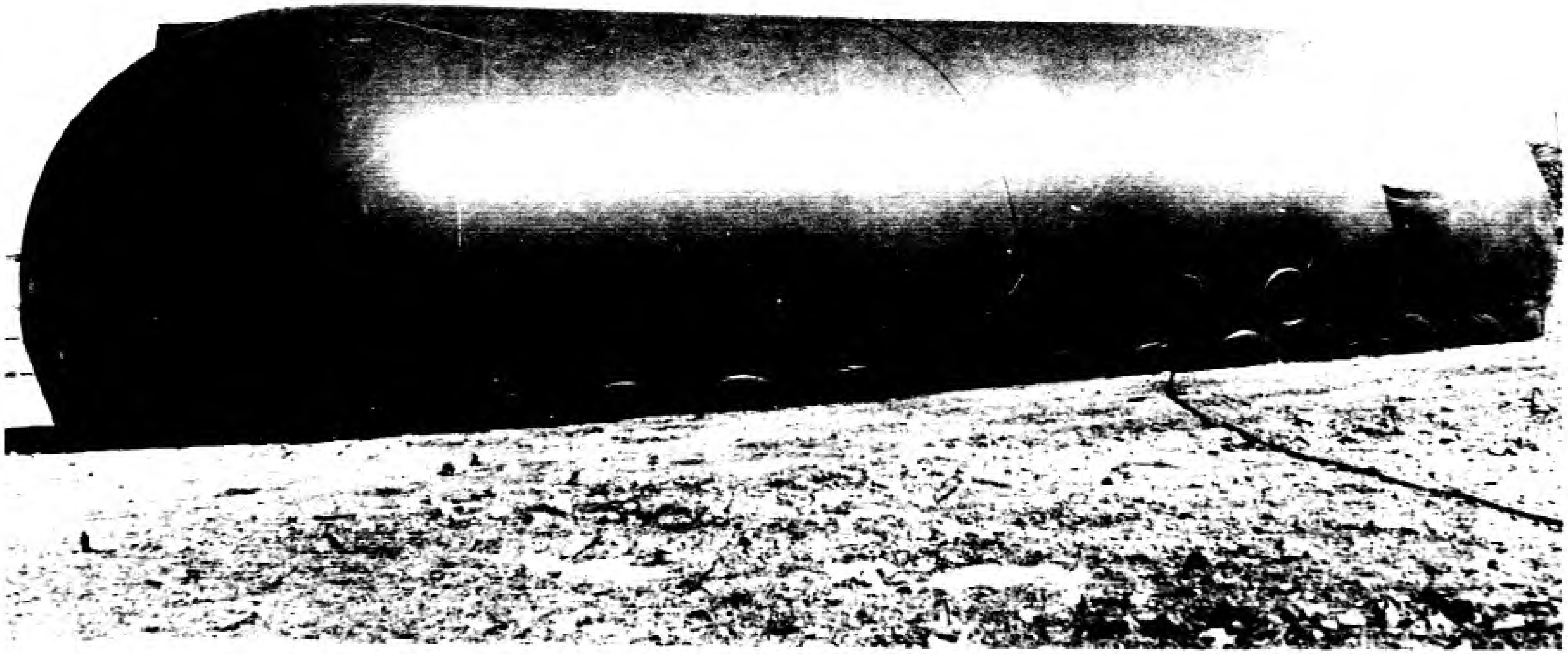

Figure 6. Tent, Nike Hercules, Air-Supported

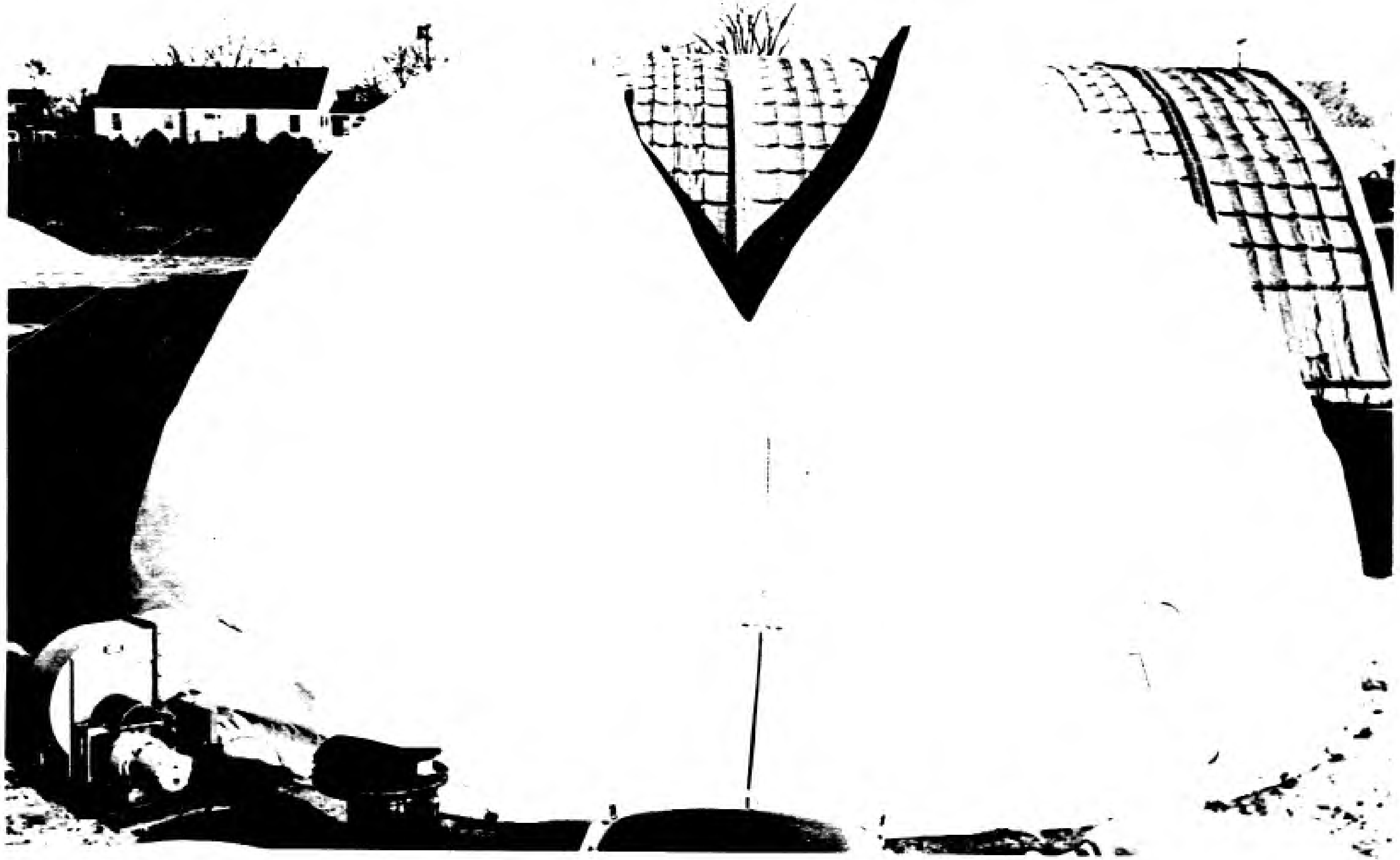

Figure 7. Tent, Air-Supported, Nike Hercules Launch Area, for Field Army

Figure 8. Tent, Air-Supported, Launcher, Hawk System

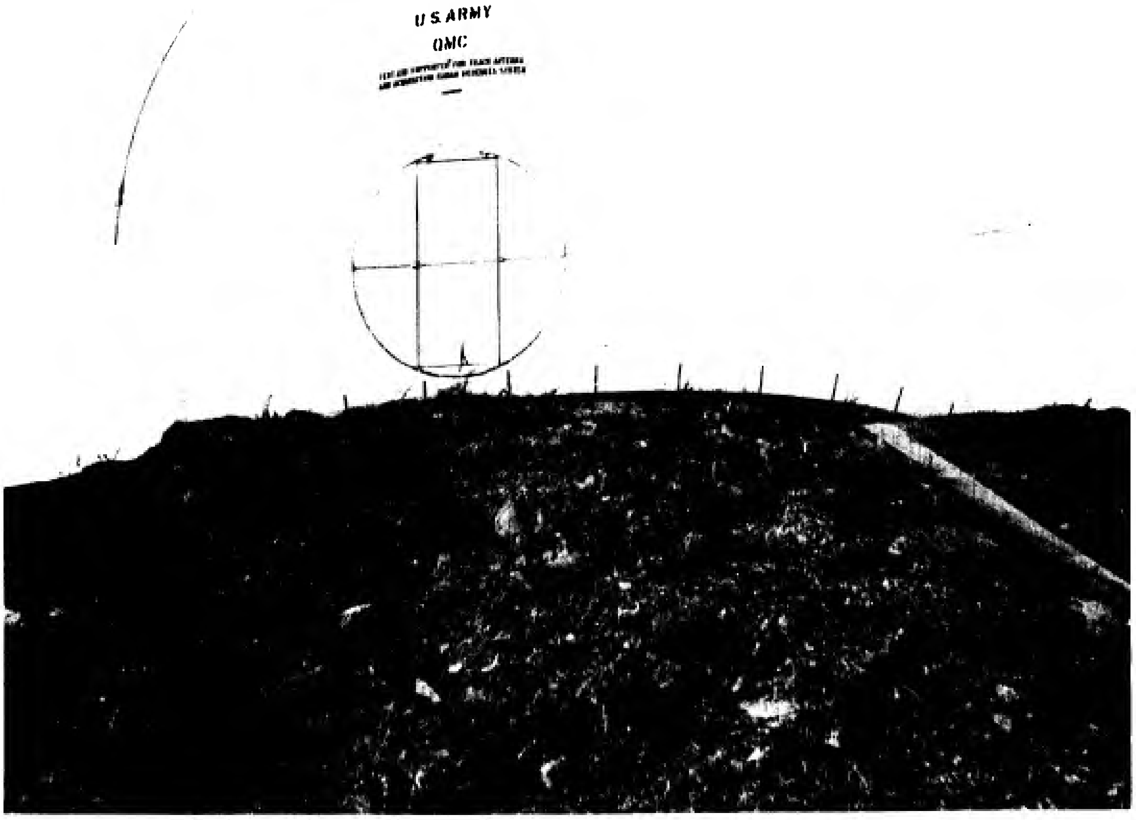

Figure 9. Tent, Radome, Air-Supported, for Track Antenna and Acquisition Radar Sets

This feature was felt necessary in the event of operational interference caused by certain environmental conditions, such as the sudden formation of ice, or the radome skin being wet from dew or rain. This device makes it possible to remove the radome quickly without interrupting sensitive tracking operations.

