THE EFFECTS OF POROSITY ON DESIGN AND PERFORMANCE CHARACTERISTICS OF PARACHUTES

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Introduction

All known parachutes provide a certain flow of air from the inside of the canopy into the flow field surrounding the outside of the canopy. This overall effect is generally accomplished by arranging vents, slots and holes in the canopy and the use of cloth with a certain porosity. Actually, we have to distinguish between the porosity of the canopy and the cloth porosity.

The cloth porosity is the measured volume of air which will flow through the unit area of cloth in the unit time at a given differential pressure.

The porosity imposed upon the canopy by vents, slots or ribbon spacing is usually expressed in percent of open spaces as related to the total design area in uninflated conditions. This type of porosity is called the geometric porosity of a parachute.

The total rate of flow from the inside to the outside of the canopy depends naturally on the porosity, resulting from cloth porosity and the porosity of the canopy and the cloth porosity. The resultant porosity effects the performance of any parachute, depending on its basic type to a larger or smaller degree. The favorable and adverse effects of the porosity and their influence on the general design and performance characteristic of parachutes shall be the subject of this paper.

The Schematic Flow Pattern

The effects of porosity upon the performance of parachutes would logically be studied on the basis of their respective aerodynamic flow pattern. The establishment of such flow pattern is normally a matter of the theoretical and experimental aerodynamics.

In the case of parachutes, the methods of the theoretical aerodynamic cannot be used since all known parachutes develop so much turbulence that the concept of potential flow is not applicable. Experimental flow pictures are naturally only schematic and average pattern, but they have been very helpful in the development of modern parachutes.

Figures 64 and 65 show the schematic flow pattern of an imporous and a porous hemisphere, respectively. The porous hemisphere has 35% geometric porosity and resembles, to a certain extent, a ribbon parachute.

A comparison of the two pictures indicates the following effects of the porosity:

      a. Flow separation where the imporous hemisphere shows attached flow.

      b. Reduction of the turbulent area behind the parachute.

      c. Reduction of the deflection of the air flow.

Consequently, porosity will change the stability characteristic, reduce the drag and increase the damping. Further considerations show that the porosity will decrease the opening force, the opening reliability and the apparent mass. The present problem of the Technology of Parachutes is to express these experimental and hypothetical facts analytically to make them useful for the design of parachutes, for the selection of the optimum type for any specific application and for the prediction of parachute performance characteristics.

Design Principles

Since the porosity so strongly affects the performance of parachutes, the skillful manipulation of the porosity is the oldest and mostly used parameter in parachute design. The other, also obvious, but much younger design parameter, is the radical shaping of the canopy. On the basis of these two possibilities, one may distinguish two schools of thought in the parachute design. The older school varies the shape only slightly and uses as main parameter the cloth and geometric porosity to obtain particular effects, while the newer school uses conventional cloth and varies the shape from the conventional type to the most radical shaping. Organizing the parachutes in accordance with their porosity, we may speak of solid cloth parachutes and high porosity parachutes. Figure 66 shows a schematic arrangement of parachutes in solid cloth and high porosity parachutes. The solid cloth parachutes, in turn, may be grouped in Flat Parachutes, Formed Gore Parachutes and Guide Surface Parachutes. The first sub-group has a variety of shapes, such as circular, square and triangular. The formed gore parachute include the semi-circular parachutes, the extended skirt parachute and parachutes with parabolically cut gores. The guide surface family has a stabilization type, universal type and personnel type. The high porosity parachutes are represented by the ring slot parachute, the ribbon parachute and the rotofoil parachute. The canopy of rotofoil parachutes has large slots

so arranged that the escaping air promotes rotation of the canopy.

Figures 67 to 71 illustrate the main types of presently know parachutes. The solid flat parachutes are all unstable; they either oscillate, glide or perform a combined motion. The formed gore parachutes are characterized by the drawn-in-skirt and a more stable behavior.

All parachutes of the guide surface family are equipped with a pronounced stabilization surface. Guide surface parachutes are specialized for Stabilization of Bombs, Mines and Torpedoes, (Stabilization type) for recovery of guided missiles, pilotless aircraft, escape capsules, ejection seats (universal type), and the personnel type is the new Air Force Personnel Emergency parachute. The parachutes of the ribbon parachute family are mainly distinguished by their geometric shape. The ring slot parachute is closely related to ribbon parachutes and ring slot parachutes are widely used at present as extraction and aircraft deceleration parachutes.

Porosity and Stability

The reason for this wide variety of parachutes is that numerous designers tried to develop non-oscillating or aerodynamically stable parachutes by varying porosity and shape. The Technology of Parachutes is still too young as to say which combination is best. The practice, however, indicates already that certain types are particularly suited for specific applications. Wind tunnel experiments show conclusively that porosity improves the stability.

Going back to the classical example of the imporous hemisphere, see Figure 72, we observe that the point of unstability shifts from 45° in case of the solid hemisphere to 15° for the porous hemisphere. That means the solid hemisphere would oscillate, glide or spiral at least up to 45° while the porous hemisphere would show an unrest in the order of 15°. An actual ribbon chute with 28% porosity is even better. This may be attributed to certain deformation of the ribbon which can not be reproduced by a solid model. Figure 73 illustrates the effect of shaping. An imporous model, resembling a guide surface parachute, is stable over the entire range, while the solid hemisphere is unstable up to 45°. A textile guide surface parachute is even more stable than the basic solid model while the solid flat textile parachute, as offspring of the solid hemisphere, is unstable only up to 25°.

