Development a Shock-Absorbent Attachment for Skydiving Shoe

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Keywords: Skydiving, Safe landing, Impact absorption, Woven, Shoe attachment.

I. INTRODUCTION

Skydiving involves high landing impact forces that place skydivers at considerable risk of lower limb injuries, which account for nearly 51% of all reported cases, with 83–90% occurring during the landing phase [1]. High-speed ground contact can exceed biomechanical tolerance limits (6.75 kN for the ankle, 10 kN for the femur, and 9.5 kN for the pelvis), leading to fractures [2]. Current practice of using standard running shoes is inadequate, as amateur skydivers experience average ground reaction forces of ~4,380 N, which approach the ankle's tolerance level, while conventional footwear absorbs only about 12.7% (~689.92 N) of this load[3]. To address this issue, the present study proposes a shoe sole attachment design to absorb and dissipate landing impact forces through compression during ground contact. The mechanism draws inspiration from automotive airbags, which reduce the forces transmitted to the human body during an accident by carefully releasing air through vent holes. Similarly, in this design, the sole attachment uses the air permeability of airbag fabric, enabling controlled air release upon compression to mitigate landing forces.

II. LITERATURE REVIEW

Skydiving often leads to a high incidence of leg injuries, with 83–90% of injuries occurring during landing. Fractures represent 47% of serious injuries, while lumbar spine injuries account for 19%[4].A Swedish study reported that 51% of all skydiving injuries involved the legs. Similarly, a Danish study analyzing 110,000 jumps found that 63% of medically treated lower extremity injuries were fractures[1]. Both studies consistently highlight that many of these injuries, approximately 83–90% occur during landing[4].

Innovative technical solutions proposed in the patent domain have introduced airbag-based soles[5]and military boots with complex pressure recoil systems[6]. One design uses a dual-airbag sandwich structure in the sole, where foam-filled airbags inflate before landing and release air upon ground contact to dissipate impact energy. Another patent features military boots with inflatable air chambers and a wax-sealed water reservoir. An electric pump pre-tensions the air chambers, while sensors trigger the release of water at landing to create a recoil effect that opposes the impact force. Existing patents propose novel impact absorption concepts but lack quantifiable evidence of force reduction. This highlights the need for a validated solution to attenuate forces during high-speed landings. A fabric-based air component, inspired by automotive airbags, offers a promising approach. By regulating fabric air permeability, collision time can be extended, reducing peak impact forces and enhancing landing safety.

III. METHODOLOGY

A. Product Description

Fig 1: Final prototype

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- Woven Midsole Component: Designed using woven fabric with controlled air permeability, this component inflates upon detecting high-speed landing velocity. It absorbs impact by compressing and gradually releasing air through the woven material, increasing collision time and reducing impact force.
- Fixing Insole Component: A component that securely attaches the system to the skydiver's shoe.
- Outsole Component: This part serves as the primary contact surface with the ground, providing high abrasion resistance.

The attachment is activated through real-time monitoring of altitude and acceleration using barometric and MPU sensors. When the MPU sensor detects a specific acceleration within a predefined altitude range, typically from ground level up to 100m, the system is triggered. It initiates air inflation within 1 second based on real-time sensor data. The inflation process continues until the skydiver reaches the ground, providing adequate cushioning to mitigate impact forces. Upon ground contact, the woven midsole component undergoes controlled compression. The woven fabric's permeability allows air to be released gradually, extending the time over which the impact occurs. This controlled air release reduces the force exerted on skydivers. As a result, the system minimizes the risk of lower limb injuries.

B. Woven Midsole Component

The woven midsole component is made using silicon-coated PA66 fabric, as shown in the specification table below.

TABLE I

Property		Specifications of the Woven Midsole	Specifications of the Automobile Airbag
Fiber type		PA66	PA66
Weave		Plain	Plain
Silicone coated		Coated	Coated
EPI		45	44
PPI		42	42
Thickness (mm)		0.3	0.4
Fabric GSM		208	240
Breaking strength (N)	Warp	2040	2560
	Weft	2060	2500
Tearing strength (N)	Warp	255	525
	Weft	280	500
Bursting strength (kPa)		348.5	350
Air permeability (L/min)		1.7	1.8

The fabric material specifications were the same as the airbag materials used in the automotive industry[7]. But the air permeability and the bursting strength of the material are calculated as per the requirement of the proposed shoe sole attachment design, as in the equations below.

The required bursting strength was determined by referencing the maximum force at which a lower limb bone fractures, which is 10 kN [2].Since skydivers experience forces arising from both body weight and impact during landing, the fabric's bursting strength must withstand the resultant force from these combined effects. For this study, calculations were performed using a maximum skydiver weight of 114 kg[8] and the standard foot area was taken as UK size 10 (29cm × 11cm). By the definition of pressure, the maximum pressure exerted on one foot can be expressed as follows.

$$P = F/A \quad (1)$$

$$P = (10\,000+114 \times 9.81) /0.0319 = 348{,}537 \text{ Pa} \quad (2)$$

To ensure the functionality of the component during deployment, the required air permeability of the fabric was calculated by analyzing the volume of air released during the complete inflation period.