(f) Tent, Air-Supported, Storage Type

This tent (Fig. 10) was procured because of the Army's interest in using air-supported tents for warehouses (18). The tent measured 40 feet wide, 80 feet long, and 15 feet high.

The tents were erected and tested in the New England area for extensive periods. They have demonstrated their capacity to withstand wind, snow, and degradation from the elements. Even though the tents were developed as an air-supported structure, this tent, when deflated, may be utilized as a tarpaulin to protect critical supplies and materiel in outside storage areas. It can be quickly inflated by blowers so that individuals and materials handling equipment will have access to supplies when necessary.

(3) Maintenance and Double-Wall Tents

Tents based on the single-wall, air-support principle, while successful in meeting special military requirements, have an obvious drawback for use as maintenance tents. This drawback is the need for special doors and air locks to permit entry and exit of large vehicles for maintenance work. Accordingly, concurrent with the development of single wall tents, the Army entered into the third phase of the development of double-wall, air-supported tents. The advantages of these tents for maintenance work are obvious. The supporting air is contained between two walls, forming the sides and roof of the tent, leaving wide open ends for entry of vehicles. Three tents of this type will be discussed: (1) Tent Set, Vehicle Maintenance, Small, Air-Supported for Arctic Use; (2) Tent, Maintenance, Multi-Purpose, Inflatable, Sectionalized; and (3) Tent, Air-Supported, Double-Wall, Assembly Area, Nike Hercules, Mobile System.

(a) Tent Set, Vehicle Maintenance, Small, Air-Supported for Arctic Use

This tent (Fig. 11) was developed as a portable tent to be carried by maintenance personnel to a disabled vehicle in the field (19).

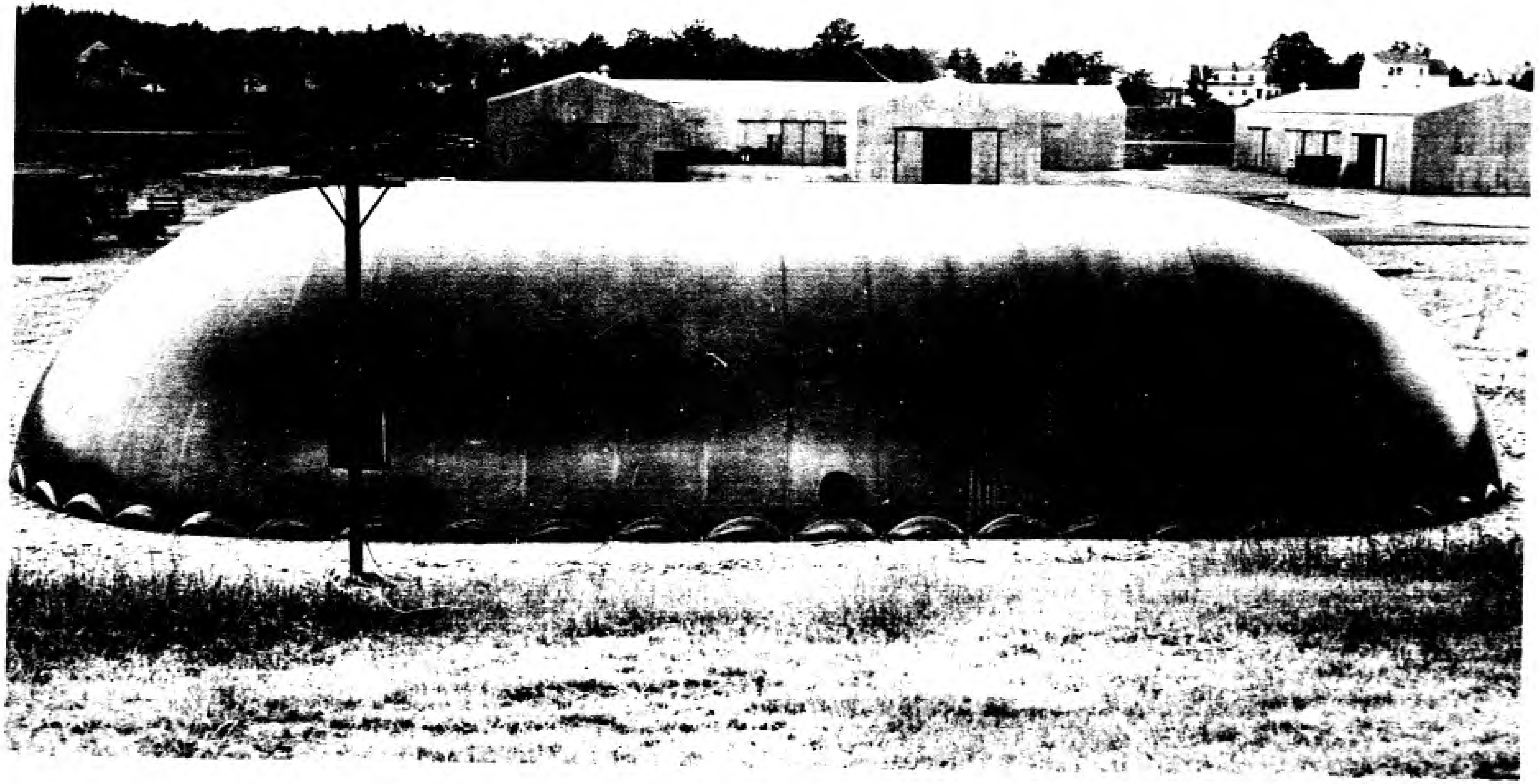

Figure 10. Tent, Air-Supported, Storage Type

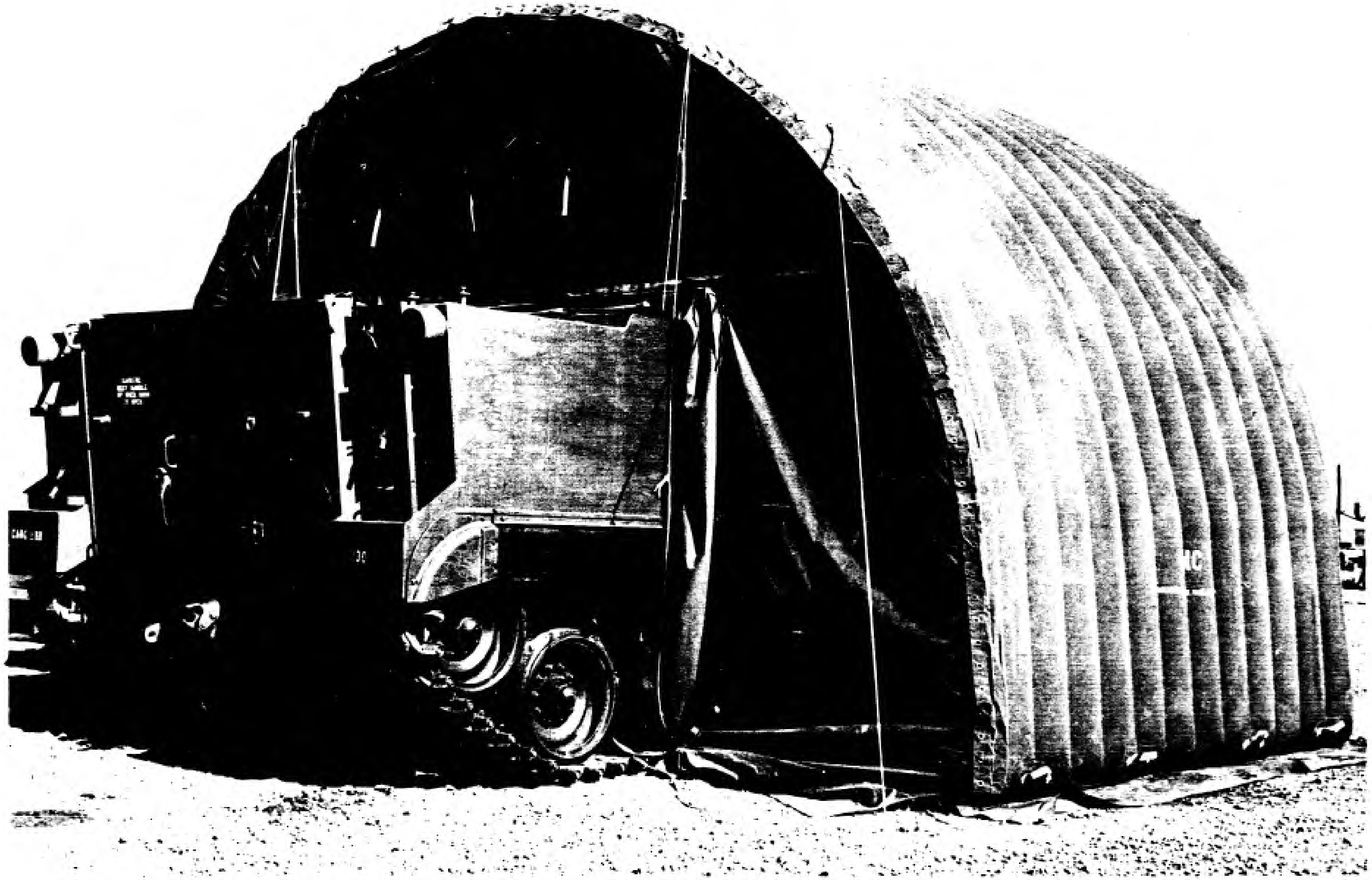

Figure 11. Tent, Set, Vehicle, Maintenance, Small, Air-Supported for Arctic Use

The dimensions of the tent are 20 feet wide, 13 feet long, and 12 feet 6 inches high. The sides and roof of the tent are double-wall construction with the walls 20 inches thick. The end curtains are single wall. The tent is of the nose-in maintenance type. It provides protection to the maintenance crews in cold climates. The tent is equipped with fitted end curtains for each of the vehicles it will service.

