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(54) **HEADGEAR SYSTEMS WITH AIR-BUBBLE CUSHIONING LINER FOR IMPROVED SHOCK ABSORPTION PERFORMANCE**

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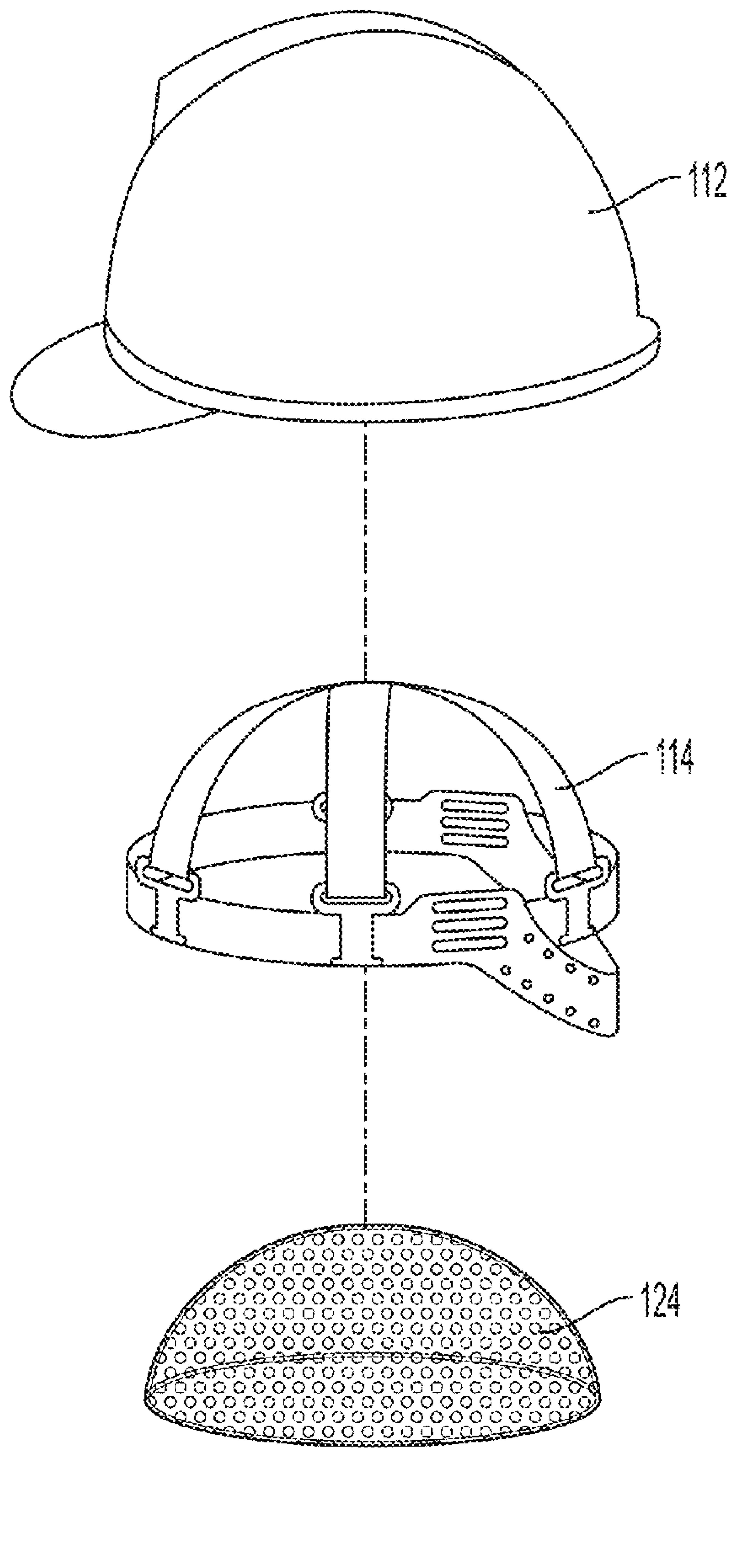
A42B 3/12 (2006.01)

(52) **U.S. Cl.**
CPC *A42B 3/121* (2013.01)

(57) **ABSTRACT**

The present disclosure provides headgear protection systems for preventing or reducing work-related traumatic brain injury and/or risk. More particularly, the disclosure provides headgear systems having an air-bubble cushioning liner to improve shock absorption performance.