The new personnel guide surface parachute of the U.S. Air Force, see Figure 74, is another example of a design, using conventional cloth and radical shaping. In this design, the stability has been carried only as far as seems required for personnel use. Wind tunnel measurements on textile models show unstability up to 7.5°, see Figure 75, while the same parachute, when imporous, is unstable up to 25°.

Comparing the typical imporous and rigid models and their respective parachutes, it is evident that parachutes with low porosity and strong shaping are at least as stable as highly porous parachutes more conventionally shaped. It is further evident that porosity improves the porosity in any case.

The question is, now, how porous may a parachute be made. From the standpoint of stability, it is desirable to build them highly porous. The reliability of opening, however, decreases as the porosity increases. The practice has proven the existence of a very definite upper limit of porosity above which parachutes inflate reluctantly or only partially, known as squidding, and these parachutes generally do not satisfy the reliability requirements of man carrying parachutes of this country. English parachute experts developed great skill in dealing with squidding parachutes. This country has shown more tendency to provide stable parachutes by aerodynamic shaping, while holding the porosity low enough to assure positive inflation under adverse circumstances.

Drag and Porosity

The flow pattern indicated that porosity reduces the turbulent area behind the parachute. It is obvious that this means drag reduction through porosity. The early wind tunnel measurements on the solid and porous hemispheres indicated a reduction of the drag in the order of 28% after introducing 35% geometric porosity.

Similar results were obtained in Great Britain. Johns and Anterson established on the basis of a large number of Wind tunnel experiments the emperical formula $C_D = C_{D_o} (1 - 2.25 \frac{u}{v})$.

The value $\frac{u}{v}$ represents the ratio of the average velocity through the cloth and the ambient velocity. Consequently, $\frac{u}{v}$ represents an expression for porosity. Figure 75 and 76 allow comparison between the conventional and dimensionless presentation of porosity. The dimensionless porosity has been called the effective porosity. It is remarkable that the effective porosity of cloth assumes a steady value after a certain range of transition. This is true at least for the stronger cloth. Apparently the cloth expands under the effect of the differential pressure and becomes geometrically more porous. After reaching a certain tension in the cloth, its geometry is established and secondary air flow depends only on the viscous drag of the cloth as a screen. The screen drag of the cloth is apparently very steady and causes an almost constant effective porosity over a wide range of differential pressure. The interesting top curve represents the effective porosity of a very thin material with a large region of transition. This cloth is used in man carrying parachutes. The 4-ounce nylon cloth is marked here in two curves. These two curves were obtained in 1950 by the Wright Air Development Center and these curves

actually initiated the study of parachute materials at high differential pressures. Both curves represent the effective porosity of two samples of nylon cloth which satisfy the porosity requirements at 1/2 inch water pressure. However, parachutes made out of the more stable cloth inflated properly while parachutes of the more elastic cloth squidded. Several parachute experiments, at different speeds, were made and it was concluded that for successful high speed parachute operation the effective porosity has to assume a certain, practically constant value at differential pressures which are expected at the actual parachute operation. The upper limit for such porosity studies was, at that time, established as 6,000 pounds per square foot. This goal has not yet been reached, but very valuable detailed information was obtained.

Opening Shock and Porosity

Besides stability and drag, opening shock is of prime importance. Many attempts have been made to develop methods to calculate opening forces. The majority of these methods are based on ingenious concepts and emperical data. The most analytical treatment has been worked out by F. O'Hara of Great Britain and Foote and Scherberg of the Wright Air Development Center. The basis of all analytical methods is the differential equation reflecting Newton Second Law (see Figure 77). This equation contains expressions for the drag, the rate of filling $(\frac{dr}{dt})$ and the apparent mass (gKr^3).

Since rate of filling and apparent mass are functions of porosity, it is again obvious that porosity and shape affect the parachute opening force. Figure 77 shows the range of force developed by the modern personnel parachute. The rate of filling $\frac{dr}{dt}$, analytically treated by O'Hara, Foote and Scherberg, increases or decreases proportionally to the ratio of inflow to outflow $\frac{u}{v}$, which has already been defined as effective porosity. Since most parachute openings occur at higher differential pressures, these opening theories must use the effective porosity in the higher pressure region. That means if one builds two parachutes to the same pattern, but out of material with different effective porosity, at a high differential pressure, the parachute with higher effective porosity will have lower opening forces regardless of the cloth porosity at low differential pressure.

A comparison between the opening forces of the two 28 foot solid flat parachutes built out of 1.1 and 1.6 ounce nylon seem to prove this speculation. The air permeability at 1/2 inch of water column of 1.6 ounce nylon is 30% higher than the 1.1 ounce nylon. However, the opening force of the 1.1 ounce nylon parachute is less than that of the 1.6 ounce parachute (see Figure 78). However, checking the effective porosity in Figure 79, one sees that at higher differential pressure the 1.1 ounce nylon is effectively more porous than the 1.6 ounce nylon.