(b) Tent, Maintenance, Multi-Purpose, Air-Supported, Sectionalized

This tent (Fig. 12) was developed to cover the entire Pershing Missile during maintenance and check out under cold weather conditions (19). The dimensions of the full size tent are 20 feet wide, 52 feet long, and 12 feet 6 inches high. The tent consists of four units of the Tent Set, Vehicle Maintenance, Small (Fig. 11), butted and fastened together. This tent has been made a component of the Pershing Missile System. Shelters are currently being procured for the Pershing System.

(c) Tent, Air-Supported, Double-Wall, Assembly Area, Nike Hercules Mobile System

The tent (Fig. 13) was developed to house the Nike Hercules missile and missile components, and to shelter personnel while performing the war heading and assembly of missiles (19). The dimensions are 48 feet wide, 72 feet long, and 24 feet high. The tent consists of six 12-foot sections joined with catenary and collar fasteners which permits personnel to join the section in cold weather while wearing Arctic clothing. The sections are hemi-cylindrical in shape and double-wall construction with the walls three feet thick. The end curtains are of single-wall construction. Each end curtain contains personnel and utility doors. This tent has been standardized as a component of the Nike Hercules Mobile System.

With the development of the Nike Hercules Assembly Area Tent, it was found that double-wall tents, 48 feet wide, are practical. The Army is currently considering the feasibility of extending the width of the double-wall tents to 110 feet for use as aircraft maintenance hangars when a requirement for this type shelter is established.

3. Scientific Design of Material For Air-Supported Tents

In completing the description of the air-supported tents developed for Army use, the production engineering phase is concluded.

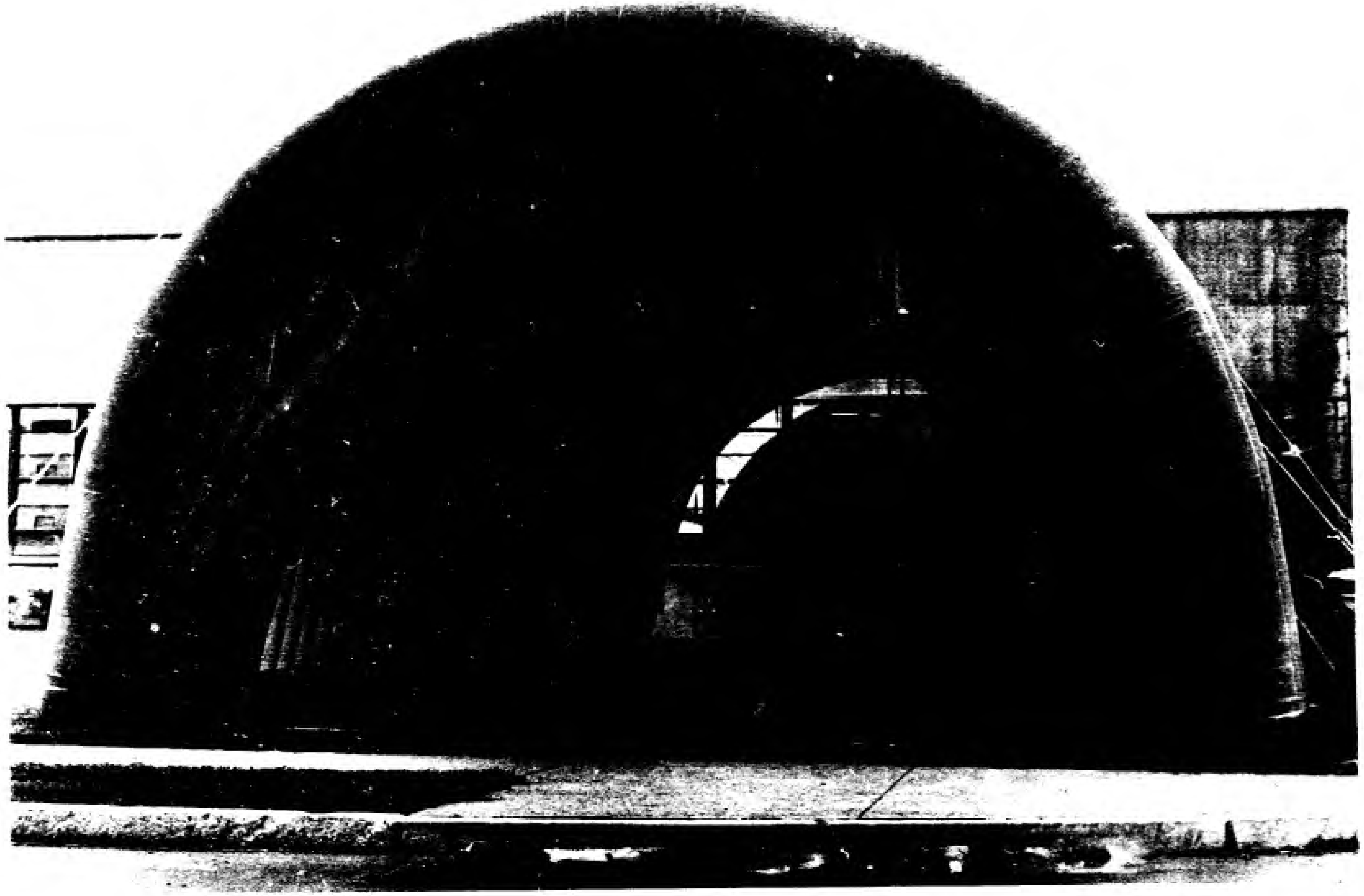

Figure 12. Tent, Maintenance, Multi-Purpose, Air-Supported, Sectionalized

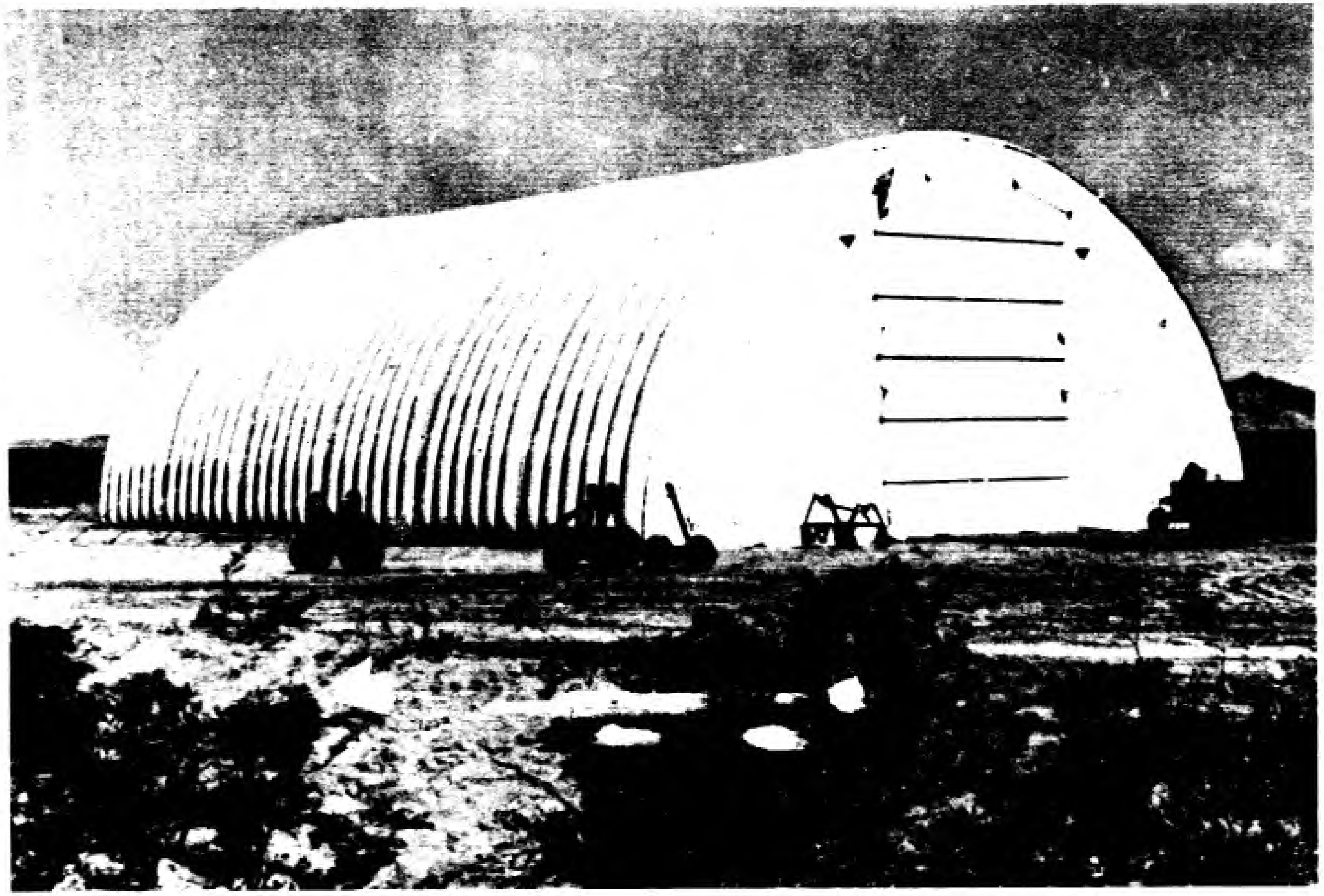

Figure 13. Tent, Air-Supported, Double-Wall, Assembly Area, Nike Hercules Mobile System

Naturally, one is curious to know more about the factors which were considered in the development of these tents. The information in support of production engineering is scientific design. It is in this area that observations were made which is felt should be shared with all agencies interested in the development of air-supported tents. These observations are limited to the following investigations:

a. Effect of shape on the aerodynamic behavior of a tent.

b. Fabrics used by the Army.

c. Discussion of some fabric properties considered important in the development of air-supported tents; i.e., weight, flexibility at low temperatures, and dielectric constant.

(1) Effect of Shape on the Aerodynamic Behavior of a Tent

As noted, the air-supported tents developed for the Army vary in shape and size from spherical radome to cover radar antenna to cylindrical tents with rounded or flat ends to cover missiles or for use as maintenance tents. Information on the design of these shelters was obtained from available sources (2,3,4,5, and 8). While the spherically-shaped radome has been subjected to aerodynamic testing from which a design manual has evolved (4), no such progress has been made for other shapes. Information for the design of Army air-supported tents of other than spherical structures was assembled from engineering data obtained from other sources (3,5, and 8).

To obtain aerodynamic data on flexible, cylindrical, air-supported tents, a limited wind tunnel study was conducted at Massachusetts Institute of Technology. The model selected for test was a 1/10th scale Tent, Nike Hercules, Air-Supported. The interesting aspects of the report of test can be summarized here.

