PROBLEMS OF PARACHUTE DESIGN AND THEIR RELATION TO TEXTILES

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The parachute was originally conceived as a life-saving device to safely and reliably lower personnel from balloons and aircraft to the ground in the event of an emergency. Because it was fabricated of textile materials, inflated and achieved its shape due to aerodynamic forces resulting from its velocity of movement through the air, it was lighter in weight, lower in cost and could be stowed in a smaller space than any other means of accomplishing the same end. The continued use of the parachute today and in the future is dependent upon these same factors of reliability, low weight, cost and volume. Other factors which are very important in most applications and mandatory in others are stability, low opening forces, good structural design, and durability to withstand repeated use under severe service conditions.

Because of their ability to reliably provide high drag with low weight, bulk, and cost, parachutes have been put to a multitude of uses in addition to life-saving. In the field of airborne operations they are presently used by paratroopers and to lower cargo, vehicles, and weapons in packages from 100 to 22,000 pounds during assault and resupply operations. In ordnance work they are used to retard the fall of mines, torpedoes, shells, bombs, and flares. In the field of guided missiles and target aircraft they are used to decelerate and recover parts of, or whole missiles and target aircraft for reuse. In the aircraft field, they are used to supplement flaps for inflight braking and to supplement flaps and brakes for landing. In survival and rescue they are used by paradoctors and rescue teams and to deliver supplies and equipment such as airborne lifeboats to survivors. For this multiplicity of uses parachutes have been designed and constructed which ranged in size from one to 200 feet in diameter and for opening forces which ranged from one hundred pounds to in excess of one hundred thousand pounds for use in a speed range from 100 miles per hour to high Mach numbers. As can readily be seen, this variety of use, size, and strength requirements naturally imposes a requirement for a wide variety of textile materials and for material of widely differing characteristics.

From these statements, then, it is evident that the ideal textile fabric for parachutes is one which possesses high strength-weight characteristics, good elongation under load, high density, high tear strength, good flexibility to stand sharp creasing, and is in addition highly resistant to injury or change in characteristics from abrasion, heat, cold, chemicals, age, insect or fungus attack and one which can still be cheaply produced in a wide range

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of tensile strengths with closely controlled porosities. It must, in addition, be capable of being readily joined together with only minor loss of strength. Since it is obvious that one textile material will not be available in the near future, to meet all these requirements,I would like to cover some of the more important parachute design problems as they relate to textiles at the present time and attempt to show which characteristics are governing for certain applications.

As a prelude to discussing specific application design requirements, however, the development of two basic parachute design approaches will be outlined since one or the other is involved in each application.

The porosity of a parachute canopy is one of the strongest variables effecting its performance. A low porosity parachute, in general, has high drag and strong opening characteristics and is therefore very reliable in opening. The usual penalty paid for this reliability, however, is that opening forces will be high, stronger construction must therefore be used for the same application velocity, and an unstable parachute will result. Early recognition of these facts led to a wide variety of designs to permit a variation in canopy porosity with the loading conditions as a means of reducing opening forces. These early attempts were to use elastically controlled single or multiple vents in the apex area, or to use elastic material inserts which exhibited a large change in fabric porosity with increased pressures. Many of these attempts showed some benefits but resulted in little or no decrease in weight and bulk and were discarded because of added complexity and cost.

In Germany in 1937, the use of ribbons to form parachute canopies was tried. These designs were perhaps the first attempts to progressively evaluate the effects of varying the porosity of a parachute on its performance. Because the porosity was largely a matter of construction, rather than of a fabric, this evaluation was not too difficult to accomplish. This evaluation resulted in the establishment of design information for ribbon parachutes which enabled approximate prediction of opening forces and stability. Later invention of the "taschengurt" or "pocket band" as a canopy opening aid made possible the use of this parachute in numerous applications where high strength, low opening forces and freedom from oscillation were important or mandatory and a weight, bulk, and cost penalty could be accepted.