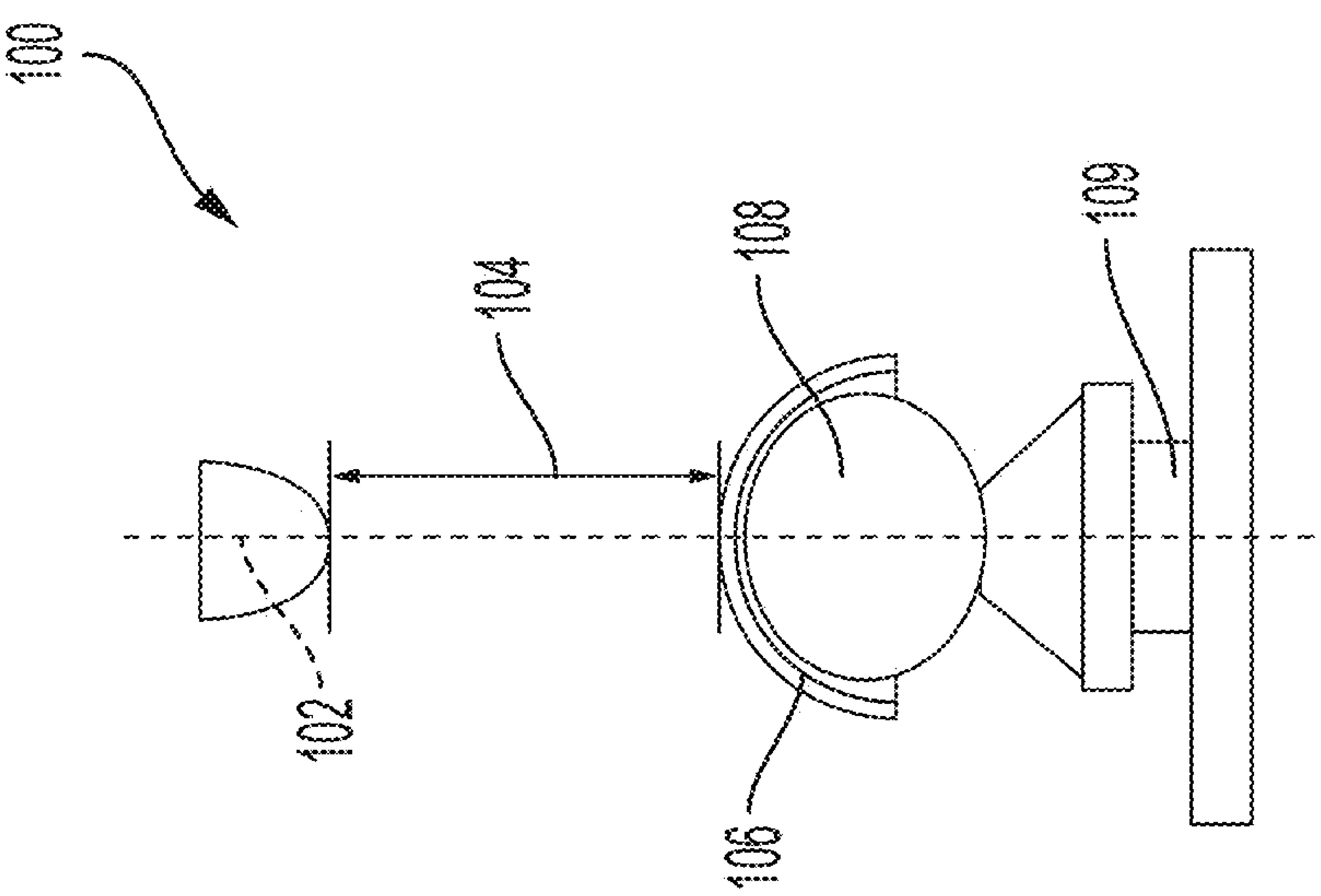


FIG. 1A

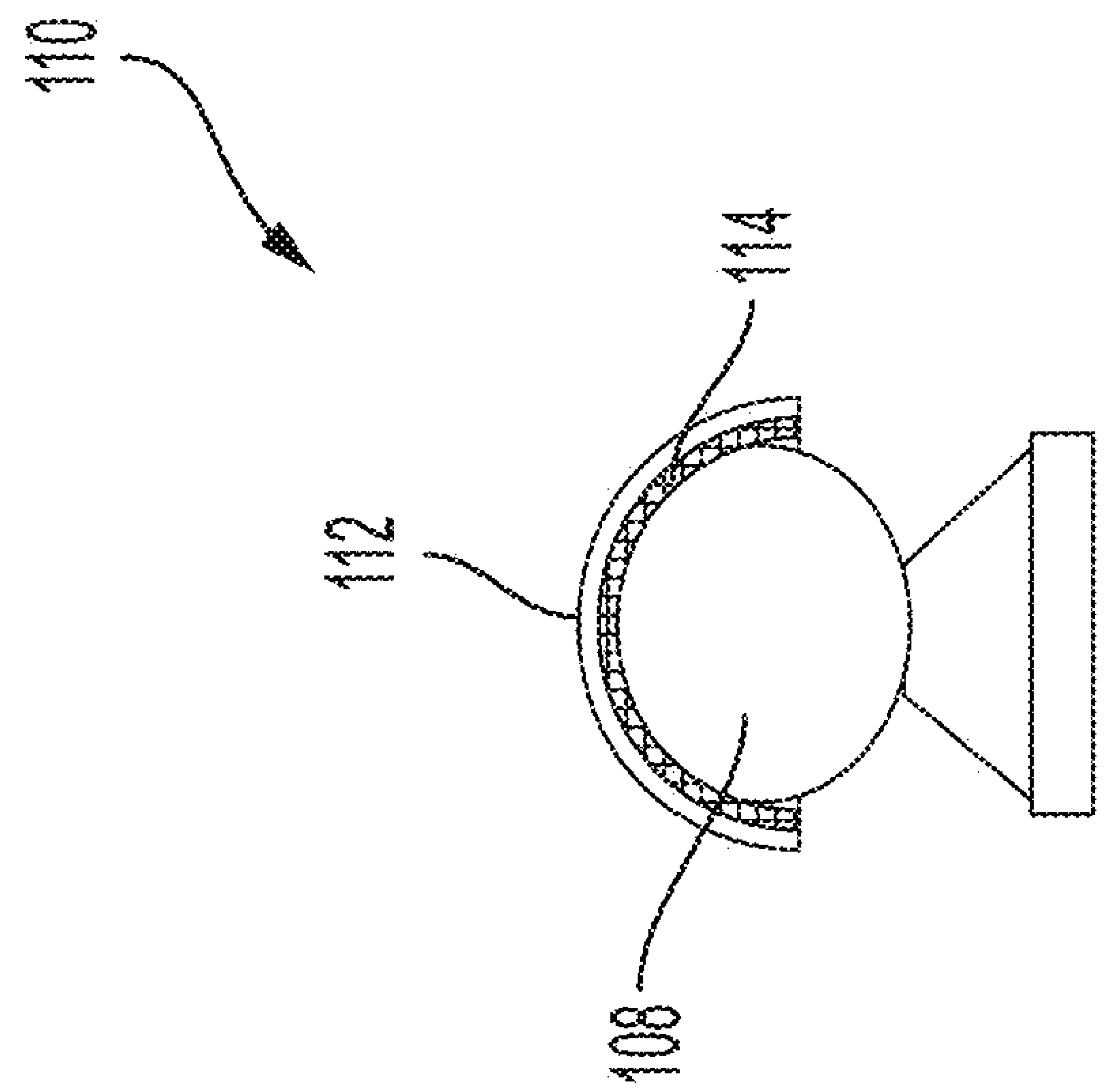


FIG. 1B

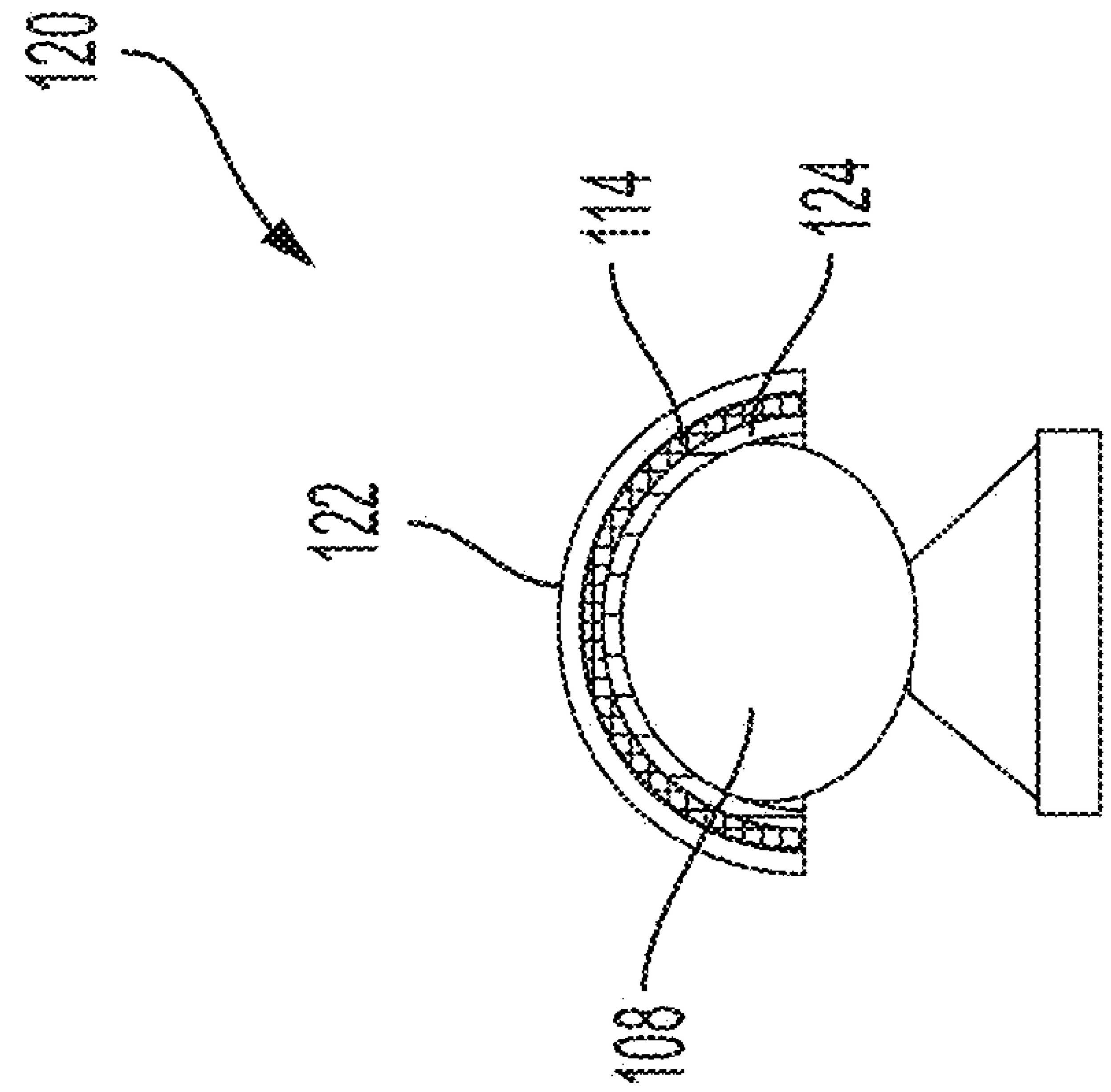


FIG. 1C

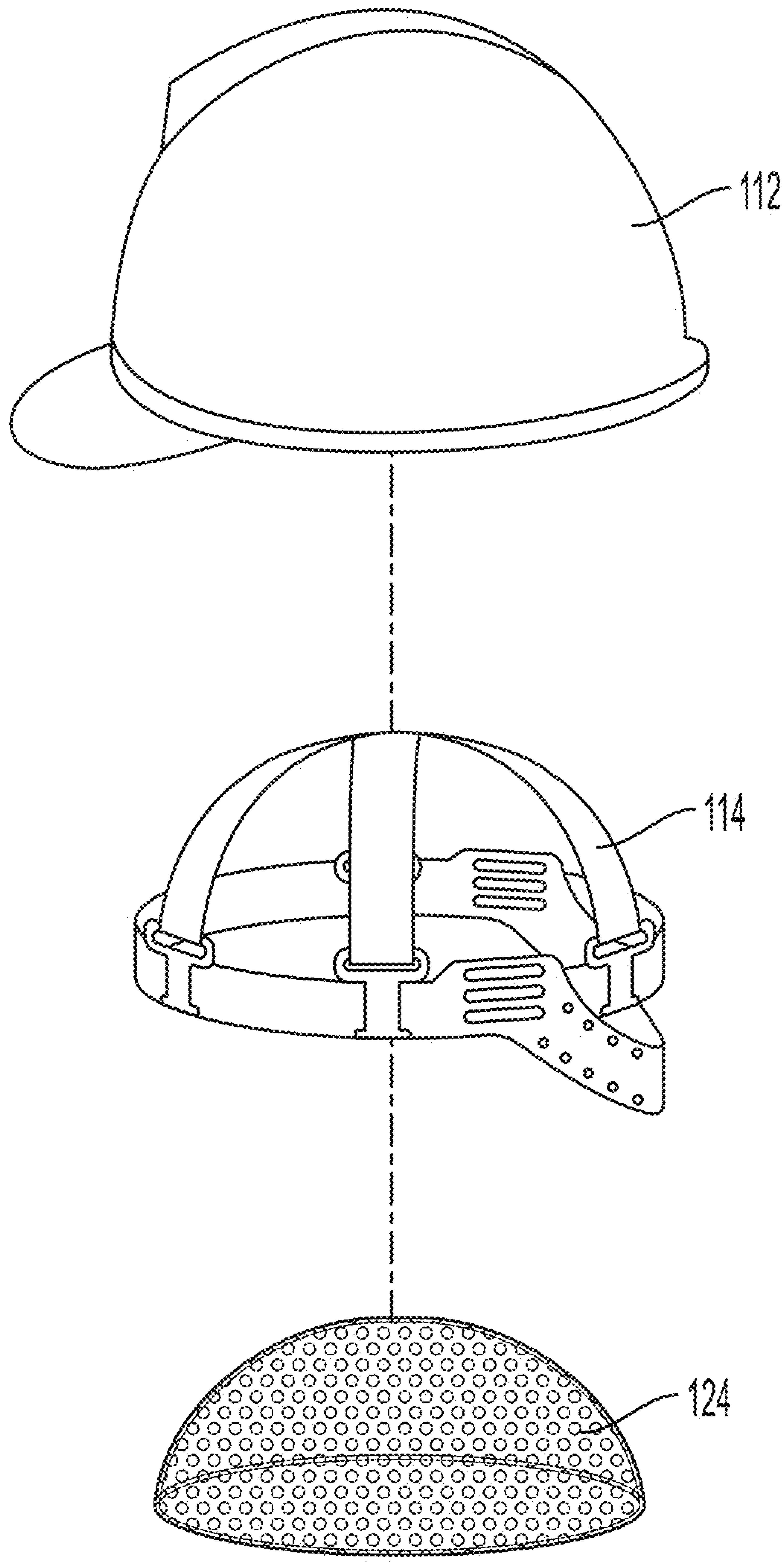


FIG. 1D

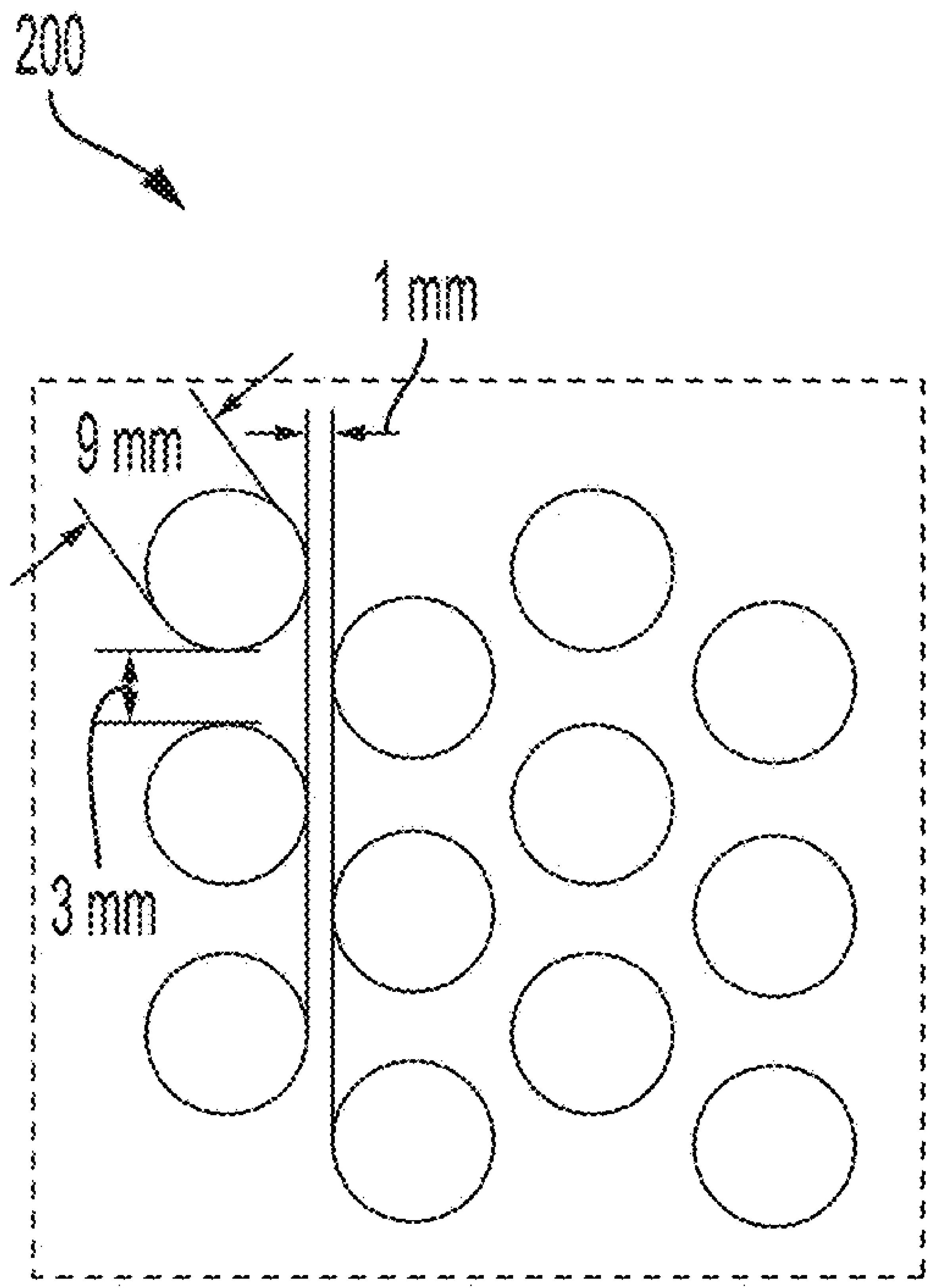


FIG. 2A

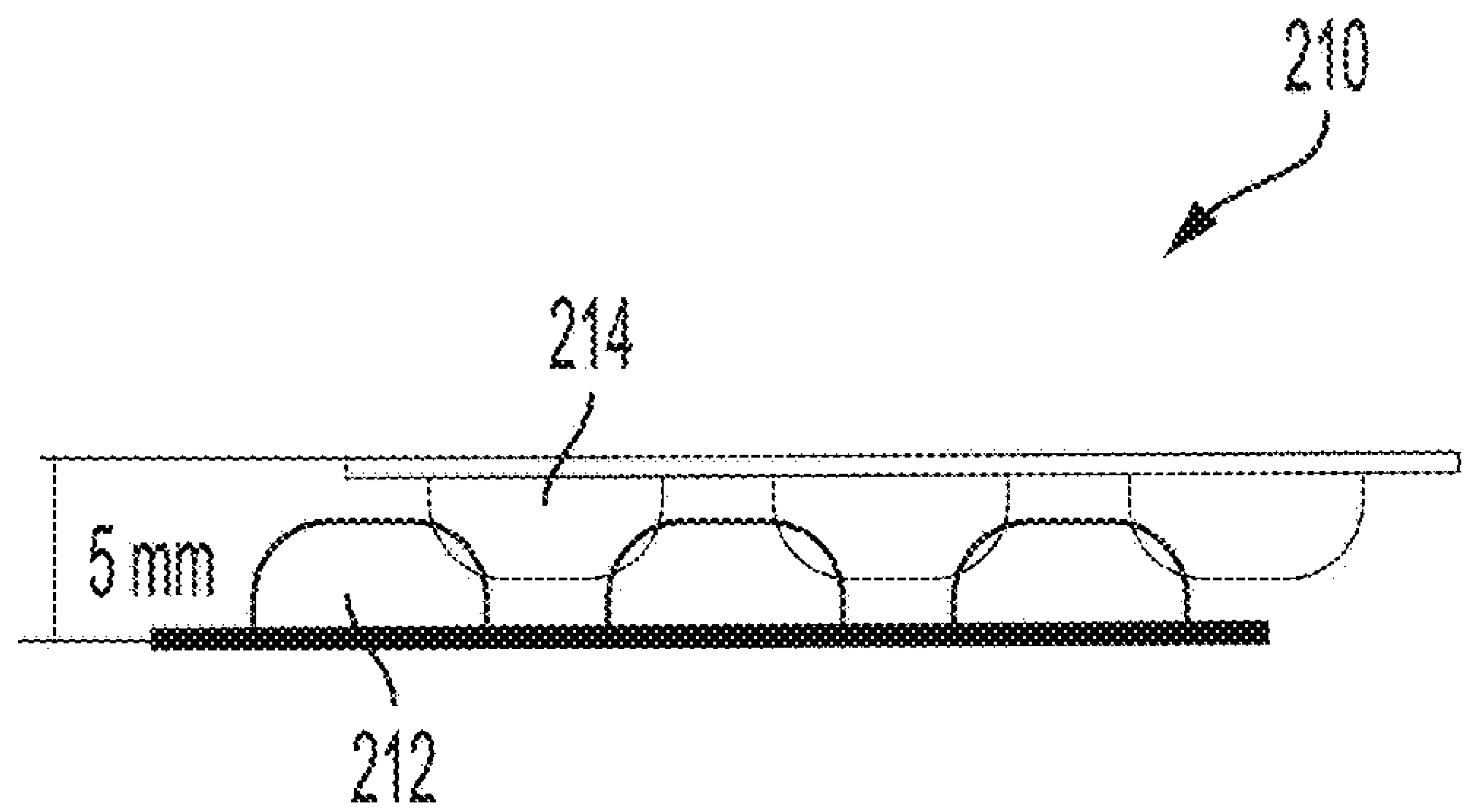


FIG. 2B

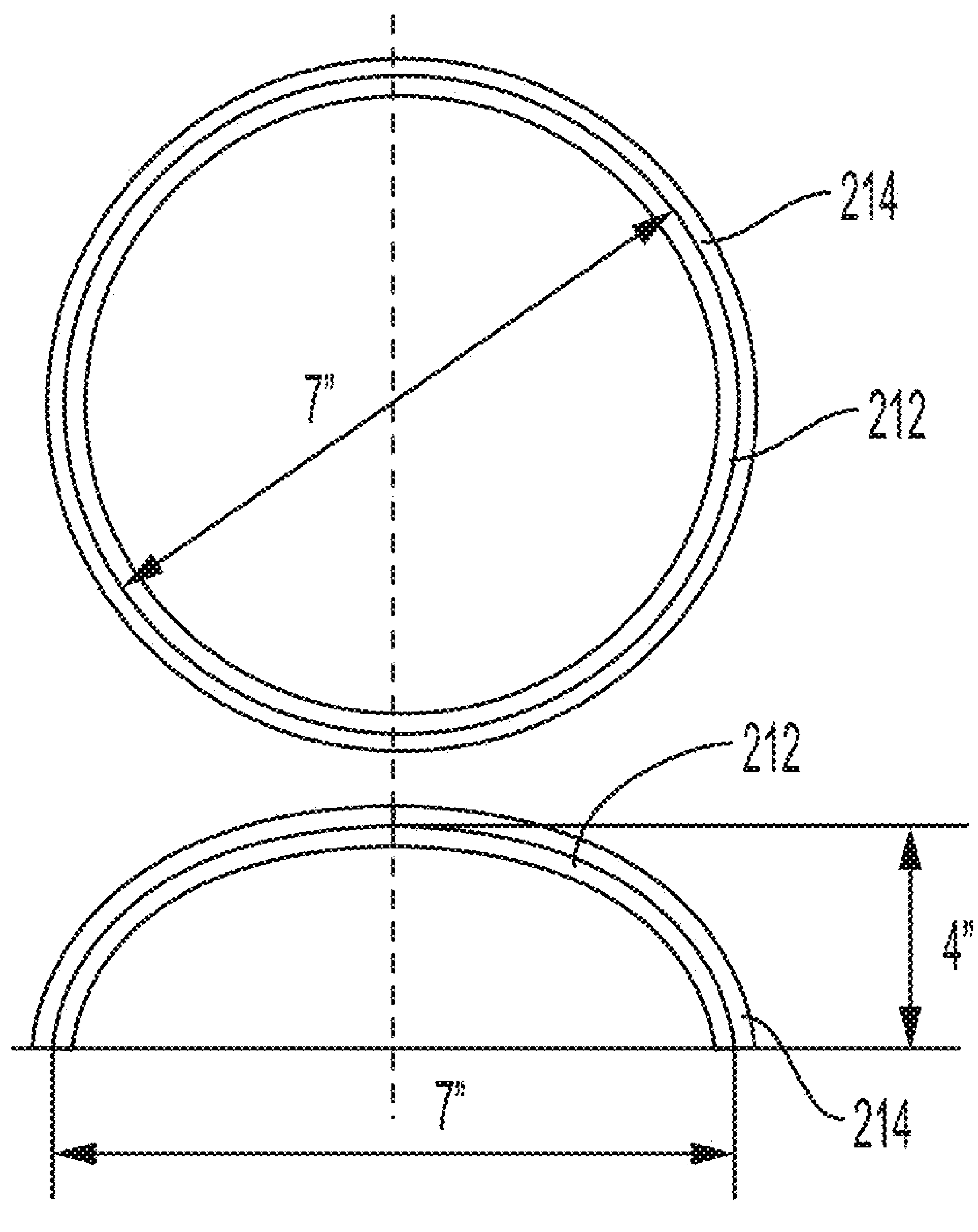


FIG. 2C

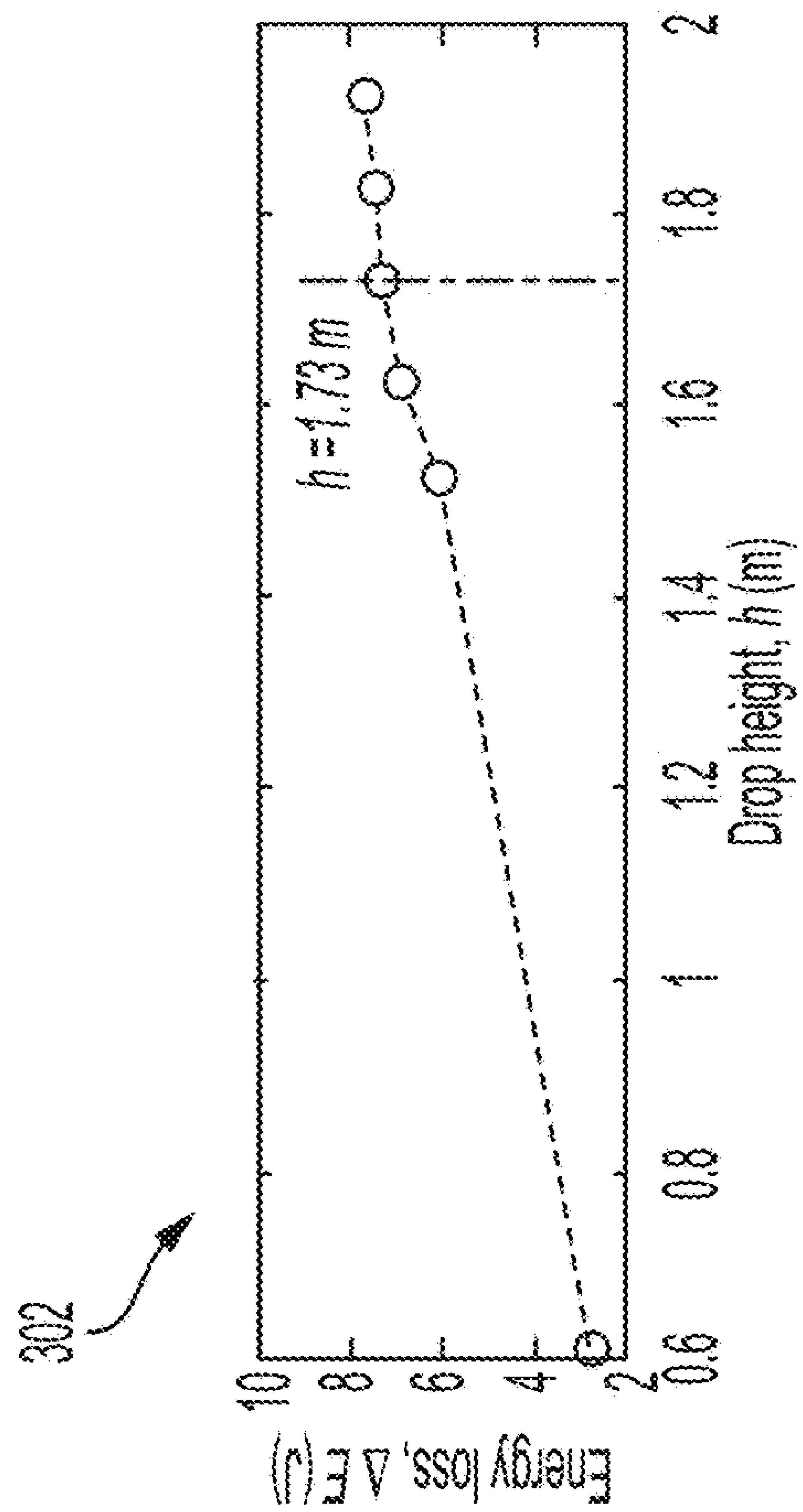


FIG. 3B

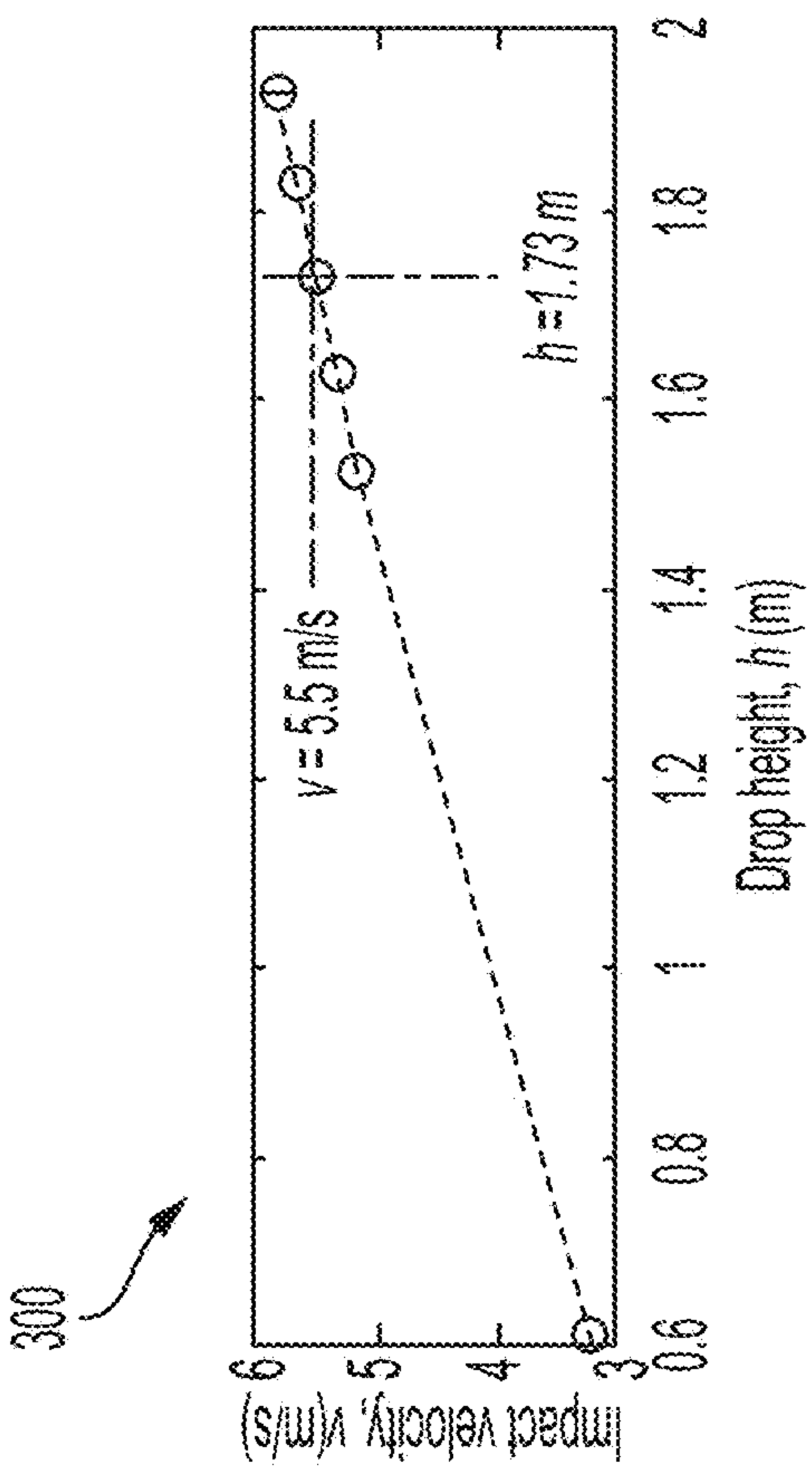


FIG. 3A

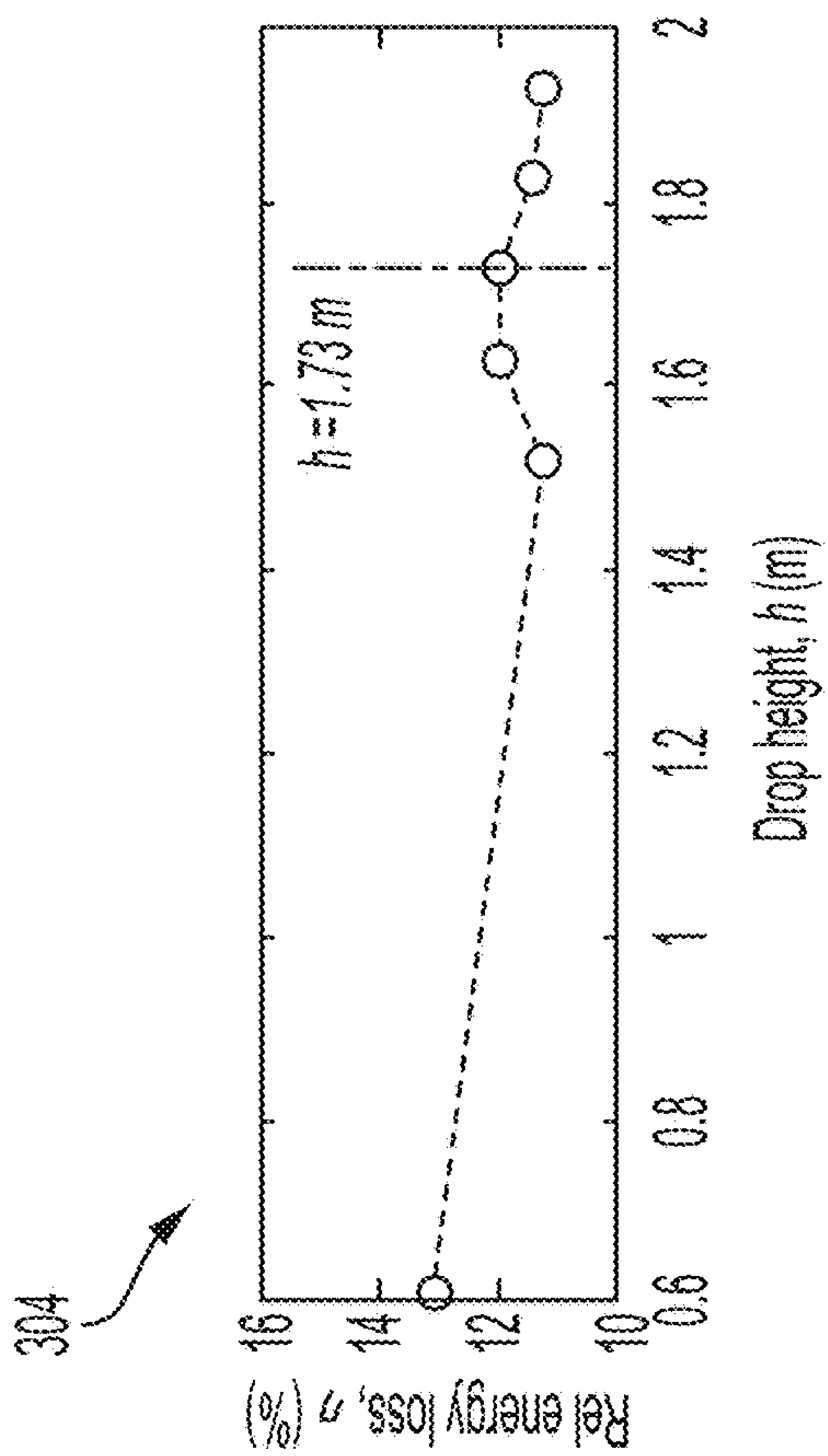


FIG. 3C

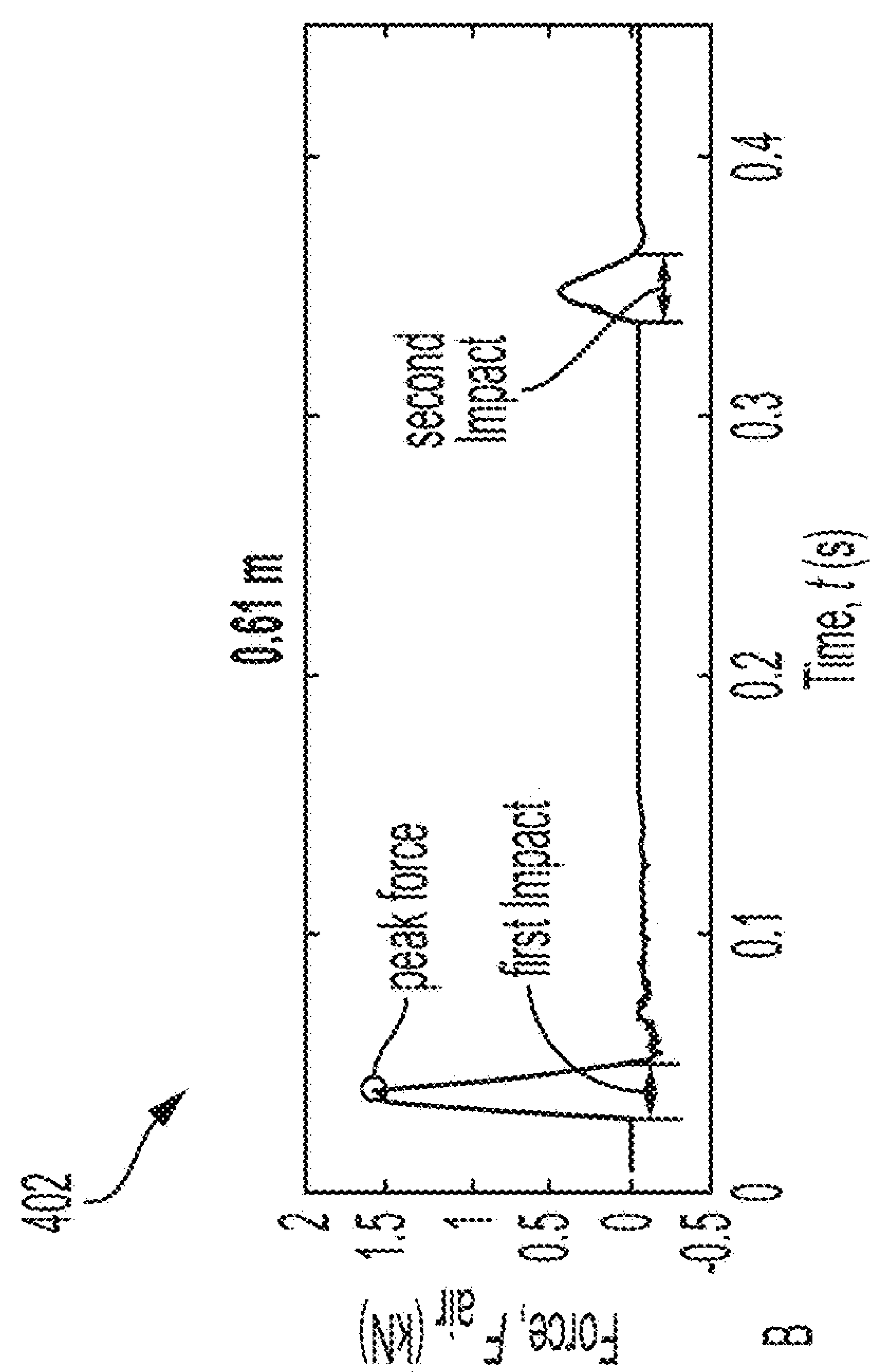

402
0.61 m
peak force
first Impact
second Impact
Force, F_{air} (kN)
Time, t (s)
B