The first of these was the development of scaling parameters (2). It was found in planning the test that the design of a model flexible air-supported tent is more complicated than a normal rigid wind tunnel model, whose shape is stable. To obtain aerodynamic and dynamic similarity between full-scale and model tents, the following parameters had to be kept the same:

Geometric shape - no wind

Inflation parameter - $\frac{\text{Inflation Pressure}}{\text{Stream Dynamic Pressure}}$

$$\text{Mach Number} = \frac{\text{Test Velocity}}{\text{Velocity of Sound}}$$

$$\text{Reynolds Number} = \frac{\text{Diameter} \times \text{Velocity}}{\text{Kinematic Viscosity}}$$

$$\text{Aeroelastic parameter} = \frac{\text{Diameter} \times \text{Fabric Elongation} \times \text{Dynamic Pressure}}{\text{Fabric Stress}}$$

$$\text{Dynamic parameter} = \frac{\text{Mass of Tent}}{\text{Air Density} \times (\text{Diameter})^3}$$

Of the above parameters those which were considered of paramount importance were: Shape, aeroelastic parameter, which is related to the stiffness of the fabric, and the dynamic parameter, which is related to fabric weight. From experience, it was known that Mach Number effects are small for cylindrical bodies with rounded ends below values of 0.25 or 150 miles per hour at sea level in air.

The Reynolds Number determines the flow pattern as it is influenced by viscous effects. Again, from experimental work, the major variation of flow usually occurs below certain values of this parameter. If one stays well above such a value, little change in the flow pattern will take place over a large variation of the parameter, and lends considerable weight in the application of the model results to full scale.

The inflation parameter is important for tent stability. From literature on air-supported radomes (4), this value is usually taken as 1; i.e., inflation pressure equal to the dynamic pressure of the air stream. In the following discussion, this value will be designated as "q".

The second interesting aspect of this study was the tent motion in the air stream. At inflation pressures below one dynamic pressure or "q", the air stream led to large deflection. For a quartering wind (Fig. 14--tent, no wind), and an inflation pressure of 1 "q", the lateral deflection of the midregion of the upstream side was about 10% of the tent diameter; for 2/3 "q", the tent flapped and the deflection was about doubled (Fig. 15). At an angle of 45 degrees, and with a 105-mile per hour wind, the tent quivered at inflation pressures of 5/4 "q" and 1 "q", but shook violently at 2/3 "q".

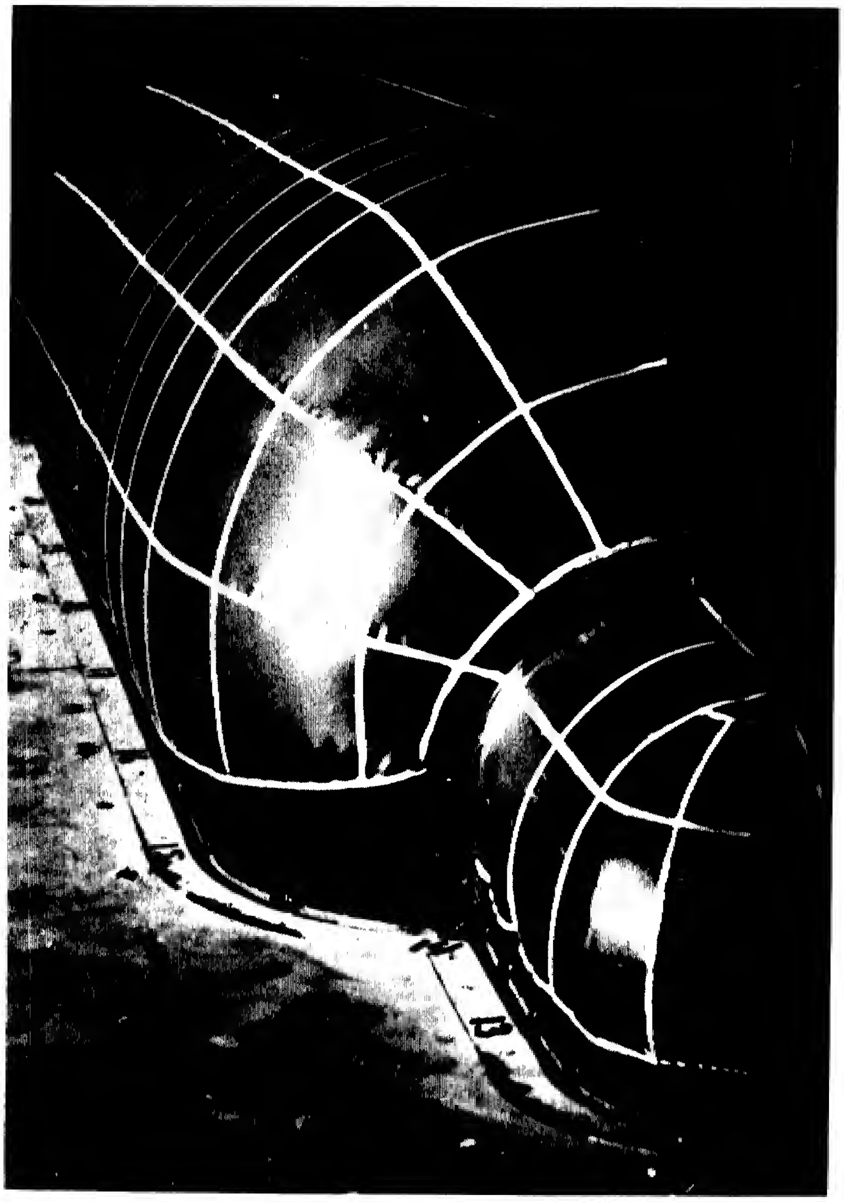

Figure 14. Wind Tunnel Test, No Wind

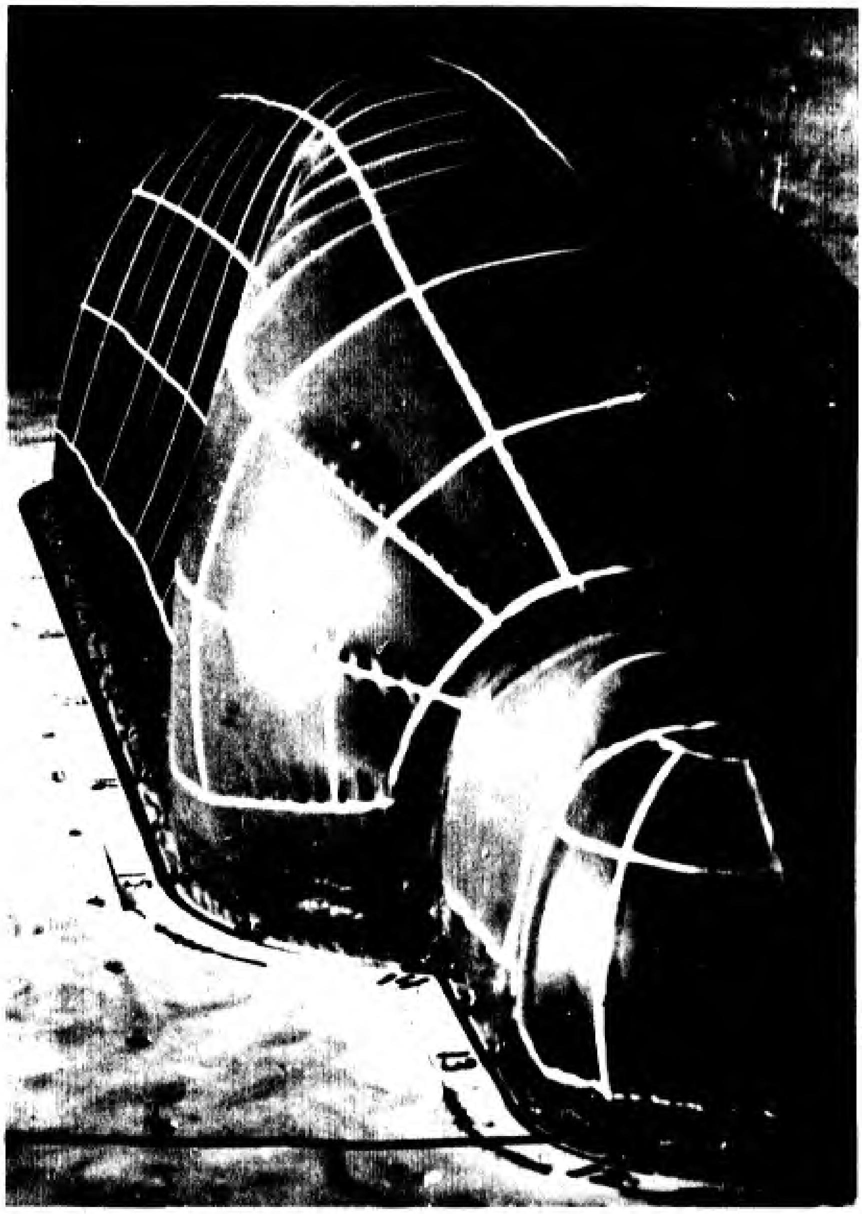

Figure 15. Wind Tunnel Test - Inflation Pressure 2/3 q, Quartering Wind

The importance of wind direction on the aerodynamic behavior of the tent cannot be emphasized too strongly. With the wind approach broadside, it was necessary to overinflate the tent 5/4 "q" to maintain stability. At 1 "q", the tent flapped violently in a periodic manner and the test could not be run at 2/3 "q". With the wind approaching the tent at angles of 135 degrees and 180 degrees, no serious motions were apparent even at the low internal pressure of 2/3 "q".

The initial wind tunnel tests were run without a zipper in the model tent. Tests were rerun with a quick-release zipper installed in the tent. The zipper installation decreased the violence of the tent motions considerably. The tent could be run broadside to the wind at 85 miles per hour with an inflation pressure of 2/3 "q". It is not known whether the air leakage through the zipper, the change in the elastic properties of the tent, the change in the inertial properties, or a combination of properties, is responsible for the improvement. The air leakage was larger than a scaled value should be because of the model zipper size. What effect this would have is also unknown.