The apparent mass is another term in the opening force equation. The apparent mass is a dynamic effect which occurs in unsteady motion. An object which moves unsteadily though a medium, experiences, in addition to its viscous drag, a resistance when accelerated and a propulsion when decelerated. This phenomenon results from the transfer of kinetic energy from the object to the surrounding medium at acceleration and vice versa at deceleration. The effect is the same as if the moving object would assume additional mass. Consequently, this imaginary mass is called the apparent mass or virtual mass.
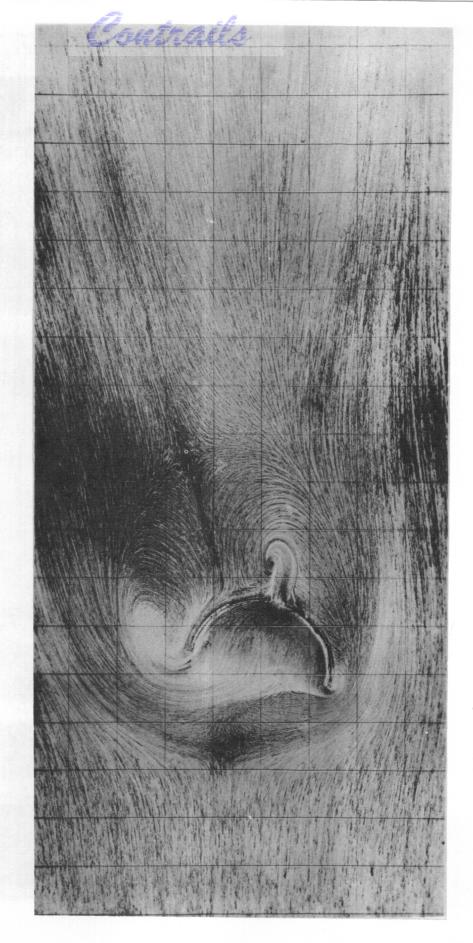
The apparent mass for a few types of parachutes has been measured as shown in Figure 80. The results show that the apparent mass differs with the types of parachutes and varies also with the effective porosity. Consequently, the porosity of the cloth enters into the opening force again by way of the apparent mass.

The concept of effective porosity opens another outlook. Contradictory to the common belief, it became known, in 1944, that the opening shock of parachutes increases with increasing altitude. From the standpoint of changing effective porosity, this may be explained as follows: from a limited number of experiments, we know that the volumetric outflow of air depends primarily on the differential pressure, and under this assumption, calculations show that the effective porosity decreases with decreasing air densities, and consequently decreases with increasing altitude (see Figure 81). Therefore, a particular parachute is effectively more porous at sea level than at higher altitudes, as Figure 82 indicates. Consequently, this parachute inflates faster, its stability is not as good, the drag coefficient is higher, and the apparent mass is relatively higher at high altitude. Faster filling alone causes shorter opening time and higher opening shocks. Experiments seem to substantiate these considerations. Hallenbeck recorded in 1944 opening forces and the time intervals of 24 foot solid-cloth parachutes at different altitudes with a constant indicated air speed of 128 mph and found time intervals in the order of 1.0 second from snatch force to peak force, and maximum forces of 1,700 pounds at 7,000 foot altitude. At 40,000 feet, the time was in the order of 0.1 second and forces went up to 6,600 pounds.
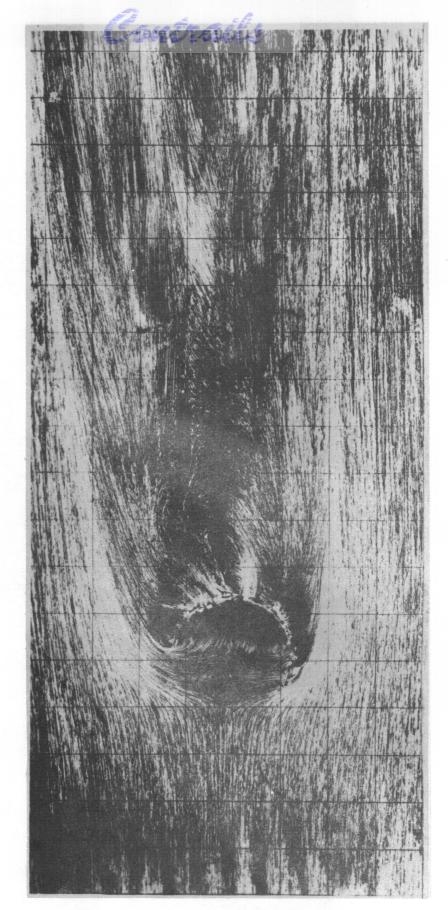
Summary

In summary, it may be said that the Technology of Parachutes is advanced to the point, where the empirical methods are being replaced by analytical treatments. The big fudge factors are being resolved in more natural parameters, and the physical properties of the parachute cloth are among the most important empirical parameters. The clear definition and the reliable establishment of these cloth parameters are essential for the advancement of the Technology of Parachutes.

Figure 64.   Flow Pattern of a Solid Hemisphere Having 15° Angle of Attack.

Figure 65. Flow Pattern of a Hemisphere with 35% Geometric Porosity Having 15° Angle of Attack.
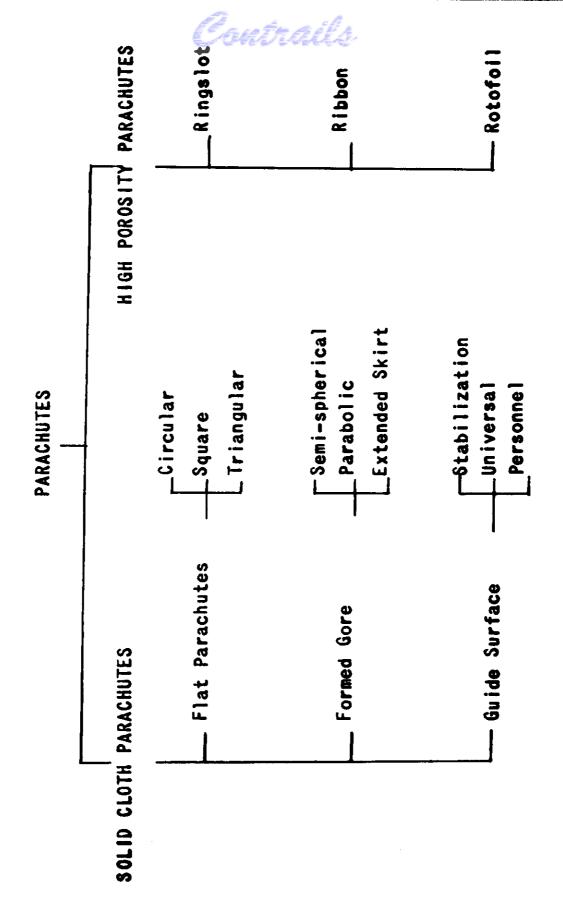
PARACHUTES