FIG. 4B

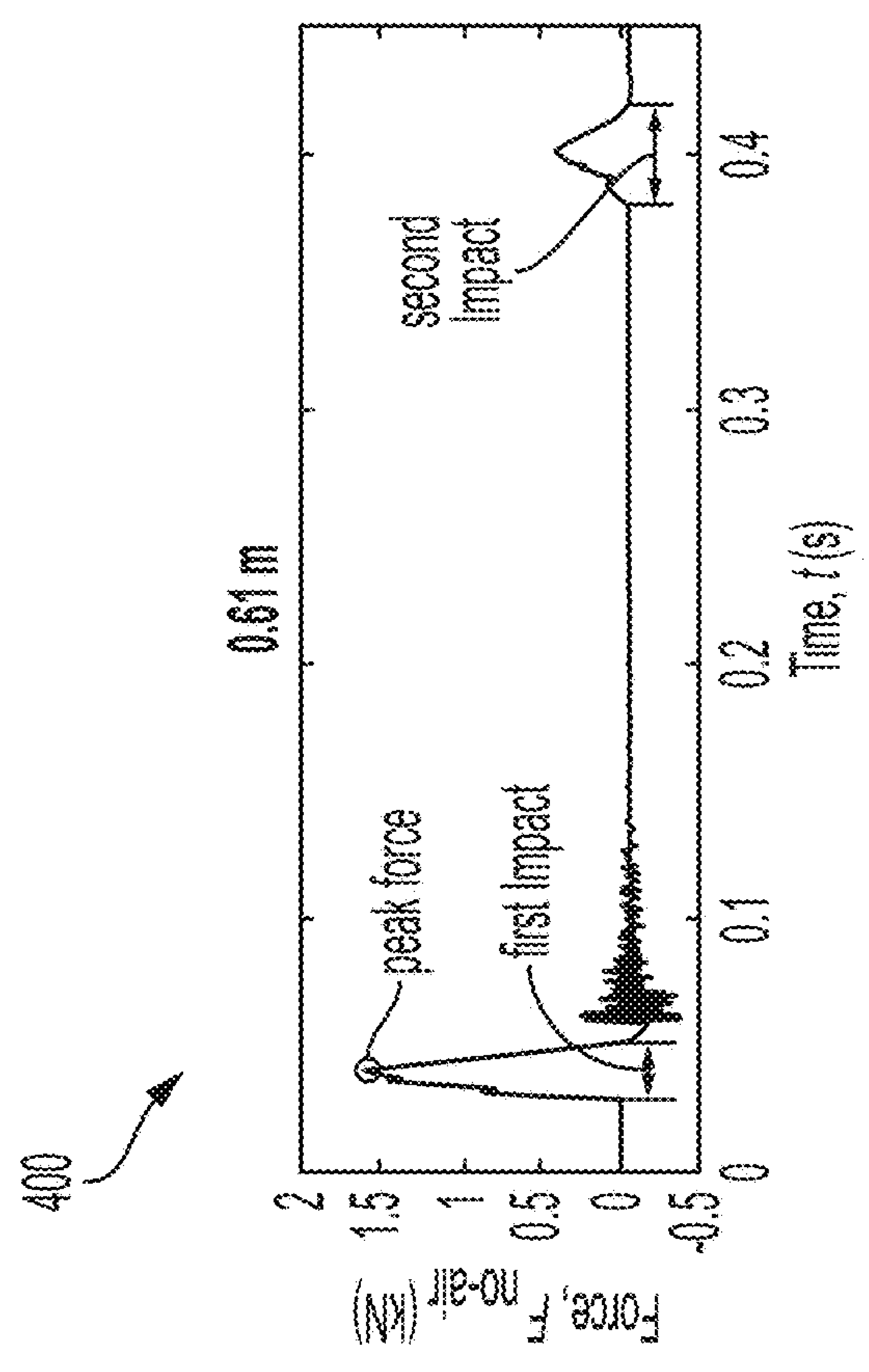

400
0.61 m
peak force
first Impact
second Impact
Force, F_{no-air} (kN)
Time, t (s)