A review of the motion picture film taken for various test conditions and tent configurations leave the viewer with a deep appreciation of the aerodynamic effects and the necessity for making allowances in the tent design to account for these effects. From these pictures, it may be concluded that inflation pressures below 1 "q" lead to serious deflections, shaking, and transient denting of the tent. In most cases, an increase in inflation pressure to 1 "q" decreases the aerodynamic effects from violent to perhaps tolerable magnitudes. Thus, the only means at hand to reduce tent vibration and flapping is to increase the internal pressure. However, work in this area has indicated that the use of spoilers or other surface modifications of the tent will improve its operational characteristics. Further research work in this area should be expanded.

The third aspect of the study is the variations in aerodynamic and anchor loads experienced with the winds approaching the tent from different angles. As expected, the lowest lift or drag loads occur with the bow or stem end facing the wind. With the bow or stem facing the wind, the over-all lift coefficient averages approximately .15 and the over-all drag coefficient approximately .06. The over-all lift coefficient increases to .75 for wind striking the tent at 135 degrees, while the over-all drag coefficient increases to .65 with the wind striking the tent broadside. Here the aerodynamic forces show a five-fold increase in lift, and nearly double this in drag, merely from the standpoint of the wind direction. How this increase in load is being dissipated by the fabric in a tent of this shape should be further investigated.

This change in loading due to the direction of wind approach is also found in the load distribution on the anchors around the tent. Fig. 16 shows the pattern of anchor loads found with the bow of the tent facing the wind. The "X" on the chart represents the anchor loads resulting from internal pressure only; the circles represent the combined load due to internal pressure and 85 mph wind. It should be noted that only those anchors around the bow and stem end appear to show an increase in load. Fig. 17 shows the pattern found with the wind approaching the tent at 135 degrees. As expected, the pattern of anchor load distributed is different in both location and magnitude.

From the standpoint of design, it was found that for this shape tent, the maximum anchor loads are about twice the average value found from the sum of inflation and lift loads. Investigation on the anchor loads for tents of other shapes is warranted. It was concluded from the above that the aerodynamic behavior of cylindrically shaped tents is sufficiently different from those reported for radomes (4) and that design information on tents of other shapes was required. Accordingly, a new study was implemented to obtain information on a theoretical basis for the design of flexible air-supported tents of the shapes shown on Fig. 18.

It is hoped that the tent shapes proposed for test will permit extrapolation of test data not only for height of the shelter; i.e., 3/8, 1/2, or 3/4 sphere or cylinder, but for length on the basis of length-to-width ratio. The new study contains a requirement for the development of fabric stress data which was not included in the Massachusetts Institute of Technology work (3). Hopefully, the design data developed in this new program will establish parameters for fabric stress which, in turn, may be used as a basis for engineering fabrics to meet the specific requirements for air-supported tents. Fabrics of efficient design should result in improved shelter performance at minimum weight and cost.

(2) Fabrics Used by the Army

The fabrics used in the fabrication of the Army air-supported tents are shown in Table I.