During the early 1940's, the English, as a result of a large number of wind tunnel experiments, established a design theory for the Exeter shaped canopy which uses fabric porosity as the major design parameter. In order to apply this theory, however, it was found necessary to revise their method of measuring cloth porosity since measurements made at low differential pressures did not give a reliable indication of porosity under parachute opening conditions. They determined that porosity measurement at a differential pressure of 10 inches of water was the minimum adequate pressure and standardized upon it. This design method required a wider range of canopy fabrics by porosity ranges than have been used in this country in order to accommodate a wide range of canopy performance and size requirements. This procedure has, apparently, been a workable one, since it has been used exclusively by them for practically all parachute design until recently.

In the early 1940's in Germany, because highly porous ribbon parachutes designed for maximum stability had exhibited unreliable opening characteristics, a new parachute was designed. This parachute, called the guide surface parachute, used low porosity fabric to insure inflation and achieved stability by its inflated shape. This, so far as is known, represented the beginning of a second parachute design approach which has come to be referred to as the radical shaping approach.

In the late 1940's in the United States, the extended skirt parachute and the personnel guide parachute were conceived as further extension of the family of shaped parachutes. During the same period, the ring slot or wide ribbon parachute and the rotofoil parachute were likewise conceived in the family of porosity controlled parachutes. Both families of parachutes have their proper uses. In each case, porosity is an important factor in performance and must be controlled. Furthermore, it has become evident that specifying fabric porosity measurement at a pressure differential of a half an inch of water is inadequate and a higher differential pressure more closely in line with pressures existing during parachute opening must be adopted in the United States as it was in England.

The first application design requirement which will be discussed is for the emergency parachute. Figure 1 lists requirements in relative order of importance. Such a parachute must be very reliable, capable of being deployed at a velocity of approximately 375 MPH for minimum altitude operation, without injury to the wearer. Its weight and bulk are to be as low as possible and rate of descent and degree of oscillation should not cause an excessive landing injury rate. It must be readily producible in large quantity production at reasonable cost. Very light-weight fabric can be used if adequately protected from damage during deployment since the parachute need only be capable of limited use. It must be capable of withstanding repeated repacking and be resistant to fungus, chemicals, and usable over a wide temperature range. For reliability, this parachute must satisfactorily pass stringent reliability tests. To do this it should utilize low porosity fabric. The low opening shock, oscillation, weight, bulk and rate of descent requirement dictate a special shaped design to achieve these aims at the possible expense of added cost.

The troop parachute has requirements similar to the emergency parachute. The relative order of importance is changed, however, as shown by Figure 2. Its reliability must be of the highest. It must provide tolerable opening shock at a speed of 175 MPH and a rate of descent and freedom from oscillation such that landing injury is a rare occurrence. It must be producible in large volume at low cost. Weight and bulk are of secondary importance and the parachute must withstand repeated use and rough handling without change in physical characteristics. It must be resistant to fungus and chemical deterioration and be usable throughout a wide temperature range. Once again a low porosity shaped canopy is indicated. A simpler more producible design of durable material should be used.

Figure 3 is a list of characteristics for aerial delivery parachutes. These parachutes, regardless of size, are used in a relatively small speed range. They must provide a high drag coefficient and be of such design that opening forces are moderate and oscillation should not exceed 15°. Reliability is not paramount. They must be constructed of durable, low-cost, readily available materials and designed for low cost production. The simplest design in which cloth porosity is the primary design parameter should be used.

Figure 4 lists design characteristics for two types of ordnance parachutes. In the ordnance field, parachutes are used to stabilize or they are used to decelerate bodies to specific terminal velocities with stabilization as a secondary objective. For stabilizing alone, a shaped parachute of low porosity fabric should be used since opening must be immediate and extreme stability is required. For retarding, either shaped or porosity controlled designs can be used. In general, porosity controlled designs of one type or another have been used to date with good results.