FIG. 4A

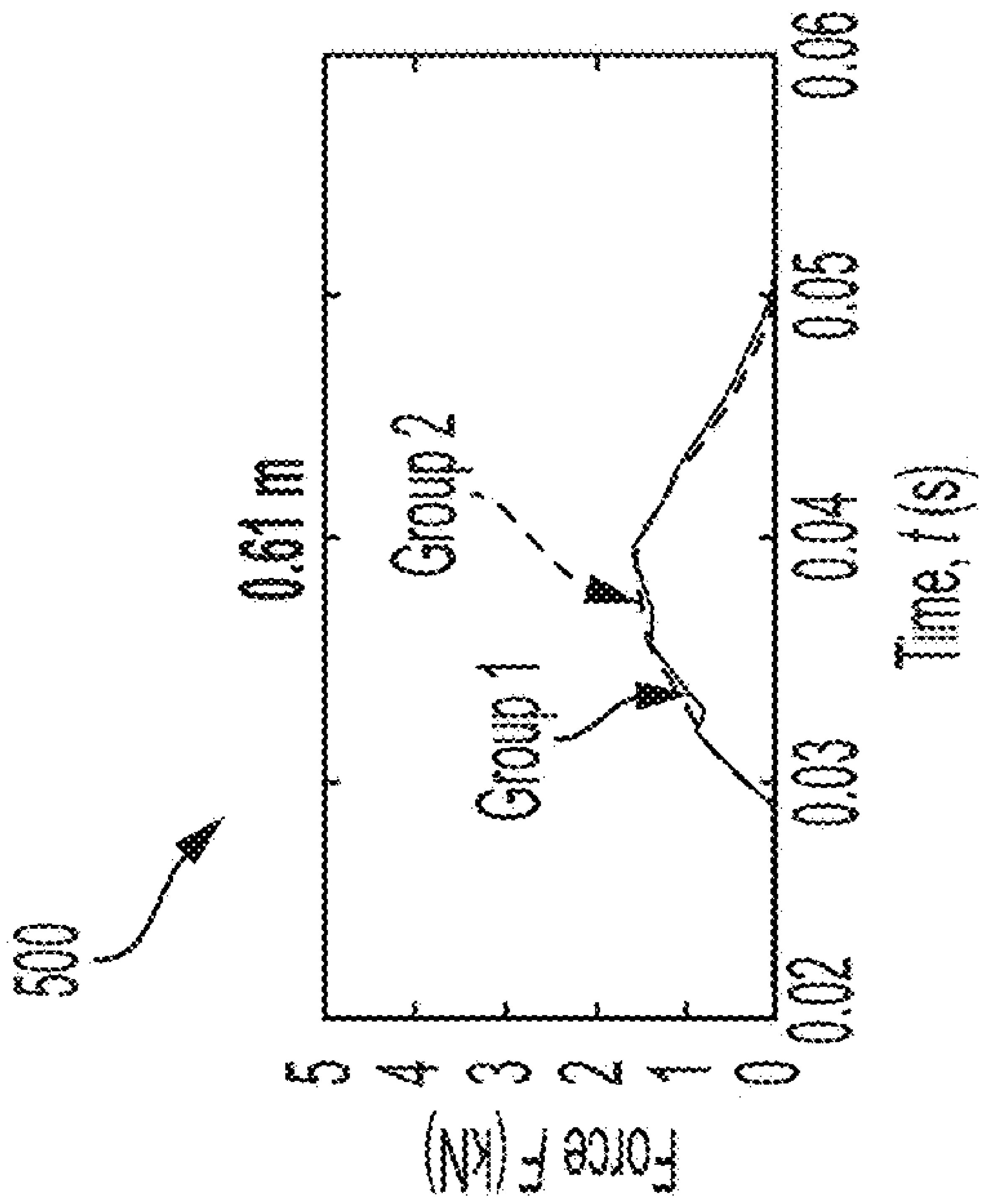


FIG. 5A

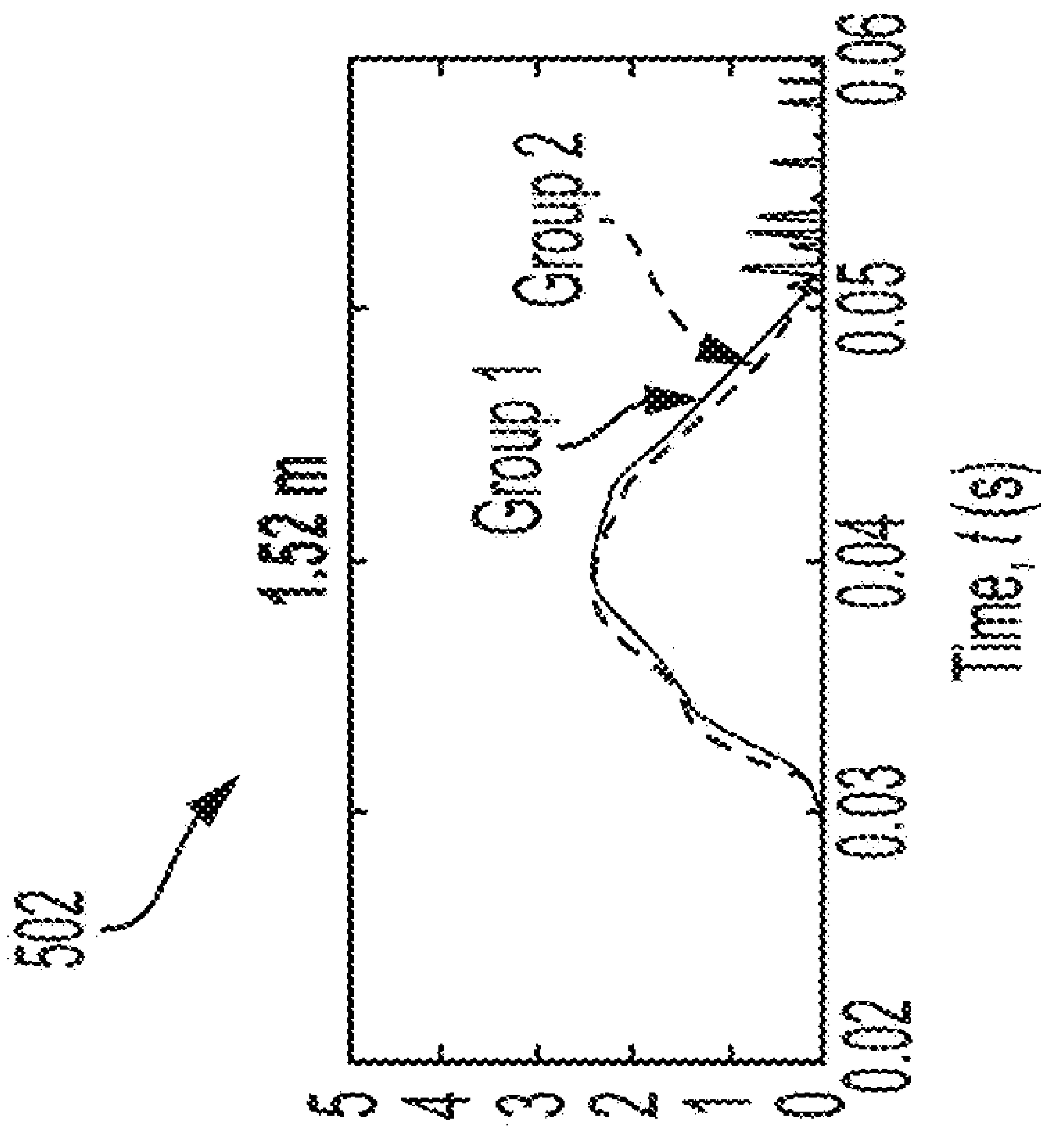


FIG. 5B

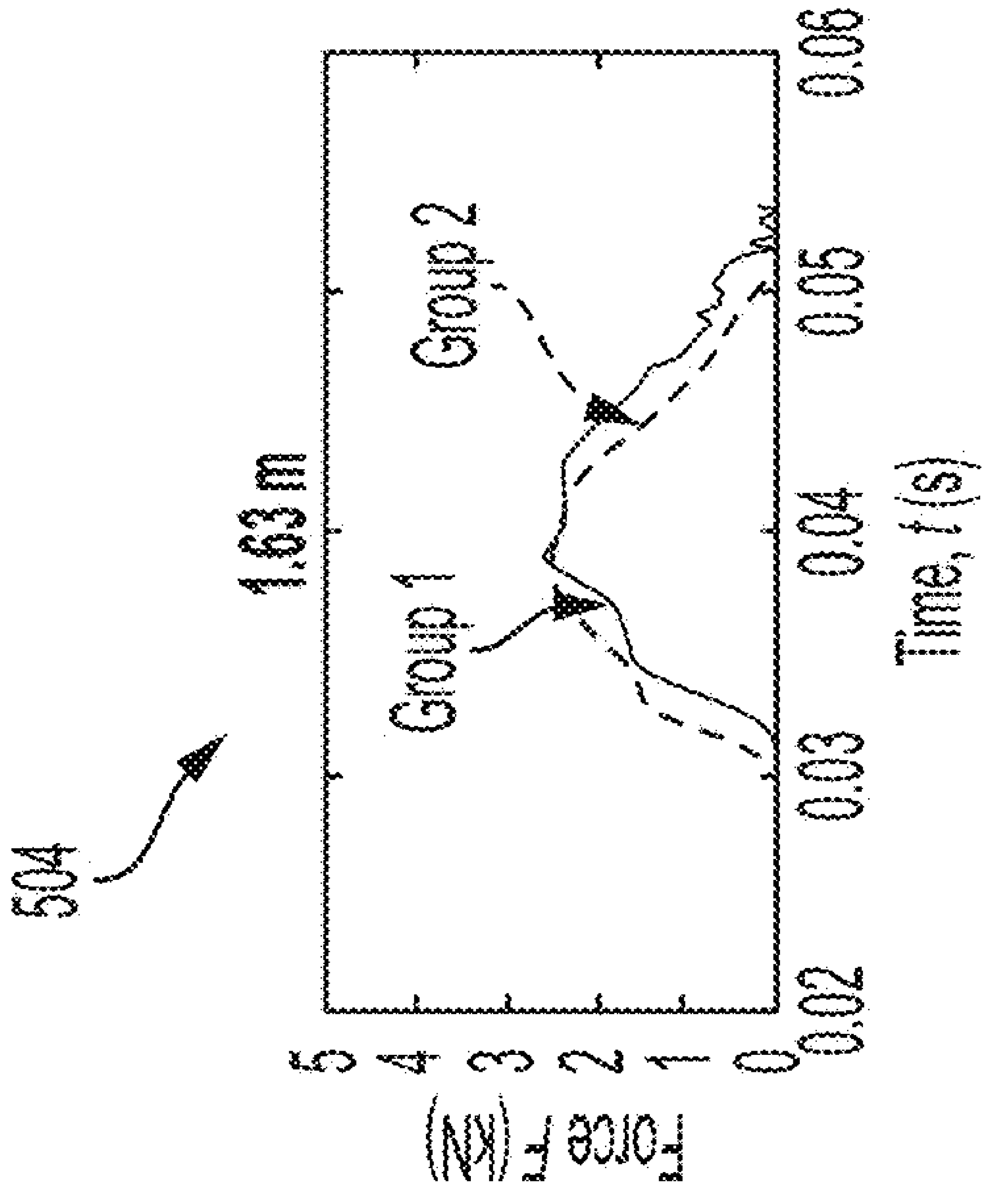


FIG. 5C

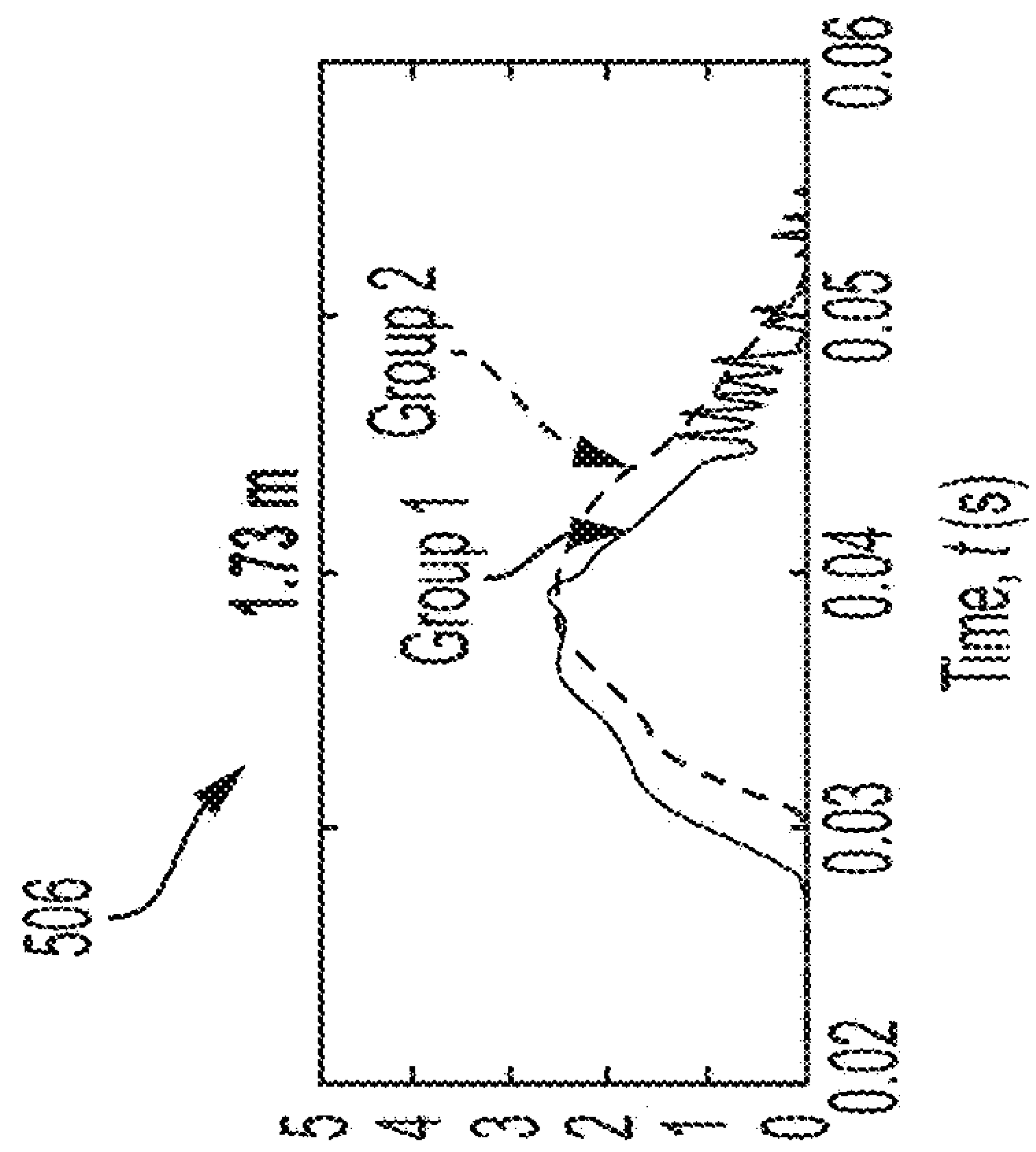


FIG. 5D

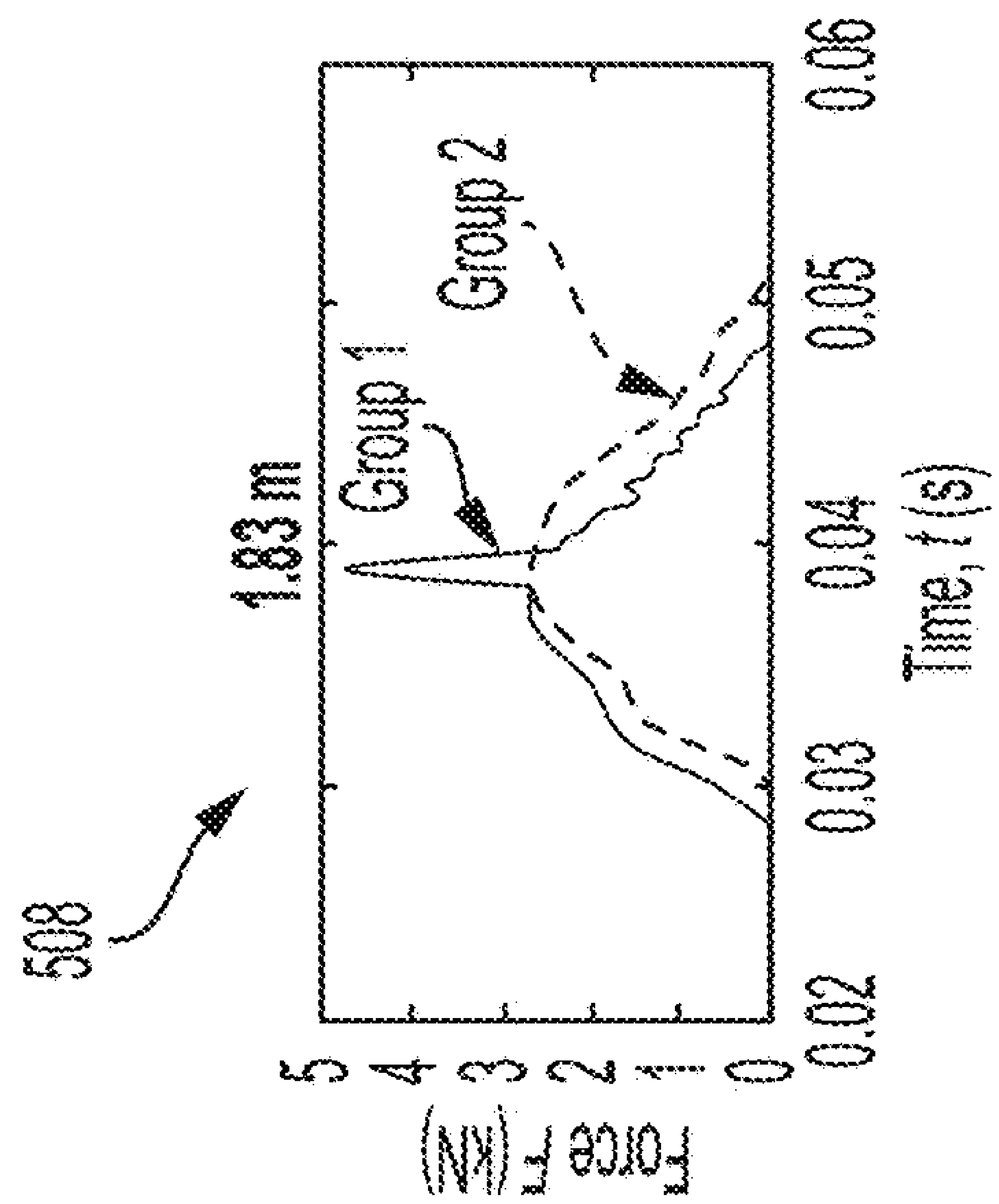


FIG. 5E

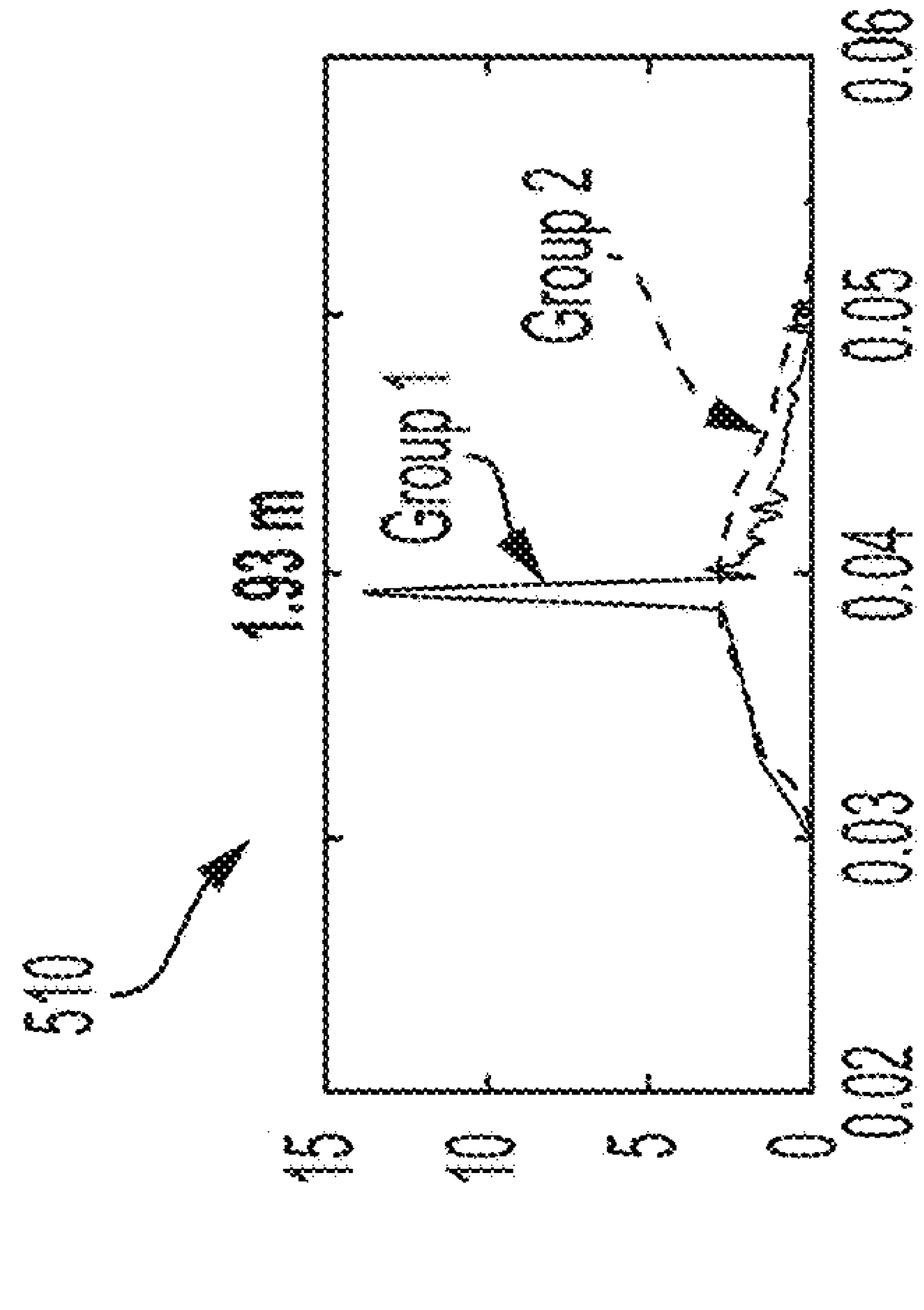


FIG. 5F

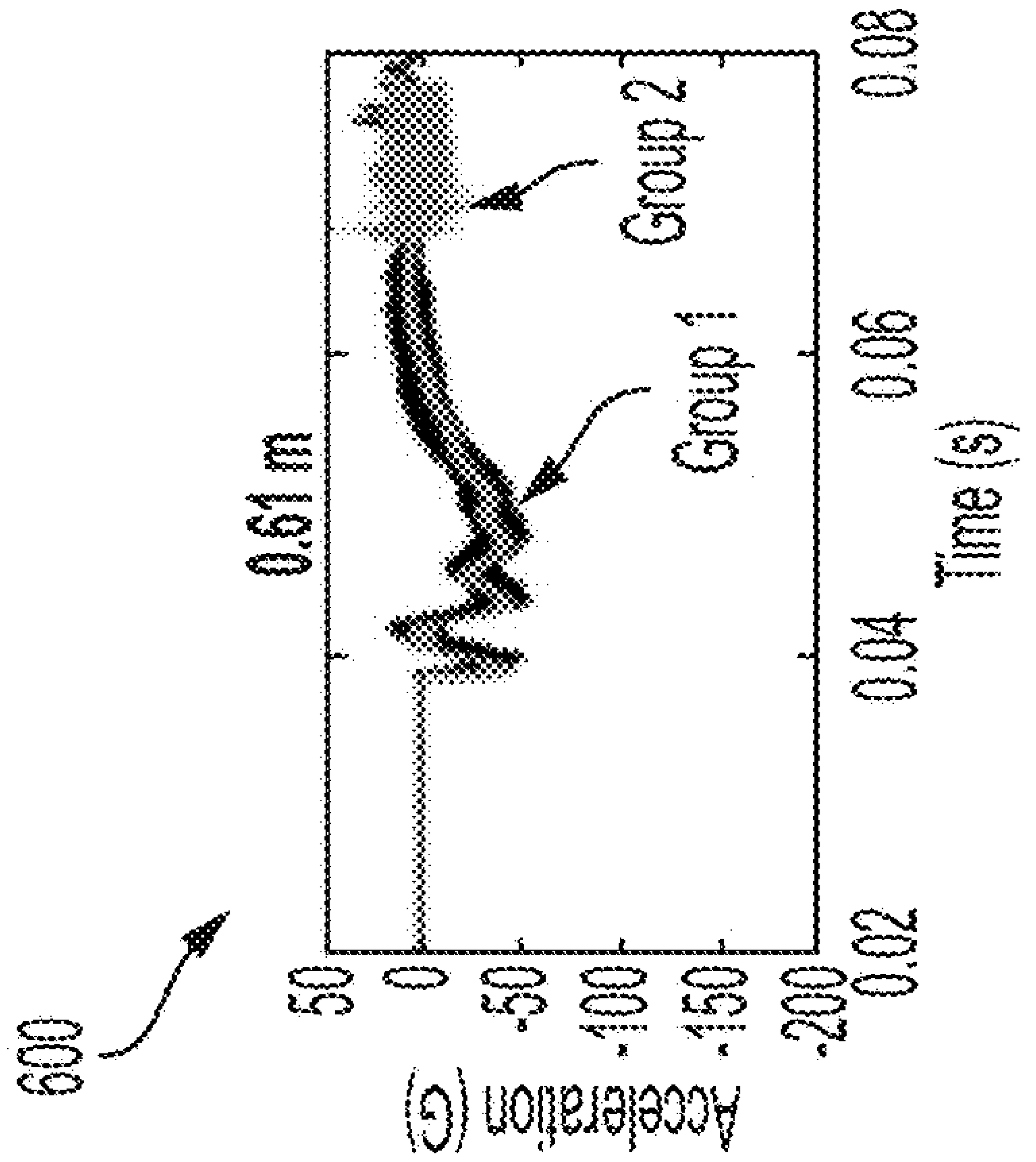


FIG. 6A

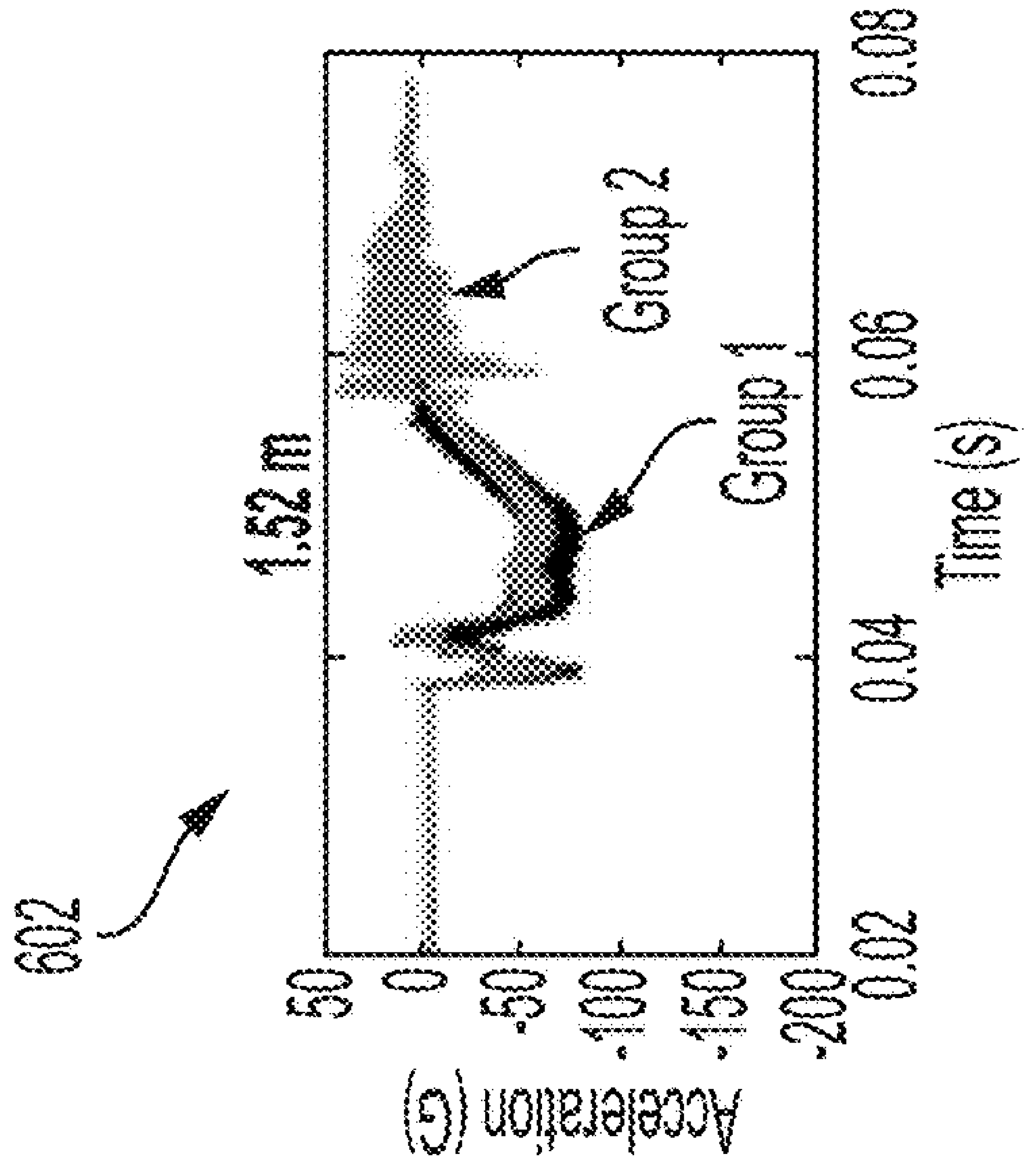


FIG. 6B

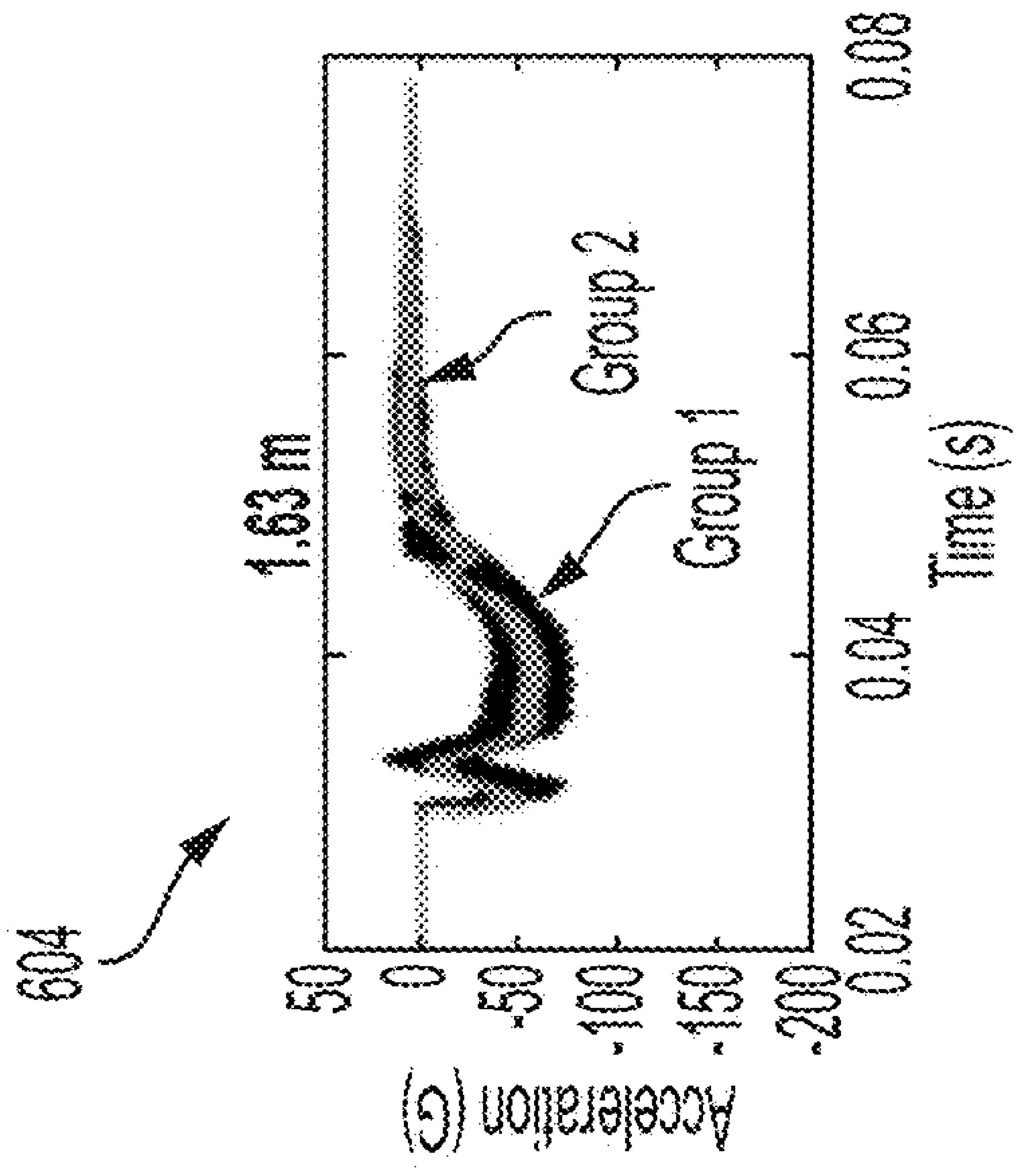


FIG. 6C

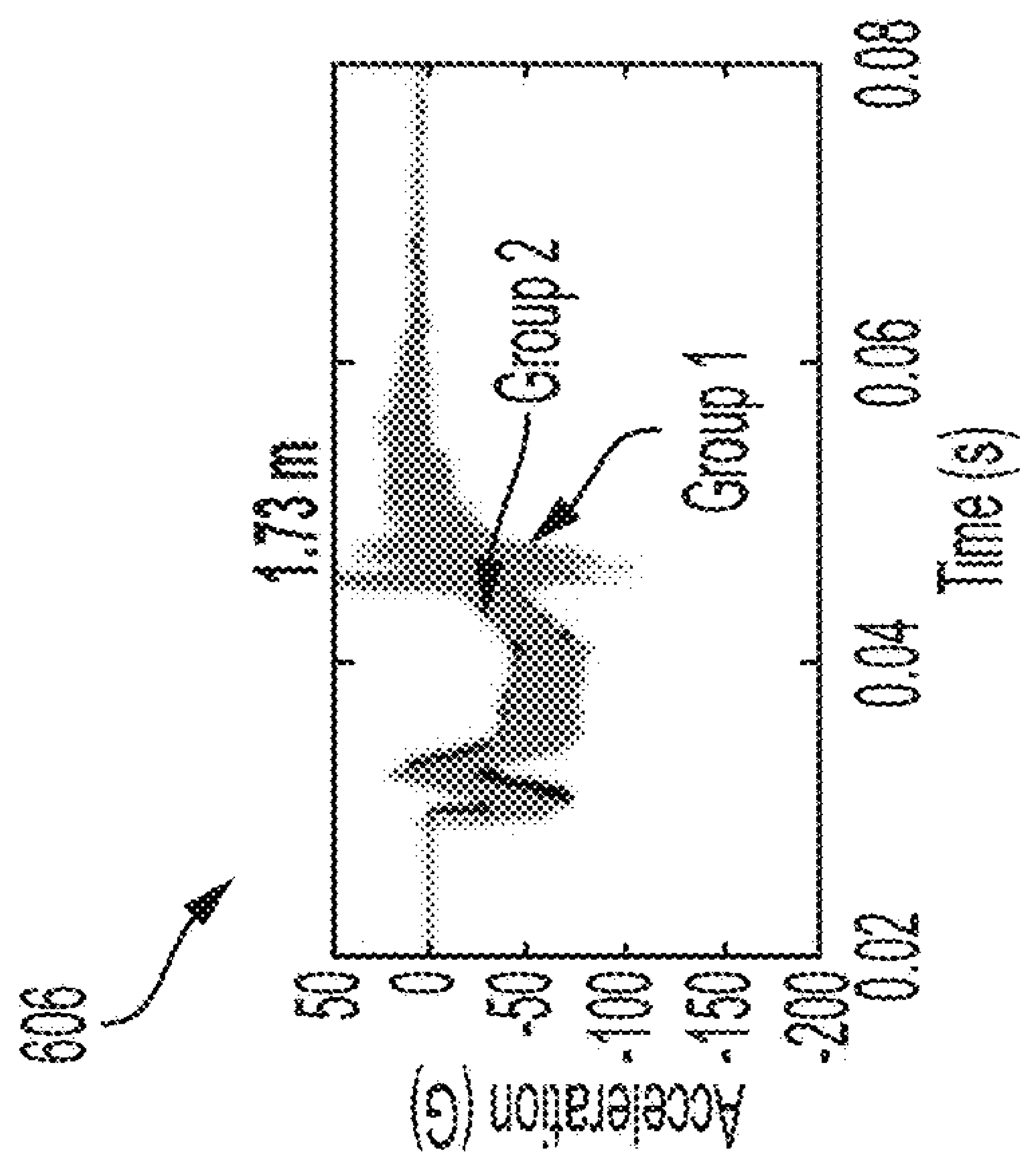


FIG. 6D

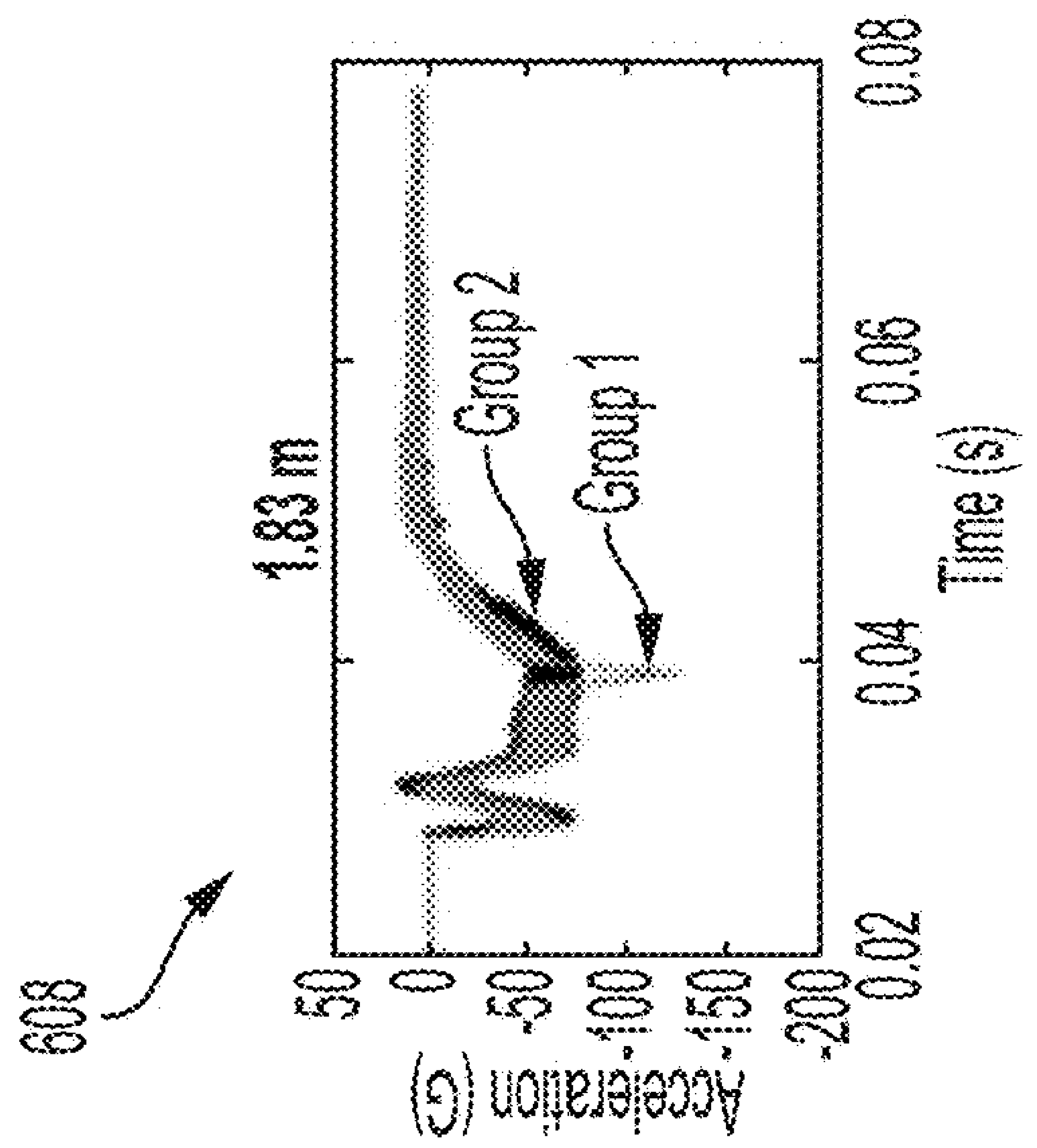


FIG. 6E

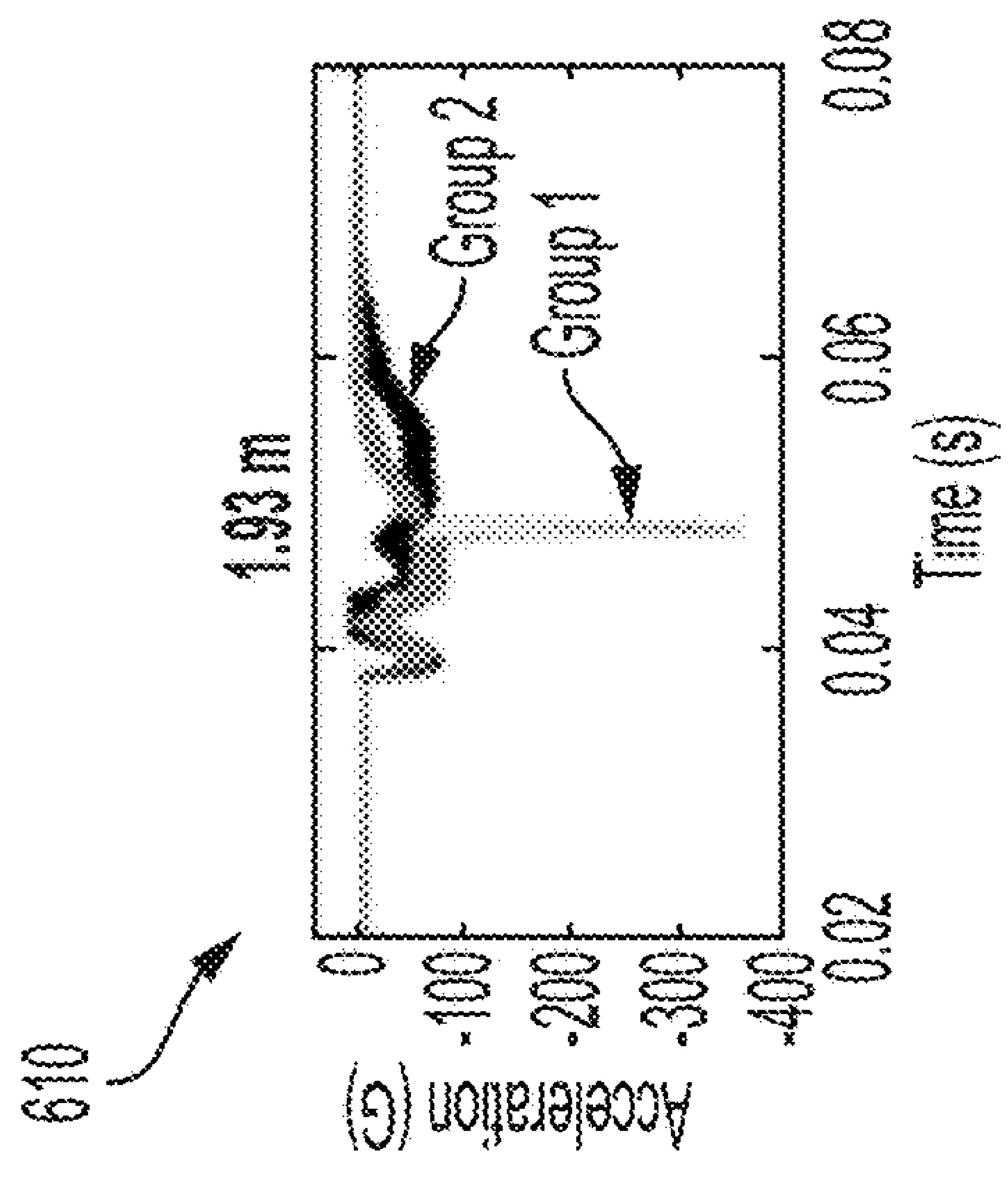


FIG. 6F

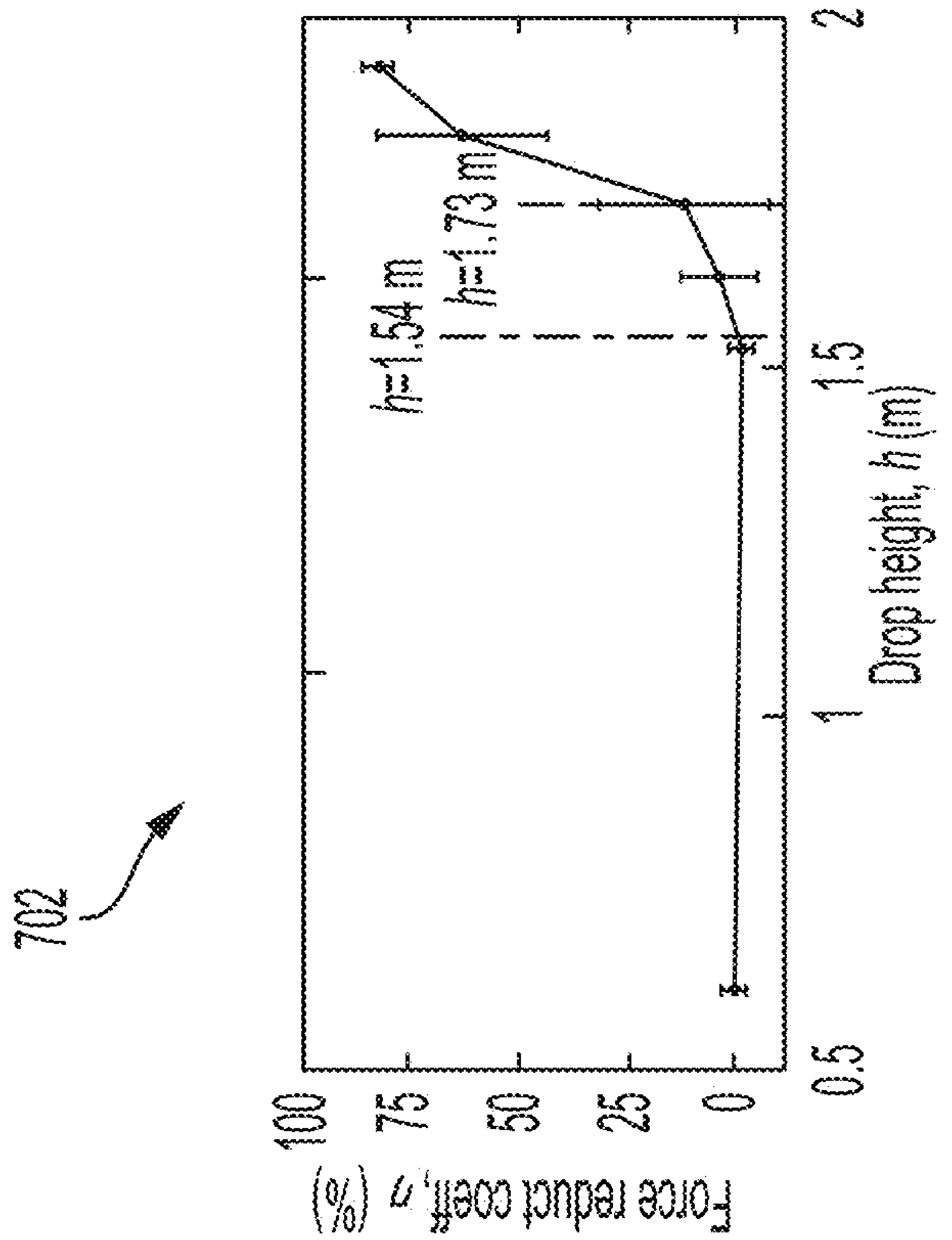

702
Force reduct coeff, η (%)
100
75
50
25
0
h=1.54 m
h=1.73 m
0.5
1
1.5
2
Drop height, h (m)

