

# Structural and permeable contortion of parachute canopy fabrics under repetitive impact loading

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The study evaluates the structural deformation and changes in air permeability in plain-woven and ripstop parachute canopy fabrics stitched at 0° and 45° seam angles under repetitive impact loading. Results indicate that specimens with 0° seam angles are highly deformed at seam lines after a single impact load and cause a significant change in air permeability. These specimens experience complete damage at the seam lines after 3 to 4 impact loading cycles. Ripstop fabric demonstrates greater dimensional stability for a 45° seam angle, while plain-woven fabric shows higher recoverability during and after relaxing from repetitive impact load cycles. The findings reveal that air permeability increases at seam lines with successive impact loading cycles. Additionally, the plain-woven fabric samples exhibit higher air permeability and increments in permeability compared to ripstop fabric samples under repeated impact loading cycles.

**Keywords:** Air permeability, Impact loading, Plain-woven, Ripstop fabric, Seam angle, Structural deformation

## 1 Introduction

The average effective lifespan of a typical parachute canopy is 1,000 to 1,600 jumps<sup>1,2</sup>. With each jump, the parachute canopy opens, deforms, or expands<sup>2,3</sup> and recovers depending upon the constructional parameters of the canopy and the level of opening shock force with corresponding aerodynamic conditions. The number of jumps and the corresponding opening shock force of the parachutes may change the canopy's characteristics in terms of tensile strength, structural configuration, and air permeability. The change in the aforementioned properties may negatively affect the parachute's performance, especially the change in canopy permeability may affect the oscillation amplitude and the average value of the drag coefficient of the parachute<sup>4</sup>. Also, the change in the dimension of the canopy may affect the parachute's performance. Since the parachute canopy is a multi-component structure, seamed by several panels and gores<sup>5</sup>, thus the opening shock force is shared through the seamlines, individual panels, and gores of the parachute canopy<sup>6</sup>. Additionally, assessing the change in the complete material properties of the entire parachute canopy is always tough as its testing demands more space, energy, and cost issues.

Previous studies have explored specific characteristics of parachute canopies, e.g., how the permeability of parachute fabric changed under various aerodynamic circumstances. Goglia *et al.*<sup>7</sup> measured the air permeability of various standard parachute cloths under pressure differentials across the cloth. Gibson *et al.*<sup>8</sup> studied the influence of the parachute fabric's porosity and air permeability during the rate of steady-state descent and also discussed the effect of the fluid-structure interactions during parachute opening and deployment. Desabrais *et al.*<sup>9</sup> determined the change in permeability and performance of the parachute canopy on repeated usage. Rondeau *et al.*<sup>10</sup> analysed the permeability of parachute fabric under steady and unsteady pressure differential. Yang *et al.*<sup>4</sup> applied the Ergun formula to explain the fabric's dynamic air permeability, or how it varies in response to pressure differences between the canopies. Zhang *et al.*<sup>11</sup> introduced the Ergun theory of porous medium to establish the model of air permeability and the differential pressure between canopies considering the airflow during the decelerating process of parachutes.

Recent studies have employed small-scale impact testing of a parachute canopy where a small rectangular seamed parachute canopy fabric is exposed to impact force to characterise the entire parachute canopy<sup>6,12-16</sup>. However, the change in structural configuration and air permeability of the parachute canopy during impact loading cycles and

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significantly (Fig. 2), especially at the seam line, compared to those with a 45° seam angle. The test specimen comprises two seam lines, and each stitch point of seam lines represents a gripping zone of warp/weft yarns. In the 0° seam configuration, the stitch points (gripping zones) are perpendicular to the warp/weft yarns [Fig. 3 (a)]. Furthermore, the present impact force causes the specimen to stretch lengthwise, and the gripping zones of the top and bottom seam lines easily pull the respective gripped weft/warp yarns toward each other. This may be due to pre-existing holes created by needle penetration during the stitching process, and these holes expand under impact loading. This pulling action of the top and bottom seam lines in the 0° seam angle of the specimen causes a type of seam damage, as depicted in Figure 2. However, in 45° seam angle, the angular orientation of the warp and weft yarns enables the yarns to be grasped by either jaw lines or seam lines [Fig. 3 (b)]. This configuration of the 45° seam angled specimen allows for greater extension and limits the