SOLID CLOTH PARACHUTES

Flat Parachutes
- Circular
- Square
- Triangular

Formed Gore
- Semi-spherical
- Parabolic
- Extended Skirt

Guide Surface
- Stabilization
- Universal
- Personnel

HIGH POROSITY PARACHUTES

- Ringslot
- Ribbon
- Rotofoil

Figure 66. Classification of Parachutes.

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Triangular

Square

Circular
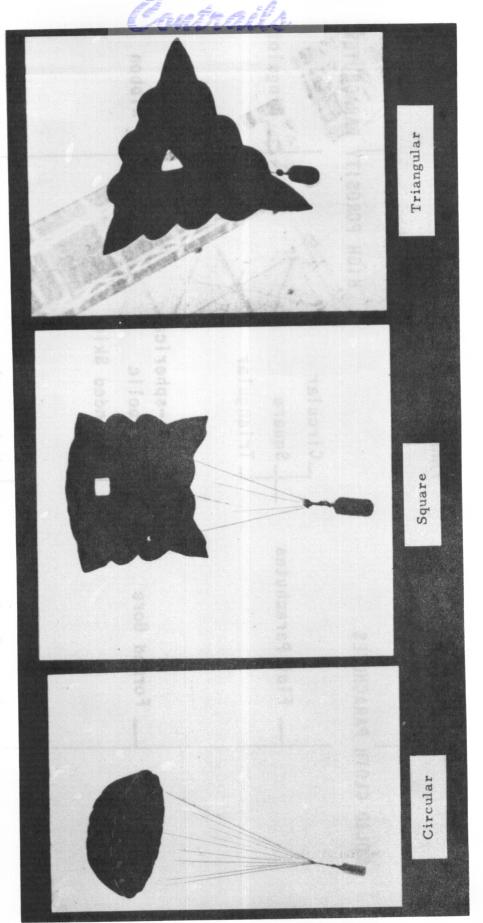
Figure 67. Family of Solid Flat Parachutes.
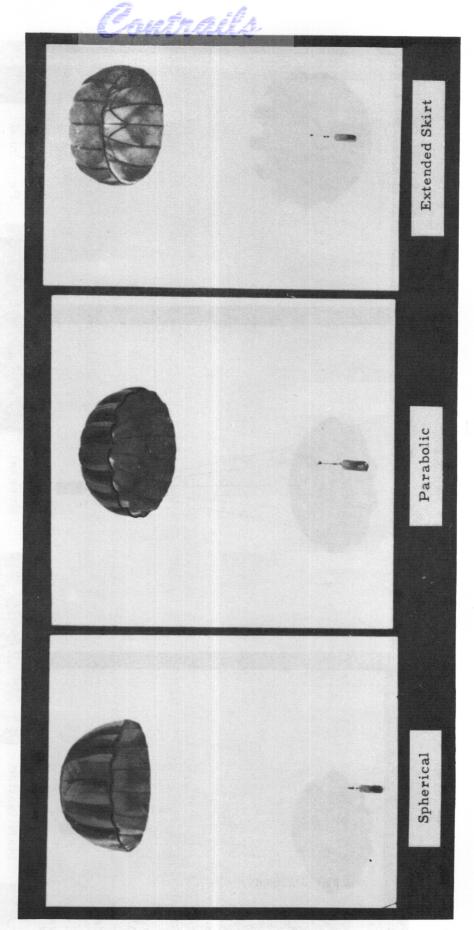
Figure 68. Family of Formed Gore Parachutes.