FIG. 7B

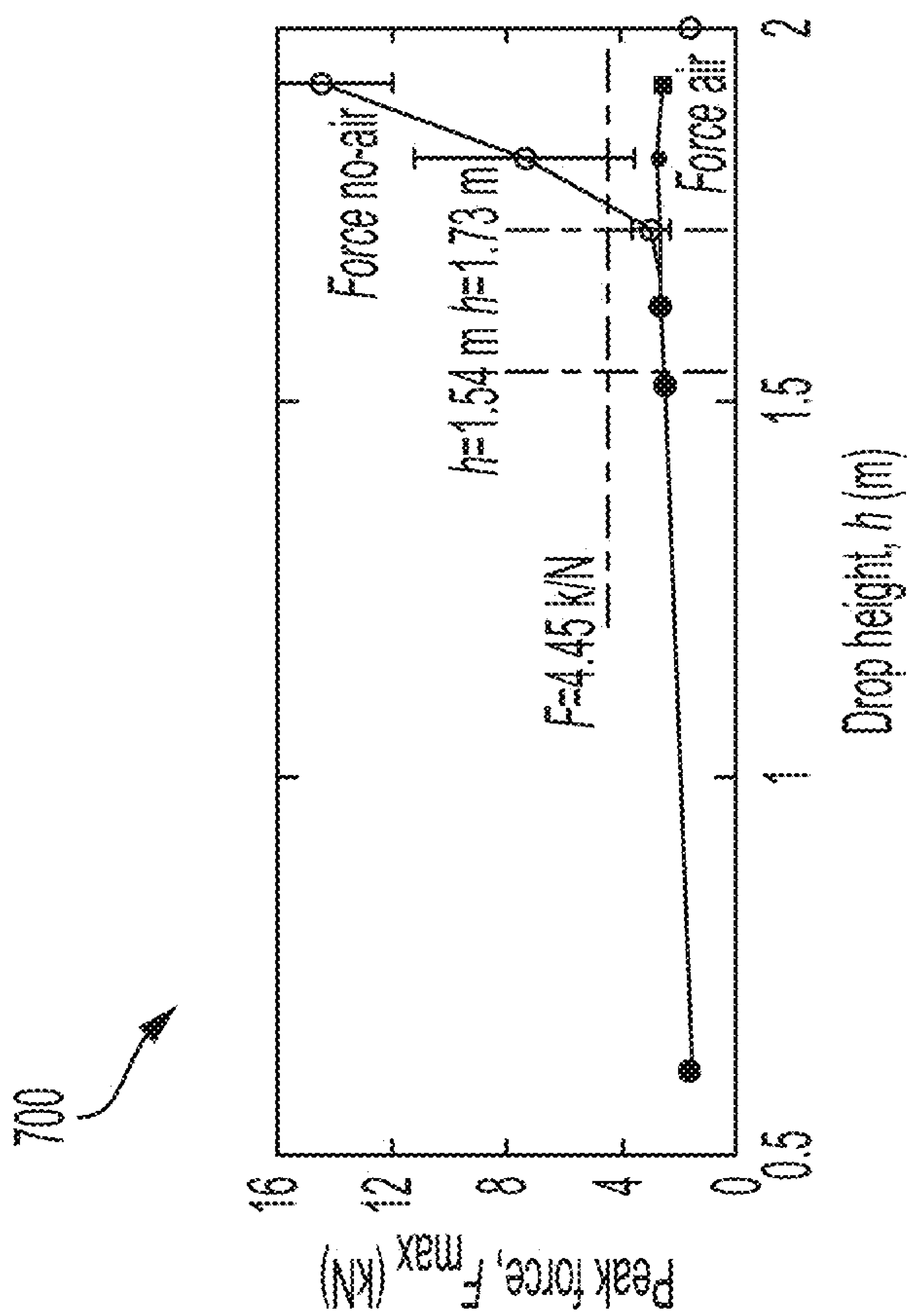

700
Peak force, Fmax (kN)
16
12
8
4
0
Force no-air
Force air
h=1.54 m
h=1.73 m
F=4.45 kN
0.5
1
1.5
2
Drop height, h (m)

FIG. 7A

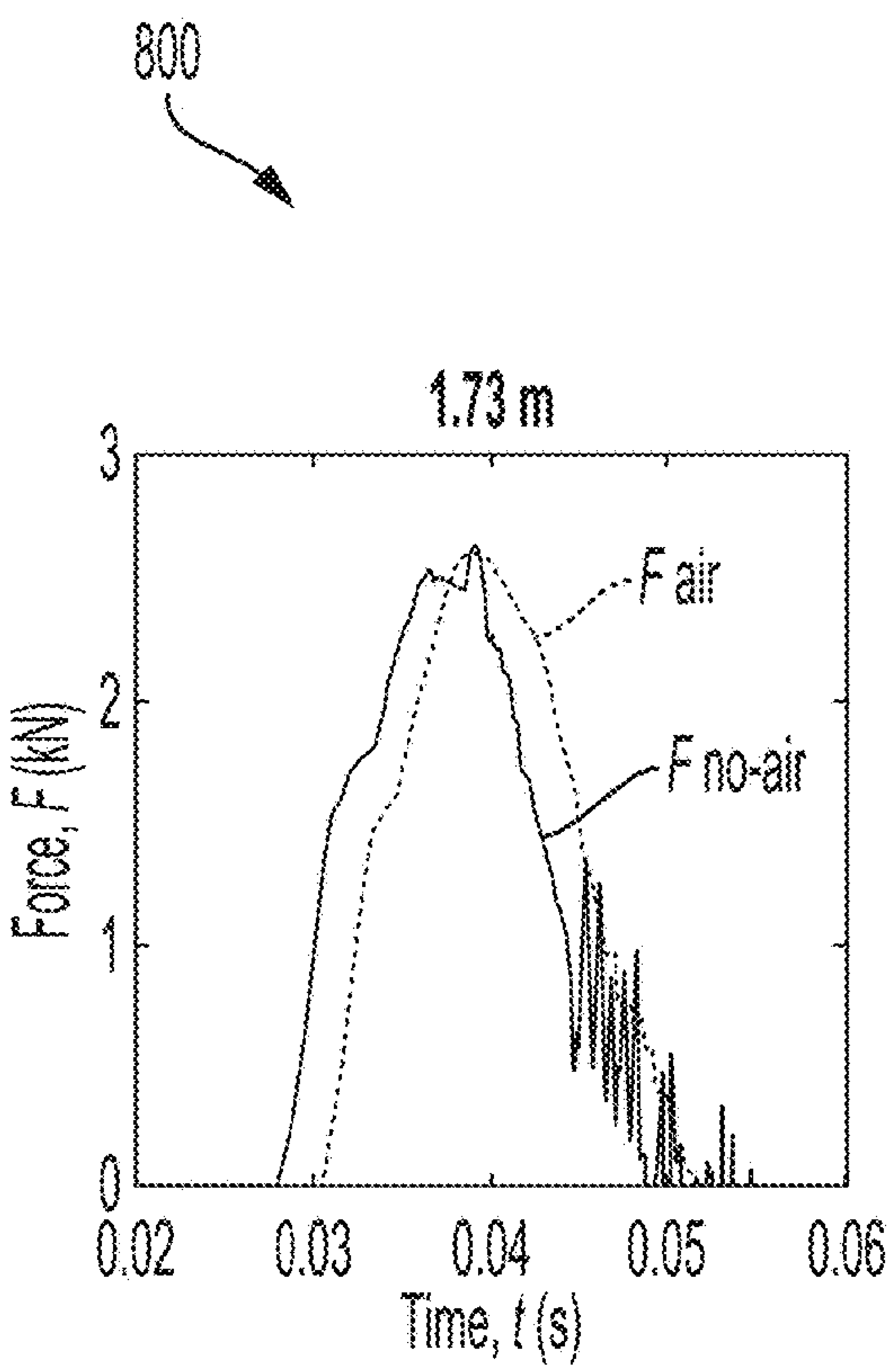

800
1.73 m
Force, F (kN)
Time, t (s)
F air
F no-air
0
1
2
3
0.02
0.03
0.04
0.05
0.06

FIG. 8A

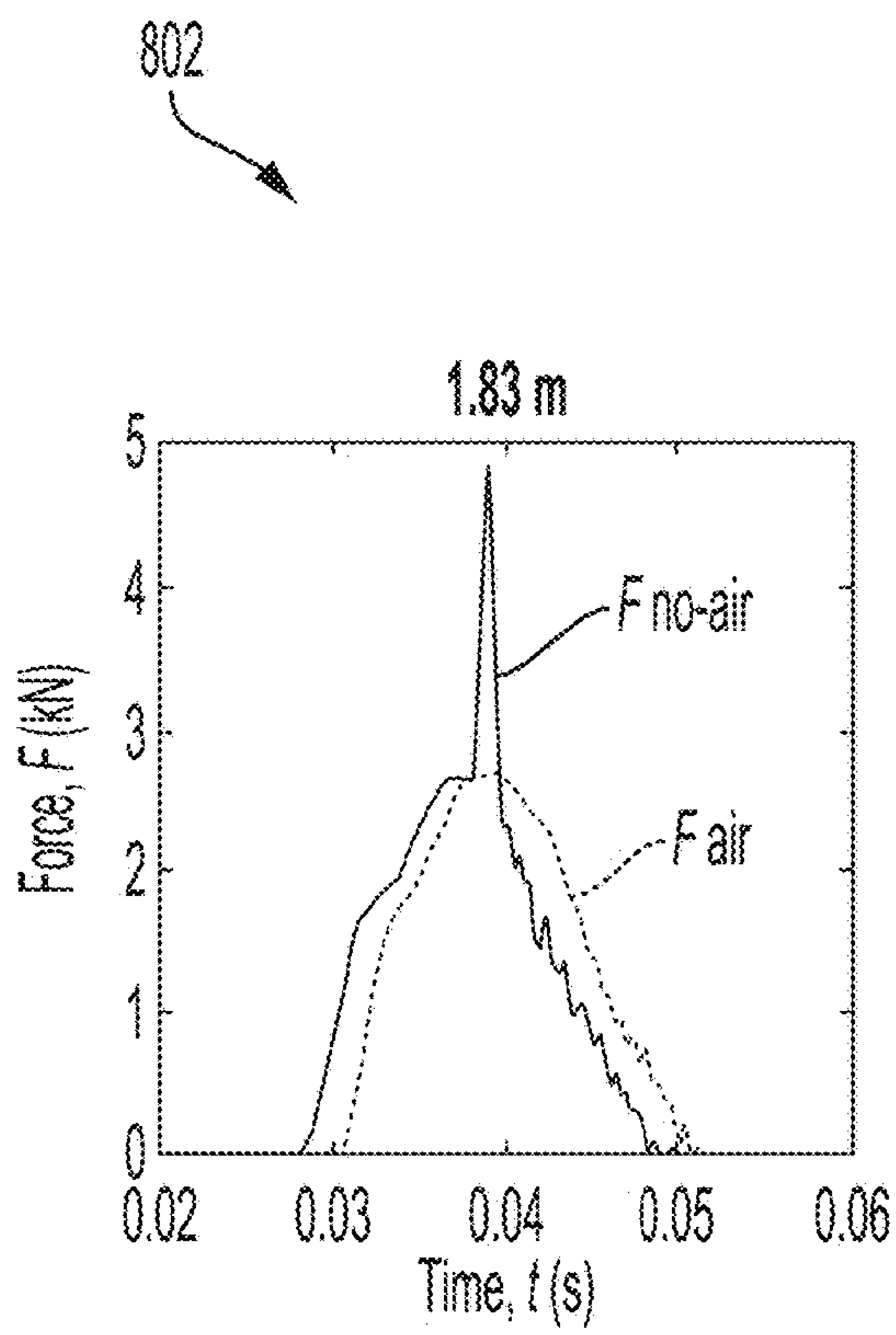

802
1.83 m
Force, F (kN)
Time, t (s)
F no-air
F air
0
1
2
3
4
5
0.02
0.03
0.04
0.05
0.06

FIG. 8B

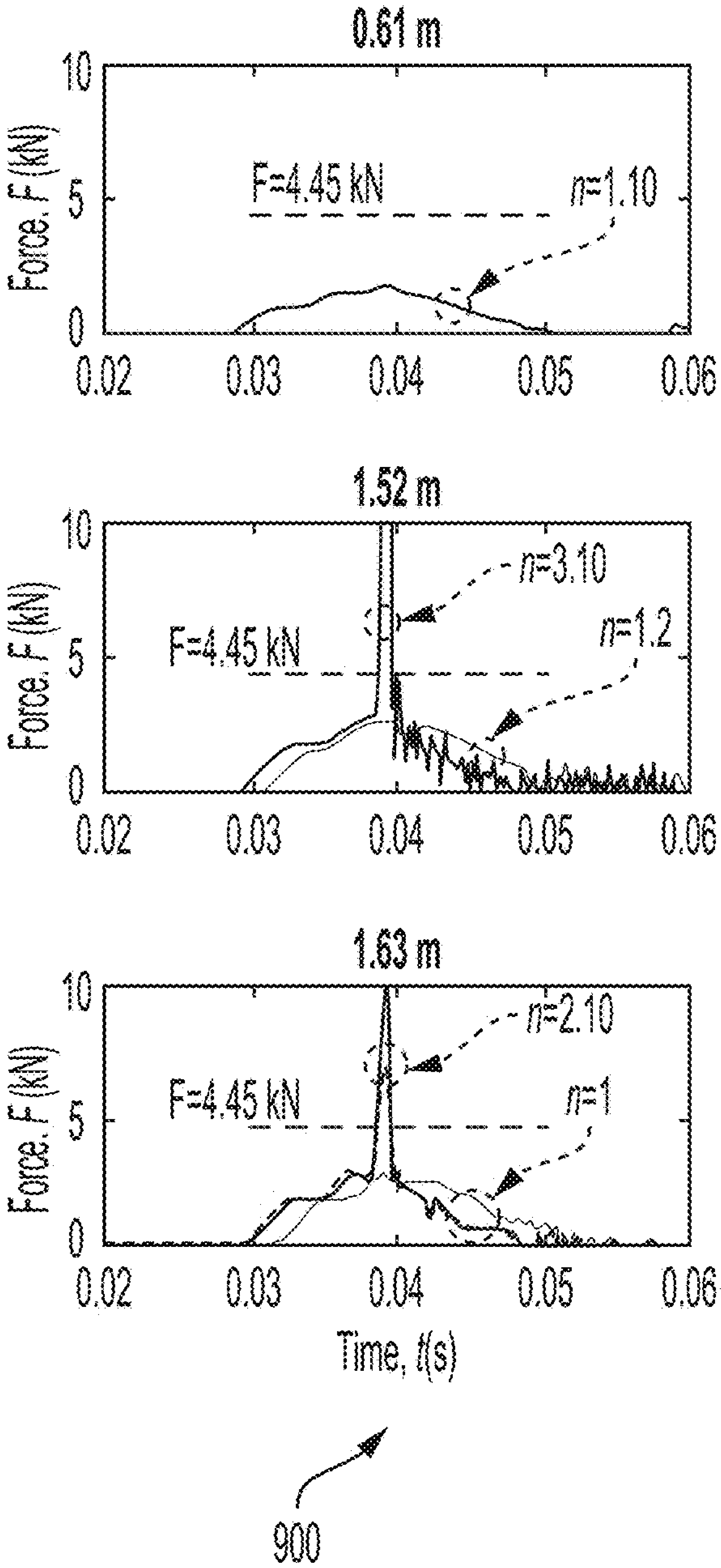

0.61 m
F=4.45 kN
n=1.10
1.52 m
n=3.10
F=4.45 kN
n=1.2
1.63 m
n=2.10
F=4.45 kN
n=1
Force, F (kN)
Time, t(s)
900

FIG. 9A

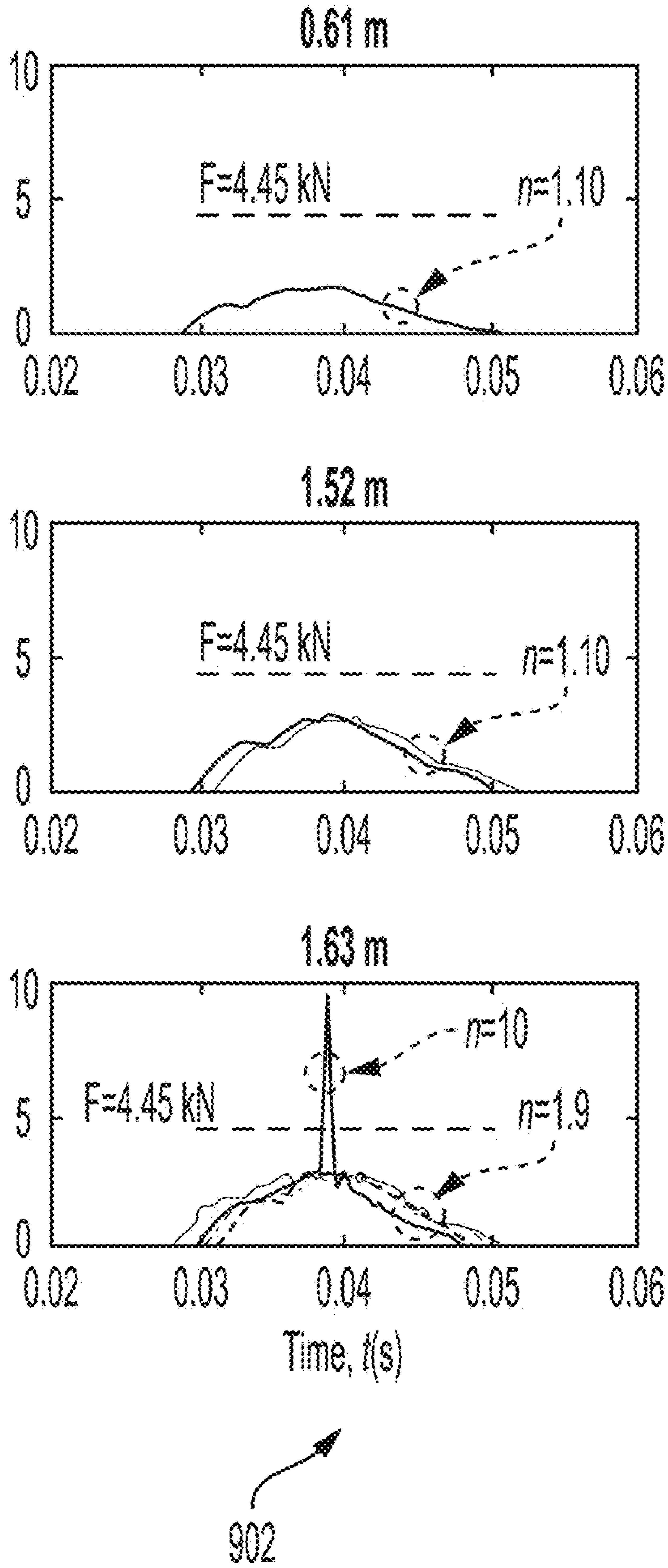

0.61 m
F=4.45 kN
n=1.10
1.52 m
F=4.45 kN
n=1.10
1.63 m
n=10
F=4.45 kN
n=1.9
Time, t(s)
902