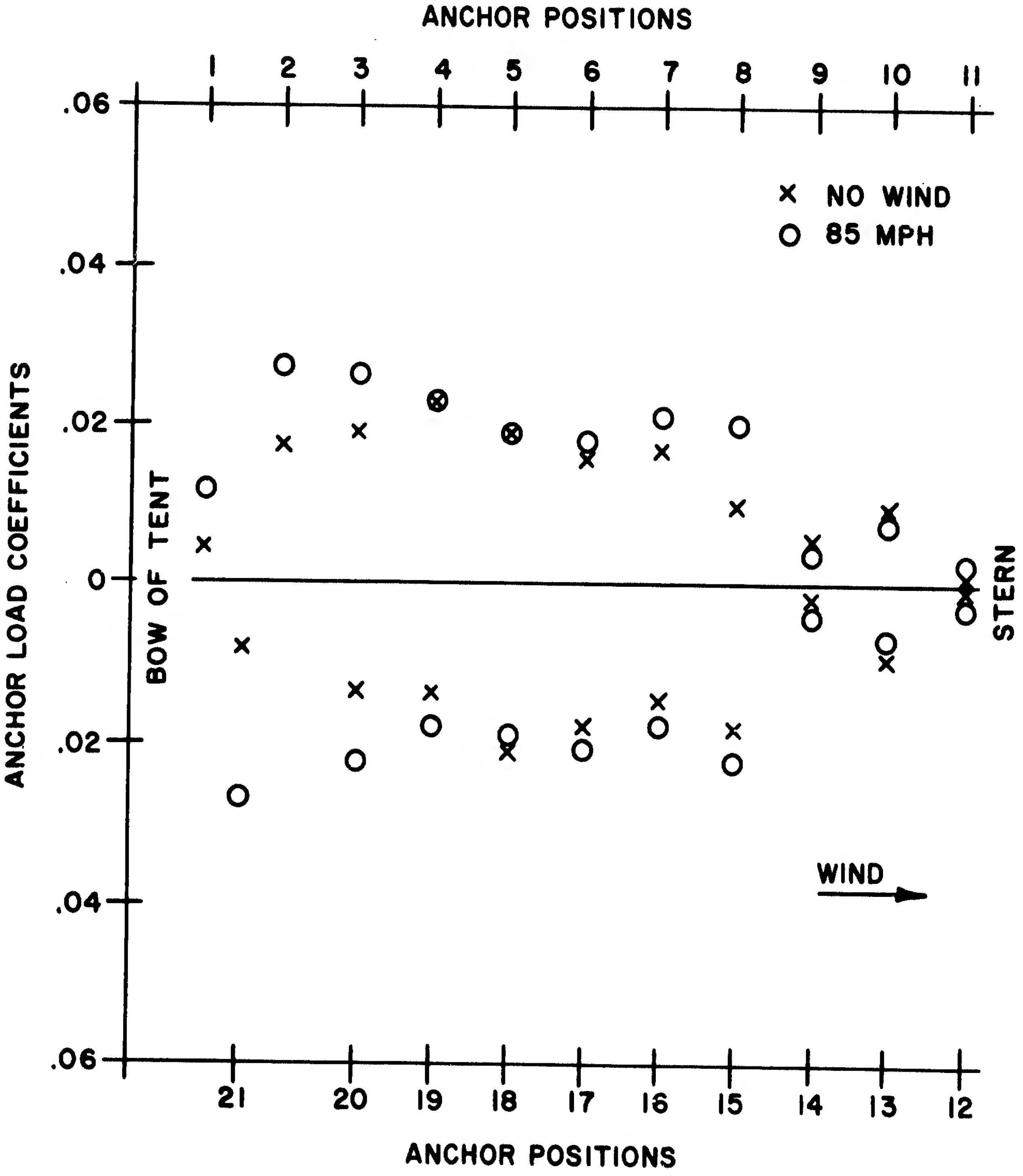

Figure 16. Anchor Loads

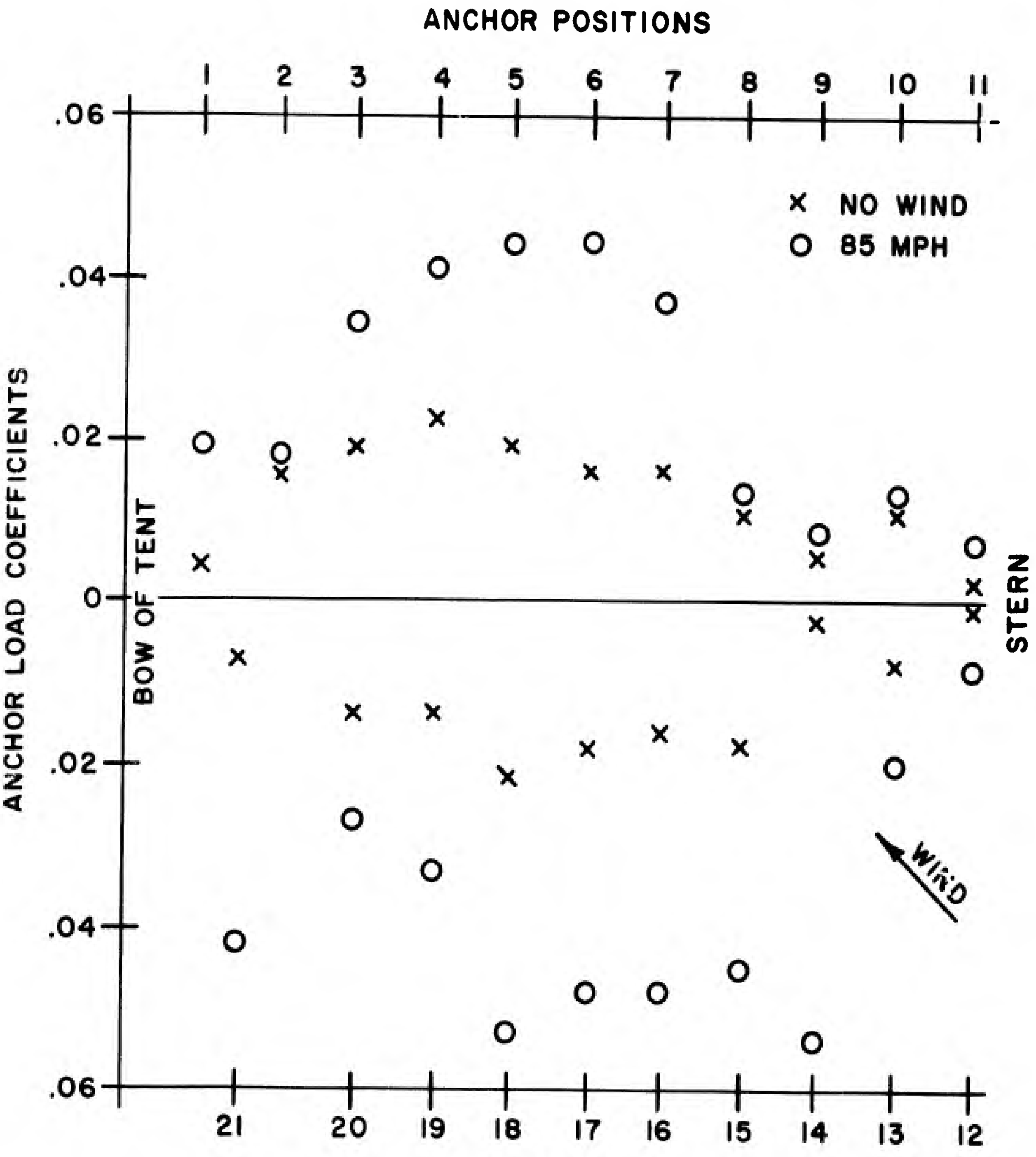

Figure 17. Anchor Loads

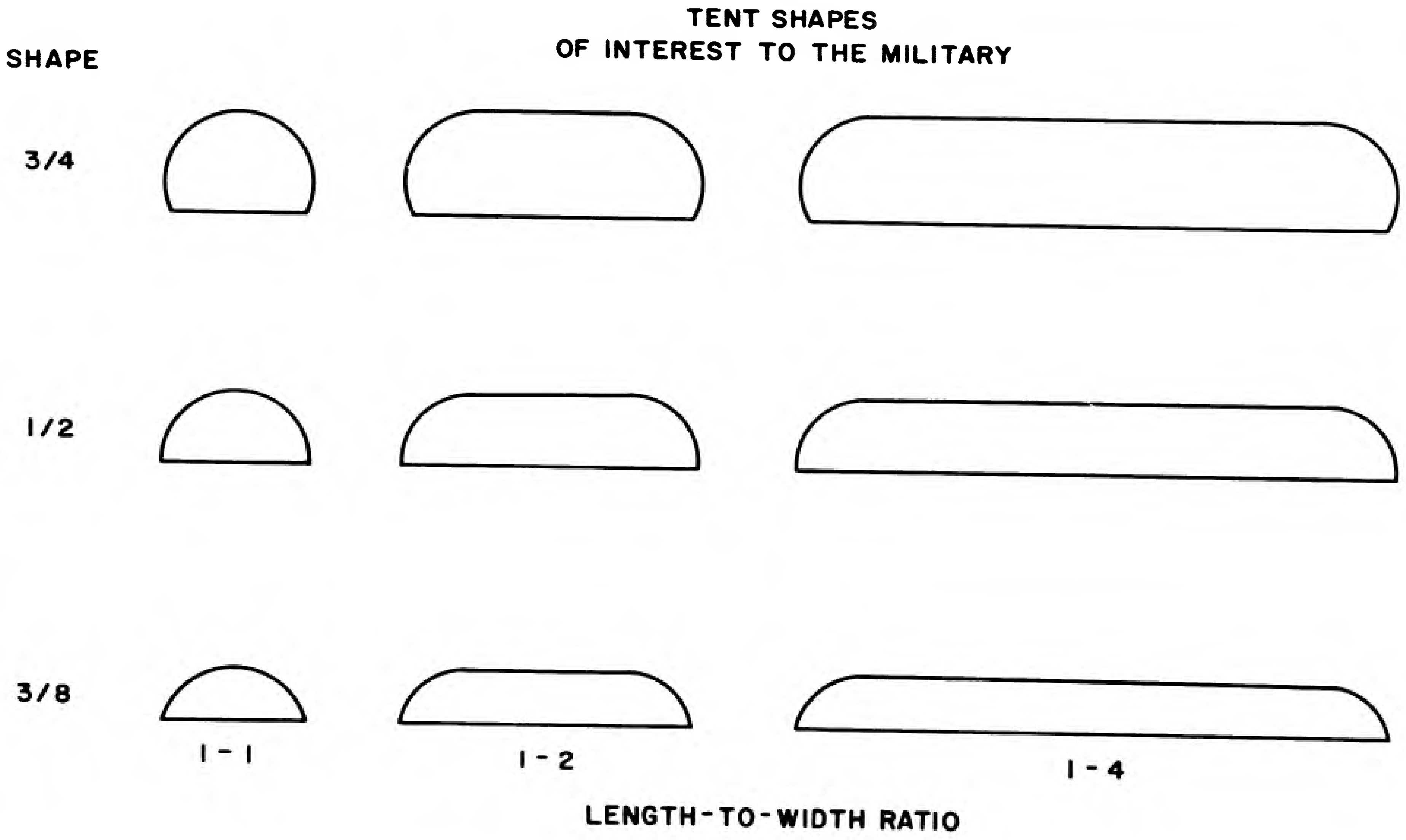

Figure 18. Tent Shapes for Wind Tunnel Tests

TABLE I

WEIGHT, STRENGTH, AND FLEXIBILITY OF FABRICS FOR AIR-SUPPORTED TENTS

	IP/DES S-62-2			Heat-Set
	Type I	Type II	MIL-C-43086	Polyester
Fiber	Polyester	Nylon	Nylon	Polyester
Coating	Neoprene and CP*		Vinyl	None
Weight oz/yd^2	14.0	14.5	19.0	9.0
Break Strgth W	160	275	300	475
lbs/sq in F	160	275	300	560
Low Temp Rqr	-40°F	-40°F	0°F	-65°F
Dielectric Constant	4.1	2.8	2.8	2.7

*Chlorosulphonated Polyethylene

The fabrics covered by IP/DES S-62-2 were developed for Arctic use where flexibility at low temperature is important. Type I polyester fabric would be used for the smaller, air-supported tents--Shelter Set, Vehicle Maintenance, Small, Air-Inflated for Arctic Use; Tent, Maintenance, Multi-Purpose, Inflatable, Sectionalized; and Shelter, Air-Supported, Vertical Check-Out (Redstone). Type II is used for the larger tents where greater strength of material is required; i.e., Tent, Air-Supported, Double-Wall, Assembly Area, Nike Hercules Mobile System, and Tent, Air-Supported, Nike Hercules Launch Area for Field Army.

The vinyl-coated nylon fabric, MIL-C-43086, was developed for tents used in temperate climates where low temperature flexibility is not critical. The tents in which this material will be used are Tent, Nike Hercules, Air-Supported; Tent, Air-Supported, Radome for Track Antenna and Acquisition Radar Sets; and Tent, Air-Supported, Storage-Type.

The heat-set polyester fabric is an uncoated fabric having extremely low porosity--2 cubic feet of air per minute per square foot at six inches of water pressure. This fabric was developed primarily to improve the flexibility of air-supported tents at low temperatures. However, by eliminating the coating finish, a reduction in the weight fabric is also realized. This fabric has been developed and successfully used in single-wall, air-supported tents. A Tent, Nike Hercules, Air-Supported, made from this fabric, has been erected and struck 70 times and has been in continuous service on outdoor exposure for 18 months. The tent is still in excellent condition. The development of a heat-set polyester fabric of lower porosity is continuing so that its use can be extended to double-wall, air-supported tents, where "O" porosity at 1 psi and higher is desired.

(3) Fabric Properties

The fabric properties listed in Table I are considered very important and warrant further discussion.

(a) Fiber Type

Early studies conducted for the Air Force (4) have shown that nylon and polyester fibers were more satisfactory than fiberglas acrylic, modacrylic and cellulosic-type fibers. Field experience with nylon radomes has been excellent. Experience with shelters made from high-tenacity polyester fibers have also proven satisfactory. Both fibers have high strength-to-weight ratios; the two fibers can be used to produce thin, relatively flat fabrics of high strength. A thin fabric of high strength is desirable, as the thickness of the fabric determines the amount of coating compound required to fill the interstices and protect the fabric. The thicker the fabric, the more coating compound, the greater the weight. Thin, lightweight, durable fabrics are prime objectives to attain in the development of fabrics for air-supported tents.

(b) Low Temperature Flexibility

The military requirements for tents to be operational at $-65^{\circ}F$ is a difficult requirement for coated fabrics to meet. It should be noted in Table I that the coated fabrics specified in IP/DES S-62-2 are not recommended for use below $-40^{\circ}F$. In service, the air-supported tents remain relatively rigid and are subjected to little flexing. However, they must be folded and packed for storage or shipment. The tents are not flat, but spherical and cylindrical in shape. The tents cannot be laid out flat and must be bundled into a badly creased and folded unit. The material must be capable of withstanding such handling without loss in strength. Flexibility is essential at low temperatures for ease in erecting or striking the tents under Arctic conditions.

Because of the stiffening of coated fabrics at temperatures of -40°F, the Army is continuing its development of heat-set polyester fabric which is flexible at -65°F. To develop a tent with a minimum of two years service life, it was necessary to use the 9 oz/sq yd, heat-set polyester fabric shown in Table I. If a fiber equal in tenacity to polyester fiber with better weathering resistance could be found, the weight could be reduced to as much as one-half this weight. The above indicates two areas of research to improve the flexibility of fabrics at -65°F. One of these is the development of durable fabric coating compounds which are flexible at -65°F; the other is the development of high tenacity fibers with improved weathering resistance.

(c) Electrical Properties of Fabrics

In cases where the radome is developed to cover radar antenna, transparency to the radar signal is required. In previous studies, (4) it has been stated that good RF transmission is obtained on air-supported shelters by keeping the thickness of the material small in comparison with the wave length. The detailed design specifications for radomes generally require a minimum one-way transmission of 90% at angles of incidence up to approximately 50. In order to meet this requirement, the thickness of fabric and coating material must be kept to a minimum and the dielectric constant of the coated fabric must be low.

In the development of the fabric for Nike Hercules Radomes used in Continental United States, the work accomplished with the Bell Telephone Laboratories, Whippany, New Jersey (9) revealed that the following electrical characteristics of fabrics would affect tracking radar signals and had to be kept at a minimum value: Dielectric constant, reflection coefficient, reflection loss, dissipative loss, and boresight effect (angular shift of the radar beam).

The assistance given to the problem by the Wheeler Laboratories, Great Neck, L.I., provided a set of empirical equations which showed the correlation found among the above parameters for reflection and dissipative losses, and the dielectric constant and fabric thickness.

To determine how the desirable electrical characteristics can be incorporated into a fabric development program for air-supported tents, it is necessary to measure the dielectric constant.

(d) Dielectric Constant

This parameter is defined as a constant factor (k) which is part of an equation which describes a property of the material related to its ability to conduct lines of force of an electromagnetic field (radar signals). This is in distinction to its electrical insulating property which is related to its ability to conduct electric current. The value of (k) may be determined from the measurement of (a) electrical capacities, (b) mechanical forces between charged conductors, or (c) wave lengths of electrical waves. All three methods yield the same result, except insofar as the value of (k) varies with the frequency of the electrical waves. The dielectric constant of air at room temperature is very nearly 1.0. For good radar transmission, it is desirable to keep the value for the dielectric constant of radome material as low as possible, approaching the value for that of air.

The present method of determining whether the electrical characteristics for a fabric are suitable for its intended use is to make the necessary electrical tests. This procedure for the development of coatings and fabrics having the minimum required electrical characteristics is costly, time consuming, and requires sensitive electronic equipment.