So, the air permeability of the fabric Q is determined by the equation (3) based on the number of air molecules released during the inflation time (n_a), molecular weight of air (M), air density (ρ) and inflation time (t).

$$Q = \frac{n_a M}{\rho t} \quad (3)$$

Based on this formulation, the air permeability requirement for the fabric is determined to be 1.7 L/min, as calculated for an inflation time of 1 second.

C. Design of the Woven Midsole

The woven midsole component is designed as a cuboid-shaped air chamber. The thickness of the midsole was determined as 9 cm based on the air volume required to transfer the total air content from the canister into the woven air chamber.

The woven fabric was assembled using a specialized sewing technique. Polyamide 66 (PA66) sewing thread with a linear density of 70 tex and a tensile strength of 5115 cN was selected to ensure seam durability under inflation pressure. To achieve airtight construction, stitching was performed using a two-thread chainstitch method.

D. The Fixing Sole and Outsole Components

TPU is used for fixing the sole and outsole components that are based on their mechanical properties and performance under varying conditions.

E. Activation System

An MPU sensor and a barometric sensor were used to activate the inflation of the woven midsole component. The MPU sensor detects the skydiver's acceleration, while the barometric sensor measures the predefined altitude at which activation occurs.

F. Impact Evaluation Test of the Woven Midsole Component

This test is designed to evaluate the reduction of impact forces provided by the woven midsole component. Four 50 kg load cells and an Arduino Nano serve used for the test

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setup. Tests were carried out both without and with the midsole under identical conditions to generate comparable force-time graphs.

A 3.6kg concrete cuboid, along with the sensor platform as shown in the Figure below, was dropped vertically from two heights: 40 cm and 60 cm. For each height, three drops were recorded to obtain more accurate values.

Fig 2: Test setup with concrete cuboid

To validate the compatibility of this attachment for the real scenario, conduct a human trial. In the second stage, a 76 kg individual performed a drop jump from a height of 40 cm.

Fig 3: Test Setup for human trial

As both the human and the concrete drop tests were carried out under laboratory conditions, the human trial was limited to a 40 cm drop. The results of the human trial were validated using the 40 cm concrete drop test, while the 60 cm concrete drop test was used to evaluate the performance of the equipment with the concrete cuboid.

IV. RESULTS AND DISCUSSION

As described in the methodology, a 3.6 kg cuboid was dropped from two different heights, 60 cm and 40 cm, both with and without the midsole. Each configuration was tested three times, and the results were plotted in Fig. 4-5.

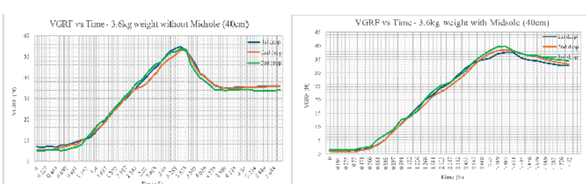

Fig 4: VGRF vs Time graph-3.6kg weight (40cm)

When the cuboid was dropped from a height of 40 cm without the midsole, the VGRF rose to 54–55 N and peaked at 3.3 s. With the woven midsole in place, the peak force reduced to 38–40 N, while the time to peak increased to 3.9 s. This showed a 28% reduction in peak force along with a 0.6 s increase in collision time.

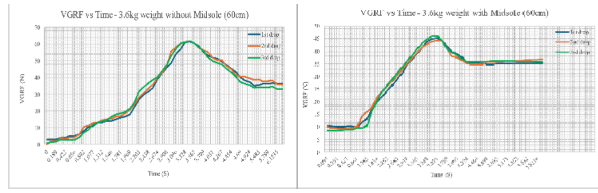

Fig 5: VGRF vs Time graph-3.6kg weight (60cm)

When the cuboid dropped from 60 cm without the midsole, the VGRF quickly reached 62 N at 3.3 s. With the woven midsole, the peak reduced to 45–46 N, and the time to peak extended to 3.7 s. This resulted in a 27% reduction in peak force and a 0.4 s increase in collision time.

The impact evaluation test with a concrete cuboid showed a reduction in impact force by 27–28%, accompanied by an increase in time to peak (or collision time) by 0.4-0.6 seconds.

To validate the compatibility of this attachment for the real scenario, conduct a human trial as mentioned in the methodology.

Fig 6: VGRF vs Time graph -76kg human trial (40cm)

During the jump without the midsole, the VGRF peaked sharply at 5700 N within 1.4 s before stabilizing at 1000 N. But with the inflated woven midsole, the peak force was reduced by over 95% to 225 N, while collision time more than doubled to 3.8 s. Since conventional footwear absorbs only about 12.7% (~689.92 N), the results show that this equipment can absorb more than twice that amount.

V. CONCLUSION

The shock-absorbent attachment for skydiving shoes using a woven midsole shows potential in reducing impact forces during landing. Initial testing indicated that the midsole may reduce peak ground reaction forces by approximately 27–28%, suggesting its effectiveness in helping to mitigate lower limb injury risks for skydivers. These findings provide a valuable first step toward developing improved protective footwear for skydiving.

VI. REFERENCES

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