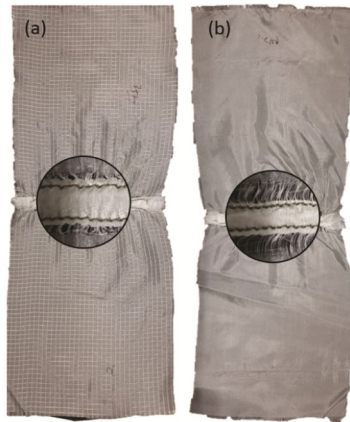


Fig. 2 — Damaged seam lines at a 0° seam angle for (a) ripstop and (b) plain-woven fabric

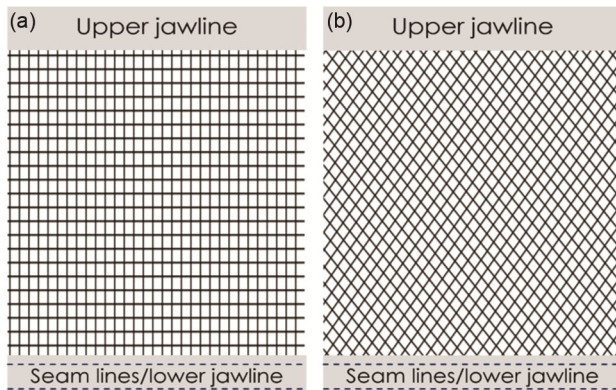


Fig. 3 — Yarn orientation for specimens seamed at (a) 0° and (b) 45° seam angle

direct transmission of impact force from one gripping zone to another, resulting in less or negligible damage than the 0° seam angle.

Ripstop fabric exhibits less deformation than plain-woven fabric (Fig. 2) as it consists of extra thicker yarn in regular intervals, creating more resisting capacity towards impact force. Moreover, both fabric specimens with a 0° seam angle lost their structure completely from the seam line after 3 to 4 impact load cycles, while the fabric with a 45° seam angle sustained (Fig. 4); thus, it continued to perform after up to 25 cycles of impact loading.

Ripstop fabric is also more resistant to elongation and recovery loss, with minimal change in structure even after repeated impacts. Figure 5 illustrates the deformation (in the form of peak extension %) and recovery with the application of impact loading for up to 25 repetitions for specimens with a 45° seam angle. It can be seen that the deformation rate of both specimens increases, and the recovery percentage decreases with the number of impact loading cycles. There is a significant difference between ripstop and plain-woven fabric for change in peak extension and recovery during the repetitive impact loading cycle. However, for both Fig. 5(a) and (b), there is no marginal increase or statistical difference for each fabric sample during the increment of the impact load cycle. This is because the difference of 5 impact cycles causes minor changes in the elastic range and results in marginal changes in elongation and recovery %. Moreover, this variation increases between the gap of 10 impact load cycles or more.

The ripstop and plain-woven structure of 45° seam angle shows good extension and recovery to repetitive impact loading. Both fabrics are constructed of nylon fibre and are expected to extend and recover in a