Extended Skirt

Parabolic

Spherical

Personnel

Universal

Stabilization
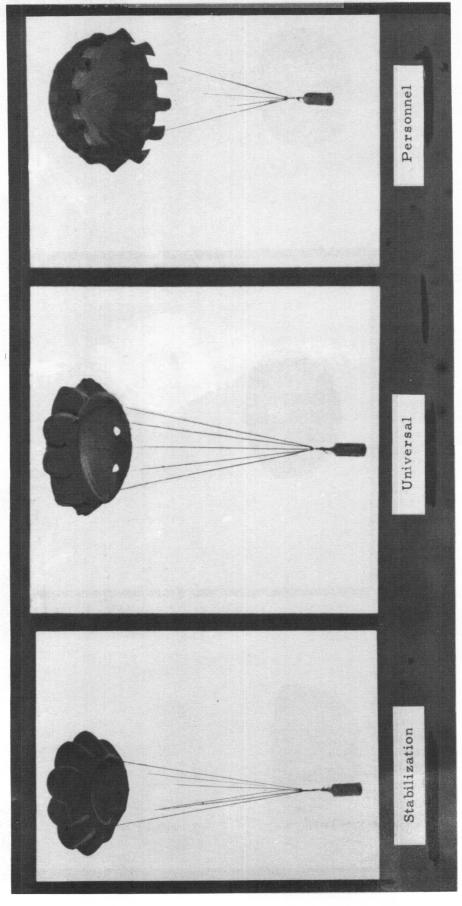
Figure 69. Family of Guide Surface Parachutes
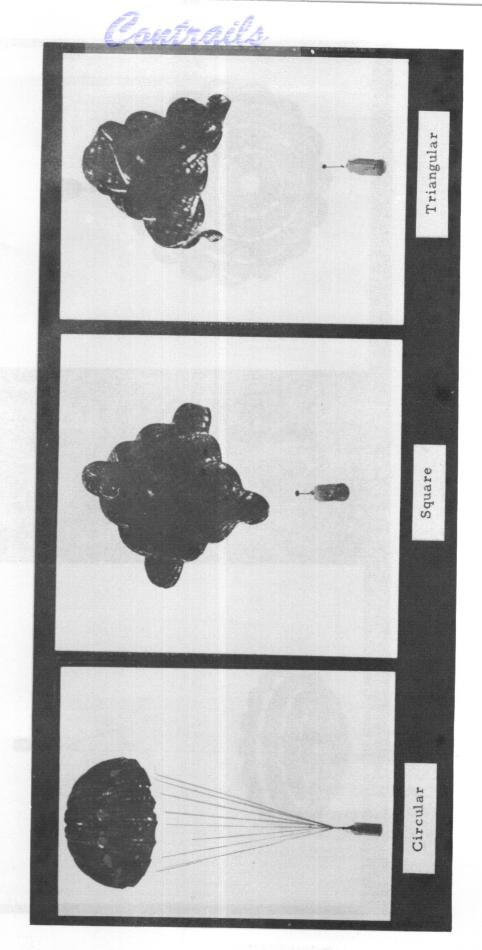
106

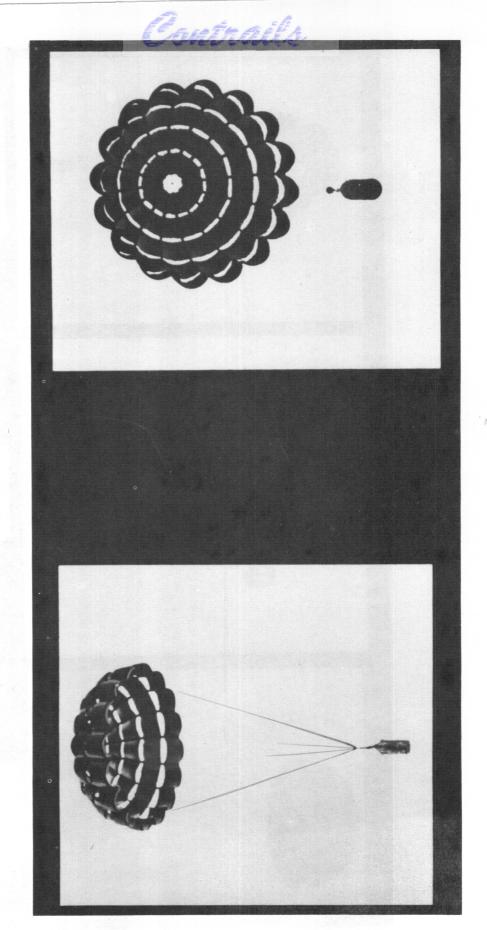Figure 70. Family of Ribbon Parachutes

Triangular

Square
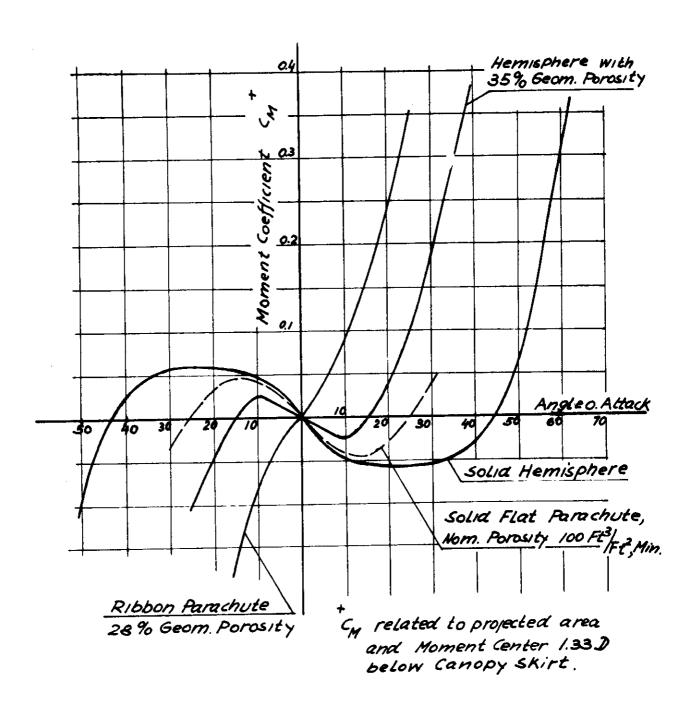
Circular

Figure 71. Family of Ring Slot Parachutes.

Figure 72. Stability Characteristic of Solid and Porous Hemispheres and
Related Parachutes.