To facilitate the development of fabrics with the desired electrical characteristics, a correlation between the electrical and physical properties of fabrics was sought. The U. S. Army Natick Laboratories sent 17 fabrics to the Bell Telephone Laboratories to be tested for electrical properties. The correlation between bulk density of the fabric and its dielectric constant is shown in Fig. 19.

The 17 specimens tested included coated and uncoated fabrics. The fabric surfaces represented varied from that of a smooth, glossy vinyl film, a matt surface chloroprene film, to that of napped, acrylic, uncoated fabric. Fiber types included were polyamides, polyesters, modacrylics, vinyls, and celluloisic. Some of the uncoated fabrics were made from yarns delustered with titanium dioxide. The coating compounds used on the coated fabrics included silicone, vinyl, chloroprene, and chlorosulphonated polyethylene. It can be seen that the relationship found in Fig. 19 can be represented by essentially a straight line.

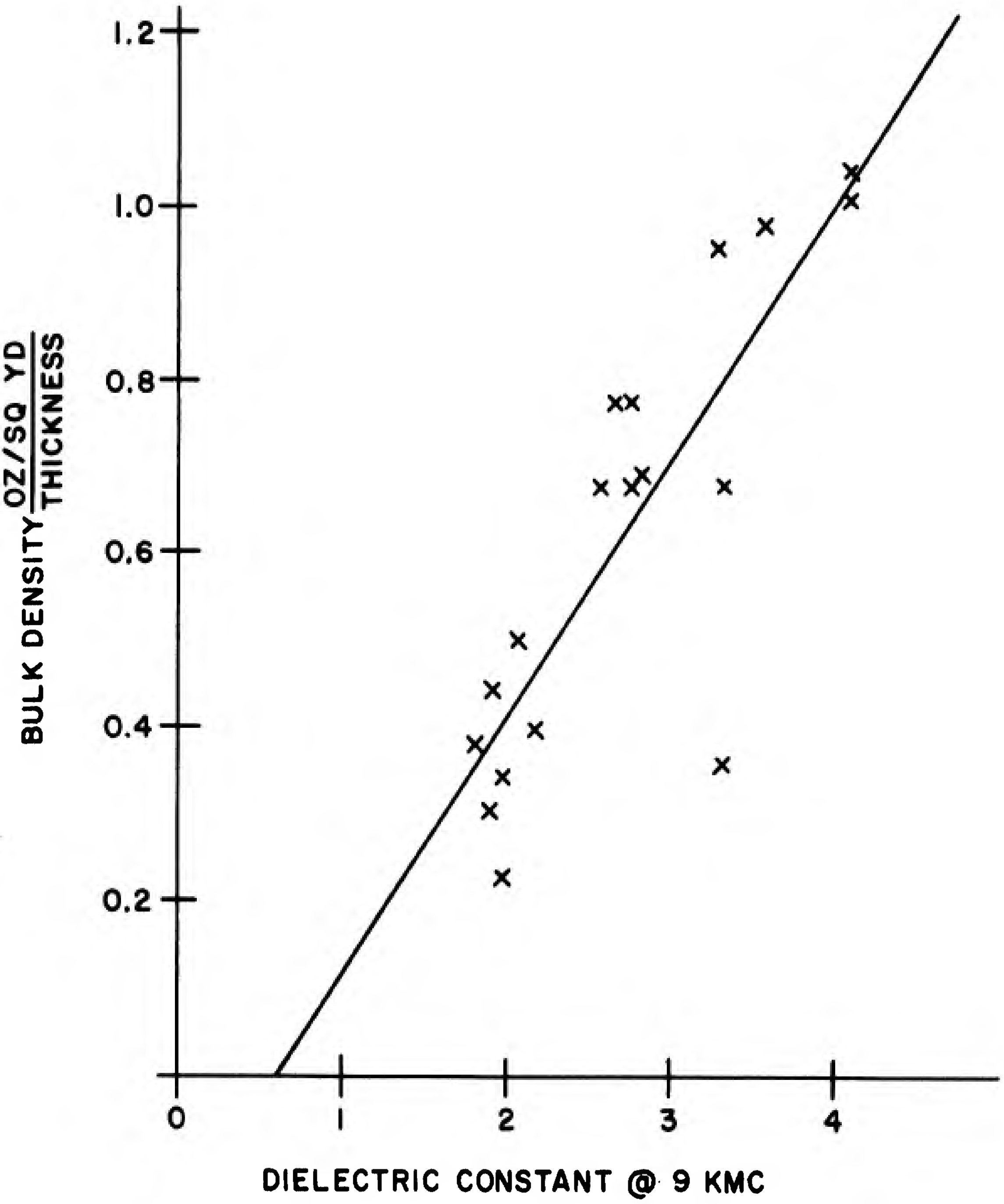

Figure 19. Correlation Bulk Density and Dielectric Constant

This correlation indicates that, given the thickness and weight of the fabric, the dielectric constant of the material can be estimated. The weight and thickness of a fabric can be determined from design information or can be measured on a finished fabric.

The information and correlation found in this study are limited to the specimens tested because of the small number of samples evaluated, and the lack of information on the ingredients used in the fabric coating compounds. According to Bell Telephone Company and Wheeler Laboratories, the relationship shown in Fig. 19, while true for the materials tested, is not applicable to the high dielectric constant materials such as water and titanium dioxide. The latter is a pigment frequently used as a delustering agent in synthetic fibers. It should be noted that the correlation holds for cellulosic fibers having 6% hygroscopic moisture and for two acrylic samples containing small amounts of titanium dioxide as a delustering agent. This suggests areas in which additional work is required to fully understand the effect of radar transmission on composite structures combining high dielectric constant material with porous fibrous structures.

Limited studies on the effect of radar transmission characteristics of carbon black and a number of metallic oxides frequently used in compounding chloroprene used in coating fabrics were reported by Cornell Aeronautical Laboratories(4). In general, it has been found that in order to obtain the best radar transmission characteristics, carbon black and metallic oxides used in the coating compounds should be well dispersed. This study apparently is also limited and further investigation in this area is warranted to determine which of the oxides and other chemicals used in compounding the coatings for fabrics have the least effect on radar transmissions through radome materials.

(4) Strength of Fabrics

The Army uses breaking strength tests for quality control of the fabric. Method 5100 of CCC-T-191, grab breaking strength, is used for control of the base fabric; and Method 5102, strip tensile, is used for control of the coated fabric. In these tests, the load is applied and measured in one direction and, depending on the direction of the applied stress, the breaking load in warp and filling is determined. As pointed out in the studies conducted by the Cornell Aeronautical Laboratory Report(4), the test methods for breaking strength used for the control of fabrics does not simulate actual use conditions. In actual use the air-supported tent is subjected to varying loading conditions--from constant uniform load due to internal pressure to varying but transient aerodynamic loads which may be at any angle to the direction of the fabric. The application of loads from aerodynamic forces can vary from a slow, gradual build-up to that of a sudden impact. Also, any vibration or motion of the tent fabric leads to motions approaching those of a whipping action. Hence, the strength of the material under various load conditions is important in the selection of the fabric for a given tent design.

A discussion of all aspects of the strength of fabric and other desirable mechanical characteristics is beyond the scope of this paper and much of this information can be obtained from literature (1,6,7,11,12,13,14,16, and 17).

It is the intent here to discuss some limited studies on biaxial stress of fabrics conducted at the U. S. Army Natick Laboratories. The work consisted of testing the burst strength of a lightweight fabric in the form of both a diaphragm and cylinder. The diaphragm burst test represents the loading condition of a fabric in the form of a spherical radome and the cylinder represents the loading conditions found in a cylindrical tent. Uniaxial breaking strength tests were also made as a point of reference. The stress data obtained for each condition of test are shown in Figure 20 and 21. Figure 20 shows the warp data while 21 shows the filling data.

In Figure 20, the uniaxial and 1-1 warp-to-filling load ratio, diaphragm burst, show the highest strength and stiffness. In the cylinder burst test, where the warp was in the hoop direction (2-1 warp-to-filling load ratio), the fabric burst at a somewhat lower strength than either the 1-1 load ratio or the uniaxial test. In the cylinder test, where the filling was in the hoop direction (1-2 warp-to-filling load ratio), the filling ruptured long before the full strength of the warp could be realized. The stiffness of the fabric appeared to remain the same for all modes of test. In Figure 21, the stress-strain behavior of the filling in biaxial stress showed the following: For the 1-1 warp-to-filling load ratio, the filling showed the highest strength and greater stiffness than the other methods of test. In the cylinder test, with the filling in the hoop direction (1-2 warp-to-filling load ratio), the strength and stiffness of the filling appears to be the same as the uniaxial test results. Where the warp was in the hoop direction (2-1 warp-to-filling load ratio), the warp ruptured before the full strength of the filling could be utilized. The above data suggest that, for load ratio of 1-1,