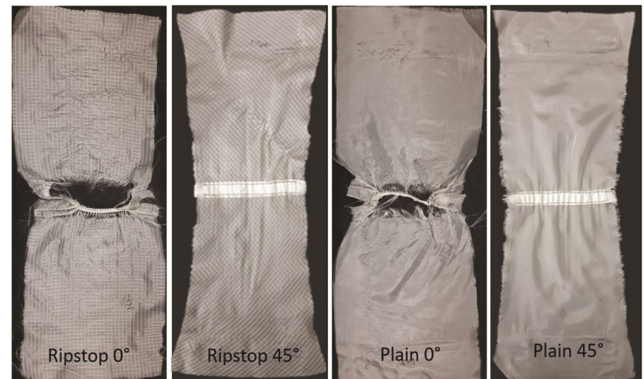


Fig. 4 — Seam failure at 0° seam angle and sustained at 45° seam angle

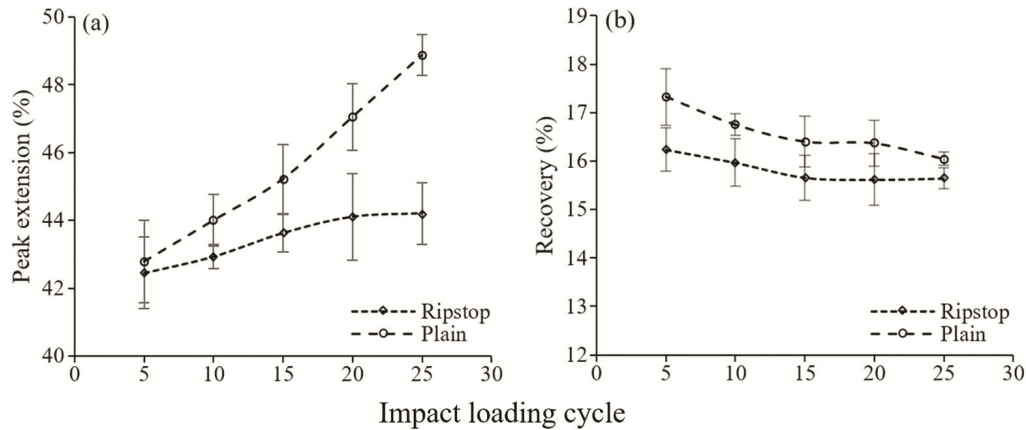


Fig. 5 — (a) Peak extension and (b) recovery characteristics of plain-woven and ripstop fabrics under repeated impact loading cycles

similar manner; however, due to structural differences between plain-woven and ripstop fabrics, the ripstop fabric specimen shows lesser extension and lower recovery under different impact loading cycles. In the ripstop fabrics, there are additional thicker yarns at regular intervals, which prevents further extension and subsequent recovery as in plain-woven structures. Due to the aforementioned construction, the degradation of ripstop fabric is minimal, with up to 25 impact cycles, resulting in no statistical change in recovery percentage. Plain-woven fabric produced a slightly higher change in recovery %. Furthermore, plain-woven fabric deteriorates more structurally than ripstop fabric when subjected to higher impact cycles. This phenomenon causes plain-woven fabrics to extend relatively more, and the mean extension percentage rises as the number of impact loading cycles increases. Due to structural damage, the recovery % of plain-woven fabric dropped after 20 impact loading cycles.

### 3.1.2 After Removal of Load

After impact loading (5, 10, 15, 20, and 25 cycles), specimens are removed from the tester and relaxed for 24 hours. Visual analysis (Fig. 6) reveals that ripstop fabric exhibits slightly higher permanent deformation than plain-woven fabric. This is due to the lower recovery characteristics of ripstop fabric. The extended length and width shrinkage comparison has been plotted in Fig. 7.

There is a clear statistical difference between ripstop and plain-woven fabric for extended length and width shrinkage after applying different impact load cycles. The length and width change simultaneously, i.e., the length expands, and the width shrinks for both specimens. However, compared to