FIG. 9B

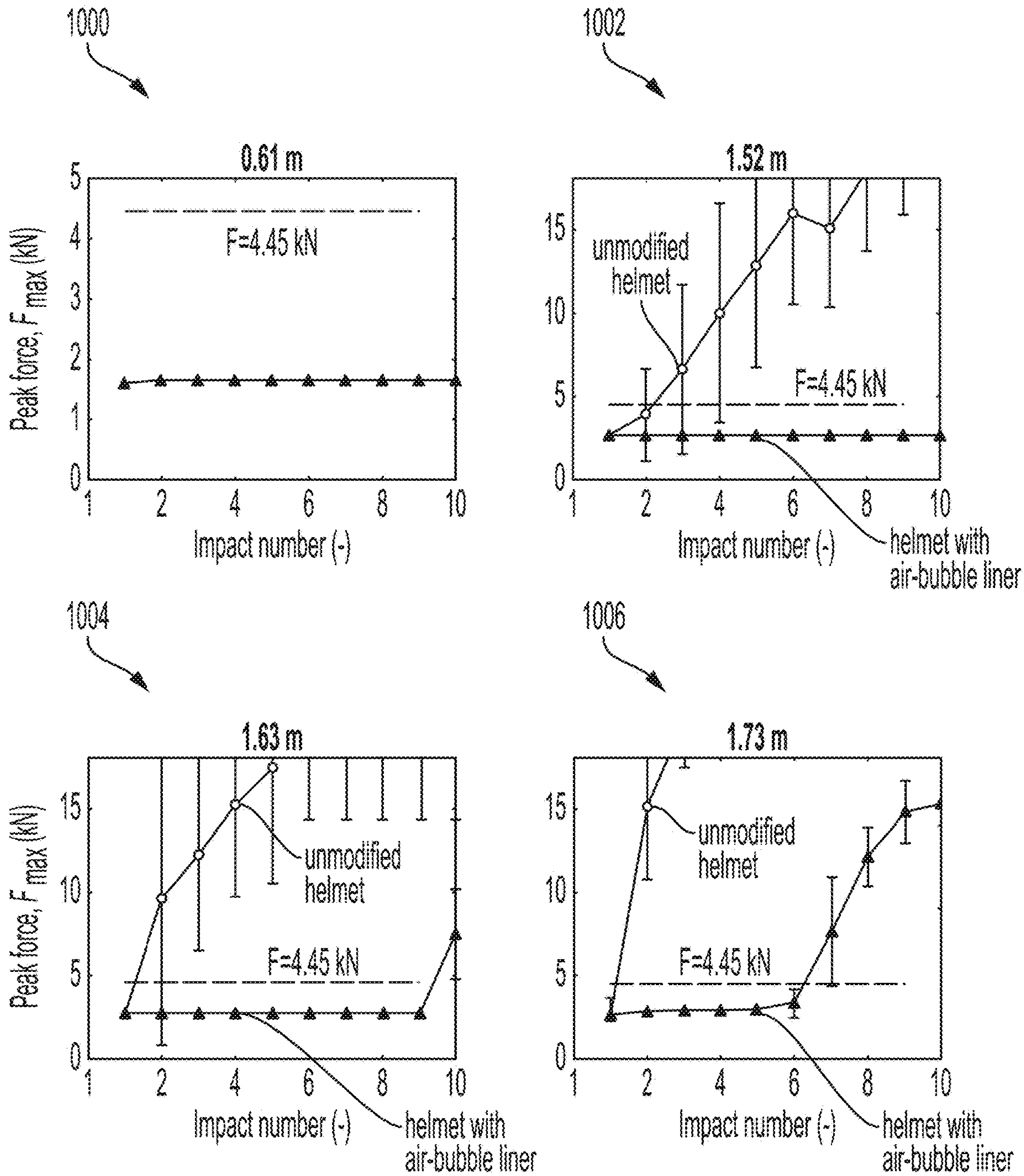
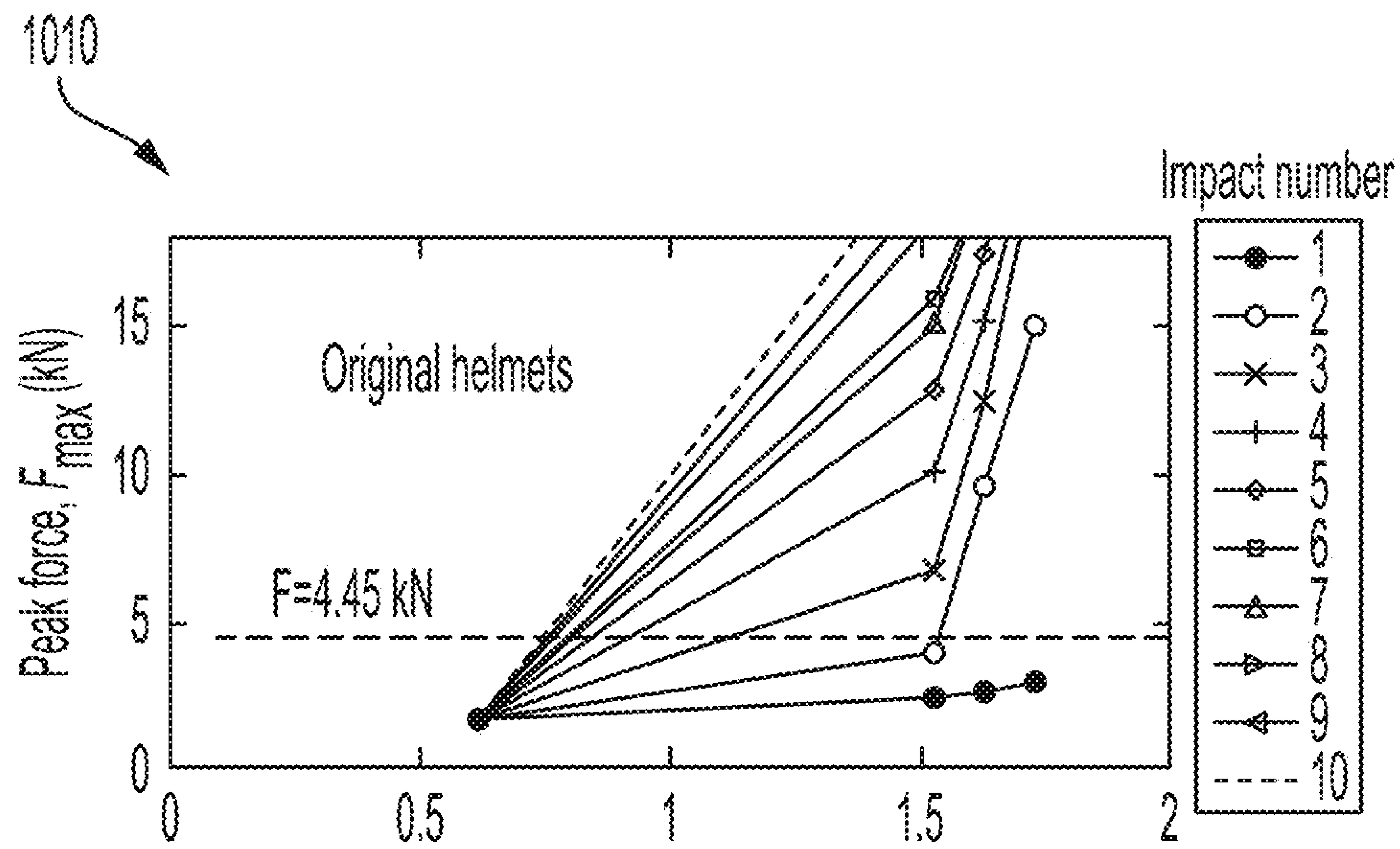

1000
0.61 m
F=4.45 kN
Peak force, F_{max} (kN)
Impact number (-)
1002
1.52 m
unmodified helmet
F=4.45 kN
Impact number (-)
helmet with air-bubble liner
1004
1.63 m
unmodified helmet
F=4.45 kN
Peak force, F_{max} (kN)
Impact number (-)
helmet with air-bubble liner
1006
1.73 m
unmodified helmet
F=4.45 kN
Impact number (-)
helmet with air-bubble liner

FIG. 10A


1010
Impact number
1
2
3
4
5
6
7
8
9
10
Original helmets
F=4.45 kN
Peak force, F_{max} (kN)
0
5
10
15
0
0.5
1
1.5
2

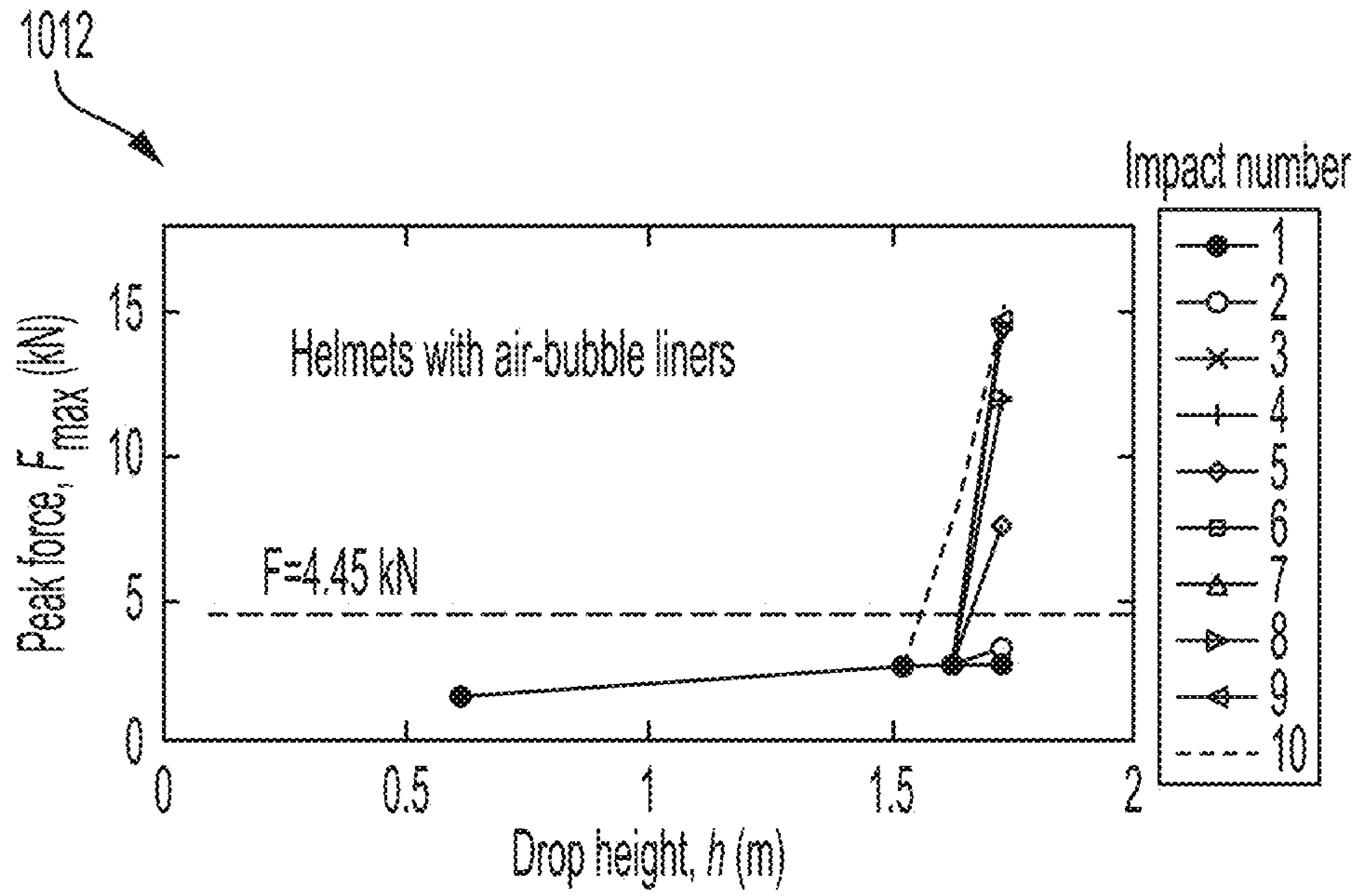

1012
Impact number
1
2
3
4
5
6
7
8
9
10
Helmets with air-bubble liners
F=4.45 kN
Peak force, F_{max} (kN)
0
5
10
15
0
0.5
1
1.5
2
Drop height, h (m)

FIG. 10B

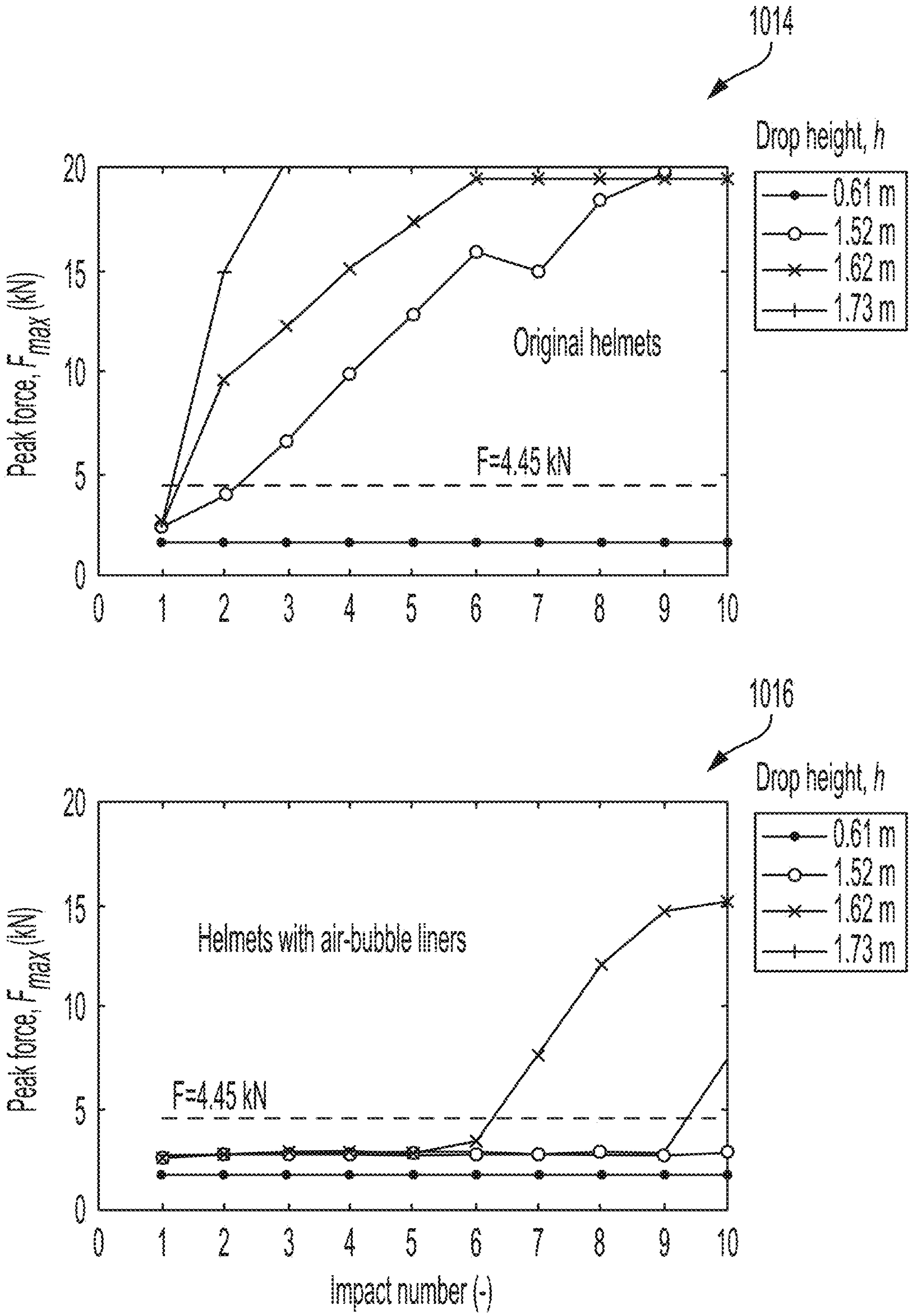

1014
Drop height, h
0.61 m
1.52 m
1.62 m
1.73 m
Original helmets
F=4.45 kN
Peak force, F_{max} (kN)
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10
1016
Drop height, h
0.61 m
1.52 m
1.62 m
1.73 m
Helmets with air-bubble liners
F=4.45 kN
Peak force, F_{max} (kN)
0 5 10 15 20
0 1 2 3 4 5 6 7 8 9 10
Impact number (-)

FIG. 10C

HEADGEAR SYSTEMS WITH AIR-BUBBLE CUSHIONING LINER FOR IMPROVED SHOCK ABSORPTION PERFORMANCE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/966,456, filed Jan. 27, 2020; the entire contents of which are hereby incorporated by this reference.

FIELD

[0002] The disclosure provides headgear systems. More particularly, the disclosure provides headgear systems having an air-bubble cushioning liner to improve shock absorption performance.

BACKGROUND

[0003] Traumatic brain injury (TBI) is a major cause of death and disability in the United States. According to the Centers for Disease Control, the number of TBI-related emergency department visits, hospitalizations, and deaths increased by 53% over the past ten years. For example, in 2014, an average of 155 people in the United States died each day from injuries that include a TBI. Those who survive a TBI can face effects that last a few days, or possibly the rest of their lives. Effects of TBI can include, but are not limited to, impairments related to thinking or memory, movement, sensation (e.g., vision or hearing), or emotional functioning (e.g., personality changes, depression). These issues affect not only individuals but also families and communities, and can have lasting negative effects.

[0004] Approximately 7.3% of traumatic brain injury cases identified by the Ontario Trauma Registry were work-related. Many epidemiological studies suggest that the work-related traumatic brain injury (WrTBI) is thought to be one of the most serious occupational injuries that occurs among construction workers. WrTBIs may result in extensive medical care, multiple days away from work, permanent disability, or death.

[0005] The industrial helmet is accepted as the most common and effective personal protective equipment to reduce the WrTBIs. Industrial or construction helmets are categorized as either Type I or Type II, according to international standards. The Type I construction helmet is the most commonly adopted helmet model used on construction sites. A Type I helmet is designed for top impact protection only, and does not provide protection for lateral impacts. A representative Type I helmet typically includes a hard shell, which is typically molded using polyethylene or polycarbonate plastics, and a strap suspension system. The strap suspension system usually plays a major role in shock absorption and impact force redistribution. The suspension system in a basic Type I helmet may usually include a synthetic woven webbing and bands of molded nylon or vinyl. In an advanced high-performance Type I helmet, there may be an additional polymer shock absorption liner between the belt suspension and shell. Since the suspension system may play a role in absorbing impact shocks in a helmet, the research and development efforts of such helmets has been primarily focused on the improvement of the strap suspension system. The suspension system of construction helmets may have different designs and may use different shock absorbing materials.

[0006] There exists a need for industrial or construction headgear system, such as helmets, with improved shock absorption performance to improve the headgear design, thereby improving workers' safety.

SUMMARY

[0007] The present disclosure provides headgear protection systems for preventing or reducing work-related traumatic brain injury and/or risk. More particularly, the disclosure provides headgear systems having an air-bubble cushioning liner to improve shock absorption performance.

[0008] In one aspect, the disclosure provides a protective headgear assembly that includes: a protective body having an inner surface and an outer surface; a shock suspension system affixed to the inner surface of the protective body having an upper surface and a lower surface, wherein the upper surface is proximate to the inner surface of the protective body; an air-bubble cushioning liner; and a strap affixed to the shock suspension system.

[0009] In some embodiments, the air-bubble cushioning layer is affixed to the lower surface of the shock suspension system.

[0010] In some embodiments, the air-bubble cushioning layer is affixed to and coextensive with the lower surface of the shock suspension system.

[0011] In some embodiments, the air-bubble cushioning layer is substantially coextensive with the lower surface of the shock suspension system.

[0012] In some embodiments, the air-bubble cushioning layer comprises one or more layers of air-bubble wrap.

[0013] In some embodiments, the air-bubble cushioning layer comprises an upper layer of air-bubble wrap and a lower layer of air-bubble wrap oriented so that a bubble-side of the upper layer faces a bubble-side of the lower layer.

[0014] In some embodiments, the first layer is adhered to the second layer.

[0015] In some embodiments, the air-bubble cushioning liner has a thickness of 5 mm.

[0016] In some embodiments, the one or more layers of air-bubble wrap have a thickness selected from the group consisting of ⅛ inch, $\frac{3}{16}$ inch, $\frac{5}{16}$ inch, and ½ inch.

[0017] In some embodiments, the protective body is a helmet.

[0018] In some embodiments, the helmet is a Type 1 industrial helmet model.

[0019] In some embodiments, the air-bubble cushioning layer is affixed to the inner surface of the shock suspension system with an adhesive.

[0020] In some embodiments, the adhesive is Dycem 50-1560Y.

[0021] In some embodiments, the upper layer is adhered to the lower surface of the shock suspension system and the lower layer is proximate to a user's head.

[0022] In some embodiments, the air-bubble cushioning liner is made from a material selected from the group consisting of low-density polyethylene (LDPE) film, high-density polyethylene (HDPE) film, polypropylene (PP) film, and combinations thereof.

[0023] In some embodiments, the air-bubble cushioning liner is dome-shaped and an upper dome surface is adhered to the inner surface of the shock suspension system.

[0024] In some embodiments, the air-bubble cushioning liner is sized to fit a user's head.

[0025] In an aspect, the disclosure provides a method of making a protective headgear assembly, including the steps of: providing a protective body having an inner surface and an outer surface; affixing a shock suspension system to the inner surface of the protective body, the shock suspension system having an upper surface and a lower surface; and adhering an air-cushioning liner onto the lower surface of the suspension system.

[0026] In some embodiments, the air-cushioning liner comprises an upper layer of air-bubble wrap and a lower layer of air-bubble wrap oriented so that a bubble-side of the upper layer faces a bubble-side of the lower layer.

DESCRIPTION OF THE DRAWINGS

[0027] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate various example methods, and other example embodiments of various aspects of the invention. It will be appreciated that the illustrated element boundaries (e.g., boxes, groups of boxes, or other shapes) in the figures represent one example of the boundaries. One of ordinary skill in the art will appreciate that in some examples one element may be designed as multiple elements or that multiple elements may be designed as one element. Furthermore, elements may not be drawn to scale.

[0028] FIGS. **1**A-**1**D are schematics showing exemplary experimental test systems as described herein, as well as an exploded view of a protective headgear assembly according to an illustrative embodiment of the disclosure. FIG. **1**A depicts an exemplary experimental set-up to measure acceleration of an impactor and the force transmitted to the base of a headform fitted with an exemplary construction helmet. FIG. **1**B illustrates an exemplary experimental system set-up with an unmodified Type 1 helmet in accordance with FIG. **1**A. FIG. **1**C illustrates an exemplary experimental system set-up with an exemplary air-bubble cushioning liner modified Type 1 helmet in accordance with FIG. **1**A according to an exemplary embodiment of the disclosure. FIG. **1**D is an exploded view of an exemplary protective headgear assembly.