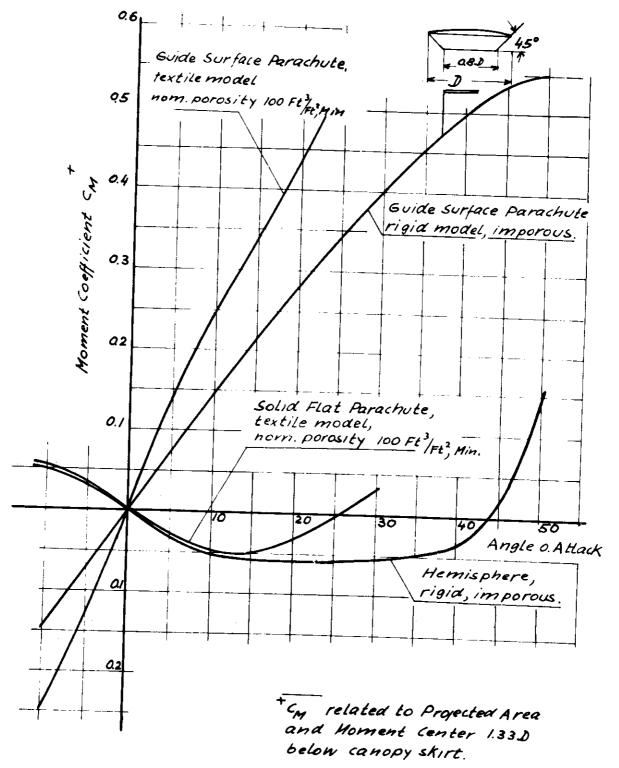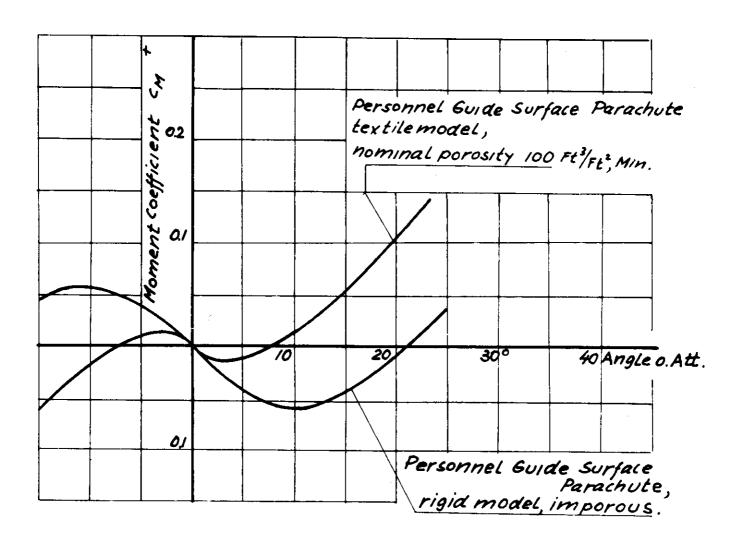Figure 73. Stability Characteristic of Solid and Porous Guide Surface Parachute.

The vertical axis is labeled "Moment coefficient c_M^+" with values 0.2, 0.1, 0.1. The horizontal axis is labeled "Angle o. Att." with values 10, 20, 30°, 40.

Personnel Guide Surface Parachute
textile model,
nominal porosity 100 Ft^3/Ft^2, Min.

Personnel Guide Surface
Parachute,
rigid model, imporous.

$^+ c_M$ related to Projected Area,
and Moment Center 1.33 D
below canopy skirt.

Figure 74. Stability Characteristic of Solid and Porous Models of the
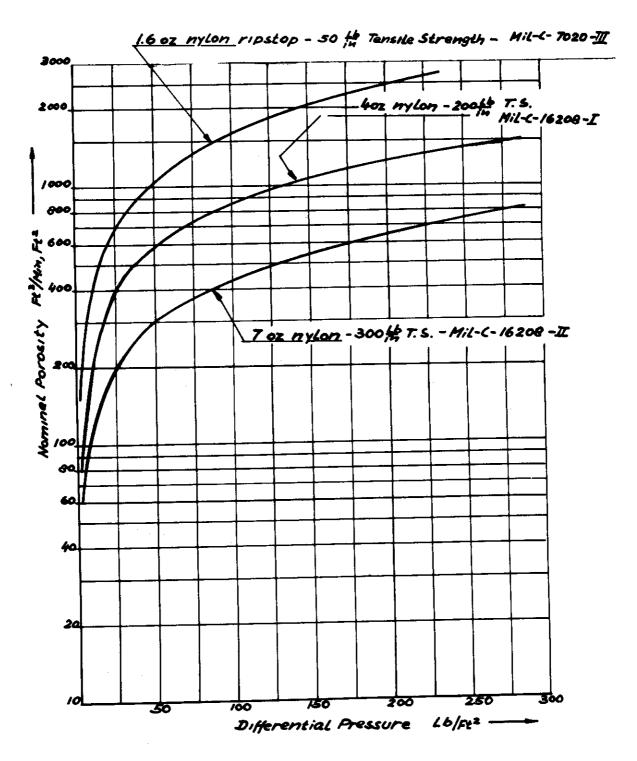Personnel Guide Surface Parachute.