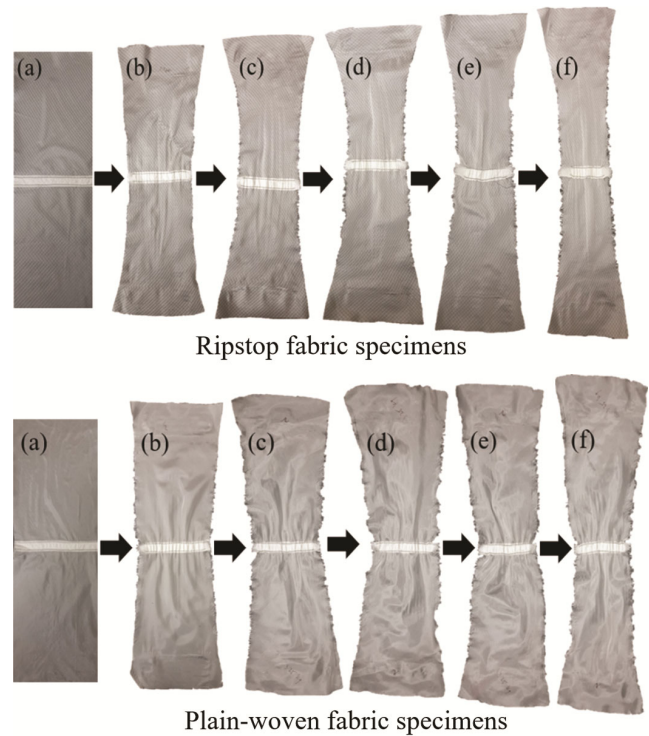


Fig. 6 — Structural changes in the ripstop and plain-woven fabric after (a) 0, (b) 5, (c) 10, (d) 15, (e) 20 and (f) 25 impact loading cycles

plain-woven, the ripstop fabric samples extend less during impact and recover less after removing the impact load (considering a 24 h relaxation). This behaviour of the ripstop fabric causes a higher permanent set in terms of extended length than plain-woven fabric (Fig. 6). With the increase in impact loading cycles, the extension in length increases for both fabric samples. Nevertheless, due to a maximum loss in elasticity, the extended length of the ripstop fabric sample suddenly increases after 15 impact load cycles. The plain-woven fabric sample shows higher

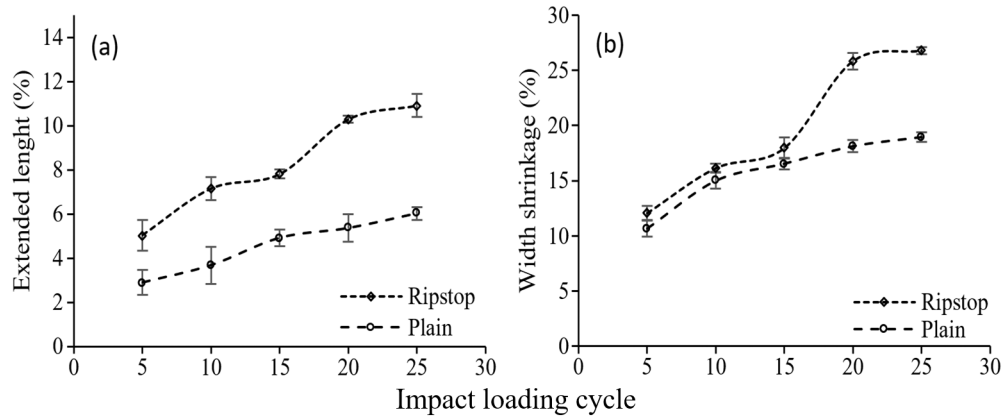


Fig. 7 — Relative permanent structural changes in (a) extended length and (b) width shrinkage for ripstop and plain-woven fabrics after different impact loading cycles

recovery during and after impact loading, which causes relatively lower permanent extension in length than the corresponding ripstop fabric.

Width shrinkage also follows a similar trend. Ripstop fabric shrinks more in width than plain-woven fabric, particularly after 15 cycles, stabilizing beyond 20 cycles as elasticity loss reaches a maximum (Fig. 7).

**3.2 Change in Air Permeability after Application of Impact Load**

The air permeability of the parachute canopy may influence its opening, steady-state descent characteristics, fluid-structure interactions, and stability of the parachute during descending<sup>8,18,19</sup>. Thus, the current study investigates the change in air permeability of ripstop and plain-woven fabrics after repeated impact loading cycles.