To stabilize, decelerate and recover missiles and targets from very high speeds, two or even three parachutes systems are required for tolerable deceleration and minimum bulk and weight. The first parachutes used to stabilize and decelerate the vehicle must inflate immediately and be almost completely free of oscillation through a wide range of velocities. Porosity controlled parachute designs cannot fulfill both of these requirements. Figure 5 lists the design characteristics for this application. Therefore, a shaped design of low porosity fabric should be used. The properties for the final descent parachute are similar to those for aerial delivery parachutes and a porosity controlled design of requisite strength should be generally used.

Figure 6 shows the design characteristics for an aircraft brake parachute. For the landing deceleration of aircraft, porosity controlled parachutes of the ribbon or more recently of the ring-slot design have been used. Either of these designs have been sufficiently oscillation-free over the range of speeds required for this application. Their low opening shock characteristics and the ease with which porosity and strength can be varied for various applications have made them highly suitable in this type of application.

Figure 7 lists characteristics of parachutes for in-flight deceleration of aircraft. For this application both ribbon and ring-slot designs have been tried. Both have been constructed and tested for the same application. A very high porosity has been found to be necessary to provide adequate freedom from oscillation over the required speed range and it appears that the designs are marginal on opening at the maximum speeds. Consequently, a shaped design is now being evaluated for this purpose.

It should be obvious from the preceding examples that a wide range of fabrics is required in parachute design both as to strength, porosity and durability. In every case, whether the design is based primarily on porosity, on shape or on a combination of both, the fabric porosity must be controlled within a relatively narrow range for satisfactory and consistent parachute performance. It should also be apparent that for heavily stressed parachutes such as those used for missile stabilization and deceleration, the fabric should show a minimum of porosity change with increase in pressure differential. For lightly loaded parachutes, such as are used for aerial delivery, a high rate of change of porosity with differential pressure should result in lower opening forces.

In the application of parachutes, certain problems arise which may be purely of material nature, which may be a combination of fabric design and fabrication processes, or which may be solved by a combination of fabric design and parachute system improvement. Some of the more urgent of these will be discussed.

Of these problems, the high temperature problem is perhaps the most urgent. In certain applications of parachutes to aircraft, the temperatures which may be expected within parachute compartments, either as a result of proximity to tailpipes, as a result of aerodynamic heating or a combination of the two, will be very high and will undoubtedly require artificial cooling. The development of new fibers or of treatments which will enable present fibers to withstand exposure to higher temperature will result in reduction in weight of air conditioning equipment needed to cool these compartments. To show the urgency of this problem, parachute compartments being designed at present and using only a limited amount of cooling air are expected to attain temperature of 300°F. Satisfactory parachute performance is expected with such a compartment temperature through use of dacron which has shown good resistance to heat degradation at such a temperature.

In the not too far distant future, it is anticipated that parachutes may have to operate at elevated temperatures due to aerodynamic heating effects in the parachutes themselves. To date, no satisfactory textile material for such a contingency is known.

Another serious problem is the friction burning or fusing of parachute canopies during deployment. It is not wholly a textile problem, however, a reduction in damage caused to the canopy when difficulty arises might be very beneficial. It can be stated that such damage occurs as a result of poor parachute deployment and subsequent partial or full inversion of the canopy. A secondary cause may be the result of drawing the parachute canopy over some portion of a pack, human body or cargo load during deployment. Improvement of deployment systems can markedly reduce the occurrence of either type of damage but not to the point of complete elimination at present. These improved deployment systems add to cost, increase weight and bulk, and increase repacking time of the parachute. In the field of personnel parachutes, these penalties appear to be justified for the sake of reliability but are not complete cures. In the field of small aerial delivery parachutes, the techniques used to deliver supplies from the aircraft and the added packing and rigging time of more complicated deployment systems do not appear to permit use of good deployment aids. As a result, heavy and durable fabrics must normally be used in such applications.