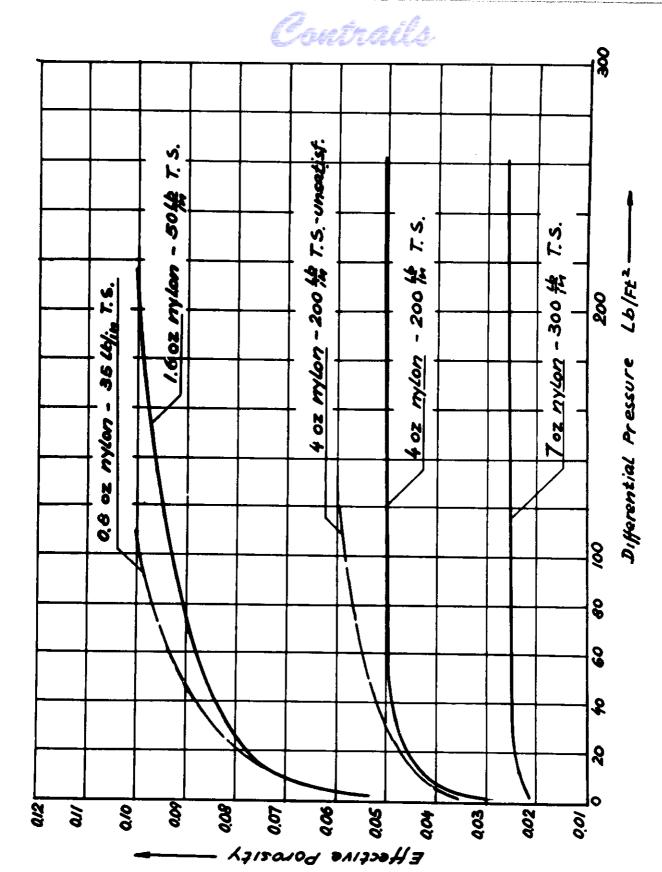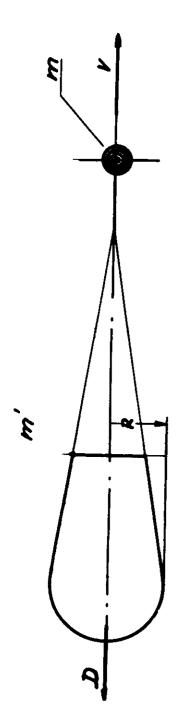Figure 75. Nominal Porosity in Ft³/Min, Ft² versus Differential Pressure.

Figure 76. Effective Porosity (dimensionless) versus Differential Pressure.

Y-axis: Effective Porosity — 0.12, 0.11, 0.10, 0.09, 0.08, 0.07, 0.06, 0.05, 0.04, 0.03, 0.02, 0.01

X-axis: Differential Pressure Lb/Ft² — 20, 40, 60, 80, 100, 200, 300

Curve labels:
- 0.8 oz nylon - 35 lb/in T.S.
- 1.6 oz nylon - 50# T.S.
- 4 oz nylon - 200# T.S.-uncoated.
- 4 oz nylon - 200# T.S.
- 7 oz nylon - 300# T.S.

$$\frac{d}{dt}(m \cdot v) = -\left[D + \frac{d}{dt}(m'v) \right]$$

$$\frac{dv}{dt} = -\frac{D + v\frac{dm'}{dt}}{m+m'}$$

$$D = \frac{\rho}{2} v^2 C_D \pi r^2$$

$$m' = \rho k \pi r^3$$

$$\frac{dv}{dt} = -\frac{\frac{\rho}{2} C_D \pi r^2 v^2 + \rho \, 3k\pi v r^2 \frac{dr}{dt}}{m + \rho k \pi r^3}$$

Figure 77. Differential Equations Governing the Parachute Opening Force.
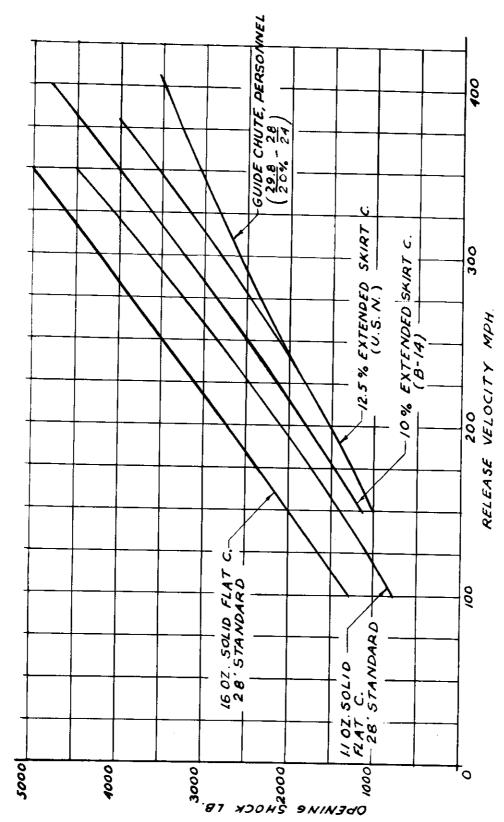
FIG.14 OPENING SHOCK OF RECENTLY DESIGNED MAN-CARRYING PARACHUTES

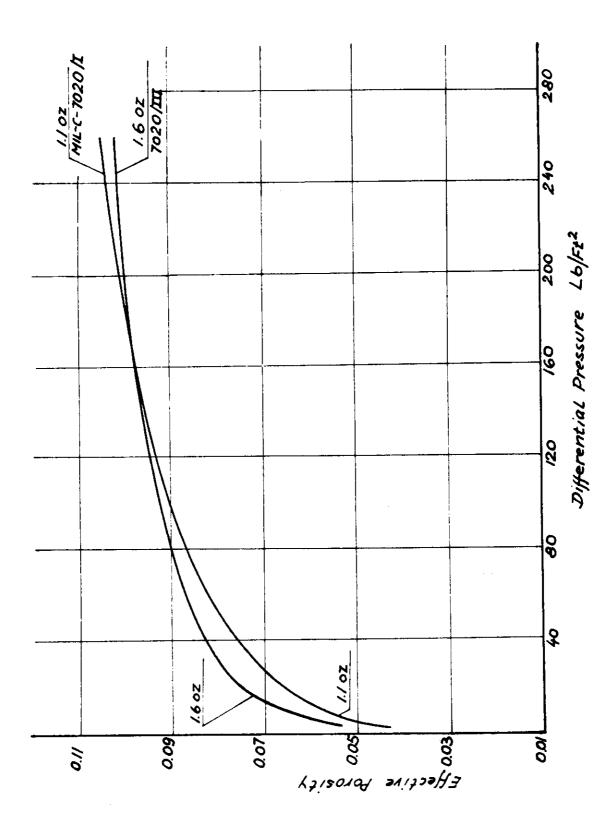Figure 78. Opening Shock of Recently Designed Man Carrying Parachutes.