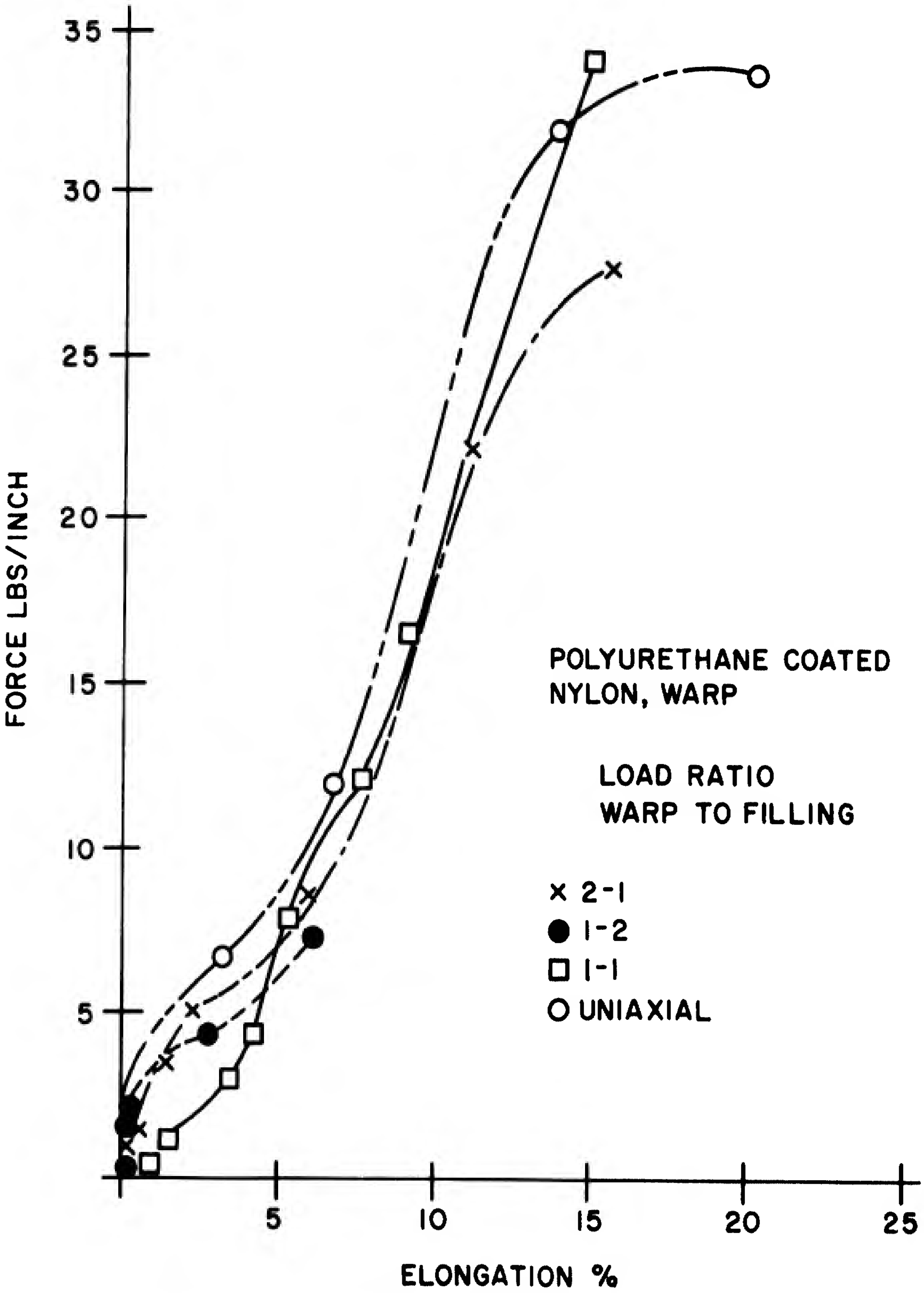

Figure 20. Burst Strength, Warp

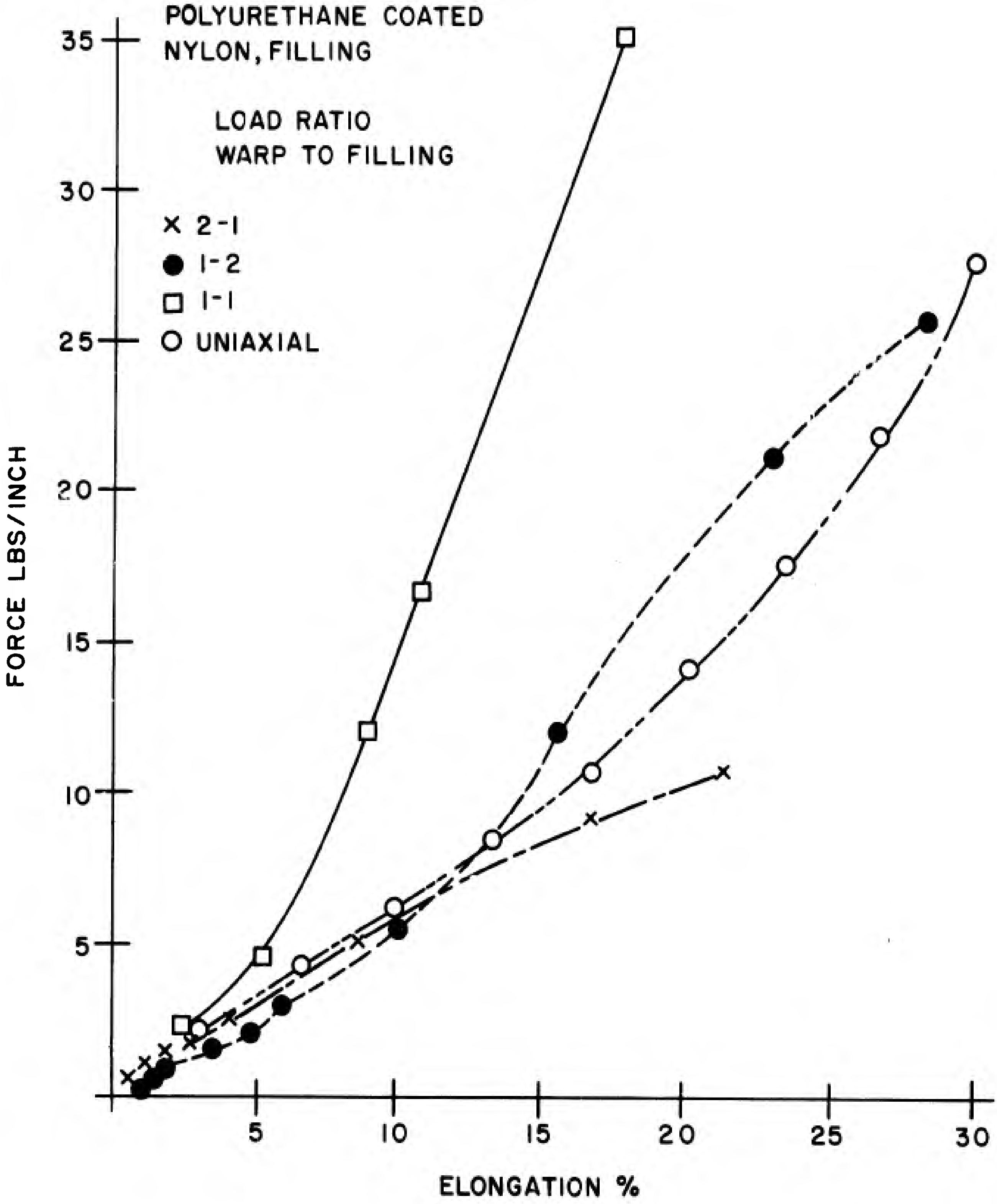

Figure 21. Burst Strength, Filling

radome construction a "square" fabric; i.e., a fabric with equal strength crimp and elongation in both warp and filling directions should be used. Studies conducted at Cornell Aerodynamic Laboratories(4) suggest that peak aerodynamic loads on spherical radomes can increase the constant uniform load, in the direction of greatest stress, by a factor of 2.1. However, since the aerodynamic loading can approach the fabric from any angle, one muxt make the fabric uniformly strong. Therefore, the premise for using a fabric equal in strength, crimp and elongation, in both warp and filling direction, is still valid. By increasing the uniform load due to internal pressure by a factor of 2.1, peak aerodynamic loads in spherical radomes would be accounted for.

From the geometry of an inflated cylinder and above tests, the stress due to internal pressure alone is twice as great in the hoop direction than in the longitudinal direction. This would indicate that the fabric for cylindrical tents should be designed with 1/2 the strength in the longitudinal direction. As indicated by the biaxial test data (Fig. 20 and 21), the yarns in the longitudinal direction barely approached 1/2 their potential strength before rupture in the other yarn system caused the cylinder to fail. Thus, for stress due to internal pressure alone, excess strength in the longitudinal direction is not needed in cylindrical tents and adds to the cost and weight of the item without increasing its performance. However, to present the full condition of loading in a cylindrical tent, the aerodynamic loading must also be considered. Data on the aerodynamic loading of fabrics in cylindrical tents are currently being investigated(2,20).

The above is a highly simplified version of matching fabric strength properties to the requirements of the tent. The obstacles encountered in determining fabric stress under dynamic conditions are well recognized, as are those for the development and production of fabrics to meet exacting end use requirements. These two objectives represent desired goals to be attained, rather than firmly established practices in common use today. The measurement of fabric stress under the dynamic conditions in the wind tunnel involves the development of techniques whereby stress concentrations in fabrics can be located and mre measured by direct or indirect means. The development of the scale for the aeroelastic parameter for fabrics in test models is the first step in this direction.

The attainment of the desired properties in the fabric is another subject which should be mentioned before concluding this paper. If fabric development were to keep pace with the development air-supported tents, one can no longer afford the time required for this development based on traditional crafts and experience. With few exceptions in the area of specialty fabrics, experience in producing fabrics to meet the requirements for air-supported tents still has to be attained. Even though the best fabrics available have been used in the fabrication of the tents developed for the Army, they were adaptations of good commercial fabric of multi-purpose use.

The traditional method for selecting fabrics for air-supported tents was on the basis that they were rugged and strong enough to exceed the maximum calculated design load for the tent. Less attention was given to strength and crimp balance in the fabric. This traditional approach to the development of fabrics for air-supported tents produces, at best, a compromise in fabric selection. The full potential of lightness in weight, durability, reliability, low cost, and size of the air-supported tent cannot be realized in this manner. It is suggested that fabrics for air-supported tents be designed utilizing information developed on the theoretical behavior of woven fabric which is subjected to biaxial stress. Some information in this area is available from the literature(7,13,14 and 17).

This approach would provide the means for an engineering analysis of material for either predicting the performance of a given fabric, or for determining which fabric would be most suitable for a particular application or for the basic design of a fabric to fit a particular application.

Fabric engineering can only be as effective as the information relative to the desired characteristics of a fabric is known. Through wind tunnel studies, military characteristics, and other available information, the Army is developing the required characteristics for fabrics to be used for air-supported tents. The studies on fabric structure and stress analysis will be extended to the design and production of fabrics to meet the exacting mechanical, electrical, and other requirements for air-supported tentage.

In conclusion, therefore, the Army has shown eleven air-supported tents developed to meet specific operational requirements. The fabrics used by the Army were described and the following problem areas were discussed:

(a) Fabric coating compounds with improved flexibility at low temperature.

(b) High-tenacity fibers with improved weathering characteristics.

(c) Studies on the dielectric constants on composite structures combining high dielectric constant materials with fibrous structures.

(d) Studies on the theoretical behavior of woven fabric subjected to biaxial stress conditions.

It is in these areas where additional research work is required to develop the full potential use for air-supported tents under all climatic conditions. Also, it was pointed out that the developments of air-supported tents and fabrics go hand in hand. It is felt that only through this approach can the full potential for lightness in weight and reliability of the air-supported tents be developed.

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