As was previously stated, missile stabilization and deceleration parachutes which must operate over a wide speed range should preferably be of a shaped design. Experience at supersonic velocity with ribbon parachutes to date has demonstrated incomplete inflation at deployment and objectionable oscillation in the low speed range following full inflation. Experience with shaped low porosity designs, on the other hand, has indicated that high frequency vibrations of some seamed portions of these canopies tend to whip seams apart even though the stitching was still intact. It is possible, therefore, that at still higher velocities, it may be necessary to develop other means than stitching for forming some seams of such parachutes to overcome this difficulty.

The use of large aircraft deceleration parachutes and the aerial delivery of heavy loads has imposed a requirement for high strength webbing risers. These must be designed for the imposed load plus a minimum safety factor. This has resulted in a requirement for webbing risers having an ultimate strength of close to 100,000 pounds. Where multiple layers of webbing have been used, a maximum strength of about 60,000 pounds has been achieved in the laboratory. It is feared, however, that poor stitching practice in manufacture, during which a sewing machine operator does not replace a blunted needle or uses too high a stitching speed, may result in marked reduction in strength of such parts even though no visual defects are evident. An extensive program of re-design of attachment means for webbing and of the webbings themselves appears required to provide a satisfactory solution to this problem.

In summary then, parachutes are used and will continue to be used only as long as they continue to reliably provide greater drag at a cost of less bulk, weight and dollars than other means of accomplishing the same results.

The parachute designer has available for use two different design approaches which can be used separately or in combination, namely the porosity control approach and the radical shaping approach. Each approach has its proper place in parachute design work.

Porosity, strength, weight and thickness are important fabric parameters in either approach and must be accurately controlled within specified narrow ranges for any parachute design, if satisfactory and consistent operation is to be achieved.

There are numerous problems which require the best efforts of both textile designers and parachute designers for adequate solutions.

EMERGENCY PARACHUTES

- Reliability of Inflation
- Bulk and Weight
- Opening Shock
- Operable at High Speed
- Rate of Descent
- Stability
- Ease of Manufacture
- Environment
- Ease of Maintenance

Figure 1. Design Requirements - Emergency Parachute.

TROOP PARACHUTE

- Reliability of Inflation
- Rate of Descent
- Stability
- Durability
- Opening Shock
- Ease of Manufacture
- Bulk and Weight
- Environment
- Ease of Maintenance

Figure 2. Design Requirements - Troop Parachute.

AERIAL DELIVERY PARACHUTES

- Durable
- Ease of Manufacture and Low Cost
- Non-Critical Materials
- Reliability of Inflation
- Ease of Maintenance
- Rate of Descent
- Stability
- Opening Shock
- Bulk and Weight
- Environment

Figure 3. Characteristics for Aerial Delivery Parachutes.

ORDNANCE PARACHUTES

Stabilization type-

- Extreme Stability
- Strength for High Speeds
- Immediate Opening Reliability
- Bulk
- Ease of Manufacture
- Environment of use
- Drag

Deceleration type-

- Strength for High Speed
- Ease of Manufacture
- Limited oscillation
- Reliability of Inflation
- Bulk
- Drag
- Environment of use

Figure 4. Design Characteristics for Two Types of Ordnance Parachutes.

MISSILE STABILIZATION AND DECELERATION PARACHUTE

- Stability over a Wide Speed Range
- Strength
- Reliability of Inflation
- Environment
- Drag
- Bulk
- Weight
- Cost

Figure 5. Design Characteristics for Missile Stabilization and Deceleration Parachute.

AIRCRAFT BRAKE PARACHUTE

- *Limited Oscillation*
- *Strength*
- *Reliability of Inflation*
- *Environment*
- *Opening Forces*
- *Drag*
- *Weight*
- *Bulk*
- *Cost*
- *Ease of Maintenance*

Figure 6. Design Characteristics for Aircraft Brake Parachutes.

IN-FLIGHT DECELERATION PCHT.

- No Oscillation
- Strength
- Reliability of Inflation
- Environment
- Opening Forces
- Drag
- Weight
- Bulk
- Cost
- Ease of Maintenance

Figure 7. Characteristics for In-flight Deceleration Parachute.