[0029] FIGS. **2**A-**2**C are diagrams showing embodiments of an air-cushioning liner according to an exemplary embodiment of the disclosure. FIG. **2**A presents a perspective view of a structure of the exemplary air-cushioning liner in accordance with FIG. **1**C. FIG. **2**B presents a cross-sectional view of the structure of the exemplary air-cushioning liner in accordance with FIG. **2**A. FIG. **2**C presents bottom (e.g., top panel) and cross-sectional (e.g., bottom panel) views of the air-cushioning liner positioned within the helmet in accordance with FIG. **1**C.

[0030] FIGS. **3**A-**3**C are graphs depicting drop test data. FIG. **3**A presents an exemplary graph of the impact velocity as a function of drop height in accordance with the exemplary experimental set-up of FIG. **1**A. FIG. **3**B presents an exemplary graph of the kinetic energy loss of the system as a function of drop height in accordance with the exemplary experimental set-up of FIG. **1**A. FIG. **3**C presents an exemplary graph of the relative kinetic energy loss of the system as a function of drop height in accordance with the exemplary experimental set-up of FIG. **1**A.

[0031] FIGS. **4**A-**4**B are graphs depicting force transmission data. FIG. **4**A presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test on an unmodified helmet in accordance with the exemplary experimental set-up of FIG. **1**A. FIG. **4**B presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test on a helmet equipped with an air-bubble cushioning liner in accordance with the exemplary experimental set-up of FIG. **1**A.

[0032] FIGS. **5**A-**5**F are graphs depicting force transmission data. FIG. **5**A presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 0.61 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with the exemplary experimental set-up of FIG. **1**A. FIG. **5**B presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 1.52 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **5**C presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 1.63 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with the exemplary experimental set-up of FIG. **1**A. FIG. **5**D presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 1.73 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **5**E presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 1.83 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **5**F presents an exemplary graph of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height of 1.93 m the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure.

[0033] FIGS. **6**A-**6**F are graphs depicting impactor acceleration data. FIG. **6**A presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 0.61 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **6**B presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 1.52 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **6**C presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 1.63 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **6**D presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 1.73 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **6**E presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 1.83 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **6**F presents an exemplary graph of the representative recorded time-histories of the impactor acceleration for a drop impact test at a drop height of 1.93 m for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure.

[0034] FIGS. **7**A-**7**B are graphs showing peak transmission force data. FIG. **7**A presents an exemplary graph of the peak transmitted forces as a function of drop height for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure. FIG. **7**B presents an exemplary graph of the impact force reduction coefficient as a function of drop height for the unmodified helmet and the helmet with the air-bubble cushioning liner in accordance with an exemplary embodiment of the disclosure.

[0035] FIGS. **8**A-**8**B are graphs showing variations in force transmission relating to helmet failure. FIG. **8**A presents an exemplary graph of the variations of the transmitted force responds around the peak of the unmodified helmet and the helmet with the air-bubble cushioning liner at a drop height of 1.73 m in accordance with an exemplary embodiment of the disclosure. FIG. **8**B presents an exemplary graph of the variations of the transmitted force responds around the failure of the unmodified helmet and the helmet with the air-bubble cushioning liner at a drop height of 1.83 m in accordance with an exemplary embodiment of the disclosure.

[0036] FIGS. **9**A-**9**B are panels of graphs showing force transmission time histories. FIG. **9**A presents exemplary graphs of the representative time-histories of the transmitted forces for the unmodified Type 1 helmet for ten repeated drop impacts and for three different drop heights, 0.61 m, 1.52 m, and 1.63 m, respectively. FIG. **9**B presents exemplary graphs of the representative time-histories of the transmitted forces for the modified Type 1 helmet for ten repeated drop impacts and for three different drop heights, 0.61 m, 1.52 m, and 1.63 m, respectively.

[0037] FIGS. **10**A to **10**C are graphs showing peak force transmission data as a function of impact number. FIG. **10**A illustrates exemplary graphs of the peak transmitted forces as a function of impact number for each drop impact height (i.e., 0.61 m, 1.52 m, 1.63 m, and 1.73 m), respectively for unmodified Type 1 helmets and modified Type 1 helmets in accordance with an exemplary embodiment of the disclosure. FIG. **10**B presents exemplary graphs of the peak transmitted forces (Fmax) as a function of drop impact heights for ten impacts for unmodified Type 1 helmets and modified Type 1 helmets in accordance with an exemplary embodiment of the disclosure. FIG. **10**C depicts exemplary graphs of the peak transmitted force (Fmax) for four drop heights as a function of impact number for unmodified Type 1 helmets and modified Type 1 helmets in accordance with an exemplary embodiment of the disclosure.

DETAILED DESCRIPTION

[0038] Approximately 7.3% of traumatic brain injury cases identified by the Ontario Trauma Registry were 24 work-related (Kim et al., (2016) Int J Environ Res Public Health 13:11). A study of an Abu Dhabi (United Arab Emirates) hospital records between 2005 and 2009 indicated that 56 (about 10%) of a total of 581 TBI cases were related to occupational activities (Salem et al., Traumatic brain injuries from work accidents: a retrospective study, Occup. Med. (Lond.) 63 (5) (2013) 358-360.). Another study of hospital records in northern Italy from 1996 to 2000 showed that approximately 15% of TBI incidents occurred in workplaces (Baldo et al., Epidemiological aspect of traumatic brain injury in northeast Italy, Eur. J. Epidemiol. 18 (11) (2003) 1059-1063.). A surveyance of the insurance records in Taiwan for 2009 showed that 11% of occupational injuries requiring hospitalization involved TBI (Lin et al., Psychological outcome of injured workers at 3 months after occupational injury requiring hospitalization in Taiwan, J. Occup. Health 54 (4) (2012) 289-298.). Construction is the leading industry for serious work-related traumatic brain injuries (WrTBI) due to the high incidence of falls and head struck-by incidents (Hino, Y., Fundamental study on relationship between human injury probability due to fall and the fall height, Work 41 (Suppl 1) (2012) 3339-3342; Liu et al., Work-related mild-moderate traumatic brain injury and the construction industry, Work 39 (3) (2011) 283-290; Lombardi et al., Work-related falls from ladders—a follow-back study of US emergency department cases, Scand. J. Work Environ. Health 37 (2011) 525-532.). Many epidemiological studies suggest that WrTBIs are one of the most serious occupational injuries among construction workers, resulting in extensive medical care, multiple days away from work, and permanent disability, or death (Hino et al., 2012; Liu et al., 2011; Lombardi et al. 2011; Thurman et al., Traumatic brain injury in the United States: A public health perspective, J. Head Trauma Rehabil. 14 (6) (1999) 602-615; Tiesman et al., The epidemiology of fatal occupational traumatic brain injury in the U.S, Am. J. Prev. Med. 41 (1) (2011) 61-67; Konda et al., Fatal traumatic brain injuries in the construction industry, 2003-2010, Am. J. Ind. Med. 59 (3) (2016) 212-220.). Approximately 15.6% of WrTBI incidents resulted from struck-by objects on the head (Liu et al. 2011; Kim et al., Traumatic brain injury occurring at work, Neuro Rehabil. 21 (4) (2006) 269-278; Coleman, V., Occupational head injury accidents in Great Britain, J. Occup. Acid. 8 (1986) 161-172.). It is generally accepted that the industrial helmet is the most used and effective personal protective equipment available to reduce WrTBI (Kim et al. 2016; Tiesman et al. 2011). OSHA (Occupational Safety and Health Administration) regulations require workers to wear a helmet to reduce risk of head injury from falling objects (OSHA, 1926.100/1910.135: Safety and Health Regulations for Construction, Personal Protective and Life Saving Equipment. Occupational Safety and Health Administration, Washington, D.C.).

[0039] Industrial helmets (also referred to as construction helmets) are categorized as Type I or Type II according to the ANSI Z89.1 standard. A Type I helmet is designed for top impact protection only, whereas a Type II helmet is also designed for protection from lateral impacts. Industrial helmets widely used in construction and manufacturing industries are mostly categorized as Type I. All Type I helmets have to pass the top impact test (i.e., Type I impact test), in which an impactor drops freely from a certain height or at a certain impact velocity onto a fixed helmet; the maximal peak transmitted impact force shall be smaller than a certain limit for the helmet to pass the test. There are three most frequently used international test standards for industrial helmets: ANSI Z89.1 (ANSI, ANSI/ISEA Z89.1: American

National Standard for Industrial Head Protection, American National Standards Institute, Washington, D.C.), EN397 (BS, EN 397:2012+A1: Industrial Safety Helmets, British Standards Institution, London, UK), and EN14052 (BS, EN 14052: 2012+A1: High Performance Industrial Helmets, British Standards Institution, London, UK). The ANSI Z89.1 standard is mainly used in North America, whereas EN397: 2012+A1 and EN14052:2012+A1 are European standards. In ANSI Z89.1 standard, the impactor has a mass of 3.6 kg, freely drops, and impacts the helmet's crown at a velocity of 5.5 m/s. To pass the test, the maximal transmitted force must be less than 4.45 kN. The impact test required by European standard EN397 specifies an impactor (mass 5.0 kg) that freely drops from a height of 1.0 m and impacts onto the helmet; the maximal acceptable peak transmitted force is 5.0 kN. European standard EN14052 is for high-performance industrial helmets. It requires the helmet to be tested not only with top and lateral impacts, but also with off-crown impacts, in which the impactor strikes onto the helmet at angles of 15°, 30°, 45°, and 60°.

[0040] Prior art Type I helmets consist of a hard shell and a suspension system. The helmet shell is typically molded using polyethylene or polycarbonate plastics. According to ANSI Z89.1, the use of chin strap is optional in Type I helmets. The suspension system plays a major role in shock absorption and impact force redistribution. Although the suspension systems of Type I industrial helmets produced by different manufacturers utilized different materials, their structural designs are similar. The suspension system in a typical Type I helmet consists of a synthetic woven fabric strips and bands of molded nylon or vinyl. The suspension molded bands are attached to the shell via a 4-point or a 6-point ratchet. In addition to a strip-type suspension, Type II helmets have a pad liner, mostly made of foam materials. There is an advanced high-performance helmet (Kask safety helmet; KASK Inc, Chiuduno, Italy) on the market, which has an additional polymer shock absorption pad liner between the strip-type suspension and shell. High performance industrial helmets will pass EN14052 tests, which are more stringent than the Type I and Type II tests in ANSI Z89.1. Since the suspension system plays an essential role in absorbing impact shocks in a helmet, the research and development efforts of helmets have mainly been focused on the improvement of the suspension system (Corrales et al., Validation of a football helmet finite element model and quantification of impact energy distribution, Ann. Biomed. Eng. 48 (2019) 121-132. Decker et al., Development and multi-scale validation of a finite element football helmet model, Ann. Biomed. Eng. 48 (2020) 258-270.). Prior art industrial helmet designs have not considered implementing air-bubble cushions because these types of cushions are generally used for protection in scenarios that involve relatively small impacts, which are not consistent with the needs of an industrial helmet.

[0041] Compared to other conventional shock absorption materials, such as rubbers and polymers, air-bubble cushions have the advantages of being light weight, low cost, and unique mechanical performance attributes. Air-bubble cushions have been widely used in scenarios where humans interact with the equipment or environment, for example, shoes, shock-absorption gloves, seat cushions, and air bed mattresses. Air cushioned soles have been used in shoes to improve shock absorption performance and comfort for decades (Falsetti et al., Hematological variations after endurance running with hard- and soft-soled running shoes, Phys. Sportsmed. 11 (8) (1983) 118-127.). In air-cushioned gloves, finger segments are cushioned by separated air-bubbles to absorb the vibrations transmitted to the hand (Hewitt et al., Anti-vibration gloves? Ann. Occup. Hyg. 59 (2) (2015) 127-141.). The vibration absorption performances of air-cushioned gloves were found to be dependent on the vibration frequencies and grip forces (Welcome et al., Tool-specific performance of vibration-reducing gloves for attenuating fingers-transmitted vibration, Occup. Ergon. 13 (1) (2016) 23-44.). The dependence of the contact stiffness of an air-cushioned glove on the air pressure and bubble sheet materials have been analyzed theoretically (Wu et al., An analysis of contact stiffness between a finger and an object when wearing an air-cushioned glove: the effects of the air pressure, Med. Eng. Phys. 34 (3) (2012) 386-393.). Air-bubble buffers have been used in hip protectors to protect the elderly from hip fractures (Song et al., Study on buffer characteristics of air cushion used as hip protector, J. Appl. Biomater. Funct. Mater. 16 (1 Suppl) (2018) 32-36; Boroujeni, S., Inflatable Hip Protectors, M. Sc. Thesis, Simon Fraser University, Vancouver, B.C., Canada, 2012.). Air cushion seats have been applied to improve the interface contact pressure distributions on the human body (Lee et al., Effects of different seat cushions on interface pressure distribution: a pilot study, J. Phys. Ther. Sci. 28 (1) (2016) 227-230.). Air-bubble cushions have been used in football helmets to provide an additional layer of padding while increasing comfort and the fit of the helmet (L. Schwartz 2011 Types of Padding in Football Helmets, SportRec). In all these scenarios, the air-bubble cushions have been used to reduce contact stress or to absorb small impact force in the contact interface between the human and equipment.

[0042] Air-bubble cushions have also been widely used in the packaging industry (W. Soroka, Fundamentals of Packaging Technology, IoPP, Naperville, Ill., USA, 2002.). An air-bubble wrap sheet—a common packing material in industries—consists of two low-density polyethylene (LDPE) films, with one bubble-shaped film being bonded to a flat film to form air-bubbles. The pressure of the initial inflation air may be varied in accordance with the sheet material properties and requirements of the package contents to be protected. Air-bubble wrapping sheets are commercially available in different thicknesses, bubble sizes, and bubble densities. For example, the air-bubble size can be as small as 3/16" (6 mm), to as large as 1" (25 mm) in diameter. The most commonly used air-bubble wrapping sheet has an air-bubble diameter of 10 mm (K. Yam, Encyclopedia of Packaging Technology, John Wiley and Sons, USA, 2009.). Compared to other packing materials, air-bubble wrapping sheet has the advantages of excellent shock absorption characteristics, light weight, insensitive to climate conditions (e.g., temperature and humidity), and high flexibility (Yam 2009). Malasri et al. (Plastic tote distribution, Int. J. Adv. Packag. Technol. 1 (1) (2013) 40-52.) showed that the impact acceleration in the contents packed with 3/16" (5 mm) and 5/16" (8 mm) bubble wrapping is about 34% less than that packed with viscoelastic foam wrapping. Despite widespread adoption of air-bubble cushions in ergonomic designs and in commercial packaging as shock absorption materials, they have never been used in industrial helmets. Moreover, no prior art applications have assessed whether air-bubble cushions would also be effective in absorbing large impact forces, such as those observed with the industrial helmets.

[0043] The present disclosure is based, at least in part, on the discovery that air-bubble cushions are able to effectively absorb and dissipate large impact forces such as those encountered in industrial work environments, and that inserting one or more layers of air-bubble cushioning in between a user's head and the shock suspension system of a helmet (e.g., a construction helmet) dramatically improves the impact absorption/dissipation characteristics of the helmet. The helmets disclosed herein can be used to improve the shock absorption performance of Type I industrial helmets. Advantageously, the helmets disclosed herein have markedly improved impact absorption/dissipation abilities relative to prior art Type I industrial helmets. Additionally, the helmets disclosed herein are lightweight and inexpensive to manufacture. Furthermore, the present disclosure provides an additional modular layer of protection (e.g., an air-bubble cushioning liner) that can be retrofitted onto presently available industrial helmets. A further advantage of the present disclosure is that inserting one or more layers of air-bubble cushioning in between a user's head and the shock suspension system of a helmet dramatically increases the endurance of a helmet under multiple impacts, thereby significantly increasing the safety of the helmet users, and increasing the lifespan of the helmet.

[0044] FIG. **1**A presents an exemplary experimental set-up **100** to measure the acceleration of impactor **102** and the transmitted force at the base **109** of a headform **108** fitted with an exemplary construction helmet **106** at different drop heights **104**. FIG. **1**B and FIG. **1**C illustrate an exemplary Group I experimental system set-up **110** with an exemplary unmodified Type 1 helmet **112** including a shock suspension system **114** on a headform **108** and an exemplary Group II experimental system set-up **120** with a modified Type 1 helmet **122** including a shock suspension system **114** affixed with an air-bubble cushioning liner **124** positioned between the shock suspension system **114** and headform **108**, respectively. It is contemplated within the scope of the disclosure that the air-bubble cushioning liner **124** can be made from air-bubble materials including low-density polyethylene (LDPE), high density polyethylene (HDPE), and/or polypropylene (PP). The unmodified Type I helmets **112** tested in Group I served as the control group. The modified Type I helmets **122** in Group II were the same as those in Group I, except they included an air-bubble cushioning liner **124**. In some embodiments, the air-bubble cushioning liner **124** is attached to the shock suspension system **114** of modified Type I helmet **122**. In other embodiments, the helmets **112**, **122** might have a strap attached to the shock suspension system **114** (not shown in the figures). One of skill in the art will appreciate that shock suspension system **114** may generally have an upper surface proximate to construction helmet **106** (e.g., a protective body) and a lower surface proximate to a user's head. FIG. **1**D shows an exploded view of an exemplary embodiment of a protective headgear assembly according to the disclosure in which a dome-shaped air-bubble cushioning liner **124** is inserted into and/or attached to the shock suspension system **114**, which interfaces with a Type I helmet **112**.

[0045] FIGS. **2**A-**2**C present a perspective view **200**, a cross-sectional view **210** of the structure of the exemplary air-bubble cushioning liner **124** used in the modified Type I helmets **122**, and bottom (e.g., top panel) and cross-sectional (e.g., bottom panel) views of the air-cushioning liner **124**, respectively. Commercially available air-bubble cushioning wrap sheets (e.g., Blue Hawk, Gilbert, Ariz.) were used for the air-bubble cushioning liner **124**. In an exemplary embodiment, air-bubble cushioning liner **124** may have a dimension of 30.5 cm×30.5 cm (1'×1'), as presented in FIG. **2**A. In a natural, undeformed state, an air-bubble in the air-bubble cushioning liner **124** may have a diameter of about 9 mm and a height of about 4 mm. The air-bubble cushioning liner **124** may also be comprised of two or more layers. It is contemplated within the scope of the disclosure that when two or more layers of air-bubble cushioning are present in air-bubble cushioning liner **124**, they may be adhered to one another in an air-bubble to air-bubble orientation (see e.g., FIG. **2**B) by any of a variety of means known in the art (e.g., an adhesive, a mechanical fastener, a bonding agent, thermal bonding, and the like). In another embodiment, the two layers may be fabricated in a sheet in which the air-bubble to air-bubble orientation of the two layers is already present (e.g., as a result of the manufacturing process). For example, air-bubble cushioning liner **124** may include a lower layer of air-bubble cushioning wrap sheet **212**, and an upper layer of air-bubble cushioning wrap sheet **214** as shown in FIG. **2**C, with their respective bubble sides being placed against each other as depicted in FIG. **2**B. In an exemplary embodiment, air-bubble cushioning liner **124** may have a thickness of approximately 5 mm in an undeformed state. The air-bubble cushioning liner **124** was wrapped on the headform **108** as depicted in FIG. **1**C and the modified Type I helmet **122** with the shock suspension system **114** was placed onto the wrapped headform **108**, such that impact force may be transmitted to the headform **108** through the air-bubble cushioning liner **124**. In some embodiments, the air-bubble cushioning liner **124** can be adhered to the lower surface of shock suspension system **114** with an adhesive sheet (not shown in the figures) such as, for example, Dycem. In an exemplary embodiment, the adhesive sheet has a thickness of 0.3 mm. In some embodiments, air-bubble cushioning liner **124** may be a circular, two-dimensional sheet that is inserted into the shock suspension system **114** and adhered to the lower surface thereof. In an exemplary embodiment, the adhesive sheet has a thickness of 0.3 mm. In some embodiments, air-bubble cushioning liner **124** may be a dome-shaped insert (e.g., shaped like a beanie hat) that is inserted into the shock suspension system **114** and adhered to the lower surface thereof.

[0046] The experimental set-ups **110** and **120** (see e.g., FIG. **1**B and FIG. **1**C) were carried out at six different drop heights **104**: 0.61 m, 1.52 m, 1.63 m, 1.73 m, 1.83 m, and 1.86 m, respectively. Four replications were performed for each of the Group I and Group II tests. A total of 48 helmet drop impact trials were performed in the study. The selected range of the drop heights **104** correspond to the specified test conditions required of Type I impact in ANSI consensus standard ANSI Z89.1, in which the drop impactor **102** is required to reach a velocity of 5.5 m/s immediately before impact, which is estimated to be equivalent to a drop height **104** of 1.54 m for a frictionless condition.

[0047] Before data collection from the experimental set-ups depicted in FIG. **1**B **110** and FIG. **1**C **120**, a pre-condition process was performed for each of the helmet **112**, **122** (Wu et al., (2019) 96: 330-339). In the pre-conditioning, a helmet **112**,**122** was placed on the headform **108**, as in the impact test, and impacted three times by the impactor **102** at a low drop height **104** (e.g., at about 10 cm or about 4 in). The force-time histories of each helmet were examined during the pre-conditioning to make sure that the helmets **112**,**122** reached a "steady state" before the data collection. The measurements of the transmitted force to the headform base **109** may become more repeatable after the pre-conditioning impact treatment. Furthermore, before the data collection, the drop tower system was calibrated to determine the system friction loss. The potential energy loss due to friction (ΔE) is estimated by the difference between the initial potential energy (mgh) and the kinetic energy involved in the impact (½mv²):

$$\Delta E = mgh - \tfrac{1}{2}mv^2 \quad (1)$$

where m (3.6 kg) and g (9.8 m/s2) are the impactor mass and gravitational acceleration, respectively. The relative energy loss, δ, is estimated by compare ΔE to the potential energy:

$$\delta = \frac{\Delta E}{mgh} \times 100\% \quad (2)$$

[0048] The raw time-history data of the transmitted force and acceleration were processed using a MATLAB program to find the maximal peaks. The relationships of the peak transmitted forces and peak acceleration to the drop height **104** were analyzed. In order to evaluate the contribution of the air-bubble cushioning liner **124** to the helmet shock absorption performance, an impact force reduction coefficient is defined:

$$\eta = \left(1 - \frac{F_{max,air}}{F_{max,no-air}}\right) \times 100\% \quad (3)$$

where $F_{max,\ no-air}$ and $F_{max,\ air}$ are the mean peak forces for Group I test (unmodified helmets) and Group II test (helmets with added air-bubble cushioning liner), respectively.

[0049] If the data collected from the Group I test are independent of those collected from the Group II test, the standard deviation of the impact force reduction coefficient, S_η, is estimated by the Taylor approximation. K. M. Wolter, Taylor Series Methods, Introduction to Variance Estimation, Springer, New York, 1985:

$$S_\eta = \frac{F_{max,air}}{F_{max,no-air}} \sqrt{\left(\frac{S_{max,no-air}}{F_{max,no-air}}\right)^2 + \left(\frac{S_{max,air}}{F_{max,air}}\right)^2} \quad (4)$$

where $s_{max,\ no-air}$ and $S_{max,\ air}$ are the standard deviations of the Group I test and Group II test, respectively.