Figure 79. Effective Porosity of Parachute Cloth in Accordance with Specification MIL-C-7020 Type I and Type II.
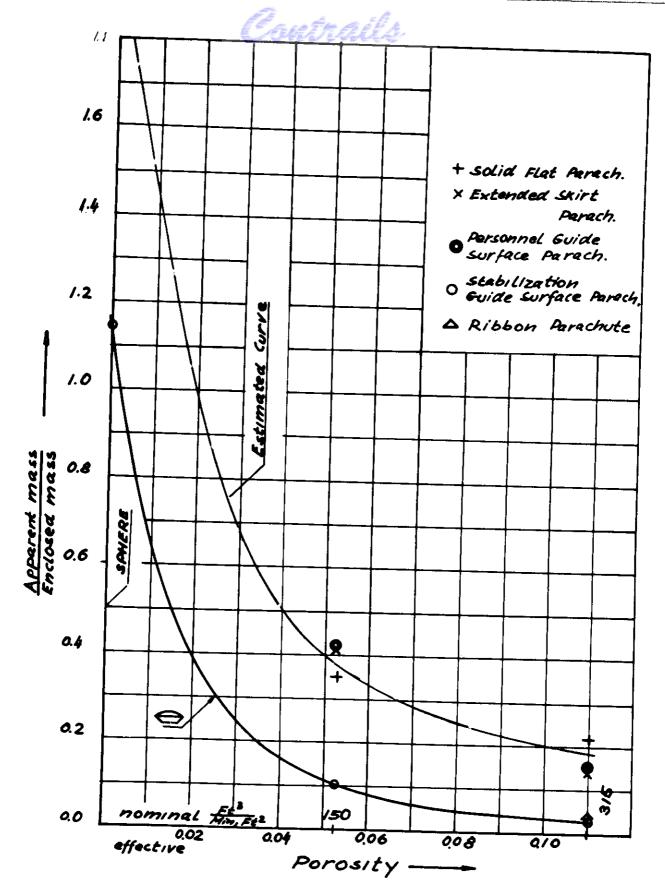
Differential Pressure Lb/Ft²

Effective Porosity

1.1 oz
MIL-C-7020/I

1.6 oz
7020/II

1.6 oz

1.1 oz

0.11
0.09
0.07
0.05
0.03
0.01

40
80
120
160
200
240
280

Figure 80. An apparent mass of Parachutes versus Effective Porosity.

1

$$u \ll v$$

$$\Delta p = \frac{\rho}{2} v^2 \qquad 1$$

Experiments indicate
Effective Porosity

$$C = \frac{u}{v} \approx const. \qquad 2$$

From 1

$$v = \sqrt{\frac{2\Delta p}{\rho}}$$

$$C_o = 0.707 \sqrt{\rho_o} \cdot \frac{u}{\sqrt{\Delta p}} \qquad 3$$

2 and 3 combined for sea level
density

Since $\dfrac{u}{v}$ is approximately constant

and $\sqrt{\Delta p}$ stands for v

$$\frac{u}{\sqrt{\Delta p}} = const.$$

Consequently, the Effective Porosity
for any density (altitude)

$$C = C_o' \sqrt{\rho/\rho_o}$$

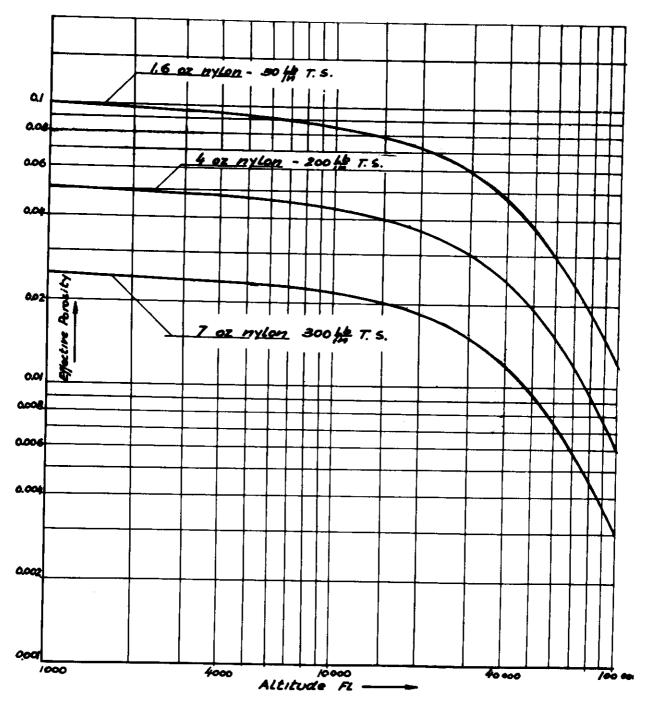Figure 81. The Effective Porosity as Function of Air Density.

Figure 82.   Effective Porosity versus Altitude.

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