For specimens with a seam angle of 0°, impact loading substantially affects the seam region more than the non-seam region. As already discussed, after a single impact load, fabric samples sewn at 0° seam angle exhibit seam shrinkage, which creates prominent holes near the top and bottom seam lines (Fig. 2). These holes increase the air permeability by about 2.5 and 3.5 times for ripstop and plain-woven fabric samples, respectively (Table 2). The air permeability in unseam areas for both fabric samples remains significantly unaffected after a single impact load. After 3 to 4 impact loading cycles, the 0° seam angle fabric loses its structure completely from seam lines (Fig. 4). Given the huge change in air permeability and complete failure of the structure from seam lines, a 0° seam angle is not recommended for parachute canopies, especially for higher payload or critical aerodynamical circumstances. Therefore, the air permeability of

Table 2— Air permeability of 0° seam angle ripstop and plain-woven fabric specimens after a single impact load

Area	Fabric type	Air permeability	
		Before impact load	After a single impact load
Seam area	Ripstop	41.2 (0.7)	117.7 (1.4)
	Plain-woven	64.5 (1.4)	214.5 (8.6)
Unseam area	Ripstop	58.0 (1.2)	58.3 (1.0)
	Plain-woven	88.3 (3.1)	88.4 (2.1)

Values in parentheses indicate standard deviation

ripstop and plain-woven fabric specimens with a 45° seam angle is evaluated after impact loading cycles ranging from 5 to 25, as shown in Fig. 8.

As shown in Fig. 8 (a), there is a statistical difference in the change of air permeability between ripstop and plain-woven fabrics for different impact loading cycles. Due to the limited number of needle holes compared to the rest of the projected area of the specimen and even due to the folded pattern of the fabric in the seam area, it shows less air permeability than the unseamed area. Furthermore, the plain-woven fabric has a looser structure (higher mobility of warp/weft yarns under constant air pressure) than ripstop fabric as it doesn't have extra thicker yarn at regular intervals; this results in both seam and unseam areas having higher air permeability comparably. Moreover, due to high random structural deformation in both seams and unseam regions, the plain-woven fabric specimens exhibit higher relative variability in air permeability compared to ripstop specimens. It is also noticeable that the number of impact loading cycles increases the air permeability, especially at the seam region, more than the unseam region for both fabric structures. This is due to the width of the seam area shrinking (Fig. 6) and the size

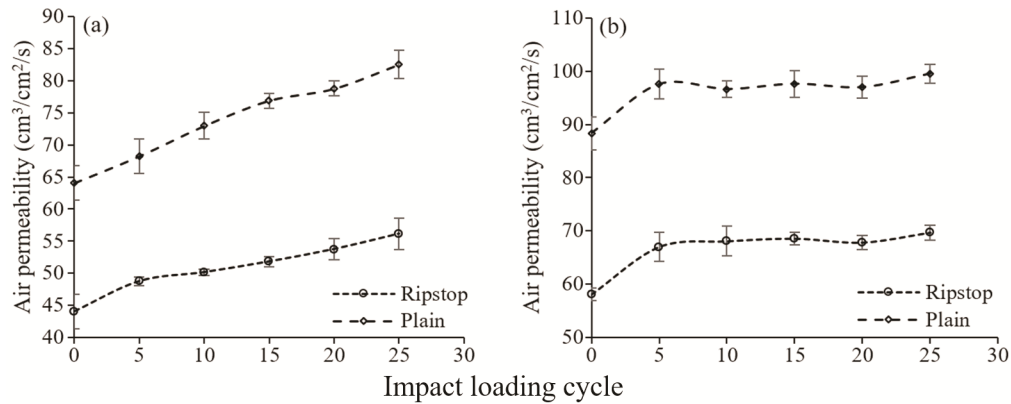


Fig. 8 — Change in air permeability of ripstop and plain-woven specimen at (a) seam region and (b) unseam region under different impact loading cycles

of the holes through which the penetrated sewing thread (needle holes) also increasing longitudinally with the number of impact loading cycles. Due to constructional differences, the ripstop fabric distorts less in the seam region than plain-woven fabric after 25 impact loading cycles, as shown in Figure 9. This results in less relative change in air permeability for ripstop fabric after different impact loading cycles.