[0050] FIG. **3**A presents an exemplary graph **300** of the impact velocity as a function of drop height in accordance with the experimental set-up **110** of FIG. **1**B and with the experimental set-up **120** of FIG. **1**C. The impact velocity, v, as a function of the drop height **104**, h, is shown in exemplary graph **300** depicted in FIG. **3**A. The ANSI consensus standard ANSI Z89.1 standard indicates an optimal impact velocity of 5.5 m/s, which was achieved at a drop height **104** of 1.73 m as depicted in the exemplary graph **300** depicted in FIG. **3**A. FIGS. **3**B and **3**C present exemplary graphs **302** and **304** of the kinetic energy loss of the system and the relative kinetic energy loss of the system as a function of drop height, respectively, in accordance with the experimental set-up **110** of FIG. **1**B and with the experimental set-up **120** of FIG. **1**C. From inferring the exemplary graphs **302** and **304**, it can be seen that the frictional energy loss of the system is dependent on the drop height and the system has a frictional loss of approximately 7 J or 12% at the optimal impact velocity (5.5 m/s) specified by ANSI consensus standard ANSI Z89.1.

[0051] FIG. **4**A presents an exemplary graph **400** of the representative recorded time-histories of the transmitted forces for a drop impact test at a drop height **104** of 0.61 m on the unmodified Type 1 helmet **112** as per the experimental set-up **110** depicted in FIG. **1**B and FIG. **4**B presents an exemplary graph **402** of the representative recorded time-histories of the transmitted forces for a drop impact test on the modified Type 1 helmet **122** equipped with an air-bubble cushioning liner **124** as per the experimental set-up **120** depicted in FIG. **1**C. Exemplary graphs **400** and **402** both present data which shows two peak forces, which are associated to the first and the second impacts between the impactor **102** and the helmets **112**, **122**. The first impact was the primary focus as it corresponds to the maximal peak impact force, one of the main factors relating to the traumatic brain injury (Mertz., (1985)). Graphs **400** and **402** demonstrate that adding an air-bubble cushioning liner **124** to the unmodified Type 1 helmet **112** may change the appearance time of the second impact, but does not alter the general characteristics of the impact time histories.

[0052] FIGS. **5**A-**5**F present exemplary graphs of the representative recorded time-histories of the transmitted forces for a drop impact test at different drop heights **104** which include 0.61 m (**500**), 1.52 m (**502**), 1.63 m (**504**), 1.73 m (**506**), 1.83 m (**508**), and 1.93 m (**510**) for the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124** as depicted in FIGS. **1**B and **1**C. FIGS. **5**A-**5**F show that, for both Group I and Group II tests, the impact duration (i.e., the time that the impactor **102** is in contact with the helmets **112**, **122**, or the impact force is greater than zero), is approximately 22 ms and it is nearly independent of the drop height **104** and the addition of the air-bubble cushioning liner **124**. Upon closer examination of the characteristics of the impact force patterns for the helmets from Group I, when drop height **104**, h≤1.73 m (FIGS. **5**A-**5**D), the force impulses may have a nearly unchanged base width and their peaks increase gradually with increasing drop height and when the drop height **104**, h≥1.83 m (FIGS. **5**E-**5**F), an additional sharp peak appears on the top of the base force impulse. This sharp force peak was very narrow (with a duration of approximately 1 ms) and had a magnitude that increased dramatically with increasing drop height. For helmets in test Group II, there was no sharp force impulse for the entire range of drop heights as depicted in FIGS. **5**A-**5**F.

[0053] FIGS. **6**A-**6**F present exemplary graphs of the representative recorded time-histories of the impactor **102** acceleration for a drop impact test at different drop heights **104** which include 0.61 m (**600**), 1.52 m (**602**), 1.63 m (**604**), 1.73 m (**606**), 1.83 m (**608**), and 1.93 m (**610**) for the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124** as depicted in FIGS. **1**B and **1**C. The magnitude of the peak acceleration for both test groups, Group I and Group II, increased gradually from 50 G to 80 G, when the drop height increased from 0.61 m to 1.74 m as depicted in FIGS. **6**A-**6**D, during which the air-bubble cushioning liner **124**

had little effect on the acceleration patters. Consistent with the variations of the transmitted forces as presented in FIGS. **5**A-**5**F, the acceleration patterns for test Group I showed a sudden change around drop heights **104** 1.73-1.83 m as presented in FIGS. **6**D-**6**, where a narrow, sharp peak appears on the top of the base pattern. As depicted in FIG. **6**F, at a drop height of 1.93 m, the magnitude of the peak acceleration reached as great as 370 G for Group I tests. The acceleration results for the helmets **122** equipped with air-bubble cushioning liner **124** (Group II) did not have these sharp acceleration peaks for the entire range of drop heights **104**.

[0054] FIG. **7**A presents an exemplary graph **700** of the peak transmitted forces as a function of drop height **104** for the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124**. FIG. **7**B presents an exemplary graph **702** of the impact force reduction coefficient (η) as a function of drop height **104** for the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124**. The mean peak forces for test Group I ($F_{max,\ no\text{-}air}$) and Group II ($F_{max,\ air}$), and the impact force reduction coefficient (η), together with their standard deviations, for six different drop heights **104** are listed in Table 1. The data presented in the table, i.e., the mean peak transmitted forces for test Group I ($F_{max,\ no\text{-}air}$) and Group II ($F_{max,\ air}$), are plotted as a function of the drop height **104** presented in exemplary graph **700** in FIG. **7**A. The peak force values for unmodified Type 1 helmets **112** in Group I ($F_{max,\ no\text{-}air}$) increased gradually with increasing drop height **104** for h<1.73 m and followed by a dramatic increase with increasing drop height **104** for h>1.83 m. In comparison, the peak force values for modified Type 1 helmets **122** in Group II ($F_{max,\ air}$) increased gradually with increasing drop height for the entire range of the drop heights. For lower drop heights **104** (h≤1.73 m), the air cushioning liner **124** had little effect (i.e., η is close to 0%), whereas the shock absorption effects of the air cushioning liner **124** increased substantially (i.e., η increase) with increasing drop height **104** for higher impact force (h≥1.73 m). The difference between Group I and Group II is analyzed using a two-way analysis of variance (ANOVA), with the data shown as a mean of four replication tests. The data presented in the table, i.e., the impact force reduction coefficient for test Group I ($F_{max,\ no\text{-}air}$) and Group II ($F_{max,\ air}$), are plotted as a function of the drop height **104** presented in exemplary graph **702** in FIG. **7**B.

not appear to reduce the impact force for a modified Type 1 helmet **122** equipped with a strap suspension system (not shown in the figures), as predicted by literature (Wu et al., (2012) Med Eng Phys 34:386-393). In this regard, the prior art teaches that adding an air-bubble liner does not reduce the impact force for a modified Type I helmet. Surprisingly, the techniques disclosed herein show that the air-bubble cushioning liner **124** showed significant effects of the shock absorption at a higher drop heights **104** (h≥1.73 m). At a drop height **104** of 1.93 m—the highest drop height **104** tested, adding the air-bubble cushioning liner **124** to a typical unmodified Type 1 helmet **112** reduced the peak impact force magnitude by over 80%.

[0056] FIG. **8**A presents an exemplary graph **800** of the variations of the transmitted force responds around the failure of the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124** at a drop height **104** of 1.73 m. FIG. **8**B presents an exemplary graph **802** of the variations of the transmitted force responds around the failure of the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122** with the air-bubble cushioning liner **124** at a drop height **104** of 1.83 m. The time-histories of the impact force around the critical drop heights **104** 1.73 m and 1.83 m were re-examined with data inferred from exemplary graphs **800** and **802** to elucidate the failure mechanism of the helmet. It can be inferred from exemplary graph **800** that the impact actuated high frequency vibrations in the unmodified Type 1 helmet **112** with the shock suspension system **114** (denoted by red solid lines) when the drop height **104** is close to the critical drop height **104**. It can be further deduced that that adding an air-bubble cushioning liner **124** helped eliminate the high frequency vibrations of the shock suspension system **114** (denoted by black dashed lines). It can be deduced from exemplary (denoted by red solid lines) appears on the top of the base force impulse. It can be further inferred that the air-bubble cushioning liner **124** may have helped remove the sharp narrow impulse (denoted by black dashed lines), thereby preventing the modified Type 1 helmet **122** from pre-mature failure. These observations are comparable with a previous study of the vibration mitigation performance of air-bubble gloves (Welcome et al., (2016) Occup Ergon 13(1):23-44), in which the air-bubble gloves were found to be effective in absorbing high frequency vibrations transmitted to the fingers, whereas they were ineffective for mitigating low frequency vibrations.

TABLE 1

Drop Height	Test Group I		Test Group II		Mean force difference		Force reduct coeff	
h (m)	Fmax, no-air Mean, (kN)	Std	Fmax, air Mean, (kN)	Std	(Fmax, no-air-Fmax, air) (kN)	p-value* (–)	η (%)	Std
0.61	1.588	0.03	1.584	0.03	0.004	1	0.3	2.7
1.524	2.48	0.03	2.515	0.05	−0.035	1	−1.4	2.5
1.628	2.645	0.24	2.541	0.02	0.104	1	1.9	8.7
1.731	2.942	0.66	2.596	0.02	0.347	1	11.8	19.7
1.829	7.329	3.87	2.687	0.03	4.642	0.002	63.3	19.4
1.926	14.405	2.51	2.521	0.22	11.884	<0.0001	82.5	3.4

[0055] FIGS. **3**A-**7**B, in summary, present data that consistently shows that the effects of shock absorption of air-bubble cushioning liner **124** in helmets **112**, **122** may be dependent on the impact magnitude. At lower drop heights **104** (h<1.63 m), adding an air-bubble cushion liner **124** did

[0057] Table 2 presents the mean peak transmitted forces (F max in kN) for Group I (unmodified Type 1 helmets **112**) and Group II (unmodified Type 1 helmets **122**) for different impact numbers and different drop heights **104**. The values shown are means of four replication tests. The impact tests were stopped once the measured peak force values reached 20 kN. The highlighted force values are higher than the force limit of 4.45 kN, which is the maximum allowable value to pass the ANSI consensus standard ANSI Z89.1. The data presented in Table 2 are illustrated in the exemplary graphs of FIG. **9**A-**10**C.

exemplary graphs **1004** and **1006**, respectively, the helmets in Group I could withstand only the first impact and they failed starting from the second impact. In comparison, the peak transmitted force for helmets in Group II started to increase only after the ninth and sixth drop impact at drop heights **104** of 1.63 m and 1.73 m, respectively.

TABLE 2

Imp #	Original Helmats (kN)								Helmets with air bubble liners (kN)							
	h = 0.61 m		h = 1.52 m		h = 1.62 m		h = 1.73 m		h = 0.62 m		h = 1.52 m		h = 1.62 m		h = 1.73 m	
n	Fmax	Std	Fmax	Std	Fmax	Std	Fmax	Std	Fmax	Std	Fmax	Std	Fmax	Std	Fmax	Std
1	1.59	0.03	2.48	0.03	2.56	0.24	2.94	0.56	1.58	0.03	2.53	0.05	2.54	0.02	2.6	0.02
2	1.62	0.08	3.94	2.75	9.63	5.76	1.5	4.25	1.65	0.04	2.65	0.11	2.58	0.01	2.7	0.2
3	1.59	0.04	6.5	5.06	12.25	5.78	20.3	2.9	1.62	0.04	2.68	0.07	2.71	0.01	2.74	0.01
4	1.52	0.07	9.96	5.53	15.14	5.45	21.45	1.59	1.63	0.03	2.71	0.07	2.76	0.02	2.79	0.05
5	1.63	0.06	12.84	6.16	17.4	6.98	>22		1.63	0.02	2.69	0.08	2.72	0.04	2.8	0.05
6	1.68	0.04	15.92	5.49	19.5	5.28	>22		1.63	0.04	2.72	0.1	2.77	0.03	3.32	0.85
7	1.55	0.05	14.99	4.67	>22		>22		1.64	0.03	2.64	0.16	2.74	0.02	7.54	3.23
8	1.53	0.05	13.45	4.81	>22		>22		1.64	0.02	2.73	0.08	2.79	0.1	12.01	1.76
9	1.64	0.05	19.73	3.88	>22		>22		1.65	0.05	2.69	0.18	2.81	0.14	14.7	1.92
10	1.62	0.01	21.16	1.25	>22		>22		1.65	0.03	2.79	0.09	7.42	2.74	15.22	0.11

FIGS. **9**A and **9**B depict exemplary graphs **900**, **902** which present the representative time-histories of the transmitted forces for the unmodified Type 1 helmet **112** and modified Type 1 helmet **122**, respectively, for ten repeated drop impacts and for three different drop heights **104**, 0.61 m, 1.52 m, and 1.63 m. It can be inferred from exemplary graphs **900** and **902** that at a lower drop height **104** of 0.61 m, the measured transmitted forced varied little and were well under the force limit F=4.45 kN (standard enforced by the ANSI consensus standard ANSI Z89.1) for ten repeated impacts for both the unmodified Type 1 helmet **112** and the modified Type 1 helmet **122**. At drop heights of 1.52 m and 1.63 m, it can be inferred from the exemplary graphs **900** that the unmodified Type 1 helmet **112** failed after the third drop impact. Contrastingly, at drop heights **104** of 1.52 m and 1.63 m, it can be inferred from the exemplary graphs **902** that the modified Type 1 helmet **112** survived ten repeated impacts with a drop heights **104** of 1.52 m and nine repeated impacts with a drop height of 1.63 m.

[0058] FIG. **10**A illustrates exemplary graphs **1000**, **1002**, **1004**, and **1006** which present the peak transmitted forces as a function of impact number for each drop impact height **104** (i.e., 0.61 m, 1.52 m, 1.63 m, and 1.73 m), respectively for Group I (unmodified Type 1 helmets **112**) and Group II (modified Type 1 helmets **122**). At a lower drop height **104** of 0.61 m depicted in exemplary graph **1000**, it can be inferred that the air-bubble cushioning liners had little effect on the shock absorption performance of both Group I and Group II. The peak transmitted forces as a function of impact number for Group I are identical to those for Group II. The peak transmitted force varied little with increasing impact number for both Groups and they were well below 4.45 kN. At a drop height **104** of 1.52 m depicted in the exemplary graph **1002**, the mean peak forces and the corresponding standard deviations for Group I increased with increasing impact number. After the second drop impact, the peak forces for Group I became greater than 4.45 kN. However, the peak transmitted forces for Group II varied little with increasing impact number for ten repeated impacts. For tests with drop heights **104** of 1.52 m and 1.73 m as depicted in

[0059] FIG. **10**B presents exemplary graphs **1010** and **1012** which illustrate the peak transmitted forces (Fmax) as a function of drop impact heights **104** (*h*) for ten impacts for Groups I and II, respectively. For Group I, it can be inferred from exemplary graph **1010** that the peak transmitted force did not vary with increasing impact number at drop height **104** of 0.61 m. At drop heights **104** of 1.52 m and higher, the peak transmitted force increased dramatically with increasing impact number and the helmets failed after the second drop impact. For Group II, it can be inferred from exemplary graph **1012** that the peak transmitted force did not change during the ten repeated drop impacts at drop heights **104** of 0.61 m and 1.53 m the peak transmitted forces increased gradually with increasing impact number at drop height **104** 1.63 m and higher.

[0060] FIG. **10**C depicts exemplary graphs **1014** and **1016** which present the peak transmitted force (Fmax) for four drop heights as a function of impact number for Groups I and II, respectively. In can be inferred from exemplary graph **1014** that for Group I, the peak transmitted force did not vary with increasing impact number at a drop height **104** of 0.61 m, but it increased with increasing impact number at drop height **104** of 1.53 m and higher. It can be inferred from exemplary graph **1016** in Group II that the peak transmitted force varied little with increasing impact number at drop heights **104** from 0.61 to 1.52 m. The peak transmitted force increased only at the 10th drop impact at drop height **104** of 1.63 m, and began to increase gradually with increasing impact number starting at the 6th impact at a drop height **104** of 1.73 m.

[0061] ANSI consensus standard ANSI Z89.1 standard requires a top impact dropping with an impactor of 3.6 kg at a velocity of 5.5 m/s, which is approximately equivalent to a drop height of 1.73 m at perfect the data gathered in FIG. **3**A. The drop height that is compliant to ANSI Z89.1 standard is approximately 12% higher than the theoretical estimations due to the frictional loss of the system. The unmodified Type 1 helmet model **112** depicted in FIG. **1**B passes the ANSI Z89.1 standard, indicating that the transmitted peak force to be less than 4.45 kN, but fails to pass EN14052—an European standard for high-performance industrial helmets, in which the helmet will be tested with an impactor of 5.0 kg from a drop height of 2.04 m; the maximal force transmitted to the helmet should be less than 5.0 kN. Data presented in FIG. **3**A-**8**B demonstrate that adding an air-bubble cushioning liner **124** to the unmodified Type 1 helmet **112** may substantially increase the shock absorption performance at high impact forces, providing better protection and making it possibly pass more stringent test standard.

[0062] It was also observed that the helmets **112**, **122** show a narrow scattering (low standard deviation value) in the peak transmitted force data when the shock absorption performance is in the stable range (i.e., h<1.73 m) (FIG. **7**). The scattering in the peak transmitted force test data becomes substantially larger once the drop height **104** is above 1.73 m, reflecting an unstable mechanical characteristics of the suspension system. The peak transmitted force data for the modified Type 1 helmets **122** with the air-bubble cushioning liner **124** show a narrow scattering for the entire drop height **104** range, indicating an stable mechanical characteristics of the suspension system for the entire test range.

[0063] Overall it was deduced that adding an air-bubble cushioning liner **124** to the unmodified Type 1 helmet **112** may substantially increase shock absorption performance for large impacts. The current data gathered in FIG. **3**A-**8**B represent the first to use air-bubble cushioning liner **124** attached to the shock suspension systems **114** of the modified Type 1 helmets **122**. The findings presented herein demonstrate that the addition of air-bubble cushioning liner **124** improves the helmets' ability to absorb and dissipate large impacts, thereby reducing WrTBI. The concept of the air-bubble cushioning liner **124** may not only be used for helmets **112**, **122**, but also be used for sports helmets to increase the shock absorption performance.

[0064] References to "one embodiment", "an embodiment", "one example", and "an example" indicate that the embodiment(s) or example(s) so described may include a particular feature, structure, characteristic, property, element, or limitation, but that not every embodiment or example necessarily includes that particular feature, structure, characteristic, property, element or limitation. Furthermore, repeated use of the phrase "in one embodiment" does not necessarily refer to the same embodiment, though it may.

[0065] To the extent that the term "includes" or "including" is employed in the detailed description or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim.

[0066] Throughout this specification and the claims that follow, unless the context requires otherwise, the words 'comprise' and 'include' and variations such as 'comprising' and 'including' will be understood to be terms of inclusion and not exclusion. For example, when such terms are used to refer to a stated integer or group of integers, such terms do not imply the exclusion of any other integer or group of integers.

[0067] To the extent that the term "or" is employed in the detailed description or claims (e.g., A or B) it is intended to mean "A or B or both". When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, A Dictionary of Modern Legal Usage **724** (2d. Ed. 1995).

[0068] Ranges can be expressed herein as from "about" one particular value and/or to "about" another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it is understood that the particular value forms another aspect. It is further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint. It is also understood that there are a number of values disclosed herein, and that each value is also herein disclosed as "about" that particular value in addition to the value itself. It is also understood that throughout the application, data are provided in a number of different formats and that this data represent endpoints and starting points and ranges for any combination of the data points. For example, if a particular data point "10" and a particular data point "15" are disclosed, it is understood that greater than, greater than or equal to, less than, less than or equal to, and equal to 10 and 15 are considered disclosed as well as between 10 and 15. It is also understood that each unit between two particular units are also disclosed. For example, if 10 and 15 are disclosed, then 11, 12, 13, and 14 are also disclosed. In this regard, ranges provided herein are understood to be shorthand for all of the values within the range. For example, a range of 1 to 50 is understood to include any number, combination of numbers, or sub-range from the group consisting 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50 as well as all intervening decimal values between the aforementioned integers such as, for example, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, and 1.9. With respect to sub-ranges, "nested sub-ranges" that extend from either end point of the range are specifically contemplated. For example, a nested sub-range of an exemplary range of 1 to 50 may comprise 1 to 10, 1 to 20, 1 to 30, and 1 to 40 in one direction, or 50 to 40, 50 to 30, 50 to 20, and 50 to 10 in the other direction.

[0069] While example systems, methods, and other embodiments have been illustrated by describing examples, and while the examples have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the systems, methods, and other embodiments described herein. Therefore, the invention is not limited to the specific details, the representative apparatus, and illustrative examples shown and described. Thus, this application is intended to embrace alterations, modifications, and variations that fall within the scope of the appended claims.

What is claimed is:

1. A protective headgear assembly, comprising:

a protective body having an inner surface and an outer surface;

a shock suspension system affixed to the inner surface of the protective body having an upper surface and a lower surface, wherein the upper surface is proximate to the inner surface of the protective body;

an air-bubble cushioning liner; and

a strap affixed to the shock suspension system.

2. The protective headgear assembly of claim **1**, wherein the air-bubble cushioning layer is affixed to the lower surface of the shock suspension system.

3. The protective headgear assembly of claim **2**, wherein the air-bubble cushioning layer is affixed to and coextensive with the lower surface of the shock suspension system.

4. The protective headgear assembly of claim **2**, wherein the air-bubble cushioning layer is substantially coextensive with the lower surface of the shock suspension system.

5. The protective headgear assembly of claim **1**, wherein the air-bubble cushioning layer comprises one or more layers of air-bubble wrap.

6. The protective headgear assembly of claim **5**, wherein the air-bubble cushioning layer comprises an upper layer of air-bubble wrap and a lower layer of air-bubble wrap oriented so that a bubble-side of the upper layer faces a bubble-side of the lower layer.

7. The protective headgear assembly of claim **6**, wherein the first layer is adhered to the second layer.

8. The protective headgear assembly of claim **1**, wherein the air-bubble cushioning liner has a thickness of 5 mm.

9. The protective headgear assembly of claim **6**, wherein the air-bubble cushioning liner has a thickness of 5 mm.

10. The protective headgear assembly of claim **5**, wherein the one or more layers of air-bubble wrap have a thickness selected from the group consisting of ⅛ inch, 3⁄16 inch, 5⁄16 inch, and ½ inch.

11. The protective headgear assembly of claim **1**, wherein the protective body is a helmet.

12. The protective headgear assembly of claim **11**, wherein the helmet is a Type 1 industrial helmet model.

13. The protective headgear assembly of claim **2**, wherein the air-bubble cushioning layer is affixed to the inner surface of the shock suspension system with an adhesive.

14. The protective headgear assembly of claim **13**, wherein the adhesive is Dycem 50-1560Y.

15. The protective headgear assembly of claim **6**, wherein the upper layer is adhered to the lower surface of the shock suspension system and the lower layer is proximate to a user's head.

16. The protective headgear assembly of claim **1**, wherein the air-bubble cushioning liner is made from a material selected from the group consisting of low-density polyethylene (LDPE) film, high-density polyethylene (HDPE) film, polypropylene (PP) film, and combinations thereof.

17. The protective headgear assembly of claim **14**, wherein the air-bubble cushioning liner is dome-shaped and an upper dome surface is adhered to the inner surface of the shock suspension system.

18. The protective headgear assembly of claim **17**, wherein the air-bubble cushioning liner is sized to fit a user's head.

19. A method of making a protective headgear assembly, comprising:

providing a protective body having an inner surface and an outer surface;

affixing a shock suspension system to the inner surface of the protective body, the shock suspension system having an upper surface and a lower surface; and

adhering an air-cushioning liner onto the lower surface of the suspension system.

20. The method of claim **19**, wherein the air-cushioning liner comprises an upper layer of air-bubble wrap and a lower layer of air-bubble wrap oriented so that a bubble-side of the upper layer faces a bubble-side of the lower layer.

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