On the other hand, the unseam area is less affected than the seam area, and the air-permeability increases after five impact loading cycles for both specimens [Fig. 8 (b)] due to instant impact load causing loosening of structure without affecting the pore size. Thereafter, the air-permeability for both specimens did not increase significantly from 5 to 25 impact loading cycles. In the unseam area, there is an increase in length and a decrease in width simultaneously under repetitive impact loading. Additionally, in both specimens, the shape of pores is changed at a marginal level with negligible change in total area. The reasons above justify the negligible change in air permeability for both specimens from 5 to 25 impact loading cycles.

Both specimens stitched at 45° seam angles show a gradual change in air permeability at the seam region with the different impact loading cycles. The unseam areas are mainly unaffected by repetitive impact load. Structural stability (change in dimension and air permeability) is more crucial while using a parachute for repeated jumps; therefore, the ripstop with a 45° seam angle can be preferred over the plain-woven fabric. Similarly, plain-woven fabric with the same seam angle lower opening force scenarios or single application (e.g., bomb or ammo dropping) as its structural stability is lower than ripstop fabric.

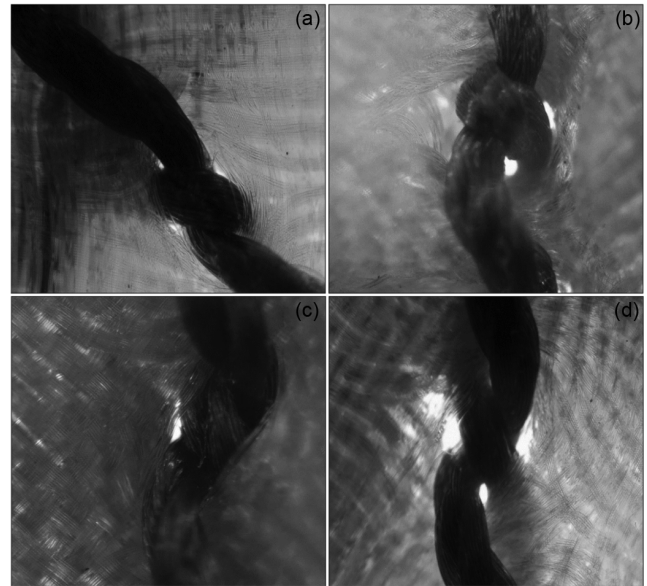


Fig. 9 — Needle penetrated holes in seamlines of (a) ripstop fabric before, (b) after 25 impact loading cycles; (c) plain-woven fabric before, (d) after 25 impact loading cycles

#### 4 Conclusion

The study demonstrates that the air permeability and structural stability of parachute fabrics are significantly influenced by seam angles and repeated impact loading cycles. Fabrics with 0° seam angle exhibit severe seam degradation after a single impact load and a huge change in air permeability. It is concluded that 0° seam angle configurations are unsuitable for critical aerodynamic scenarios and repeated use due to rapid seam line deformation and structural collapse within a few loading cycles. Reinforcement using parachute tape could mitigate seam line damage in such configurations. Fabrics with a 45° seam angle demonstrate greater resilience, with

ripstop fabric offering higher structural stability and lower changes in air permeability, making it ideal for repeated use and durability-focused applications. In contrast, plain-woven fabric, with its higher extension and recovery characteristics, is more suitable for single-use scenarios like bomb or ammunition deployment. These findings underscore the importance of fabric type and seam orientation in optimizing parachute canopy performance.

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